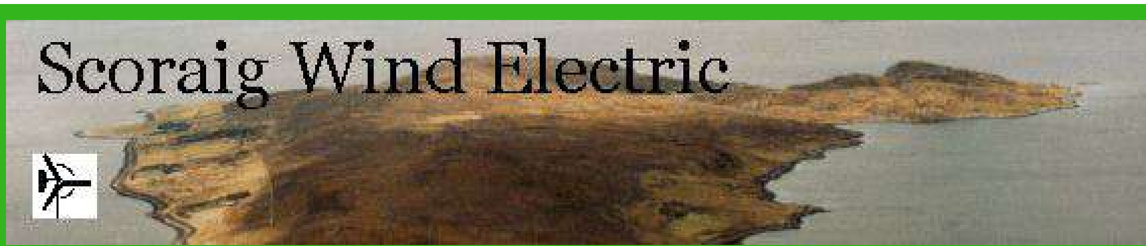


Hugh Piggott's Homepage
updated 12th June 2003

hugh@scoraigwind.co.uk

Windmill building workshop courses

I am now selling the **'Axial flux alternator windmill plans'**(workshop notes from my courses)

Here are my other books.

Quick links to stuff on this site	Homebuilt windpower - general information	Blade theory	Blade carving - diagrams	Blade carving - colour pics	Power performance testing of small wind turbines
Free downloadable pdf files for blade manufacture and other aspects of small wind/battery systems	Permanent magnet alternator construction manual - free download in acrobat pdf	Using a servomotor as a pm generator	Notes for brakedrum builders - extra information to supplement my plans	Differences between the 'European' and the 'North American' versions of the brakedrum design	Magnet suppliers
Technical stuff about load control circuits	Current in 3-phase cables	Performance and noise curves for **the AirX turbine** from Paul Gipe's personal research program are now available here.	Power performance testing of small wind turbines		
Windmill building workshop courses	Pictures of the most recent course in April USA	Pictures of the most recent course at CAT in Wales	Scoraig 2003 course		

My books

New '**Axial flux alternator windmill plans**' for sale

Scoraig where I live : Our house

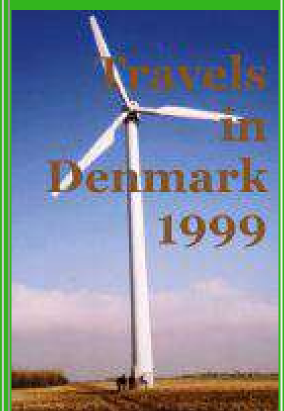
Tour of the Scoraig wind turbines in year 2000

More information about Hugh

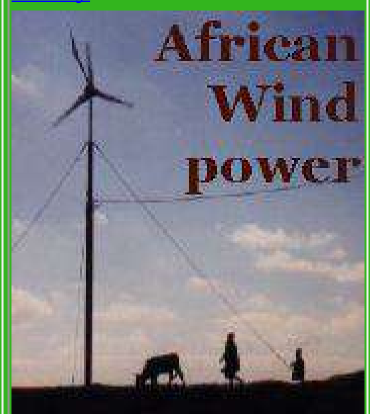
Scoraig Wind Electric **renewable energy installation service** - new grants available in the UK

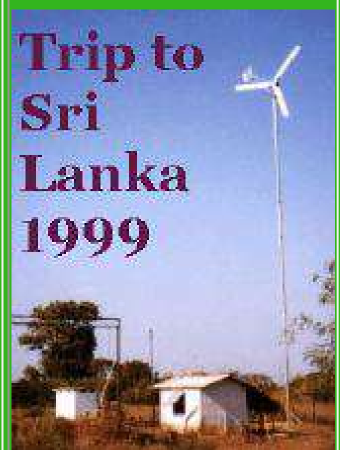
Renewable energy options for electricity supply on the Isle of Eigg

A report on the potential for small hydro, wind and photovoltaic systems on the island



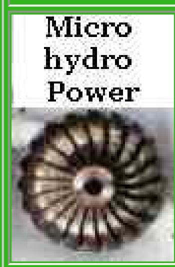
Information about African Windpower and the AWP36 wind turbine,some picsand its history

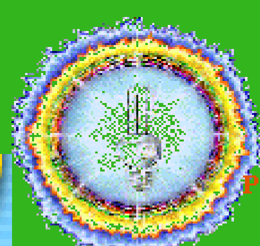




pmg construction manual is now available for free download IN DANISH (på Dansk)

Free downloadable pdf files for blade manufacture and other aspects of small wind/battery systems.





Email me at: hugh@scoraigwind.co.uk

Or (if you must) send snail mail to:
Scoraig Wind Electric, Dundonnell, Ross shire, IV23 2RE, Scotland, UK,
UK phone 01854 633 286, fax 01854 633 233.
international phone +44 1854 633 286, fax +44 1854 633 233.
Mobile 077 1315 7600

I respond much quicker to e-mail than to letters!
I do reply to all reasonable e-mail questions.
Letters often get no reply.

Abundant RE sell the AWP36 turbine in the USA

African Windpower

---

crow electric make brakedrum windmills for tipi dwellers in Wales

Claus Nybroe at windmission, the small-wind guru of Denmark, with exciting alternators for self-build

---

Ampair wind and water turbines are about as near to 'fit and forget' as you can get!

Proven make really

substantial wind machines, for rough weather and the long haul.
As seen on Castaway 2000.

A site with both windmills and woolly bits!
Clive (DCW) Wilkinson
PowerSense
Dunnose Head Farm
Falkland Islands

Wind and sun are a UK company who specialise in grid connected solar, and other applications which use inverters.

Home Power magazine is the Hands-on Journal of Home-Made Power.
A shop window of small scale renewable energy in the USA, with some 'homebrew' stuff too.

An e-mail chat list on small wind systems.

Picoturbine are marketing my books in the USA with great efficiency. You can use a credit card on this site.
"We provide plans, books, videos, and kits for renewable energy education and homebrew projects. Projects are available for fifth grade through adult at this time."

---

www.electrichorse.co.uk  is George Glaister's site for **electric-powered mopeds**.

 E-mail me at: hugh@scoraigwind.co.uk

"How to build a wind turbine"

Workshop courses

with Hugh Piggott

Courses remaining this year:

5 Oct 2003 CAT in Wales (now full)
Sri Lanka in December (not just me but lots more)
Next year
Four Winds in Edinburgh 15th March 2004
?SEI on Guemes Island in Washington USA? april 2004??
Scoraig 8-15 May 2004
finland?
LILI?

---

workshop course notes for sale (July edition)

Some **previous courses** photo pages:

2001	Scoraig Aug 2001 	SEI Guemes Island WA USA Oct 2001 	
2002	Scoraig May 02 		CAT October 2002 

2003	Scoraig May 03 	SEI Guemes Island WA USA April 2003 		Four Winds Edinburgh February 03 

Each day, a modest amount of theoretical introduction will lead to workshop sessions with opportunities to gain hands-on experience of carving wooden blades, winding coils and fitting magnets into purpose built alternators for windpower, wiring, fabrication, erection and all aspects which can be covered as time allows.

A complete wind turbine will be built from scratch and erected. Full drawings are provided as part of the course.

I should stress that these courses are to teach you how to build a wind generator, so please do not expect that you will go home with a completed wind generator.

More info

"Thankyou for an incredibly exciting and interesting course. It really taught me and revised for me a whole number of things, from aerodynamic physics to welding and I hope that in the not to distant future we shall have a wind turbine up... "

Scoraig 8-15 May 2004

The cost of the Scoraig course is £500 per head, including accommodation at Shanti Griha. Concessionary rates may be negotiable. There may also be space for partners/friends to stay at Shanti Griha during but not partaking of the course.

This will be the fourth year we hold a course here on Scoraig at the
Shanti Griha site. The courses are small (about 7-8 people) but lively
and successful. We always complete one wind turbine during the project, and make progress in the construction of others. The main project is a 2.4 metres diameter wind turbine with wooden blades and a permanent magnet alternator. Output is about 500 watts electrical.

To book a place on the scoraig course, please send me Hugh Piggott a deposit of £100 at

Hugh Piggott
Scoraig
Dundonnell
Ross shire
IV23 2RE

Keep in touch closer to the time to arrange for car-sharing from nearby railway stations. I will meet you with a boat and take you across to Scoraig from Badluarach jetty. I shall also take your gear to Shanti Griha by quad bike and trailer. Meanwhile you can walk the two miles and enjoy the views of many small wind turbines along the way.

When driving to Scoraig, take the A9 to Inverness, then follow signs towards Ullapool. Follow the Ullapool road as far as Braemore junction and turn left for Dundonnell. (**Do not** turn left onto the A832 Gariloch road at Garve - wait until **Braemore** where you see the sign for Dundonnell.) After Dundonnell, watch out for signs to Badluarach, and take a right turn down to the jetty.

Four Winds Inspiration Centre

Edinburgh 15th March 2004 (date to be fixed soon)
£300.00 per place. Six day course
to book a place - e mail (click here)
or Telephone/Fax:
0131~332~2229

Purpose of the Build your own wind turbine workshop courses :

To inspire, empower, and inform participants who wish to build small wind turbines. To cater for people from all backgrounds, age-groups, nationalites, and educational levels. To provide some basic theoretical understanding, and to develop the necessary workshop skills and confidence to enable participants to undertake small wind turbine construction projects safely.

Course at Liverpool in 2000.

Scope of workshop course - goal and objectives:
A six day course in which the participants learn as much as they are personally capable of learning about small wind turbine design and construction. Each day, a modest amount of theoretical introduction will lead to workshop sessions with opportunities to gain hands-on experience of carving wooden blades, winding coils and fitting magnets into purpose built alternators for windpower, wiring, fabrication, erection and all aspects which can be covered as time allows. Participants who bring their own ideas and materials to the course will be welcomed and given assistance where possible.

We would hope to complete one wind turbine during the project, and make progress in the construction of others. Where participants have brought the materials, they will be able to take the complete (or partially complete) components (blades, alternators..) home with them. Other work in progress will remain on site for use in future courses.

COURSES AT CAT IN WALES

I help to teach more general windpower courses at CAT in Wales twice each year. They include some self-build material and also wind system design, gridlinked systems, theory of wind engineering etc... for all comers.
The next course takes place in NOVEMBER 2004.
Phone 01654 705981/703743 for details or click here.

 -- 

More information about Hugh

Axial flux windmill plans

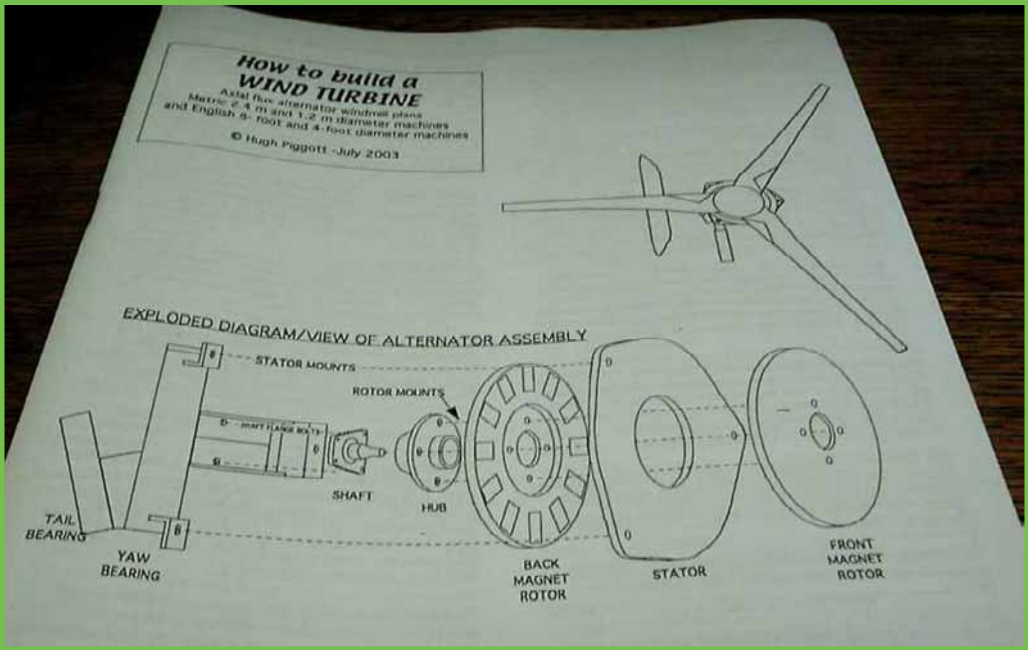
hugh@scoraigwind.co.uk

The term 'axial flux' refers to a type of alternator where the magnets are mounted on **disks** and the flux between them is parallel to the axis of the shaft. This is unlike conventional alternators whose flux is radial across the air gap. The brakedrum alternator is a radial flux type.

Lately I have been developing construction techniques for axial flux alternators. I have made a construction manual available for free down load from this site. Since then I have taught a lot of courses and my ideas have moved forward. I have made the process simpler and I have made the alternator much more powerful by using neodymium magnets.

The July edition of the plans is just freshly printed!

(with black and white photos)



You can see pictures of the construction process in action during my my latest workshop course in the USA by going to the picture pages for the course. There are two slightly different versions of the design - one using inches and one using metric measurements. Both are described in full.

There is a lot of exciting new stuff going on at the Otherpower discussion board where Dan is extending the design and using old Volvo parts to do it based on what we did on the course in April. Dan has made a page about his latest machine.

I am now selling the 'axial flux windmill plans' (workshop notes for my courses)

Prices including shipping:

UK £10.60

Europe €17

World US$ 21

Please send cash and not checks or money orders from overseas. UK cheques in pounds are OK

If you send foreign currency money orders the bank will steal half of it. If you send cash it will get here safely.

Here is my address.

Hugh Piggott
Scoraig Wind Electric,
Dundonnell,
Ross shire,
IV23 2RE,
Scotland, UK

Or you can pay by credit card at paypal with the button below

---

Dear Hugh,
I just finished your latest book. Damn, it's good. Great information and written very clearly. If you are ever near Denver Colorado and want to get a beer let me know.
Sincerely.
John Steele

---

also now available from FORCEFIELD

Other books

This is a pre-publication edition, produced in small batches. A final version will be available in a few months. This document will probably supercede the brakedrum plans although they will still be of interest to some readers. It's easier to build and involves less hunting around for parts. The brakedrum idea has a lot going for it, but it's not the way I would do it now (ten years on).

We progress our ideas.

The plans describe how to build **two machines**. Both have axial flux alternators and 3-bladed wind rotors.

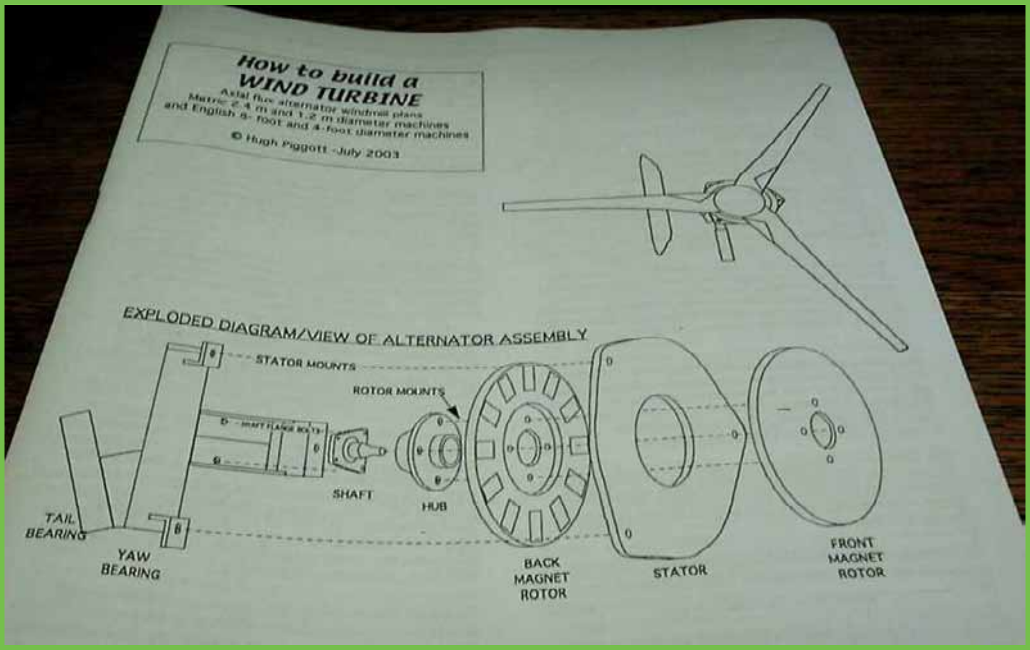
The large one has an eight foot diameter rotor and 500 watt output.
The smaller one (below) is half the diameter and one quarter of the output.
We only use a single magnet disk on the smaller machine.

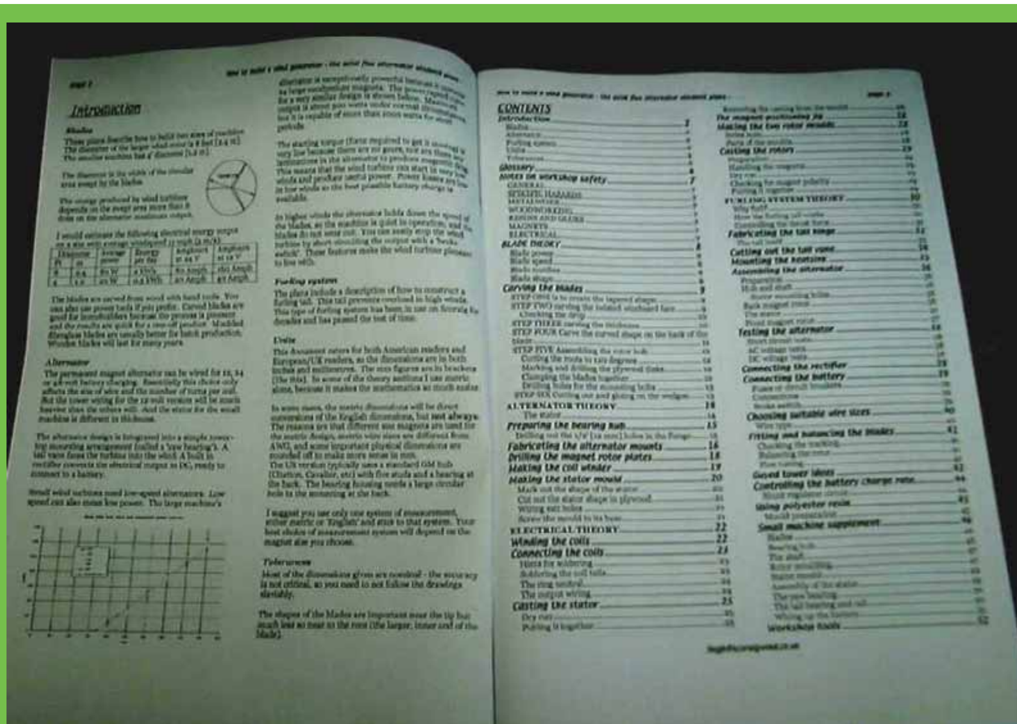
"I like the plans and the info, I really feel like I understand everything in it....
What I really liked was the way the "Little Pancake" machine was thrown in at the end. With just a couple of pages we have a complete constuction plan, once we know the principals. Reminds me of house plans, all you need is some drawings, notes, a good material list and someone to ask questions when you get stuck. "
Ron Dinishak

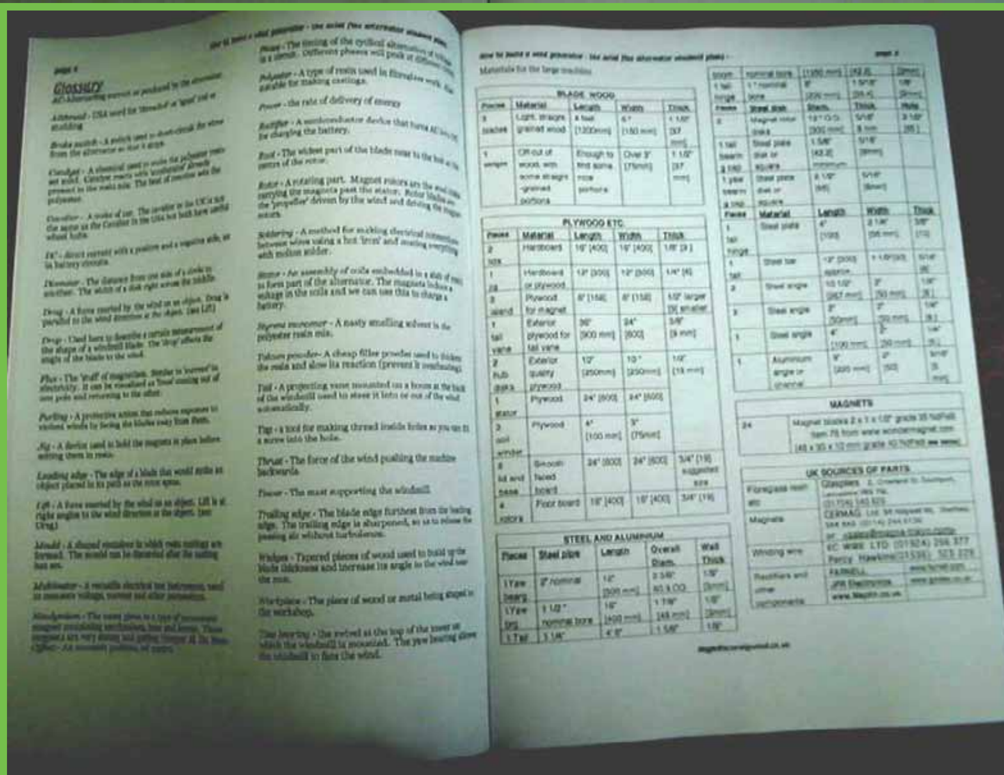
CONTENTS (52 pages including cover)

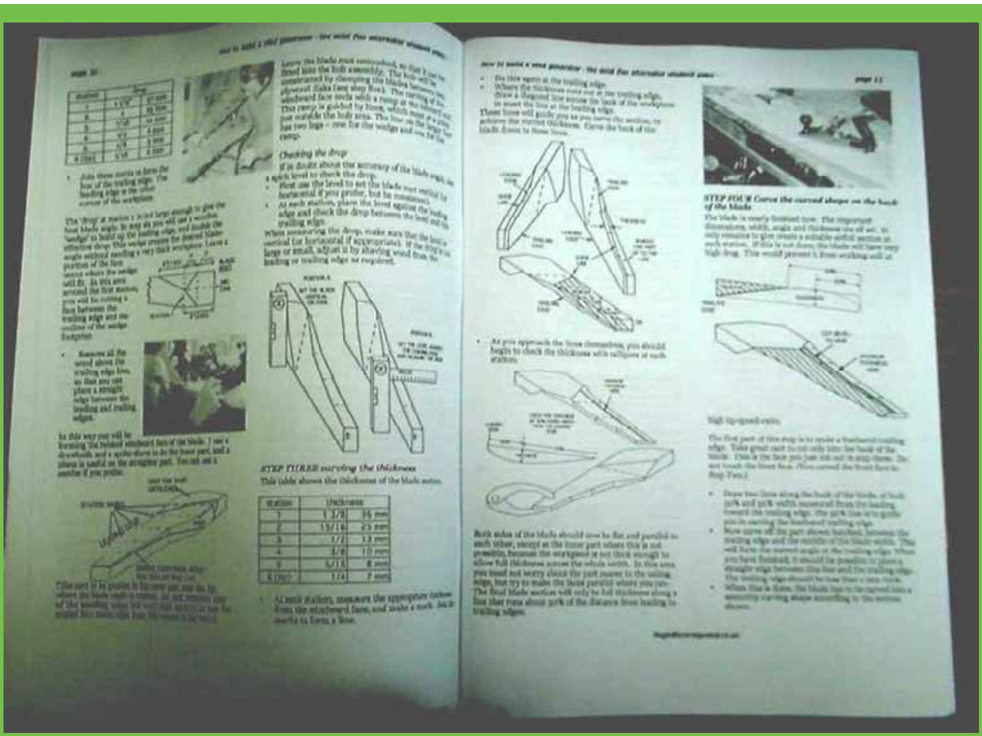
Some snapshots.

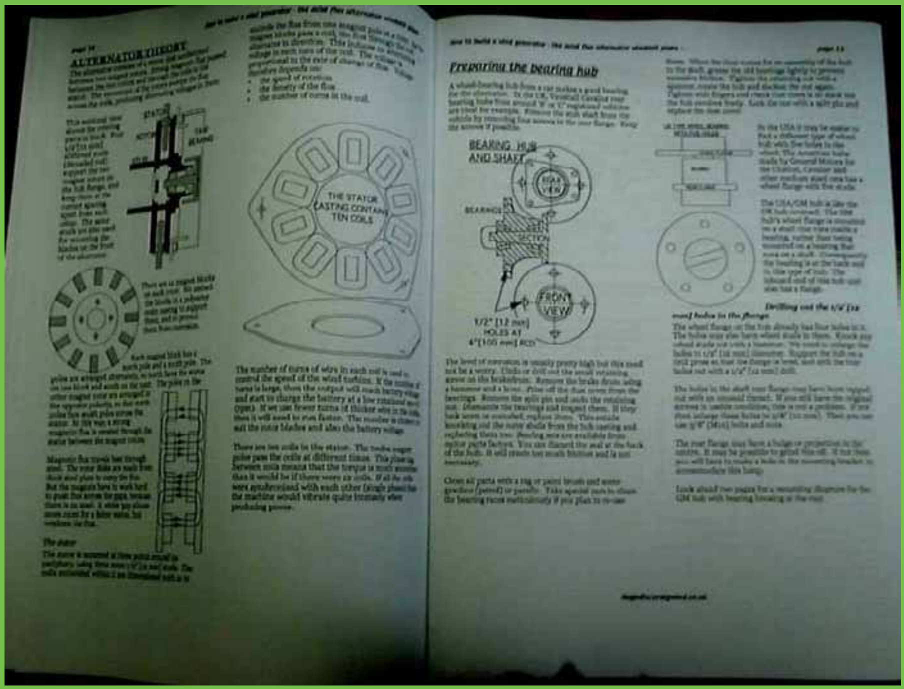
The cover changes as I bring out new editions.... the latest is July 2003, with black and white photos included for th first time.

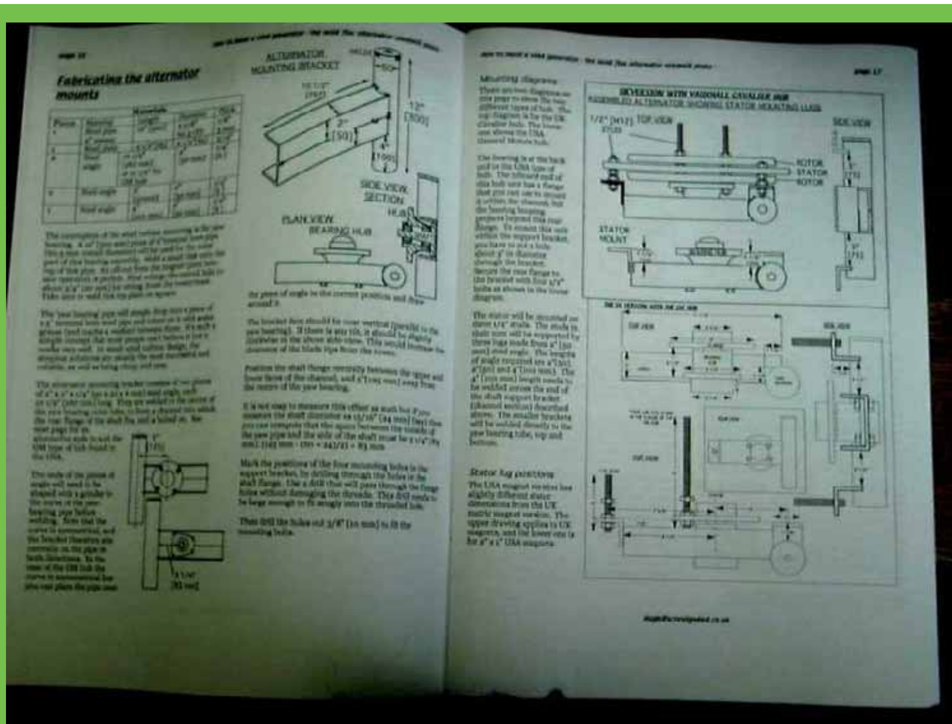


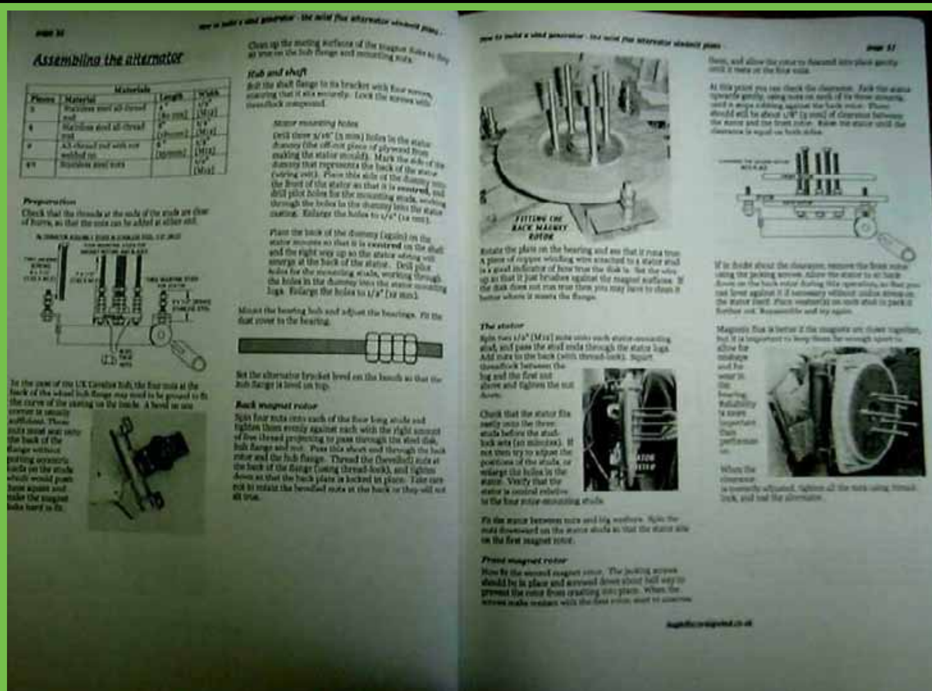


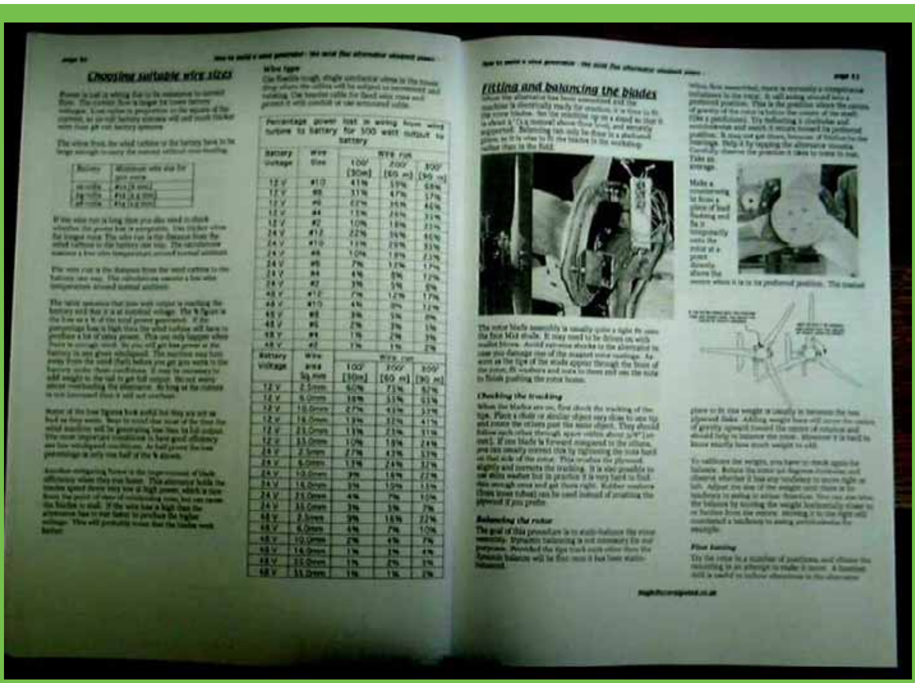





ALTERNATOR THEORY
Preparing the bearing hub
BEARING HUB AND SHAFT
FRONT VIEW


Fabricating the alternator mounts


Assembling the alternator


Choosing suitable wire sizes
Fitting and balancing the blades
Balancing the rotor

PMG booklet page

PMG stands for permanent magnet generator. This booklet describes how to build one. It was prepared in year 2000 by Hugh Piggott, for Intermediate Technology Development Group (ITDG), as part of an overseas aid project for DfID. It is not confidential; in fact the object is to disseminate it widely.

The latest version of the booklet can be downloaded in pdf format here

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Feedback is more than welcome. Please let me know what you think.

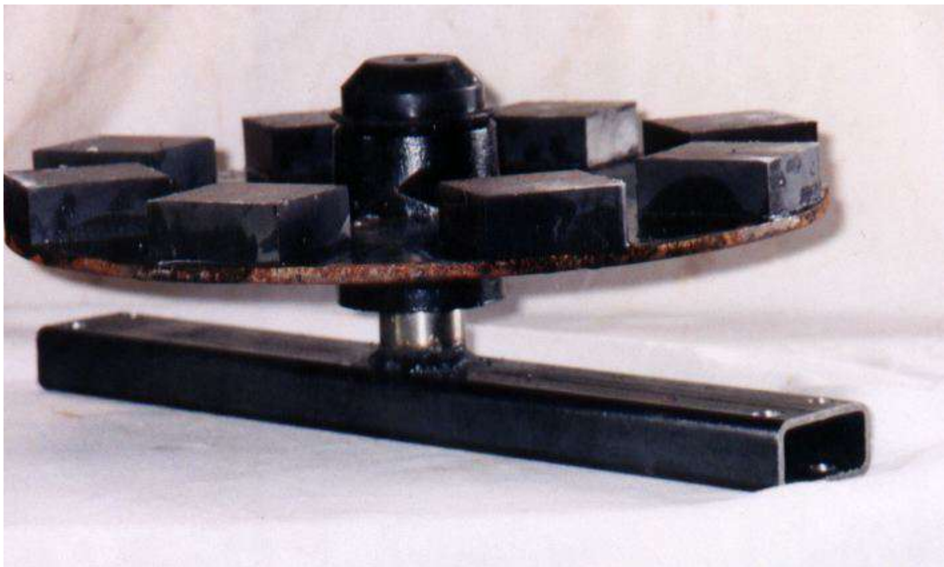
Steel disks for the pmg can be obained in the UK from Andy Taylor phone 01305 861001 for £6 each.

--
From: taywind@supanet.com
To: hugh.piggott@enterprise.net
Subject: windmills
Date: Thu, 29 Aug 2002

Dear Hugh
I have built a number of axial field pmg's (down loaded from your excellent website) and I am very pleased with them. I have recently had a batch of mild steel discs 305 dia. x 6mm with a 65mm hole at the centre as per plans lazer cut (very nice finish).
and I thought that some pmg constructors or would be constructors may have difficulty in cutting out or obtaining such discs. I would therefore be happy to supply discs at a very good price of six pounds each plus postage. I hope this could help others to enjoy constructing there own pmg/windmill as I have. I can be contacted by e-mail or phone 01305 861001 or snail mail at 18 Tillycombe Road, Portland, Dorset, Dt51lg, England. Yours sincerely Andy Taylor

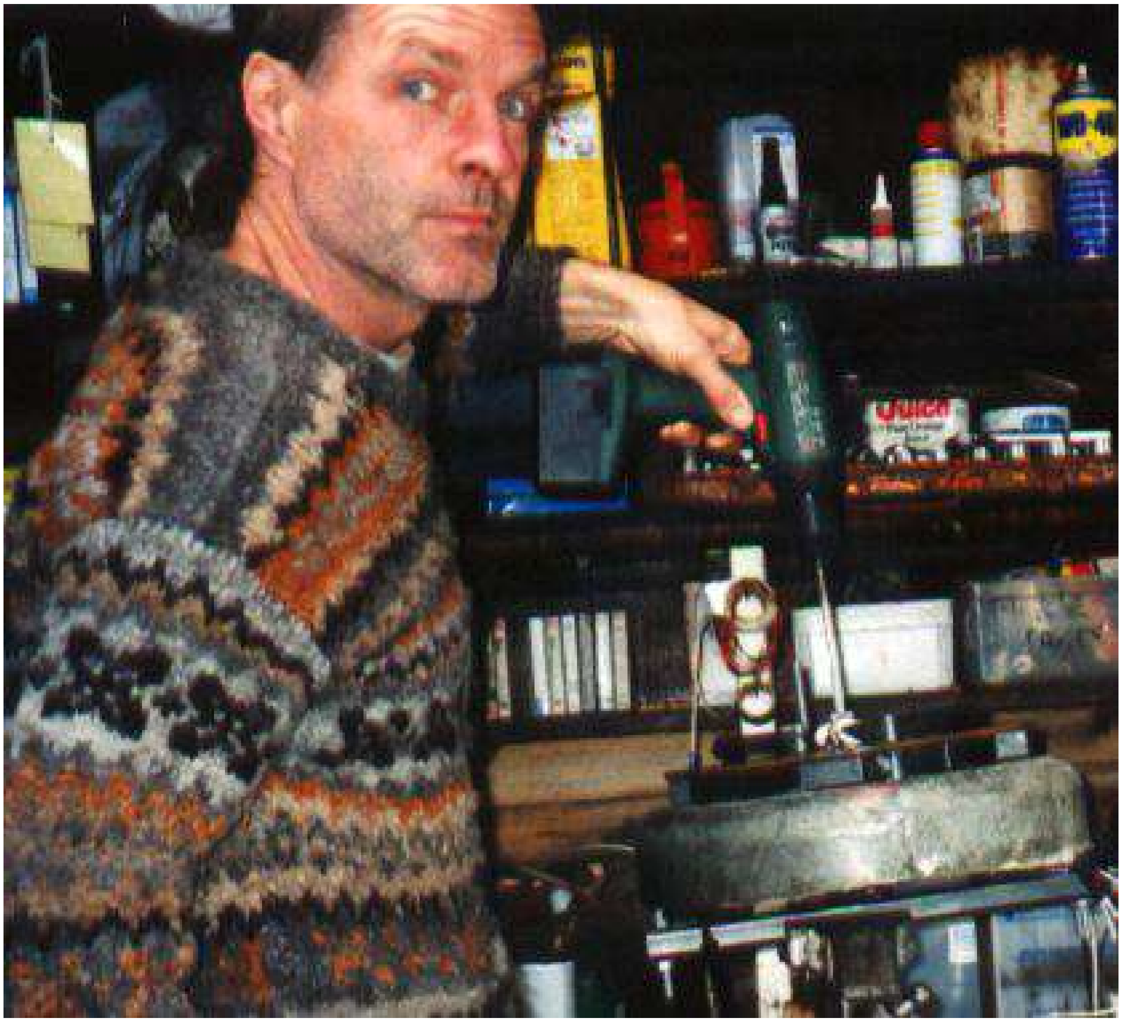
--

The pmg is intended for small wind turbines (although it can also be used for battery charging hydro turbines). It is of the 'axial flux' type. Magnets are fitted to steel disks and spun past coils. Here is a picture of magnets on a wheel bearing. Later I learned to embed the magnets in resin so as to prevent them from flying off at high speed. All this is covered in the booklet.



Here's a picture of the stator which is the stationary bit which holds the coils. The coils are set in resin. Here below the resin is clear so you can see the coils embedded within. A magnet rotor passes on each side of this disk and produces AC voltage in the coils.

Another magnet rotor fits on top of the stator. Next, in this early picture, I am spinning the alternator with a power drill to collect data about the output at various speeds.



Here is a set of pictures detailing the way the stator is cast in a mould

And here is the rotor casting process:-

Assembly...

and flight :-)

I am also teaching courses where you can learn how to do this.

Hugh Piggott

PMG construction manual

Hugh Piggott - Scoraig Wind Electric - February 2001 comments welcome at hugh.piggott@enterprise.net

Contents page

This manual was commissioned by
Dr Smail Khennas
Senior Energy Specialist
Intermediate Technology
The Schumacher Centre
for Technology and Development
Bourton Hall
Bourton on Dunsmore
Warwickshire
Tel +44-1788-661 100
Fax: +44 -1788 44-(0)1788-661 101
Email: smailk@itdg.org.uk
Url: http://www.oneworld.org/itdg
Url:http://www.itdg.org.pe
Company Reg No 871954, England
Charity No 247257

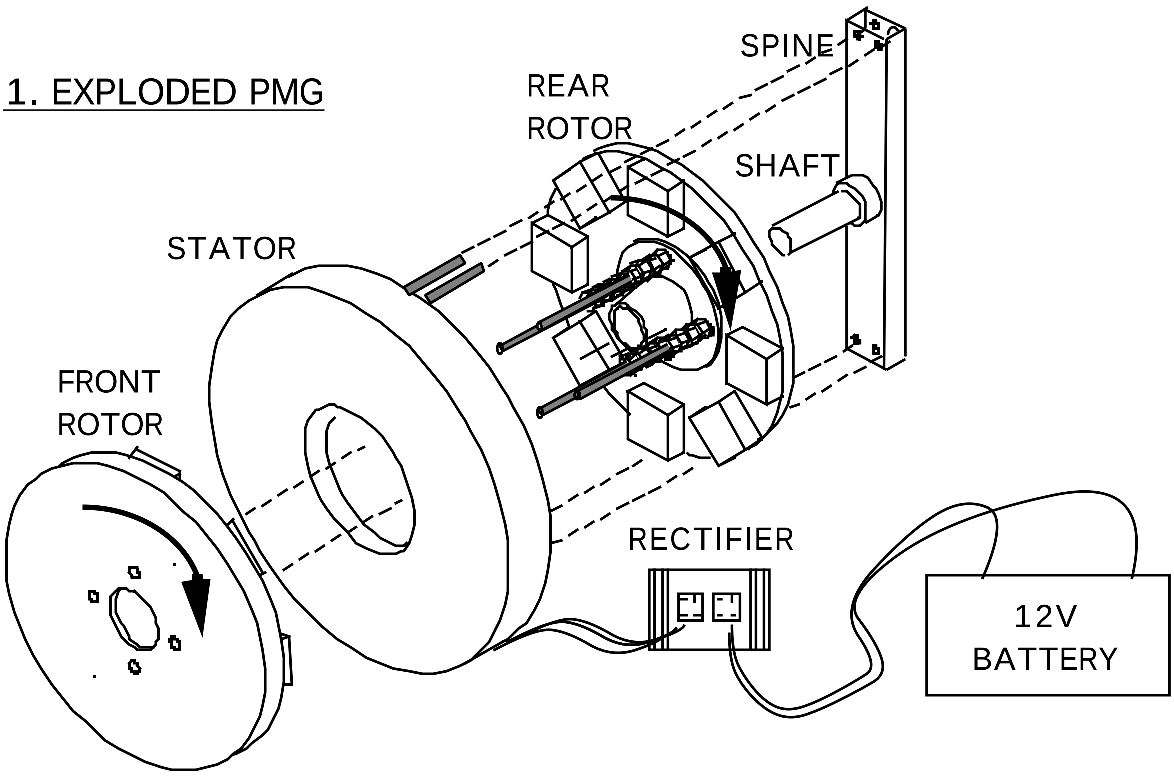
with funding from the UK government DFID

On site assembly in Peru

1. Introduction

This manual describes how to build a 'permanent magnet generator' (PMG). We can also call it an 'alternator', because it generates alternating current (AC). It will not generate 'mains voltage' or 'utility power' AC. It generates low voltage, 'three phase' AC, and then changes it into 'direct current' (DC) for charging a 12 volt battery.

What this PMG is made of



The PMG (see diagram 1) consists of:-

- A steel spine and shaft.
- A stator containing coils of wire
- Two magnet rotors
- A rectifier

The stator contains six coils of copper wire, cast in fibreglass resin. This stator casting is mounted onto the spine; it does not move. Wires from the coils take electricity to the rectifier, which changes the AC to DC for charging the battery. The rectifier is mounted on an aluminium 'heatsink' to keep it cool.

The magnet rotors are mounted on bearings, which turn on the shaft. The rear rotor is behind the stator, and enclosed within it. The front one is on the outside, fixed to the rear one by long studs which pass through a hole in the stator. The wind turbine rotor blades will be mounted on the same studs. They will turn the magnet rotors, and move the magnets past the coils. Magnetic flux passes from one rotor to the other through the stator. This moving magnetic flux is what produces the electric power.

Building the PMG

This manual describes how to build the PMG. Read right through it before starting.

Section 2. is a list of materials and tools for the job.

Section 3 explains how to build the special tools (called jigs) and the moulds which are needed. You can build more than one PMG with them. There are many possible ways to make these jigs and moulds, but there is only room in this manual to describe one way to do it.

Section 4 is about the stator. It describes how to wind the coils of enamelled copper wire, and cast them in resin, using the jigs and moulds.

Section 5 shows how to build the magnet rotors, using magnet blocks and steel disks, set in another resin casting.

Section 6 shows how to assemble the parts into a whole PMG. It explains how to build the mechanical parts, how to balance the rotors, and what is required to connect the wiring from the stator.

Section 7 is about testing the PMG. It contains procedures for checking that it is correctly balanced and ready to use. It describes the options for connecting up the electrical output. It also explains how to connect the PMG to the battery.

Section 8 contains additional information about the use of polyester resins, and about using the PMG for hydro power.

What this PMG can do

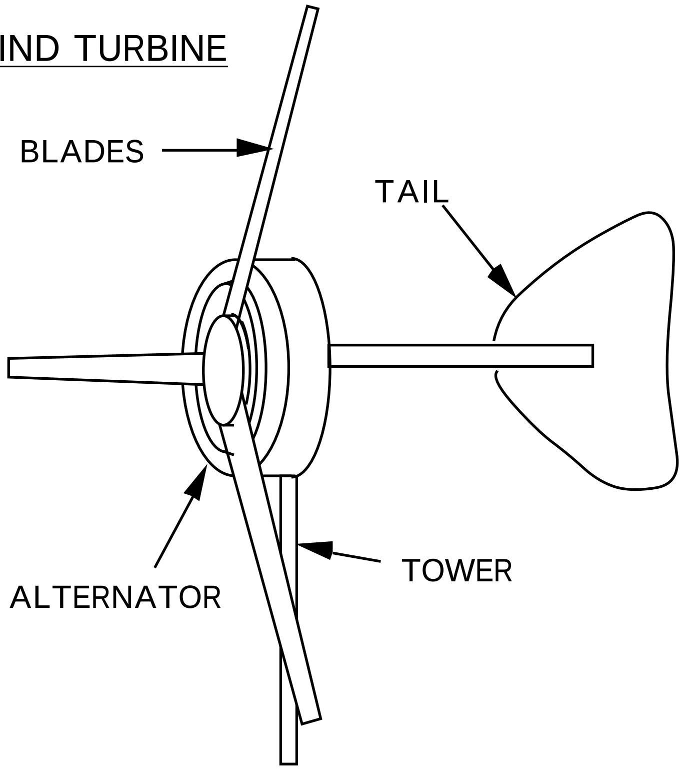
This PMG is made for small wind generators (see diagram 2). To build a complete wind generator, you also need

- a tower : perhaps a steel pipe, supported with guy ropes,
- a 'yaw head' swivelling on the tower top,
- a tail, to keep it facing towards the wind,
- a set of blades, to turn it.

The spine of the PMG bolts on to the yaw head. The blade assembly fits on to the front of the PMG. The yaw head and tail need to be so constructed that the wind generator will turn from strong winds, to protect itself. (This manual does not describe the blades, tower, or yaw head.)

On test at Scoraig

2. WIND TURBINE



The PMG works at low rotational speed. The chart shows the power output of the PMG, charging a 12 volt battery. At 420 rpm it generates 180 watts, which is 15 amps at 12 volts (15A x 12V = 180W).

At higher speed, the PMG can generate more power. But high currents cause the coils to heat up, and so the efficiency gets worse as the output current gets higher. For higher speed it is better to change the stator coils, either by using different size wire, or by changing the way they are connected.

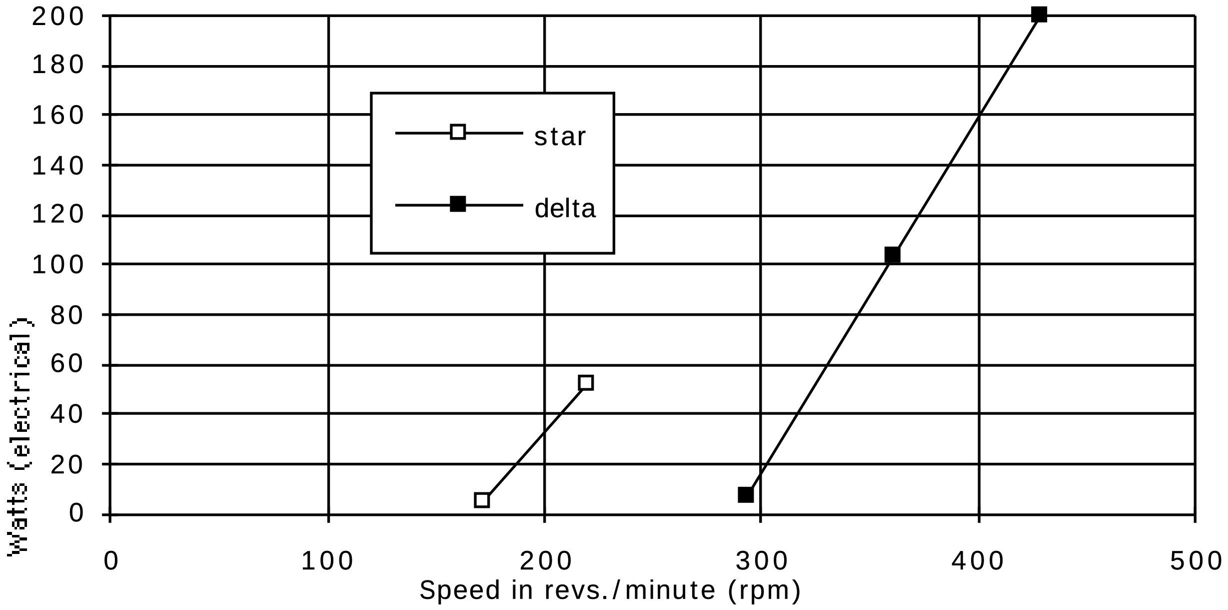
If the PMG is always used at higher speeds, it is better to use thicker wire, which can carry more current without getting so hot. Using thicker wire means there are fewer turns on the coils, which means that the PMG would not work at low speed.

To use the same PMG for both low and high speeds, it is possible to change the connections. There are two ways to connect the stator wires to the rectifier. They can be connected 'star' or 'delta'. See Section 7 for a detailed description of the star and delta connections.

See diagram 3 for the graph of power vs. speed. Star begins to work at low speed (170 rpm). Delta gives more power, but only at higher speed. Star is good in very low windspeeds, and delta is better in higher winds.

A bigger version of this PMG would be able to give higher power at lower speed.

3.GRAPH OF POWER VS. SPEED



Caution

Take care when building and assembling the PMG so that the magnets cannot come loose. This can happen under extreme circumstances. Loose magnets rubbing on the stator can then destroy the PMG.

- Follow all the instructions for casting the magnet rotors - do not simply glue the magnets to the steel disks.
- Do not hit the magnet rotors with hammers during assembly.
- Take care that there is at least 1mm gap clearance between the magnets and the stator, on both sides. (For heavy duty, or high speed, use a larger gap.)
- Do not run the PMG at speeds faster than 800 rpm on a wind turbine. (When the wind turbine yaws, large gyroscopic forces will flex the shaft, and the magnets may touch.)
- Do not mount the rotor blade assembly directly onto the front magnet rotor disk, at any point away from the studs. Mount it only onto the studs and nuts themselves, which come through the disk.
- When mounting the PMG on the wind turbine yaw mount, keep the box section 'spine' of the PMG vertically upright, and not horizontally cross-wise.

2. List of Materials and tools

Materials for PMGs	No. per PMG	size	Total wt. grams
FIBREGLASS SUPPLIES			
Polyester resin (premixed with accelerator)			2700
Catalyst (peroxide)			50
Talcum filler powder			1200
Fibreglass mat (1oz/sqfoot)		1 sq metre	300
Colouring pigment resin (if required)			50
plasticene or putty			
STAINLESS STEEL			
stainless steel wire		2mm x10metres	200
MAGNETS			
Grade 3 ferrite magnet blocks (premagnetised)	16	20 x 50 x 50mm	4000
ELECTRICAL			
Enamelled winding wire		14AWG or 1.7mm (or 17AWG - see p.44)	3000
flexible wire (about 14AWG size)		same size x 6 metres	
solder and sleeving for connections			
1/2 inch masking tape			
Bridge rectifiers	2	25A 200V single phase	
Heatsink for rectifiers			250
STEEL			
Box section tube ('RHS') for spine	1	380 x 50 x25 x 4mm	1100
Magnet disk (or octagonal) plates	2	6mm x 305mm Outer Diameter	6000
10mm threaded rod ('studding')		1000mm	500
10mm nuts	32		300
10mm washers	16		
8mm threaded rod		400mm	125
8mm nuts	8		50
5mm nuts and bolts for rectifiers	2	5mm x 20mm	
Shaft		25mm x 150mm	500
MECHANICAL			
Bearing hub to fit shaft, as described in Section 6	1		1250

Spine, shaft, hub and magnet rotor

Materials for moulds and jigs

Composite floorboards (other ideas are possible) and wood glue
Sand paper, wax polish
(Polyurethane varnish, and PVA release agent, if available.)
Paint brushes, and thinners to clean them
13mm Plywood for jigs and formers and stator mould centre
Steel rod, or pipe, for coil winding machine
Small pieces of steel plate or thick sheet metal

Bolts (with nuts and washers)	diameter	length	For
2 with butterfly nuts	6mm	60mm	coil winder
4	10mm	25mm	balancing with jig
1	12mm	150mm	stator mould

Tools

Safety goggles, face mask, gloves, etc. as required

Workbench with vice
Welder
Angle grinder
Hacksaw, hammer, punch, chisel
Compasses, tape measure, angle gauge.
Spanners: 8, 10, 13, 17, 19mm : two of each.
Tap wrench and M10 taps for outer holes in magnet rotors.
Brass wire to gauge the heights of magnets

Pillar Drill Press
Drill bits 6,8,10,12mm
Holesaws 25mm, 65mm

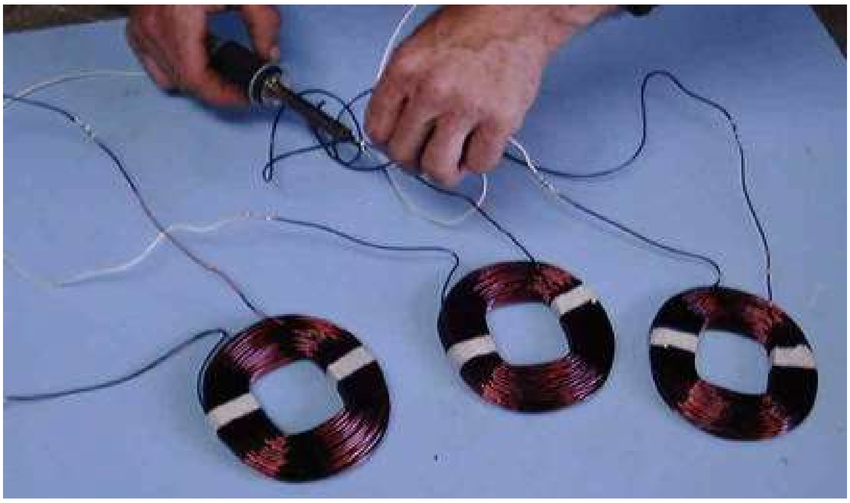
Wood lathe, or a substitute as in Section 3
Chisel for wood lathe
Jigsaw to cut wood

Scales to weigh resin. Dispenser for catalyst, plastic buckets, scissors.

Soldering iron, resin-cored solder, wire cutters, sharp knife.

3. Jigs and Moulds

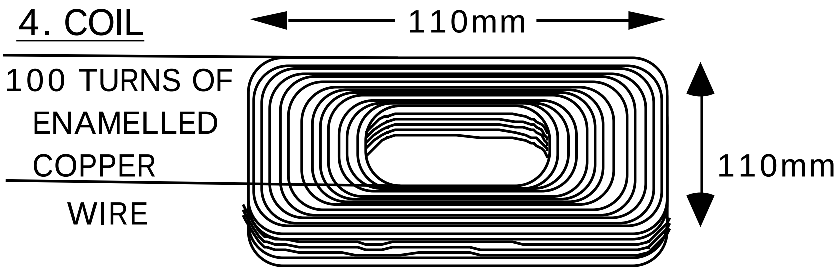
This section describes how to make the jigs and moulds for building a PMG. Once you have made them, they can be used again, to build more PMGs.



Some coils for the stator

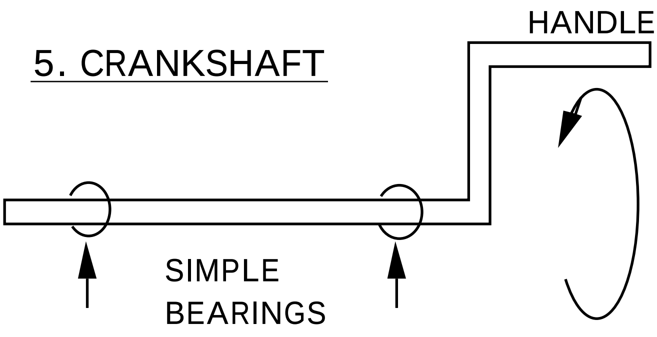
Coil winding machine

The PMG stator contains six coils of copper wire (see diagram 4).



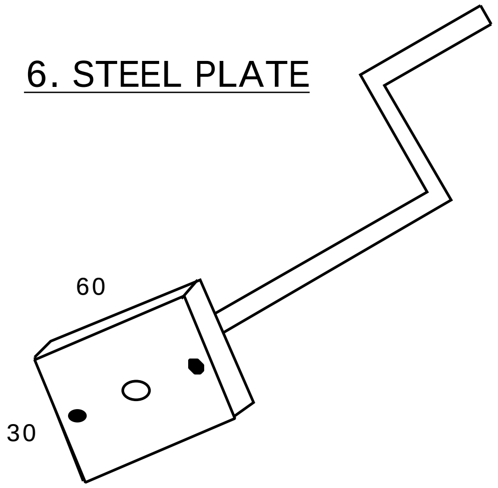
The coils will be wound on a plywood coil-former.
The former is mounted on the end of a crankshaft, between cheek pieces.

- Make a crankshaft, turned by a handle (see diagram 5).



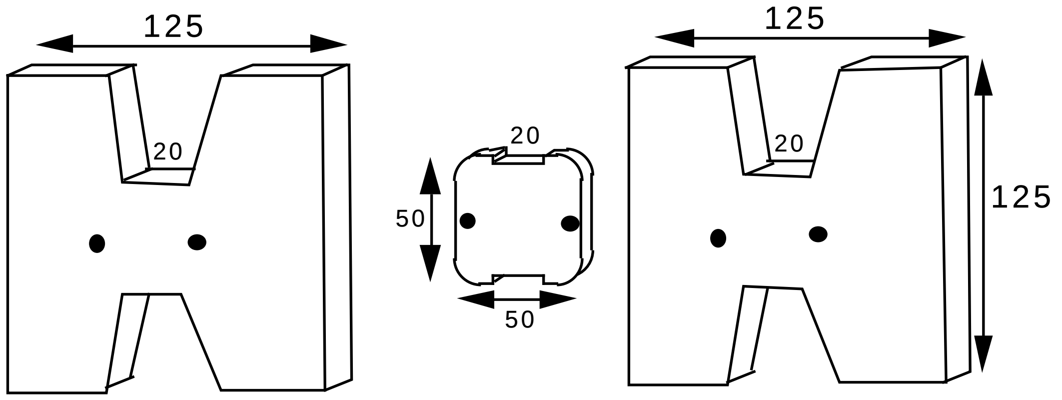
- Cut a small flat steel plate 60 x 30 x 6 mm (suggested sizes) and fix it securely or weld it to the end of the crankshaft as shown in diagram 6.
- Drill 2 holes, 6mm diameter and 40mm apart, centred on the shaft.

6. STEEL PLATE



- Cut out 3 pieces of 13mm plywood as in diagram 7.

7. COIL-FORMER AND CHEEK PIECES



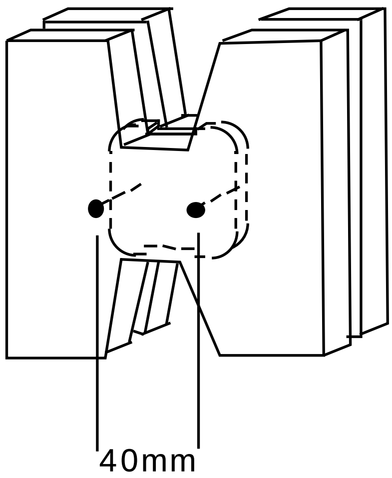
The coil former is 50mm by 50mm by 13 thick. It has rounded corners. The two 'cheek pieces' are 125mm by 125mm. There are 20mm wide notches top and bottom in each. The notches are for putting masking tape under the coil, so that it can be taped up before removing it from the former.

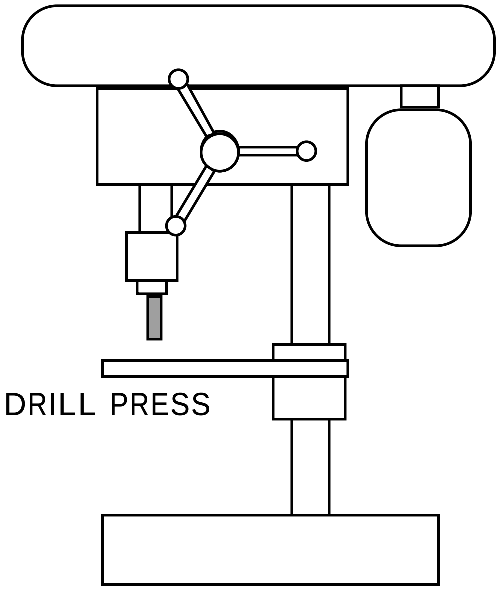
- Stack the pieces with the notches in line (diagram 8), and drill holes for the mounting bolts.

The holes are 6mm diameter and 40mm apart.
Use a drill press to drill the holes exactly square to the plywood.

8. DRILLING THE 2 HOLES

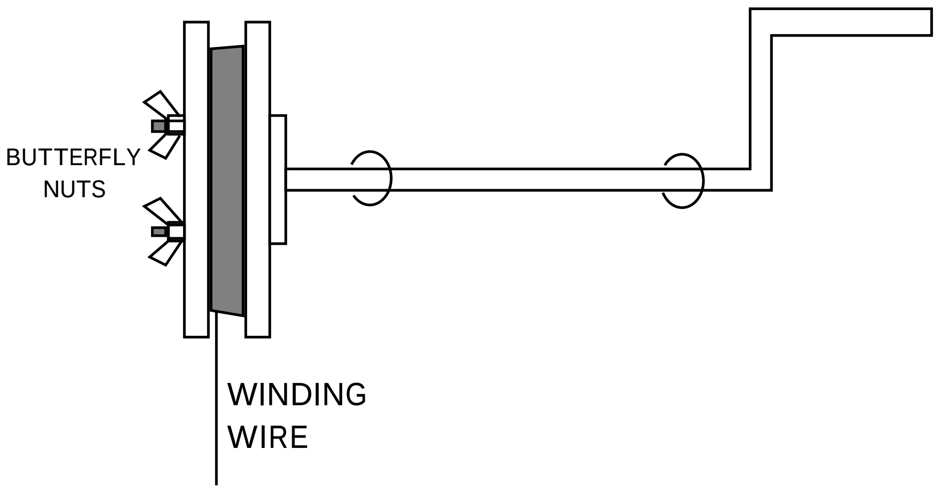
STACK THE THREE PIECES
LIKE THIS:-





- Pass two bolts through the holes in the flat plate, and bolt on the cheekpieces , with the coil-former between them. Use butterfly nuts if possible. (diagram 9.)

9. FITTING THE COIL FORMER AND CHEEK PIECES

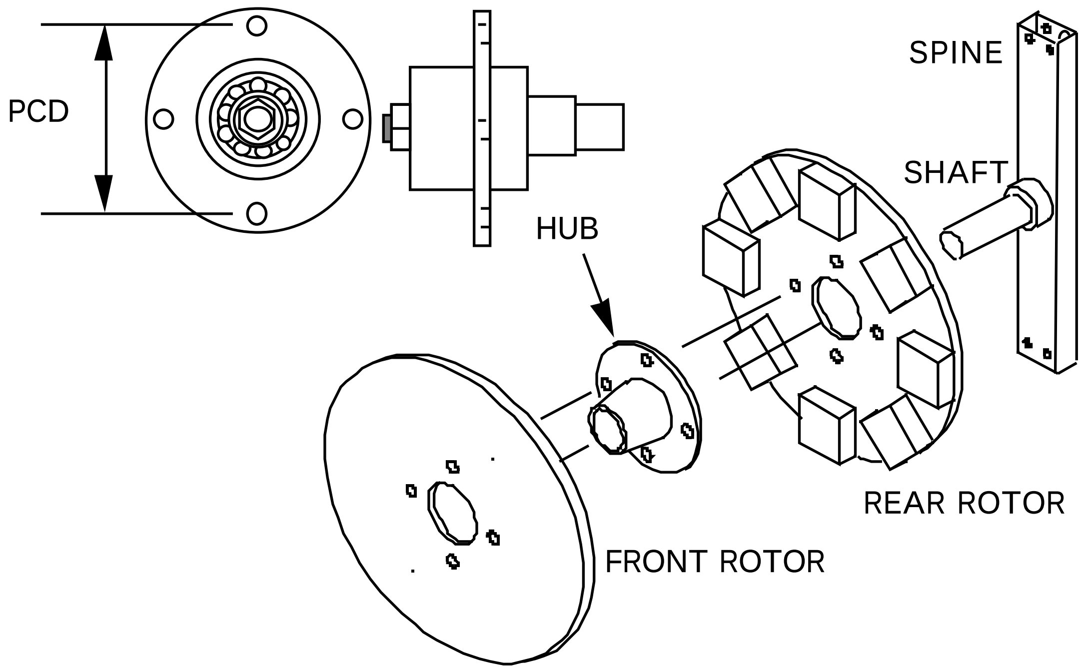


Jigs for the rotors

PCD jig for drilling holes

The magnet rotors are mounted on a bearing hub (see diagram 10). The hub has a flange with holes in it. For example there may be four holes on a 102mm (4 inch) 'pitch circle diameter' (PCD). Or you may have some other arrangement. This will depend on what kind of hub it is. Here we shall say 102mm PCD.

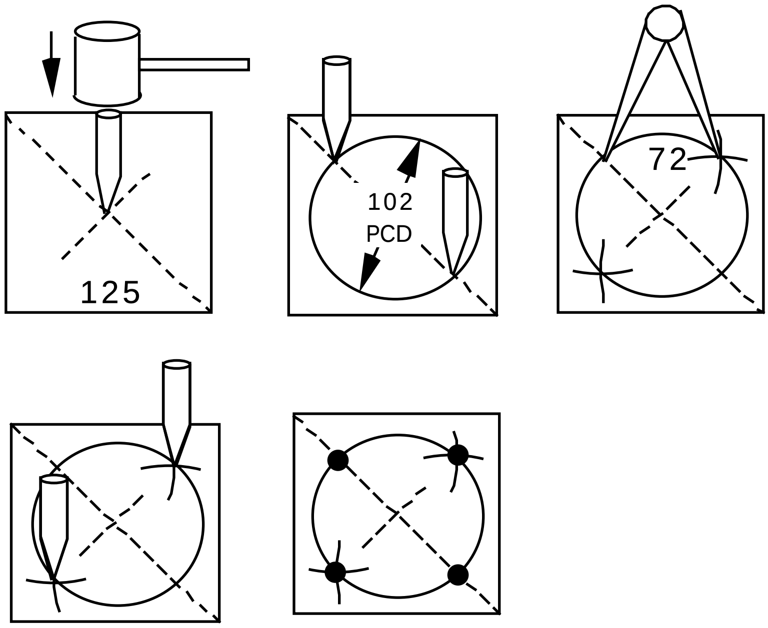
10. THE BEARING HUB PCD



The PCD jig will be used to drill holes in the rotors etc.
It will also be used to balance the rotors.
The holes must be marked and drilled very precisely. (See diagram 11.)

- Cut a square piece of steel plate 125mm by 125mm.
- Draw diagonal lines between the corners and mark the exact centre with a punch.
- Set your compasses at 51mm radius (or to suit whatever PCD). Draw a circle.
- The diameter of the circle is the PCD of the holes in the hub.
- Punch both places where one line meets the circle.
- Set your compasses at 72mm. Mark two points exactly this distance from the first two, on the circle. (If you have a different PCD, this size would not be 72mm. Find the size by trial and error.)
- Drill four holes exactly 72 mm apart on the circle. Use a small drill first and then a larger one.

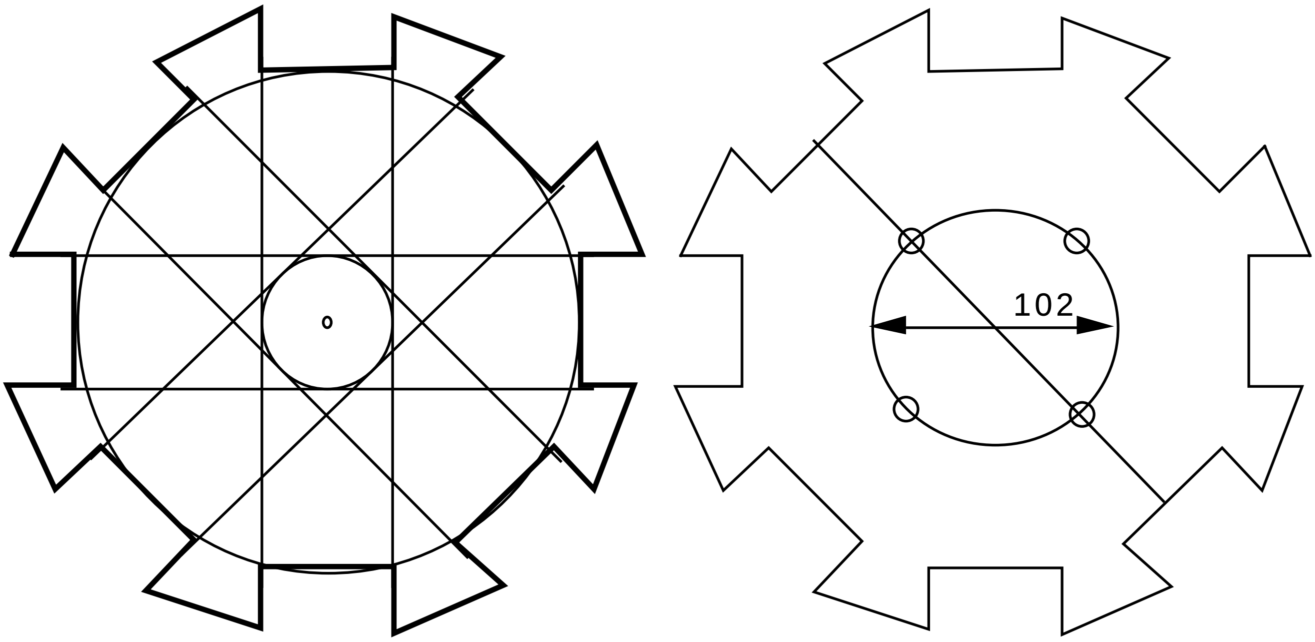
11. MARKING AND DRILLING THE PCD JIG



Magnet positioning jig (See diagram 12)

This jig is for putting the magnet blocks into the correct places on the steel disks. Only one jig is needed. Make the jig from 250x250 mm plywood or aluminium sheet (not steel).

12. THE MAGNET POSITIONING JIG



- Mark the centre of the workpiece.
- Draw three circles, with diameters 50mm, 102mm and 200mm, on this centre.
- Draw a pair of parallel straight lines, as tangents to the 50mm circle as shown.

- Draw 3 more pairs of straight lines at 45 and 90 degree angles to the first pair.
- Using these lines, mark the magnet positions, and cut out the jig along the bold lines as shown in the diagram.
- Draw a line connecting two opposite magnet centres.
- Place the PCD jig on top of the 102mm circle, aligned with the magnet centres, and drill four holes to match the four holes in the steel disks.

Making the moulds

Make moulds for the stator and rotor castings. They can be turned from wood or aluminium. Another method is to make plaster or clay plugs on a wheel, like a pot. The shape of the plug would be the shape of the outside of the stator. Then make a fibreglass mould on the plug. The surface of each mould must be perfectly flat.

The moulds need to be strong and smooth. It is not easy to separate the stator casting from the moulds. Hammer blows are usually needed.

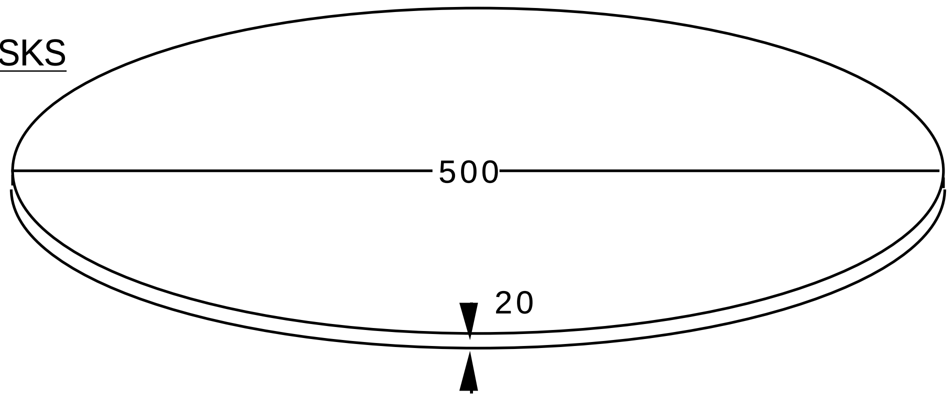
It is a good idea to wind one coil (see section 4) before making the stator mould. This coil should fit neatly in the mould.

Here is one way to make the moulds, from composite wooden floorboard sheets, using wood-turning.

Stator Outer mould

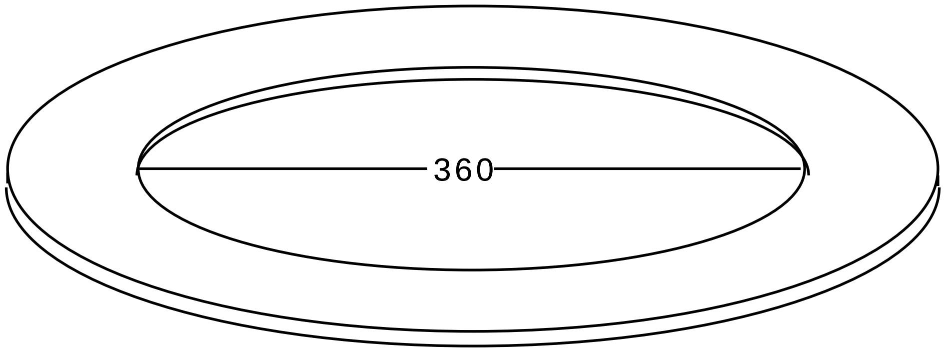
- Cut out several disks of flooring sheet (see diagram 13), approximately 500mm diameter.

13. DISKS



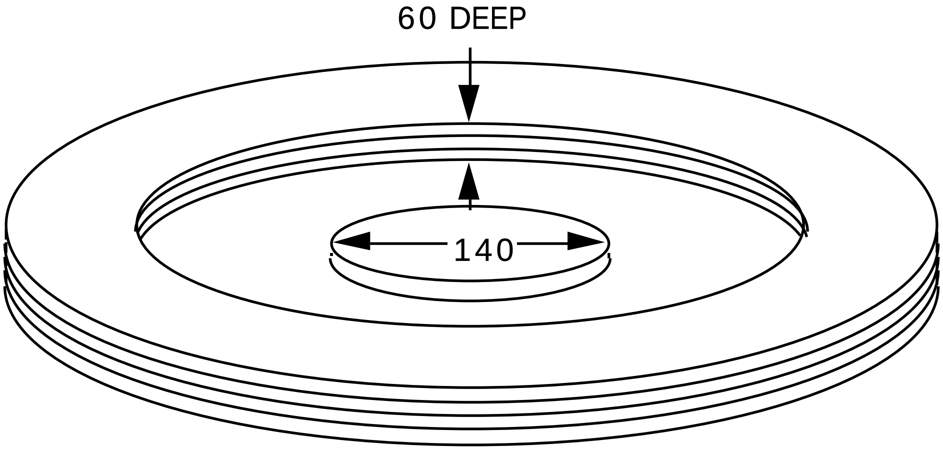
- Take all but one of the disks, and cut circular hole in each, 360mm diameter to form rings (see diagram 14).

14. RINGS



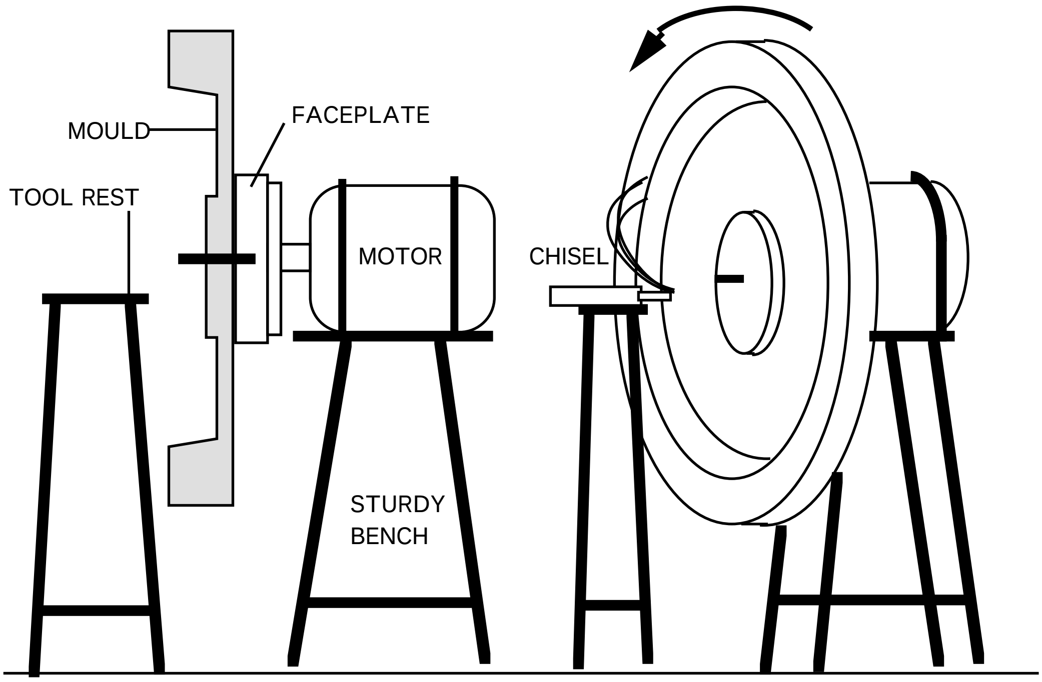
- Draw a circle 360 mm diameter on the remaining disk
- Drill a 12 mm hole at the centre of this disk, to help with centring.
- Glue the rings on top of the remaining disk, to form a stack, with a hole 60mm deep (diagram 15). Use plenty of glue at the insides of the rings.
- Cut out a small disk of 15 mm plywood, 140 mm in diameter, and drill a 12 mm hole at its centre.
- Placing a 12 mm bolt through both holes, glue the small disk into the exact centre of the hollow. Use plenty of glue at the edge of the disk.

15. STACK



- Mount another piece of wood or board onto a lathe, a motor or the wheel hub of a small vehicle (for example a 3-wheel taxi). This is a the faceplate (see diagram 16).
- Spin the faceplate and use a pencil to make a very small circle at the centre.
- Drill a 12mm hole precisely at this centre. Hold the drill parallel to the shaft.
- Screw the glued stack onto the faceplate, using a 12mm bolt to centre it. Use four woodscrews through the disk and into the faceplate.
- Check that the face of the mould runs true. You can do this by holding a pencil close to it while it spins. Where the pencil makes marks, the face is 'high'. Loosen the screws and insert pieces of paper between the faceplate and the stack, on the opposite side from the pencil marks. Tighten the screws and check again.

16. TURNING A MOULD

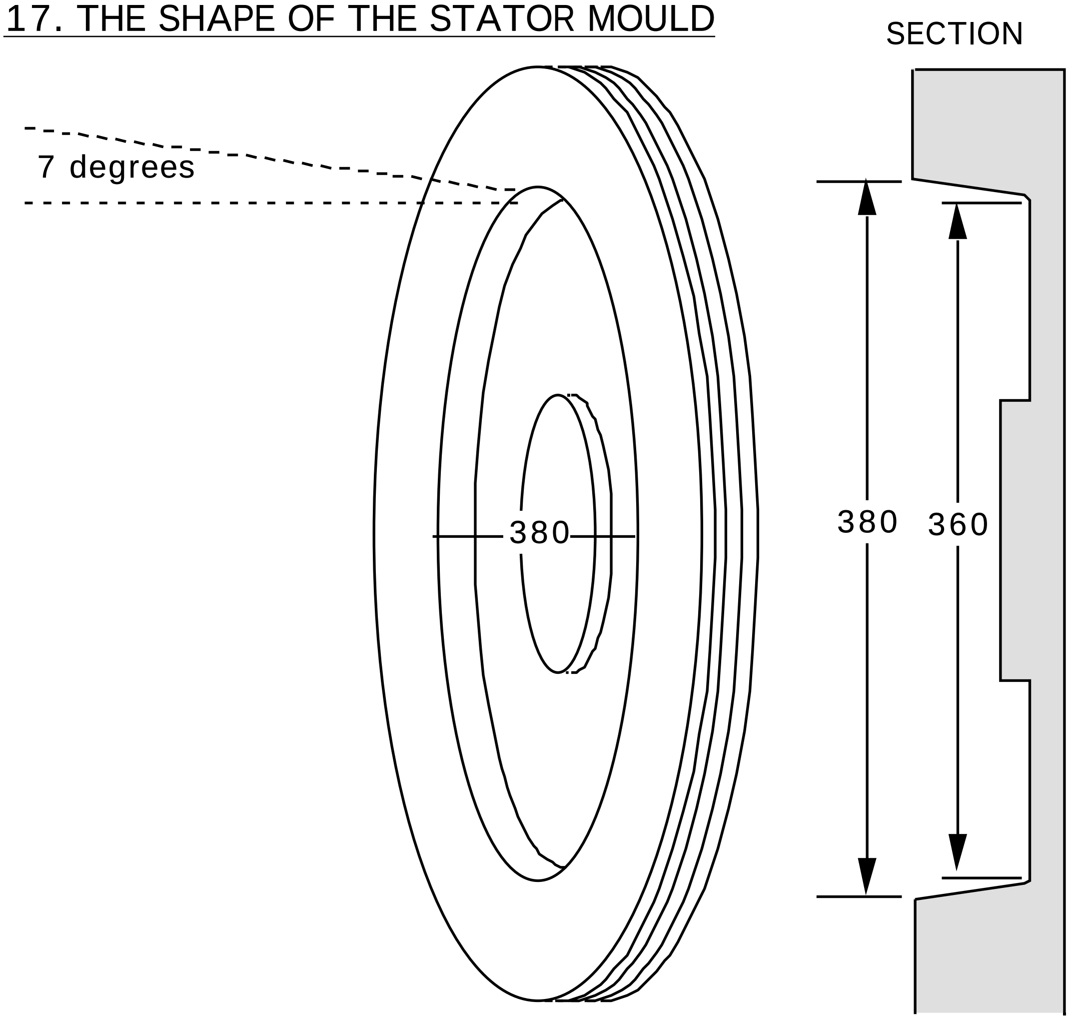


Now it is possible to shape the mould with a chisel. Wear a mask over your mouth to avoid inhaling the dust. Beware of loose clothing, which may become caught in the rotating mould.

Turning a stator mould on an electric motor

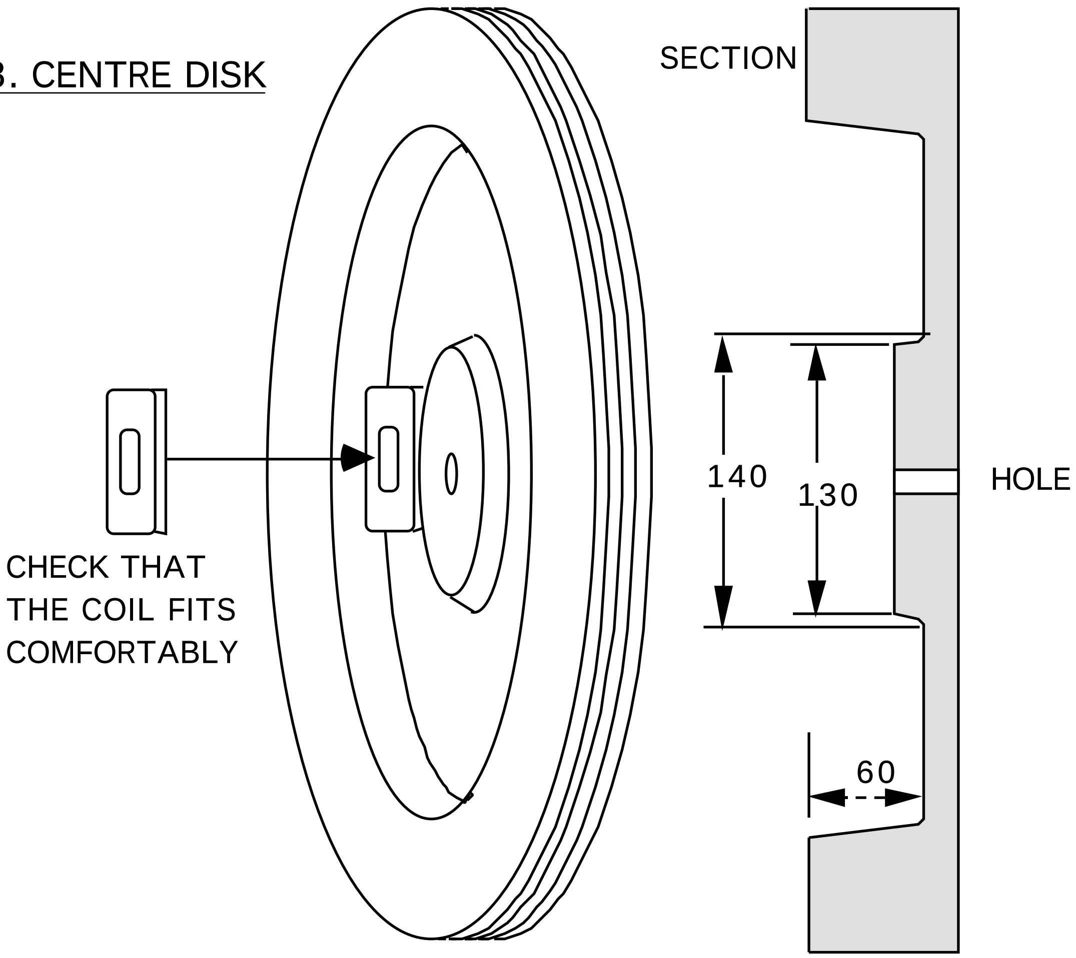
- Cut a smooth surface on the inner edges of the stack (diagram 17).
- The surface tapers at about seven degrees.
- The overall diameter at the outer edge is 380mm
- The diameter of the flat face is 360 mm.
- The corner inside is smooth (slight radius) not sharp.

17. THE SHAPE OF THE STATOR MOULD



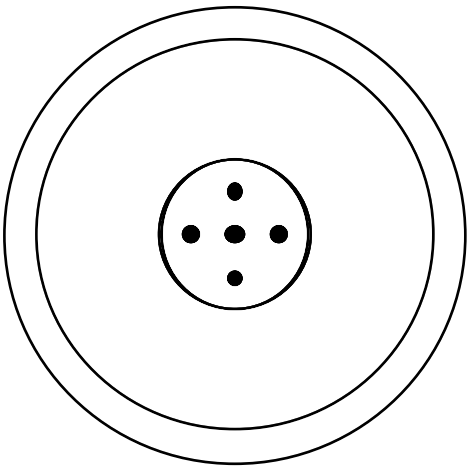
- Turn the inner disk down to 130 mm diameter on the face (see diagram 18), with a taper. The corners are rounded as before.

18. CENTRE DISK



- Place a coil against the face of the mould and check that it fits comfortably - if not, then the hollow must be made a little larger, or the centre disk a little smaller. In the end, the coil's centre must be at 250 mm from the mould centre.
- Remove the mould from the lathe or motor.

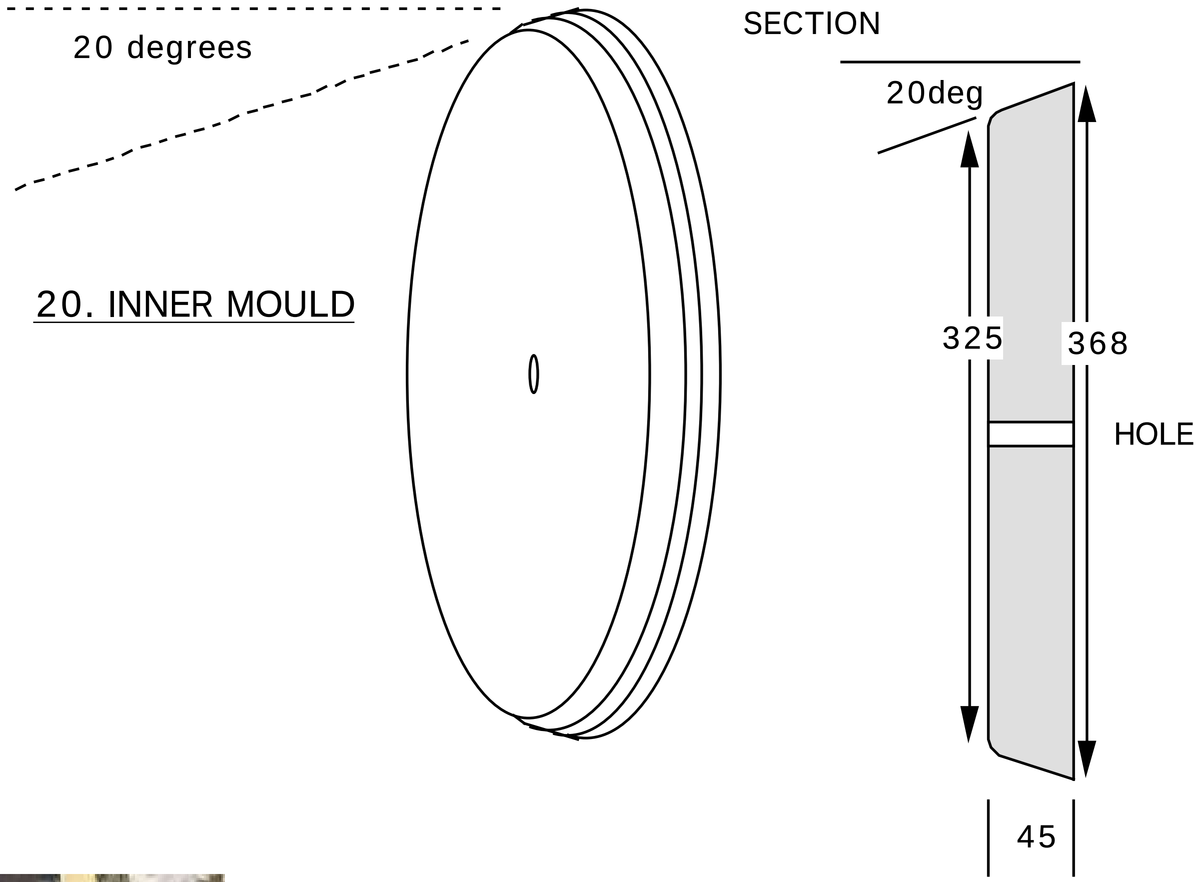
19.HOLES IN THE MOULD



Drill four holes in the central part which are used to separate the two moulds (diagram 19). Screw some small pieces of plywood onto the underside of the mould to make 'feet'.

Stator Inner mould

- Cut disks with diameter 370mm



20. INNER MOULD

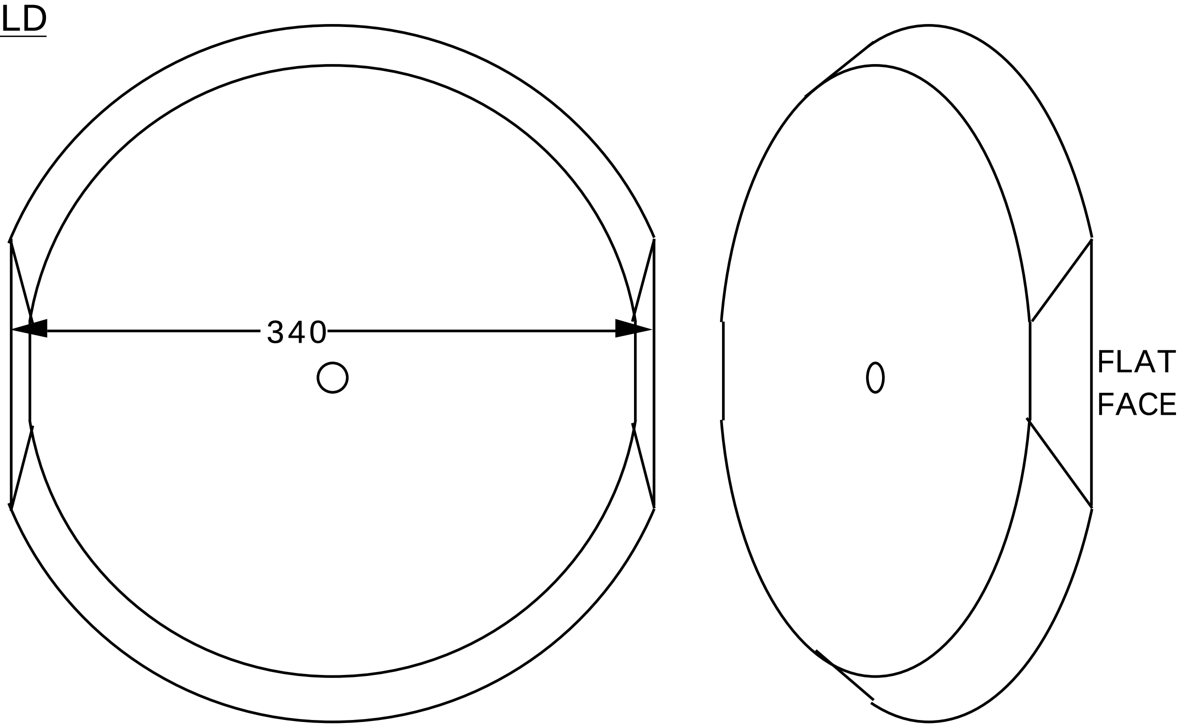
Sawing flat faces
on the inner mould

- Drill a 12mm hole at the centre of each
- Glue them into a stack (diagram 20), using a 12mm bolt to centre them.
- The stack is at least 45 mm thick, better 50 mm.
- Turn a 20 degree taper on the rim, and round off the corner, so that the diameter reduces from 368mm to 325mm.

- Check that the outer mod fits over the inner mould, with a 6mm gap all around the edge. Then remove the inner mould from the faceplate.
- Draw 2 lines on the larger face of the mould, 340mm apart (diagram 21)

- Cut two flat faces, as shown in diagram 21

21. CUTTING FACES ON THE INNER MOULD



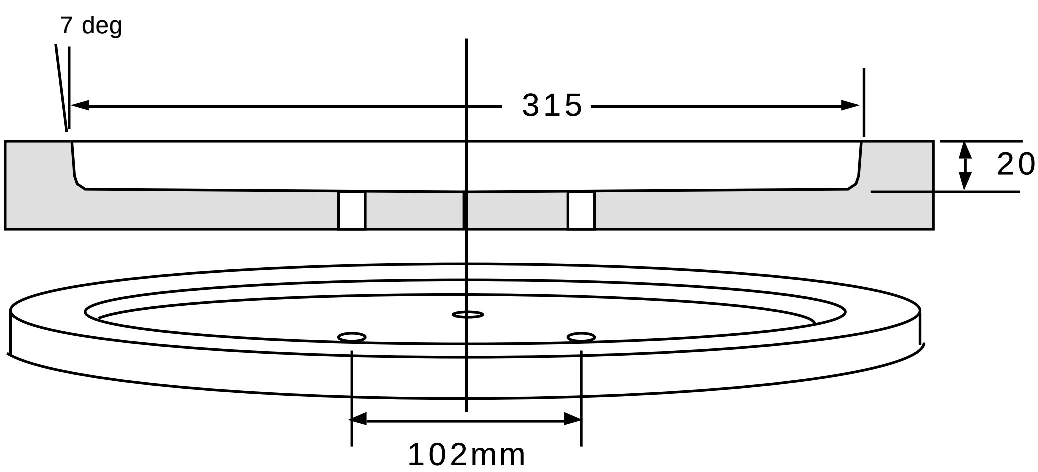
These two faces will create a thicker casting around the mounting studs.

Magnet rotor moulds

The PMG needs two magnet rotors. Only one mould is needed, but production is easier if there are two moulds, so that two rotors can be produced at one time.

The outer mould (diagram 22) is similar to the stator outer mould, but simpler

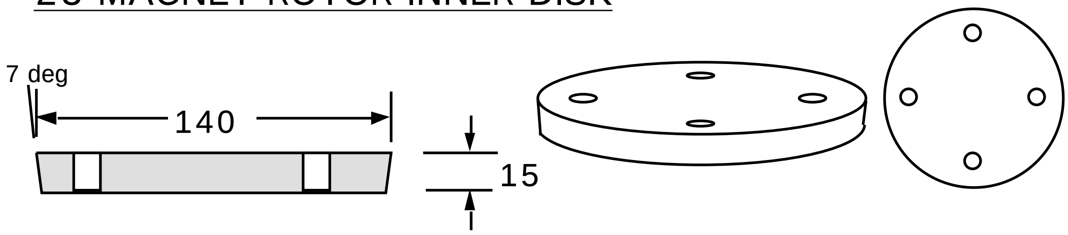
22. ROTOR MOULD



Use the PCD jig to drill four holes to match the holes in the magnet disks.

Each magnet rotor also needs an inner disk mould (diagram 23), with the same pattern of four holes.

23 MAGNET ROTOR INNER DISK



All moulds are sanded down to a very smooth surface, and finished with polyurethane varnish and wax polish. Do not use ordinary paint on the moulds. The heat of the resin process will cause the paint to wrinkle and spoil the appearance of the casting.

Rotor mould being made and used

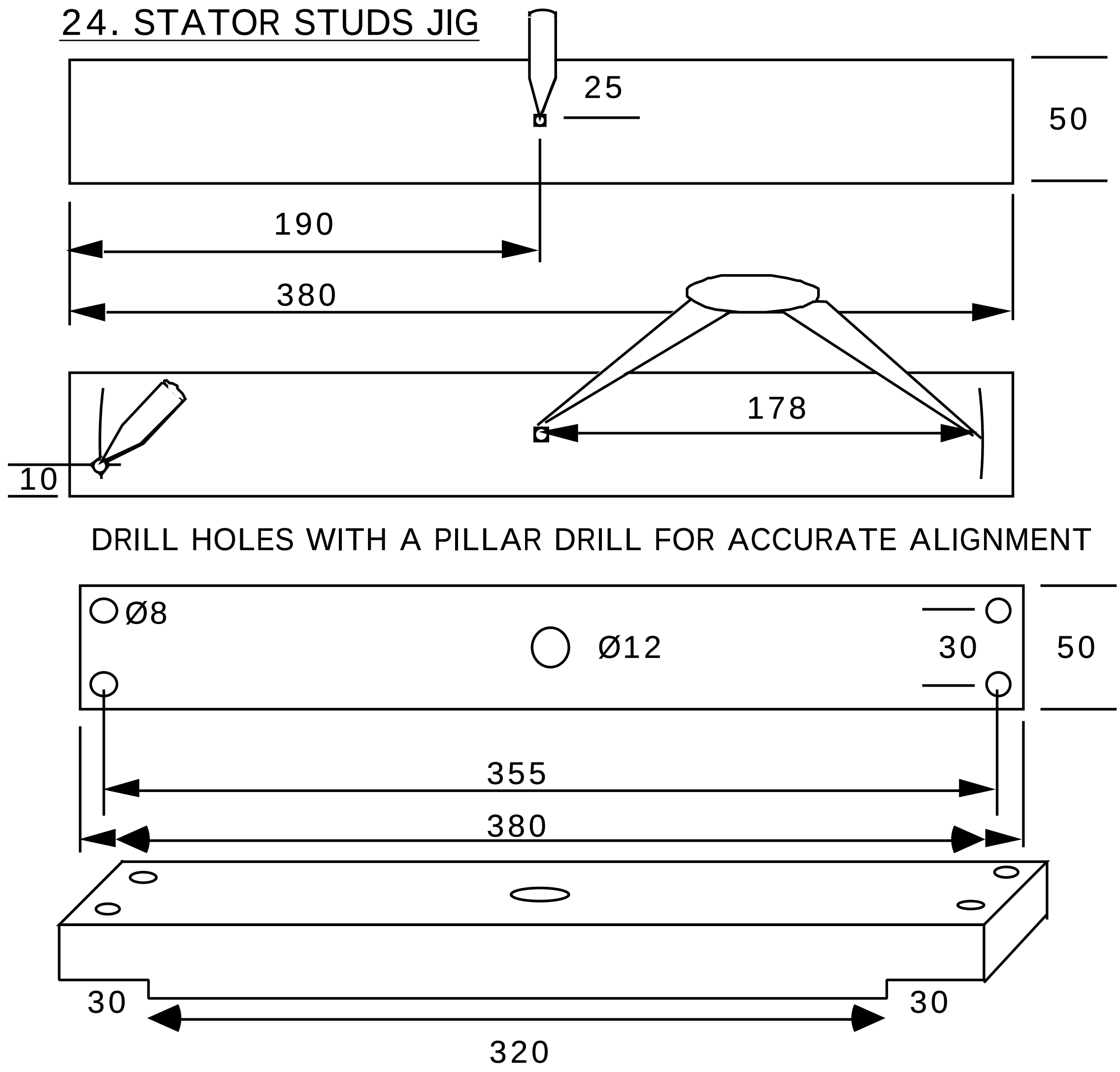
Jigs for the stator

Stator studs jig (see diagram 24)

The stator needs four 8 mm supporting studs cast into it. These studs need a jig to hold them in place, until the resin is set. This jig is made from wood 380 x 50 x 25mm. It must be made precisely, or the studs will not fit the spine later.

- Make a punch mark at the exact centre of the largest face (see diagram 24).
- Use dividers or compasses to mark arcs at a radius of 178 mm from this mark.
- Punch four marks on these arcs, 30 mm apart and 10mm from the edge.
- Drill through with an 8mm drill (using a smaller size first to be accurate). Use a drill press, to drill the holes truly square.
- Remove some of the underside of the ends of the piece of wood, so as to prevent contact with the fibreglass resin.

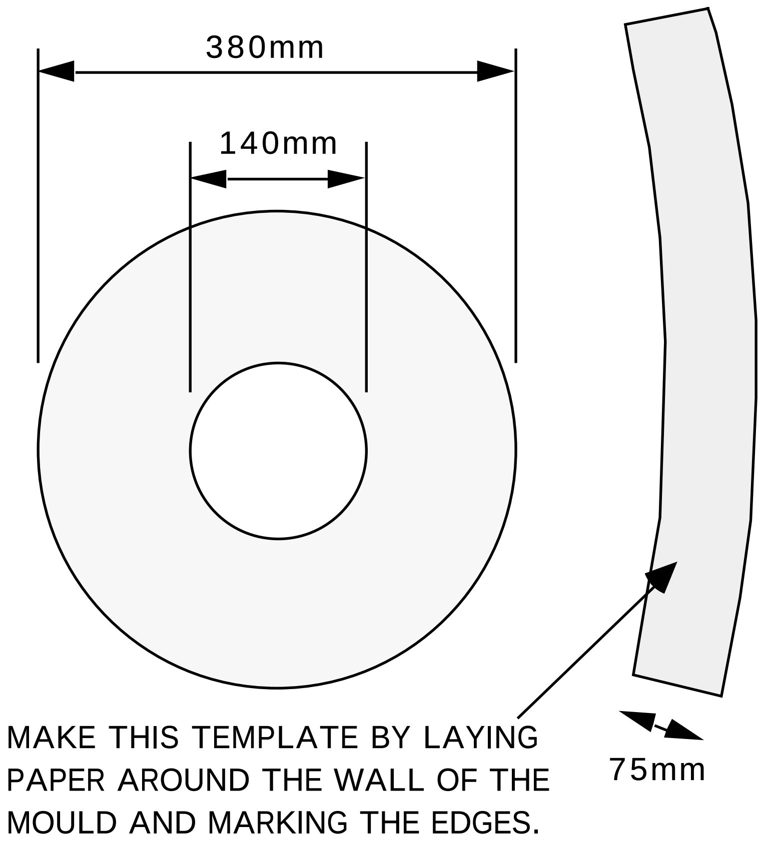
24. STATOR STUDS JIG



Paper templates (see diagram 25)

Fibreglass 'chopped strand mat' (CSM) is to be used in the stator. Make some paper templates for cutting out the pieces of CSM. Later you can lay the templates on the sheet of CSM, draw around them with a felt pen and then cut the pieces out.

25. PAPER TEMPLATES FOR GLASSFIBRE CSM



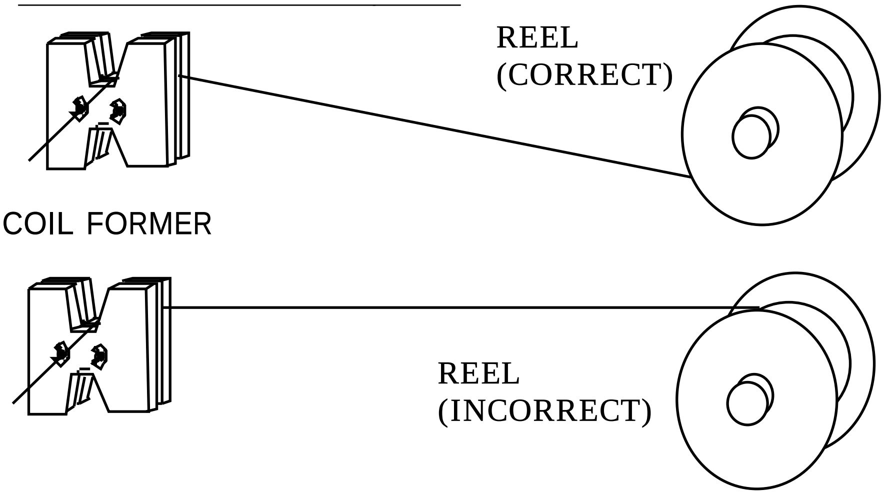
4. Stator construction

This section tells how to make a stator, using the jigs and moulds from section 3. It is a good idea to wind a coil before making the stator moulds, so that the mould can be checked for correct fit.

Winding the coils

• Mount the reel of winding wire on an axle behind you, in line with the coil former. The wire should form an 'S' bend as it winds onto the coil (diagram 26).

26. CORRECT WIRE FEED

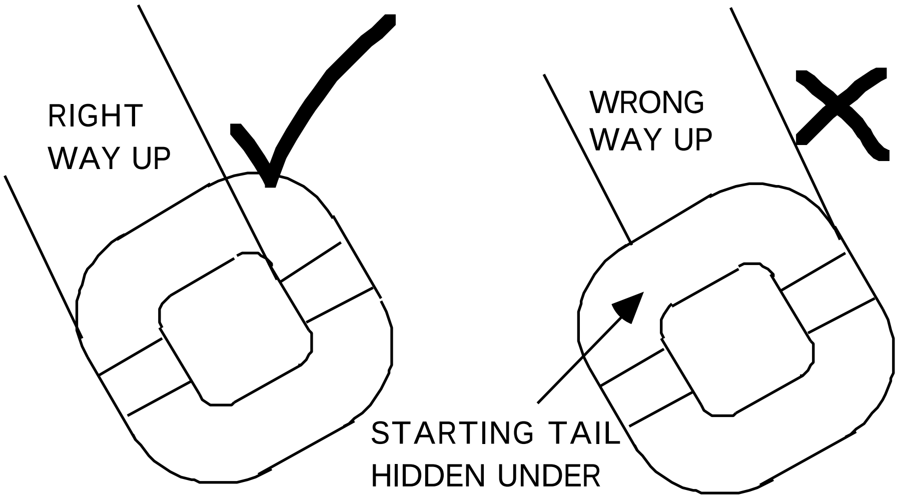


- Bend the tail of the wire 90 degrees, at a point 100mm from the end. Do not handle the bend any other part of the wire; leave it straight. Bent wire does not make a compact coil.
- Place this bend in the notch, so that the tail hangs out.
- Twist the tail loosely around one of the butterfly bolts.
- Grip the wire between the reel and the winder in a piece of rag to keep it tight.
- Wind the handle of the crankshaft.

The first turn lies against the cheek piece on the side where the tail comes out. The other turns lie against each other neatly, without crossing over. Build the coil up in even layers. Count the number of turns carefully. Normally there will be 100 turns.

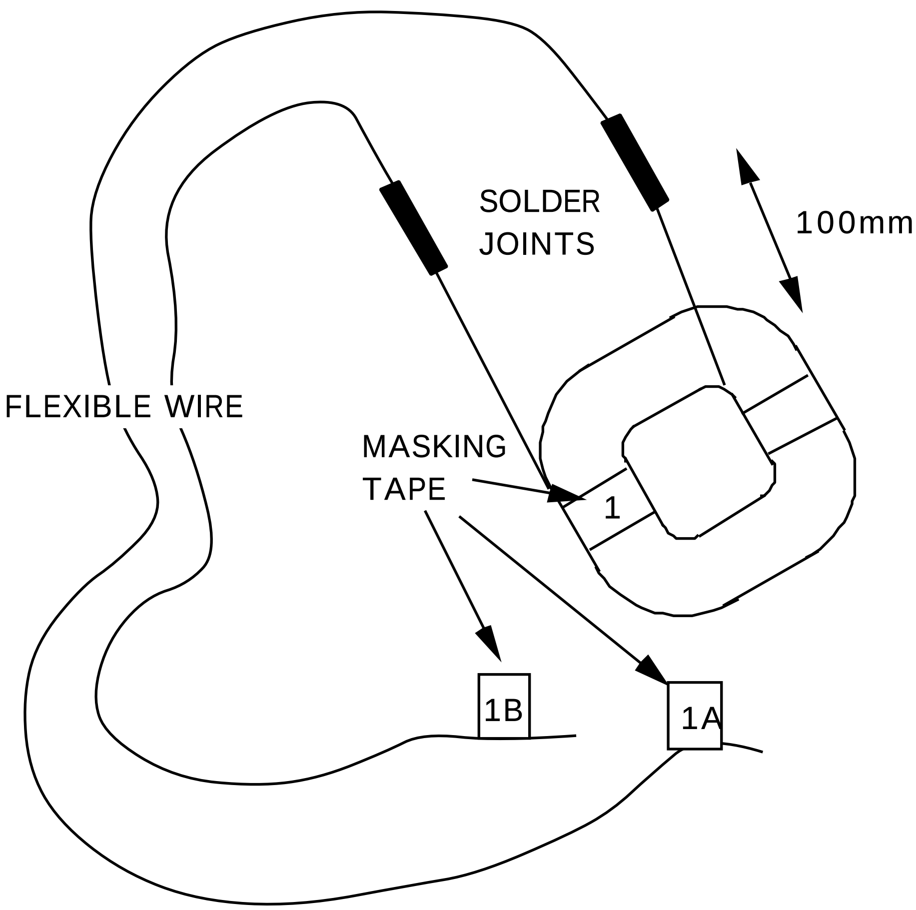
- When the coil is complete, pass a piece of sticky tape under the coil on both sides and bind it tightly. Do not cut off the winding wire until this is done, or the coil will spring out, and loosen. Cut the tail of wire 100mm away from the coil.
- Remove the coil from the former, and wind five more coils in exactly the same way.
- Place the coils on a table (so that they are all exactly the same way up (diagram 27) Check that the starting tail is on the upper surface, and not hidden under the coil.
- Number the coils 1-6, writing on the masking tape.

27. THE COILS MUST ALL BE THE SAME WAY UP



- Scrape the enamel off the last 20mm of each tail of enamelled wire, until it is all bright copper. (A hacksaw blade makes a very good scraper, when the edge has been sharpened with a grinder.)
- Solder on tails of flexible wire (diagram 28).

28. SOLDERING ON TAILS OF FLEX



Suggested lengths of flexible tails:

coils 1 and 6 - 800 mm flex
coils 2 and 5 - 600 mm flex
coils 3 and 4 - 400 mm flex

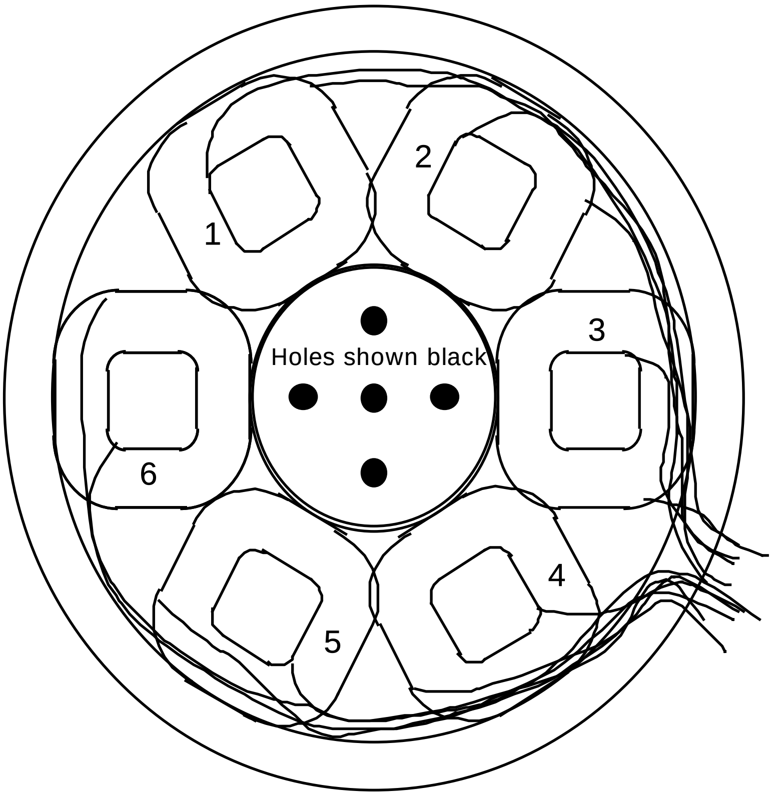
- Cover the soldered joints with sleeving. Leave no bare copper showing.
- Label the tails with the coil number and the letter A or B.

A is for the start of the coil, B is for the finish. Do not mix them up.
Or use two colours: black flex for the starts and white for the finishes.

- Lay the coils out in the outer mould.
- Check that they will fit comfortably, and that the tails are long enough to remain within the mould until the exit point between coils 3 and 4.

It is important to lay all the coils the same way up.

29. THE COILS IN THE MOULD



Preparations for stator casting

The stator casting will contain:-

- six coils
- polyester resin and talcum powder (and perhaps pigment)
- fibreglass mat (CSM)
- four studs of 8mm x 100mm threaded rod

Also, be sure to have the moulds prepared properly. Sand them, seal them, polish them. If PVA release agent can be got, then use it.

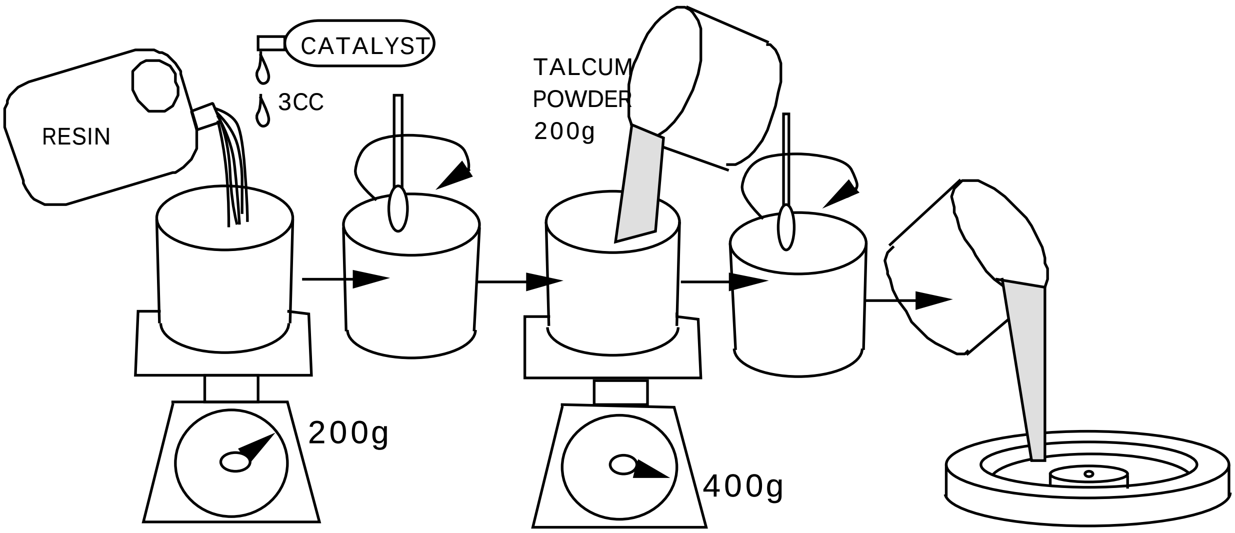
Cut out pieces of fibreglass CSM, using the templates. There will be 2 circular disks for laying flat in the outer mould. You also need enough curved strip pieces to cover the inside wall of the outer mould in a double thickness of CSM. Overlap 25mm between pieces.

When you are sure that you have everything to hand, start the resin casting process. It is a good idea to read through the procedure first, and check that you understand it all before you start. There are notes on polyester resins in section 8.

The stator casting procedure

Diagram 30 shows the procedure for weighing out the resin and the talcum powder. The talcum powder is only used for bulk mixes (not thin layers with CSM), to prevent overheating, and to thicken the mix. Different mixes use different weights - follow the step by step instructions below. Diagram 31 shows all the parts coming together.

30. MIXING POLYESTER RESIN



Mix resin with catalyst thoroughly but slowly to avoid churning in air bubbles. Add any talcum powder only after the catalyst is mixed. When the resin is mixed, use it at once. After a few minutes in the mixing bucket, it will heat up, and begin to set.

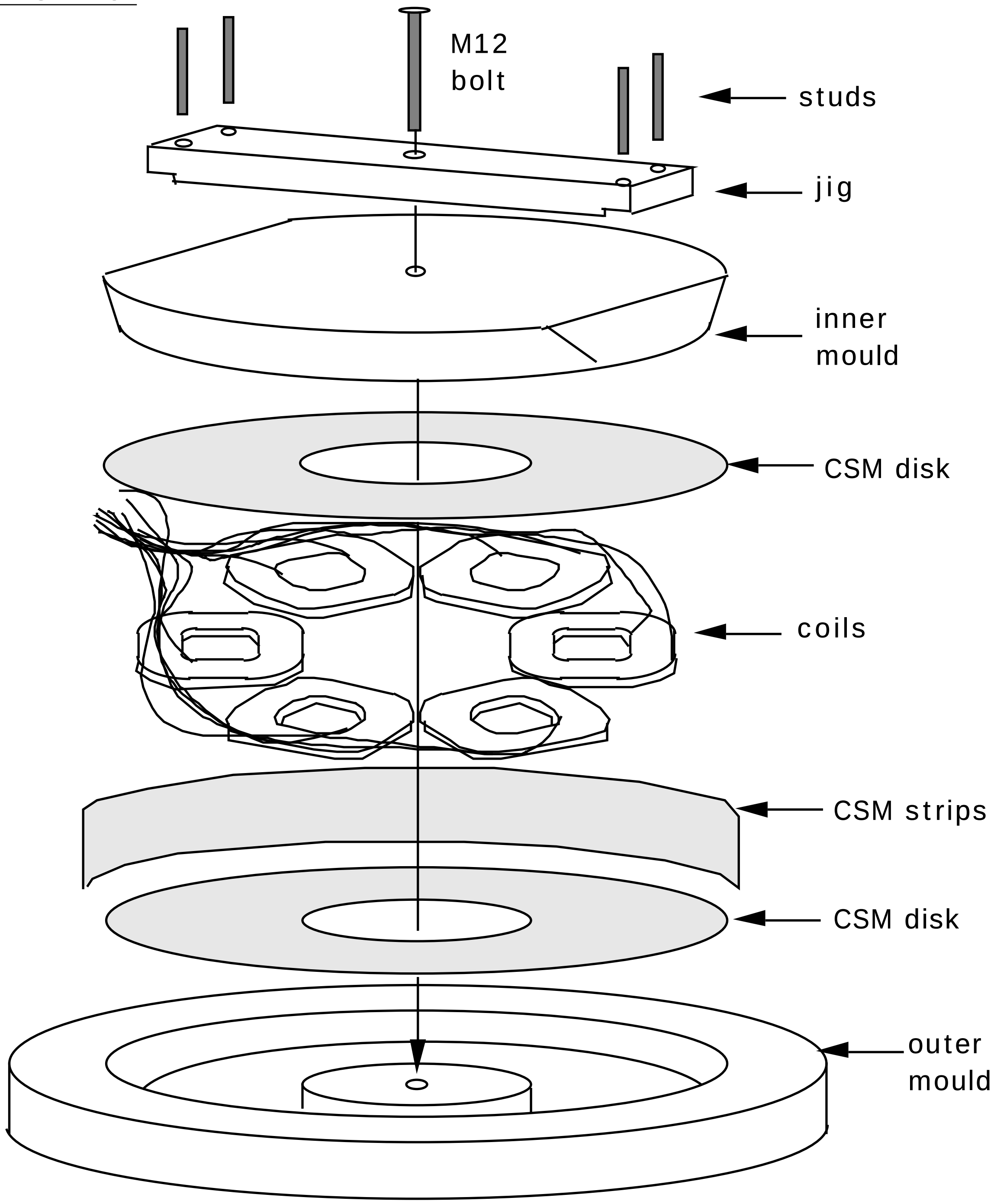
Use exactly the right amount of catalyst. Resin casting needs less catalyst than normal fibreglass work (about half the time). When the workshop is hot, put in less catalyst. Casting thick layers of resin, put in less catalyst. If in doubt, make some trial mixes of resin, to find out the correct amount of catalyst.

If there is no PVA 'release agent', then take care not to wipe the polish off the mould with brush strokes. Apply the resin with a 'prodding' action.

- Place the outer mould on some newspaper on a workbench.
- Mix 200g of resin, with 3cc of catalyst (and 15-30cc of pigment for colour, if required). Use no talcum powder in the first two mixes.
- Paint this resin all over the inside of the outer mould. Do not paint it on top of the island in the centre.
- Apply one layer of fibreglass mat (CSM), and paint more resin over it again, with a poking motion to remove bubbles. Work the resin into the CSM.
- Apply a second layer of CSM to the wall, but keep one disk for later.
- Put the coils into the mould. The wire tails all come out in one place, between coils 3 and 4.
- Mix another 100 g of resin with 2cc catalyst. Pour this over the wires of the coils so that it soaks in. Avoid making 'pools' of resin.
- Mix another 600g of resin with 9cc catalyst and 600g of talcum powder. Pour this mix into the spaces between the coils. The resin should fill the outer mould until it is level with the island at the centre.
- Shake the mould vigorously, to remove air bubbles. Rotary motion and vibration will help the resin to settle, and help any air bubbles to rise .
- Mix another 200g resin with 3cc catalyst and only 100g of talc. Put the second CSM disk over the coils and paint it with this mix. Thoroughly wash out the paint brush with thinners.
- Put the inner mould down inside the outer mould, and fit the 12 mm bolt though the centre of both. Tuck the wiring neatly into the space between the moulds. One flat spot on the inner mould sits over the part where the wires come out of the stator. The resin will rise up the sides. Some resin may spill out.
- If necessary, pour resin gently into the gap between the moulds until it rises to near the top of the female mould. You may need to mix another 100g of resin with 1.5cc of catalyst to do this. Keep notes of the amounts of resin used, for next time.
- Place the jig (for the studs - diagram 24) over the inner mould, with one end over the wire tails. Tighten the 12mm bolt with a nut. Insert the four 8mm studs into the holes, with nuts on top. The studs should be immersed in resin for about half of their length.

Six stages of the rotor casting procedure

31. STATOR CASTING ELEMENTS



The casting is now complete. It should become slightly warm, and harden within hours. If it does not begin to set within a few hours, then put it in a warm place to speed up the process.

When the resin is fully hard, remove the casting from the mould. Be patient and gentle if possible. Remove the jig from the studs. Tap the two moulds apart, using a bolt in each of the holes around the central hole. Knock the casting out of the outer mould by turning it over and knocking the edge of the mould gently against the floor.

5. Rotor construction

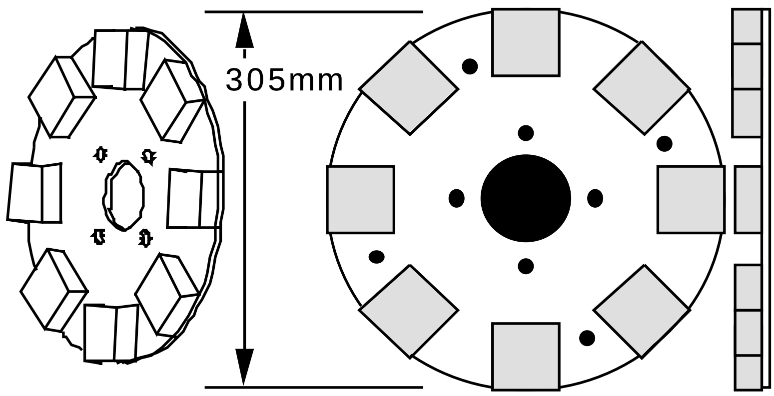
The magnet rotor is also a casting. There is also a procedure later for assembling the parts. First collect together the magnet plates, magnet blocks, stainless wire rope, etc. as described next.

Magnet plates

Each magnet rotor is built on a steel disk, 6mm thick. See diagram 32. Do not use aluminium or stainless steel for this disk! The disks have to be made of magnetic material. The disk has holes to mount it to the hub - in this manual the hub has four holes, each 10mm diameter, on a circle at 4 inches (102mm) PCD. If a different hub is chosen, then all the jigs and moulds must match this hub.

At the centre of the disk is a 65mm diameter hole. There should also be four holes drilled and tapped (threaded) for M10 rod between the magnet positions, at 220mm PCD. Screw four pieces of M10 rod, 20mm long, into these holes. These will bond to the resin and help to secure the casting onto the disk.

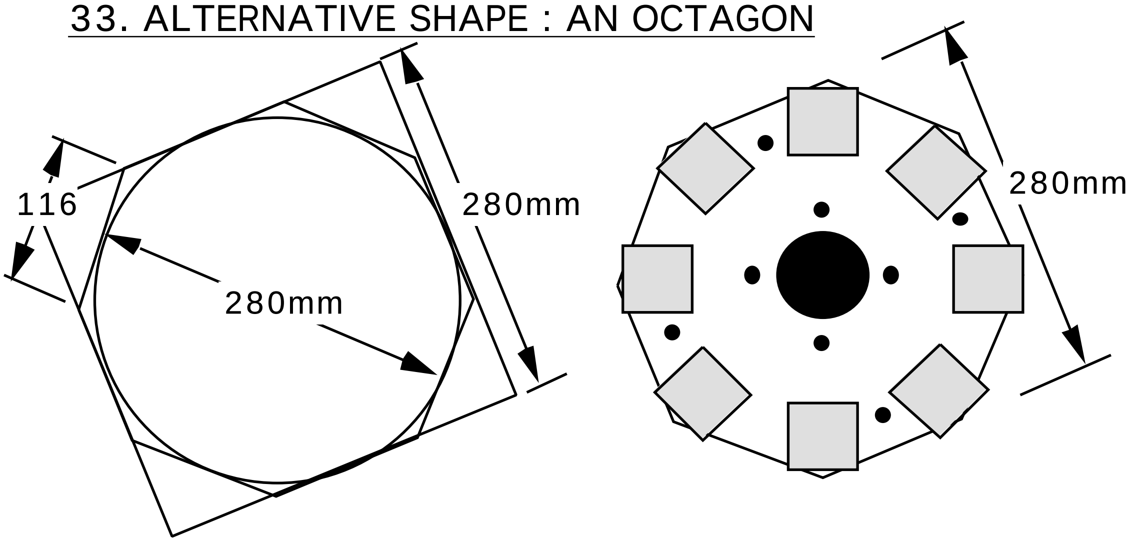
32. MAGNET ROTOR DISK



The magnet plates must be flat, not warped. It is not easy to cut the outer circle without warping the plate. A guillotine can cut steel plate into an octagon (see diagram 33), without warping the plate. This is an alternative way to make the rotor disk. First cut a square, draw a circle on it, and then cut off the corners at 45 degrees. The length of each edge is 116 mm.

The magnets will be placed on the corners of the octagon.

33. ALTERNATIVE SHAPE : AN OCTAGON



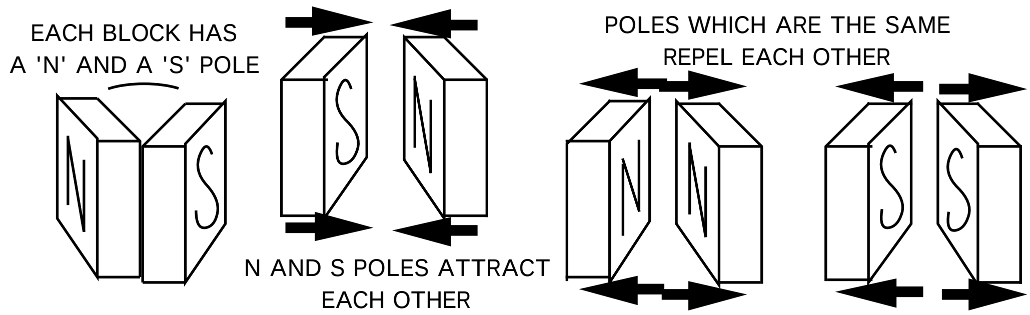
The central hole is made with a hole-saw or it can be cut out on a lathe.

Grind the steel disks until they are bright and clean, just before putting them in the mould for resin casting. Remove any grease with spirits.

Magnet blocks

There are 8 magnet blocks on each rotor. Each block has a north pole and a south pole (see diagram 34).

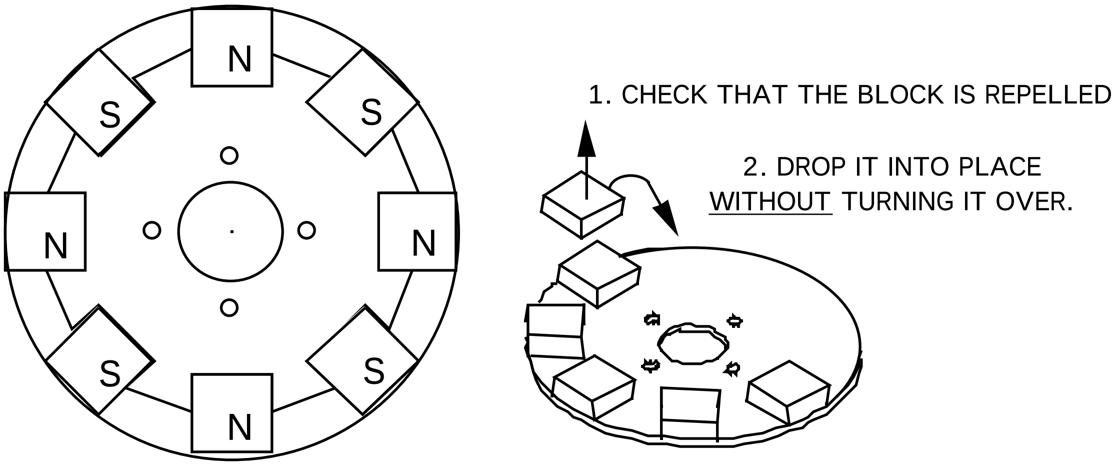
34. POLES ON THE MAGNET BLOCKS



Take care when handling the magnets. Magnets can damage floppy discs, music tapes, credit cards and other magnetic media. Separate them from each other by sliding them sideways. They attract each other with strong forces. Take care not to let them fly together - they may break. Never use a hammer to assemble the PMG. You may break a magnet or break the resin holding it.

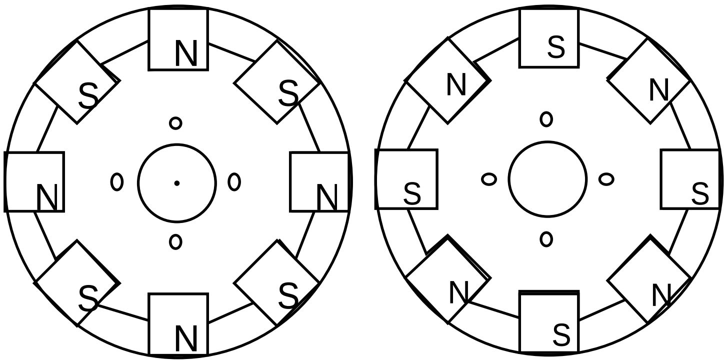
The top faces of the magnet blocks on the disk must alternate N-S-N-S-... There is a method to check that you are doing this correctly, as follows. Each time a magnet block is placed, hold it so that it repels the one before (see diagram 35). Then place it without turning it over. When they are all in, check with another magnet: it will be attracted, repelled, attracted, repelled, by each magnet in the circle.

35. PLACING THE MAGNET BLOCKS



The two magnet rotors must attract each other when the mounting holes are aligned. Check that the magnets next to the holes on one rotor are different from the ones next to the holes on the other rotor (see diagram 36).

36. THE TWO ROTORS ARE NOT THE SAME



Stainless Steel wire

When the PMG is turning, the magnets will try to fly off the rotors. There is a large centrifugal force pulling the magnet blocks to fly away. When we started building these PMGs, the magnet blocks were simply glued to the steel disks. When the PMGs turned fast, the magnets flew off, and the wind generators were destroyed.

Now we embed the magnets in a resin casting. Resin alone is not strong enough to hold the magnets. It should be reinforced. Wrap wire around the outside of the magnet rotors to hold the magnets in. Steel wire is strong enough, but steel would take the magnetism from the magnet blocks. We use stainless steel because it is not magnetic and it does not spoil the effect of the magnets. Stainless steel wire cable is used on fishing boats.

Before using any resin assemble the parts dry. Put the stainless steel rope around outside the magnets five times, and cut it off with a grinder or chisel. Tape it in several places so that it is in a coil, ready to drop into place later.

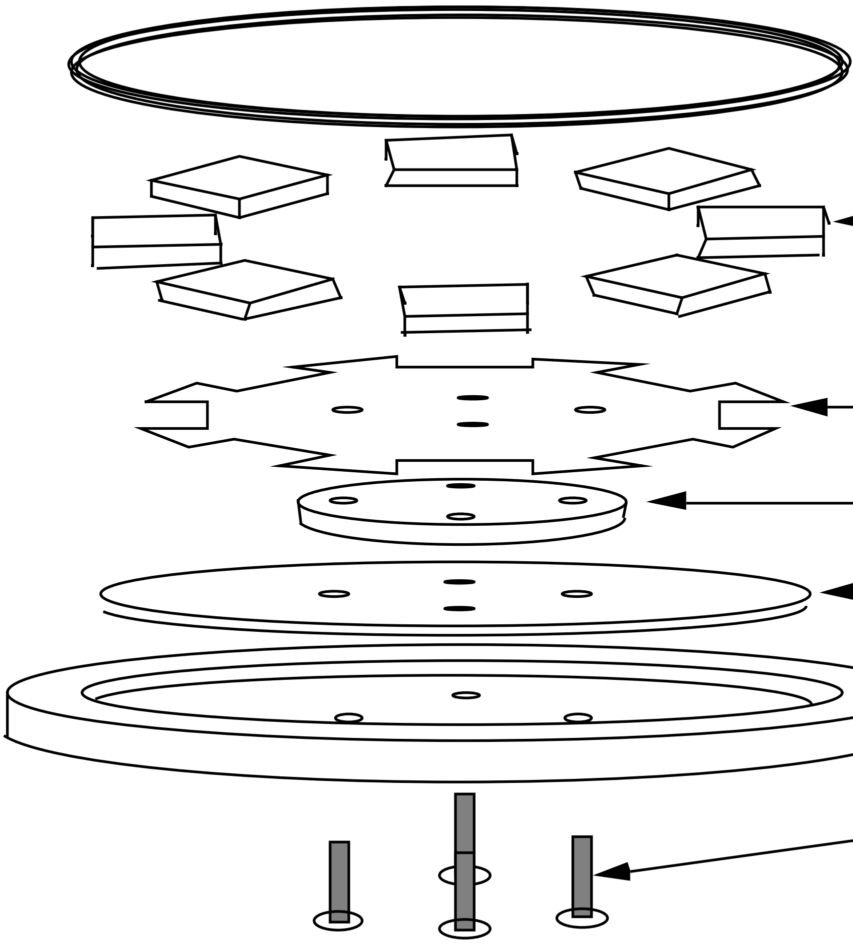
Rotor casting procedure

Before starting, check that everything is ready:

- the moulds are prepared with polish or release agent,
- the magnets and the magnet disks are clean and bright (no grease),
- 16 strips of CSM are ready to fit between the magnets
- the stainless steel wire is cut to length and taped
- the magnet positioning jig is ready

The amounts of resin mentioned in this procedure are enough for two magnet rotors.

37. MAGNET ROTOR MOULD ASSEMBLY



- Place four bolts through the holes in the outer mould, from below (see diagram 37). Lay a steel disk in the outer mould. Place the inner mould on top. Check the taper, and place the smaller face down, so that it can be easily removed after casting.

- Mix 200g of resin with 3cc catalyst. Paint it all over the steel disk. Add 20g of pigment for colour if required. Mix 100g talcum powder with the remains of the resin. Pour this mix around the edge of the disk until it fills the gap, level with the top of the steel disk.

- Place the magnet positioning jig onto the bolts. Place the magnet blocks on the steel disk, within the positioning jig. Take care that the poles of the magnets alternate - north, south, north, south.. Before you place a magnet on the disk, check that the underside of the magnet is repelled by the one next to it (diagram 35). When all the magnets are in, remove the positioning jig, and use it for the next magnet rotor. Remember : position the magnet blocks differently, so that the two rotors attract each other.
  Take care not to knock the magnets out of place, or they will slide together under the magnetic attraction.

- Fit nuts to the four bolts and tighten the central disk down onto the steel disk.

- Mix 500g of resin with 7cc of catalyst. Add 300g talcum powder. Lay small strips of CSM between the magnets and into the gap at the edge. Add resin until the CSM is soaked. Poke it, or vibrate it, to remove bubbles.

- Lay the coil of stainless steel wire loosely around the outside of the magnets, below the top of the mould. Do not let the wire fall below the magnets. Let it sit on the CSM. Take care not to move the magnets around.

- Mix 500g of resin with 7cc of catalyst. Add 300g talcum powder. Fill the spaces between the magnets until the resin mix reaches the top of the mould.

Leave the rotor castings to set hard (several hours) before you remove them from the moulds. Be patient when removing the rotors from the moulds. Do not use violent hammer blows which may damage them. Hit the mould, and not the rotor.

Four stages of the rotor casting procedure

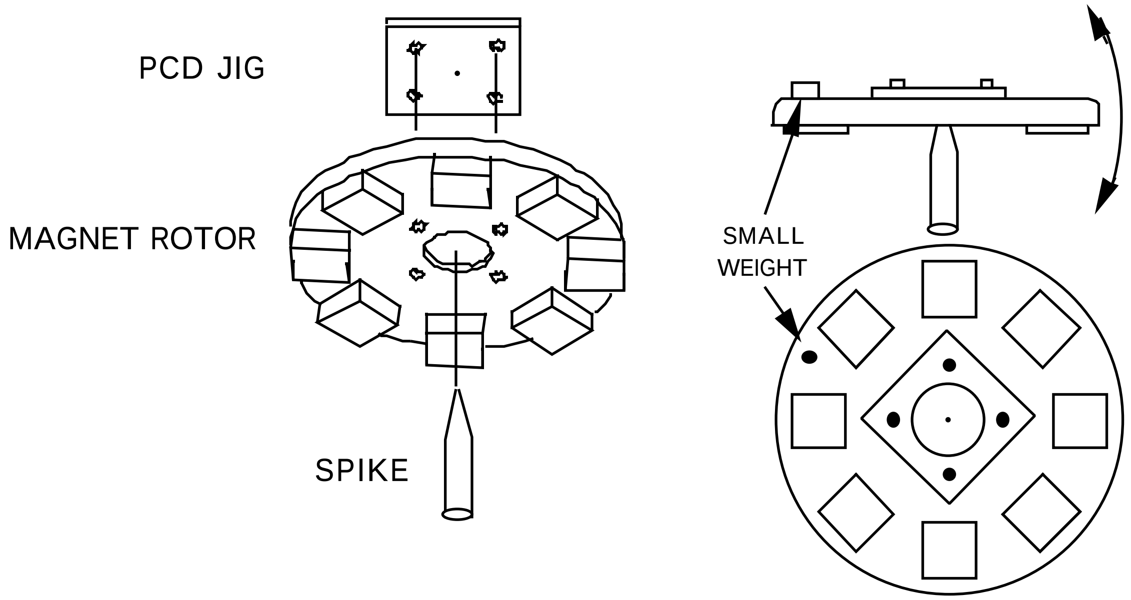
6. Assembly

Rotor balancing

Each rotor should be balanced, or the PMG will shake when it is turning. The whole PMG needs to be balanced again at the end, because the rotors may not be mounted exactly centrally. A different procedure is used for the final balancing in Section 6.

To balance a magnet rotor (see diagram 38), first attach the PCD jig (from diagram 11), using four bolts. Then balance the rotor on a spike as shown:

38. ASSEMBLY OF THE BALANCING JIG AND SPIKE



If the rotor will sit level, then it is balanced. If it will not sit level, then add small weights to it, or drill out some of the resin between magnets, until it will sit level. Turn the PCD jig around on the rotor, and check it again. Replace any weights with pieces of M10 threaded rod, screwed into holes in the resin between the magnets.

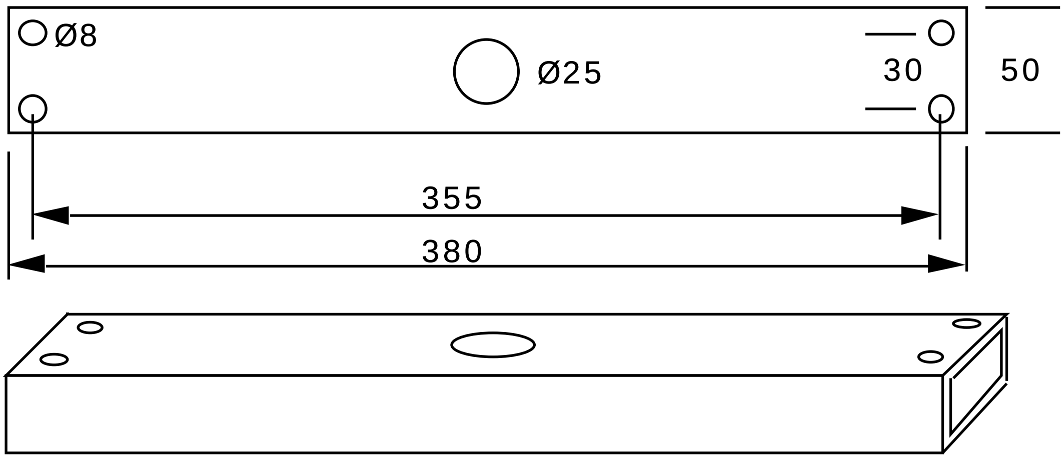
PMG spine and bearing hub (see diagram 39)

Make the spine of the PMG from a 380mm length of 'box section' steel tube 50x25x4mm (sometimes called RHS). Mark the exact centre of one large face, and then mark four 8mm holes, in the same way as for the 'stator studs jig'. It could also be possible to use the stator studs jig to help drill the holes.

The hole at the centre is 25mm (or to suit the shaft used). Drill this with a hole-saw, or bore it on a lathe.

39. THE BOX SECTION SPINE

DRILL HOLES WITH A PILLAR DRILL FOR ACCURATE ALIGNMENT

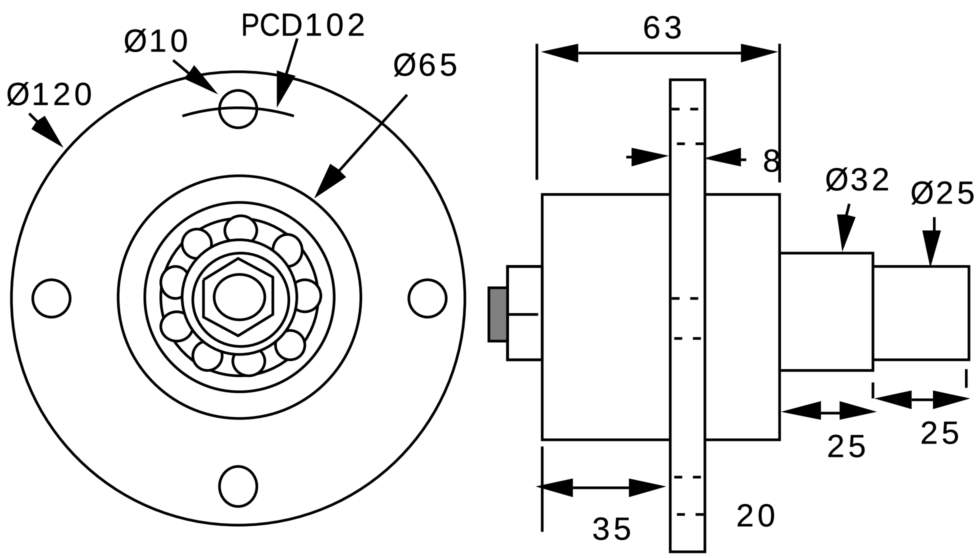


Weld the shaft in the 25mm hole. Take care to hold the shaft as square as possible (90 degrees) to the spine, when welding it.

The bearing hub (diagram 40) fits on the shaft. It has two 50x25 mm deep-groove ballraces in it, with a spacer between them. It needs a plastic cap over the end to keep dirt out of the bearings.

Do not forget to grease the bearings. Pack them with grease around half of their circumference only. Do not fill them entirely or they will become stiff to turn.

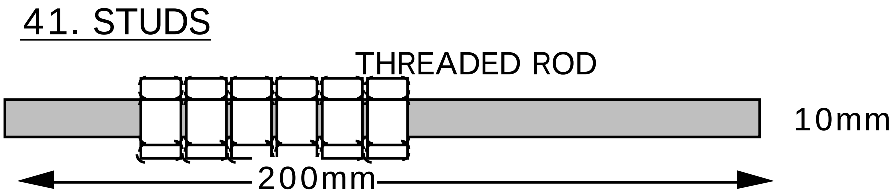
40. THE BEARING HUB



Photos show the rear magnet rotor being fitted

PMG assembly

- Cut 4 pieces of M10 threaded rod, each 200 long. They are used as studs to hold the magnet rotors to the hub. The wind turbine blades will also mount onto these studs.
- Put 6 nuts onto each stud) see diagram 41).
- Fit the studs through the holes in the bearing hub, from the front
- Put the rear magnet rotor onto the ends of the studs.
- Put a nut on the end of each stud, and tighten the other nuts down, so that the rear magnet rotor is attached to the back of the hub flange. The outer end nut should be sealed with paint or thread-sealant.
- Place the spine in a vice with the shaft upward. Place the hub onto the shaft. Do not hammer the magnet rotor while fitting. Fasten the hub to the shaft with a nut and split pin. Do not over tighten the nut. Fit a dust cover over the end of the bearing hub.



- Rotate the magnet rotor past a piece of brass wire. Do not use steel wire, because it is attracted to the magnets. The magnet faces should all be at the same height +/- 0.5mm. If not, use very thin shims between hub-flange and rotor-disk, to adjust the rotor.
- Using a spirit level, adjust the spine in the vice until the magnet rotor is level. Check both ways: north-south and east-west.
- Take the stator. Fit one 8 mm nut onto each support stud. Screw them right down.
- Place the stator over the rear magnet rotor

and fit its support studs into the holes in the spine. Fit more 8 mm nuts to the ends of the studs.

Fitting the stator

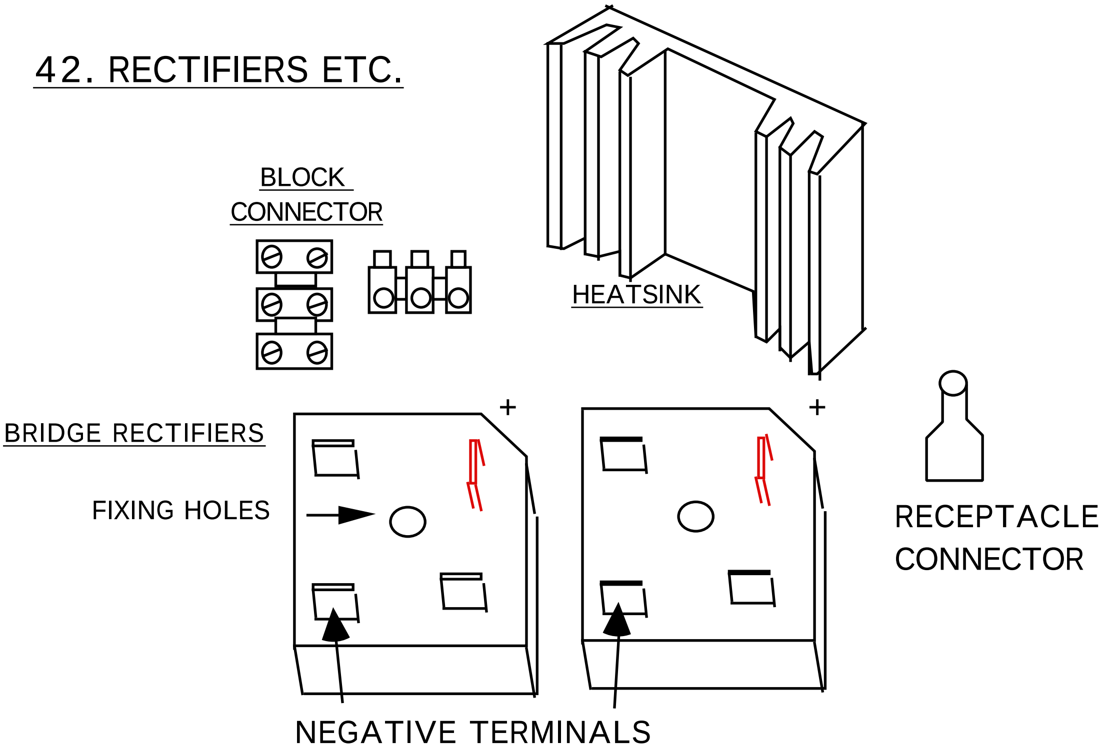
- Slowly lower the stator, and rotate the rear magnet rotor. Keep the stator level in both directions. You will hear a sound when the highest magnet touches the stator.
- Use the nuts to raise the stator equally 1mm on all four studs.
- Fit some washers to the 10 mm studs which hold the rotors. Always the same number of nuts and washers on each stud. A total of six nuts and two washers may be enough. Then fit the front magnet rotor.
- If the front magnet rotor is less than 1mm from the stator at any point, then add more washers under it. If it is much more than 1mm from the stator then remove washers. To find the correct number it is necessary to remove washers until it begins to rub the stator. Then add 1mm.
- When the front rotor is 1mm from the stator, then fit more nuts on top, and tighten them securely.

Fitting the front magnet rotor

Electrical Parts

The next section (Section 7) will describe how to connect the rectifier to the stator. I recommend using two 'single phase bridge rectifiers' (see diagram 42). They come in blocks 30 x 30 mm. The positive terminals are both connected to the battery positive terminal. (They are often at right angles to the other three.) Both negative terminals are connect to the battery negative. The remaining four terminals are for AC connection to the stator. You will probably only need to use three of these, connected as desired to suit the speed (see Section 7).

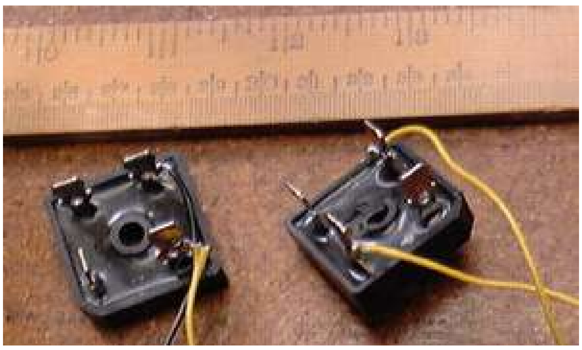
42. RECTIFIERS ETC.



'Block connectors' are useful for connecting the wires from the stator. Alternatively soldering or crimping would be fine.

Use solder, or crimped 'receptacle' connectors, to connect wires to the rectifiers. Take care not to overheat the rectifiers while soldering. Bolt the rectifiers onto the heatsink, which will probably look like the one in the diagram, but can be any piece of aluminium approximately 250 grams or more in weight.

Keep all the connections under a weatherproof cover.



Two bridge rectifiers

7. Testing and connecting

Check that the PMG has no faults before it is put into use. It will be much easier to correct the faults now, than to return the unit to the workshop later.

Mechanical testing

Mount the spine vertically in a vice. The magnet rotors are free to move. The shaft is horizontal, as it will be in a wind generator. Check that the wires are not touching each other, creating a short circuit which makes the PMG harder to turn.

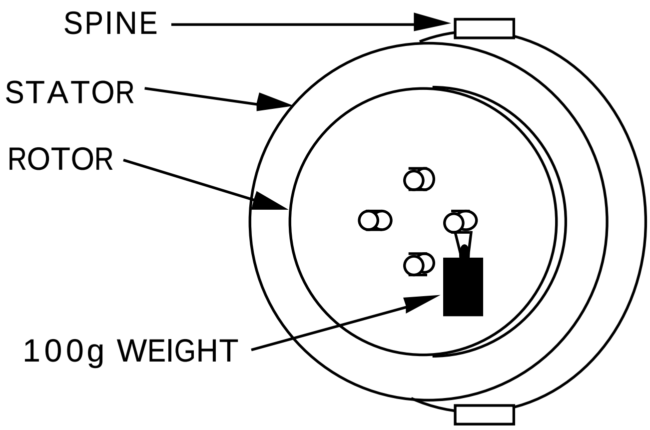
Check that the rotor will spin freely.

Spin the rotor and listen for sounds. There should not be any scuffing or brushing of the rotor, as it turns. It should spin freely for several seconds and gradually come to a halt. If it slows down rapidly then there may be an electrical fault, or the bearings may be over-tightened.

Grasp the stator with both hands. Push one side backward while pulling the other side forward, while the rotor is spinning. It must not touch the rotor. If there is a rubbing sound, then it may be necessary to disassemble the PMG and assemble it more carefully, with more space between the rotor and the stator. Or it may be possible to correct the problem by making minor adjustments to the stator mounting studs.

Stop the rotor with one of the studs in the 3 o'clock position (diagram 43). Hang an object weighing 100 grams on this stud. The rotor should begin to turn clockwise. If it will not turn, then the bearings may be over-greased or too tight.

43. HANG A WEIGHT ON ONE OF THE STUDS



Checking the balance

The rotors have already been balanced in section 6. The wind turbine blades must also be balanced in the same way. When the unit is assembled, you should check the balance again using the new procedure below. This is necessary because the rotor disk may not be perfectly central on the PMG shaft.

Repeat the starting test (diagram 43) with each of the four rotor studs in the 3 o'clock position. Try different weights, and find the lightest weight which will start the rotor turning. If one stud needs much more weight than another, then the rotor is not balanced. Fix small weights to the rotor until the balance is correct.

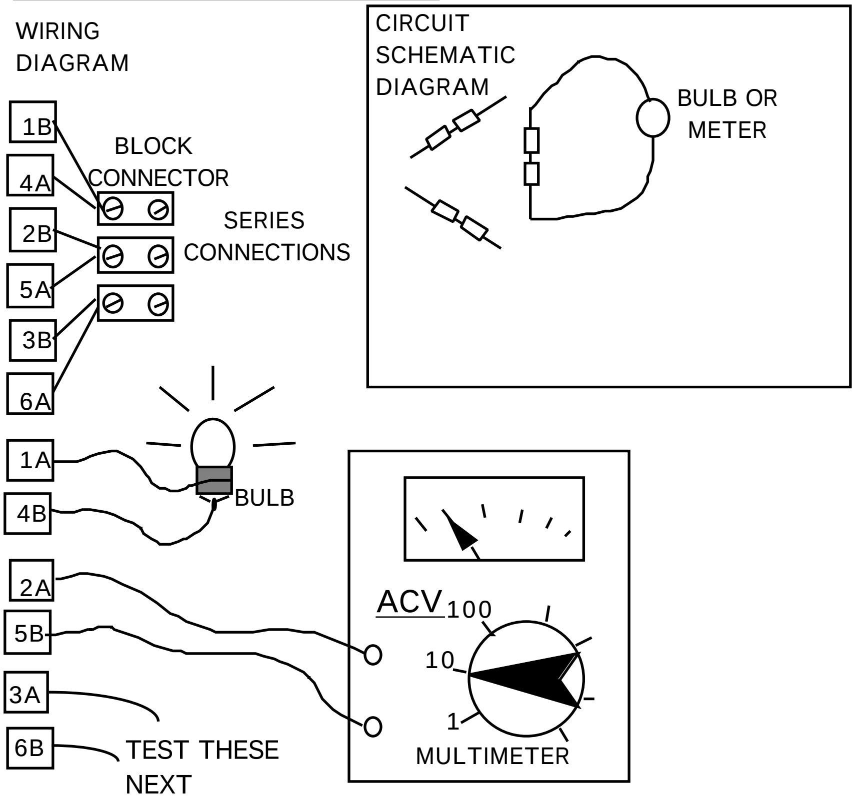
Electrical testing

Coil connection test

It would be helpful to have a multimeter when testing the PMG, but it is possible to do some basic tests with a 3 volt torch bulb. See diagram 44.

- Connect the wires 1B to 4A, 2B to 5A, and 3B to 6A. (Series connections of pairs of coils which are in the same phase.)
- Set the multimeter to '10VAC' or similar (if you have one).
- Connect the meter, or a bulb, between the wires marked 1A and 4B.

44. TESTING THE COILS



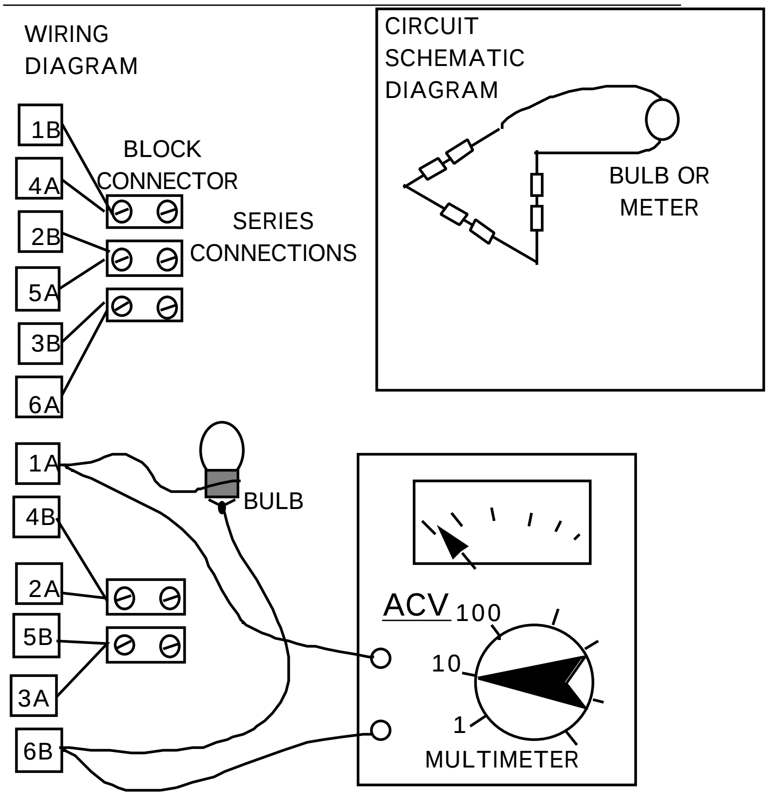
- Rotate the PMG slowly by hand, about one revolution per second.
- The meter should give a reading of about two volts, or the bulb should flicker.
- Repeat the test with two more pairs of wires: 2A and 5B, 3A and 6B.
  In each case the result should be the same.

If there is no reading, or a very low reading, then check that the series connections (1B-4A, 2B-5A, 3B-6A) are correct. If all these connections are good, then it is possible that one coil has been reversed (placed upside-down).

If any coils have been reversed, then it is necessary to do another test (see diagram 45), to find out which one is at fault. Connect 4B-2A and 5B-3A as shown in the diagram. Now test between 1A and 6B. There should NOT be more than a very small voltage. If there is a voltage, or the bulb lights up, then reverse the connections (swap A for B) on the coils until the voltage drops to a very low level.

When the faulty coil has been found, label the tails again, with A and B at the correct ends.

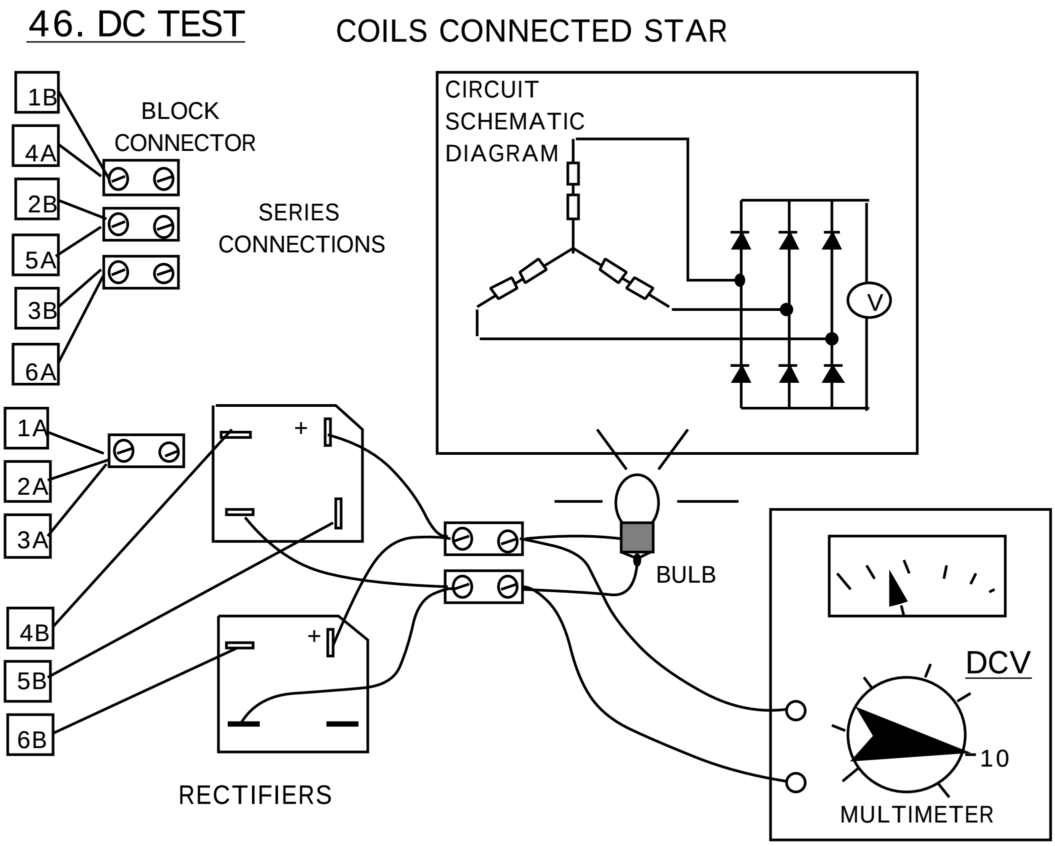
45. CHECKING FOR A REVERSED COIL



There will always be a small voltage in this test, because the coils are not perfectly positioned in the mould. If the test gives more than one volt, then it should be possible in future to make a better stator by placing the coils at exactly equal distances apart in the mould.

DC output test

When these tests have been completed and the results are correct, then connect the rectifier, as shown in diagram 46. Connect the tails 1A, 2A and 3A together. Connect each of 4B, 5B and 6B to any three of the rectifier AC terminals (marked with 'S' symbol). This is the 'star' connection. Connect a bulb to the output. If possible, also a multimeter on 10 VDC (or similar).



Rotate the rotor by hand as before, approximately one revolution per second (60 rpm). The meter should show a steady reading around 4 volts DC (or 3 volts with the bulb present). The bulb should glow with a steady light, not flickering as before.

If there is no reading, or the bulb flickers, then there is a faulty connection or a faulty rectifier. Check the connections carefully. Try another rectifier.

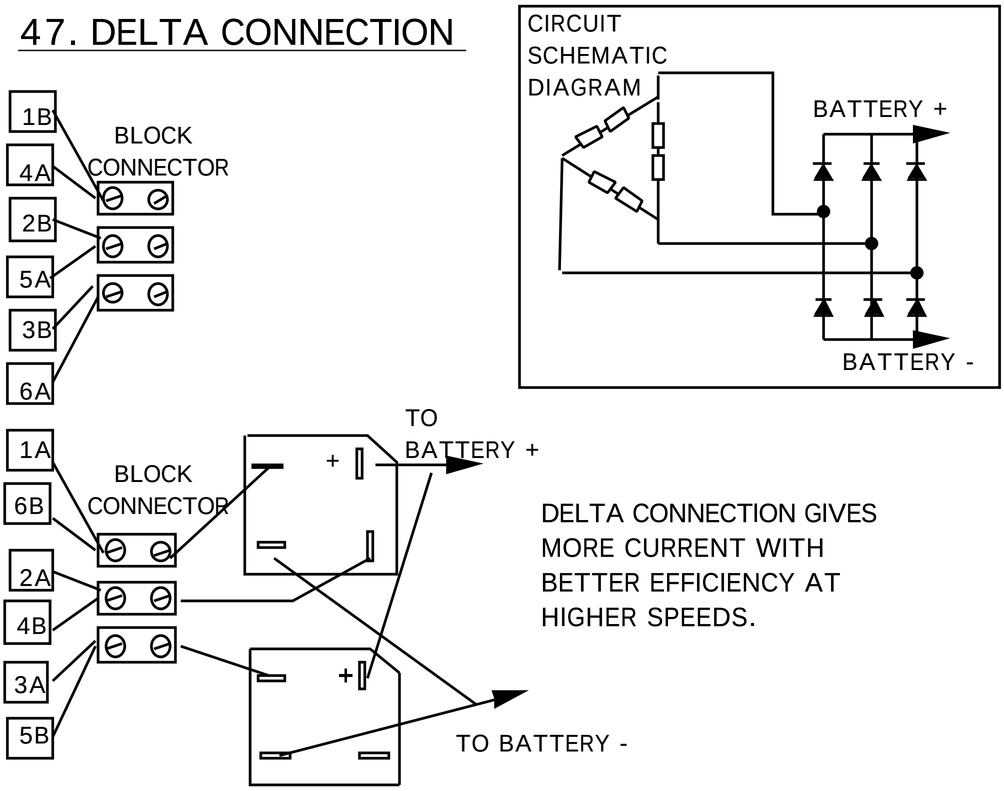
You can also test the PMG without a bulb or a meter. Simply connect the positive and negative wires from the rectifiers together (all four) in a 'short circuit'. Now try to turn the PMG. It should be stiff but smooth to turn. If it trembles as you turn it then there is a fault.

Connecting the PMG to the 12 volt battery

Star and Delta connections

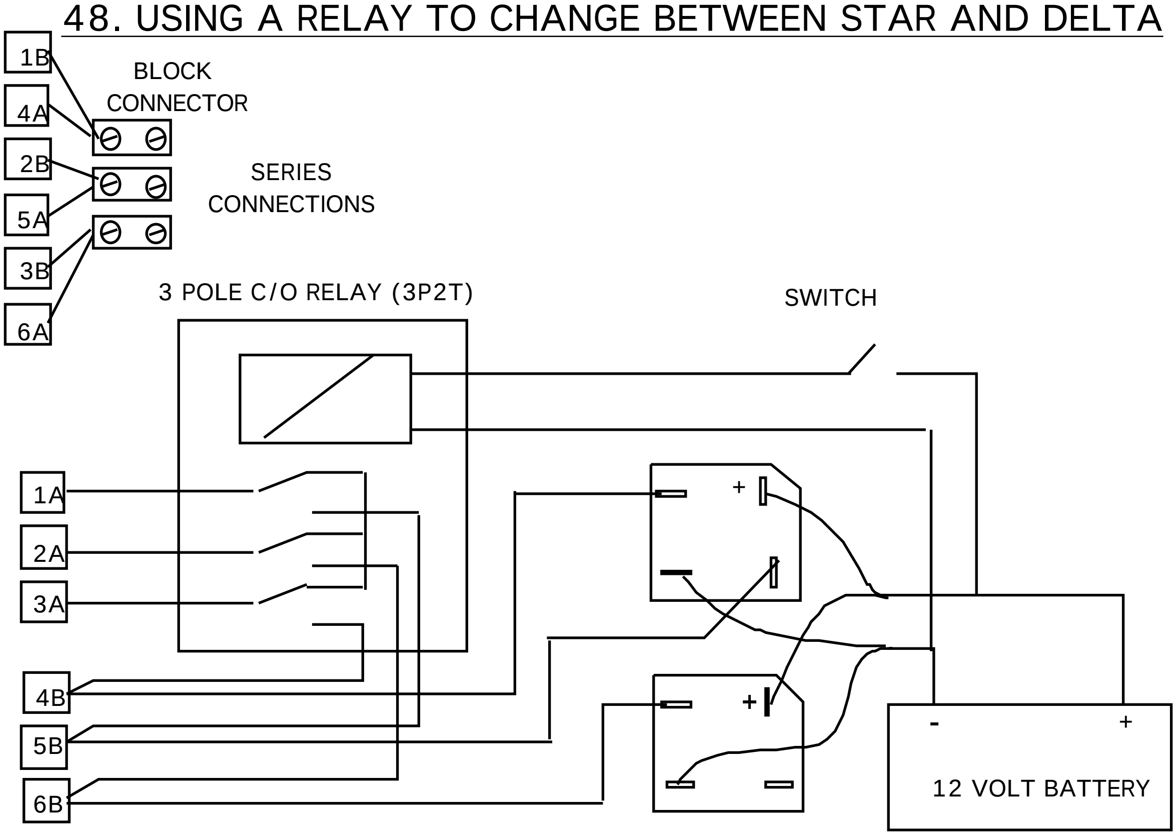
For low windspeeds, connect the coils 'star' as above. For high winds, and higher current output, connect the coils 'delta', as in diagram 47.

47. DELTA CONNECTION



It is also possible to wire a relay (see diagram 48) which will switch the connections from star to delta and back as desired.

48. USING A RELAY TO CHANGE BETWEEN STAR AND DELTA



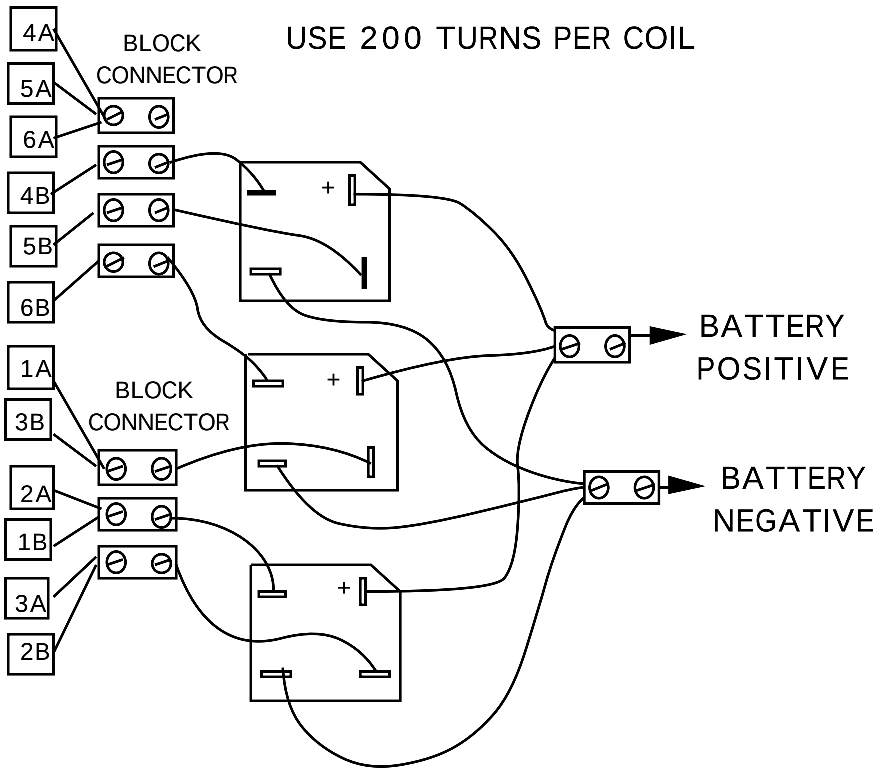
Yet another option for connecting the stator

At the time of writing this document, the above arrangement (using a relay to change the connections) is still under development. Later, an electronic control circuit will be available to automate the changeover. This is all very complex, and it so it can go wrong.

If you do not wish to have to change the connections between low and high windspeeds, then the PMG will still work. However, the efficiency will be slightly less. Three are two options:-

- If you expect mainly low windspeeds, then you can simply use the star connection shown in diagram 46.
- If you also need higher power in higher winds, you can use a 17AWG wire (1.2 mm diameter) to wind coils with 200 turns each. Then you can connect one group in delta and one group in star as shown in diagram 49. Note that you need six AC terminals on the rectifiers so you will need three rectifier blocks.

49. STAR/DELTA CONNECTION



PMG-to-Battery Cable size

The cable from the PMG to the battery can be either three-phase-AC or DC. If the rectifier is mounted at the wind generator, then it will be DC. This is only slightly more efficient than three phase AC.

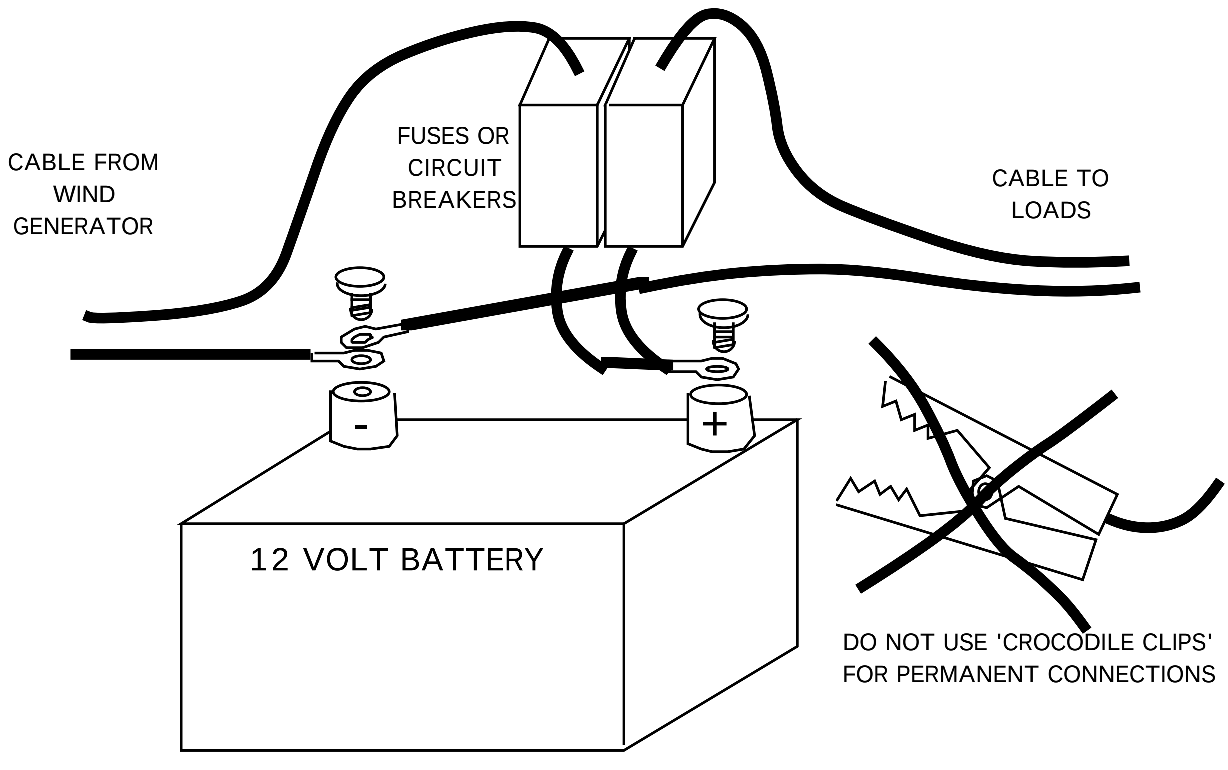
At 12 volts, the size of the cable must be large. Even if the current is only 15 amps, it is advisable to use a heavy cable. For a distance of 20 metres, the recommended size is 6 mm^2 (10AWG). The diameter (thickness) of each copper wire is about 3mm. A 15 amps current flowing in this cable will lose 15% of the power from the wind generator as heat in the cable. If the cable is longer, it should be heavier, in direct proportion.

Electrical Safety

There is no danger of electric shock from a 12 volt battery. But if the wind generator is disconnected from the battery, and running fast, then the voltage will be higher than 12 volts, maybe as high as 50 volts. Do not run the PMG at high speed without a battery connected.

The battery contains stored electrical energy. When there is a short-circuit fault in the wiring from the battery, for example the positive and negative wires touching each other, this energy is released in a very high current. The cable will heat up and burn. Therefore it is necessary to use a fuse or a circuit breaker on every wire which attaches to the battery positive terminal. Use one fuse for the wind generator and a separate one for the cable to the load (the lights, or whatever uses the power). See diagram 50.

50. CONNECTING THE BATTERY



Battery acid is bad for the clothes and the skin. Do not splash it. Be especially careful of the eyes. If there is an accident, the best cure is to flush with plenty of water.

Batteries produce hydrogen gas, which is very explosive. Do not make sparks near a battery or it may explode, and throw acid in the eyes!

Battery Charging

Lead acid batteries should be kept in a charged condition. In the case of a wind powered system, you may have to wait for a wind to charge the battery. But be careful not to discharge the battery too deeply, or to keep it too long in a discharged state, or it will be damaged (sulphated) and become useless. Stop using a battery before it is fully discharged. If there is a problem with the wind generator, then charge the battery from another source within two weeks.

Charging the battery too hard will also damage it. At first, when the battery is discharged, it is safe to use a high current, but later the current must be reduced or the battery will overheat and the plates will be damaged. The best way to fully charge a battery is to use a small current for a long time.

Watch the battery voltage. If the battery voltage is below 11.5 volts, then it is being discharged too much. If the voltage is high (over 14 volts) then the battery charging current is too high. Use less current or more current in the loads to correct these problems. If there is no voltmeter available, then the user should watch the brightness of the lights and follow these rules:-

- Dim lights, mean low battery. Use less electricity!
- Very bright lights mean too much windpower. Use more electricity!

A good way to use more electricity is too charge more batteries in windy weather, perhaps charging batteries from neighbours' houses.

There are simple electronic circuits which can regulate the battery voltage automatically. They are called 'low voltage disconnects' and 'shunt regulators'. If the user is not willing to watch the battery voltage, then it is necessary to fit a disconnect and a regulator.

8. Additional information

Using polyester resin

Polyester is the plastic substance used in fibreglass work for building boats, car body parts, etc. Various things are added to it to make it work better for various jobs. Talk to your supplier and explain what the resin is to be used for. Your supplier should be able to help you.

Hardeners

There are two systems used to harden polyester resin, and each system uses two chemicals. For resin casting and most fibreglass work we use peroxide and cobalt. ('Body filler pastes' use the other system.)

Cobalt is a purple fluid. Ask the supplier to mix the right amount of cobalt into the resin. After it is mixed, the resin must be stored in the dark, or it will harden.

Peroxide is a hazardous chemical. Avoid contact with skin. Store in a PVC container, in the dark, below 25 degrees C. Never mix it with cobalt (except for the cobalt already in the resin), or it will explode. Mix very small quantities (about 1-2%) of peroxide with resin or it will overheat.

Wax-free 'Air inhibited' resin 'B'

This type of resin is used for 'gel-coats' on boat moulds, where the resin is going to be built up in stages. We do not recommend using this resin for the PMG. Any exposed surface will remain tacky indefinitely. Ask for resin 'A', or better still 'casting resin'.

Thixotropic additive

A special powder of very light silica is often added to resin to make it thicker, so that it is easier to spread it with a paint brush. This powder is not needed for casting resin . If it is already added, it does no harm.

Styrene monomer

Approximately 35% of the resin as supplied is styrene monomer. This is used for thinning the resin. It causes the smell. It is possible to add a little more styrene monomer (10%) to make it more liquid.

Pigment

Pigment is used to colour the casting, if a coloured finish is desired. Add pigment to the first mix, which will be on the outside of the casting. Add no more than 10% pigment to the mix. It is not necessary to add pigment to the resin. Without pigment, the casting is transparent and the coils are visible.

Fibreglass

The resin has almost no strength without fibreglass. It is available in sheets of 'chopped strand mat' (CSM). It is also possible to buy just chopped strands, and to mix them with the resin. This is useful for the magnet rotor castings. Add a little resin to the fibreglass, and press out all the air bubbles, before adding more resin.

Talcum powder

Talcum powder is a cheap filler which can be mixed with the resin after the peroxide has been added. It makes the resin mixture much cheaper, and a little thicker. Resin can be mixed with up to twice its own weight of talcum powder. The powder also helps to reduce the heat build-up in large resin castings.

Using painted moulds in Peru

Mould preparation

Polyurethane varnish

Ordinary paint should not be used on moulds. Better to use nothing. If possible, use polyurethane varnish. This will prevent moisture coming out of a mould made from wood, plaster or clay. Smooth the varnish off with sandpaper before polishing it.

Polish

Polish the mould several times before using it first time. Rub all the polish off with a rag and then leave it some hours and do it again. Silicone polish is not compatible with PVA release agent. Use wax polish.

PVA Release agent

Paint this over the mould and let it dry. It forms a sheet of PVA, which greatly helps to separate the casting from the mould.

Using the PMG for hydro power

The PMG can also be used for charging batteries from small hydro turbines. It will be ideal for low head, low power sites, because it is efficient even when producing only a few watts. It can also be used for higher head higher power sites, because it is capable of high power outputs at high rpm.

There is a danger of rust damage to the magnet rotors in a very humid or wet environment such as in a hydro application. It is advisable to galvanise or plate the steel components with zinc.

Low head sites

Here are some examples of conditions where the PMG could work without modification (connected delta). It would need a simple 'impulse' runner mounted on the front magnet rotor.

Head (metres)	10	10	5
Flow (litres/second)	1	5	5
Net Power(watts)	40	200	100
pcd runner (cm)	37	27	23
speed (rpm)	325	440	360

High head, high power

At higher rpm, higher power is available from the PMG. Doubling the speed can also double the output voltage and the current, offering four times as much power with the same efficiency as before. The PMG may overheat under these conditions, so it may be better to keep the current the same, and have better efficiency. Much will depend on whether the water is used for cooling.

In any case, increasing the speed improves the PMG's power handling abilities considerably. It would be risky to run a wind turbine at high speeds, because of the problem of gyroscopic forces on the rotors, but this problem does not arise with hydro power, because the shaft axis is fixed.

If higher voltage is not required, then the stator winding can be changed to give 12 volts (as before) at the higher speed, but deliver higher current without overheating. This is done by connecting the coils of each phase in parallel instead of in series. Or the coils can be wound with fewer turns of thicker wire. This is better still, because parallel and delta connections can suffer from parasitic internal currents.

Do not use the star/delta connection (diagram 49) for hydro power where the speed is constant. There is no advantage.

SEI Homebuilt wind generators workshop

Guemes Island April 2003

Main picture page

hugh@scoraigwind.co.uk

"The most fun you can have with your pants on!"
(Dan Bartmann of wondermagnet.com)

Thanks to **Ian Woofenden** for providing many of the pictures on these pages.
These pages may be **slow** to load because I have gone for high resolution images in this case.
If you have a slow connection, why not go off and get a breath of air
or make a cup of coffee and come back soon.

More courses
Solar Energy International
Axial windmill plans for sale

Links to other picture pages of the workshop course (click on a pic)

--

sorry about the smell, Rani :-)

Miscellaneous pictures.........

Why does the sun never come out for the group photo?

This is the bigger of the two machines we finished during the course. Rotor diameter is 8 feet (2.4 metres).


Guemes Island Resort, where we stayed. Chris Freitas of Ouback stops by with his wireless winch.

Robert Preus came to talk to us. Robert is the distributor for African Windpower in the USA. There was one AWP machine in the classroom, and another on a 150 foot tall tower across the road. The one on the tower looks pretty small.

Later, Robert gave us a talk about how wind turbines fail. In the picture below he has a hub from a Jacobs machine.

Andy Gladish was in charge of metalworking but he can also do **stick** welding.

Here are Dan Fink and Dan Bartmann. They supplied the magnets, the wire and some music.

They also worked hard on the smaller of the two machines. Here Dan Bartmann applies some subtle persuasion.

An evening session on 'magnets at work and play'

Course staff from top left : Ian Woofenden (SEI and Home Power), Brain Faley (Shoreline Power), Andy Gladish and BJ Daniels of Guemes
Hugh Piggott, and Win Anderson and Michael McGuinnes of Guemes
We were using Win's shop for the week. BJ and Win helped with tbe woodworking.

Dan Whitney came back and brought the machine he built last time using a Ford truck brakedrum.

Putting the larger machine onto the tower for erection. The tail is a map of the island.

The big machine is on the tall tower (twenty feet up but still not nearly tall enough) and the little 4' diameter machine is on a short stand in the foreground.

Of course we had no wind to speak of and the best I saw was a 7 watt ouput.

Later we did truck testing of the small machine. I recorded 30 amps output at 16 volts. But to get that output I had to hold down the furling tail and we had to hit about 45 mph. Not very scientific, but lots of fun!

At 30 mph we got about 10 amps at 15 volts and the tail was starting to furl.

Links to other picture pages of the workshop course (click on a pic)

--

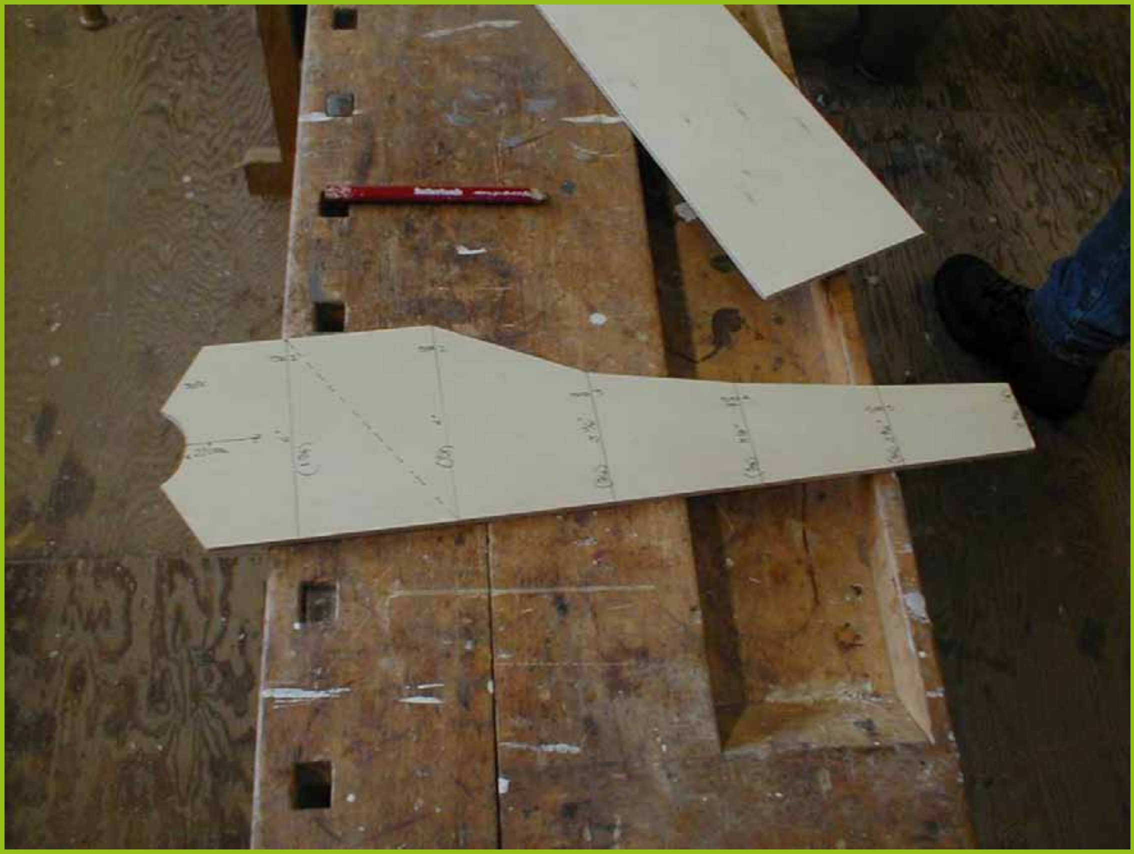
sorry about the smell, Rani :-)

Blade carving at the homebrew workshop

Guemes Island April 2003

Main picture page

More courses Solar Energy International Axial windmill plans for sale



The first thing that BJ and Win did was to make templates for the blade shapes so we could select our wood and then draw around the shapes.

Jim and Doug marking out the blade shapes.

Rani on the bandsaw cutting out the blade chord width taper.

Adam makes three of the small blades the same shape.


ES

Doug and Justin figure out the ramp at the root of the blade.

Ryan using the draw knife. Nice work.

The slow approach is to kerf the wood out by cross-cutting.

Dan and Kelly. Kelly came to the last course, and brought his machine back to show this course.

Ellyn using one of many approaches to cutting out the 'scoop'. I prefer to use the draw knife for this job.

Dylan using a scraper.

Drilling holes in the hub for mounting the blades on the front of the alternator.

Two ways to hold the hub still while getting the tips equally spaced.

The blades on the alternator (8' diameter machine).

Main picture page

More courses Solar Energy International Axial windmill plans for sale

Metalworking at the homebrew workshop

Guemes Island April 2003

Main picture page

More courses Solar Energy International Axial windmill plans for sale

We had a nice big open space beside Win's shop for metalwork.
Later in the course we also used this well ventilated area for the resin casting.

Ellyn cleaning up some disks

Aaron got the bandsaw working. Slow but sure. Also good for fancy work.

We knew to look away during welding - but I can't resist a picture.

The holes in the disks were too small for the GM hubs we had available, so we had to enlarge the holes.

Andy getting the disks to run true before drilling.

Peter drilling through the hubs and into the steel disks for perfect alignment.

Brett making the alternator mounting brackets. Note the large hole for the bearing housing (below).

Tacking the stator lugs on.

Two of the three mounting frames we built for the larger machine.

Andy cuts the end of the tail boom into a bird's mouth to fit the hinge.

Cutting surplus plate off the top of the tail hinge outer tube.

Welding the tail boom to the hinge outer pipe.

Kelly and Aaron check out the high end stop for the tail boom.

Justin tacks the 'T piece' to the tail vertically.

Main picture page

More courses Solar Energy International Axial windmill plans for sale

Resin casting at the homebrew workshop

Guemes Island April 2003

Main picture page

More courses

Solar Energy International

Axial windmill plans for sale

Barry cutting out the shape of the cheeks for the coil winding machine.

Ray cutting out a stator mould.

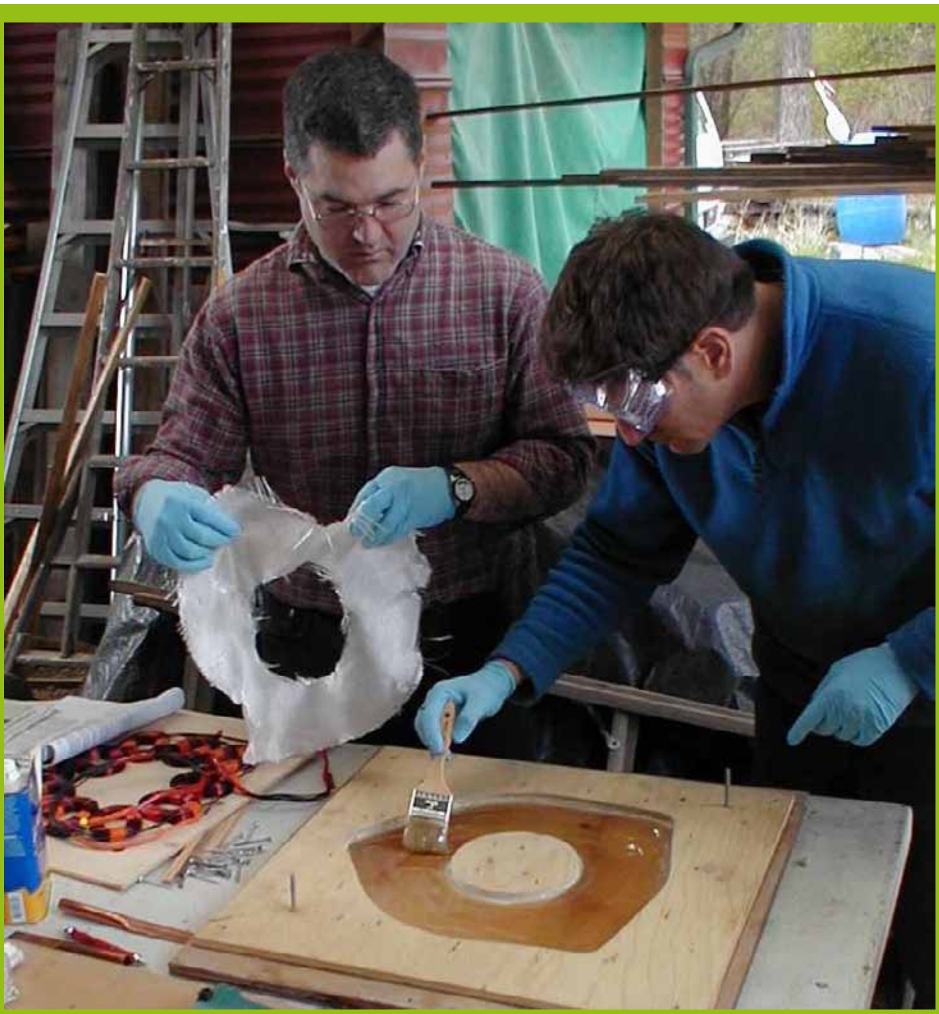
Coil winding. Andy Swingler at work. Aaron and Dylan piling up coils.

Jonathan and Dan cleaning the enamel off the wires ready for soldering.

Brian Faley was in charge of the resin cast components. The electrical and magnetic parts of the alternator were cast in polyester (fibreglass resin).

Brian, Hugh and Rani looking at the coil connections and how the wires will emerge from the stator.

Jim and Jim mixing resin. Measuring out the catalyst with a syringe.

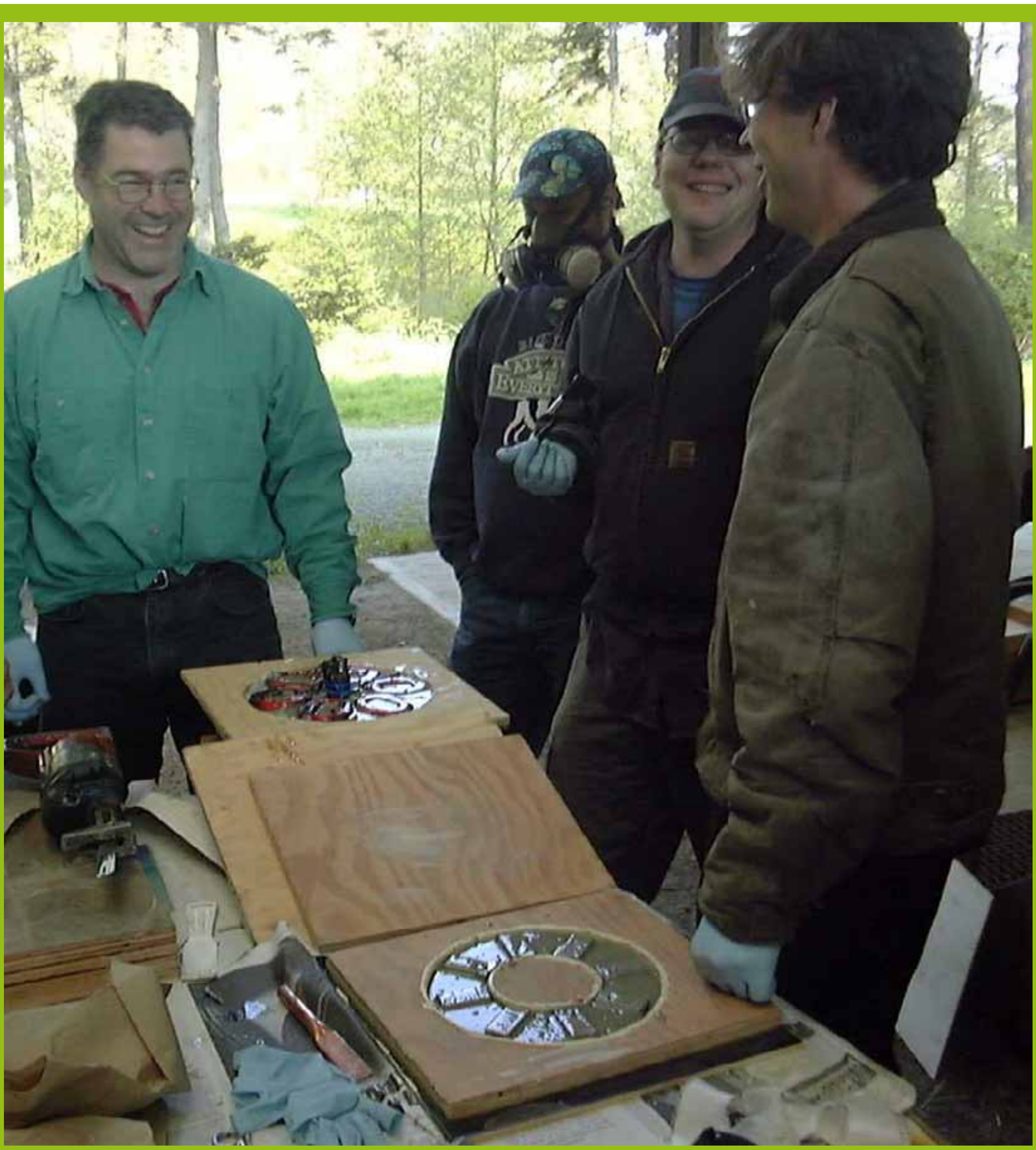


Adding magnets. The respirator is to protect against styrene monomer solvent fumes from the polyester resin.

Find the Magnets at this address

Mike tightening down the island. He has to be very careful the magnets don't grab his wrench (American for spanner).
The magnets did get him first time he tried.

Jim VanGorden getting the stator out of the mould. The wires are holding it to the cover.



The Dans working on the castings for the small machine.
Below is a close-up of the stator mould showing how we keep the shaft alignment square to the stator disk.
There is only one magnet rotor in the small machine. But the stator is cast onto the end of a tubular shaft.

[Find the Magnets at this address]

Castings curing under the heat lamps. We should have put these castings out in a shed. Too many people suffered nausea and headaches from the fumes.

Main picture page

More courses Solar Energy International Axial windmill plans for sale

Wind turbine assembly at the homebrew workshop

Guemes Island April 2003

Main picture page

More courses Solar Energy International Axial windmill plans for sale

The small (4' diameter) machine assembly

We have built the alternators and carved blades for the smaller machine on a couple of courses in recent months, but this was the first course on which we finished one with tail and everything.

Dylan does some benchtesting for the Dans

We found out that one coil was upside-down. Some keyhole surgery was required to reverse the connections.

The complete machine with its furling tail on. The tail is a map of Guemes island. Looks good doesn't it?

More bench tests.
The new improved version of the yaw head for the small machine ->

Assembly of the larger machine was routine.

The stator on and ready for the front magnet rotor.

Bench tests

Win adds his tail.

Brett and Justin balancing the blades.

Main picture page

More courses Solar Energy International Axial windmill plans for sale

African Wind Power 3.6m diameter wind turbine

Green 1999

Here is some further information about the 3.6. See also the Temaruru page.

The wind turbine is available in battery charging format for 12, 24, 48 or other voltages as required. A high voltage version with transformers is being tested. Pumping versions are planned.

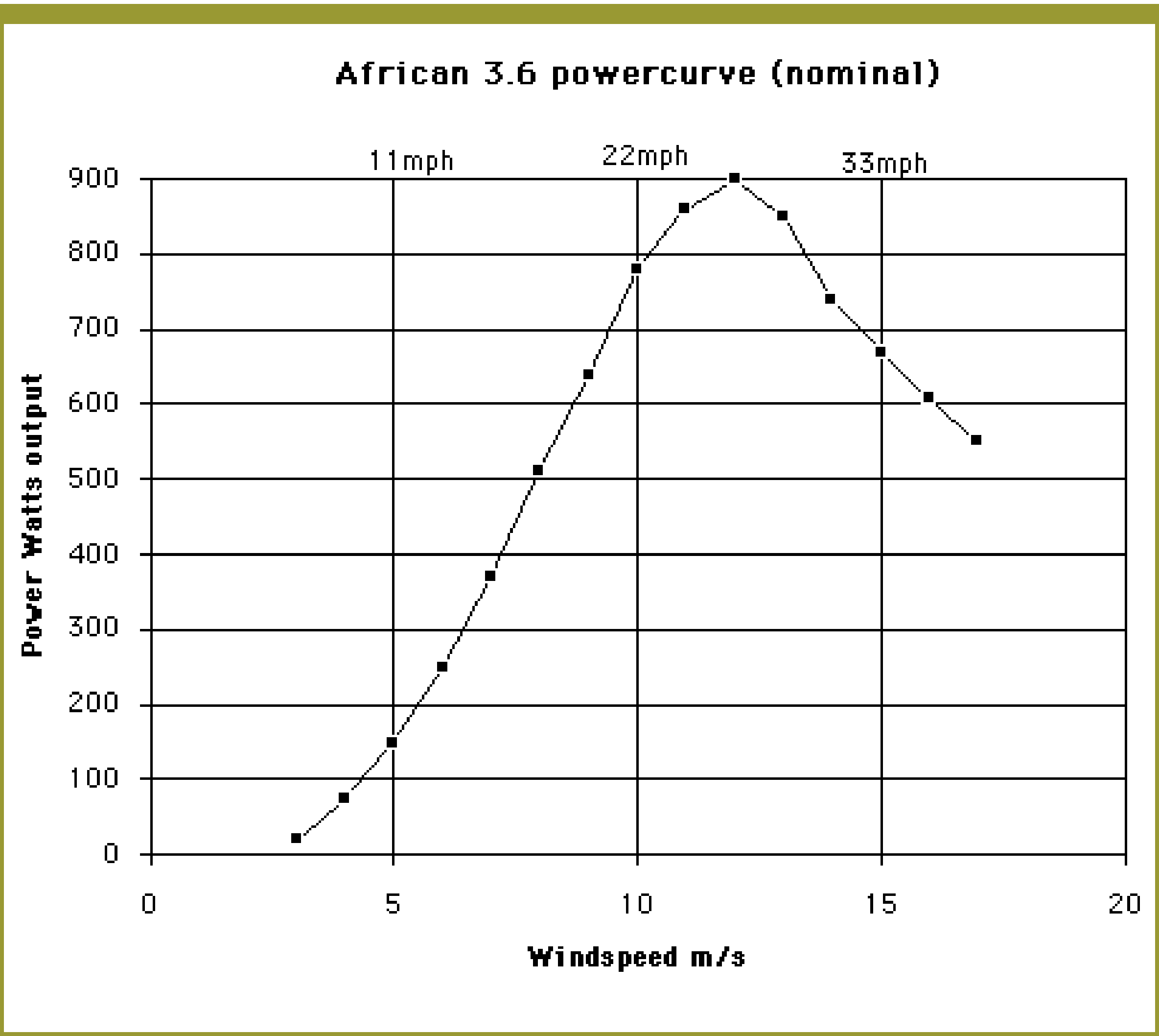
"Nothing tells you more about a wind turbine's potential than rotor diameter."

- Paul Gipe

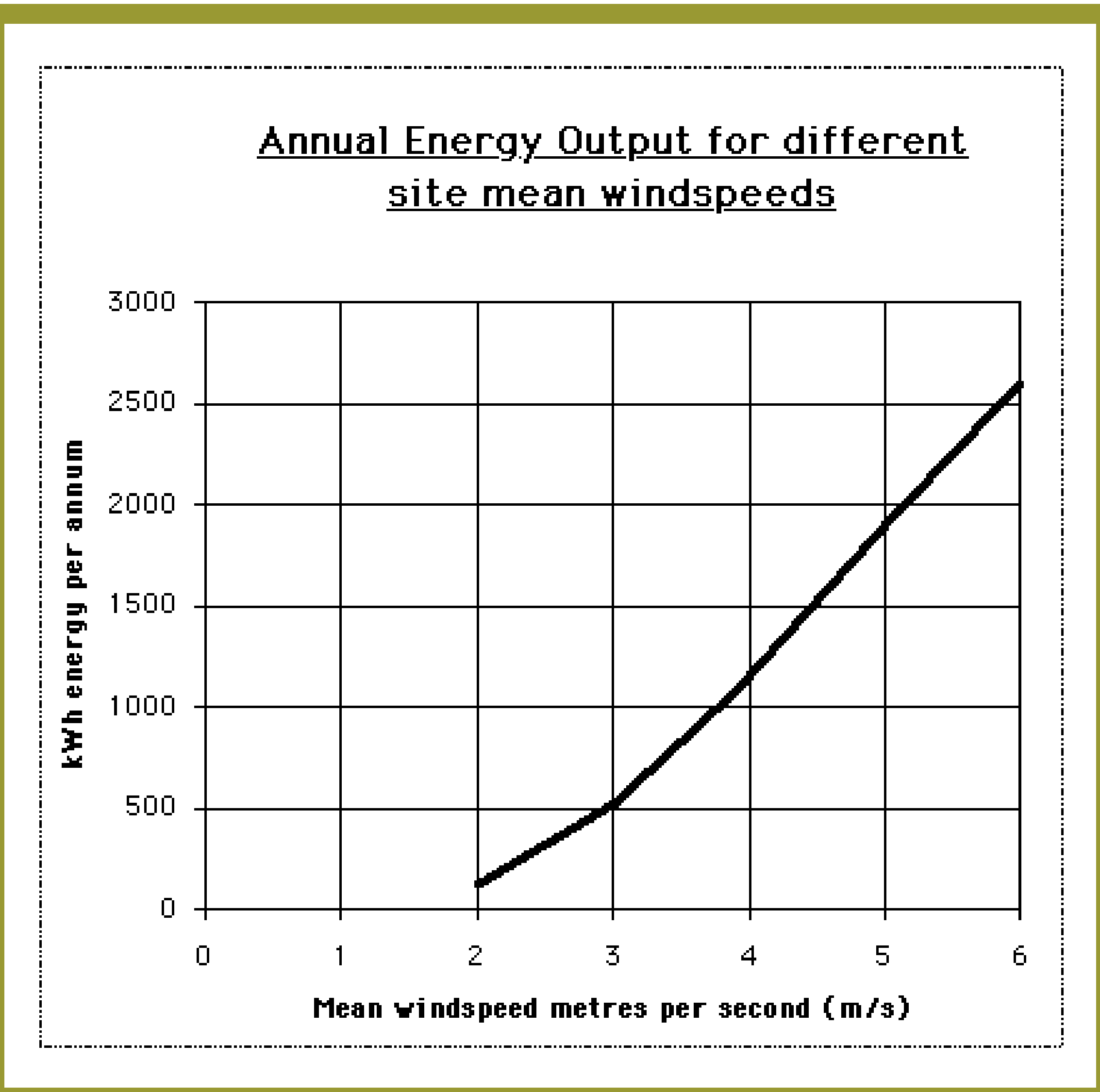
-Wind Energy basics, Chelsea

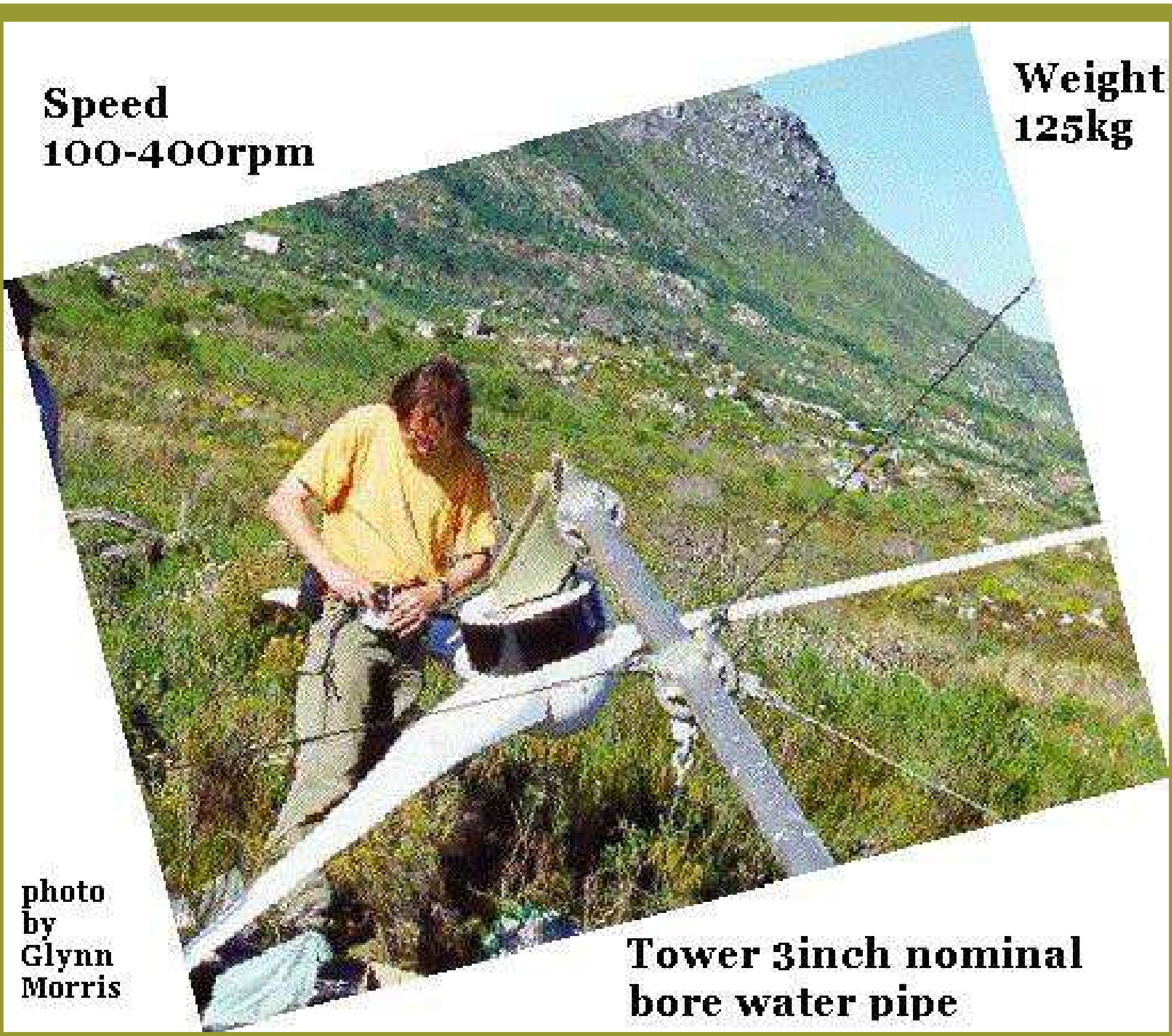
Power curve

Here is the nominal power curve for the 3.6 machine. Power curves vary between different voltages, and there have not been sufficient funds to produce a complete set of data, but we are working on it.



Notice that the diameter of the machine is large compared to it's maximum power output, and this gives it the torque to deliver good power in lower windspeeds, when other machines are unable to catch as much wind. We believe it is more important to have a steady, day to day supply of amphours into the battery, than to have a high peak-power rating.


Annual Energy Output for different site mean windspeeds
3000
2500
2000
1500
1000
500
0
kWh energy per annum
0
1
2
3
4
5
6
Mean windspeed metres per second (m/s)



This is a 'heavy metal' wind turbine, built for low speed and long life. In this picture you can see the alternator (black) and the 3 blades (white). The tail had not yet been attached to this unit. Assembly usually takes place at ground level, and then the tower is erected using a simple hand hoist (Tirfor). The tower is supported by steel wire guy ropes.

Evolution

First built for Zimbabwe Energy Research Organisation (ZERO) by Manx

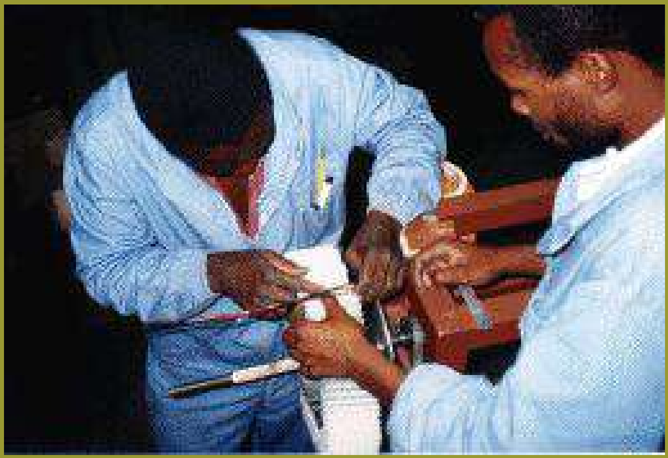
Wind Energy Services (consultants) in 1996, the wind turbine design was commercialised by African Windpower of Harare and badged the pt3600. Detailed design has been by Scoraig Wind Electric throughout.

The wooden blades of the original were replaced by fibreglass, and the tail was simplified.

On the left is a 1999 production unit from Powertronics. Tens of machines have been produced for local customers in Zimbabwe and the export market. With the new African Windpower factory, production will be stepped up. A 5.5 m diameter machine is actively under development. Smaller machines around 2 m diameter, will be available later.

(click to see larger image)

Here are parts of the alternator. The magnet rotor (top left) is cast from iron. It runs on the main shaft. The blades are bolted to the face this rotor. Inside the rotor are ferrite permanent magnets. The magnets move past the laminated core of the stator which contains stationary coils of copper wire. On the right you can see the stator being wound.



The alternator is heavy because it has many magnets and coils in it. Lighter alternators generally run at higher speed. These lighter wind turbines are noisier and wear themselves out sooner.

Click to see an enlarged picture. The wind turbine is protected against high winds by a simple, passive system which has been tested in winds exceeding 100mph, without incident.

As wind grows stronger, and maximum power is reached, the turbine is 'yawed' sideways from the wind. This prevents the blades from overspeeding. There a minimum of moving parts involved.. no springs.. no highly stressed components.(click)

Mick Sagrillo writes about the AWP 3.6:

This is a very simple machine that does what it is supposed to do. It is quite heavy duty and build to last a long time. The turbine is easy to install, with simple tools. I am most impressed with the turbineís slow speed and quiet operation. It is refreshing to see that a modern wind generator can be manufactures that is absolutely quiet in its operation.

This is a very nice machine. I only wish someone in the US could build something as good as the AWP. We could use the competition, to say the least. And the low speed reliability. This is heavy metal, which is right in line with my ideas on wind turbine design. Nice job!!!

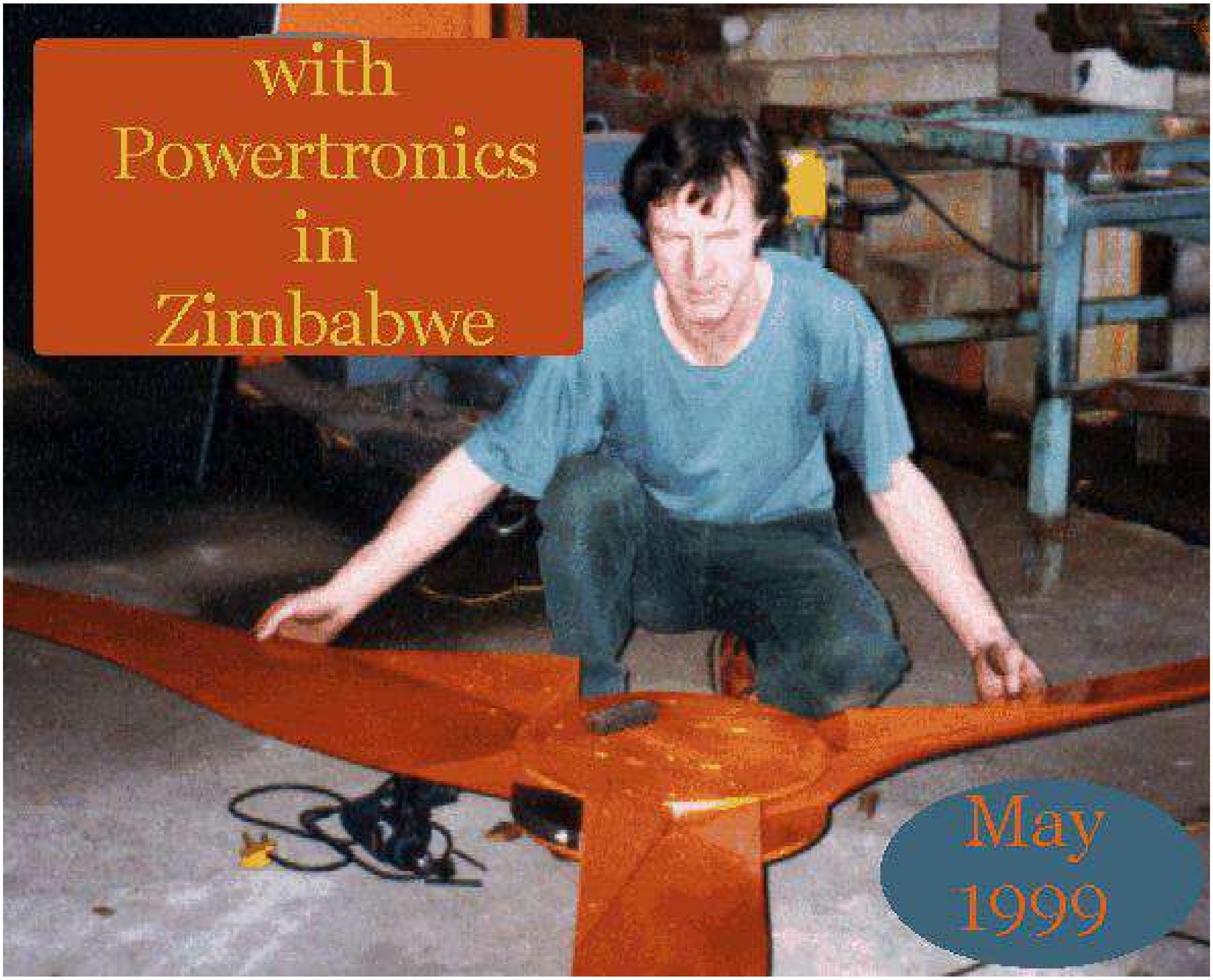
---

for information about availability in the USA contact "Robert W. Preus" <rwpreus@yahoo.com>

Some pictures from my trip to Africa - Hugh Piggott - Scoraig Wind Electric

My email address and My homepage

Note: this page below is mostly quite large graphics, so you may need to wait a while..



Temaruru is a site in the eastern highlands where Powertronics of Harare has installed a stand alone community wind power station. There are four machines. Each has 3.6m diameter and nominal 1kW power rating.

This wind turbine is the commercial version of the ZERO project in 1996 or, more recently, the Powertronics 3600. Manx Wind Energy had me design it. I also use one to power my home in Scotland. A new company African Windpower has been set up to manufacture the machines.

The site at Temararuru is a showpiece for African Windpower.
Sited prominently on the road from Nyanga, it catches the eye, as well as the wind.

In an area far from the grid, this is a massive increase in available electric power for people and small businesses.

Power is stored at 48 volts DC in a 400 amphour battery, at the power centre, and converted to 220 volt AC using Powervision 3kW sine wave inverters. Powervision is a joint venture of Powertronics and Innovision (of Denmark)

Future developments will include installation of solar modules to supplement the wind turbines, and maintain the supply in calm weather. A battery charging facility will be offered at the power centre, along with low energy lights, solar modules and other electrical supplies.

Powertronics, the parent company is a power electronics manufacturing company in Harare. African Windpower is starting operations in an adjacent unit.

I want to introduce you to some of the guys there.

In the above picture, Oloff Smyth (right) is the managing director of Powertronics who has pushed the windpower process forward against the odds for the last few years.
Duncan 'Dragon' (on the left) is a "Groovy Engineer", on contract with powertronics/powervision.

Forbes Marufu (in the middle of the small pic) is an independent electrician who slings the overhead wires.

Finally here are a few of the guys who do the hands-on work, in the back of the Powertronics factory. Here they are posing with the new 4kW alternator. On the left is Rogers the fibreglass specialist, on the right is Thinkmore who does all the windings. Who was that guy in the middle again...?

don't forget to check the African Windpower 36 page for more details.

My email address andMy homepage and that's all for now... from Hugh.

Home-Built Windpower

hugh@scoraigwind.co.uk

This page is designed to help those who plan to build their own wind turbine. I hope you find it useful.

I am teaching **workshop courses** in wind generator construction, here in Scotland and also in the USA and Wales.

My booklist **updated 29th August 2003** is at the bottom of this page.

Links to other good sites for home made windpower:-

http://www.otherpower.com
Windstuffnow
Chuck Morrison's site
Andy Little's site
Dave Allender

Otherpower's discussion board is full of fast moving action on the windmill building front with pictures.

What size of wind turbine do I need, and what can it give me?

Before you do anything else, you have to know how much power your windturbine is likely to produce and make sure that the speed of the rotor blades matches the speed of the alternator (or whatever produces the electricity). If you fail, and the alternator is too fast or the rotor too slow, for example, then you will not produce any power.

I am going to use some rough scans of a few tables from my book **Windpower Workshop** chapter 1, which will help you with the overall design of your wind machine. I am using scans because the original files went in the sea with my computer back in '97.

The first table tells you **how much power** you can expect from a wind machine, when you know how big it is, and how strong the wind is.

Table 1.1 Instant Power Outputs in Watts

Windspeed:	2.2m/s 5 mph	4.5m/s 10 mph	10 m/s 22 mph	20m/s 44 mph
Blade diameter 1m	1	6	70	560
Blade diameter 2m	3	25	280	2,300
Blade diameter 3m	7	60	630	5,000
Blade diameter 4m	12	100	1,120	9,000

This table gives you an idea of how much power your windmill may produce. It assumes a modest power coefficient of 0.15. For example, a two metre diameter windmill in a ten metre per second wind might produce 280 watts. Do not be fooled by the apparent precision of the figure. In reality you may get between 200 and 400 watts, depending on what 'power coefficient' you can attain.

Readers in the USA should note that one metre diameter is about 3 feet, and 3 metres is ten feet.

Clearly, size matters, but windspeed matters even more.
And above all do not forget **SAFETY**, which must be a paramount concern.
There is a whole chapter on the subject in the book.

Wind turbines are usually designed to work best in the range 3 - 12m/s, but windspeeds as high as 12m/s are not common (everyday) occurrences, so don't expect to get such high power outputs often enough to be relied on. It is usually a good idea to avoid very high power (high wind) operation altogether, unless you plan to use the machine for heating purposes on rare occasions. To avoid damage in high winds, you will need a good control system which reliably protects the machine from the wind's fury.

In terms of **what you can run** from the wind system, the average power is more useful information. From this average you can then work out how many Amphours of battery charge per average day you might get.

Table 1.2 Average Power Outputs in Watts

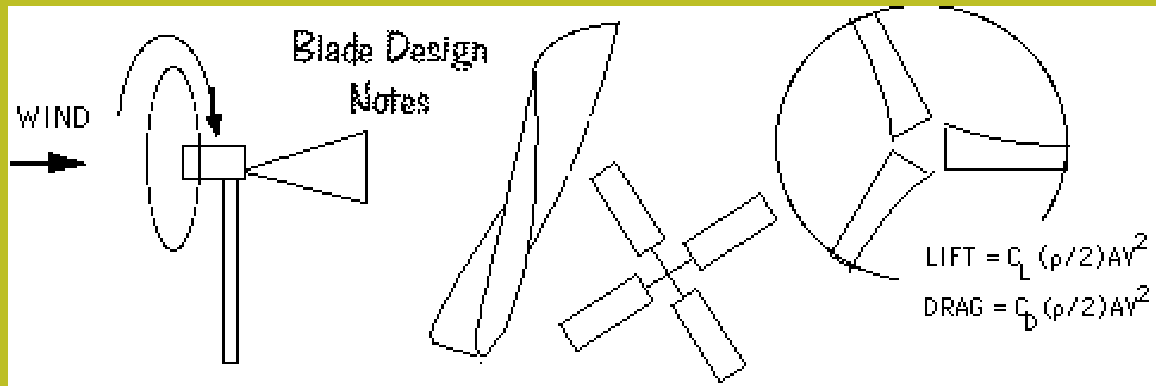
Average windspeed:	3 m/s 7 mph	4.5m/s 10 mph	6 m/s 13 mph
Blade diameter 1m	4	13	30
Blade diameter 2m	15	51	121
Blade diameter 3m	34	115	272
Blade diameter 4m	60	204	483

4.5m/s or ten mph is a typical average windspeed, for an open site with few obstructions.
A 2 metre diameter machine would probably give about 50 watts average output
(although it might produce 200 watts or more at times).
An average output of 50 watts may not sound much, but over a 24 hour period you can expect
50W/12V x 24h = 100 Amp-hours of charge (on average) into a 12 volt battery.
This is sufficient to run five 'energy efficient' lamps, each using 2 amps, for ten hours.
In reality, some of the energy will be lost in the process of charging and discharging the battery,
but you get the general idea, I hope.

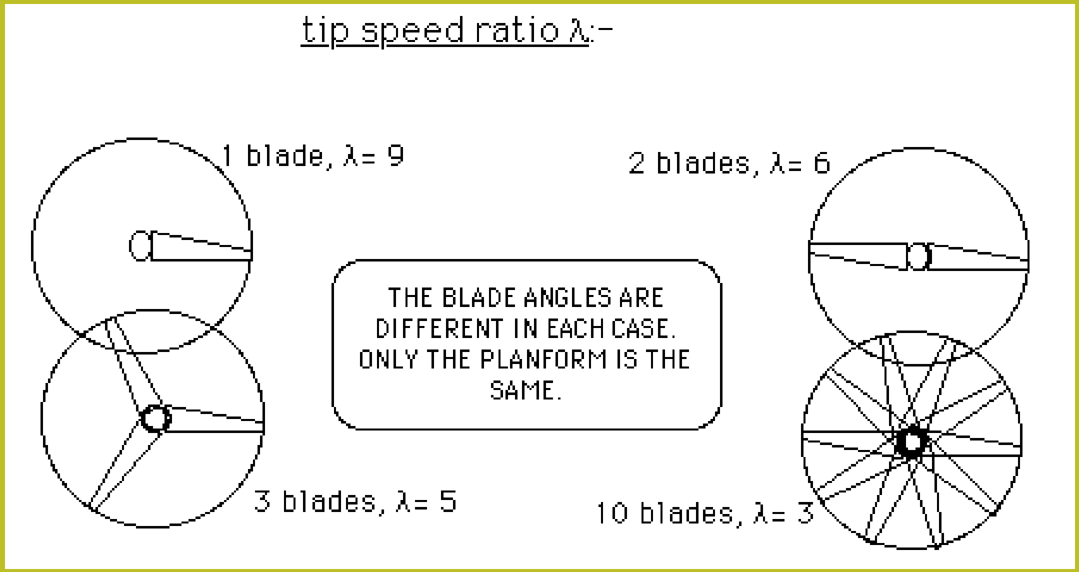
Once you have chosen the size of wind turbine, you need to design the blades and find or build a generator or alternator to match them.

Blade design

To design the blades, may find it useful to study some notes I have put on the web at another site:-
a short course in blade design I prepared for the Centre for Alternative Technology.

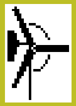


Your main decision will be choosing the **tip speed ratio** of your rotor blades.
The 'tip speed ratio' is how much faster, than the windspeed, the blade tips travel.
High tip speed ratio means more speed, low tip speed ratio needs more blades.
On the whole, high tip speed ratio is better, but not to the point where the machine becomes noisy and highly stressed. This next diagram show four rotors, designed to run at different tip speed ratios.



The tip speed ratio will determine how fast your wind turbine will want to turn, and so it has implications for the alternator you can use.

Here are three on-line guides to the detail of how I make blades:

- Detailed instructions for making a set of blades,  to run at tip speed ratio 5.5 or thereabouts.

- Colour pictures of the blade carving process 

- Chuck Morrison has produced a set of templates for carving blades according to my books.

- Wind stuff now blade design software (based on my ideas)

There is also a guide to fibreglass blade manufacture on my download page

Table 1.3 Rpm for Various Turbines + TSRs

Power (watts)	Diameter (metres)	TSR=4	TSR=6	TSR=8	TSR=10
10	0.4	2032	3047	4063	5079
50	0.8	909	1363	1817	2271
100	1.2	642	964	1285	1606
250	1.9	406	609	813	1016
500	2.7	287	431	575	718
1000	3.8	203	305	406	508
2000	5.3	144	215	287	359
[illegible]000	8.4	91	136	182	227

Following through our example of the 2 metre (six foot is 1.8m) diameter machine, and choosing a tip speed ratio around 6 we find that the machine will run at about 600rpm. This leads to the biggest problem in home-built windpower. You will not find an alternator or generator which will give your required power (250 watts) while running at that speed. So you will either have to use gearing to change the speed, or build or adapt a special machine. The second option is the better of the two.

Finding a suitable alternator....

Check at **Windmission** where you may be able to buy a purpose built permanent magnet alternator (PMG).

Or again you can use a **permanent-magnet "servo" motor** from a surplus store in the **USA**

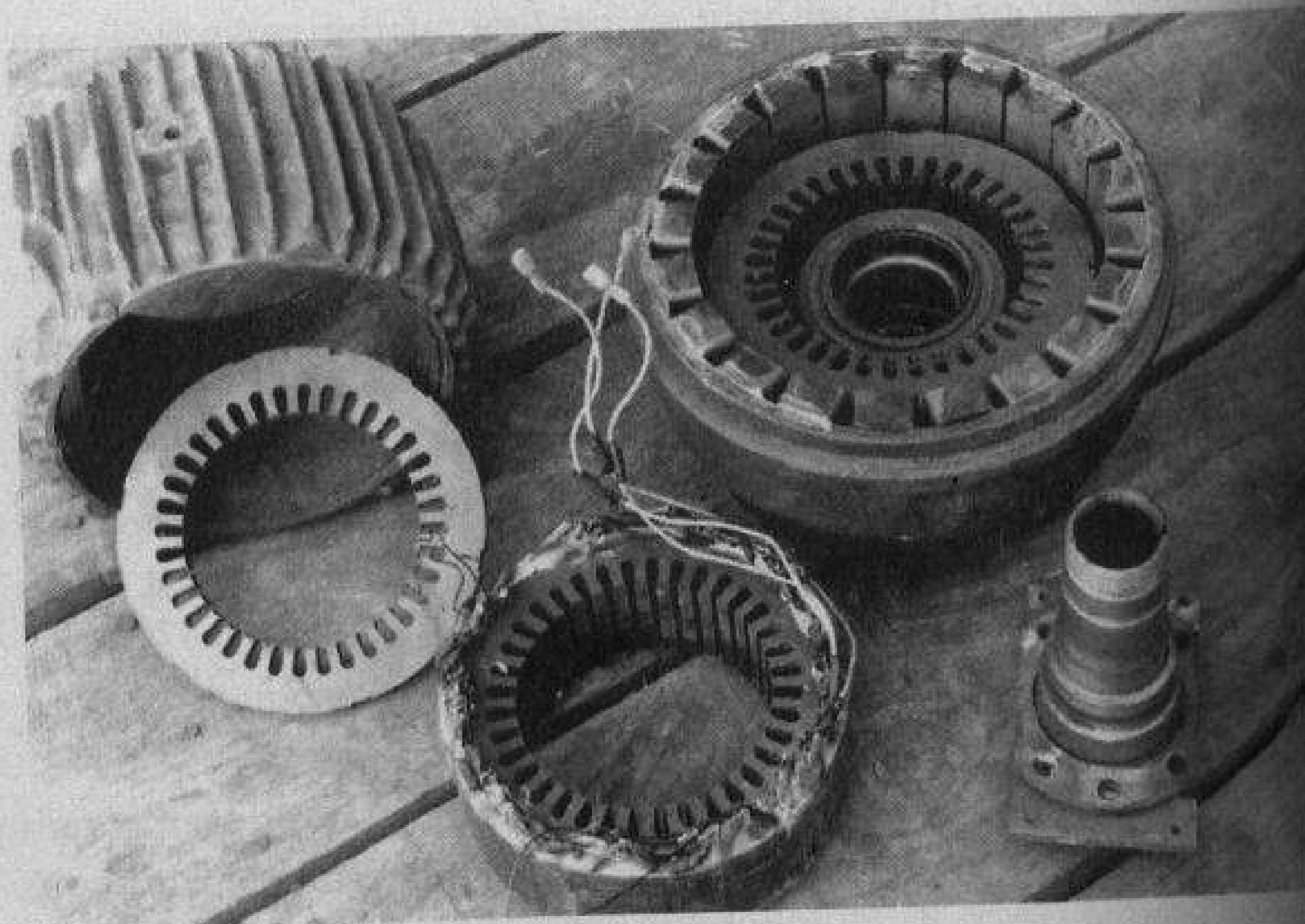
or a 'Smart drive' washing machine motor from new zealand (see ecoinn  **)**

or try a czech alternator at http://mgplast.web.worldonline.cz/

Alternator design

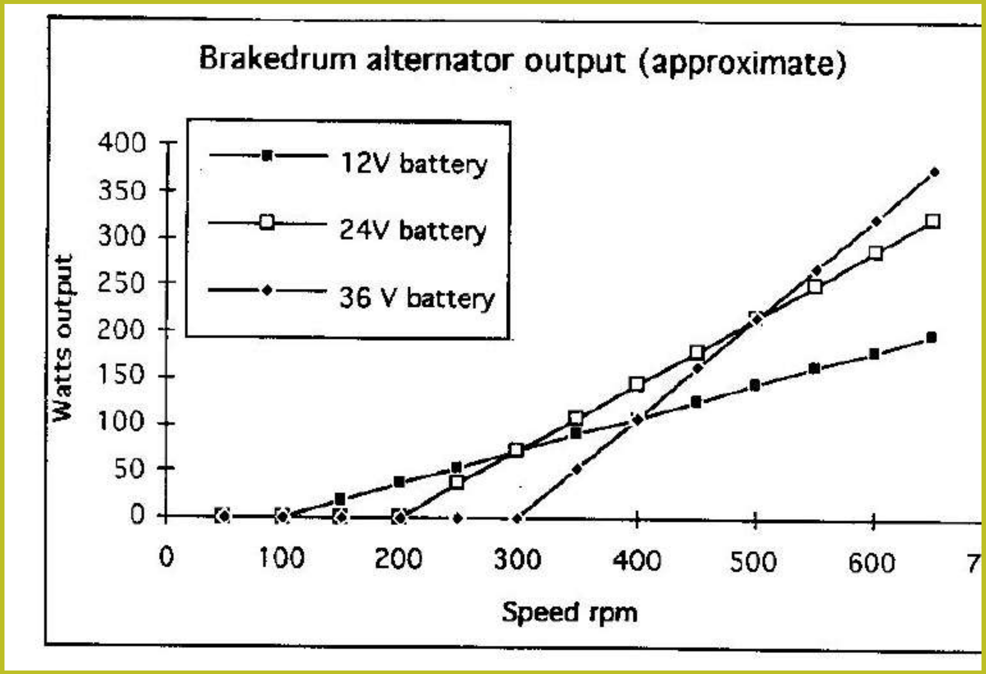
There is plenty of advice on the subject in Windpower Workshop, and I have also produced detailed plans for building a low speed alternator from the brakedrum hub of a small truck or van.
My Axial flux alternator plans are even easier to use because the parts are easier to find and the stator is easier to assemble.

A Brake Drum Alternator



Bits of a DIY brake drum alternator.

The brakedrum alternator has quite a good power/speed characteristic for small windpower as shown in the graphs below:-



North american readers be interested in workshops and detailed plans in Ontario, Canada with Robert Budd 519 524-8097 for construction of the north american version (ford truck) brakedrum wind turbine. Bob also sells a video.

For people who are building the brakedrum machine, I have prepared an update page with some questions answered.

More help for homebuilders at www.otherpower.com wind alternators
latest alternator in May 2003

try Windstuffnow for an alternator recipe

A book "the homebuilt dynamo" by new zealand author Alfred T. Forbes is available from Technohippy at ($US20) (English 15Pounds).AIRFREIGHT to door. It explains in great detail how to build your own permanent magnet alternator. This is one fat glossy book. Also avaialble from picoturbine.

Help with finding magnets for building your own alternator here.

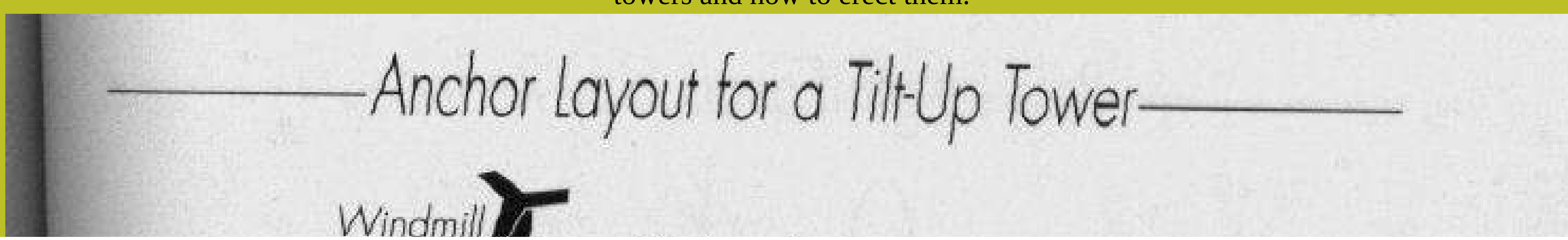
Finally, (last but not least!) here is a link to a free public domain on-line alternator construction manual in pdf format.
I developed this design as an aid project for Intermediate Technology Development Group (ITDG) with funding from the UK government.

Click on the image above to contact Phil.

Other Aspects of the design

Control is very important. Your wind turbine needs controls to prevent it from overspeeding in gales. I use a furling tail arrangement. Later I shall post an explanation for this but meanwhile you will have to buy one of my books.

Windpower workshop does not go into the **details** of construction quite so deeply for any single machine, but it covers a lot of ground, including towers and how to erect them.



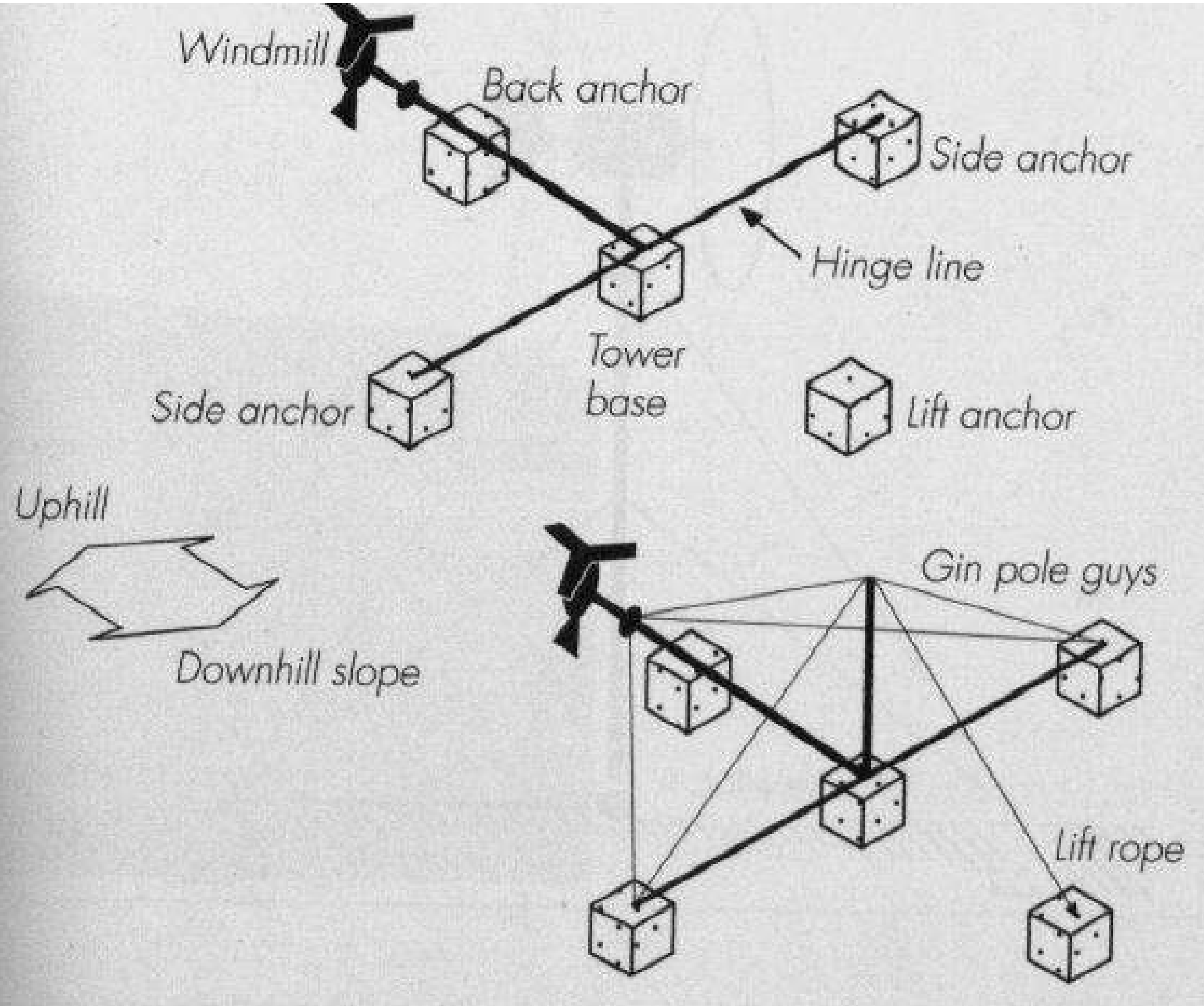


Fig 8.10 The lift anchor is downhill and the side anchors and tower base are on the same contour.

(see Fig. 8.10) The two anchors in line with the hinge on the

Booklist

updated 29 August 2003

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Scoraig
Dundonnell
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UK

You can also send cheques or money orders but only in pounds. If you send dollar or other currency checks or orders or drafts then the bank will take half of it when I try to change it to useful cash here.

I do not recommend you send cash by registered mail or special delivery since these often get lost. Regular post is the most reliable and also the cheapest. I have never known cash sent by regular post to go missing. If registered delivery cash does not arrive, then I usually send the books anyway but I much prefer if you do it my way or use paypal.

If you want to pay by credit card, then click on the Paypal links and set up a paypal account. This does not take long and is useful anyway.

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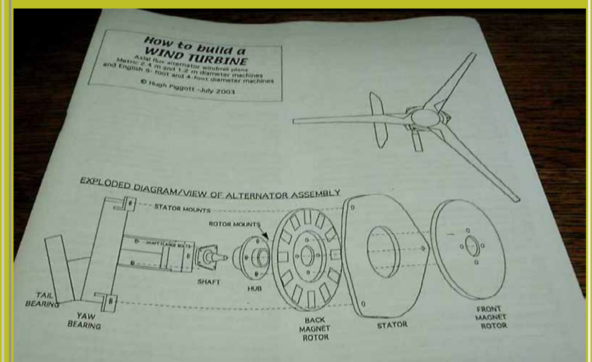
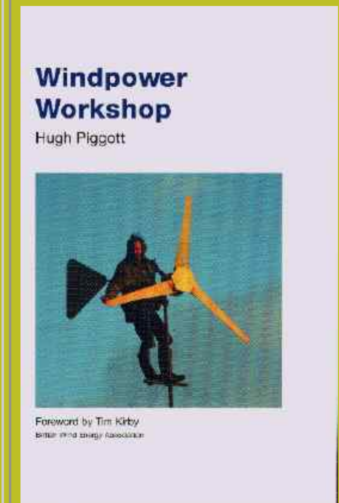
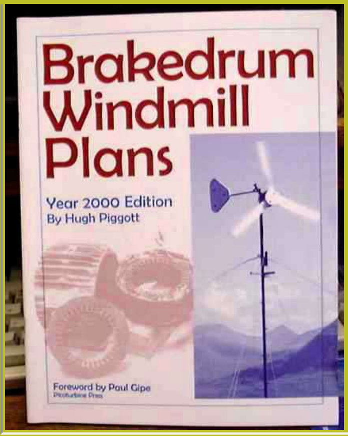
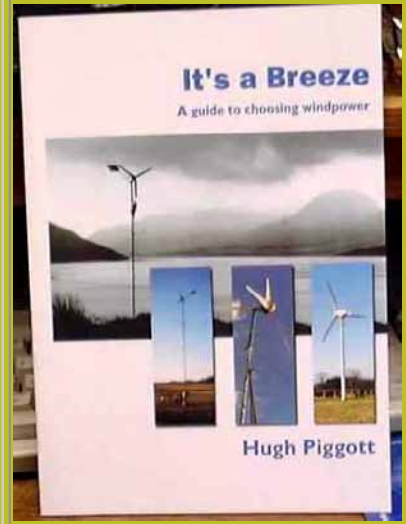
	July 2003 windmill plans used for notes in [workshop courses.](#) 47 pages with diagrams describe in detail how to build 2 sizes of wind turbine including the alternators and blades. The 8 foot diameter turbine has 500 watt output. The 4 foot diameter one has 100 watt output. Units in metric and 'English'	Cover price £ 10.00 shipped in UK £10.60 GBP Europe €17 EUR World $21 USD	This is a pre-publication edition, produced in small batches. A final version will be available in a few months. Currently available only from me and from FORCEFIELD in the USA	You can pay me by credit card at paypal with the button below. Paypal will need you to set up an account but thisis basically a useful thing and quite quick. £14 inclusive of carriage/mailing VISA MasterCard BUY NOW

 [click for reviews and more information]	1997 reprinted frequently 154 pages A book dedicated to building your own working windmill for electricity production. Details of generator choice and design, blade construction, furling systems, towers, wiring, battery charging, heating, alternator design, modifications for car alternators and generators, and everything else you will need to know.	Cover price £12.00 shipped in UK £13 GBP Europe €21 EUR World $24 USD		You can pay me by credit card at paypal with the button below. Paypal will need you to set up an account but thisis basically a useful thing and quite quick. £16 inclusive of carriage/mailing
	In 1993 I produced plans for building a windmill based on a permanent magnet alternator from the brakedrum of a van. This is an updated edition year 2000. 34 page detailed, step by step guide to building a 300 watt windmill with 2.1metre (7 foot) diameter. I have built one and it has worked for years on the hill near my house,	Cover price £8.00 shipped in UK £8.60 GBP Europe		

	producing an average output of 100 watts (at the battery). Readers may need to adapt the method to suit their own brakedrum. It is a simple, robust and efficient windmill, but quite large and heavy.	€14 EUR World $16 USD	
	2001 edition, is packed with information for those who want to buy and install a windpower system. Whatsize of windmill do you need? What are the options on offer (in the UK). Living with windpower, etc. 31 pages. contents page	Cover price £6.00 shipped in UK £6.60 GBP Europe €11 EUR World $13 USD	Centre for Alternative Technology Europe's Leading Eco-Centre PicoTurbine

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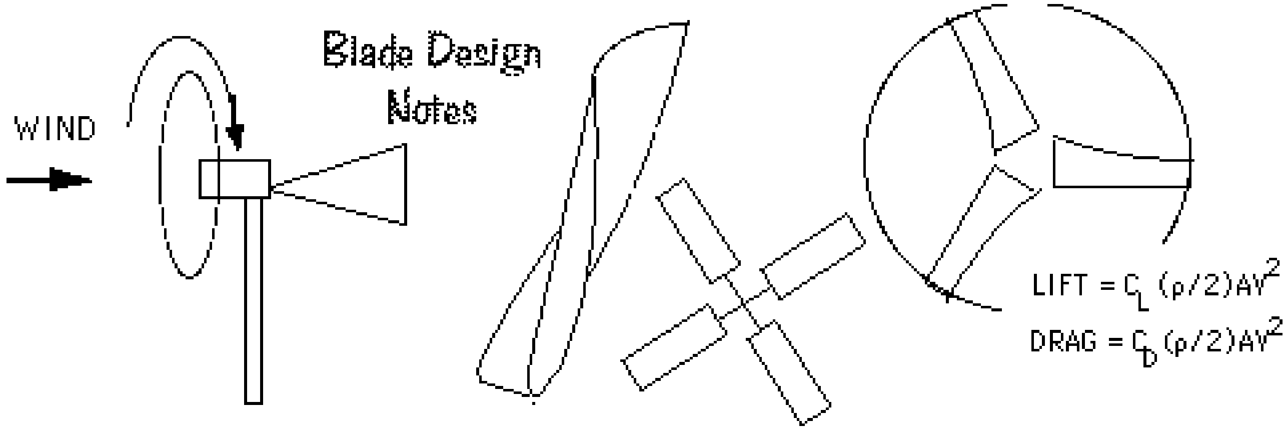
Hugh Piggott - back to my home page..


Scoraig Wind Electric



Notes based on a session during the Centre for Alternative Technology Windpower Course
Notes written and taught by Hugh Piggott with input from Claus Nybroe.

The first time I did this talk at CAT they threw me in with no preparation, "Just come as you are!" and I had to wave my arms about a lot. Since then I have done it countless times, but I still get more than a few blank looks. It's probably the most obscure bit of the course. Finally after about ten years, I have produced a full set of notes. Sorry I did not explain Betz's theorem, or 'tip speed ratio'. Buy my book 'Windpower Workshop' and read the whole story :-)

The notes were originally a series of graphics file documents (GIFs) written in a logical order. To see them in GIF format go to Ian's site where I put them before I had my own page.

PDF download>>>>>>>>>>

thanks to "F. Marc de Piolenc" <piolenc@mozcom.com> for the pdf document

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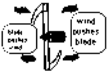
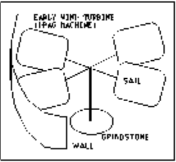
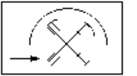
Wind turbine rotor blades take power from the wind by slowing it down

This is done by applying a force to the wind, and the wind applies that same force to the blades





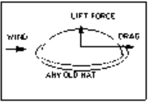
Objects in the path of a stream of air experience a 'downwind' force called drag.

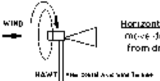


The drag force was used by the earliest wind turbines. It is easy to understand how this force causes the blades to turn, but such rotors are very slow and the blades which are moving upwind actually slow the rotor down

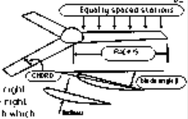
Drag is the force of wind pushing straight downwind

But there is another force called lift which always works at right angles to the wind direction



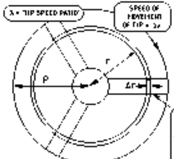


Horizontal axis wind turbine blades never move downwind, so they can get no help from drag forces. Instead they use lift



To create a blade design we need to specify the chord width and blade setting angle β at each of a series of stations along the span of the blade

At each station we will create the right shape of the blade to produce the right loading (lift) for the bit of wind with which it will have to deal



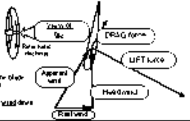
The process of calculating the best loading and hence the best shape is known as 'finite element analysis', and it looks at what each bit of the blade needs to do

THE BIT OF THE BLADE AT RADIUS r SWEEPS A FRACTION OF THE TOTAL SWEPT AREA AND HAS THE JOB OF SLOWING THIS BIT OF WIND DOWN BY THE RIGHT AMOUNT TO SATISFY THE BETZ CRITERION

THE AREA OF WIND IT SWEEPS WILL BE 2πrδr
ITS HEADWIND WILL BE (r/R)λV
WHERE λ IS THE TIP SPEED RATIO AT WHICH WE WOULD LIKE IT TO WORK

The apparent wind which a blade 'sees' is altered by its own speed through the air

This headwind adds to the real wind to give the apparent wind, which creates the lift and drag forces



The headwind rotates the direction of the forces on the blade
The Drag force opposes the blade's movement
The Lift force assists the blade's movement
Both forces also push the blade downwind and slow the wind down

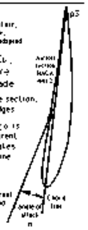
The mathematics of lift and drag

$LIFT = C_L (\rho/2) A V_a^2$

$DRAG = C_D (\rho/2) A V_a^2$

where ρ is the density of air, A is the area of blade, and V_a is the apparent windspeed

Lift and Drag forces depend on the Coefficients C_L and C_D, which in turn depend on the cross section of blade we are using, and on the angle α at which the wind strikes the blade



The chord line is the longest line in the section, joining the leading and trailing edges

The angle of attack α is the angle the apparent wind direction makes with the chord line

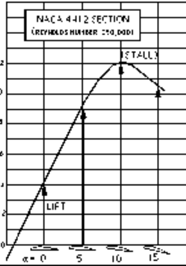
You cannot calculate the lift and drag coefficients

They are measured experimentally in wind tunnels, and recorded in books.

Here is a typical graph of lift vs. angle of attack α

As α increases, so does the lift, until a point is reached where the blade stalls.

Most flattish objects will give a similar sort of LIFT/α curve
But cambered, streamlined sections yeild better lift/drag

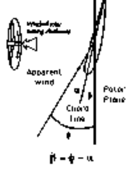


When designing a wind turbine rotor, the <u>angle α</u> will depend on the angle of the apparent wind φ, and the blade angle β

So we have control over α, and thus control over the lift and drag produced by the blade

We shall need to optimise the lift force, to satisfy the Betz criterion, but the blade will not work well unless the <u>drag</u> is minimised

So we have to choose a section and an angle of attack, where the <u>lift/drag ratio</u> is high

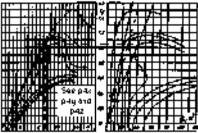


$$\beta = \phi - \alpha$$

Finding the exact best angle α can be an involved process, because the lift and drag coefficients depend on both the <u>section</u> and the <u>Reynolds number</u> (a measure of the size and speed of the blade)

THE REYNOLDS NUMBER IS 68500 X CHORD (m) X APPARENT WIND SPEED (m/s)

IF D=2m AND λ=5 AND V=5m/s THEN REYNOLDS NO IS ABOUT 120,000

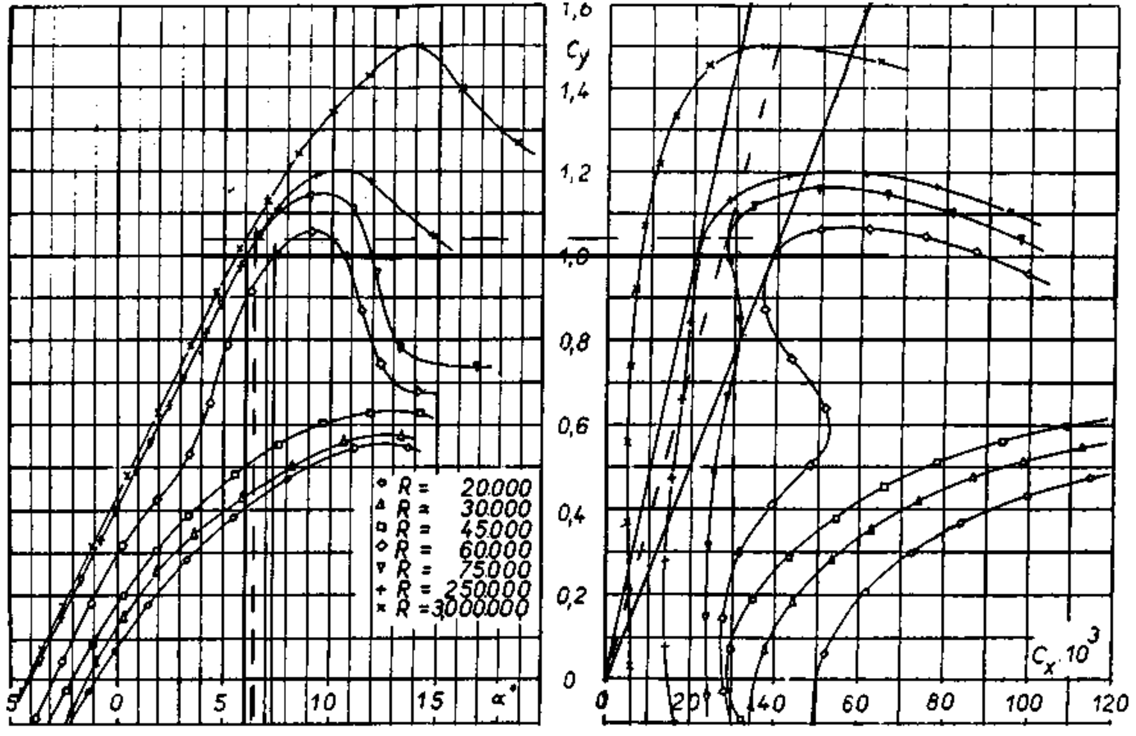


On the left is a pair of graphs which again relate to the NACA 4412 section for several different Reynolds numbers.
The lefthand graphs show <u>lift/α</u>.
The righthand one shows <u>lift/drag</u>.
The straight lines through zero, represent particular lift/drag ratios.
Best lift/drag ratio for a given Reynolds number occurs where the lift/drag line is rotated as far as possible anticlockwise, so that it just touches the curve as a tangent.
For the NACA 4412, this point of contact is where C_l is about 1 and α is about 6.

Note that low Reynolds number leads to poor lift and low lift/drag ratio, which can pose problems for rotors with narrow chord widths in low winds. There are other sections (eg 4415 and 4424) which have better performance than the NACA 4412 at low Reynolds number.

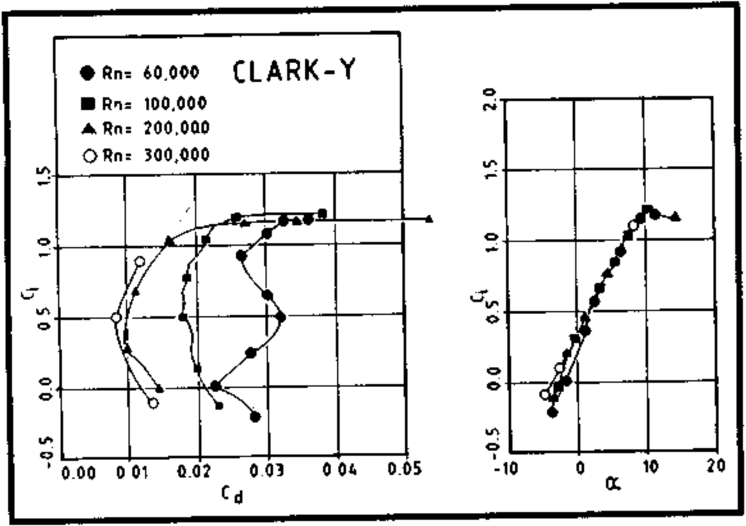
In practice, most sections will produce their best lift/drag at an angle of attack around 5 degrees, so <u>as a general rule</u>, where detailed data is not available, we can say that the blade angle β should be set to give this angle of attack, thus

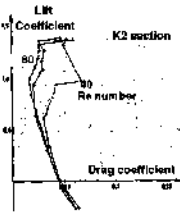
$$\beta = \phi - 5$$



c_y
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0
5
0
5
10
15
α°
0
20
40
60
80
100
120
$c_x \cdot 10^3$
○ R = 20.000
△ R = 30.000
□ R = 45.000
◇ R = 60.000
▽ R = 75.000
+ R = 250.000
× R = 3.000.000

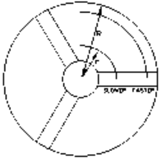
WIND TUNNEL TEST POLARS

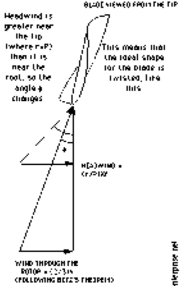




Lift
Coefficient
K2 section
80
80
Re number
Drag coefficient

To specify blade angle β we need to know the <u>angle φ</u> at which the apparent wind strikes the rotor plane





CALCULATING THE CORRECT BLADE SETTING ANGLE β

β = φ − α

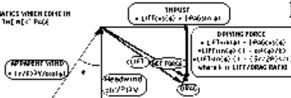
WHERE TAN(φ) = (2V/3)/(r/R)XV
= 2R/(3rX)

SO THE BLADE ANGLE β IS

β = ATAN(2R/(3rX)) − α

WHERE α IS USUALLY AROUND 5 DEGREES

MORE MATHEMATICS WHICH COME IN USEFUL ON THE NEXT PAGE



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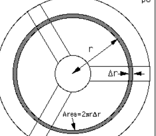
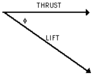
Having worked out β we still need to work out the Chord width. Here is the logic:

Each blade element has a certain band of wind to process. As radius r grows smaller near the centre, the amount of wind in the band gets smaller too.

The outer parts of the blade therefore do the most work. The inner part is less important but needs a different shape.



To satisfy Betz, the wind in each part of the swept area of the rotor must be slowed down to 1/3 of its upstream velocity, and this slowing is done by the THRUST force, which is very closely related to the LIFT force.



NEGLECTING DRAG (very small error), THRUST = LIFT $\cos(\phi)$

FOR BETZ, THRUST = $(4/9)\rho A V^2 = (4/9)\rho(2\pi r\Delta r)V^2$

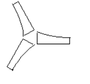
AND WE KNOW THAT LIFT = $CL(\rho/2)BC\Delta r(\text{APPARENT WIND})^2$
$= CL(\rho/2)BC\Delta r(\lambda V(r/R)/\cos(\phi))^2$

where B is the number of blades,
CL is the lift coefficient,
C is the chord width,
at radius r,
and V is the free windspeed.
BCΔr is the area of blade used to produce lift at radius r.

THIS LEADS TO A ROUGH EXPRESSION FOR THE CHORD WIDTH C WHICH WILL PRODUCE THE RIGHT AMOUNT OF THRUST TO MEET THE BETZ CONDITION

$$C = \frac{16\pi R\,(R/r)}{9\lambda^2 B}$$

WARNING: FOR SIMPLICITY, WE HAVE ASSUMED THAT CL AND COS(ϕ) ARE BOTH ABOUT =1.
THIS EQUATION WORKS BEST FOR THE OUTER PART OF THE BLADE ONLY.



CONCLUSIONS

C IS INVERSELY PROPORTIONAL TO RADIUS r.
so the blade shape should be tapered

C IS INVERSELY PROPORTIONAL TO BLADE NUMBER B
so fewer blades will be wider blades

C IS INVERSELY PROPORTIONAL TO TIP SPEED RATIO **SQUARED**
so doubling speed means cutting blade width down to 1/4

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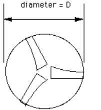
Back of envelope blade design:-

1. Choose rotor diameter D to suit your power requirements

Diameter (m)	(Watts) Power
1	50-100
2	250-500
3	500-1000
4	1000-2000
5	2000-3000



2. Choose a tip speed ratio λ.

You are free to use is trial and error here. I suggest you opt for a tip speed ratio between 5 and 8.

Tip speed ratio will affect rpm.
shaft speed=$60\lambda V/(\pi D)$ rpm

3. Decide how many blades B to use

(B=3 is the best.
Or try $B=80/\lambda^2$)

4. The width of the blade C in the outer portion, will be :

$$C= 4D/(\lambda^2 B)$$

For example if D=2m, and tip speed ratio = 7 and B=2, then C = 4x2/49x2= 0.08m (or 8cm).
The outer part is the most important, but the inner part should be made wider, to help with starting torque.

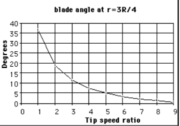
IF YOU HAVE A GENERATOR WITH KNOWN POWER OUTPUT AND KNOWN RPM, AND YOU WANT TO BUILD A WINDMILL TO FIT THAT, THEN YOU MAY FIND THIS FORMULA USEFUL:

DIAMETER = (POWER(47λ/RPM)^3)^0.2
('^0.2' MEANS THE FIFTH ROOT)

FOR EXAMPLE IF POWER = 500 W
AND RPM = 300 RPM
AND CHOSEN TIP SPEED RATIO = 5
THEN BEST DIAMETER WILL BE

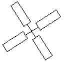
DIAMETER = (500x(47x5/300)^3)^0.2
= (500x(0.783)^3)^0.2
=240^0.2=3metres

5. To find the best blade setting angle β, read it from this graph:-



THIS IS BASED ON THE IDEAL ANGLE FOR A POINT NEAR THE TIP.

STRAIGHT, UNTAPERED, UNTWISTED BLADES
IN PRACTICE MANY WIND TURBINE BLADES ARE BUILT WITH CONSTANT WIDTH AND CONSTANT BLADE ANGLE, LIKE THIS. THERE IS SURPRISINGLY LITTLE LOSS OF EFFICIENCY BY MAKING THIS COMPROMISE.



BUT THERE ARE OTHER GOOD REASONS TO USE A TWIST AND A TAPER:

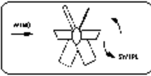
BETTER STARTING

STRONGER BLADE ROOT

Factors affecting the power coefficient

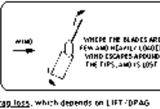
(Where the lost energy goes)

<u>Loss 1</u> is the wind which escapes around the side of the rotor. Betz figures out that the <u>best we can do is catch 0.593</u> of the power and that to catch even that much we need to <u>slow the wind down to 1/3</u> of its upstream, free velocity V.



<u>Loss 2</u> is the lost power in the <u>swirl</u> created by high torque rotors. Glauert figured out that this is worst at low tip speed ratios.

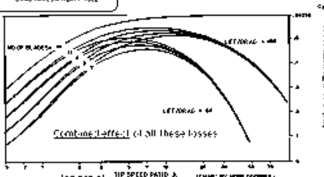
<u>Loss 3</u> is due to the fact that we are not able to be everywhere at once. When there are only a small number of blades, the thrust loading is higher, and some wind prefers to go around the tips. This is known as <u>Tip loss</u>.



DRAG FORCE = LIFTFORCE/ε

SO LIFT/DRAG MUST INCREASE WITH INCREASING TIP SPEED RATIO OR DRAG TAKES A HEAVY TOLL

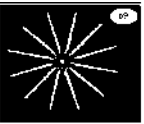
<u>Loss 5</u> is <u>drag loss</u>, which depends on LIFT/DRAG ratio. It gets worse for high tip-speed-ratio rotors, where the lift force is rotated furthest from the direction of blade movement.



So what is the <u>best design</u> for a wind turbine rotor?

From the graphs, it looks as if a tip speed ratio around 5 is ideal, with as many blades as possible. The trouble with having lots of blades is that they have to be very narrow, or run at very low tip speed ratio for Betz, to satisfy the Betz condition.

The perfect wind turbine rotor has an infinite number of infinitely narrow blades


Source: Windmission

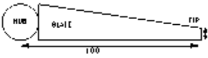
The 'windflower' type of rotor (right), created by Claus Nybroe at Windmission, follows this logic.

HERE IS A 12-BLADED WINDFLOWER ROTOR DESIGNED FOR TIP SPEED RATIO λ = 5.6 (ROUGHLY). THIS IS THE MOST EFFICIENT SHAPE OF ROTOR.

IN PRACTICE THIS APPROACH IS RARELY USED BECAUSE THE ROTOR IS TOO SLOW. AT HIGHER TIP SPEED RATIOS, 3 BLADES WORK BETTER, IN SPITE OF THE LOSSES.

Due to the low Re-numbers the blade profile must be carefully selected and rather thin. To obtain strength and torsional stiffness, this requires a composite structure and skilled workmanship.

Here is a less ambitious planform shape for a blade.



IF $C = \frac{16\pi R(R/r)}{9\lambda^2 B}$

THEN $B = \frac{16\pi R(R/r)}{9\lambda^2 C}$

AT THE TIP, C = R 7/100, SO B = 80/λ²

$B = \frac{80}{\lambda^2}$

RULE OF THUMB ONLY FOR THE BLADE DEPICTED

Once you have chosen a blade planform, then the number of blades is dictated by the <u>tip speed ratio λ</u> –

THE BLADE ANGLES ARE DIFFERENT IN EACH CASE. ONLY THE PLANFORM IS THE SAME.

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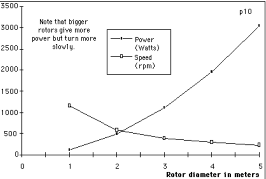
High speed blades
(pros and cons)

The graph to the right shows the speeds and electrical power outputs of windmills with a range of rotor sizes, running at tip speed ratio of 5, in a 12m/s rated windspeed.

For this graph, power is calculated on the basis of rotor Cp=0.25 and other losses=40% overall, which is easily possible for small wind turbines. (Other losses are friction, iron, copper and rectifier losses to produce the electricity output.)

Good machines will exceed this performance.



Choice of rotor size (diameter) depends on power required.

Choice of tip speed ratio λ depends on many factors. High tip speed ratio results in higher shaft speed is more efficient for generating electricity, which often outweighs these disadvantages:-

1. Noise from the blades is higher
2. Vibration in case of 2-bladed (or 1-bladed).
3. Blades edges, at high air-speeds suffer erosion.
4. Reduced rotor efficiency, due to drag, and tip loss.
5 Starting difficulties, if the shaft is stiff to turn.

STARTING TORQUE CAN BE ESTIMATED FROM THE FORMULA

$$\text{TORQUE} = \frac{V^2 R^3}{(\text{DESIGN TIP SPEED RATIO})^2}$$

FOR EXAMPLE A 2m DIAMETER WITH TIPS SPEED RATIO λ = 5 ROTOR IN A 4m/s WINDSPEED WILL HAVE STARTING TORQUE

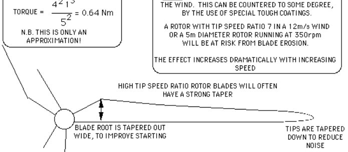
$$\text{TORQUE} = \frac{4^2 1^3}{5^2} = 0.64 \text{ Nm}$$

N.B. THIS IS ONLY AN APPROXIMATION!

BLADE TIPS TRAVELLING AT SPEEDS IN EXCESS OF 80m/s WILL SUFFER FROM EROSION OF THE LEADING EDGES DUE TO IMPACT OF SMALL PARTICLES BORN BY THE WIND. THIS CAN BE COUNTERED TO SOME DEGREE, BY THE USE OF SPECIAL TOUGH COATINGS.

A ROTOR WITH TIP SPEED RATIO 7 IN A 12m/s WIND OR A 5m DIAMETER ROTOR RUNNING AT 350rpm WILL BE AT RISK FROM BLADE EROSION.

THE EFFECT INCREASES DRAMATICALLY WITH INCREASING SPEED

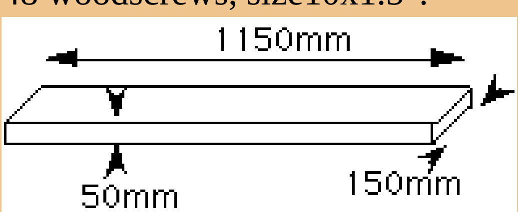


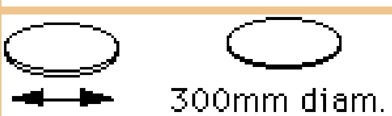
Carving Wooden Blades

The following instructions will help you to produce a 3-bladed wind turbine rotor, which you can use to drive a low speed permanent magnet alternator or other arrangement to produce electricity. Diameter is 2.3 metres (90 inches) and the tip speed ratio is about 5.5. There is a color picture at the bottom of the page (so maybe it will have loaded by the time you get there). For more info see my self build books page.

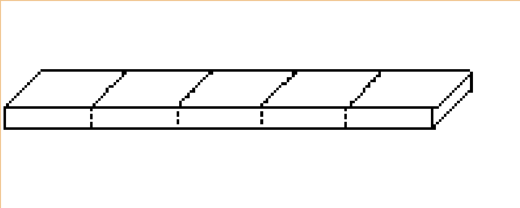
Tools
You will need some or all of the following tools:
saw (+jigsaw+bandsaw..)
chisel (+mallet)
plane
spokeshave
draw knife (recommended)
callipers, compasses
square
tape measure
ruler
pencil
spirit level
drills size 4,8 and 25 mm
Keep your tools very sharp, and always work with the grain of the wood, to prevent it splintering. Grip the workpiece firmly to a bench with a G clamp. If a tool judders or sticks, try sliding it sideways as you cut. A sawing motion like this gives more control.

Materials you need:
3 pieces of wood, 150mm by 50mm, by1150mm long (6" x 2" x 3'9"). Lightweight softwood is the most suitable. Select pieces which are free from knots or sapwood, with a straight, close grain, and well seasoned (dry). Imported Oregon Pine is ideal, but expensive.
2 plywood discs, 12mm (1/2")thick, 300mm (1') in diameter, exterior or marine plywood.
4 off M8x90mm (5/16ths by 3.5") bolts.
48 woodscrews, size10x1.5".



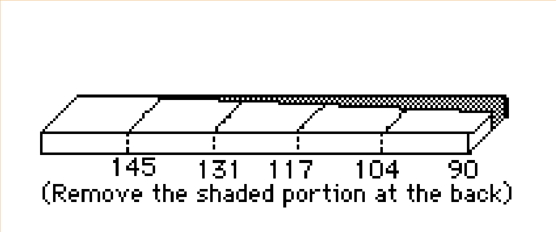


Start by marking out the pieces of wood. Measurements are made at the 'stations' of which there are five along the length of each blade, equally spaced at intervals of 230mm.
ï Mark the position of each station, and draw a line right around the piece, using a square.

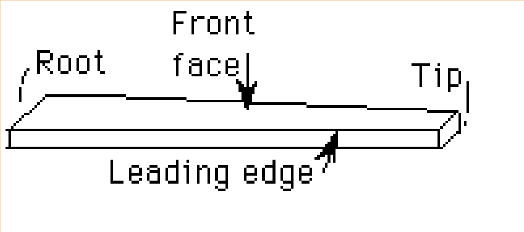


The left hand end is the root of the blade, and the fifth station is the tip, at the right hand end of the piece.
The first shaping operation is to taper the blade, so that the tip is narrower than the root. The width of the first four stations are 145, 131, 117, and 104mm. The width of the tip is 90mm.
ï Measure these widths from the top edge which is nearest to you.

If there are any knots in the piece, try to arrange it so that they are in the triangular piece at the back which you will remove.

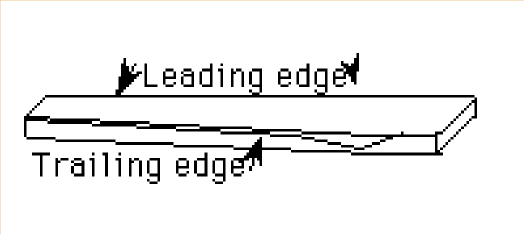


You can use a bandsaw for this, or cut the waste out in sections using a saw and chisel.
ï Plane the newly cut surface smooth, straight and square.

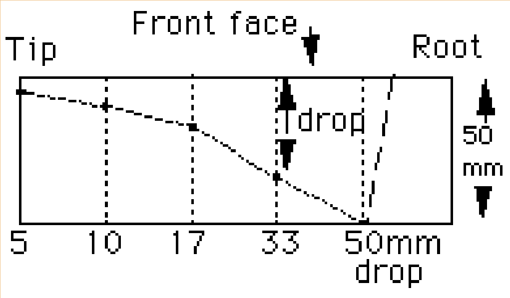


The blade is beginning to take shape now. The tip moves clockwise, viewed from upwind, so the leading edge is the one nearest to you. The front (or windward) face should be perfectly flat at this stage. If not, then
ï Plane it flat, checking with a spirit level across the piece, to remove any twist which may have arisen through warping.

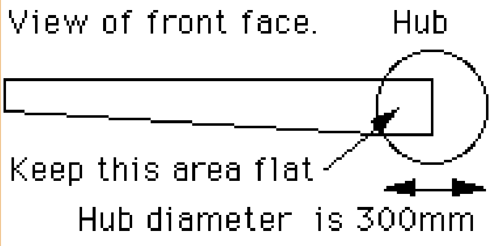
The next stage of the operation is to create a deliberate twist in the blade. First you must turn the piece around, so that the leading edge is at the back.



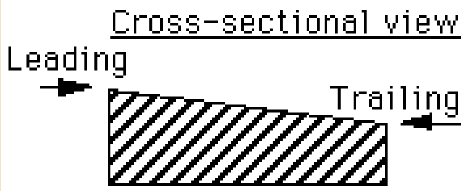
ï At each station, draw a line on the newly cut face, square to the front face.
ï Mark a point on each line, a certain distance down from the front face (the 'drop').



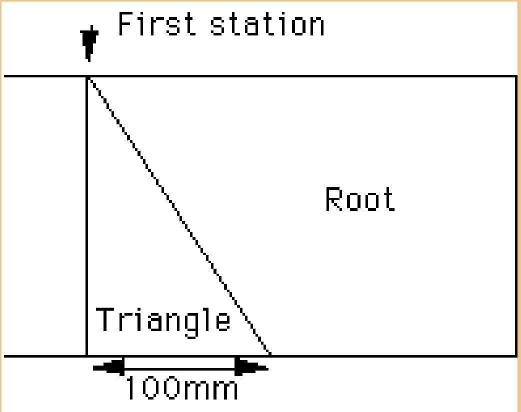
The drawing shows newly cut face, with the thickness of the wood exaggerated, for clarity.
ï join the dots to draw the line of the trailing edge of the blade.
At the root, the line rises to the front face at a steep angle. The root is left as 150 x 50mm timber for assembly into the hub.



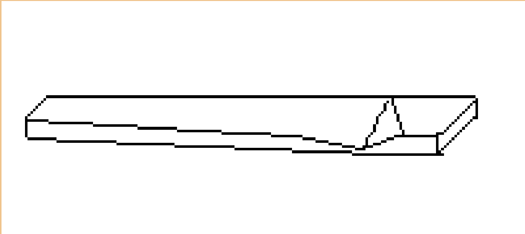
The next carving operation is to put the twist into the blade, using the line you have drawn.
ï Lay the piece down with the front face uppermost, and carve away all the wood above the trailing edge (pencil line), so that you can lay a ruler between the leading and trailing edges.



When you get near the hub, the wood returns to full thickness in a triangular ramp, as in this front view:



You should now have a piece of wood tapered slightly, with a twisted face hollowed out of the 'front'. This will be the windward side of the blade.



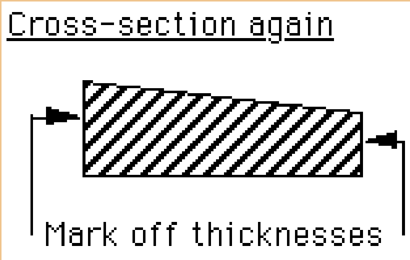
The next step is to reduce the thickness of the piece, so that it is the correct thickness at each station. The thicknesses are 25,20,18,15, and 11mm at the tip.

ï Lay the piece of wood with leading edge uppermost, and make a mark at the correct distance from the leading edge, at each station.

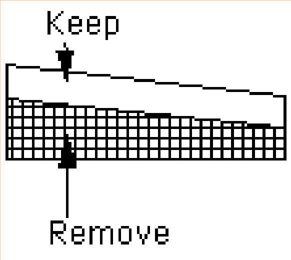
ï Join the dots with a line.

ï Do the same relative to the trailing edge,

Now there are two lines, which will guide you as you cut off the waste wood.

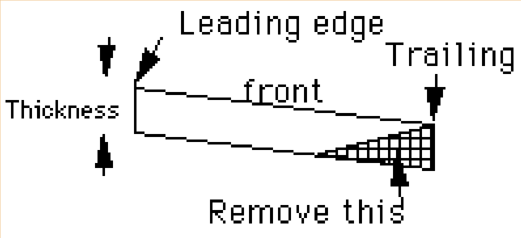


ï turn the piece so that the front face is underneath, and cut away the waste until you get close to the lines you have drawn:



As you work the piece down to the right thickness, it is more accurate to use callipers to check the actual thickness at each station. Measure how many more millimetres need to be removed, then write it in pencil on the workpiece, at each station.
ï Resume shaving off the wood.
At the root, be sure to leave the hub disks area untouched, same as you did with the front face.

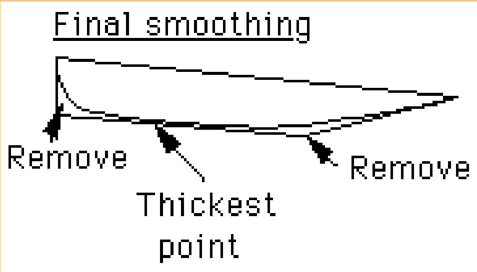
You should now have a tapered, twisted blade, with the correct thickness, but the cross section is still a crude parallelogram shape, which is not sufficiently aerodynamic. The final stage of carving your blade is to give it an airfoil 'section'.



ï Start by feathering off the trailing edge. Plane off wood from the back until you have a sharp edge, less than a millimetres wide, bevelled at the angle shown.
Try to make the light shine on the edge, so you can easily see how much is left to go.

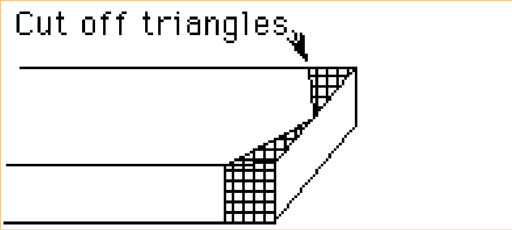
Finally the section needs rounding off into a smooth 'wing shape'. Take care not to reduce the overall thickness. The thickest part should be about 25% back from the leading edge.
ï Draw a line along the back of the blade, 25% back from the leading edge, and avoid cutting the line.

Keep removing the corners, running your fingers over the surface of the back of the blade or watching the way the light casts shadows as it rakes across the wood. Use sandpaper if you must, but a really sharp spokeshave, set very fine, is lovely to use.



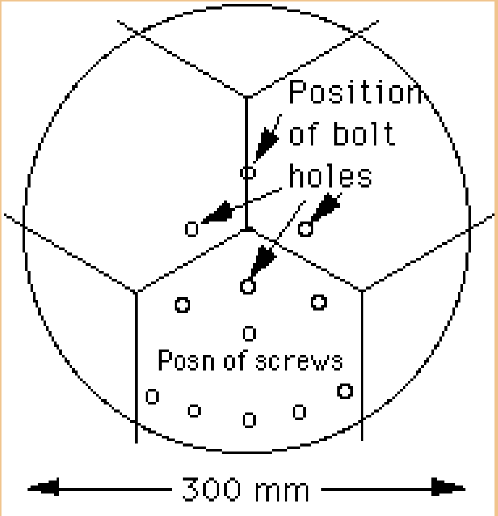
Assembling the rotor blades

Each blade must be cut to a point at the root, so that they will fit snugly at the hub.
ï Measure the exact centre of the blade root, and draw lines out to the edges, at an angle of 60degrees to each edge. Do this front and back, then cut along the lines

: 

The blades can now be laid out with all three roots fitting together. They are supported in this position by the two plywood disks, one on each side.
ï Make pencil marks on the blades, 152mm from each root (front and back), to help you to centre the plywood disks.

The disks will need pre-drilled, countersunk holes for the screws.



ï Lay out and drill the screw holes.
I suggest 8 screws on each side of each blade, in the pattern shown. They must clear the bolt holes, which will be at 38mm radius. The easiest way to lay out the screw holes neatly is to scribe circles on the plywood, with compasses, and then walk the compasses around the circle, marking six equal 60degree angles. Take every second mark as the centre of a blade, and measure from there.

ï Clamp the hub together securely, and check that the blades are equally spaced.
Measuring from tip to tip and adjusting them is the easiest.

ï Check that the tips are all the same height above the bench on which the plywood sits.

This will ensure that they 'track' properly (follow each other through space).

ï Screw the hub together tightly.

ï Drill out four 8mm holes for the mounting bolts, equally spaced around a circle of 76mm diameter.

Drilling the bolt holes is best done with a drill press if possible. In any case take care to drill the holes square to the plywood.

ï Drill the centre of the hub out with a 25mm bit (or similar) to allow cooling air to reach the alternator.

ï Screw small blocks of plywood to the back of the hub, to permit air flow across the front of the alternator.

While dismantling the hub for painting, take care to mark each blade with a number of shallow holes, and mark the disks to match.

Painting the blades

It may be easiest to unscrew the blades, to paint them and the disks.

The leading edges need special treament, either with epoxy resin or 'leading edge tape'. If you are using epoxy resin, it is best to plane off about 3mm from the leading edges and rebuild it with a paste mixed with epoxy and aluminium powder.

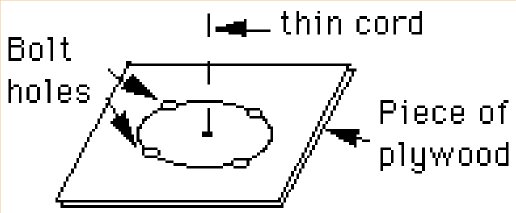
ï After applying resin if any, prime the wood carefully ,and apply plenty of coats of gloss paint. Sand it well before the final coat.

I do not recommend the use of epoxy coatings unless you are sure that the coating will never be damaged. Water within an epoxy coating cannot escape, whereas other paints will breathe.

I do not recommend varnish, since it degrades much faster than paint in ultra-violet light.

Balancing the assembled rotor.

It is essential to balance the blades carefully. The aim is to ensure that the centre of gravity of the assembled rotor is exactly at the centre of rotation, i.e. the centre of the mounting.



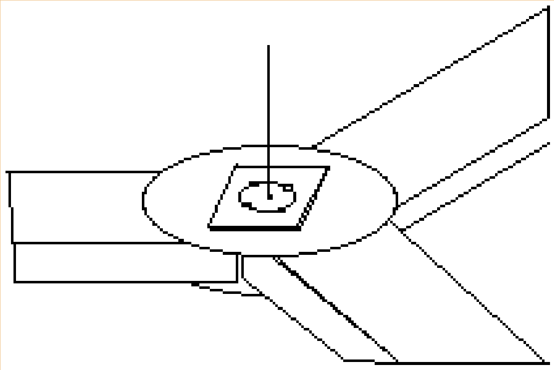
ï Make a jig like this, from a piece of plywood. Drill a tiny hole at the centre and four 8mm holes, correctly spaced to suit the mounting bolts. Thread a piece of fine cord (eg fishing line) through the centre hole, and lock it with a tiny screw in the hole.

ï Bolt the jig onto the rotor assembly, and hang it from the cord. It should hang level. If not, then make it hang level, by adding small weights to it.

Pieces of lead flashing are ideal, but old nuts and washers are adequate. Before you screw the balancing weight on for good, check your jig for accuracy:

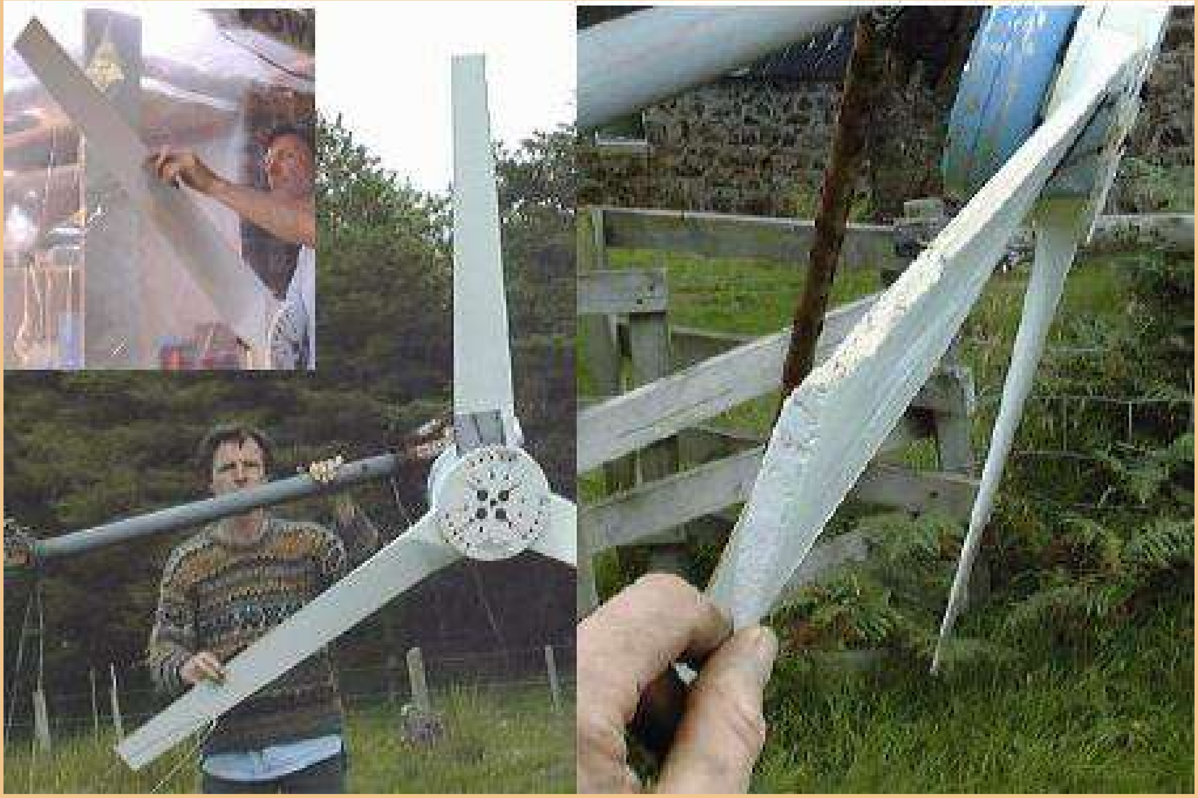
ï Remove, rotate and replace the jig in a different position.

The rotor should still hang level.



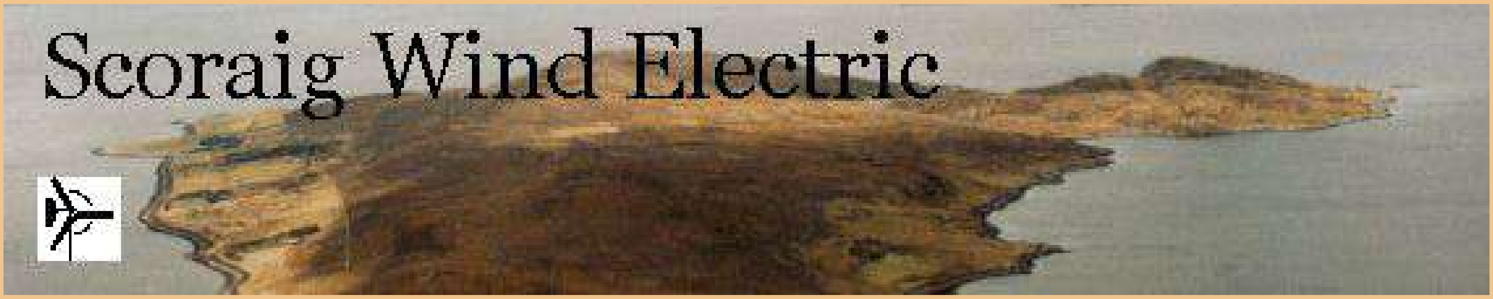
These instructions were used for a project (the 'windkit') which I entered into with Proven Wind Turbines, based on an alternator which they were able to supply at the time. For more detailed plans and instructions see my other books.

Here is what it looks like now (August 1999), after 4 years in action:



It looks as if I forgot to put epoxy resin on the blade edges! Otherwise it works fine. The grey patch on the topmost blade is a piece of lead flashing (used in roofing) screwed on as a balance weight. Normally a smaller weight will do!

Hugh Piggott - back to my home page..



Blade Carving Pictures

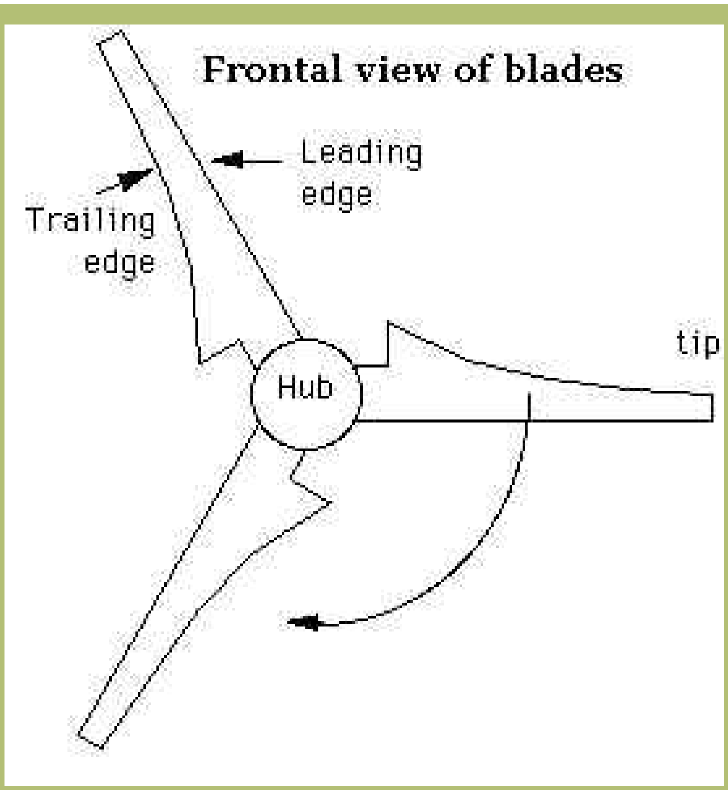
with Liselotte

(text + pictures by Hugh)

This is a series of colour pictures showing the process of carving a small wind turbine blade. The blades in this example are very small, but the same method works for blades up to 2 metres in length.

Click on a colour picture to see it enlarged - or you may want to open it in another window.

The ideal shape for a high speed blade is strongly tapered at the root.



The dimensions were worked out for each station, using a spreadsheet.
We glued a fin onto the root to achieve the large chord width we wanted.

The next steps were to mark each station along the blade,
and then mark the desired width at each station.

 then join up the marks. 

The drawknife is a nice tool to use for shaving it down to width.

(But a bandsaw is quicker if available.)

..

Finish it off smooth and square with a spokeshave..

The top face of the workpiece needs to be flat for the next part.
Check each station with a spirit level..

. turn it back up on edge.

Mark the trailing edge 'drop' at each station and join the marks..

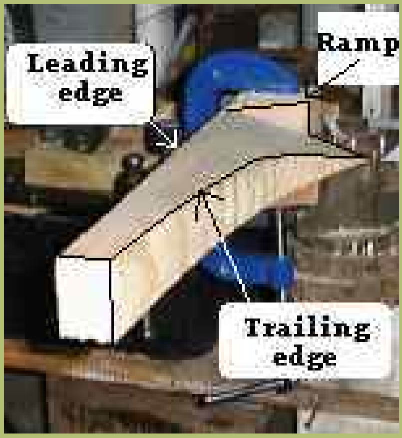
Then lay it down again and carve off everything above the trailing edge line, creating a twisted face on the blade

..

A line across the face from leading to trailing edge should be straight..

At the root we use a triangular ramp to bring the wood up to full size again, for mounting in the hub



Now mark the required thickness of the blade at each station,
on both leading and trailing edges


Turn the blade over, and remove all the wood above these two lines.

Liselotte is using a saw and chisel to roughly hack the bulk of it off.

 .. .. 

and finishing with a drawknife

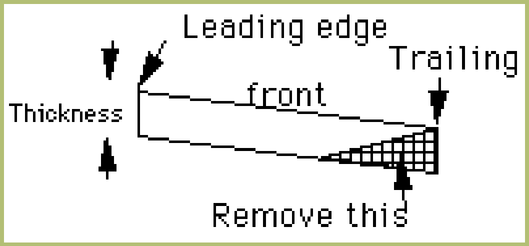
 .. 

It's getting thinner now

Checking the actual thickness with callipers

The important place to check thickness is near the middle of the blade,
but toward the leading edge - this is where the thickness must remain full.

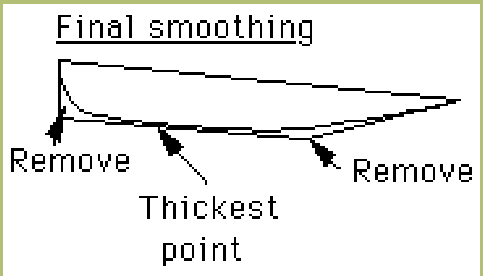
The next job is to feather off the trailing edge to a fine edge,
at the correct angle.. Here is a sectional view, seen from the tip.



We turn the workpiece upside down, to remove the wood from the back.

 [..](#) 

After that we smooth off all the corners and make a nice smooth shape for the blade section.



 [..](#) 

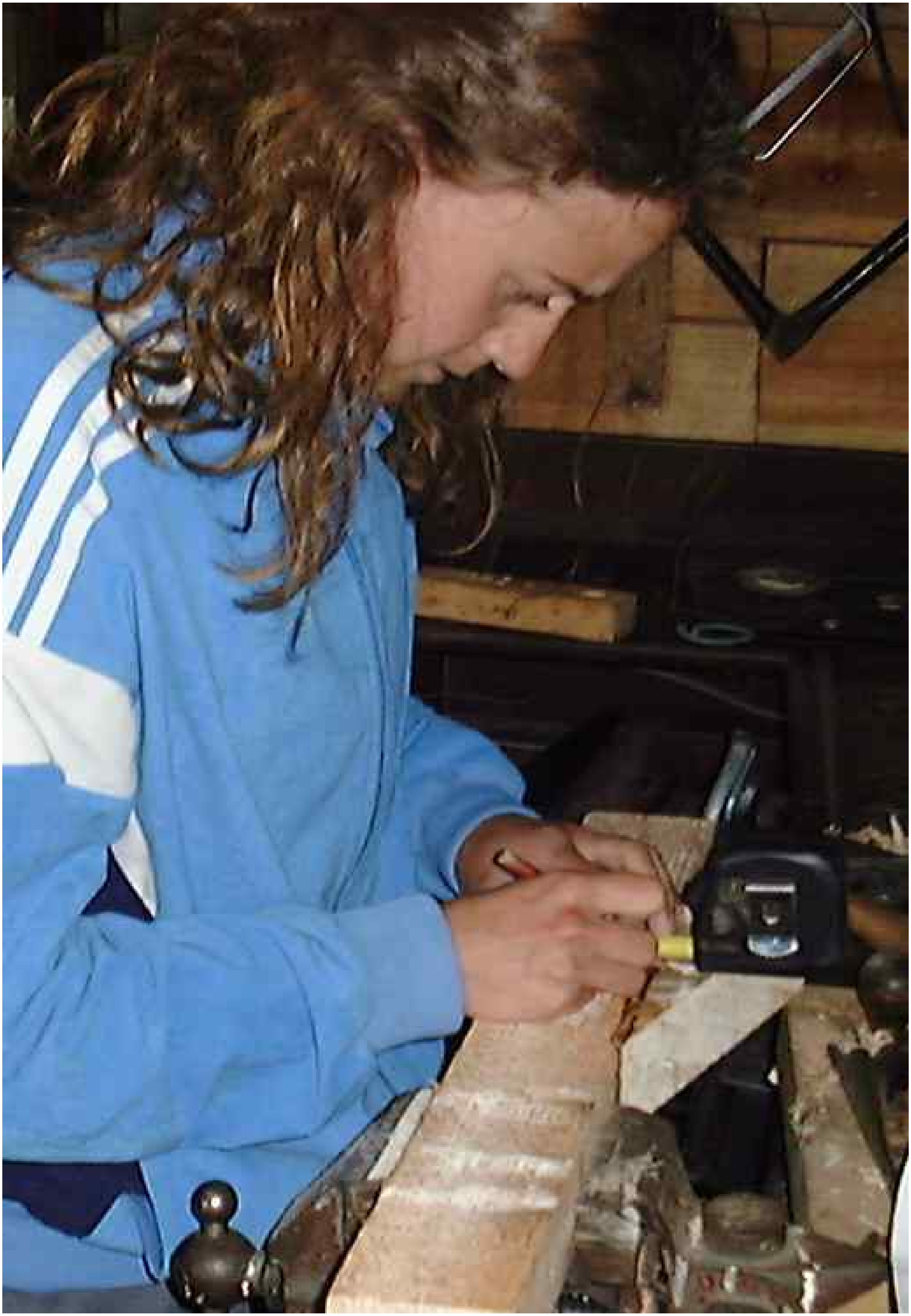
And the finished result is rather nice :-)

 ..  .. 

See also Carving Wooden Blades for a more technical description of the process.

and here is the rotor on test in Norway in November


Scoraig Wind Electric




RECORD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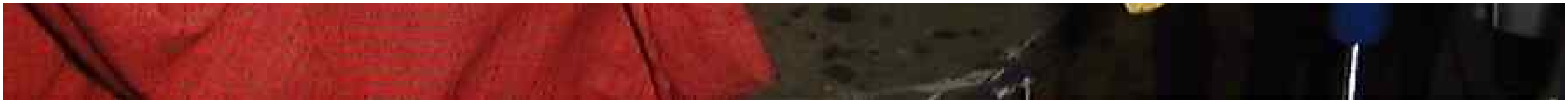


BIKE
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POWER PERFORMANCE TESTING

Scans of a document by the International Energy Agency in 1990. This prescription for performance testing of wind turbines was conceived in 1982-3 and the 1990 document is substatially the same with some small refinements which I have mostly excluded to save space. there is a similar standard test procedure by the AWEA 1983 which I could scan but it's very similar. Averaging interval is 30-90 seconds in the AWEA doc, and the anemometer should be 1.5 - 6 rotor diameters upwind of the rotor.

I am probably breaking all sorts of copyright rules by putting this stuff on my site. Please let me know and I shall remove it! Seems a good idea though. These docs were given to me for nothing and I wish to pass them on in the same spirit.

Hugh Piggott

RECOMMENDED PRACTICES FOR WIND TURBINE TESTING

1. POWER PERFORMANCE TESTING

2. EDITION 1990

Edited by

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I HAVE CUT OUT THE BEGINNING AND END OF THIS BOOK TO REDUCE ITS SIZE - Hugh

4. FIELD TESTING METHODOLOGY

4.1. General

The basic power performance characteristics of the WT shall be defined by the power curve, see Figure 4. The power curve shall consist of data collected from field tests conducted under "natural" atmospheric conditions (that is, the wind turbine tower is stationary and exposed to the natural wind). Data obtained from analytical WT model calculations, bench tests, "constant velocity" tests (towing tests) or wind tunnel tests shall not be employed to generate the WT power curve.

The atmospheric conditions shall be described primarily be the meteorological parameters, wind speed, air temperature, air pressure and wind direction, while the key parameter of the WT is the net power. Sections 4.2 and 4.3. state the specifications and locations of the test monitoring instruments.

4.2. Measurement of Atmospheric Conditions

- Specification and Location of Monitoring Instruments

4.2.1. Wind Speed

The anemometer employed to measure the wind speed should have a distance constant of 5 m or less. It should have an accuracy of ± 0.1 m/s or better over the speed range from 4 m/s to 25 m/s.

Calibration of the anemometer shall be conducted in such a way that it can be verified that the accuracy has been maintained during the test period for the machine under test. The calibration test procedure and test results, including the date of calibration, should be provided in an appendix to the machine test report (see section 7). Calibration by an independent laboratory using traceable standards is recommended.

Use of a secondary calibration source (anemometer manufacturer, etc.) is acceptable as long as traceability is maintained.

The guiding principle of anemometer placement shall be to minimize interference effects from the WT, the meteorological tower and the local topography.

The test anemometer shall be located at a height above the terrain surface, equal to the hub height. However, variations may be considered provided they adhere to the following guidelines:

a) for WT having hub heights greater than 10 m, the anemometer elevation shall be at hub height ± 10% of the hub height.

b) for WT having hub heights less than 10 m, the anemometer elevation shall be at hub height ± 1 m.

The test anemometer shall be placed between 2 and 6 rotor diameters from WT, see Figure 1. The tower centre line shall be the reference for the placement requirement on the anemometer.

For vertical-axis WT, the reference diameter to be used to define the distance between the anemometer and the WT is the maximum rotor diameter.

NOTE: Recent experimental evidence indicate, that more attention should be paid to proper placement of the anemometer on the meteorological tower.

NOTE: Recent experimental evidence indicate, that more attention should be paid to proper placement of the anemometer on the meteorological tower.

A placement at the top of the tower will normally cause no problems and is recommended, whereas boom mounting may cause an appreciable error in measured wind speed if not carried out properly.

At the time of writing, no specific recommendations can be given, except that the distance of the anemometer from the mast, which is normally used, seems to be adequate, whereas the distance between the boom and the anemometer should be increased considerably over what is most often seen in practice.

4.2.2. Wind Direction

The wind direction shall be monitored in order to eliminate atmospheric data influenced by the WT or the meteorological tower as described in Section 4.2.1. and Section 4.5.3.

The wind direction measurement shall be accurate within ± 3 degrees. The transducer shall be located on the meteorological tower at the same height as the anemometer.

Care should be taken to avoid mutual interference between the anemometer and the wind direction sensor (wind vane).

4.2.3. Air Temperature and Pressure

The temperature and pressure measurements shall be made in accordance with common meteorological practice.

Air temperature and pressure shall be measured at the site so that net power can be corrected to the reference air density as described in section 5.2. The accuracy in the determination of the air density shall be better than ± 1%, and the accuracies of the temperature and pressure transducers shall be good enough to meet this demand.

4.2.4. Other Environmental Parameters

Snow or rain may considerably affect both anemometer readings and power output, and data obtained during such conditions should be handled with care.

To quantify the effects of such conditions, separate tests may be carried out, following the recommendations in all other respects.

4.3. Measurement of Parameters of the Machine under Test
- Specification and Location

4.3.1. Rotor Speed

The Rotor speed should be measured with an accuracy within ± 1% of rotor speed at rated power.

This measurement may be omitted in the case of a nominally fixed speed wind turbine.

4.3.2. Net Power

The power monitoring instrumentation used for the test shall have a cumulative accuracy within ± 0.5% of the WT Rated Power. When testing a Wind Turbine Generator, the electric power is to be measured applying a three-phase watt-meter with a response time less than 1 second, and which measures the true r.m.s. value of the power. When testing small battery charging wind turbines, the accuracy range may be exceeded.

Calibration of the instrumentation shall be conducted in such a way that it can be verified that the accuracy has been maintained during the test period. The calibration shall be traceable to International Standards.

The measurement of power shall be performed in a manner that ensures that only the rate of

The measurement of power shall be performed in a manner that ensures that only the rate of energy delivered to a load is measured.

For measurements of quantities describing the quality of power reference is made to the separate part of these Recommendations on Quality of Power.

4.3.3. Applied Load

The applied test load shall be representative of the likely consumer load situation. Its key physical parameters shall be measured and documented consistent with the guidelines of this document and good engineering practice.

The applied load shall be placed in the WT power circuit, or its equivalent, in a manner which ensures that all of the net energy output of the Machine under Test is delivered to the load. Care shall be exercised to measure only the energy output delivered by the Machine under Test.

4.4. Data Acquisition System

Automatic digital data acquisition systems are recommended. Careful attention shall be given to the accuracy and resolution of any analog-to-digital (A/D) converters used in the data acquisition system, since they can potentially affect the outcome of an analysis procedure.

The data acquisition system shall be linear over the entire frequency/amplitude range of the test parameters.

Care shall be exercised to avoid sampling rates which are integer multiples of the fundamental frequency of net power.

The minimum sampling rate shall be 0.5 Hz.

4.5. The Test Procedure

4.5.1. Overview Comments

All aspects of the Test Procedure shall be clearly and definitively documented so that every physical test condition could be duplicated at any later point in time. A detailed Test Plan shall be written which addresses each applicable item in Section 4 of this document as well as the additional activities necessary for the proper conduct of the test and the maintenance of the Machine under Test.

All data shall be reviewed for accuracy and consistency on a periodic basis during the test to ensure maximum reliability of the data. Appropriate test logs shall be maintained to document all events during the test.

4.5.2. Collection of data

During the test period, readings shall be taken continually with a minimum sampling rate of 0.5 Hz, of wind speed, wind direction, net power and, if necessary (see Section 4.3.1.), of rotor speed.

Measurements of air temperature, air pressure and other environmental parameters need only to be taken once for each test period of max. 1 hour duration. For test periods lasting more than 1 hour, these parameters shall be recorded once per hour.

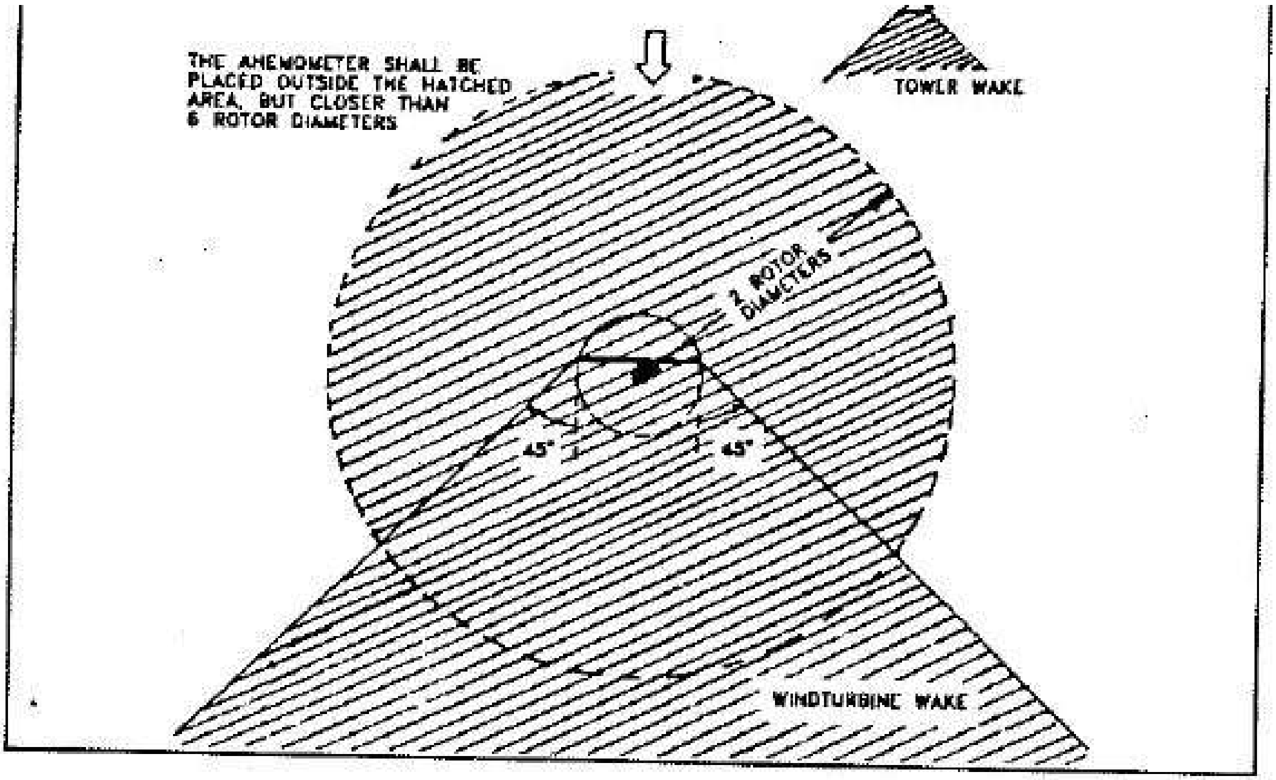

Figure 1. Sketch, showing area around the wind turbine where wind speed measurements cannot be made.

4.5.3. Elimination of Erroneous Data

If - for any reason - the measurement of any one of the sampled quantities is erroneous, the data sample shall be discarded.

If, during the course of the test, the test anemometer is in the wake of the WT rotor or structure, the measured wind speed will deviate from the free stream wind speed. To make sure that the wind speed measurement is not disturbed by the WT, data where the anemometer is within a sector downstream of the WT as defined in Figure 1 shall be discarded.

Data, where the anemometer might be in the wake of the tower, on which the instrument is mounted shall be discarded.

Data where the anemometer (and/or the WT) might be affected by nearby obstacles, like buildings, trees or other wind turbines shall be discarded (see Section 3).

The wind direction to be used in this procedure shall be the 10 min average wind direction.

Data obtained when blades are noticeably contaminated by the attachment of ice, dirt, salt or insects shall be discarded.

4.5.4. Limitation on Modifications and Adjustments to the machine under Test

Any adjustment or modification made to the machine during the test period shall be reported. Also, an engineering assessment of the impact of these changes on the WT performance shall be provided. Adjustments to either the load or generator field or their equivalents shall not be made in any sort of synchronization with the taking of data.

Any maintenance or repair of the machine under test required during the test period shall be reported.

In the case of a standard production model WT, the maintenance instructions of the manufacturer shall be followed.

In the case of a standard production model WT, the maintenance instructions of the manufacturer shall be followed.

Cleaning of contaminated blades (insects, salt) may be done if it is a part of the regular servicing of the machine, and mentioned in the machine manual.

4.5.5. Data Base Requirements

The total data base is formed of one or more continuous test periods, each of limited duration. Data records of less than 15 min. duration shall not be included in the data base.

To the extent it is possible the recording periods shall be chosen "randomly" in such a way

1. that no particular characteristics of the machine are favoured or depressed,

2. that no special climatological situation (except for rain and snow) is chosen or avoided for arecording period so as to enhance or degrade the performance.

The data shall be carefully examined for gross errors (see Appendix 1) both related to instruments and data acquisition system, and the specific test conditions (Sections 4.5.3 and 4.2.4.). Data recognized or suspected of being defective shall be discarded.

Prior to further data analysis, the data shall be reduced by means of pre-averaging of the recorded raw data. Within certain limits it can be shown, that the information contained in the data - with respect to power production - is only marginally affected by pre-averaging, i.e. the accuracy of the final power curve does not depend on how the data are averaged, as long as the pre-averaging time is longer than 1 minute.

However, for convenience, and to match the climatological standard on which the derivation of wind speed frequency distributions are based, 10 min. preaveraging of the data should be used

NOTE: A shorter pre-averaging time does not reduce the total required testing time, as the number of data sets per bin multiplied by the pre-averaging time shall be constant

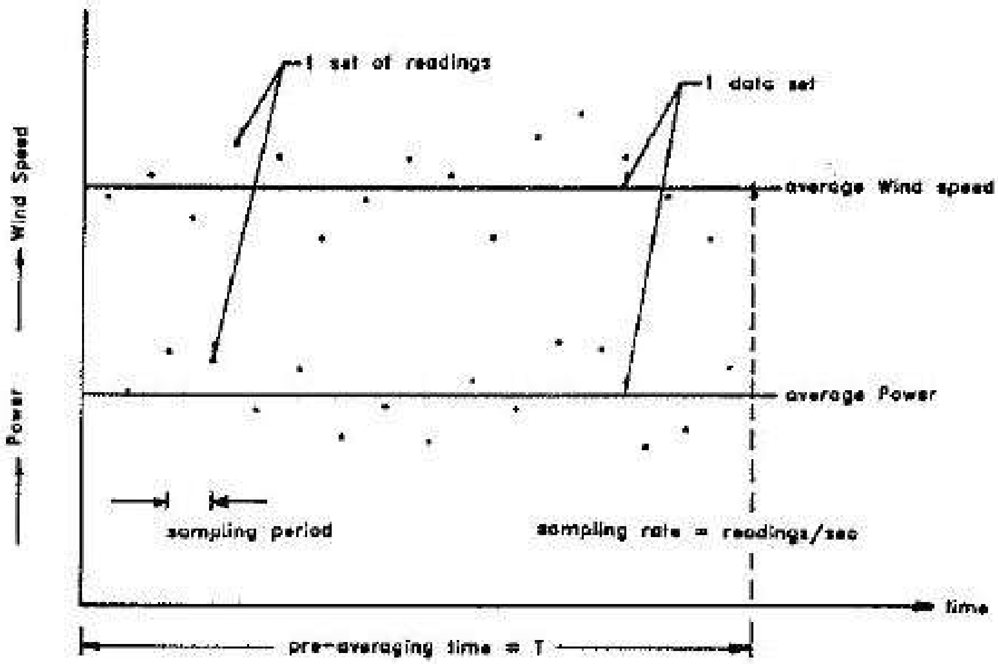

Figure 2. Sketch, illustrating the pre-averaging process.

Given a sampling frequency n and a pre-averaging time T sec, each set of averaged data shall be formed from (T•n) consecutive sets of readings, see Figure 2. No set of original readings must be included in the formation of more than one averaged data set.

The test shall not be considered complete until the following conditions for the reduced (averaged) data have been met:

* Maximum power (in averaged data) shall be experienced.
* Zero or negative power (in averaged data) shall be experienced in atleast 2 concutive bins below nominal cut-in wind speed, (see Section 5.3.).
* Each bin shall as a minimum contain data corresponding to 30 min. of recording, i.e. at least three 10 min. average values. Appendix 1 may be used as a guideline..

5. ANALYSIS OF FIELD TEST RESULTS

5.1. Wind Shear Correction

When Section 4.2.1. is adhered to, no corrections need to be applied to the wind speed reading for anemometer height different from hub height.

5.2. Correction of Power for Air Density Variations

Before data analysis according to section 5.3. is carried out, corrections to the data sets for air density variations must be applied.

The aim of the corrections is to bring the power curve and the calculated mean power as close as possible to the values which would be obtained if the measurements were all carried out at a standard air density at sea level of 1.225 kg/m³ (1013.3 mbar, dry air, 15 degrees celcius or 288.15 degrees Kelvin).

For a stall controlled wind turbine each 10 minute average net power value shall be corrected by applying the following formula:

$$P_S = P_T \left[\frac{1.225}{\rho_T}\right]$$

where P_S = Power corrected to standard conditions

P_T = Uncorrected average power

ρ_T = Test air density

ρ_T is calculated from 288.15

$$\rho_T = 1.225 \left[\frac{288.15}{T}\right]\left[\frac{B}{1013.3}\right]$$

where B = Barometric pressure, mbar

T = Air temperature, degrees Kelvin

T = t + 273.15

t = air temperature in degrees Celcius

For a pitch regulated WTG the correction is the same as for a stall controlled WTG as long as the measured power levels are below 70% of rated power.

For measured power levels above 70% of rated power, the correction applies instead to wind speed (and not to power) according to the following expression

$$V_S = V_T \left[\frac{\rho_T}{1.225}\right]^{1/3}$$

where V_T is the measured, uncorrected wind speed, m/s

V_S is the wind speed corrected to standard conditions

Care should be taken not to apply air density corrections to fractions of the power which are not dependent on air density, such as gearbox and generator losses.

If for instance the relation between net power P and rotor power P_R is of the form

$$P = \alpha P_R - \beta$$

With α and β constant, then the correction of power for air density variations should be

$$P_S = \frac{1.225}{\rho_r}(\alpha P_R) - \beta$$

This will be the case for grid-connected, constant speed WTG, where the electric losses normally will be proportional to the power produced, while the mechanical losses in the drive train will be rotor speed dependant and hence constant for a constant speed WTG.

5.3. Determination of Power Curve from Data

After the data reduction and the correction of data, data analysis is to be performed using the Method of Bins. In this procedure, the wind speed range of operation of the WT is divided into a series of intervals (bins). The speed range of operation is defined as wind speeds from 1 m/s below WT cut-in wind speed to cut out wind speed. The wind speed bin widths between 1 m/s below cut-in wind speed and the lowest wind speed with maximum power shall be 0.5 m/s. The wind speed bin widths between the lowest wind speed with maximum power and cut-out wind speed (or 20 m/s whichever is less) may be increased to 2 m/s. A data set - as described in section 4.5.5. - consists of the 10 minute average of both the wind speed and the net power. Data sets shall be accumulated in the bins, the wind speed determining the specific bin, see Figure 3.

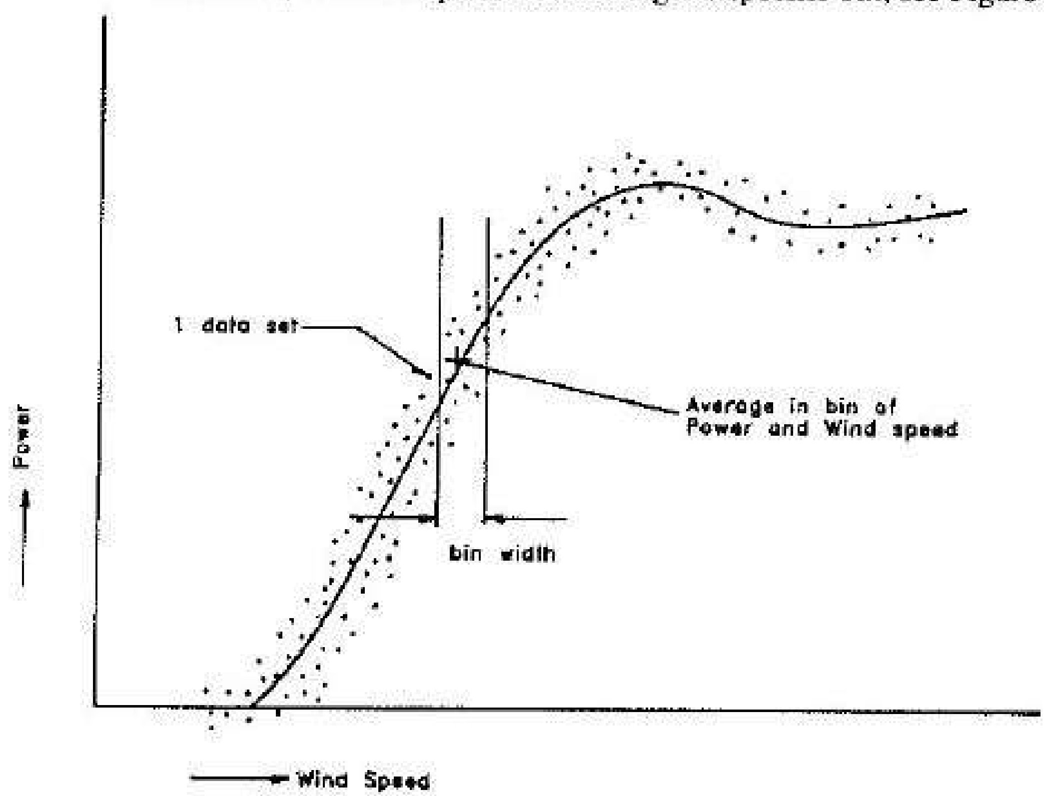

Figure 3. Bin-averaging of data sets.

Then the ensemble average of the data sets in each bin shall be determined by dividing the summed value of the wind speed data sets by the number of data sets, and by dividing the summed value of the net power by the number of data sets, i.e.:

$$V_i = \frac{1}{n_i} \sum_{j=1}^{n_i} V_{ij}$$

$$V_i = \frac{1}{n_i} \sum_{j=1} V_{ij}$$

$$P_i = \frac{1}{n_i} \sum_{j=1}^{n_i} P_{ij}$$

Where V_{ij} = j - t h 10 minute average of wind speed in the i - th bin
P_{ij} = j - th 10 minute average of net power in the i th i - th bin
n_i = number of data sets in the i - th bin.

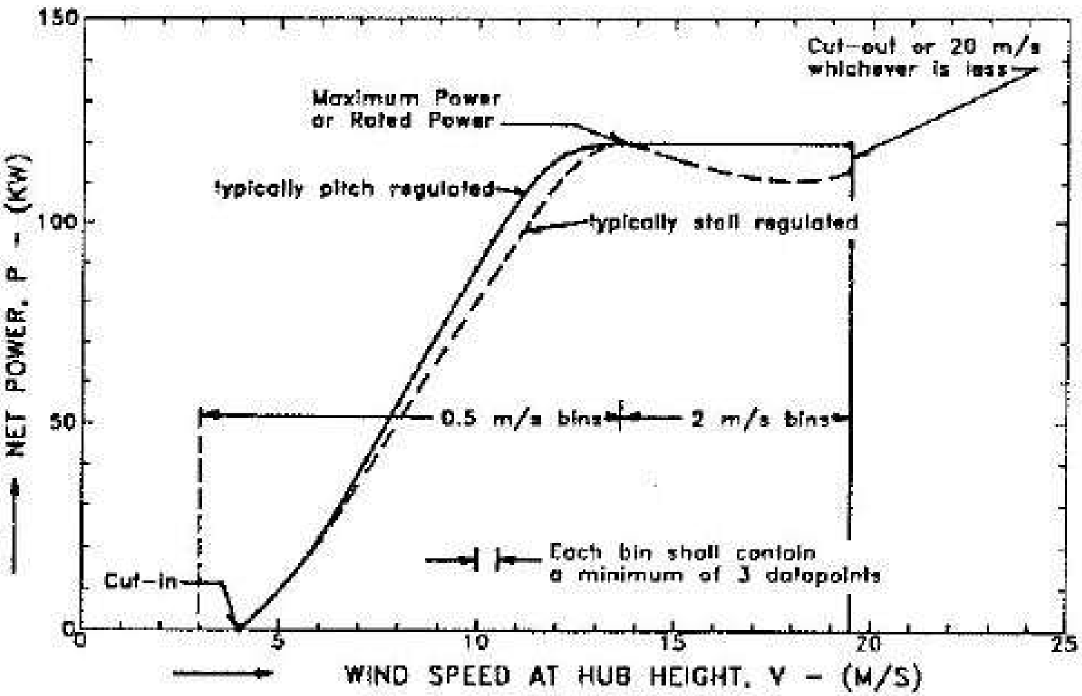

Figure 4. Examples of typical power curves.

The ensemble averages (V_i, P_i) are then plotted and a curve fitted through the plotted points. This curve is the WT Power Curve.

The minimum conditions of section 4.5.5. must be met before the curve is established.

The Power Curve is a linearly scaled Cartesian coordinate system graph of WT net power, corrected for air density variations, (ordinate) versus wind speed, (abscissa). See figure 4 as a detailed example.

Both scales start at zero. The ordinate scale should extend to at least 110% of the WT Maximum Power. The abscissa should extend to a wind speed of at least 20 metres/second.

The Power Curve is to be displayed graphically as indicated in Figure 4, and in form of a table as shown in Figure 5.

bin no.	bin interval	number of data sets	bin averages		
			wind speed	net power	rotor speed
i	m/s	N_i	V_i - m/s	P_i - kW	rpm
1	3.0 - 3.5	12	3.27	-6.22	42.5
2	3.5 - 4.0	18	3.73	-2.34	
3	4.0 - 4.5	26	4.28	2.36	
4	4.5 - 5.0	19	4.76	5.08	
5	5.0 - 5.5	33	5.24	11.81	nominally fixed speed
.	.	.	.	.	
.	.	.	.	.	
.	.	.	.	.	
21	13.0 - 13.5	14	13.22	119.7	
22	13.5 - 14.0	22	13.76	120.4	
23	14.0 - 16.0	11	15.07	116.5	
24	16.0 - 18.0	5	16.93	111.8	
25	18.0 - 20.0	4	18.87	113.1	

Figure 5. Example of table containing the results of the method of bins analysis.

6. DERIVED RESULTS

6.1. Power Coefficient (C_p)

The Power Coefficient is determined as

$$C_p = \frac{P}{1/2\ \rho\ AV^3}$$

Where P is net Power, watts

ρ is air density (1.225 kg/m³)

A is rotor swept area, m²

V is wind speed at hub height, m/s

6.2. Mean Power (MP)

The Mean Power is determined as

$$MP = \int_0^\infty f(V) \cdot P(V) \cdot dV$$

where f(V) = probability density function of wind speed,

and P(V) = experimental power curve.

Care should be taken in the numerical integration for the determination of MP in order not to

Care should be taken in the numerical integration for the determination of MP in order not to introduce too large errors. MP shall be presented as a function of the annual average wind speed $\overline{V}$, Figure 6, assuming that the probability density function of wind speed is a Rayleigh distribution:

$$f(V) = \left(\frac{\pi}{2}\right)\left(\frac{V}{\overline{V}^2}\right) \exp\left[-\left(\frac{\pi}{4}\right)\left(\frac{V}{\overline{V}}\right)^2\right]$$

where $\overline{V}$ = Annual average wind speed at hub height. The uncertainty of MP shall be calculated and presented as a function of $\overline{V}$. The method of Appendix 1 may be used.

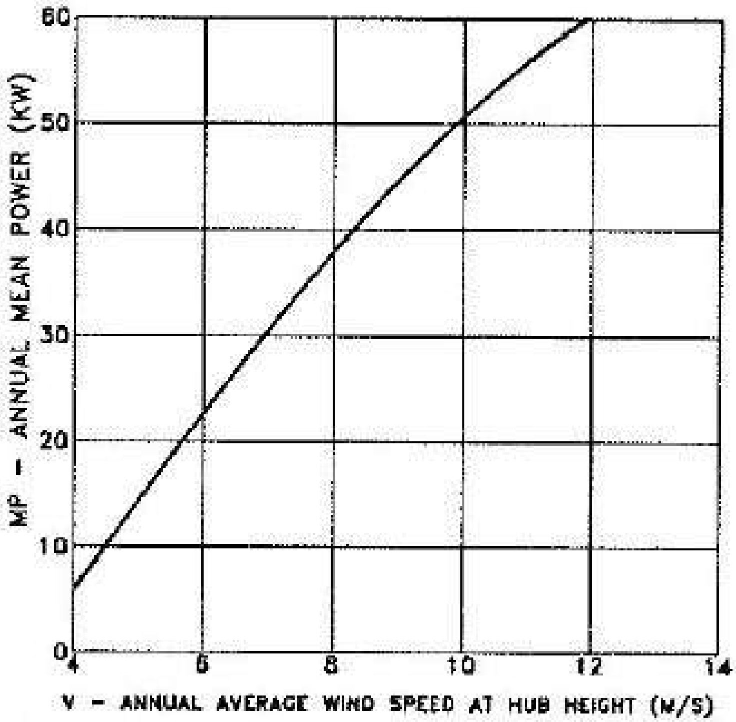

Figure 6. Example of a plot of Mean Power as a function of annual average wind speed, assuming that the probability density function of the wind speed is a Rayleigh distribution.

6.3. Annual Energy Output, 100% Availability (AEO)

The Annual Energy Output (AEO) in kWh is then given by

AEO = (8760 hrs)•(MP).

6.4. Annual Energy Output, Real Availability (AEOA)

The Real Annual Energy Output (AERO) is given by

AEOA = AEO•TA

where TA (Technical Annual Availability) is the time fraction of the year the wind turbine is technically ready for operation, whether the wind conditions are suitable or not. Unless determined through a long period of monitoring (more than a year) the TA will be an estimate, based on experience with wind turbines similar to the machine under test.

based on experience with wind turbines similar to the machine under test.

6.5. Influence of Environmental Parameters on AEO and AEOA

In stating AEO and AEOA for a particular site, the influence on AEO and AEOA of snow, rain and insect contamination of blades must be considered (see Section 4.2.4. and Section 4.5.3.).

That's it folks. If you insist, I can scan more but the rest of the book is relatively dull.

[Hugh Piggott]()

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Created for Intermediate Technology Development Group (ITDG), as part of an overseas aid project for DfID.

SMALL WIND SYSTEMS FOR BATTERY CHARGING.

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- PMG construction manual see this page for details and download
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more about the guide for development workers:

Background:
This booklet outlines the potential for using small wind generators to charge batteries ï typically motorcycle, car or lorry batteriesï for use in households where mains electricity has not yet reached. In many countries of the world this is the case for the majority of the population, and in some rural areas almost all the population.
The background to this booklet is a UK Government-funded project entitled "Small Wind Systems for Battery Charging" that was undertaken in Peru, Sri Lanka and the UK. The project demonstrated the potential market for small wind energy systems and the economic and technical viability of locally manufactured, low-cost small wind battery charging units, suitable for use in remote areas of developing countries. This booklet is one published output of the project. There are also technical manuals for generator manufacturers, blade manufacturers and installers. Most of the practical information explained in this booklet is taken from pilot installations in Peru and Sri
Lanka.
This research on small wind energy systems for battery charging is the result of a collaborative effort involving numerous contributors.
The project was managed by ITDG (also known as the Intermediate Technology Development Group) under a contract to the UK Department for International Development.
The overall international project was co-ordinated by Dr Smail Khennas, Senior Energy Specialist from ITDG with support from Simon Dunnett. The field work in Peru and Sri Lanka was
respectively managed by Teodoro Sanchez and Rohan Senerath, with support from Sunith Fernando.

Simon Dunnett, Dr Smail Khennas and Hugh Piggott (a UK technical consultant for the project), are the authors of this guide for development workers considering the use of small wind energy systems in rural households
The views expressed in this report are those of the authors and do not necessarily represent the views of the sponsoring organisations, the reviewers or the other contributors.

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more about the blade booklet

Wind rotor blade construction

Small Wind Systems for Battery Charging

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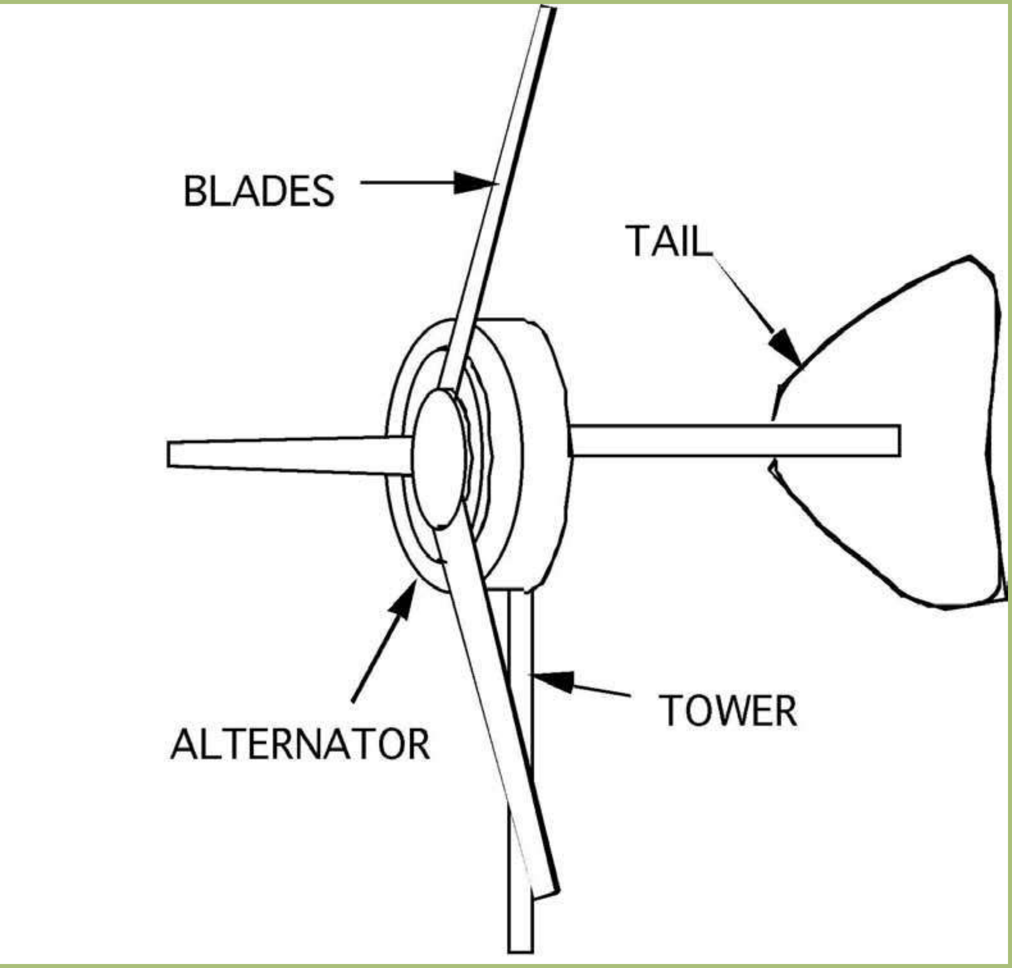
BLADES
TAIL
ALTERNATOR
TOWER

Department for International Development, UK

SMALL WIND SYSTEMS FOR BATTERY CHARGING

A guide for development workers

Contract R 7105

By Simon Dunnett, Smail Khennas and Hugh Piggott

In association with : ITDG-UK; ITDG Peru and ITDG South Asia **July 2001**

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Cover photo: Wind Turbine, Sri Lanka <u>Simon Dunnett</u>.

SMALL WIND SYSTEMS FOR BATTERY CHARGING

A guide for development workers

PREFACE

How to use this booklet

This booklet will deal with some of the non-technical aspects of promoting wind energy for rural electrification, as well as giving a guide to needs assessment, resource assessment and technology choice. Examples from Peru and Sri Lanka are used to illustrate some issues. For a more detailed look at the wind generator itself, see the technical manuals produced along with this booklet concerning generator and rotor manufacture (details are given in Appendix I).

Part 1 gives an overview of the technology of domestic scale wind generation. It looks at the technology itself as well as site and resource assessment, needs assessment and economics. Part 2 looks at the bigger picture; how small scale wind energy can be part of a sustainable supply of energy to rural areas.

INTRODUCTION

The electricity grid can provide households and communities with reliable, high quality, predictable and cheap electricity, but this is far from the norm for the majority of the world's population. Whilst being in the forefront of many governments' stated development objectives, widespread electrification is still the dream rather than the reality for most.

Electricity can bring many benefits; for those in the developed world it is taken for granted. In areas without the grid, some households use motorcycle, car or lorry batteries to power radios or TV. This small amount of energy can disproportionately improve the standard of living for the poorest. When there is enough to also provide lighting, it can improve children's opportunities in later life by enabling them to study after dark.

Such batteries are often charged in the nearest town, which can be costly in terms of money, time and convenience. At a suitably windy site (discussed in section 2) small wind generators provide a better option for charging the batteries. Automotive batteries are not ideal for this charge/discharge use, but they are a popular choice because of first cost considerations.

Photo 2: a 12 volt car battery used for radio and TV in Sri Lanka (Simon Dunnett,)

Why wind energy is an attractive option

There is a large market of existing battery users

In Sri Lanka, for example, it is estimated that 300,000 households use car or motorcycle batteries for radios/TV. There is a substantial market for a convenient and clean battery-charging system.

Batteries can be charged close to the household, saving time and money

For example, a study of villages in Sri Lanka (see appendix I) found that over half of the households use automobile batteries to power radio and TV sets. The battery sizes were 60 and 90 Ampere-hour (Ah). Recharging involved a minimum cost of Rs.30 (US$0.50) and a trip of 6km twice per month, just for radio and maybe some black and white TV use. This cost may now (from more recent studies) be estimated at US$1.00

The amount of energy available from the batteries can be increased, and new batteries will not have to be purchased so frequently

At a good site, and with careful energy and battery management, the average amount of energy available to be used by the household will be greater when the battery is being gradually charged, than if it is charged periodically and used until it is flat. If battery power is used for lighting, this can reduce the expenditure on kerosene and dry batteries, which is estimated at a further Rs.280(US$5) per month in the above study. Furthermore, batteries actually suffer damage from deep discharge, and this renders them useless more quickly than if they are kept charged by a wind generator.

Photo 3: A child with an electric lamp. Kerosene is not only expensive but its fumes pollute the household air. (Simon Dunnett,)

Wind energy is more environmentally benign than many alternatives

Although energy is used in the wind generator's manufacture, once in operation it does not consume fossil fuels and does not emit greenhouse gases. Because the electricity produced and used for lighting displaces the use of kerosene, the household environment improves. Wind generators produce some noise, but for machines designed to revolve at low rotational speeds this is much less than higher speed generators, and certainly far quieter than a diesel generator set. The visual and noise impact of the type of system described in this booklet has not caused concern at any of the test installations.

Wind energy is cheaper than the alternatives

Where the wind resource is good, energy produced in this way can be cheaper than using solar photovoltaics or diesel generator sets, particularly if the fuel supply is far from the user. If the site is located near a river or stream, hydropower should be investigated first, since this can be more competitive. Mains electricity, if it is available, is likely to be cheapest of all, on a per-unit basis. In remote areas however, the cost of connection may considerably exceed the cost of meeting local needs though wind-(or solar)-battery systems.

How can wind energy be made more attractive?

Battery power can be an intermediate step before grid connection

Grid connection is the preferred choice of most households, even if it appears unlikely to occur within the next ten years or so. If the grid is planned to arrive in the short term (within 2-3 years), it may be more prudent for the household to wait, providing initial connection charges and tariffs can be afforded. In the medium term, there may be a reluctance to invest in wind generators, especially if it is perceived that they cannot provide grid-quality electricity (230V, 50Hz). This need not be the case, however, since the output from the battery, charged by a wind generator, can be modified to run AC (alternating current – similar to mains electricity) appliances. If the grid does arrive in the future, these same appliances can be run from the mains, or the use of the wind generator continued. Second-hand wind generators can find a ready market in areas where the grid has not arrived; this can reduce the risk of purchase.

Households can share one generator

At a good site, and with a suitably-sized machine, two or three households can be connected to a battery bank to form a mini grid. If the system operates at a higher voltage (where suitable appliances are available) line losses can be reduced. A high level of co-operative spirit is required for this kind of project. One advantage is that the cost of the machine and infrastructure can be shared, making the initial investment more attractive. Larger wind generators are also more cost-effective than small ones. (Photovoltaic installations do not have this benefit of scale.) Maintenance can be easier – with a greater pool of people to draw from both tasks, and the cost of outside help, can be shared if necessary. It may be possible to add extra power sources to the system if it is large enough. Extra diversity from solar or engine-driven sources will improve the reliability of the supply during calm periods.

Locally manufactured machines can be maintained more easily and provide local employment

Small wind generator technology is well established internationally, so what are the advantages of manufacturing systems locally? There are four good reasons to take this approach rather than to rely on imported technology.

Firstly, locally produced machines are likely to be cheaper to buy, especially where foreign exchange is scarce and the local market is not large enough to negotiate discounts.
Secondly they will be easier to maintain, because local technicians will understand them. Many small wind generators have failed prematurely due to poor understanding of the technology.
Thirdly the machines will be more suited to local conditions – a machine designed to charge yacht batteries might not be suitable for inland wind regimes and car batteries.
Lastly, local manufacturing enterprises are used, which helps create jobs.

There are risks involved however. The main ones are the wider manufacturing tolerances and limited choice of raw materials in small engineering workshops where the wind generators are likely to be made. Although this has been allowed for in the design highlighted in this booklet, it does result in larger and weightier machines.

Why doesn't everyone use wind generators?

The importance of the wind regime

The most important factor in the success or failure of any wind energy installation, whether it is a commercial wind farm or small-scale battery charging, is the strength and nature of the wind resource. The average windspeed of a site is a good guide to whether it is suitable for a wind generator or not. Since the energy in the wind varies in proportion to the cube of the windspeed, a site with a windspeed of 4m/s (9 mph) can potentially only harvest half the energy of a 5m/s (11mph) site.

However, the average windspeed only gives an indication of the suitability of a site. A site with high and low seasonal winds can have the same average windspeed as a site with a steady windspeed all year round. If a generator was placed on the former site, energy may well be wasted during seasons of high wind, and batteries run flat during low wind seasons. A steady moderate wind regime is better than a high but variable one, as described in more detail in section 2.

Set-up costs can be high

In general, renewable energy technologies have to make use of resources that are not very energy-dense; that is, a large quantity of the resource has to be used to produce one unit of energy compared to fossil fuels or nuclear energy. This tends to result in relatively large machines or systems to convert this diffuse energy into electricity, which can be relatively expensive. In the case of wind generators, a further burden is the need for a generator that revolves at the same slow speed as the blades (since this is preferable to a geared transmission). Generators are generally less efficient at low speeds, so a heavier machine is used to compensate.

In order to put the generator and blades in the path of the wind, the whole arrangement needs to be put on the top of a tower, which takes time to prepare and erect. Finally, it may be necessary to house the batteries and control circuitry in a weatherproof building that may be some distance from the user's house, which will need to be connected to the battery, using distribution cables. The whole installation process usually needs to be supervised by an expert or the manufacturer.

'Wind generators don't work here'

There is often a perception that wind generators are not suitable for use in a particular area, or even country. This is usually because bad experiences in the past and tales of poor performance have warned people away from the technology. There are commonly two reasons why wind generators get this tarnished reputation.

Aid agencies in the past have set up inappropriate pilot sites, with the best of intentions, which typically use technology imported from the donor country. Whilst this works well in the right setting, all too often the machines either fail to perform as expected or are wrecked in the first monsoon storm. The strengths and weaknesses of wind generators may have been misunderstood, and the unfamiliar technology may have been too difficult to troubleshoot.

The other main reason is the lack of available wind data. Windspeeds measured at ground level at a few sites are generalised countrywide, and the conclusion is that the wind just does not blow hard enough. Both these experiences can be avoided by using good design and research.

Lack of a holistic approach

There are other reasons why wind generators are not as widespread as maybe they should be. Chief amongst these is the lack of support for the industry and users. An elegant technical solution to a problem is unlikely to succeed without proper marketing, after-sales support and finance packages. A holistic approach needs to be taken, and this may involve some level of government regulatory backing or financial support.

PART 1: WIND ENERGY TECHNOLOGY FOR BATTERY CHARGING

1. Understanding Wind Generator Technology

The type of wind generator discussed in this booklet has been designed for use in households in moderately windy areas with no access to grid electricity. It is suitable for local manufacture, and has been designed to be as inexpensive as possible. The basic features (shown in *Figure 1*) are common to most small wind generators, but there are some original ideas in the ITDG design.

The wind system comprises; the generator, blades, and tail vane mechanism, tower, charge controller and batteries. Each component is described briefly below. For more detailed technical information please see the technical manuals that accompany this booklet (see Appendix II).

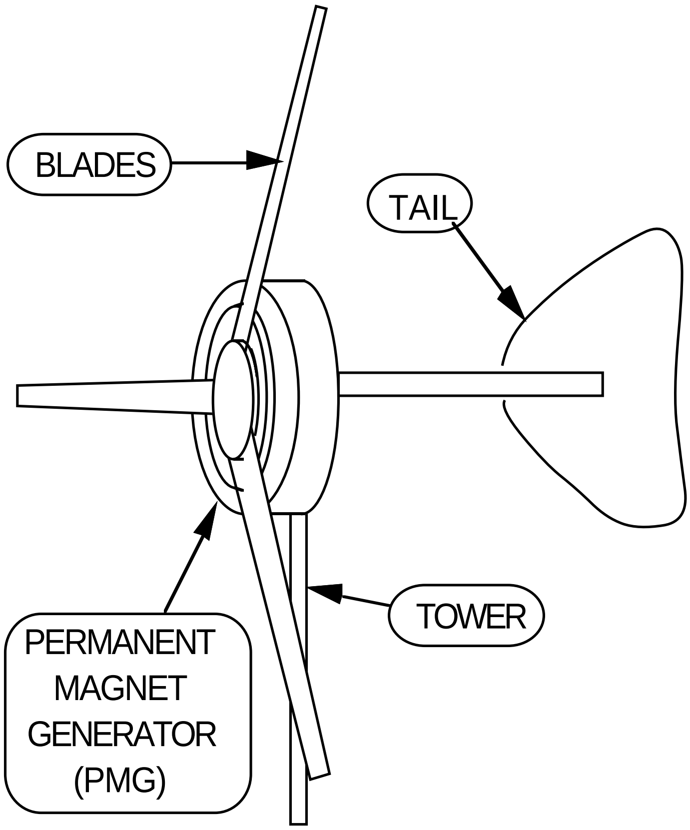


Figure 1: Parts of a typical wind generator

The Permanent Magnet Generator (PMG)

The ITDG generator is shown in exploded form in figure 2. The magnet rotor disks are mounted on a bearing hub so they can rotate on the shaft. They are directly driven by the blades of the wind generator. Almost every small wind generator on the market uses a directly driven permanent magnet generator (PMG) of some similar type. They are specially designed and built for the purpose of extracting power from the slowly turning blades with best efficiency and minimum complexity.

Between the rotors is a stator, cast from plastic resin, holding coils of copper wire. (Most other PMGs use a laminated steel core for the stator instead.) The ITDG PMG is constructed as far as possible using readily available materials and off-the-shelf components. It can be manufactured in a modest workshop having basic engineering equipment.

Photo 4 : Stator manufacture in Peru (Hugh Piggott)

Electricity is generated when the magnets on the magnet disks rotate past the coils embedded in the stator casting. The magnetic field induces a voltage in the coils which is ultimately fed to the batteries. At low rotational speeds the voltage is insufficient to charge the battery, but when 'cut-in' windspeed is reached, a current flows into the battery so as to charge it.

The magnetic field through the coils reverses as the magnet poles in the rotor disks pass them, so the voltage produced alternates also, which means that the generator produces alternating current, or AC. The coils are arranged 'three-phase' to make most efficient use of the space available, and

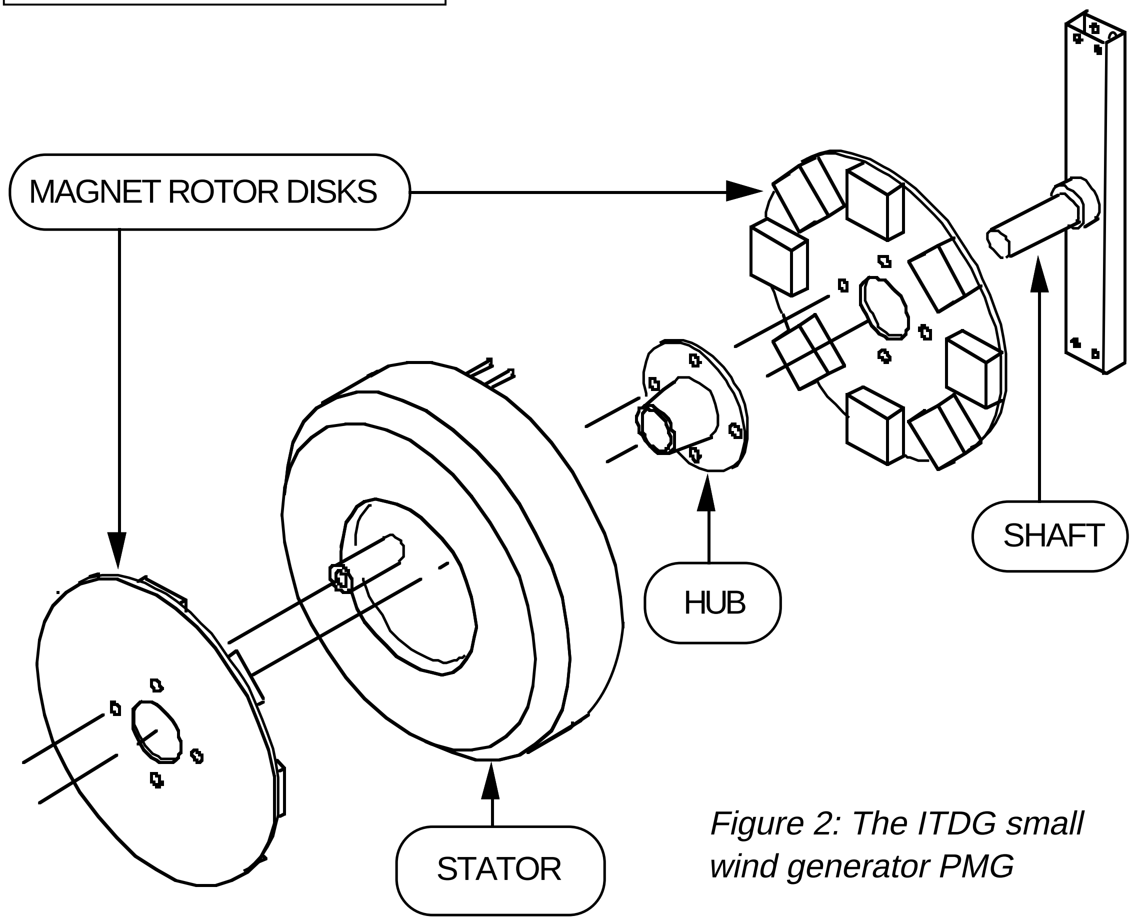


Figure 2: The ITDG small wind generator PMG

deliver a smooth output. The three-phase AC is converted into direct current, or DC, so that it can charge the battery. The device which converts AC to DC is called a rectifier.

The blades

Modern wind turbine rotors usually have two or three blades. A larger number of blades would create more turning force (torque), but would not be capable of driving the PMG fast enough to generate the required voltage, because it would turn more slowly. The higher speed rotor actually catches slightly more power than the slow one would. The rotor blades and the PMG are both very carefully designed to match each other's speed and power, so as to extract the maximum energy from the wind.

The output of the wind generator over time depends more on the amount of wind swept by the blades than it does on the power rating of the PMG. Electricity generation is especially valuable during low wind periods, when the battery otherwise becomes discharged. At low speeds power output depends only on the area of wind swept by the blades. The rated power output only occurs in stronger winds, so it is not seen under these conditions.

Photo 5 : Three bladed wind turbine by IT Peru. Blade diameter 1.7metres (IT Peru)

If the PMG is not connected to a battery or other electrical load, then the blades will overspeed, like an engine at full throttle, out of gear. The machine will become noisy and may vibrate so much that parts come loose and fall to the ground. To prevent this type of problem the following things are important:

- Keep the wind generator connected to a load at all times.
- The wind generator must have an effective furling system for high winds.
- The blades should be carefully balanced so they run smoothly.

Tail vane mechanism

The tail vane is used to face the machine into the wind. It also includes a mechanism which comes into play when windspeed exceeds a certain level (usually around 10 metres per second). It 'furls' the generator and blades out of the full force of the wind, by swivelling the whole machine on a bearing (the yaw bearing) at the top of the tower. A simple mechanism using gravity on the tail vane maintains the generator and blades facing the wind when the wind is moderate, but turns it sideways-on in very strong winds. This system is essential to protect the blades from overspeed and the PMG from damage. There are several similar mechanisms which can be employed to furl the machine in this way.

Tower

The tower raises the generator, blades and tail vane to a height where the wind is stronger and smoother than at ground level. The tower is as high as possible above all surrounding obstacles. Trees and buildings will affect the wind to a height almost double their own height, but practical considerations, such as expense, safety and maintenance limit the height to between 10m and 20m.

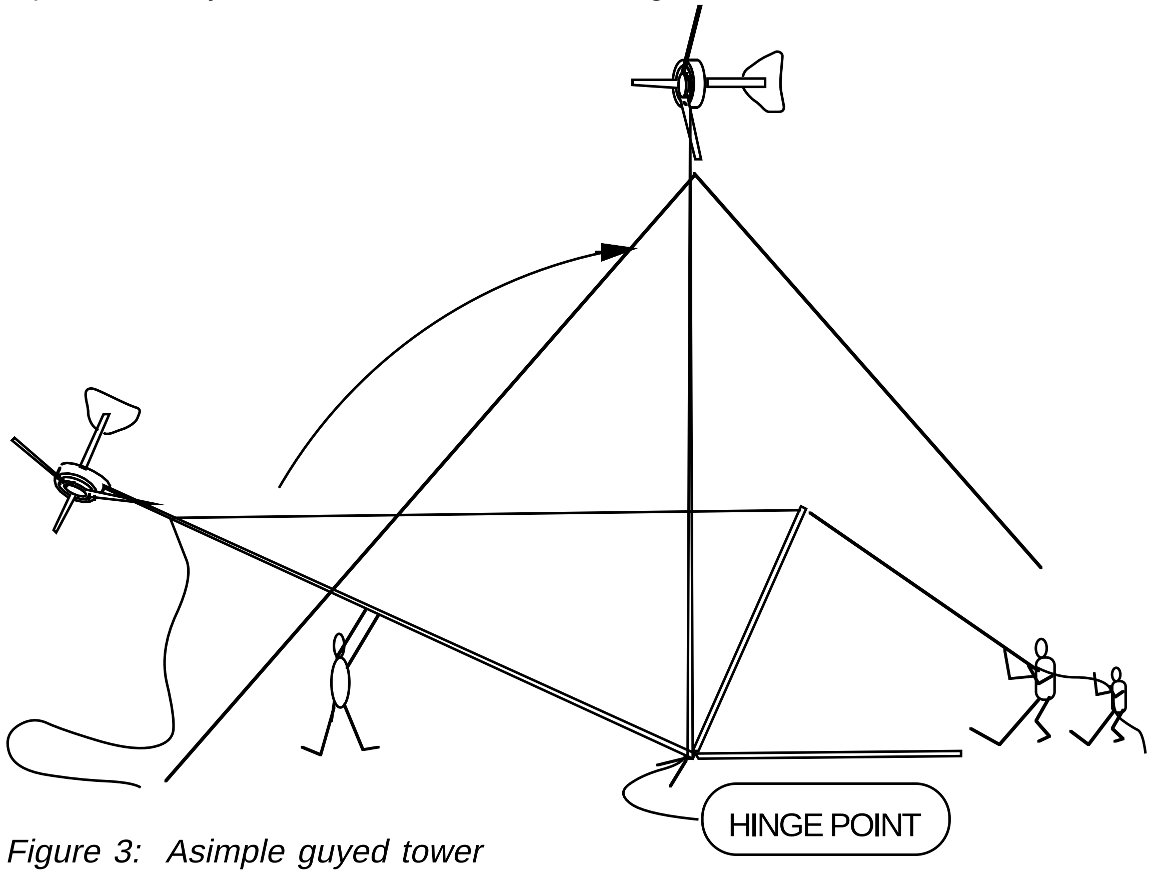


Figure 3: Asimple guyed tower

The simplest towers are usually steel water pipe, held vertical by one or two sets of guy wires. The guys are anchored into the ground firmly, but the base of the tower is usually hinged to allow for the lowering of the generator for maintenance or repair; see Figure 3.

Photo 6 Raising a guyed tower with poles and ropes in Peru (Hugh Piggott)

Electrical controls

Charge controller

The charge controller is there to prevent damage to the batteries. If the batteries are near to full charge, but the wind is blowing strongly, the charging current needs to be reduced to prevent damage to the battery. The charge controller will divert some power from the generator away from the battery and into a ‘dump load’. This can be anything from a series of bulbs to a heating coil – in the simplest systems this excess energy is wasted.

Charge controllers for solar PV systems are not suitable for wind generators because they unload the wind turbine by disconnecting it from the battery.

Different types of battery require different settings in the charge controller. For example, sealed batteries are charged at a lower voltage to prevent gassing, whereas vented batteries are allowed to charge more vigorously and produce gasses.

Low voltage disconnect

Batteries are easily damaged by excessive discharge. A device that cuts off the current from the battery to the user load (light and other circuits) at a pre-set low voltage can prevent this. Such a device is often called a 'low voltage disconnect'. This sort of device is recommended where users will attempt to use energy from the battery until it runs out. With education and user vigilance such devices are unnecessary.

Inverter

Inverters are used to convert the low voltage DC from the battery (usually 12V) into mains type 230/240V AC. Higher output-quality inverters are better for most purposes, but these can add substantially to the cost of the whole system. Lower cost inverters have lower output, and/or

Photo 7: Left to right: Inverter, charge control circuit, and dump load, in Sri Lanka. (Simon Dunnett,)

lower protection against abuse. Inverters generally make sense for small networks of households with a central generator, since the additional cost can be shared, and the cable runs are long enough to require the higher voltage supply.

Load control

In more sophisticated systems, and especially where there is more than one household using the batteries, an individual load, or a group of loads, can be individually controlled to match demand and supply. These different loads will be switched on and off depending on the state of the battery charge and this can be done randomly or sequentially.

Batteries

For stand-alone wind systems, where a constant supply of electricity is desirable, it is essential to have a battery to store electricity for when the wind is light. The battery also regulates the voltage of the system, which would otherwise vary wildly with windspeed and cause damage to equipment.

It is likely that car or lorry batteries will be used with the system described in this booklet, either because they are already being used or because they are cheap. However, deep cycle batteries are more cost-effective in the long run, for windpower systems.

Vehicle batteries are not ideal since they are designed to be only partially discharged before being steadily charged by the vehicle alternator. It is therefore important that they are cared for well. This means guarding against over-charge and over-discharge, and also topping up the electrolyte with pure water as required. Frequent discharge and charging of these batteries will inevitably wear them out.

Photo 8: Wind generator control cabinet and car battery. (Simon Dunnett, Sri Lanka)

The optimum battery technology is a matter for urgent debate within the small scale renewable energy world. Where possible you should consider the option of using deep cycle batteries rather than automotive ones. They will last much longer, and ultimately give better value for money. The widespread, short-term use of automotive batteries for rural electricity supplies is likely to cause serious environmental pollution problems from lead contamination in the future.

Fuses and circuit breakers

Overcurrent protection is as important in small wind systems as in households on the grid. Fuses and breakers prevent too much current from flowing in circuits or appliances, causing damage or fire through faulty wiring. A battery can deliver very high currents under short-circuit conditions, so fuses or circuit breakers are highly recommended for fire safety.

A typical system

A typical system is shown in figure 4. The main components are the wind generator and tower, battery, charge controller and/or load controller, distribution cables, fuses, and household appliances. An inverter can be included, if necessary, to give mains voltage power. The battery and controls may be located in a powerhouse built for the purpose.

Several batteries can be connected in parallel to the same source, and will share the charging current. The most discharged battery will consume the bulk of the power. If a battery is defective, it can drain power from other batteries connected to it.

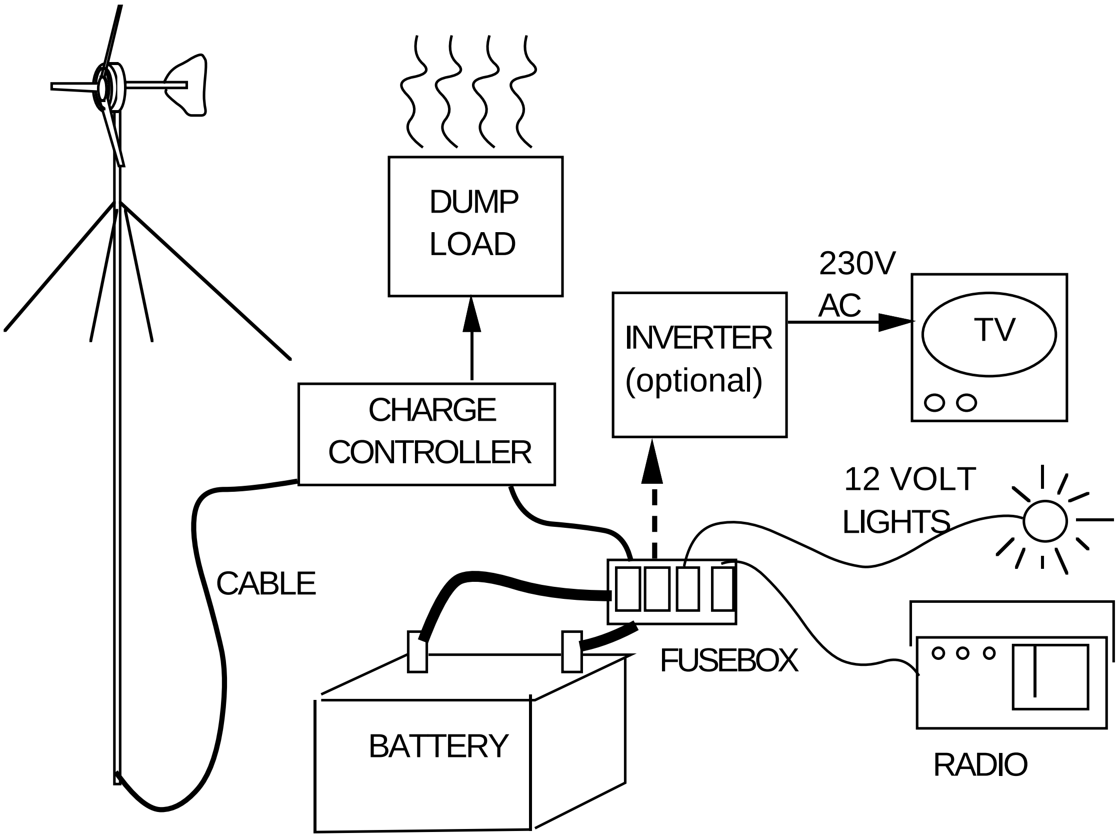


Figure 4 : A typical system

DC or AC?

DC, or direct current, is the only type of electricity that you can get straight from batteries, and is suitable for running DC appliances. It is convenient to use DC with small wind generators for charging batteries. There are two disadvantages, though.

- The range of 12V DC appliances available may not be large. It is always possible to use equipment designed for use with cars and boats, but the choice is limited.
- The other disadvantage is the higher power losses in cables associated with higher currents. (Using low voltage requires a higher current in amps, for a given power in watts, because power = volts x amps. Loss increases with the square of current, which is a problem when the cable is long as there is more resistance in the system. A current of ten amps creates one hundred times the loss of a current of one amp, for example, because the square of ten is one hundred.)

The supply from the mains grid is AC electricity. There is an international standard which is 230V, 50Hz, used in many countries. Most wind generators produce non-standard AC, which is then converted into DC before it enters the battery. In order for the household to use 230V AC, the battery supply must be reconverted into standard AC through an inverter. The inverter can be expensive and add significantly to the whole system cost, so it is important that the pros and cons are understood. This additional cost, and potential failure of the inverter, are the main disadvantages of AC, although users also need to be aware of the additional safety requirements needed with this higher voltage. The advantages are that common electrical appliances are designed for AC and the householder may prefer AC for this reason. Also, the losses due to the heating of long cables are greatly reduced, meaning more power is available for appliances. Some of this benefit is offset by power losses in the inverter incurred during conversion of DC to AC however.

Vehicle 12 volt bulbs are a little brighter than conventional 230V bulbs of the same power rating, but AC power from an inverter can be used to run ‘energy efficient’ compact fluorescent lamps which are many times brighter. The final decision may come down to consumer preference and available finance. Automotive light bulbs are cheap and reliable, but it would probably make sense for a group of households sharing a wind generator to invest in an inverter. The use of AC would allow households to use the same appliances if the grid were to arrive in the future.

It should be made clear that a higher voltage (230V AC) does not guarantee a more powerful electricity supply. Using an inverter may make the supply more efficient and versatile, but electricity from a small wind generator stored in an automotive battery is a very volatile resource, which ought to be used sparingly, especially during calm weather.

Matching needs, the wind and the generator

If the windspeed is low, and the energy produced by the wind generator does not meet the needs of the users, then the battery will become discharged and other sources of power will be needed. When the wind exceeds demand, then energy will be wasted in the dump load, unless efforts are made to offer battery charging services to neighbours or find other uses for the surplus power. Wind is an unreliable resource which is likely to vary over time, which leads to both of these problems.

To avoid disappointment and wasted opportunities, the system should be designed with estimates of inputs and outputs appropriately matched, and with strategies in place to deal with the variations in the resource.

In the section 2 we shall look at how to assess the potential of the wind resource and section 3 describes how to assess the amount of energy required to meet a given need.

In practice, windspeeds are not predictable, except as an approximation. User loads are also unpredictable, and will tend to grow to fit available supply. The best approach is to gain a common-sense understanding of the order of magnitude of the resource, and of the relative energy consumption levels of different types of load. If this data can be interpreted to the users, then there is a good chance of the system operating successfully.

2. THE WIND POTENTIAL

It has already been stated that the energy in the wind is proportional to the cube of the windspeed; for example, if the windspeed doubles the energy available goes up by for example a factor of eight ($2^3 = 8$). This usually means that the minimum average speed should not be less than 3m/s.

Measuring the wind

Measuring the windspeed accurately can be a difficult task when resources are limited. To do a proper job will involve erecting an anemometer (or two) at the site in question, and correlating the readings with long term meteorological data that is available for the region in question. Finding suitable data may be very difficult, especially when the entire country's windspeed data is based on a few dozen anemometers placed at head height near airstrips. Unless you are planning to install a few generators at the site you are monitoring, it may not be financially viable to invest in an anemometer at all. Fortunately, there are less precise, but more accessible, ways to tell if your site will be any use.

Anecdotal evidence.

The first method, and the least accurate, is to use anecdotal evidence. There is little possibility of being able to calculate potential energy generation figures from such unscientific data, but you may be able to get a rough picture of seasonal patterns. You may have to think twice, for example, if you are told that the wind doesn't blow at all for two months out of the year, but is more than adequate for the rest of it.

Beware of statements such as 'the wind never stops blowing here'. Even long term residents in an area can be surprisingly unobservant. Every location has some calm weather.

The local vegetation

Longer-term patterns, such as prevailing winds, are often evident from the way shrubs and trees have grown. Subjected to long-term pressure from mainly one direction, vegetation will visibly grow away from the wind. The extent of the distortion gives a strong clue as to the strength of the wind. Again, you cannot use these observations to calculate the wind's strength accurately, but they may help to build a picture.

A word of caution – make sure that you are not observing the natural tendency of vegetation to grow towards the sun rather than away from the wind! The further you travel from the equator, the lower the sun is in the sky and the more pronounced this tendency. Also, the lack of growth in one particular direction may not mean that there is no wind – simply that there is no dominant wind direction.

The Beaufort Scale

The second method uses recorded observation over a sustained period. Table 1 (based on the Beaufort Wind Scale) shows how you can tell roughly, without measuring equipment, what the speed of the wind is (in metres per second or m/s) at a particular instant.

Table 1- Beaufort Wind Scale

Beaufort number	**Description**	**Wind Speed** m/s	**Observations**
0	Calm	0	Tree leaves do not move; smoke rises vertically
1	Light Air	1-1.5	Tree leaves do not move; smoke drifts slowly
2	Slight Breeze	2-3	Tree leaves rustle; flags wave slightly
3	Gentle Breeze	3-5.5	Leaves and twigs in constant motion; light flags extended
4	Moderate Breeze	6-8	Small branches move; flags flap
5	Fresh Breeze	8.5-10	Small trees sway; flags flap and ripple
6	Strong Breeze	11-14	Large branches sway; flags beat and pop
7	Moderate Gale	14.5-17	Whole trees sway
8	Fresh Gale	17.5-20	Twigs break off trees
9	Strong Gale	21-24	Branches break off trees; shingles blown from roof
10	Whole Gale	24.5-28	Some trees blown down; damage to buildings
11	Storm	29-32	Widespread damage to trees and buildings
12	Hurricane	33+	Severe and extensive damage

Beaufort 1 and 2 carry no useful power. The winds which are of most interest are Beaufort numbers 3, 4 and 5. At Beaufort 6 and above, the furling system will operate.

To use the Beaufort scale correctly, it will be necessary to keep a log of the windspeed observed several times during the day, ideally over a period of at least a year.

Anemometers

A good anemometer, with datalogging equipment, will cost several hundred US dollars. This will give very full data for the windspeed on the site, enabling you to predict the performance of small wind generators with confidence. The data can also be compared with regional meteorological sources (if any) and thereby extrapolated into long term data.

Demonstration installations

A limited wind monitoring budget could be used instead to pay for a small wind system installation, which could prove or disprove the point in a much more practical way. As we shall see later, the performance of a small wind system is influenced by a multitude of factors. It is not easy to predict the available energy output of the system with confidence, even given the best possible data for the wind.

A small windpower installation serving a practical purpose can answer the question of whether the technology is effective in a given area. Care must be taken to install it according to best practice, and a degree of monitoring is essential. Much can be learned from this exercise with a minimum of financial outlay. Of course, if unsuitable equipment is chosen, then the project may fail even though the conditions are potentially favourable. This cannot therefore be seen as a complete substitute for meteorological studies.

Where to site the generator

Even in an area where you are confident of an adequate wind regime, you can still site the generator incorrectly. Perhaps more importantly, at marginally suitable sites, you can substantially improve the likelihood that the technology will succeed by placing the generator sensibly.

The higher the better

The windspeed generally increases the further from the ground you are, which is why generators are placed on towers. You can help increase the windspeed at the generator by using the local topography – site the generator on the highest bit of land nearby or on the top of an open hill if possible. Be careful not to site the machine too far from the household though, since you will have to spend more on transmission lines and some power will be lost as heat in the cables.

Photo 9: A wind generator on an open site. The tower should be as tall as possible, and well above the tree tops. (Simon Dunnett, Sri Lanka)

Out in the open

It is important (where possible) to avoid buildings and vegetation on the ground. Farmers know that a good way to shield delicate crops from the wind is to plant a windbreak. Consider the prevailing wind direction and place the generator upwind of unintentional windbreaks (i.e. before the wind is affected by them). The negative effect of the windbreak when wind is blowing from other directions must be recognised. The turbulence caused is felt a very long way downstream of obstructions, so place the generator above them if at all possible, or use a higher battery voltage (reducing the cost of the cable) to enable you to place it several hundred metres away/uphill in the open.

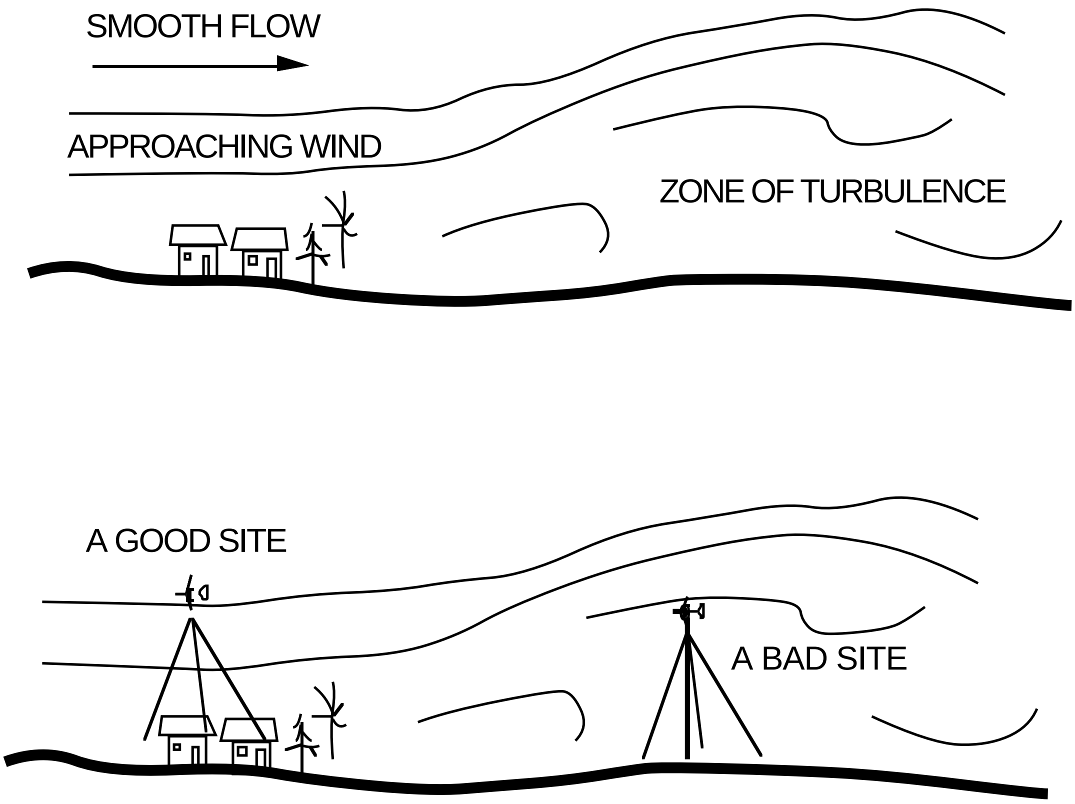


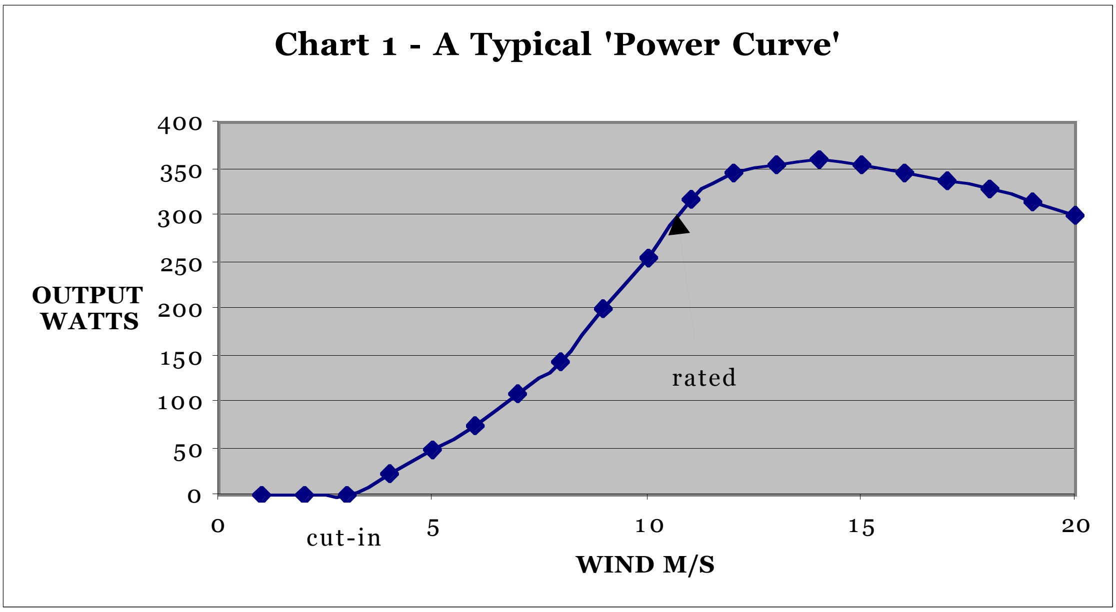
FIgure 5: The zone of turbulence behind an obstacle is twice as high as the obstacle itself, and extends ten times as far downwind.

Safety considerations

Avoid siting the tower above areas where people live, work or pass by. Parts of the wind generator may fall to the ground under storm conditions, and it is not unknown for the whole tower to collapse. Make a realistic assessment of these risks when siting the tower. Where safety concerns conflict with optimum siting, safety must be paramount.

How much power will a wind generator produce?

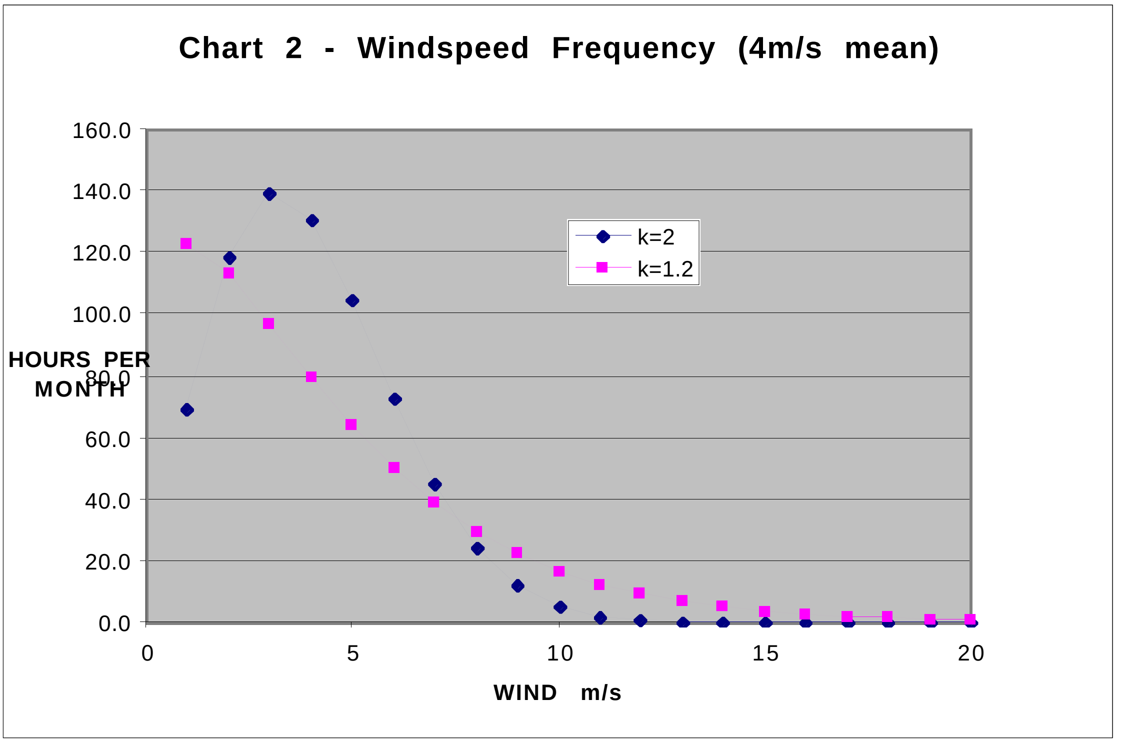
Wind generators produce no power in at low wind speeds, below about 3m/s. Above the ‘cut-in’ windspeed, the power output will increase with increasing wind, until rated power is reached. Sometimes even more power is produced at certain windspeeds, but the output tends to level off as the furling system comes into operation.



The graph of power versus windspeed is known as the 'Power Curve'. Chart 1 is an example of a typical power curve for a wind generator with 2 m rotor (blades) diameter and 300 watts rated output. It represents short term instant power levels, rather than longer term energy production (average power).

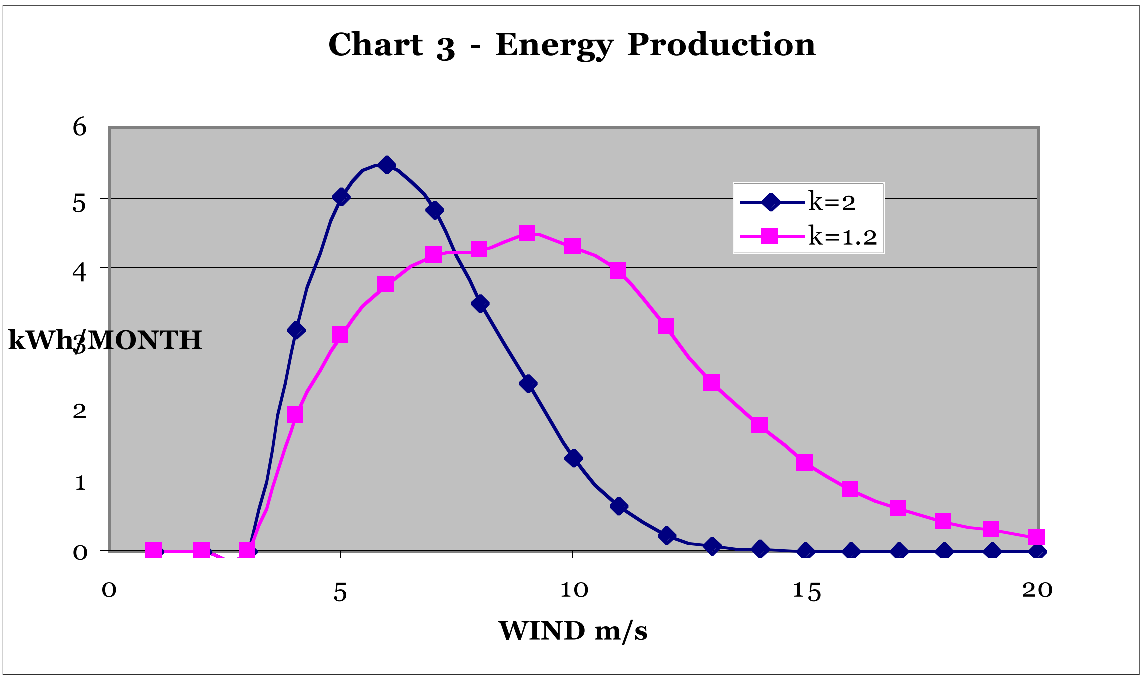
It is interesting to compare this Power Curve with the actual windspeeds encountered on low wind sites. In chart 2 showing Windspeed frequency, we take as examples two sites, both with mean windspeed 4m/s. The shape of the windspeed distributions (how much the wind varies) can be characterised by a 'shape parameter' k. The first example has the sort of windspeed variation typical in temperate climates (k=2) and the second has a wider ranging distribution (k=1.2).

In the first example (k=2) the wind is mostly around 2-5 m/s, so it makes sense to look at what the wind generator is doing in these conditions. The 'Rated Power' of the wind generator has little relevance to this situation. The energy captured will depend on the area of wind swept by the rotor blades.



In the second example (k=1.2) the wind is often very low and therefore useless. A wind generator will not be reliable as a single power source in this situation, but may work well alongside solar panels in a hybrid system. Higher winds are experienced more often than was the case in our first example, so we can expect to see the wind generator reach its rated output at times. These occasions may well coincide with cloudy weather, associated with passing storms, when the solar panels are not producing well.

The windspeed frequency chart tells us how many hours in each year a certain windspeed will occur. The Power Curve tells us how much power we can expect during those hours. By combining them we can find out how much energy is produced at each windspeed over the course of the year. The energy per month figures are simply calculated by multiplying the hours per month by the power produced at each windspeed. This is shown on the chart 3 labelled Energy production.



In the first example the total energy production over the month is 27 kWh, whereas in the second example, where the wind varies widely, a total of 41 kWh is produced. However most of the energy in the latter case comes during the relatively short periods of higher windspeed, and will be hard to exploit effectively unless the wind generator is a part of a larger system with alternative sources of power and a larger battery.

Predicting the output of a wind generator is therefore a difficult task, requiring large amounts of accurate data for both the site and the machine itself. Site data is expensive to acquire. Data for the machine is available from manufacturers, but is usually inflated. (There is no incentive for manufacturers to publish accurate data, and every incentive to select advantageous 'data'.) The curve presented in the above example is relatively modest and it yields 'real' results.

The task of calculating the available energy from a given machine on a given site is almost impossibly complex. The best approach may be to make an informed guess and then refine this in the light of practical experience. As a rule of thumb, for quick calculations, we can use this equation to estimate the energy per month:-

kWh energy per month = (rotor diameter in m)^2 x (mean windspeed in m/s)^3 / 10

Table 2 gives some rough figures which can be used as the basis for such estimates.

Table 2 – Approximate Energy production in kWh per month for various sizes of wind generators on various sites.				
	Mean windspeed for the site			
rotor diameter	3m/s	4m/s	5m/s	6m/s
1m	2	6	10	20
2m	10	25	50	70
3m	20	60	100	160
4m	40	100	200	280
5m	60	160	300	430

:
In the final calculations, allowance has to be made somewhere for energy losses in the system: the cables, the battery, and the inverter are all guilty of consuming energy, which therefore does not reach the end-user.

Losses are especially high at higher windspeeds, because the cables are carrying full current. Under these circumstances, the battery may well be fully charged, and the charge controller therefore would be dumping power. Power generated at low windspeeds is of much greater value to the end user, which is why it pays to choose a wind generator with large blades, rather than a high power rated generator.

Photo 10 : A 3.6metre diameter wind generator on a 3.5m/s site in rural Zimbabwe (Hugh Piggott)

3. ASSESSMENT OF NEEDS

When you have assessed how much power you may expect from a wind generator, you need to calculate how much energy you need for a given application. This will largely depend on two factors – the nature of the present and future energy needs of the household, and the number of households that are to use a single generator.

Household energy use

Photo 11: A wind powered 'compact fluorescent' is used as an outside light in Sri Lanka, to keep elephants away from the house and crops. (Simon Dunnett)

Things which use electrical power are called 'loads'. There is a wide variation in the amount of power used by loads. Electric heaters and cookers use too much power to be run from a battery supply, unless the wind regime is very good or a large generator is affordable. For heating loads of this type it is better to look at improved cookstoves, biogas, and improvements to household insulation in the first instance. Although the generator can be designed to 'offload' excess power through a heating element when the batteries are full, this is operated automatically for the protection of the system rather than the convenience of the user.

It is possible that the household will be using automobile batteries to power lights, radio or TV already, but it is important to look at what electrical end uses would be possible in addition to the existing ones. For example, where kerosene lamps may be used in some rooms; it is likely that compact fluorescent bulbs can replace these, at least during windy periods. It may be possible to light external areas for safety or convenience also. Sewing machines, computers, and water pumps are other possible load options.

As well as determining end uses (loads), it will be necessary to estimate the total time that these appliances will be used during the day or week. This is in order to distinguish between the power required at any particular time, and the total energy consumed.

Power and Energy

Energy is measured in watt-hours (Wh) or kilowatt-hours (kWh). It is the ability to do work.
Power is measured in watts (W) and kilowatts (kW). It is the rate at which the work is done.

So a 20W bulb running for one hour will consume as much energy as a 10W bulb running for two hours (20 Wh or 0.02kWh). If the bulbs are being supplied from a battery continuously, the 20W bulb will run the battery down twice as fast as the 10W bulb. It is therefore important to calculate exactly how much energy is required per day or week, see how many batteries will be needed (if you have a choice) and match that to the size of the generator.

Number of households

In areas where there is a good wind and there are two or more households close together, with similar energy requirements, it could make sense to share one generator and battery bank. As mentioned in the introduction, this can be advantageous financially. Calculations for the size of the system are similar to those for a single household.

It is important to ensure that each household connected to a single generator is able to manage their energy use effectively. In a simple system, where load control is not automatic, users will have to ensure that they are not excessive in their energy use. This applies to a single household with a single generator too, of course, but when more than one household is sharing a supply of electricity, the potential for disputes is present. Some ways to overcome this are:

Individual batteries for each household

Rather than charging a common battery bank, it could be possible to charge individual batteries in rotation. Without the use of electronic controls, this would need to be done manually and a suitable rotation system worked out. During windy weather it would be advisable to connect all the batteries. Windspeed varies in such a random fashion that it would be very hard to ensure equal measures of charge into each battery in the short term.

Battery charging for a fee

If a transmission line for each household is impractical (because of the cost and energy losses), or a suitable power-sharing arrangement cannot be settled on, one solution may be for each household to carry batteries to a charging point and pay a fee for each recharge. We shall look at this arrangement as a business model in a later section on economics. Although more inconvenient than a fixed supply cable, this would ensure that each household pays equally for the amount of electricity that it consumes. It would also make the energy available to a more widely dispersed community.

The disadvantage is that the batteries will be more deeply cycled (fully charged to nearly discharged) than they would be if each household were permanently connected to the wind generator. In the latter instance the wind energy would meet the demands of the loads directly for much of the time.

Load limiters and low-voltage disconnects

Load limiters are used on small hydro (water powered) systems where the maximum power is limited. When connected to each distribution line, they ensure that a set current level is not exceeded – one household will therefore not be able to use a disproportionate amount of power. This solution will not prevent the high energy use, for example by leaving lights on overnight, so it is less suitable for a battery system.

Low-voltage disconnects

disconnect the supply line from the battery running to the household if the voltage falls below a set level. This ensures that no power is drawn from a near empty battery. Running auto batteries flat frequently substantially reduces their life.

Electronic load controllers (ELCs)

A more sophisticated form of control is to use electronic load controllers. ELCs can be used to regulate the amount of current drawn by each household, ensuring that the current lies within a maximum and a minimum value. Some ELCs work at the household level, monitoring individual loads, while others work centrally, monitoring individual households. ELCs are more common with micro- hydro installations, so advice regarding their use with wind power needs to be sought before considering their use with wind systems.

Calculating energy needs

Examples 1 and 2 describe the energy needs in Sri Lankan village households. These are rough calculations, so rounding the figures off is appropriate. Example 1 concerns an individual household; Example 2 is a small group sharing one generator.

The household in Table 3 has decided to use 12V appliances, since they have been using an old car battery for some time to power a radio and TV occasionally. They will need to purchase some low energy DC bulbs for lighting.

Table 3: Example 1, Single Household

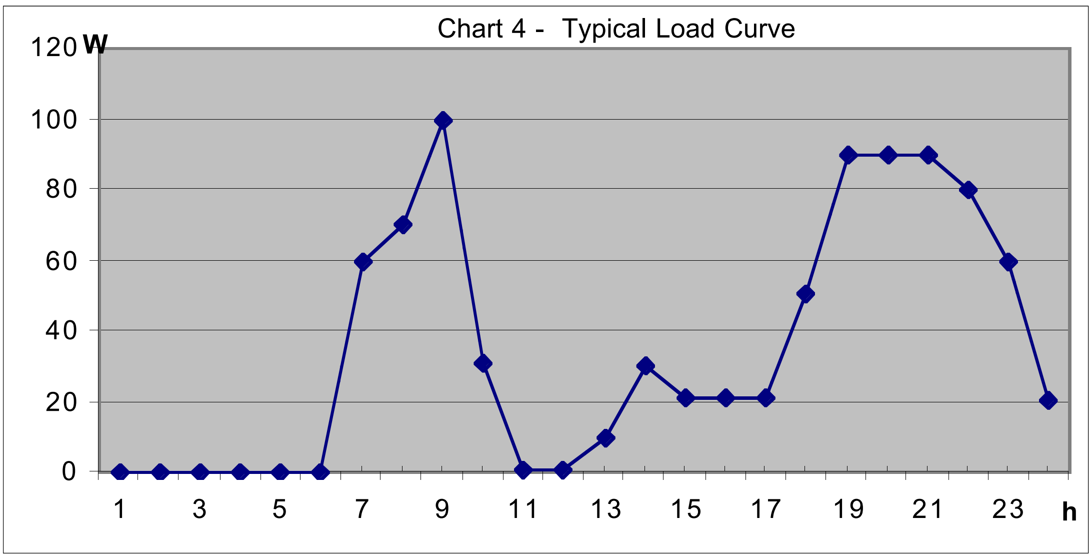
Appliance	Power rating – W	No	Hours of use per day	Daily energy demand – Wh	Monthly Energy Demand kWh
Fluorescent lamp	20	3	4	240	7
Black & White TV	30	1	4	120	4
Radio-cassette	10	1	5	50	1.5
Total energy required				**400Wh**	**12.5kWh**
Total with battery losses (x1.25)				**500Wh**	**16kWh**
Maximum power required	**100W**				
Average power required (Total Wh/24))				**21W**	

Interpretation

The first and second columns lists the appliances used, and their power ratings. The third column lists the number of each appliance. The fourth column indicates the period of time for which they are all used in hours per day. By multiplying all second third and fourth columns together we find the daily energy demand in watt-hours (Wh). The final column indicates monthly energy consumption (found by multiplying the daily energy by the number of days per month). The answer is large enough to be expressed in kilowatt hours (kWh). 7300Wh = 7.3kWh, for example and this can be rounded off to 7kWh.

The maximum power demand in the next row is computed by adding up all the power from all the appliances. This could be helpful in choosing cables, or an inverter, to meet the peak demand.

Example 1 is a simplified table. In order to determine the peak demand it is necessary to break down the demand on an hourly basis and draw the average load curve which as follows for the single household (see Chart 4).



Finally the average power can be found by dividing the energy per day by the 24 hours in the day. Average power gives a more immediately meaningful idea of the system size than energy-per-day figures do (although they actually add up to the same thing, just using different units of measure).

Power demands won't exactly match supply at any given moment. The use of batteries effectively smoothes out this mismatch, and allows the user to draw energy when the wind is light or not blowing, and store energy when the wind is strong. So as long as the average power going into the battery is the same as the average power coming out of the battery over a period of a few hours (or as long as the capacity of the battery(ies) allows) the household shouldn't run out of electricity, even if they use more than the average power for a while. This means that the generator only needs, on average, to produce the average power requirement rather than the peak power requirement. In reality it will need to produce more than the loads consume because of energy losses in the system.

Example 2 Three Households

The same methodology applies for the three households shown in Table 4, sharing one generator, except that they preferred to use mains appliances, necessitating the use of an inverter:

Table 4: Example 2, 3 Households sharing one generator

Table 4: **Household 1**

Appliance	**Power rating – (W)**	**No**	**Hours of use per day**	**Daily energy demand Wh**	**Monthly Energy Demand (kWh)**
Fluorescent lamp	20	3	4	240	7
Black & White TV	30	1	1	30	1
Radio-cassette	10	2	5	100	3
Total energy				**370Wh**	**11kWh**
Total with battery losses (x1.25)				**460**	**14**
Total with inverter losses (x1.1)				**510Wh**	**16kWh**
Maximum power required	**110W**				
Average power required (Total Wh/24))				**21W**	

Table 4 **Household 2**					
Appliance	**Power rating – (W)**	**No**	**Hours of use per day**	**Daily energy demand – Wh**	**Monthly Energy Demand (kWh)**
Fluorescent lamp	20	3	4	240	7
Black & White TV	30	1	1	30	1
Radio-cassette	10	2	5	100	3
Butter churn (AC motor) (~2 hours per week)	**200**	**1**	**0.25**	**50**	**1.5**
Total energy				**420Wh**	**12.5kWh**
Total with battery losses (x1.25)				**525Wh**	**16kWh**
Total with inverter losses (x1.1)				**580Wh**	**18kWh**
Maximum power required	**310W**				
Average power required (Total Wh/24))				**24W**	

Table 4: **Household 3**					
Appliance	**Power rating – (W)**	**No**	**Hours of use per day**	**Daily energy demand – Wh**	**Monthly Energy Demand (kWh)**
Fluorescent lamp	20	3	4	240	7
Radio-cassette	10	1	5	50	1.5
Total energy				**290Wh**	**8.5**
Total with battery losses (x1.25)				**365**	**10.6**
Total with inverter losses (x1.1)				**400Wh**	**12kWh**
Maximum power required	**70W**				
Average power required (Total Wh/24))				**17W**	

Table 5 summarises this information for the three households:

Table 5 : Summary of Totals for 3 Households	Household 1	Household 2	Household 3	Total
Monthly energy required from batteries	16kWh	18kWh	12kWh	46kWh
Maximum power required	110W	310W	70W	490W
Average power required	21W	24W	17W	62W

Matching needs - the wind and the generator

Having done the calculations to see how much energy is required for each scenario, this demand needs to be matched to the available supply, and the battery storage requirement worked out.

Steps to be followed:

- In an ideal world you should first collect data regarding the local wind regime. Find the average windspeeds for each month of the year, so those 'lean' months can be identified and battery storage increased if practical, or backup strategies can be thought out. It is equally important to record maximum gust speeds when the wind is seasonally strong, so that the wind generator can be strengthened if necessary.

- From the average windspeed you can calculate the expected energy output from the wind generator, based on its characteristics. See the previous section 2 on 'Wind potential'.

- Compare energy needs and energy availability for the average windspeed at your site. Remember to allow for losses in the system. You can now decide whether it is viable to use a wind generator.

- Decide upon the amount of battery storage you need (and if appropriate, compare with what you already have). As a rule of thumb, it is desirable to have enough storage for up to one week using essential loads only. This is usually equivalent to about 3-5 days of normal use. Much depends on the abilities of the users to understand the limitations of the system, manage it sensibly, and use alternative energy sources (kerosene etc) where necessary to prevent excessive discharge or system shut-down.

Table 5: Available energy at two example locations	Example 1 – Single household	Example 2 – Three households
Average windspeed at site	4m/s	4.5m/s
Monthly energy needs	16kWh	46kWh
Energy available from 2m diameter wind-gen	25kWh (from table in last section)	36kWh (using 'rule of thumb')

From Table 5 it can be seen that the average windspeeds at the two locations are 4 m/s and 4.5m/s respectively. There appears to be enough wind energy available in Example 1, but not in Example 2.

The options available in Example 2 are:

- Use two wind generators. This would provide more than enough capacity.
- Use a larger wind generator. There should be other sizes available from the manufacturer. But be clear whether you are buying a prototype machine built-to-order. It is better for the customer to use a fully tested product.
- Reduce loads in all households.
- Supply two households instead of three.
- Use a load control strategy as outlined in the previous section.

Since the average windspeed has only been approximated, it may be worth going ahead anyway. An average windspeed of 5m/s instead of 4.5m/s could make the option of supplying all three households quite feasible and in any case, patterns of use are never fixed, but depend on availability and on a multitude of imponderable factors.

Battery sizing

Apart from the safety, the days of autonomy is a key parameter in *sizing and choosing the battery* .

A battery is charged and recharged over a period of hours or days. This is the 'cycle'. Two parameters are important in the life expectancy of a properly maintained battery:

- the number of cycles a battery can support.

- the change or the depth when a battery is discharged. E.g. a daily discharged of 10 % will provide a longer life expectancy if the same battery is discharged, say, with 20 %. The *maximum depth of discharge* a battery can support without being damaged depends on the types of the battery. The figures in table 6 are usually quoted;

Photo 12: A traction battery from a forklift truck can be deeply cycled over 1000 times (Hugh Piggott, UK)

Table 6

Maximum depth of discharge (DOD) according to different types of batteries

	DOD	Technology
- Car batteries	50 % (0.5)	Lead acid (30 cycles approx.)
- Special solar PV batteries	80 % (0.8)	Lead acid with special features (large reservoir of electrolyte, low antinomy lead plates, space below the plates for debris to collect.(1000s of cycles at 50% DOD)
- Nickel Cadmium	up to 100 % (1.0)	Nickel Cadmium maintenance free, longer life but very costly (1000s of cycles at 100% DOD)

For renewable energy (wind and PV) systems lead acid type, long, deep cycle batteries are recommended. But car batteries are often used because they are many times cheaper, and they provide good service for a short time.

Photo 13: Deep cycle' Solar' battery in Sri Lanka. Twelve 2 volt cells with 900 Ah capacity are connected to make one 24 volt battery with 900 Ah capacity. Height is 700mm. On the left is an inverter. (Hugh Piggott)

Sizing the batteries

Four steps must be followed:

Step 1: Calculation of the daily energy production (Ep) in Watt hours (Wh). This step has been detailed in the previous sections. (For example take the single household using 400Wh/day.)

Step 2 : The choice of autonomy (N) of the number days required by the system About 3-5 days are typical figures for small wind systems. (Take 3 days.)

Step 3: Maximum allowable depth of discharge : D (as a decimal fraction, say 0.5 for 50% - see previous section)

Step 4: Battery Voltage : U. Usually the voltage is 12 or 24 V. (Take 12 volts)

The capacity expressed in Amp hours (Ah) will be obtained from the following formula:

C (Ah) = {Ep .N}/ {D.U}

In our example
Ep = 400 Wh. Assuming an autonomy (U) of 3 days, and battery voltage of 12 V, the battery Amp hour capacity will have to be:

C (Ah) = {Ep .N}/ {D.U}={400 x 3 }/ {.5 x 12 } = 200 Ah

It would be appropriate to use 3 or more car batteries (60Ah) or two or more lorry batteries (90Ah) for this application. If the household has fewer batteries (say 90Ah), then the period of operation without wind will be shorter. In such cases, only essential loads (Radio) can be used from the battery during calms. During windy weather this smaller battery would soon be full, and it would be wise to offer charging services to neighbours.

Conclusion

The examples show how important it is to have an understanding of the power available in the wind, and the energy used at the household level before going ahead with a project. One of the greatest obstacles that wind energy at this scale faces is the mismatch between expectation and performance with poorly designed systems.

4. ECONOMICS OF SMALL WIND SYSTEMS

The primary target group of small wind systems are low or middle-income people in remote areas. Usually the purchasing power of this category is not high and their financial assets are modest. Mechanisms to finance up-front capital are crucial for a wider dissemination. This section looks at real examples where project teams worked on prototype systems.

Manufactured cost

To estimate the manufacturing costs and the possible selling price, project teams visited diverse workshops that work in the field of wind energy, and the manufacturers and/or distributors of the different materials used.

The itemised costs are shown in Table 6 for a generator in Peru.

Table 6: Itemised costs for generator

ITEM	Cost US$	Total US$
1. Rotor		
Materials	26.50	
Manufacturing	14.70	
Hub	41.20	
Moulds and Models	4.70	
Taxes and profits (38%)	33.10	120.20
2. Support and accessories		
02 Tubes 2" x 6 m	88.20	
Cable 1/4" x 75 m	41.20	150.00
Others	20.60	
3. Generator		
Materials[1]	80.00	
Manufacturing	44.20	
Taxes and profits (38%)	46.97	170.57
Total US$		**440.77**
Total £		**293.00**

In the case of Sri Lanka the costs are slightly higher because an inverter (approximately US$ 50) has been included in the total costs in order to obtain AC. Other costs included are the cable and the charge control regulator. Although the capital cost is around US$ 500, credit and subsidies during the first years will be necessary to develop the market. Lessons drawn from this project show that beneficiaries who are currently using batteries are very interested in purchasing a

[1] According to the progress report for alternator design, Hugh Piggott, March 17, 1999

wind machine by instalments. This is mainly based on the savings and the convenience from the availability of local source of energy.

Financing ownership by battery charging services

The up- front capital may be difficult for a single poor household to afford if they want their wind battery charger to be of exclusive use for one family. However, it may be possible to establish a small business of battery charging for their neighbours. They then may be in a position to break even after two years. The details are as follows:-

Calculating battery charging capabilities

The batteries they currently use are car batteries (about 60 Ah), with 50% discharge each time. To recharge these batteries, with allowance for efficiency (add 25%), means 30 Amp x 12 V x 1.25 (efficiency)= 450 Wh of energy, say roughly 0.5kWh. If we consider a 2 metre diameter wind generator on a 3.5m/s site (the lowest useful mean windspeed) the energy produced monthly is about 17kWh/month or 0.6kWh/day average. So the wind generator can charge one battery each day, as a rough average. In reality it can charge several batteries on some windy days, and none on calm days. As we have seen it would take several car batteries to make all the incoming wind energy available for use at a steady rate.

Household battery use

At present rural families who charge batteries do so once or twice a fortnight (this represents about 30Wh/day). If we assume that a poor family wants to have its wind battery charger, they can charge one day a week for themselves and 6 days a week for business. This would first of all double the amount of energy per week they can use. Also, in theory, charging two other batteries each week will allow them to have enough money to pay for the unit in less than four years (see table 7). In any case if they only have one battery, they will frequently have surpluses, and it will be no hardship to use surplus power for profit. Much will of course depend on the actual windspeed, its variability and on the availability of local customers for the service.

Payback calculation

The first and most important constraint for poorer families wishing to buy a wind generator is the availability of credit. From these assumptions (avoided costs[2] and sale of services to neighbours), a simple payback period[3] could be calculated.

These calculations are based on very conservative figures. We are assuming that the avoided cost is just one dollar per week (recent evidence supports this figure). We have also assumed that selling battery charging services to other users

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[2] The avoided cost is the cost that the user would have had to support if the wind generator were not available. This is in fact the price of the service currently paid for charging the battery at the nearest town.

[3] The payback period (usually expressed in years) is the amount of time for a project to return the up- front capital or initial investment.

(households or small businesses) is on average available only 3 weeks out of four. One week may occur during the month when the wind regime is not sufficient enough to cover the needs of the owner and to generate a surplus electricity for sale. When wind resources are sufficient wind generators might be the preferred option as a similar investment on solar PV will not allow a surplus to be generated and sold to nearby users.

Table 7:Payback period

Avoided costs US$	Income from selling services (US$	Up-front investment (US$)	Payback period (years)
52	52x2*0.75= 78	450	3.46 Year

At a good site (with 4.7m/s mean windspeed), approximately 500 kWh a year can be generated. Assuming a down time of 20 %, the annual production is estimated at 400 kWh. At a discount rate of 10 %, the levelised energy cost is US$ 0.12 per kWh. This figure shows that when the full potential of the wind generator is used either for personal consumption and /or to sell the service to other consumers, the levelised cost per kWh compares very well with electricity from the grid. However, in almost all countries, grid electricity is subsidised which means small wind systems or other decentralised energy options should target areas which are unlikely to be connected in the mid (5 years) or long term.

A more sophisticated calculation in which the Internal rate of return (IRR) and the Net Present Value (NPV) are calculated also shows that the wind energy systems could be a profitable business if in addition to the avoided costs, the user is able to supply energy service to the neighbours.

Table 8: Financial viability of small wind generator enterprise

Parameters: **Technical parameters** Wind generator life expectancy : 20 years Rated power: 100 W **Economic parameters** a- Investment and running costs capital costs: US$ 500 maintenance costs: 5 % of total investment = 25 of year 1 b-Income - Avoided costs 1 US$ a week - Income generation : 78 batteries charged per year at 1 US$ year 1 **Financial parameters** Discount rate = 0.12 Escalator : 3 % applied to income and maintenance costs Loan: 30 % of total cost, repayment over 3 years at a commercial interest rate of 18 % **Results: IRR = 21 % , NPV = 228**

A positive NPV and an IRR of 21 % are indeed good indicators of the sustainability of this business. It should also give a positive signal to financial institutions, governments and donors who are willing to support alternative credible and cost-effective options to an energy model based on renewable and non-polluting resources.

PART 2: SUSTAINING THE TECHNOLOGY

FROM PILOT PROJECT TO WIDESPREAD USE

This section looks at the bigger picture; what are the factors and issues involved in moving from a few small projects to a sustainable industry where NGO's and donors are not needed? This is a demanding challenge and will be difficult to achieve without careful thought and the involvement of a wide range of stakeholders. The following sections look at institutional and organisational support, financing mechanisms, support to manufacturers and the policy environment, and how these organisations and institutions can be used to enable more households to benefit from improved electrical services.

1. THE DEVELOPMENT OF A WIND ENERGY SECTOR

This section deals with some of the factors involved in 'scaling up' from a pilot project or programme to a sustainable industry. The growth of wind energy in Denmark, where commercial wind energy began, and Mongolia, where small wind generators have been most successful, are discussed as examples of good practice. They also emphasise the need for a long-term approach.

Photo 14 :Typical Danish wind turbine from circa 1982 (Wind-matic a/s)

The Danish Experience

Wind energy technology development in Denmark was achieved through the combined efforts of enthusiastic amateurs with a concern for the environment and a government concerned about the impact of the 1970's oil crisis. Most early machines were small (compared to the large wind machines in use today). The Government established a national research centre to promote common standards and to conduct future research into wind turbine technology. Danish turbine manufacturers now guarantee a 98 per cent availability rate (in other words down for maintenance for only 2% of the time) for their turbines, and statistics show that the availability rate in practice is around 99 per cent.

The early machines of 25 kW with 10.6 metre rotor diameter may still be found in Denmark. Today the most widely sold turbines have a rated power output of 750-1000 kW, and a rotor diameter of 48-54 metres. Despite the increasing commercialisation of turbine manufacturing, more than 80 per cent of the 5,700 wind turbines in Denmark are owned by wind energy co-operatives, or individual farmers. 100,000 Danish families own wind turbines or shares in wind co-operatives. Danish power companies are obliged to pay 85 per cent of the retail electricity price for the wind energy purchased from privately owned wind turbines.

In Denmark, the interest on loans to purchase wind turbines is tax deductible from the private income of the individuals in a partnership. Wind Turbine Guilds were established to represent the mutual interests of the turbine owners to electricity boards, authorities, and manufacturers. Dialogue with manufacturers helped ensure quality, service and warranty improvements and proper insurance contracts. The second main aim of the Guilds was to share information about the potential for wind power to individuals, the press and policy makers. Even though individually owned wind turbines continued to be erected, the guild turbines were the ones that had influence on development, and they still have.

The Mongolian experience

Over 130 ,000 stand alone, small wind generators are being used by nomadic people in Inner Mongolia. The wind systems are mainly used by isolated households. The vast majority of machines are of 100 W rated capacity. A typical small system provides electricity for lighting, TV and radio (130 kWh/a). The main livelihood of these people is livestock - sheep and goats (cashmere). The Chinese government estimates that even by the year 2020, the number of households too remote for grid connection to be economically viable will be 350 ,000.

Research started in the 1970s and the first demonstration of small wind generators in Inner Mongolia was set up in 1977. After 1978 the Inner Mongolia Science and Technology Commission became involved in a second initiative which provided training and maintenance services. At this time problems with insufficient demand, quality and technical issues inhibited sales of machines. A further initiative in 1980 resulted in the setting up of a network of service centres, which now covers 60% of the region. A wider programme was run between 1984 and 1989, during which time sales took off. A subsidy of 15% of system cost was made widely available from 1986. Although still in place, this has been kept at the same monetary value, making it much less significant now. Herdsmen have always paid for wind generators using their own money; in the 1970s they received salaries, but now they generally raise income from livestock sales.

Common lessons

The Inner Mongolian story has highlighted some issues that appear to be important for the long-term stability of a small wind generator industry:

- Economics has not been the main driving force in the dissemination of wind generators, and this indicates that subsidies have not, therefore, played a major part in the success of the programme. It was the introduction of a broadcasting station in Inner Mongolia in 1980 that created a demand for TVs, and consequently a surge in demand for wind generators. This demonstrates the importance of identifying demand, and attributing a value to it.
- Effective feedback loops comprising service centres to collect information, manufacturers motivated to take action, and research centres to provide

expertise have led to products suited to the needs and capabilities of the consumers.

- A total system package should also be made available to ensure that potential benefits of the technology are realised, especially at the start of the programme. In addition, the weak link in any total system should be identified and addressed.
- Successful companies are relatively small and rely heavily on wind generator sales, so it is argued that companies should be selected on the basis of their commitment to the success of the product and their ability to respond to feedback from the market.
- The importance of demonstration projects should be stressed as almost all respondents learned of the technology from friends and neighbours or the Science and Technology Commission. The other aspect of a demonstration is that it highlights design faults, initiating the feedback loop to manufacturers.
- Another interesting feature is that no credit system was needed in Inner Mongolia. However, users have capital assets in the form of sheep and goats, which can readily be converted at the local market.
- Also, the authorities provided training at several levels, yet the most commonly reported source of information at the user level was written instructions. This shows how printed instructions can make up for shortcomings in training and extension services.

There are some interesting comparisons to be made between the two cases of Denmark and Inner Mongolia. In the first case, wind generators provide over 10% of the country's grid electricity and the technology is used world-wide. In the second case, wind generators provide electrical services to a large number of marginalised people.

The first common element is how the technology started small and developed piecemeal, rather than starting with large and high technology machines.

Secondly, there are important feedback mechanisms between consumers, manufacturers and government that lead to the better design of machines, programmes and policy.

Thirdly, wind generator owners and electricity users are often the same people, either individually or collectively. Ownership of the technology, both literally and through participation in its development, can overcome many of the social problems associated with technology that has been 'imposed' from outside.

Fourthly, the motivation for using wind energy has to be clear from the start. In the case of Denmark, the prime motivation for individuals is environmental protection; in Inner Mongolia it is access to services that need electricity.

2. INSTITUTIONAL SUPPORT

Institutional support, from an organisation established to offer services of one sort or another, advice, a regulatory environment or funding, is essential. A question often asked by sceptics, and a valid one at that, is 'if it's such a good idea, why is no one doing it already?' The answer to this question may well be the lack of institutional support in an environment where it is difficult for small business to flourish unaided, for NGOs to reach their 'target beneficiaries', for donors to feel they have spent money wisely, and for households to feel the long term benefits of development projects.

To illustrate the point, some of the agencies involved in the ITDG project are described below, in particular those in the UK and Sri Lanka. Agencies will vary, since the realities on the ground will be different in each case, and this project has been a learning experience in itself.

Institutions Involved in the ITDG Project

ITDG

ITDG is an international non-governmental organisation which specialises in helping people to use technology for Practical Answers to Poverty. It was founded in 1966 by the radical economist Dr EF Schumacher to prove that his philosophy of 'Small is Beautiful' could bring real and sustainable improvements to people's lives. ITDG had previously promoted the use of micro hydro power to enable poor communities to have access to electricity, principally in Nepal, Sri Lanka and Peru. The potential for the use of small wind generators was identified by ITDG offices in Peru and Sri Lanka, and preliminary data and experiences were collected to see whether a technology development project was feasible. A proposal, written and submitted to the UK government, was subsequently funded.

Photo 15 : IT Peru working on the Small Wind Turbines Project (Hugh Piggott)

ITDG's usefulness to the project has been twofold in this instance. Firstly, through its history of working with communities via its country offices, it has an established credibility both with donors and grassroots organisations. This was helpful to ensure that the initial idea was taken seriously, and communities were willing to work with ITDG, because they knew about the organisation. Secondly, the organisation took overall responsibility for the project management, and was able to organise and co-ordinate the separate groups and individuals that made a contribution to it.

UK Department for International Development

The UK DFID was the main funder for the project and contributed around 90% of the financial resources. As both a source of funds, and a government body, DFID required regular reports on the project progress as well as a requirement that the project fitted with their development philosophy. This imposed both a bureaucratic necessity and a measure of accountability during the running of the project that helped ensure it met its original objectives. In this case, the provision of funds was the primary reason for working with such an institution, but secondary advantages include access to a broad group of researchers in the field, international credibility and wide dissemination of project results.

Institution of Electrical Engineers (IEE), UK

The IEE were not officially connected to the project, but were a useful 'peer review' group. The IEE contains a large pool of expertise; presentations concerning some of the more technical aspects of the project were made to groups of IEE members, and their feedback was useful as the project progressed.

Imperial College, UK

Imperial College was involved at an early stage of the project. An MSc thesis was produced by a student who looked into the nature of the demand for electrical services in selected villages in Sri Lanka, based on field visits and survey data. This analysis was important in defining the wind generator specification and also pointed towards some of the social complexities on the ground.

VINIVIDA, Sri Lanka

A partner organisation with ITDG in Sri Lanka, called VINIVIDA, had been working with numerous ITDG projects for a decade. VINIVIDA has a permanent staff of about 15 persons and works in the areas of rural transportation, food processing, rainwater harvesting, agriculture, nutrition, and rehabilitation of abandoned village irrigation tanks. It also operates a revolving credit fund. VINIVIDA is an example of a local institution often called a CBO (Community Based Organisation). CBO's have links with communities, villages or households that are difficult to establish if you are a national or international institution working alone. VINIVIDA helped to carry out the project market survey and to identify potential pilot sites.

GIDES, Sri Lanka

A second partner organisation in Sri Lanka was called GIDES which has also been working with several ITDG SL projects. Formed in 1995, GIDES is registered, as a social service organisation, with the Department of Social Services and with the Provincial Council. It works in the areas of organic farming, promotion of home gardening, rural transportation, small enterprise development, wind power for rural electricity supply, and rehabilitation of abandoned village irrigation tanks. GIDES also operates a revolving credit fund which was used to provide finance for households wishing to purchase wind generators.

Photo 16: a demonstration wind/biomass project in Sri Lanka (Hugh Piggott)

REDS, Sri Lanka

REDS stands for Rural Enterprise Development Services which is a subsidiary of the Sarvodaya Movement in Sri Lanka. REDS helped the project by establishing necessary contacts for getting fibreglass expertise for the generator manufacturer.

Wind Project Research Team, Sri Lanka

Although not a formal institution, the Wind Project Research Team comprised two academics from the University of Motaruwa, Colombo, the director of a private energy research company, and the wind project manager from ITDG Sri Lanka. The Wind Project Research Team supervised the prototype testing in Sri Lanka and provided some technical support during the design process. The University link enabled some testing to be carried out with University staff and students

Institutions in General

In general, support institutions can be divided into the following groups:

International Institutions

These include international non-governmental organisations (INGOs) such as ITDG and OXFAM; pan-national groups such as the UNDP and World Bank; and multinational companies such as Shell. International institutions are usually approached, either because they provide funds for projects or programmes or because they have a degree of influence with national government.

National Governments

National governments either provide funding for projects or programmes or establish the regulatory or legal framework in which to operate. It is therefore important to find out what support is available from government (e.g. grants, subsidies or tax credits for renewable energy schemes) or what policies are designed to help or hinder renewable energy projects.

Academic Institutions

Academia can be very useful for providing high quality, often well motivated, researchers and academics. The relationship is often complementary; on their part they can be involved with practical, field-based projects, whilst their expertise is cost effectively available to the project manager. Academia can offer both engineering and social science input and adds credibility to the project team.

Funding and Financing Institutions

Much has been written about the need for affordable credit for households and entrepreneurs. Institutions that organise and/or provide finance are very likely to be involved to some degree or another. These can take the form of state or private banks, donors or micro-credit organisations.

District Institutions

Local government is the most obvious form of district institution. They are very likely to be involved with issues such as siting of wind generators, planning of local energy services, etc. The relevant local government department needs to be aware of any activities that may touch on their area of responsibility; for example, grid-connected wind generators can pose a risk to workers doing maintenance if they are unaware of their existence.

Local Institutions

Local institutions, usually non-governmental, form the link between the project team and the beneficiary community or households. Local groups have local knowledge and are likely to be trusted by the community that they represent or serve. The chances of project success are heightened if these groups are involved throughout the project; they often form the conduit for feedback when problems occur, and are in a position to offer advice and support both ways.

Manufacturers Associations

Very new industries often work effectively in co-operation as well as competition. Manufacturer or Trade Associations are good at pooling resources to present a professional face to potential clients, and have influence at policy level. Often trade associations require that certain standards are met in order to become a member; this minimum standard can reassure customers and lead to better products or services. If they do not exist already, it is worth considering establishing them as part of the project.

Dissemination Institutions

When projects go wrong they endanger the whole sector, often by word of mouth, but good practice is much more difficult to spread. The involvement of dissemination networks and written and broadcast media can be very beneficial. Dissemination networks, often internet based, allow researchers and project workers to exchange experiences and ideas. The media can reach a widespread audience of potential customers or beneficiaries, and a well thought out dissemination strategy can give donors value for money.

How Should Institutions Become Involved?

As can be seen by the institutions outlined above, there are a large number of parties that could become involved, and this could require full-time co-ordination. The answer depends very much on the nature of the project and its ambitions. It would be difficult to persuade an organisation intent on erecting only one or two turbines at one particular site to involve the World Bank, but where a regional programme is being considered this may be necessary. Donors will often like to see involvement from many institutional 'stakeholders', so this may be a necessity if funding is required. At the very least, a checklist of institution type should be drawn up. Those that are legally obliged to be involved should obviously be included; others can be prioritised depending upon their usefulness to the success of the project. Informing as many institutions as possible of the existence of the project costs little and can have large benefits in the long run.

3. BUSINESS DEVELOPMENT

Introduction

Wind generators will ultimately be used by a large number of households if the household can perceive the benefit, the generators are affordable and they perform as expected. Development Organisations can help to publicise the benefits of wind energy through projects and pilot studies, but in the long run the technology will have to be sustained by a manufacturing sector. This section looks at ways in which this sector can be helped.

In the long term, the best situation for a manufacturer to be in is to have his or her products being bought by at least a minimum number of customers year-on-year that enables the business to be viable. It is unlikely that generous external support will be available into the mid and long term, so it is important that manufacturers can utilise available support at the early stages of production when their business is most vulnerable. This section looks at some measures that can be taken to help support a fledgling wind generator manufacturing sector.

Technology Transfer

It is unlikely that small manufacturers have the time or capacity to develop wind generator designs from scratch. They are likely to be approached by an individual or institution who has developed an idea or design and who has undertaken a selection process of suitable manufacturers. The institution may be a University, NGO, or Government Department who wish to take a prototype design a step further. The manufacturer may be asked to produce a number of different designs, or a batch of a proven design. Either way, it is important that the manufacturer understands his or her role from the start, and is paid adequately for their work. For example, it should be made clear at what stage the manufacturer is required to offer support to customers should technical problems arise; who is responsible for technical improvements to the design; who

Photo 17 : Technology transfer in a small workshop : PMG construction (Jytte Piggott) owns design copyright, if any; who is ultimately responsible if products fail due to design faults, etc. As already mentioned, the exact level of technical backup for the manufacturer in the type of situation described is an important parameter to be understood at the beginning to avoid leaving the manufacturer feeling abandoned with an inferior design, or the institution held responsible for unauthorised manufacturer alterations.

A suitable arrangement may consist of the manufacturer keeping a performance log of customer machines and reporting back to the institution or individual regularly, in exchange for technical help for a given period. As operating experience is gained, the manufacturer should become aware of potential or actual design faults and be able to gain assistance in rectifying them. In the longer term, the manufacturer can offer an appropriate guarantee to customers based the likelihood of faults occurring.

Training

The training of manufacturers, both technical and on business matters, can be of great benefit. It is difficult for small manufacturers to keep abreast of technological developments and new products, so help in this area could be the spur for some to take up the technology. General courses on the benefits/constraints of wind energy, as well as courses looking into design and construction should be considered.

Supporting the Market

As mentioned at the start of this section, the best help for manufacturers would be a healthy market for wind generators. Although this may exist in theory, i.e. sufficient wind resources, low electrification rates, current use of auto batteries, sufficient resources or credit available to buy generators and the lack of feasible alternatives, not much will happen unless the consumer is aware of the product and the manufacturer is aware of the market. Support to the market should therefore be directed towards achieving the twin goals of consumer and manufacturer awareness raising.

Marketing

Marketing is usually low down on a small manufacturer’s list of priorities. This is usually because marketing takes time and money and/or marketing skills are not available. However, at the stage when a manufacturer is confident enough in the product to think about selling it in volume, marketing is crucial to success. Help with marketing can come in several forms, from help with market research, production of marketing literature, securing advertising space, improving the company image, and better product design. Some marketing can be co-ordinated through Trade Associations to keep costs down, or focused on individual manufacturers with the help of marketing experts. Once the technical challenge of producing an appropriate product has been achieved, equal effort needs to go into its marketing.

Subsidies

If wind generators are to compete in the energy market effectively and offer remote households the chance of improved access to electricity, it may be necessary to consider a subsidy scheme. Subsidies can support manufacturers if the price charged to consumers has the subsidy element included, i.e. the wind generator is cheaper than it would otherwise be. The manufacturer can then claim the subsidy back from the body administering it, which could be an NGO or Government department. Subsidies may not be crucial, though, as was seen in the Mongolia example given earlier in this booklet. Careful thought needs to be given as to how subsidies are directed and who they are intended to benefit. For example, subsidies on manufacturing components, such as magnets or electronic components, could help the manufacturer to keep costs down and improve profitability. Whether or not these savings are passed on to consumers is up to the manufacturer (and market). Not only subsidies must be transparent but it is also important to develop a strategy to phase out the subsidies over a reasonable period of time which could be between 5 to 10 years depending on the context of each country and the competition from fossil fuels.

Fiscal Measures

Fiscal measures are those that can be implemented by national or regional government. They can help manufacturers by reducing the overall cost of owning and operating wind generators.

Tax Incentives

Tax incentives are also a form of subsidy, but are usually part of a national policy to promote renewable energy rather than for the direct benefit of manufacturers. Tax incentives only work in favour of the target group if they are paying tax in the first place. For example, a reduction in an indirect tax on renewable energy equipment, such as value added tax, could reduce the cost of wind generators to the consumer. On the other hand, reducing the rateable value of property using renewable energy will not affect those not paying rates. The overall aim should be to reduce the initial high equipment cost to the consumer, which is a characteristic of renewable energy

Net Billing

Net billing may be appropriate for more a grid connected household, or households that share a wind generator. Net billing allows excess electricity from the wind generator to be sold back to the Electricity Company via a grid connection at a market rate. This is an attractive idea, not only because it can provide a limited income, but also because it allows wind generators and the grid to work side by side. As mentioned earlier in this booklet, a major disincentive to owning and operating small wind generators is the expectation of a grid connection in the short or medium term, so allowing net billing can overcome this obstacle. Net billing is rare, though, so this option needs careful research.

Institutions

Trade Associations

Trade associations can be useful for manufacturers because they can act as a communication channel for new ideas and market intelligence, they can represent manufacturers to the Government or in the media, and they can promote the technology to the general public. They can also offer guarantee schemes and a mark of quality assurance. Trade Associations are usually independent bodies that require subscriptions from members. They may or may not have charitable status. If a wind energy programme is being run by a donor or government, Trade Associations are a useful vehicle for identifying approved manufacturers and distributing subsidies. Such associations can be set up as part of a programme, or supported if necessary if they already exist. If a large scale wind generator programme is being considered, Trade Associations can enforce standards with carrot of subsidy distribution and the stick of penalties for poor performance.

Knowledge Sharing and Disseminating Lessons Learnt

Knowledge sharing encapsulates much of the above discussion. Manufacturers need to be aware of the market potential, and households need to be aware of the opportunities afforded by wind energy, as well as its limitations. An NGO can perform a catalytic role by providing information to consumers and manufacturers. In many ways this is the most appropriate role for them to take.

Networks and Newsletters

Networks are useful for keeping Development Organisations informed about what is being done in the sector and for sharing experiences, forming partnerships, etc. For example, networks can help avoid replication of effort by the sharing of good practice and project results.

Newsletters perform a similar function, but are usually devised to inform a wide audience about the work of a single organisation or network of organisations. Newsletters can be targeted quite effectively, both at grassroots organisations and at institutions and government.

Workshops

A classic end-of-project activity is a dissemination workshop. These can be very useful, especially when genuine progress has been made in a project. The most effective workshops bring together a wide variety of stakeholders and should include household beneficiaries or their representatives. Careful thought should be given to maintaining the momentum in the days, weeks and months following a workshop, since it is easy to see this activity as a final act. It is especially important is to maintain contact with policy makers or donors in order to help secure a future for household and wind related activities.

Publications

Distinct from newsletters, publications can provide a more thorough method of disseminating lessons learnt. Of course, this publication forms part of such an activity. Issues can be looked at in more depth and information can be referenced by a wide variety of readers. It is important that publications are useful – although this sounds like an obvious statement to make a poor publication can do similar damage to the reputation of the technology as bad design. Thought should also be given to the method of publication. Increasingly, the Internet is being used to publish material. This method can be cheap and easy, and allows the publisher to monitor where the publication is being downloaded or read from. As a compliment to traditional media, the Internet can be extremely useful.

4. THE POLICY ENVIRONMENT

If the use of wind generators to provide electrical services to those with few other options is to move from the pilot and demonstration stage to one of widespread use, it will be necessary to have policy barriers removed by government, or better still positive support. In both Denmark and Inner Mongolia, government was involved at the early stage of technology development and later stages of providing the necessary policy frameworks.

The Inner Mongolia programme had no external support (e.g. non-governmental organisations, NGOs), but it is assumed that any programme driven by an NGO would need the support of a host government. A government needs to be prepared not only to commit resources to a programme, but also to commit itself to supporting the programme over a long period of time. For the wind generators, the lead time from first research to sustainable sales was around 20 years, which is well in excess of the planning horizon for political parties in most democracies.

Since in the 1970s the power purchasing policies of the local utilities has varied wildly (offering prices between zero and the retail price of low voltage electricity). Parliament legislated a purchasing price of 85 per cent of the retail price of electricity. An incentives programme in the form of capital grants for installation of wind turbines was established in the late 1970s. The scheme was finally abolished in 1989, when a (then 10 per cent) capital grant was dropped. The basic support mechanism for wind energy in Denmark is now is a partial repayment of the CO^2 tax paid on wind electricity. (CO^2 tax is levied on all electricity regardless of its origin, thus requiring a repayment scheme to avoid hitting renewable energy sources like wind). Currently the government is studying a so-called green certificate market based scheme which will be combined with a Renewable Portfolio System requiring electricity consumers to buy an increasing share of their electricity from renewable sources.

Ten policy suggestions for the promotion of small wind systems

1. Research and Development. Establish R+D facilities for the development of locally appropriate technology
2. Provide preferable loans for renewable energy projects
3. Give incentives for community groups to power their community in the form of tax breaks, if appropriate, or grants
4. Allow small wind generators to be grid-tied in the future (if technically possible) and allow consumers to be power providers
5. Provide a preferential rate of VAT on renewable energy equipment
6. Establish electrical standards for household wiring and equipment
7. Promote wind energy through the media
8. Support the development of trade associations for manufacturers and installers
9. Provide nationwide wind data
10. Collect operational data for every generator in use.

CONCLUSION

This booklet has sought to outline some of the issues involved in using wind energy for household electrification in areas where grid electricity has not arrived. Reference has been made to an ITDG/DFID project in Sri Lanka and Peru, where small battery charging wind generators have been designed, manufactured and installed in several pilot sites. The booklet has been aimed at development organisations that are thinking about running similar projects or anyone with an interest in the subject.

Perhaps the most important conclusion to draw is the need to monitor continuously all aspects of the provision of this form of electrification. This entails ensuring that sites chosen have adequate wind; the technology has been designed thoroughly; manufacturers have a grasp of the product and the market; and users know what to expect from the technology and how to use it effectively. Research and development is a continual process, even when the technology is competing in the open marketplace.

APPENDIX I : Summary of Survey Data in Sri Lanka.

	Mahagalwena	Muthapanthiagama	Periappaduwa
Existing lighting	Kerosene and dry batteries	Kerosene and dry batteries	Kerosene and dry batteries
Monthly Expenditure/HH	Rs280 (8%)	Rs290 (6%) [mean}	Rs290 (6%) [mean}
Percentage using auto batteries	67	71	65
Battery cost	90Ah Rs3400, 60Ah Rs3400	90Ah Rs3400, 60Ah Rs3400	90Ah Rs3400, 60Ah Rs3400
Average daily electrical consumption	70Wh	73Wh	58Wh
Charges/mnth	2	2	2
Journey time/charge	2hrs 40min	1hr 30mins	50mins
Cost per recharge	Rs40-45	Rs30	Rs35
Cost for dry batteries/mnth	Rs150		
Willingness to pay	Rs3000 initial, Rs400/mnth		

APPENDIX II : Technical manuals

Two further publications are available related to the project ‘Small Wind Systems for Battery Charging’:

‘PMG Construction Manual’, written by Hugh Piggott, details the steps necessary for a small manufacturer to produce the permanent magnet generator designed as part of this project.

‘Wind Rotor Blade Construction’, written by Teodoro Sanchez, Hugh Piggott and Sunith Fernando, looks at the construction of the rotor blades which attach to the generator.

These documents are available as free downloads from web sites. For hard copies of either of these publications, contact ITDG UK, Schumacher Centre, Bourton Hall, Bourton-on-Dunsmore, Rugby, UK, CV23 9QZ.

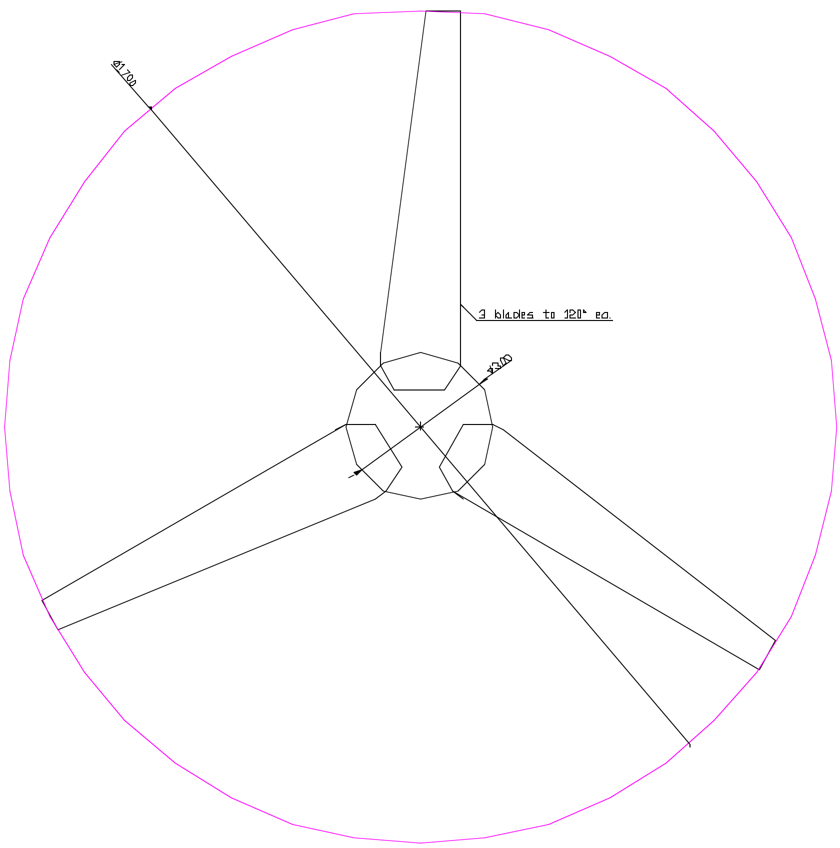
Department for International Development, UK

Wind rotor blade construction

Small Wind Systems for Battery Charging

Contract R 7105

By Teodoro Sanchez Campos ITDG, Sunith Fernando and Hugh Piggott



In association with : ITDG-UK; ITDG Peru and ITDG South Asia

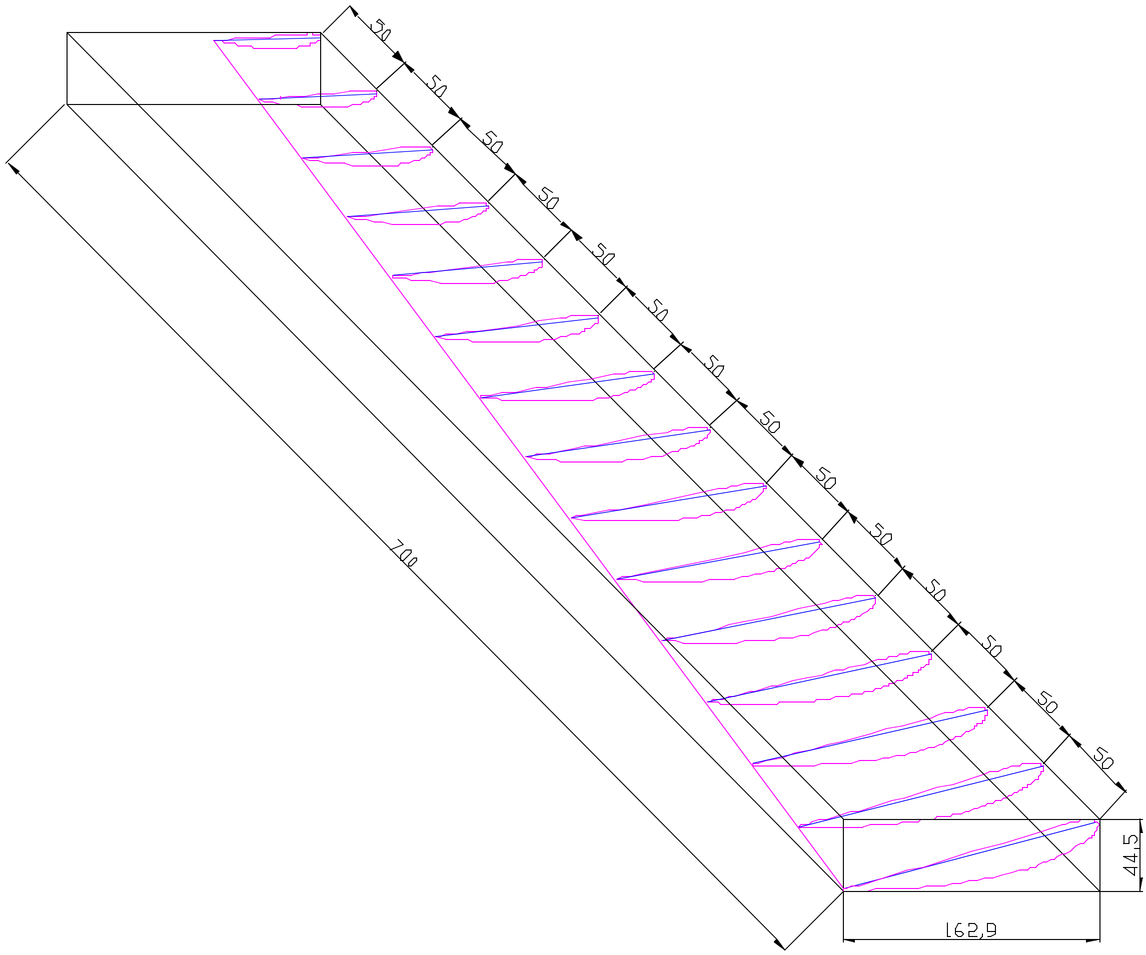
This research on small wind energy systems for battery charging is the result of a collaborative effort involving numerous contributors.

The project was managed by Intermediate Technology (known as The Intermediate Technology Development Group or ITDG) under a contract to the UK Department for International Development.

The overall international project was co-ordinated by Dr **Smail Khennas**, Senior Energy Specialist from ITDG with support from Simon Dunnett. The field work in Peru and Sri Lanka were respectively managed by Teodoro Sanchez and Rohan Senerath.

Teodoro Sanchez Campos (ITDG Peru), Sunith Fernando (Sri Lanka) and Hugh Piggott (a UK technical consultant for the project), are the authors of this booklet on the rotor blade manufacture.

The views expressed in this report are those of the authors and do not necessarily represent the views of the sponsoring organisations, the reviewers or the other contributors.



This diagram shows the shape of a blade pattern.

Wind rotor blade construction

Small Wind Systems for Battery Charging

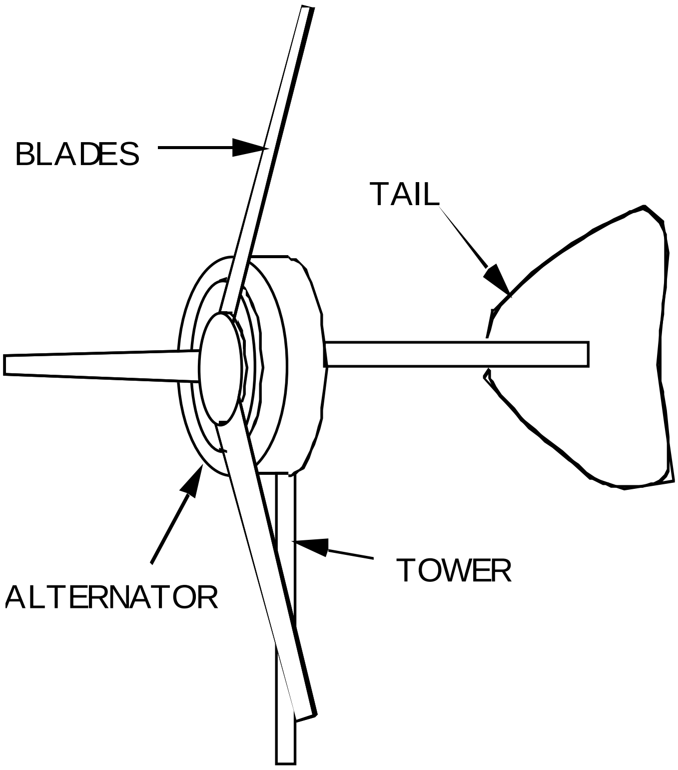
CONTENTS

1. Introduction

The wind generator

This booklet is to assist manufacturers in make the blades, or 'wind rotor' for a small wind generator. Another booklet tells how to build the permanent magnet generator (PMG). The wind rotor will be fitted to the PMG. It turns the PMG, and the PMG charges a battery.

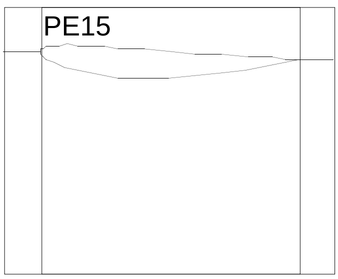
The PMG and rotor blades have to be mounted on a 'yaw bearing' at the top of a tower (usually made from steel pipe). The wind generator also needs a tail to make it face the wind. The tail must also automatically turn the wind generator away from strong winds to protect it from damage. The yaw bearing, tail and tower are not described further in this booklet.



The wind generator is suitable for family needs such as lighting and radio, powered by a 12-volt battery. It is for low and medium windspeeds, common in Peru and Sri Lanka, where the wind turbine is being built.

The blades described in this book are made from fibreglass, (although would also be possible to make them from wood.)

Steps in the wind rotor construction procedure



1. Choose a design for the blades, and make templates from paper or thin aluminium sheet. Copy the drawings

in Appendix II for the templates. The templates will fit the outside of the blades exactly.
2. Use these templates to make a three dimensional pattern in the shape of the actual blade. One can carve a pattern from wood. Or metal sheet or foam could be used instead.
3. Around the pattern, cast fibreglass moulds. We might make enough moulds for a full set of blades for one rotor (three moulds for a three bladed rotor).
4. Use the moulds to make the blades.
5. Make a hub for the blades and assemble the rotor.

If the production team have no experience with fibreglass resin, they may need to ask an expert for help.

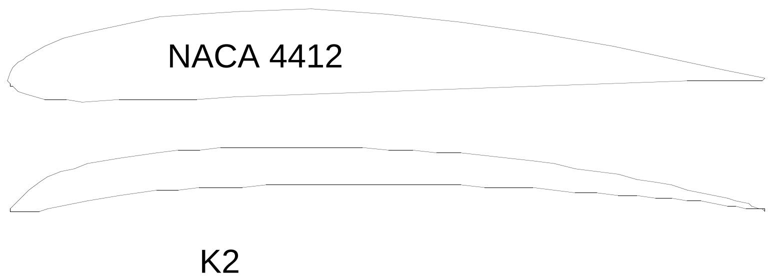
We will need to test the strength of the blades, and balance them, so they will be safe and run smoothly.

The two rotor designs

Here are the main features of the two rotor designs described in this booklet:-

Country of origin Designer	Peru Teodoro Sanchez	Sri Lanka Sunith Fernando
Blade section	NACA 4412	K2
Diameter	1.7metres	2.0metres
Tip speed ratio	5	6
Number of blades	3	2

SECTION
The ‘blade section’ is the shape of the blade in cross-section (cut at 90 degrees). The NACA4412 section is made from two skins with space between. The K2 section can be solid fibreglass resin.

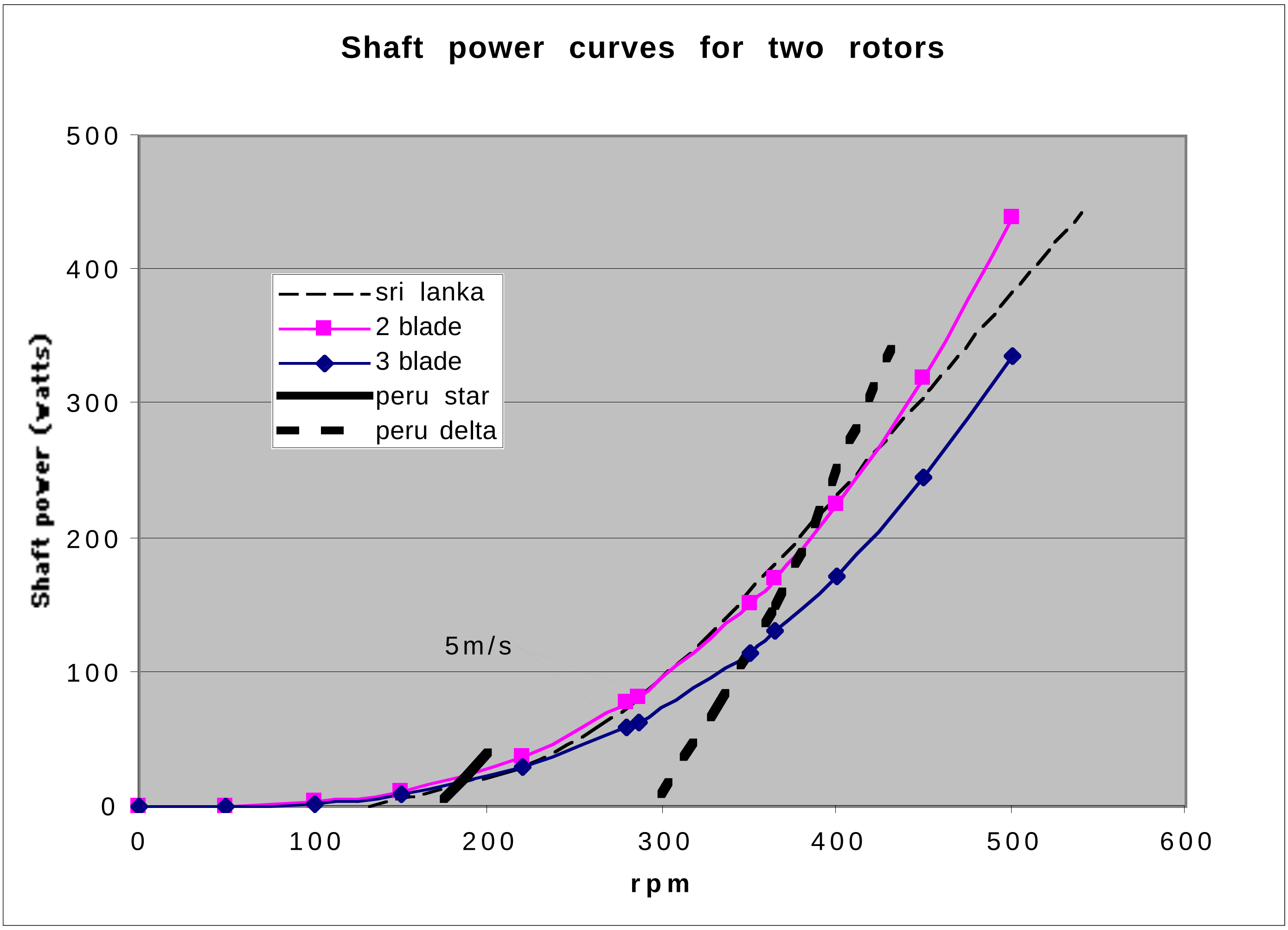


DIAMETER
The larger, 2.0 metre diameter rotor will sweep across more wind, and therefore it can produce more power, in a given windspeed.

TIP SPEED RATIO
The ‘tip-speed-ratio’ is the speed at which the blade tip should run compared to the windspeed. The shaft speed in revolutions per minute (rpm) depends on the tip speed and the diameter.

$$\text{Rpm} = \text{windspeed} \times \text{tip-speed-ratio} \times 60 / (\text{diameter} \times \Pi)$$

The main reason why the two blade rotor can work at higher tip-speed-ratio is that it only has two blades. The smaller, three bladed rotor will have a slower tip-speed, but will run more smoothly because it has three blades.



Each rotor is carefully designed to work well with the PMG used in each country. The PMG used in Peru has thicker magnets and a different way to connect the windings. Above is a chart of the power produced by the two rotors over a range of speeds (based on the theory). The chart also shows how much power is needed to drive the alternators in Sri Lanka (dotted) and Peru (two curves for two connections). The 2-bladed rotor (purple) designed in Sri Lanka produces exactly the power required for the alternator used in Sri Lanka. The 3-bladed rotor (blue) from Peru is designed to match the two different cases for the Peru alternator : star connected and delta connected.

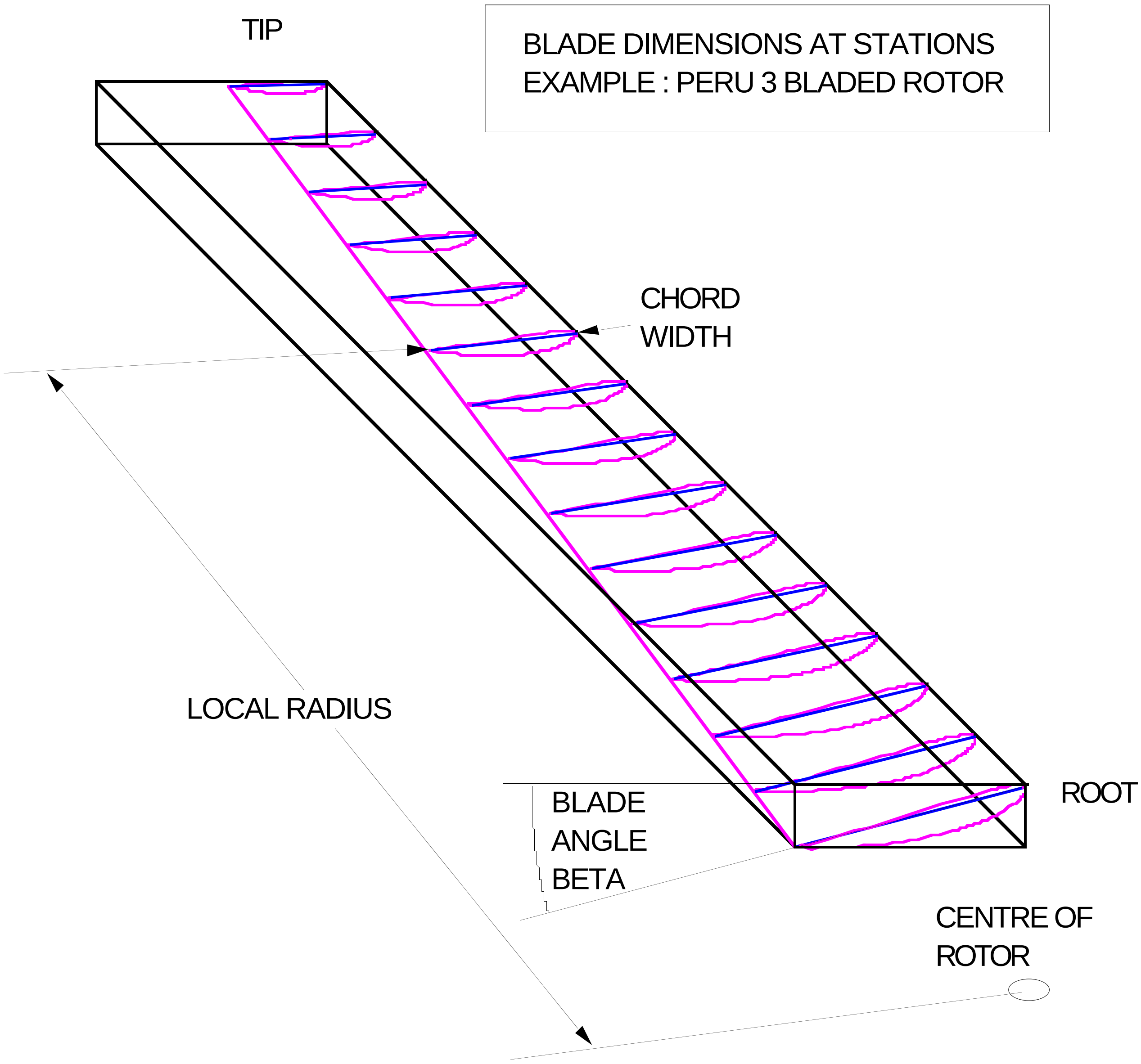
At a windspeed 5 metres/second, the two rotors will produce 80 watts and 60 watts of mechanical (shaft) power respectively at 286 and 280 rpm respectively. This point is marked on each curve.

The speed of the wind rotor depends on how it is loaded. If the PMG is disconnected from the battery, the rotor will become unloaded and will run much faster. We try to avoid running the wind rotor unloaded, because it is noisy and stressful.

The shapes of the blades

The dimensions of the blades are listed in Appendix I. The blades are defined at a number of 'stations'. SEE FIGURE 'BLADE DIMENSIONS AT STATIONS' BELOW. Each station has a 'local radius', which is the distance of the station from the centre of the rotor. For each station there is a 'chord width', which is the width of the blade, from one edge to the other.

The 'chord line' is defined as the longest line within the blade section, and it joins the leading edge to the trailing edge. The 'blade angle' (beta) is the angle between the chord line and the plane in which the rotor spins. Given the local radius, chord width and blade angle at each station, we can construct the shape of the whole blade. This is done in Appendix II.

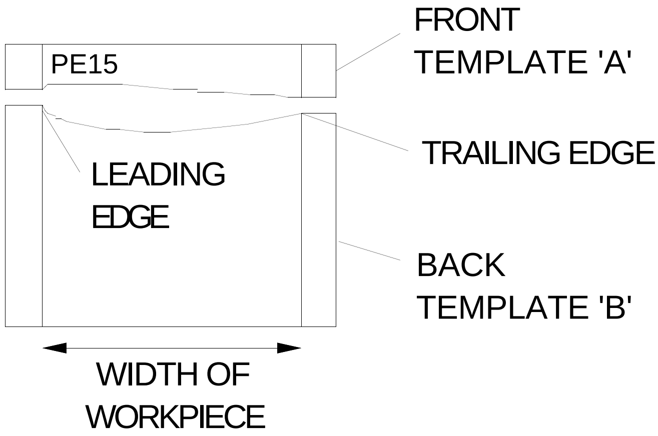


At the root, the shape of the blade changes from an airfoil section into a shape which is suitable for the hub assembly

2. Templates, Patterns and Moulds

Templates

Choose a blade design and make photocopies of the templates in Appendix II. Either cut out these copies and use paper templates to make the pattern, or alternatively use thin aluminium sheet for the templates.



Transfer the shape to the aluminium sheet using carbon paper to trace it, and/or using a punch through the paper to mark the aluminium with the lines.

Each template drawing has 3 areas within it:
1. A blade section (remove this)
2. A front template A
3. A back template B (turn it over and use it when carving the back of the pattern)

The vertical lines on the template show the width of the workpiece for the pattern after it has been tapered. The angle of the blade section is the exact blade angle. The top edge of template A is exactly 10mm from the top surface of the blade. The bottom of template 'B' is 60mm below the top surface.

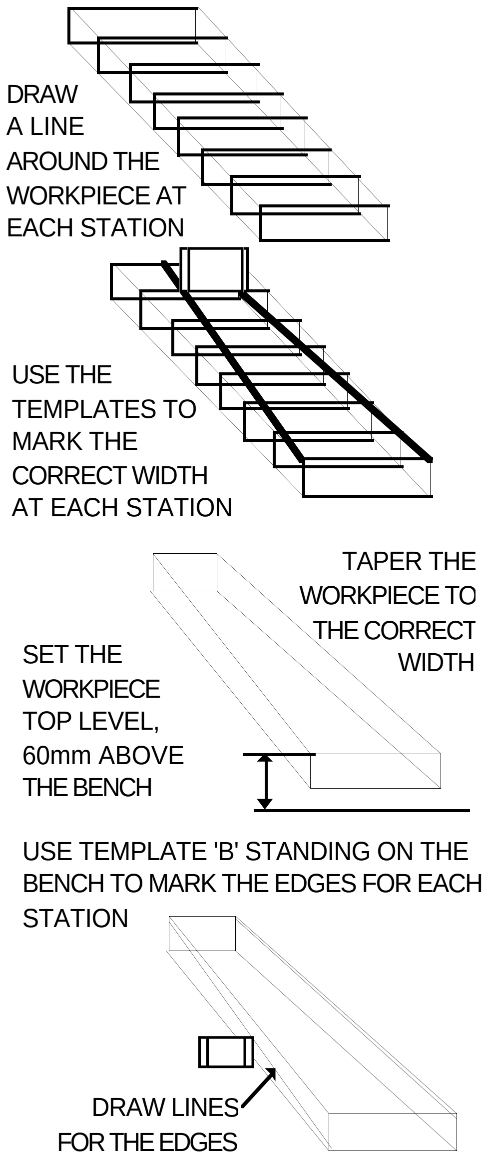
Patterns

The pattern is an object which is exactly the shape of the blade. Use it to make moulds for the blades. There are various ways to make a pattern. It can be made from wood. This is normal. However, wood can warp, and change its shape. It is important to choose a very stable wood. In Peru they have used Coava, which is a hard wood with good stability.

Sunith Fernando in Sri Lanka tried a wooden pattern initially but warping became a problem. "For K2, which is a slender profile, I made the pattern out of two materials. First I got a steel sheet (~ 0.8 mm thick) rolled into K2 outer profile – more or less, and then filled the inside with a paste that we use to fill up dents of automobile bodywork (we call it Cataloy paste). I used the paste to fill up the outer profile also as a thin layer. Then I filed the hardened cataloy paste to the required profile. Thereafter, I got the blade pattern cast in aluminium. It is the aluminium pattern that I gave for fibreglass work."

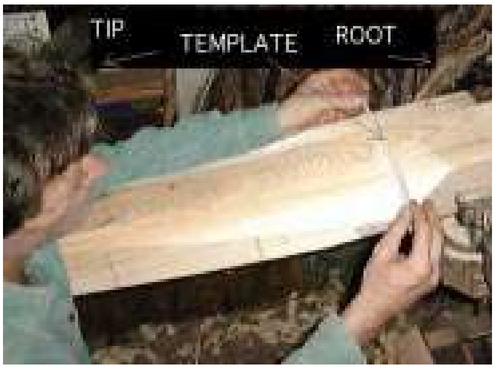
For the construction of the wooden pattern follow this procedure:
a). - Buy a rectangular block of wood 45mm x 165mm x 700 mm. The wood should be dry enough before starting the work of carving.

b)- Mark the position of each station. Then draw two lines along the wider faces using the 'workpiece width' on the templates, and cut the wood to the correct width at each station.



c)- Use the templates to mark a leading edge line and a trailing edge line. These are the lines where the two moulds will meet. Here is how to mark these lines: The top of the workpiece should be 60mm above the level of the bench. The right hand side of each template 'B' is the trailing edge. Place it on the bench, against the left hand side of the workpiece as shown, and mark the trailing edge. Do this at each station and then do the same for the leading edge.

d)-Then carve the curved shape of the blade pattern, checking very carefully with the templates at each station.



The templates in Appendix II are printed in such a way that one should look at them from the tip of the blade inward. Place the template over the workpiece at its station. When the pattern is finished, the top edge of the template should be exactly level, and the leading and trailing edge lines should meet the lines drawn earlier on the sides of the workpiece.

Making two separate patterns

The moulds for the blades will made in two pieces: one for each side of the blade. It is possible therefore to use two patterns instead of one, one for each mould. If there are two patterns, they do not have to be thin, like the blade itself. They can be made from big thick pieces of wood, which will not easily warp.

The photo (last page) shows a pattern being carved from a wooden workpiece which has been built up out of three pieces of wood glued together.

Finishing of the surface.

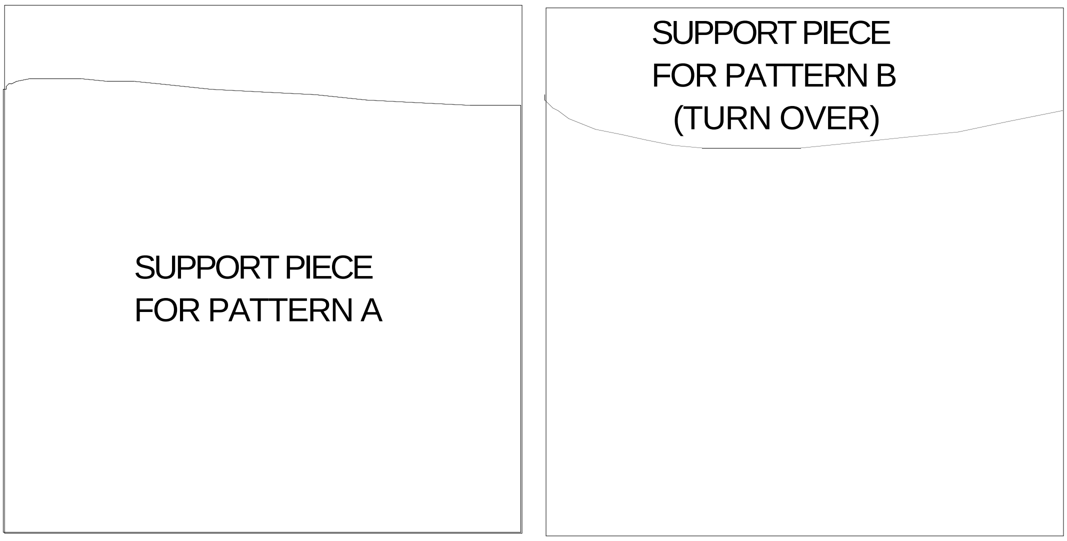
The finishing of the surface is an important feature because the quality of the surface of the blades will depend on that, therefore it is recommended to use some substance to feel tiny imperfections of wood, and later polish the surface until it looks as regular as possible, paint the pattern and polish again until it is soft enough or good enough to be used as a pattern.

An alternative idea : making patterns from metal

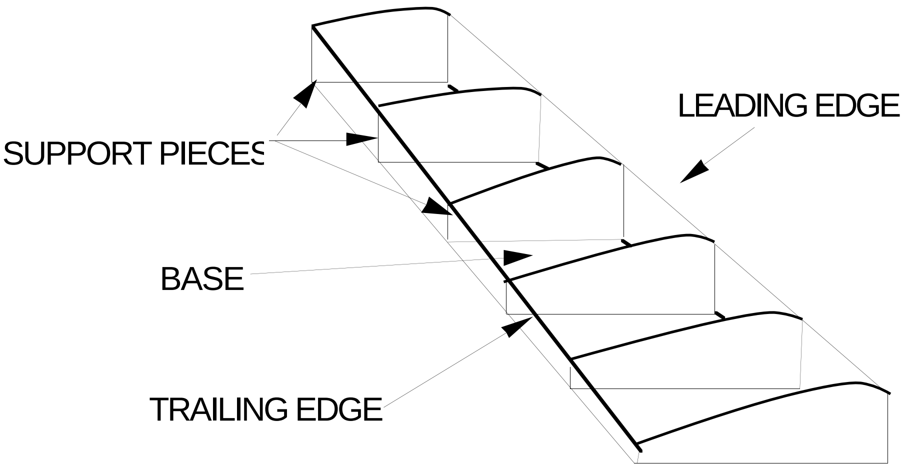
First I must state that this idea has not been tried at the time of writing. It is possible to make patterns for the blades using sheet metal wrapped over metal formers (support pieces). Make two patterns - one for each mould. One is for the back of the blade, and one is for the front.

Cut out the support pieces using the template shapes in Appendix II.

They will be used to support the pattern surface sheet, rather than just to check its shape.



Glue all the support pieces onto a level base at the correct spacings, and then glue a surface sheet down onto them tightly.



There are yet more, other ways to make the patterns. It is possible to make them from foam, cut with a hot wire. This method is popular with model makers.

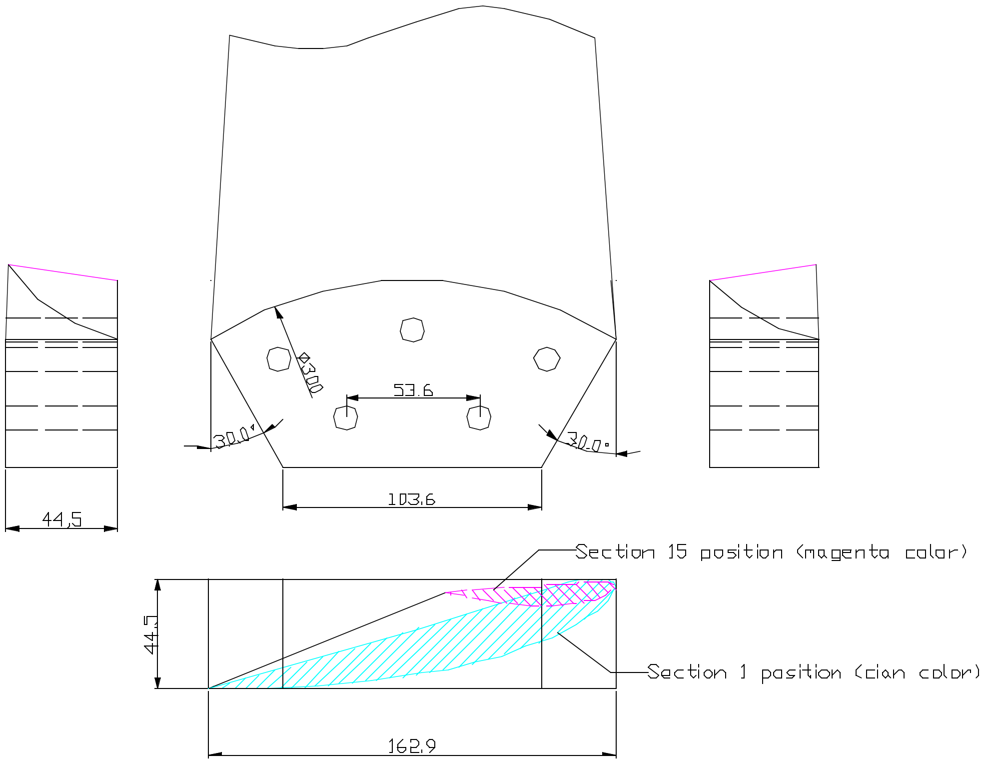
Probably the simplest method is to carve them from wood, as described above.

Making the moulds

In Peru, the moulds were manufactured in fibreglass. "The mould is done in two pieces, therefore it is convenient to be careful with splitting the blade into two parts, (or with the splitting line)

"The moulds can be of different materials, resin and fibreglass is always a good option, however it does not have a long life, it is expected that each mould can be useful to produce up to 50 or 60 units of blades.

"Therefore in some cases it would be preferable to use metal ones. Aluminium is a good alternative and it is widely used for fibreglass products."



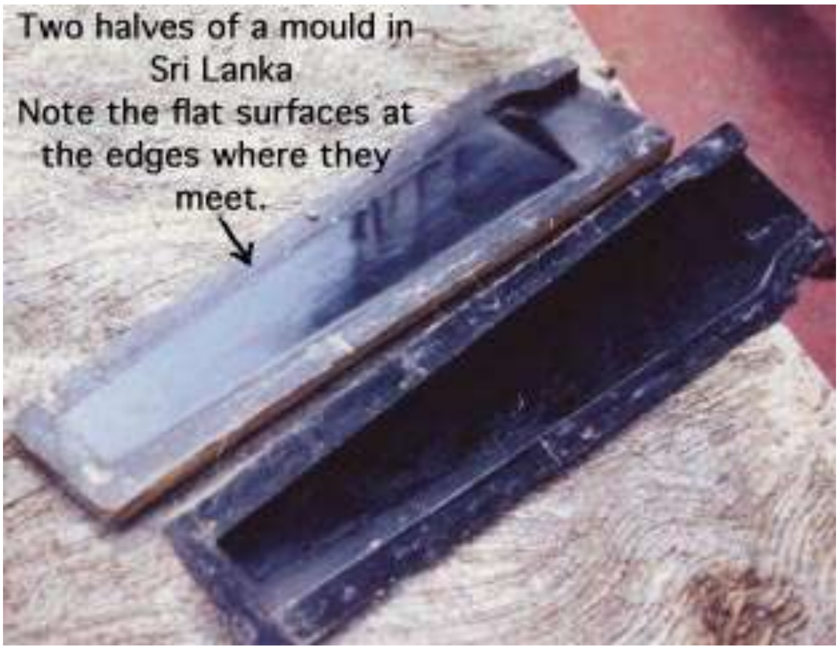
The blade root needs to be shaped to mount easily onto the wind generator. In Peru the root shape is as shown above. All three blade roots are clamped between two steel plates. The transition between the root (mounting portion) and the blade (airfoil section portion) is to be made smoothly. Avoid using sharp curves which would weaken the fibreglass.

The moulds for the Sri Lankan blades are shown to the right. They were made in fibreglass on an aluminium pattern. One side of the K2 mould is convex, because the upwind side of the blade is to be concave.

<u>The two halves of the mould</u>

When making the first half of the mould, use only one face of the pattern. Make a flat surface around the edges of the pattern which will later become the faces where the two moulds will meet. This can be done with fibreglass resin, wood or plasticene or any material which is easy to work. Take care to follow the edges of the pattern very exactly. When the first half mould has been made one can destroy this flat surface.

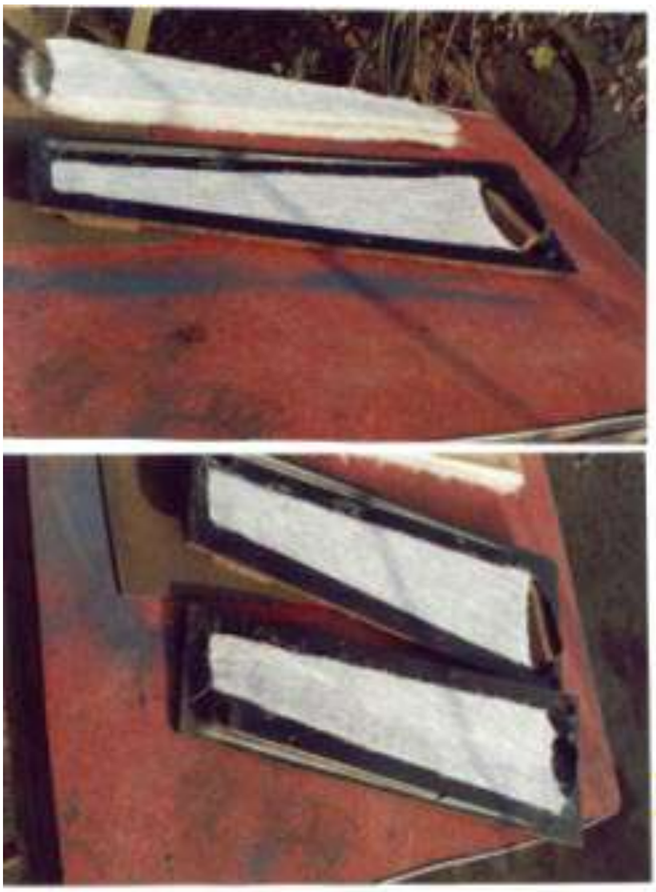
It is a good idea to make two holes in the flat surface at the edge of the first half, so that the second half will have two lumps. Later, we will fit the two halves of the blade together inside the moulds. If the lumps are in the holes then the two halves are correctly lined up.



When making the second half of the mould, place the first half against the other side of the pattern. Polish the flat surface around the edges, in the same way as the pattern, so that the fibreglass resin will not stick to it. Make the second half of the mould cover the pattern and also the flat surface, so that the two moulds fit each other perfectly.

If there will be two separate patterns for the two halves of the mould, take great care that the final blade will be the correct shape when the halves are put together. It would be easy to alter the thickness of the blade by inaccurate patterns.

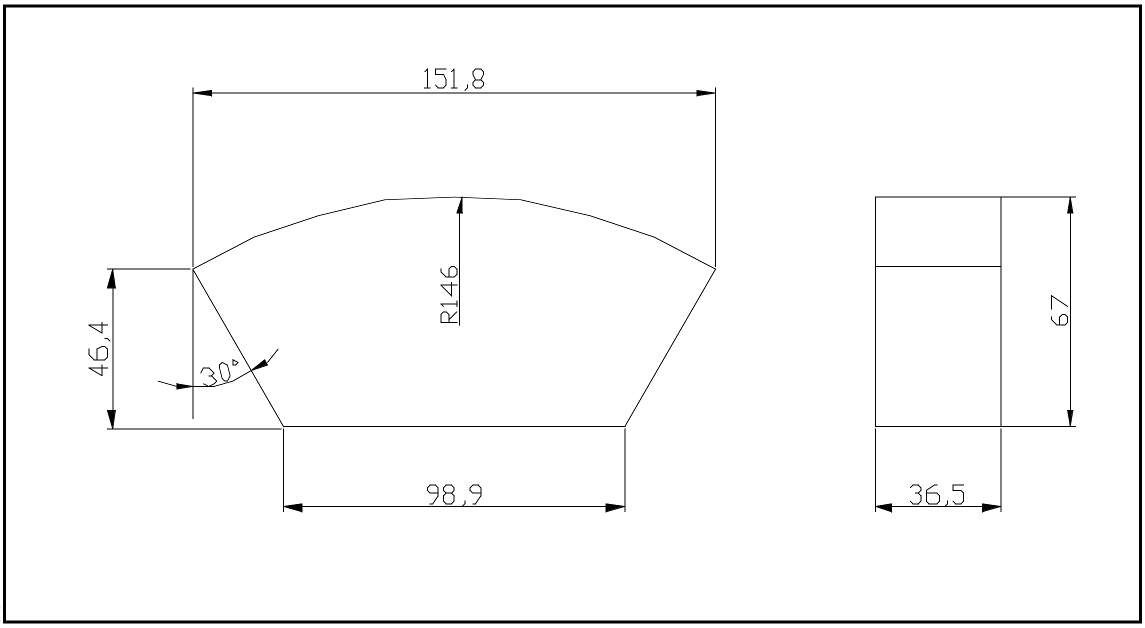
3. Blade construction



The procedure in Peru is as follows.

a) The mould should very clean before using the resin and fibreglass. Use alcohol or other solvent to clean it.
b) Use some substance to facilitate the mould separation from the blade when it is ready.
c) Paint a thin layer of resin in each side of the mould, then a layer of fibreglass (approximately 1mm).
d) Again a layer of resin on top of the fibreglass, and so on until there is approximately 3 to 4 mm thickness
e) In the root end of the blade it is possible to use a piece of wood (see diagram below) in on top of one of the sides in order to lower the quantity of fibreglass and resin.
f) Also in the root of the blade there should be holes in order to assemble the blades to the central hub.

Wood:



g) Once the 3 to 4 mm of fibreglass have been placed each side of the mould, the next step is to join the halves and tie them together. It is advisable to put some resin in the borders of the moulds in order to fill all the small gaps.

h) Finally, after joining the two pieces of the moulds, it is necessary to use bolts to clamp it. Leave it to set for about 12 to 15 hours.

On the right is a picture of the finished blades.

The outer portion of each blade is hollow. The Sri Lankan rotor has solid blades.

Another option is to use a foam core inside the blade. This can make it stronger if the bending stress causes problems (see section 4).

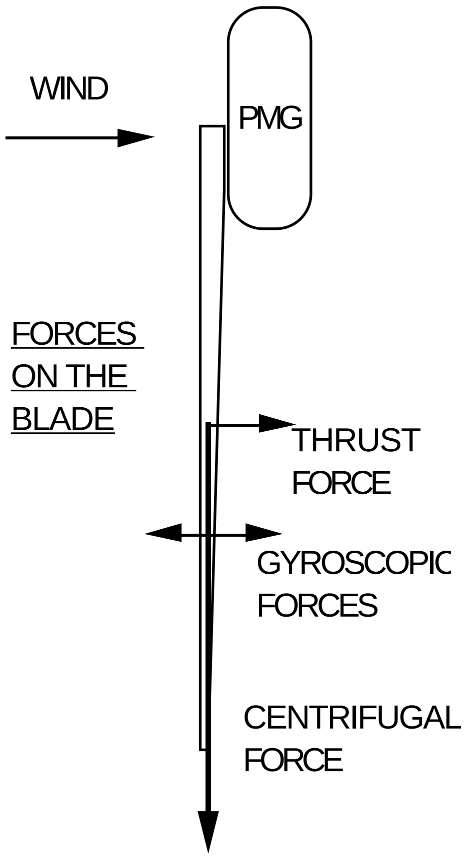
The outer layer of the blade (gel coat) must be waterproof, with no cracks or fibres on the surface. If water enters the blade, it degrades the strength and changes the balance. If the piece of wood in the blade root becomes wet and then dry, then the blade root will work loose in the hub mounting.

If the blades run for long periods in strong winds, then the leading edges will be eroded. A special adhesive tape is available for protecting the leading edges. Or they can be repaired with cataloy resin, and re-balanced as part of routine maintenance work.

4. Testing for strength

It would be wise to ask an engineer to check the structural design strength of the blades one is building. It is possible to calculate whether the stresses in the fibreglass skin are safe or not. We need to have a safety margin to allow for unexpected events, and for fatigue.

The main stresses on small wind turbine blades arise from centrifugal and gyroscopic forces. The centrifugal force on the blades when they are running at full speed (around 500 rpm) will be approximately 100 times the weight of the blade. If a blade weighs 1.5kg, then the centrifugal force will be around 1.5kN (equivalent to 150kg weight) at this speed. At 1000 rpm the force will be equivalent to 600 kg. This speed could arise if the tail furling system does not work correctly for example.



Wind thrust on each blade is only 50-100N (5-10kg). Thrust force imposes a bending stress on the blade, which adds to the stress from the centrifugal force. Gyroscopic bending moments could also be of that order of size (but rapidly alternating).

For peace of mind and safety it would be wise to test a sample blade by hanging and swinging weights on it until it breaks. This will indicate how large the factor of safety is (if there is one).

If there is a problem with inadequate strength in the blades, then increase the amount of fibreglass, especially in the root area. The resin has no real strength except to bond the glass fibres. If possible, use ‘uni-directional’ fibreglass mat. It may not be easy to find, but it is has double the tensile strength for the same weight. This is a big advantage where the main forces are inertial (centrifugal, and gyroscopic).

Blades will tend to crack at ‘stress concentrations’ where the skin undergoes sharp changes in shape. Try to keep the blade skin smooth and straight in its transition from the airfoil portion to the root portion.

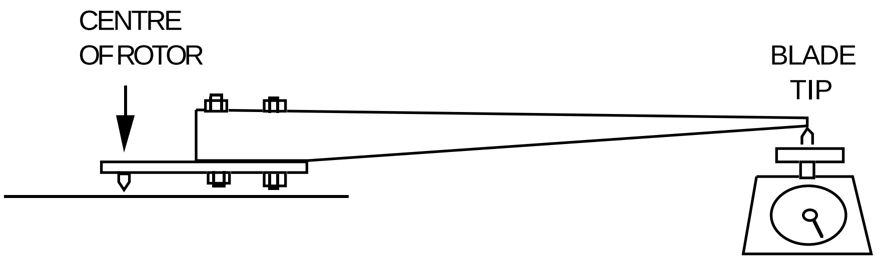
Blade failures are dangerous and very discouraging. When they occur, it may be necessary to recall and reinforce or replace a large number of blades. It is better by far to ensure that the blades are sufficiently strong at the start of manufacture.

5. Balancing and mounting

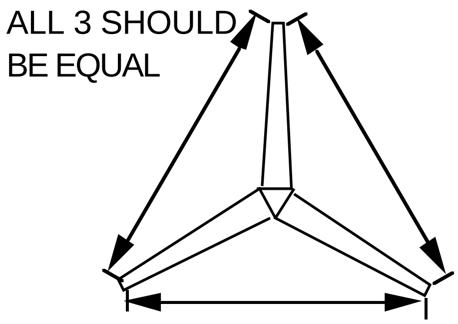
Balancing the rotor

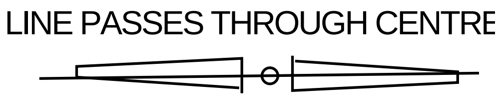
If the wind rotor is not balanced then the wind generator will shake as it spins. After hours and days of shaking, parts will begin to drop off. Usually the tail is first to go. It is important to balance the wind rotor carefully. Here are some steps to balance the rotor blades:

1. Support each blade at the root, and weigh the tip. Each blade should have the same tip weight. In order to do this test accurately we support all of the blade roots in exactly the same way. Make a jig which supports the blade root at the centre of the rotor.



2. Mount the blades on the rotor hub accurately. If there are three blades, then the distance between the blade tips must be the same for each pair. If there are two blades then the line between the tips must pass exactly through the centre of the rotor.





3. When the blades are mounted on the wind generator, check that the tips pass though exactly the same space as they turn. One blade tip should not be in front or behind the others.

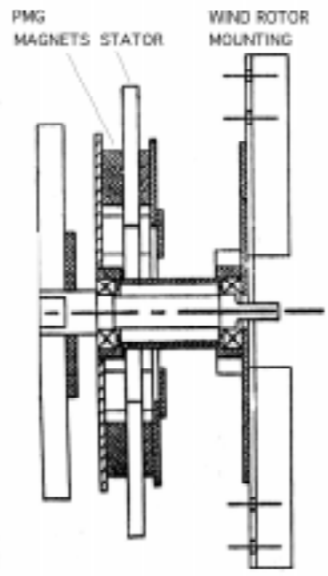
4. Use the balancing techniques described in the PMG manual to check the balance of the whole assembly before using it.

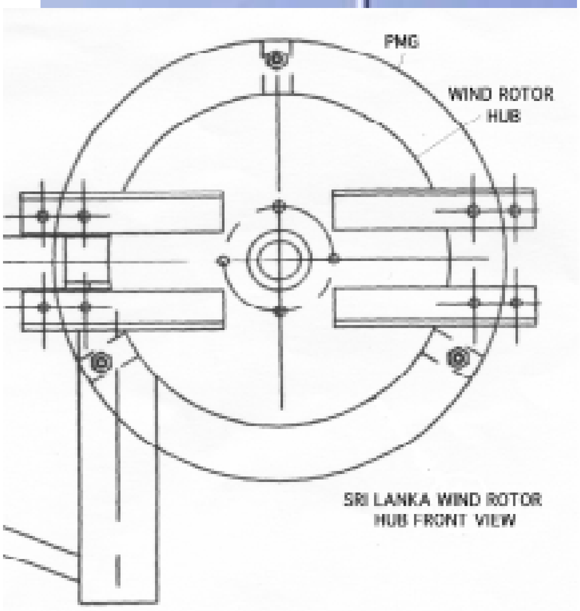
Mounting the rotor blades

The blades must be securely bolted to a central hub which fits on the PMG. Do not bolt the blades directly to the front magnet-rotor, because the gyroscopic forces on the blades will stress the magnet rotor and cause the magnets to hit the stator.

In Peru, the blades are 'sandwiched' between two steel plates. This makes a simple, strong hub. See also the diagram on the cover of this booklet.

In Sri Lanka, the two blades are bolted into a hub which is constructed as a part of the PMG. The rotor hub is an extra plate welded to the front of the PMG bearing-housing tube. Each blade is cradled between two pieces of steel angle which are welded to the plate.





Appendix I :Blade design details

Sri Lanka K2 blade design by Sunith Fernando

Blade station	Local radius	Local speed ratio	Flow angle	Actual chord - m	Re Number	Recalc C_l	Recalc alpha	Recalc Blade angle beta	Actual beta degrees
1	0.2	1.2	29.1	0.180	7.72E+04	1.76	22.9	6.1	11
2	0.3	1.8	20.3	0.170	1.02E+05	1.38	11.0	9.3	10
3	0.4	2.4	15.5	0.160	1.25E+05	1.15	6.6	8.9	9
4	0.5	3.0	12.5	0.150	1.44E+05	1.00	4.7	7.8	8
5	0.6	3.6	10.5	0.140	1.60E+05	0.90	3.7	6.8	7
6	0.7	4.2	9.0	0.130	1.73E+05	0.84	3.2	5.8	6
7	0.8	4.8	7.9	0.120	1.82E+05	0.80	2.9	5.0	5
8	0.9	5.4	7.0	0.110	1.87E+05	0.77	2.7	4.3	4
9	1.0	6.0	6.3	0.100	1.89E+05	0.77	2.7	3.7	3

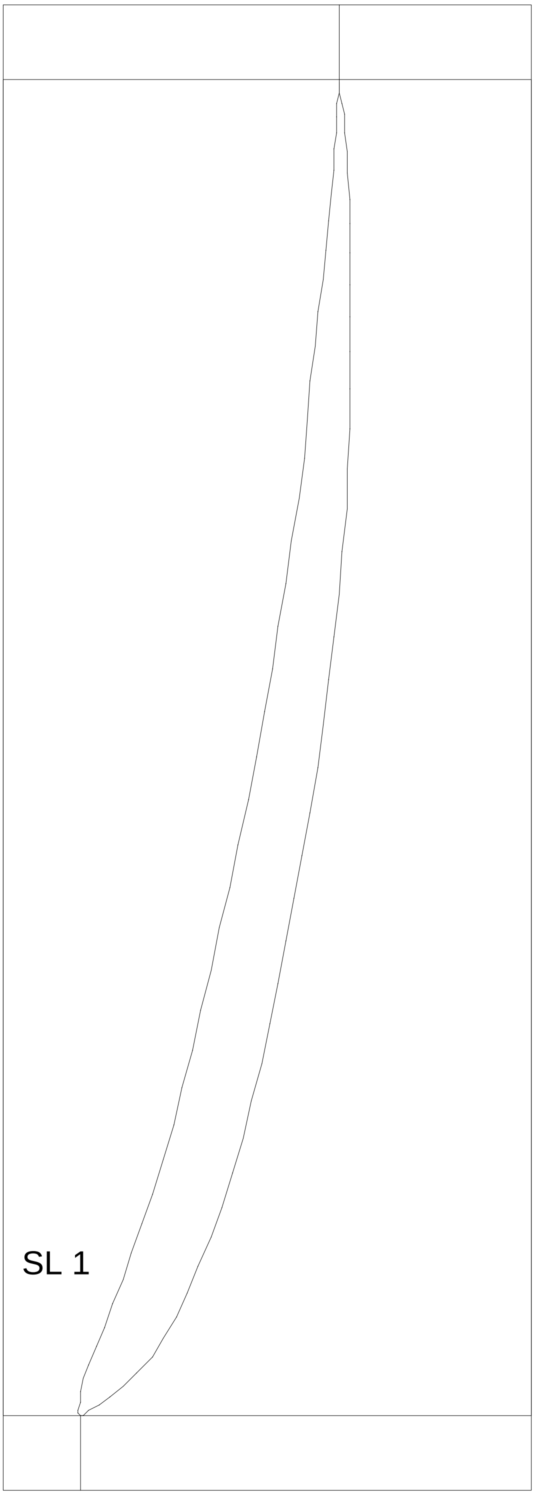
Peru NACA4412 blade designed by Teodoro Sanchez

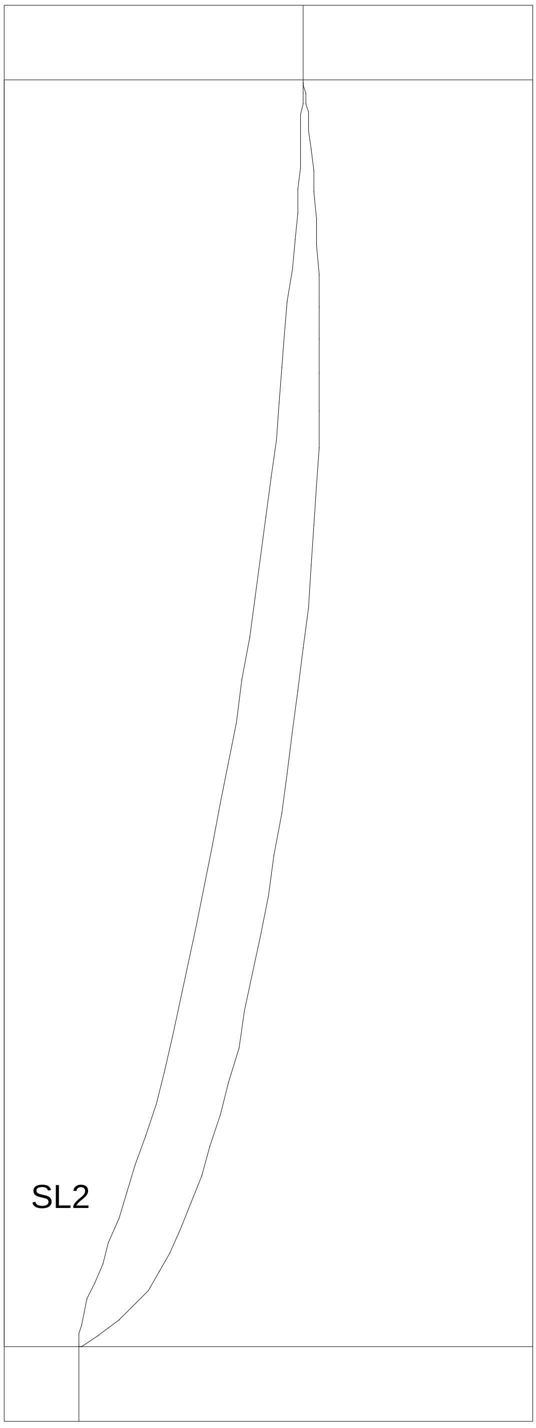
Blade station	Local radius metres	Chord width metres	Blade angle beta degrees
1	.15	.1679	14.5
2	.2	.1608	13.6
3	.25	.1537	12.7
4	.3	.1466	11.8
5	.35	.1395	10.9
6	.4	.1324	9.9
7	.45	.1253	9.1
8	.5	.1182	8.2
9	.55	.1111	7.3
10	.6	.104	6.3
11	.65	.0969	5.4
12	.7	.0898	4.5
13	.75	.0827	3.6
14	.8	.0756	2.7
15	.85	.0685	1.8

APPENDIX II : BLADE TEMPLATES ACTUAL SIZE

THESE TEMPLATES ARE VIEWED FROM THE TIP
LOOKING TOWARD THE CENTRE OF THE ROTOR

TEMPLATES FOR SRI LANKA 2-BLADE DESIGN USING K2 PROFILE
- 9 STATIONS -





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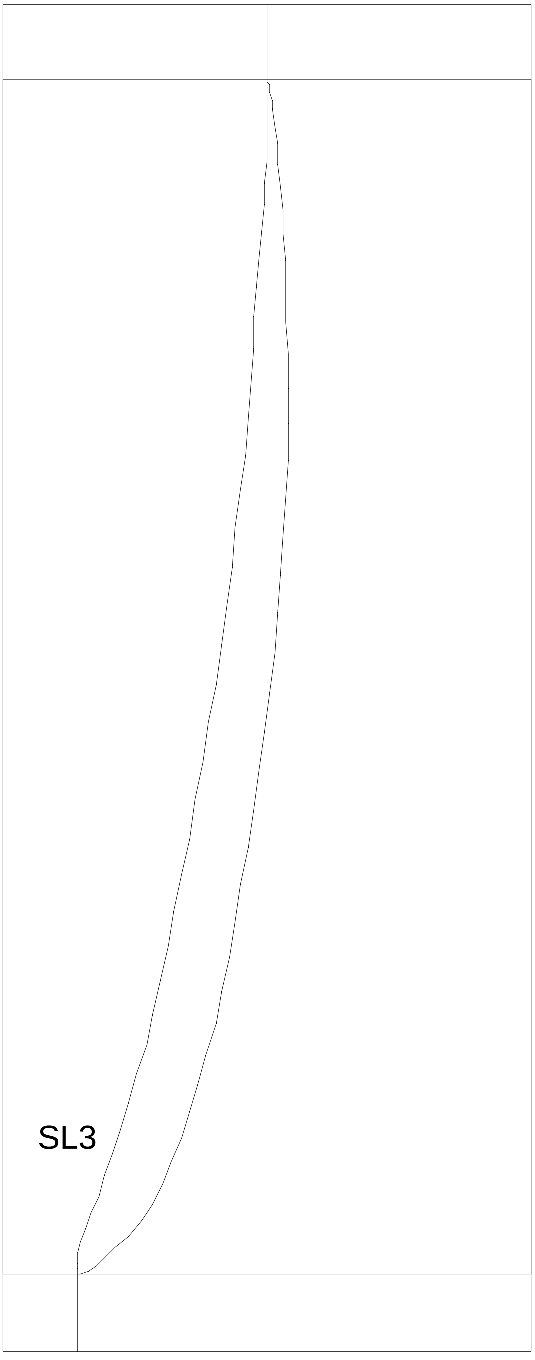
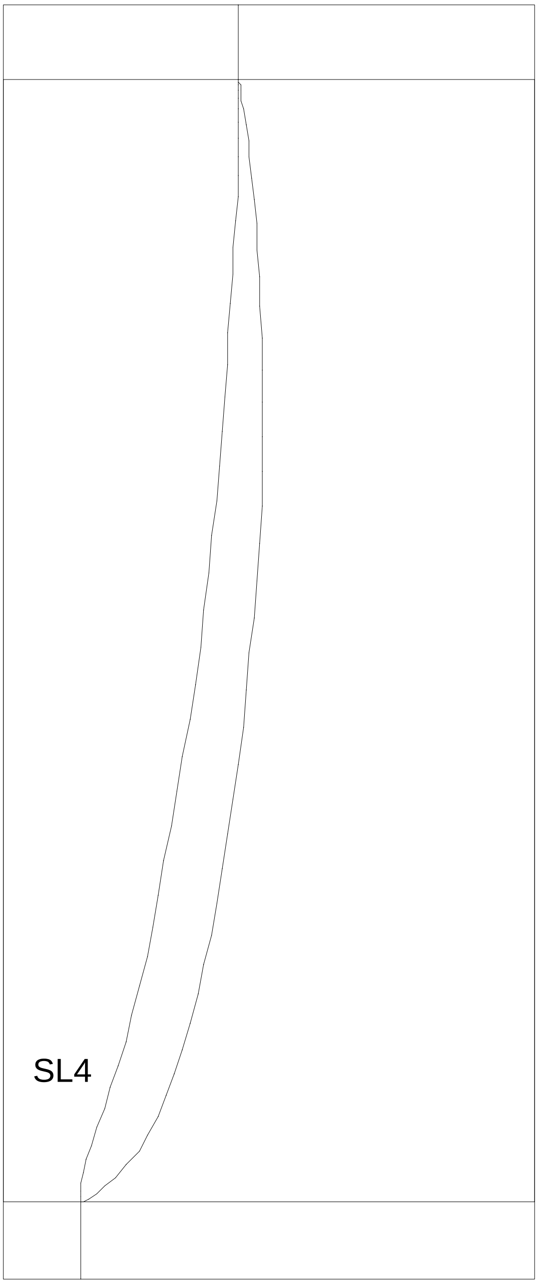
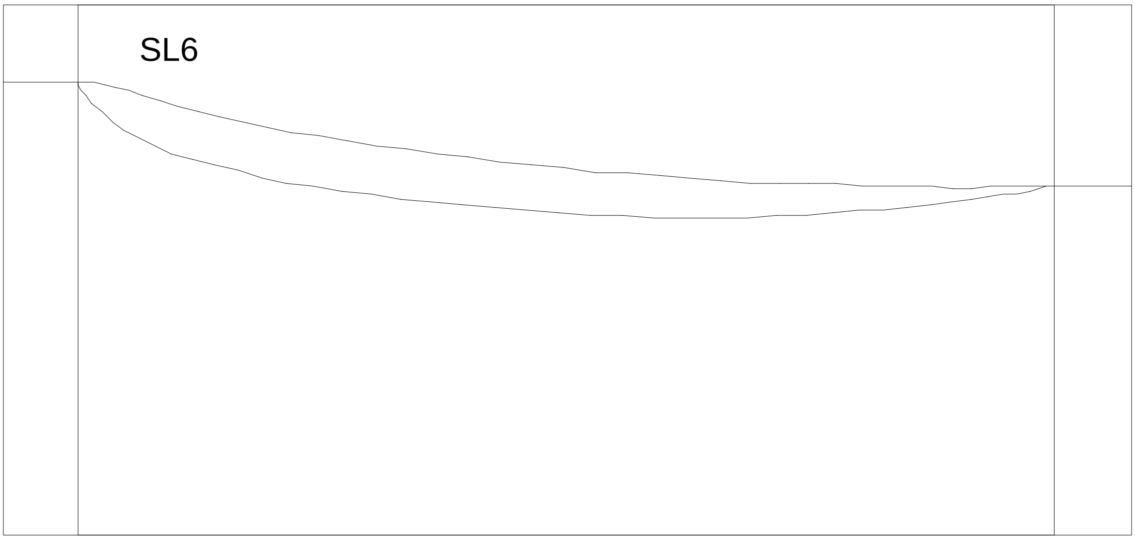
- 9 STATIONS -





TEMPLATES FOR SRI LANKA 2-BLADE DESIGN USING K2 PROFILE
- 9 STATIONS -



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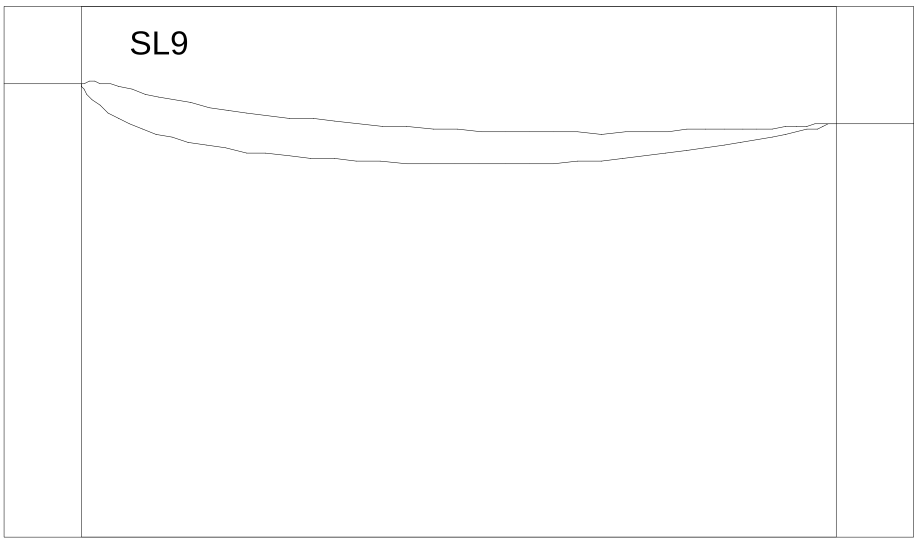
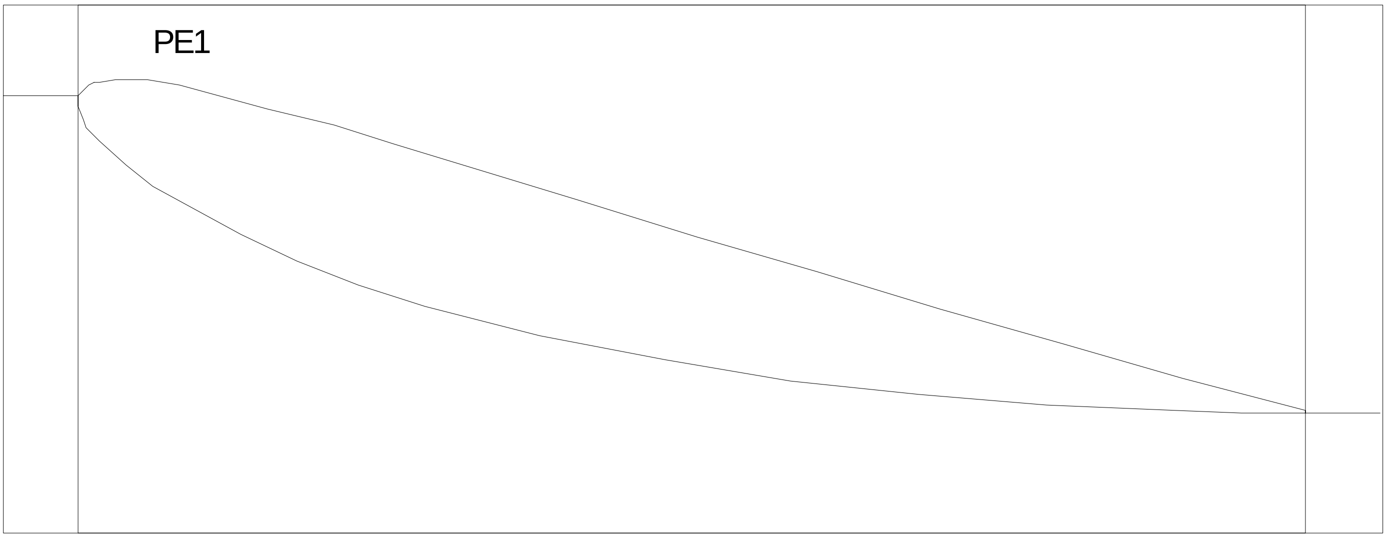
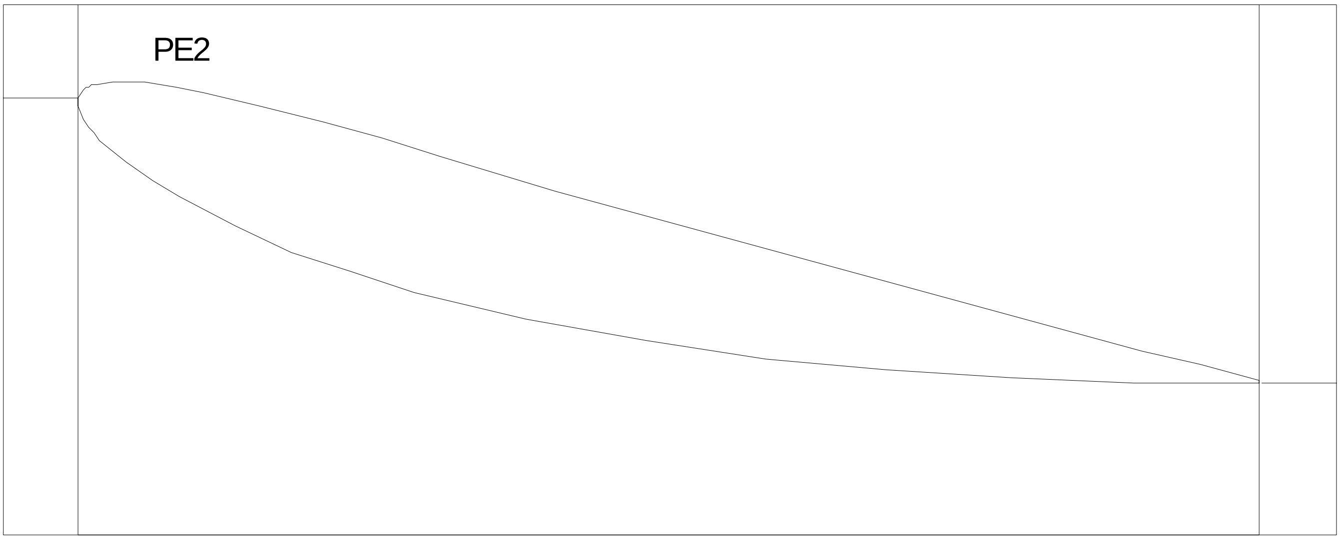
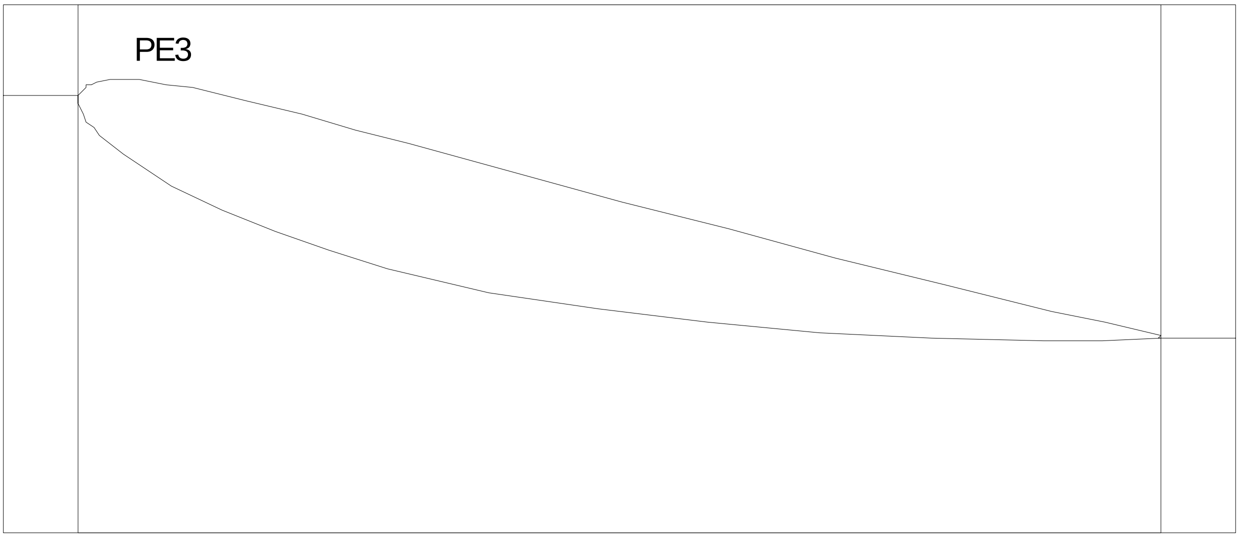
- 9 STATIONS -



TEMPLATES FOR PERU 3-BLADE DESIGN USING NACA 4415 PROFILE
- 15 STATIONS -







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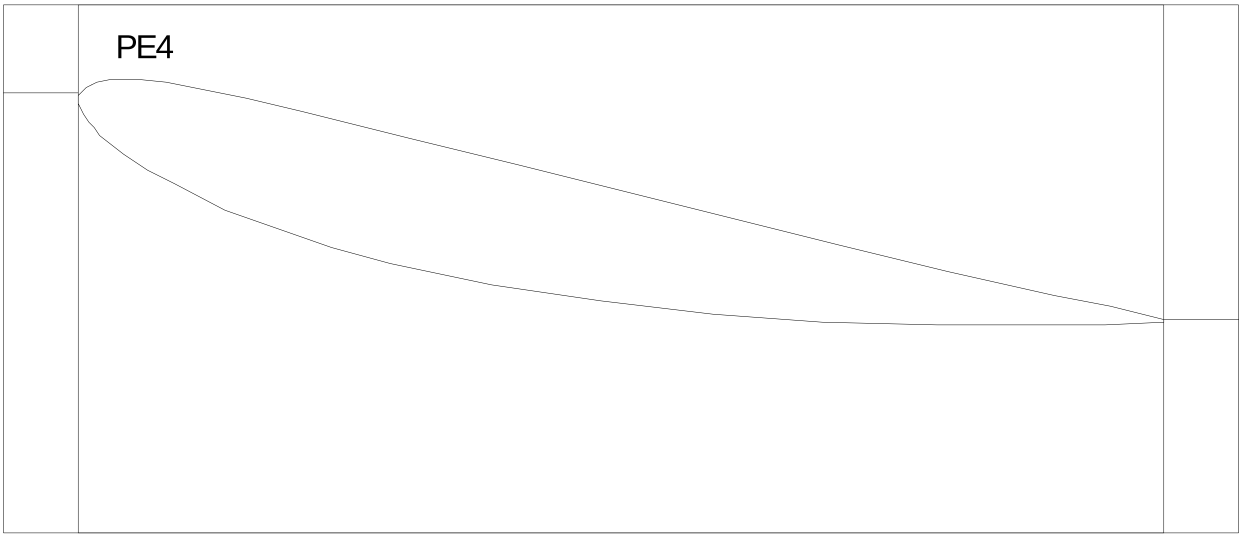
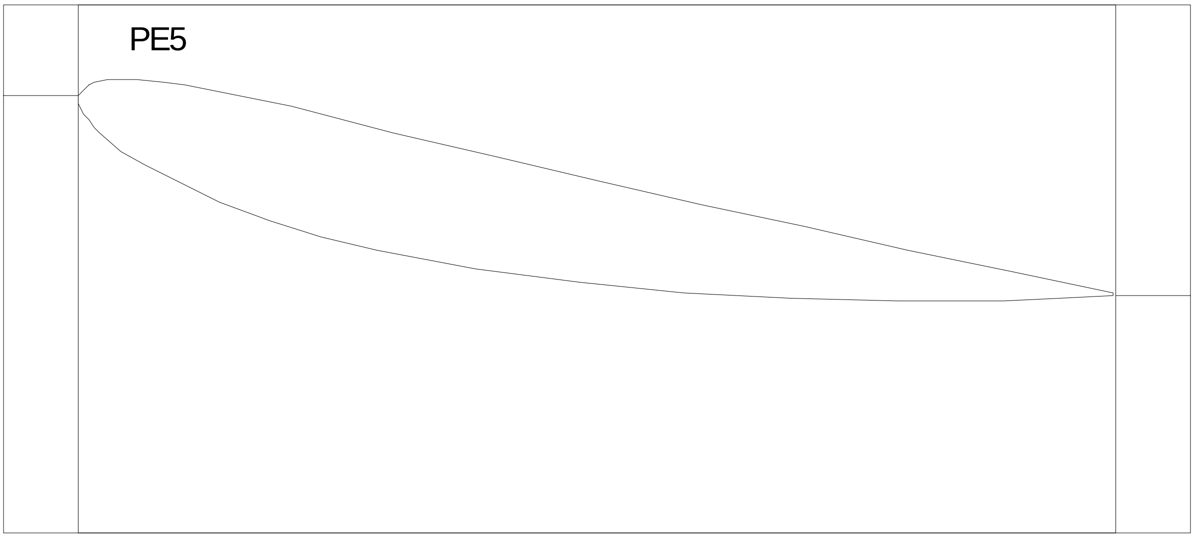
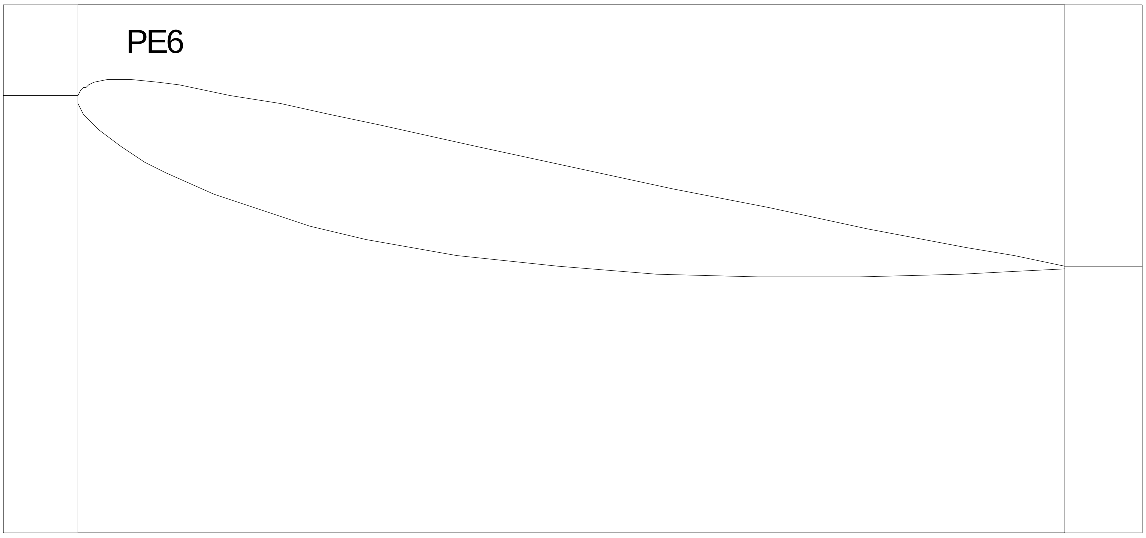
- 15 STATIONS -







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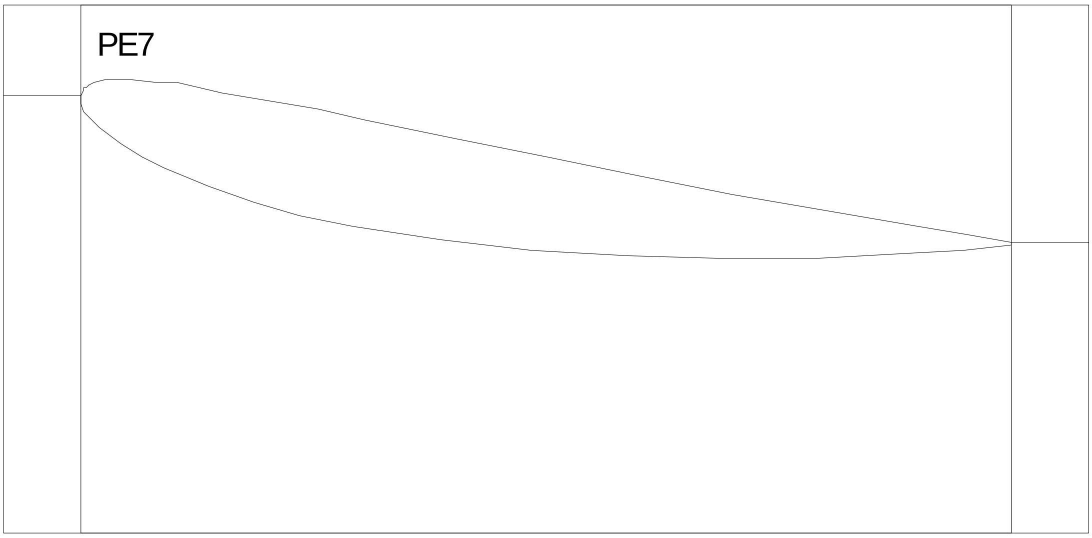
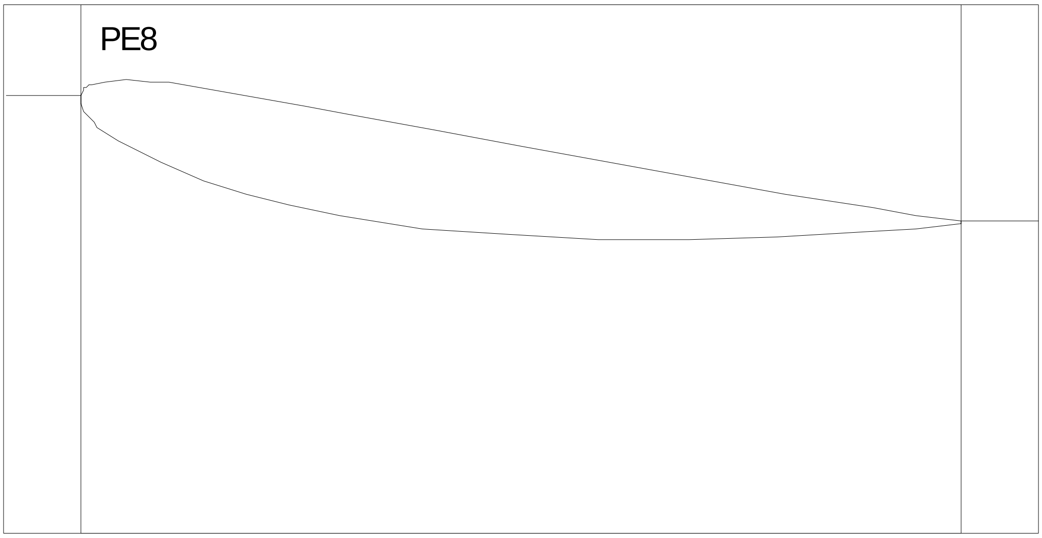
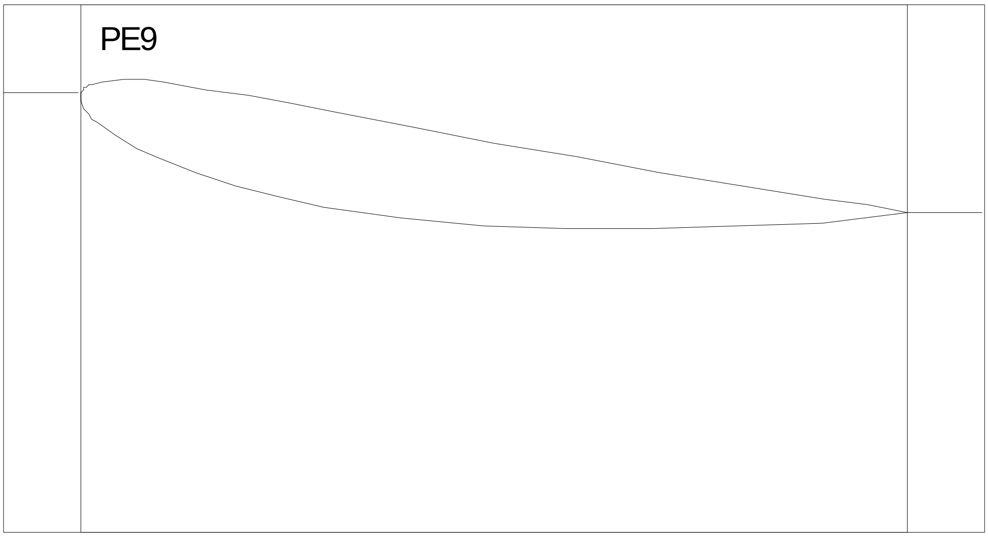
- 15 STATIONS -







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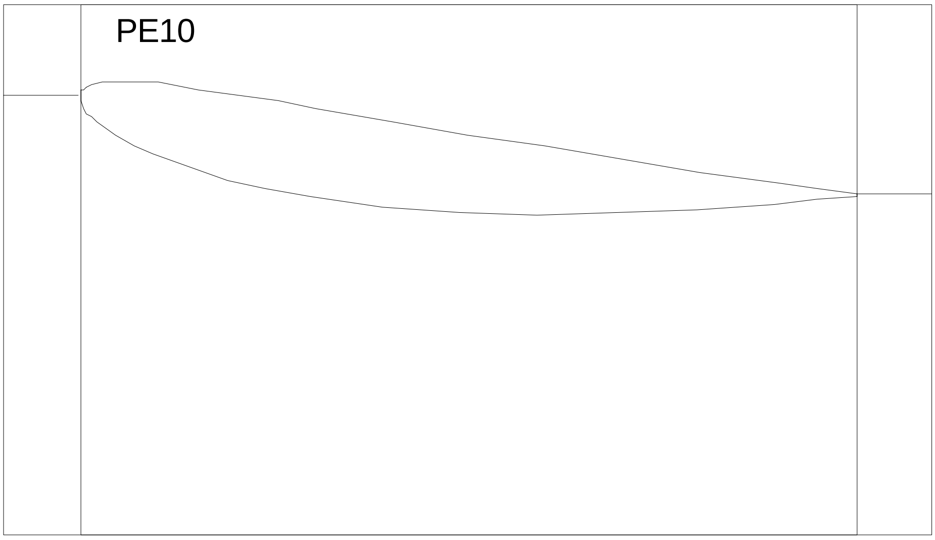
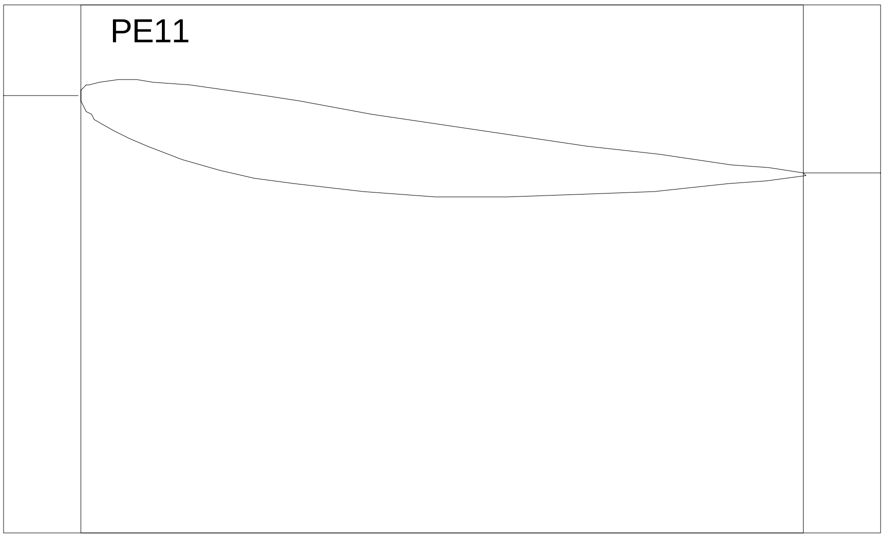
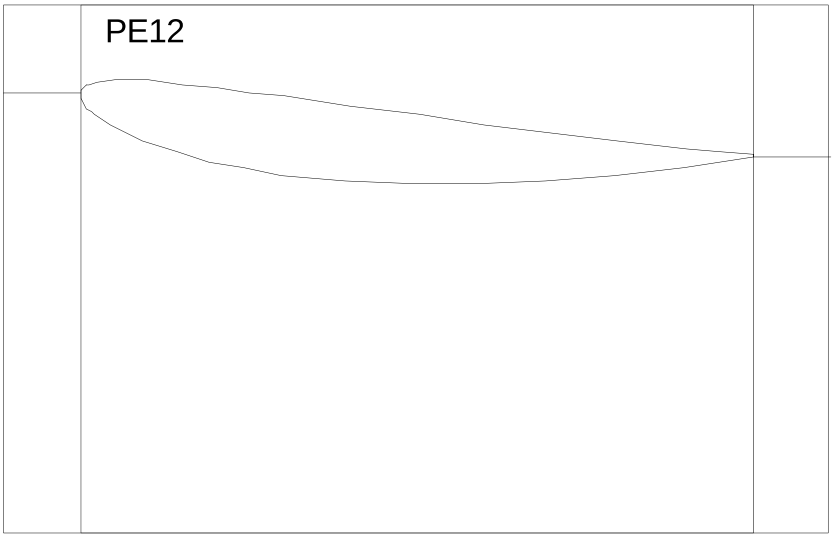
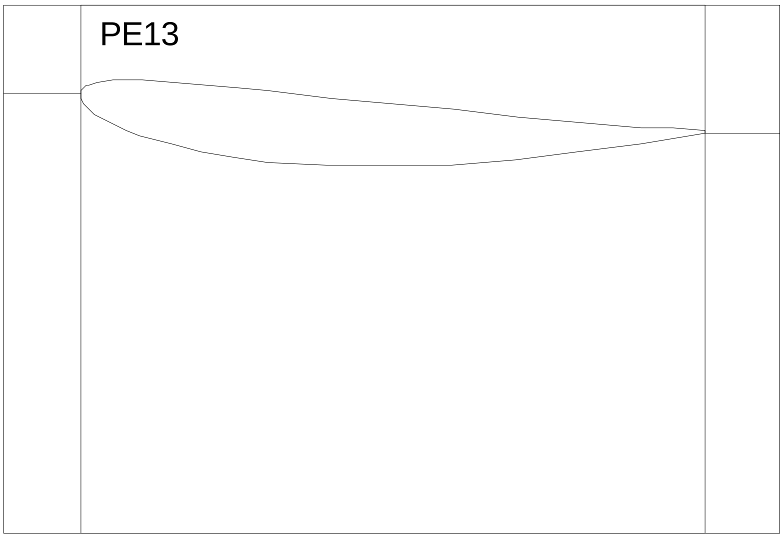
- 15 STATIONS -

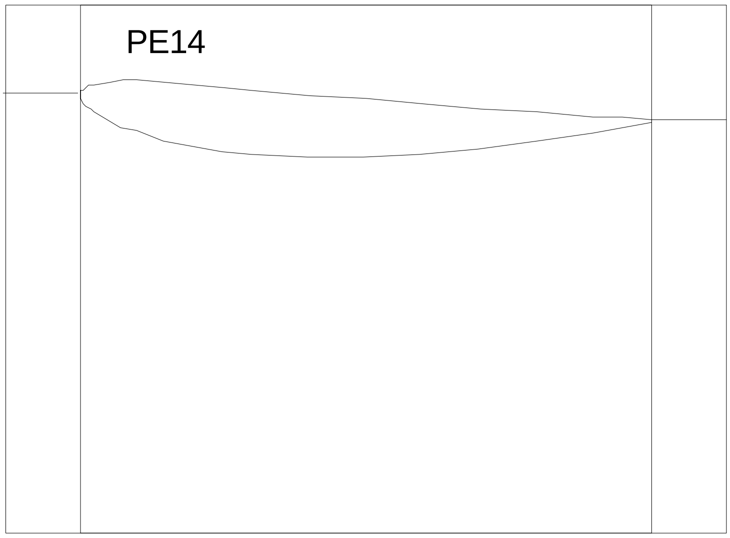


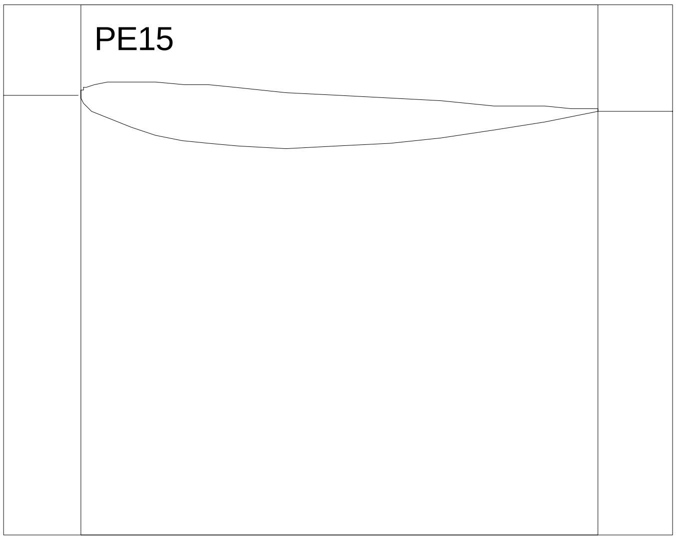




TEMPLATES FOR PERU 3-BLADE DESIGN USING NACA 4415 PROFILE
- 15 STATIONS -







BACK

Mailing-List: contact awea-wind-home-owner@egroups.com
X-Mailing-List: awea-wind-home@egroups.com
X-URL: http://www.egroups.com/list/awea-wind-home/

From: "Jones, Martin" <mjones@tqtx.com>

Date: Tue, 31 Aug 1999 16:56:19 -0500
extract

The best I've found for use as low-RPM generators are the **permanent-magnet "servo" motors** such as those sold by Surplus Sales in Lincoln, NE. For about $30 they will sell you a permanent-magnet motor that will put out about 5-10 amps at battery-charging voltage, at an RPM consistent with direct drive-props. Also, most of these motors have large-diameter (~3/4") shafts and a four-hole face-mount. Typical size is about 4" dia by 7" long.

If you want the details of how my homebuilt works, using the servo motor, email me privately as it is a long file. Also, I have some detailed characterization data for the motor's output vs RPM and load, from which I derived a generator voltage constant and the output impedance. It was fairly linear.

Marty Jones
mjones@tqtx.com

Marty again.. (13 Oct 1998)

For someone into this as a hobby, I think using a PM motor rather than building your own generator/alternator is the best way to get your feet wet.

If you are going to build a generator/alternator from scratch, there aren't many references. Hugh Piggot has published several pamphlets, which he sells (not cheap, considering how small they are), on home-building low-RPM generators using brake drums and auto axles.

If you're interested in rewinding an auto alternator for low-RPM operation, one good reference is "Electronic Design of Alternate-Energy Projects", by

R. Andrew Motes. He has some other interesting items in there as well, though much of the material is dated as far as electronic technology is concerned.

I built my wind generator using a permanent-magnet DC motor as the generator. My particular model was a 48-volt motor, cost $29 (I think) about 3 years ago, and has a 5/8" shaft. The case is 4" by 7", has a 4-hole face-mounting pattern, and is totally enclosed. I use it to produce about 100 watts at 15 volts in a moderate wind.

I bought two of these motors, and coupled the shafts so that one could serve as a variable-speed drive for the other while I took output data vs load and RPM. I varied the speed using a variable-output-voltage power supply. I can get 12 volts (open-circuit) at around 300 RPM. As electrical load is increased, the shaft speed must also increase to maintain output voltage.

One advantage of using this type of motor as a generator is that it produces very "high-quality" DC - the large number of poles on the commutator produces low ripple that is very easily filtered. If someone wanted to power communications equipment, this would probably be a good choice. In my application, I'm limiting current to 5-10 amps, which is in the range of the motor's operating current under some load conditions. I've pulled 5 amps into a dummy load for several hours and noticed no heating of the generator. The "motor" of the experimental motor-generator pair runs substantially warmer than the "generator".

A trick I found helpful when testing the motors was to place both of them in the "vee" of a piece of angle iron. This holds them (they are almost perfectly cylindrical) such that the shafts are along a common axis, and the shafts can actually be pushed nose-to-nose and coupled temporarily using strong duct tape. A couple wraps of the tape also holds the motors in the angle iron. Measure RPM using a taped-on magnet and solenoid with a frequency counter. If you can't get this stuff together, a crude estimate can be gotten with a stopwatch and a long piece of string - time how long it takes to wind up on the shaft.

The measured generator constant for open-circuit voltage is 26.5 rpm per volt, and output resistance is 1.24 ohms.

So if I wanted to produce 5 amps at 12 volts, I would need to generate an open-circuit voltage of:

12 + (5)(1.24) = 18.2 volts

and the rpm required is:

(18.2)(26.5) = 482.3 rpm

This is in a very good range for a direct-drive propeller. For more information on propeller speed ranges and output-power potential versus diameter and blade design, you can read almost any text on wind generators. I think the Motes book I referenced earlier also has this information.

Anyway, I got these motors from Surplus Center in Lincoln, Nebraska. This particular motor is no longer listed in Surplus Center's current catalog, but I think they have several similar ones.

Weight is about 10 pounds (my guess).

One downside of using a PM motor as the generator is that there is no way to internally regulate the output voltage. You have to have an external regulator, or just use a battery bank large enough that you don't worry about overcharge. If you don't have anything else between the battery and the generator, you need a diode to block reverse current. Remember, this thing is really a motor, and in absense of enough wind to generate charging current, the battery will power the motor and spin the rotor.

Another downside is that such a motor is generally not designed for thrust loads on the shaft, so if it were a permanent installation I'd try to rig a thrust bearing to prevent wearout of the motor bearings. Also, the brushes will eventually wear and need to be replaced, but since my application (and presumably yours) is temporary power, it's not a problem.

Marty Jones
mjones@tqtx.com

BACK

Brakedrum alternator update (updated October 2002)

I am building up this page on the web to help people who are following my brakedrum windmill plans. For details of how to obtain these plans see my books page. I am always willing to help readers who have problems, or who wish to develop new variations on the design based on different sizes of parts or different voltages. Send me an e-mail with full details to hugh@scoraigwind.co.uk

On this page:-

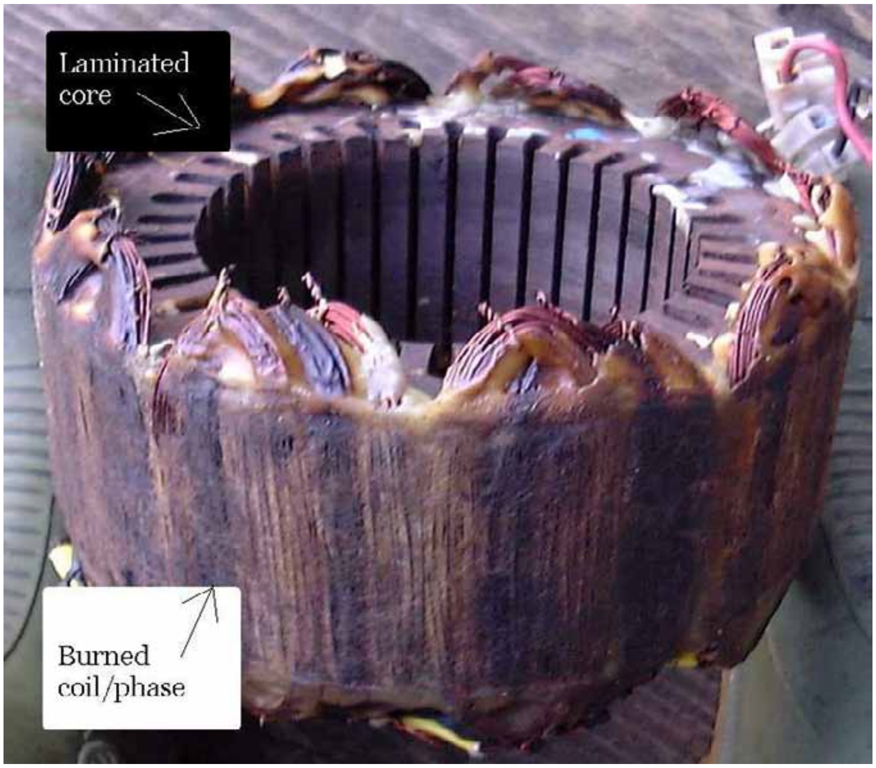
To clarify the differences between the solaced european and n american version of the design see this page

Magnet supplies - some links on this page. Magnets for the north american version (3x2x1" ferrite) are now available from wondermagnet.com for $5 each.

It has to be said that building a wind turbine is not like mowing the lawn, it is rather a challenge, and although my books will be an enormous help, they cannot make it into an exercise like assembling a kitchen unit from a flat pack. Not yet anyway. Maybe one day...

Problems seem to centre on the production of the stator. I have to agree that this is the hardest part to make. Here below are two pictures of the stator, for a start. It's an old one and has suffered some overloading on one phase due to a short circuit. This helps to pick out the shape of the phase which is burned - the middle coil in each heap.

As you can see, the air gap between the surface of the laminated core and the surface of the magnets is filled up with copper wires. This is how we extract the maximum power. At the ends (beyond the ends of the core), the coils overlap and are too thick to fit in the airgap - but this is not a problem because they are not in the air gap. The ends can be folded down hard if necessary, to make them fit the available space, but be careful not to damage the insulation.



A lot of people have recently started to ask how to get hold of laminated cores like this. Do not buy them as new or secondhand items! They are available for next to nothing as **scrap metal** from yards which specialise in dismantling and recycling old electrical and other goods to sell off the metals. Here in the UK they are called scrap dealers or non-ferrous metal dealers.

There is much more about the laminations for the n american version in an e-mail message below. Take care when selecting a stack of lams that you avoid or remove any fastenings or welds which might short circuit the laminations together near or at the outer edge. These will cause high 'eddy currents' to flow which will waste power and slow the machine right down.

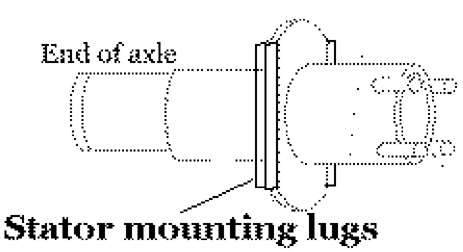
Fitting the stator into the space between the magnets is another cause of grief.

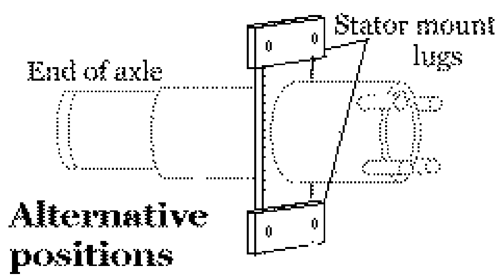
It is very important indeed that the coils lie flat. The former which clamps them in place is a critical tool, and it has to be made very carefully. The surface of the former has to be absolutely true, without hollows which would cause high spots. An easier way to make the mould (I am indebted to Bob Budd for this tip) is to start with a layer of card on the core to represent the coils. Then lay a thin piece of sheet metal over the card so it has the exact right shape. Then place a crude wooden former behind the sheet metal and fill the space between former and metal with resin - epoxy, or even body-filler polyester resin will do. This procedure will allow you to make a very accurate mould without painstaking woodcarving.

Before gluing the magnets into the brakedrum, first check that the stator will fit in the available space between the magnets. Some magnets can be placed within the drum 'loosely' for the purpose of this test. You want to have 1-2 millimetres (40-80 thousandths of an inch) all around the stator for a comfortable clearance. If the fit is too tight, then I suggest you skim the brakedrum inner bore on a lathe (or have this done in an automotive workshop - it is a normal job). This will give you more space to play with.

Here is an excerpt from an e-mail correspondence about how to mount the stator securely and centrally:-

>After purchasing and reading the subject book, I find that there is a
>lack of information on how you mounted the stator (laminated core) to
>the axle assembly. This seems to be an important procedure missing from
>the "Putting it All Together" section of the book. Can you supply any
>details on this?
Happily. Last week I had a similar enquiry and was shocked to see how little help I give on the subject in the plans. Before that, no one had pointed it out, even though many successful alternators have been built. The plans have been on sale for seven years and I frequently update them to respond to comments such as yours.
> Without these details, the subject book title is
>misleading because incomplete plans are really not plans at all. They
>become nothing more than a series of "ain't this cute" ideas.
In reality is never possible to get the same component parts as I have used. Everyone has different sized parts from different sources. So it is essential to be flexible and find your own solutions for details. I assume this is what others have done. But now you point it out I can do much better by explaining it.
Begin by measuring the size and spacing of the slots in the stator, which used to carry the coils. Find a size of bolt (or threaded rod) which fits snugly into the bottom of a slot. Place four such bolts through four slots. wedge the stator inside the drum, while the drum is on its bearings on the axle. Measure the size and shape of lug needed to hold the end of the each bolt.
Bolts through the slots, into the holes in the lugs. Choose bolts (or long pieces of threaded rod) which fit snugly and carefully position the holes so that the bolts are in the bottoms of the slots. Centre the stator carefully and then weld the lugs in place on the back plate flange.
The shape of the lugs and their position will depend on the shape of the brake system. If there is no flange in the right place to weld the lugs onto then make up tabs from strips of 1/4 inch steel flat bar.Drill holes at the outer end of each strip.
Let me know if this is not clear :-)





North american version coil dimensions.

From: "Andrew Purvis" <andrew.purvis@telus.net>
Date: Sun, 16 Mar 2003 08:24:06 -0700
Subject: [a-w-h] North American brake drum PMA

I'm in the process of building Hugh Piggott's brake drum PMA.Ý

I've got a couple of questions, and thought I'd share my experience to this point.

The rear axle was easily located at a self service wrecker. I was fortunate, however, that someone else had already removed the core (the internal gears) and the half shafts. This saved me work, and reduced the cost. The wrecker has it down to a science and has a separate price for the hubs, axle housing, core and half shafts. Because it was self service, I did have to have enough tools to remove the axle from the vehicle. The resulting weight was about 175 pounds.

I found a motor of about the right size on my first trip to the local motor repair shop. It's a 20 hp motor, considerably larger than the 5 hp required for the UK version, so I think I got lucky. There probably aren't very many of those that get tossed. The downside of such a large motor is that it weighed 150 pounds even after I removed the end plates and the rotor.Ý The laminations turned out to be 9 1/2 inches instead of the 9 5/8 called for in the plans, but I think I'll make do.

To split off the case of the motor I put a metal cutoff blade on my circular saw. This had the advantage of allowing me to control the depth of cut fairly accurately, so there was almost no damage to the laminations. I actually didn't quite cut all the way through, and used chisels to pry apart the case enough for it to break at the cut. I had to make another cut on the opposite side to get the case to break in half. I discovered that the second cut should be EXACTLY half way around, or the laminations have to be pried out of the slightly larger half.

Now to the questions. I'm just about ready to test fit the magnets into the drum. After a comment from Hugh that I saw in the archives, I started to wonder if the magnets would actually all fit. Based on my calculations, it's going to be close, but probably leave no gap. How important is the 1 mm gap between magnets? I've seen some mention of flux leakage directly from one magnet to the other, but I'm wondering how significant this will be. The less shaping of the magnets that I have to do, the better. Turning the drum slightly larger won't be an option because the laminations are already on the small side.

The second question has to do with the air gap. It looks like I'm going to have a gap of about 4.5 mm. How badly will this affect the performance of the machine?

Thanks for any comments.

Andrew

\>
\>The laminations turned out to be 9 1/2 inches instead of the 9
\>5/8 called for in the plans, but I think I'll make do.

Yes I think that is a better size actually. Bob's sizes are a bit tight.
\>
\>

>Now to the questions. I'm just about ready to test fit the
>magnets into the drum. After a comment from Hugh that I saw
>in the archives, I started to wonder if the magnets would
>actually all fit. Based on my calculations, it's going to be
>close, but probably leave no gap. How important is the 1 mm
>gap between magnets?

the magnets can touch each other if you like. That's fine. They have quite high reluctance anyway, so there will not be much increase in leakage this way. I like to fill the space with magnets if I am using ferrites.

>I've seen some mention of flux leakage
>directly from one magnet to the other, but I'm wondering how
>significant this will be.

Very significant. But in this case you have limited space for magnets so you might as well jam them in. You will get better flux this way than with smaller magnets.

>The less shaping of the magnets
>that I have to do, the better. Turning the drum slightly
>larger won't be an option because the laminations are already
>on the small side.

You could use a thicker winding. That would be OK. A larger gap between magnets and lams is not a problem. You gain on copper and lose slightly on flux density so overall it is no big deal.

>
>The second question has to do with the air gap. It looks like
>I'm going to have a gap of about 4.5 mm. How badly will this
>affect the performance of the machine?

That sounds quite small to me now. You might make it bigger. Fill it with copper but keep a sensible amount of mechanical gap. I'd suggest making the stator first and then deciding whether to skim the drum larger. Aim for a 1.5mm clearance between coils and magnets.

From: "Andrew Purvis" <andrew.purvis@telus.net>
Date: Thu, 20 Mar 2003 13:59:51 -0700
Subject: Re: [a-w-h] North American brake drum PMA

On 20 Mar 2003 at 8:04, Ron Dinishak wrote:

But its easy for a first time builder to miss that and more importantly the coil former listed on page 18,third column of Y2K is too small. The legs of the coils have to be longer than the laminations or else the ends of the coils will over lap in the airgap and the stator won't fit. I used something like 410mm(4.5") for my leg length. (The second time I wound the stator.) :)

Thanks for pointing out the coil former problem. I hadn't noticed the the leg length for the UK version was bigger the the lamination thickness. Duly noted in the plans now.

I've decided to increase the coil thickness to 4.5 mm. This will hopefully allow me to put in a double coil of 0.8 mm wire (that I painfully recovered from the recycled motor itself) reducing the resistance to half. By double coil, I mean simultaneously winding 2 sets of wire in parallel and joining the ends, giving the equivalent of about 1.1 mm wire (based on cross-sectional area). My calculations say that the coil will still be less than 10 mm thick in the other dimension. I've yet to do a test coil to see how much the real world is going to interfere.

Keeping the mechanical air gap at 1.5 mm gives a total air gap of 6 mm. My drums are well worn, so minimal turning (mostly taking off the ridge on either side of where the shoe contacted) will give me a enough room for the magnets and even a bit of space between then (especially since I've already hand ground off about 0.5 mm of each inside corner - magnetic filing are a real pain). It also helped that the nominally 1X2X3 magnets from Magnetsource were actually 25X50X75 mm.

Andrew

A message about the details of the spreadsheet formulae

To: Bruce Gebbeken <ideneh@yahoo.com>, awea-wind-home@yahoogroups.com
From: hugh piggott <hugh@scoraigwind.co.uk>
Date: Fri, 9 Feb 2001 14:07:49 +0000
Subject: Re: [a-w-h] Those windmill formulas...

At 2:04 pm -0800 8/2/01, Bruce Gebbeken wrote:
I purchased from R.A.M. some time ago the 1999 edition of "The Brakedrum Windmill" original design by Hugh Piggott. Those folks included Hugh's Mathematical Model of the Brakedrum Alternator on the back page.

the spreadsheet is also available on their technical page at http://www.ramdesign.on.ca/windmill/tech_.htm

Now I have some questions on the formulas that I hope someone could help this old goat out on, if it is not too much trouble;

Feedback is always welcome, so I can improve what's on offer.

*1). Total power generated, in watts, your basic I*R.*

mistake. I*R is volt drop. V*I is power.

*The formula shows P = VBAT * I, shouldn't this be P = VALT * I ?*

No. VBAT is the actual voltage when the battery is connected. VALT is the 'open circuit voltage' which you only see when disconnected.

2). The determination on wire diameter, in mm. Does this formula work outside of the brakedrum alternator,

NO see, my 'assumptions':
1. I assume that the stator winding is 2.5mm thick, in a total gap of around 4mm.
This determines the available space for the wire, and hence the wire size you can use.

and what does "0.7" and "0.5" represent anyway? Are they constants?

yes. DWIRE = 0.7*(W/T)^0.5
All these formulae are rules of thumb using constants. 0.7 is a constant which works for this situation. (W/T)^0.5 is computer-speak for 'square root of' W/T.

3). Hugh assumes that the alternator is wound Star. How are the formulas affected when winding Delta?

if the coils are re-connect delta then the output voltage VALT will be reduced by a factor of 0.58 (=1/root3). Internal resistance R is reduced by a factor of 1/3.
VALT =N^2*L*W*T*RPM/260000000
R =(L+W)*N*T^2/W/26000
But star connection is marginally more efficient.

4). Are the alternator formulas affected by the type of magnets used?

Yes this assumes the use of ferrite magnets. The magnets need to be 20-25mm thick, and at least 32 mm wide.

My basic electronic theory says yes, however I am getting older and duller. What formula correction would be used for, say, Ceramic vs. Neodymium?

My researches have not reached the point where I can make a confident statement about that. Neos ought to give about 3 times the flux, but there are many factors.

5). When using these formulas to modify the alternator, at what speed formula-wise should I consider physically cutting out the alternator to keep from melting it into a blob at the base of the tower? This of course means electrically.

You need to look at the internal LOSS =I^2*RI and consider whether the temperature rise will be excessive. The answer will depend on how well cooled the stator is. There is no accurate formula which can tell you that a particular size of wire can carry a particular current in a winding.

If you keep the power output down, then the alternator will last for ever. If you thrash it, then the windings will fall off the laminations after a few years.

6). Now allow this old man one last question. Without going out to buy a Rosenberg ($90), or re-purchasing the more complete "Direct from Hugh Version" of the Brakedrum Alternator with the enclosed formuli, is there a place to download updated versions of these *and other alternator formulas? They seem to be no longer on the PicoTurbine web site as mentioned in my book.*

I am always <mailto:hugh@scoraigwind.co.uk>here to answer questions, and I endeavour to improve the design where I can. I have started a page a http://www.scoraigwind.co.uk/brakeupdate where I try to put helpful stuff. This message may well find its way onto that page later.

I did this design almost eight years ago now and of course I have had plenty of brand new ideas since then. The old brakedrum idea is not the be-all and end-all for me, by any means.

--
Hugh

Scoraig, Scotland
http://www.scoraigwind.co.uk

To: "James L. Jacobs" <grannie613@juno.com>, awea-wind-home@yahoogroups.com
From: hugh piggotthugh@scoraigwind.co.uk
Date: Mon, 19 Feb 2001 18:00:48 +0000
Subject: Re: [a-w-h] Brakedrum alternator

At 5:41 am -0800 19/2/01, James L. Jacobs wrote:
>After buying Hugh Piggott's "Brakedrum Windmill Plans" a week ago I
>decided to visit the local pull-it-yourself auto junkyard to check
>availability and price of the Ford 3/4 ton rear end. I was dismayed at
>the price: Ecology recycling in San Diego, Calif. wants $175 !

You could get a lower price if the differential gearbox is beyond repair.

> The shape
>on these brakedrum varies significantly from the drawings; the hub
>containing the bearing extends ~4 inches out from the flat area on the
>drum where the wheel lug nuts are located. This feature will make it
>difficult to attach the prop assembly.

It is possible to use either of two 'fixes' for this problem. Either bolt the rotor direct onto the end of the bearing hub, or build it around the hub. Both of these have been done successfully. If the rotor is very large then it may not sit comfortably on the end of the hub and a piece of steel plate can be used to extend the bearing surface into a larger flange.

>
> But I did not give up.

That's what it's all about. Real life throws up challenges like this. For fuller details of the north american version of the alternator, contact Robert Budd in Ontario http://www.windmill.on.ca

> I noticed that while most vehicles had front disc
>brakes there were still a few with front drum brakes. Some of the drums
>were quite large and would seem to be appropiate for the task. The price
>of drum+spindle is $54....certainly easier to remove and more affordable.
>
>Has anyone used one of the front drum/spindles to build the alternator?

I see no reason why a front hub should not be suitable so long as the brakedrum is deep. It's hard to find them though.
--
Hugh

Laminations

At 2:48 am +0000 4/5/01, gbrecke@yahoo.com wrote:
>I finally broke down and ordered the N.A. version of Hugh's brake
>drum mill. I have all the bits except the proper sized laminations.
>The closest I've found so far is 9 1/4 inch diameter.

Lams are often a problem, it seems. I have never built one of the North American version yet. Robert Budd is the man. The magnets for this version are now available from wondermagnet.com

I found out recently that the north american version has a problem with inadequate space for magnets if the drum is exactly 12 inch internal diameter. The drum actually needs to be skimmed out on a lathe to accept 16 magnets if they are really full 2 inches wide (50mm is OK). Skimming out brake-drums is a very standard operation which should not cost much to do (and may have already been done if you have an old one).

> The local scrap
>dealer and two rewind shops have been very enthusiastic and have
>actually volunteered to pile up motor cores for my return visit. As
>soon as you tell them you're attempting to build a motor out of a
>brake drum, they seem to become interested and helpful.

fun, isn't it :-)

>
>I want to point out that I have only looked at about twenty-five 3
>phase motors so far, so it's not that I can say I'm having a
>hard
>time finding the proper laminations. But I really am curious to know
>how others are making out? I also saved this 9 ? inch set of lams
>just in case I don't find the 9 ? inch set.

Ideally you want 9.5/8 or even 9.3/4 inch lam diameter for that. A smaller lam gives you more room for maneouvre with the airgap though and even more room for a heavier winding if you want to. There is some loss from having too small lams but you can still get a result. 9.1/4 seems very small. One idea to improve that would be to glue steel pole pieces onto the magnet faces, which would narrow the gap. Or you can take a 10 inch lam and skim it down. Try not to short circuit the lams to each other.

I have put some useful extra ideas about the brakedrum building process on http://www.scoraigwind.co.uk/brakeupdate

>
>After spending some time reading various threads, I see that there
>are a few individuals that have mentioned making their own
>laminations. This has caused me to think of ways to produce such a
>thing in small numbers. The other day, I visited a good friend who

>specializes in water jet cutting. He explained that cutting a stack
>of laminations would be no problem for a water jet cutting machine.
>If you are not familiar with this technology, small garnets are
>injected into the water stream and do the actual cutting.
>
>There are several potential benefits to this method of forming
>laminations, small batches are possible, and Unlike a punch die, you
>can change the CNC program to improve your design if necessary.
>Since the cutting is done under water, there is no heat distortion.
>As I see it, the water cut laminate might even look better than a
>part off a punch press?

sounds good but how much does it cost??

>
>If moderate amounts of laminations were to be created, a large stack
>of sheet metal could be inserted in the tank, and the CNC program
>could cookie cut rows and columns of same.
>
>Hmmm, I wonder how much interest there would be in a set of custom
>laminations for the brake drum machines?

Incidentally there are a couple of things to watch out for when using old lams. Beware of rivets near the edge which can short circuit the lams and create eddy currents. They act like coils but the current flow within the lams and not the copper. Remove any such rivets or straps, and clamp the lams using bolts through the slots. Another thing to watch for is slots or flats on the circumference. Fill these with resin loaded with iron filings to get the best results.

I am always here to offer help where I can.
--
Hugh

Scoraig, in Scotland.
http://www.scoraigwind.co.uk

======================

At 02:21 PM 5/11/02 -0700, Daniel Day wrote:
>Hello all,
>
>First of all, many thanks to Hugh, John, Randy, Joseph and
>Larry for their answers on- and off-list to my question last
>weekend.
>
>I fot a scrapped motor and cut open the case in order to get
>out the core. In cutting open the case, I messed up big
>time: not realizing the core is just inside the case, I cut
>into the core, and thus the laminations are now shorted to
>each other by the cutting slag. Thus, question 1: Can this
>core be saved?
>Assuming it can be saved by (I assume) just detaching the
>laminations from each other, filing off the slag and
>re-stacking the laminations, I would also like to ask the
>best solvent for removing the motor windings from the inside
>of the core.
>
>The core is about 10-1/4" in diameter. It looks like a brake
>drum with a 12" ID will be about the right size.

>
>Dan Day
>Corbett, OR

Dan,
I don't think you need to worry about what you have done to the core. There is always some electrical connection between the laminates in a core. Just file or grind off the slag.
As for a slovent for removing the windings, I suggest elbow grease.:) What I do is use a band saw to cut thru the copper near the laminates on one side and then pry the turns out the other side with a screw driver or some other prying device.

Jim Hannon
================

Hi Dan,

Just a my two cents here.

You only really have to remove the outside welds that hold the lams together. It was strange when I first saw them too but, thats how the big motor lams are held together. That's why the lams are "shorted." It is not the power loss that's a big deal. The problem is when you glue your coils over those welds, the welds will act like shorted coils and make heat and melt the glue. Just grind them out and don't worry about it.

This part is NOT recommended but included for those that want to take the lams apart;
{
I took my lams apart and cut them down with tin snips so it would fit. It wasn't half as bad as it sounds.
Came out pretty good and round. The problem I had was when I tried to glue it all back together. The wet epoxy is like oil, slipping and sliding around. Then when I finally got it where I could clamp it, I couldn't clamp it perfectly flat. It has little vallies where the clamps were and hills where they weren't. Next time I'll glue about 6mm(1/4") at a time and glue those pieces together. Bottom line: Don't take it apart, Unless you just can't resist. I wanted to pratice so I could try to make a stator with slots and compare the performance difference.
}

Another thing I found out was: You don't have to glue the magnets in right away. You can wait until you've completed the stator. Just in case you need some more clearence. Grinding the magnets should be avoided but, it is much, much easier to do with out them glued in! Plus in case you change your mind, after hand testing, you can get your magnets back.

Thanks RonD

Rectifiers (diodes)

From: "Jack Crain" <crainknives@hotmail.com>
To: hugh@scoraigwind.co.uk
Subject: Re: more info
Date: Fri, 21 Sep 2001 17:41:31 -0500

> Hi ,
>
> I just got the Brakedrum Windmill Plans ....That is what I was writing aboutÝ.. The rectifiers spoken of on page 17 and are not in the list of parts...

Ooops. Nobody has pointed that out before that I can remember

> Are all rectifiers the same ....can you putÝany rectifiersÝany sizeÝany voltage on this windmill?

The rectifier(s) have to be able to handle the full output current. I normally use 2 'single phase' rectifiers. If you expect (say) 20 amps output then you would want at least 15 amps rating on the rectifiers but they are cheap so it is worth over-rating them. You can parallel them to get more current if you cannot find a high enough current rating. Voltage ratings usually start at about 100 volts and this is sufficient.

> The Plans do not say or explain how it is hooked up .Last paragraph on page 17 says .connect the + side of the battery to one side "of the rectifier?" and connect the -of the same battery (to the other side of the rectifier?"

There is a diagram on page 18 which I thought was quite clear.

> ....yes I guess the rectifier would get hot. This is not real clear , is that correct, I am trying how about a little help before I buy another set of plans.

It does get warm. It is normal practice to put it on a heatsink to prevent overheating which would occur if it was not cooled in any way.

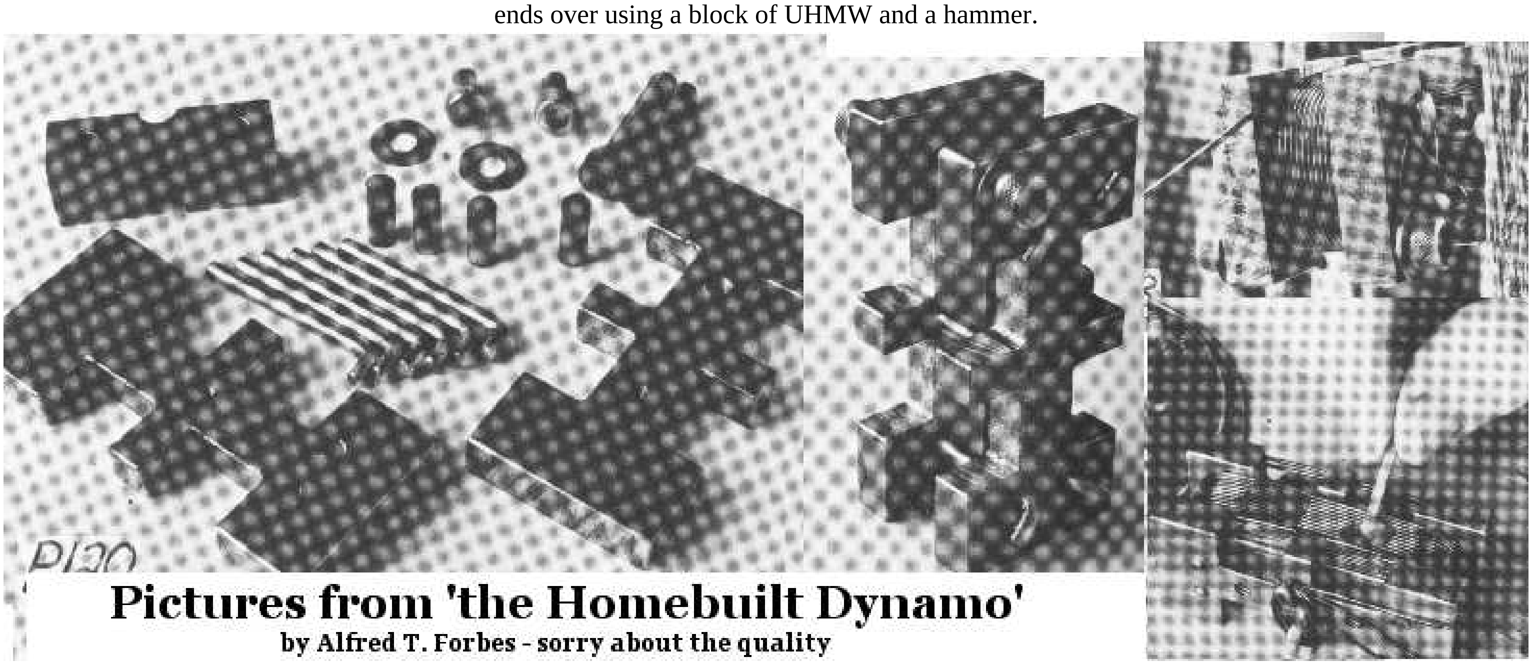
This is what they usually look like-

Fitting coils to the stator laminations - another way to go about it.

Here is a stator wound by Thomas Moar <thomasmoar@xtra.co.nz>. He sets the coils in resin as he winds them and shapes them to fit so that they can be fitted to the stator as shown. Every second coil is bent down, and the others lie on top, so the connections will be different from those where you glue the coils in piles of three at a time. See page 16 diagram 9 you should use the bottom diagram (second example) and not the first example.

Thomas moar wrote:

My coil winding jig is similar to the one shown in " The Homebuilt Dynamo" except that I used Aluminum alloy for the side plates. I found that a few drops of unthickened resin applied to the windings would find its way completely round the coil thus giving a rigid coil after the resin has cured,also it does not adhere to the alloy when fully cured. I made up a jig to bend the ends of the first 15 coils over, I used UHMW plastic for this to avoid damaging the enamel. After clamping this in my bench vise I tapped the ends over using a block of UHMW and a hammer.



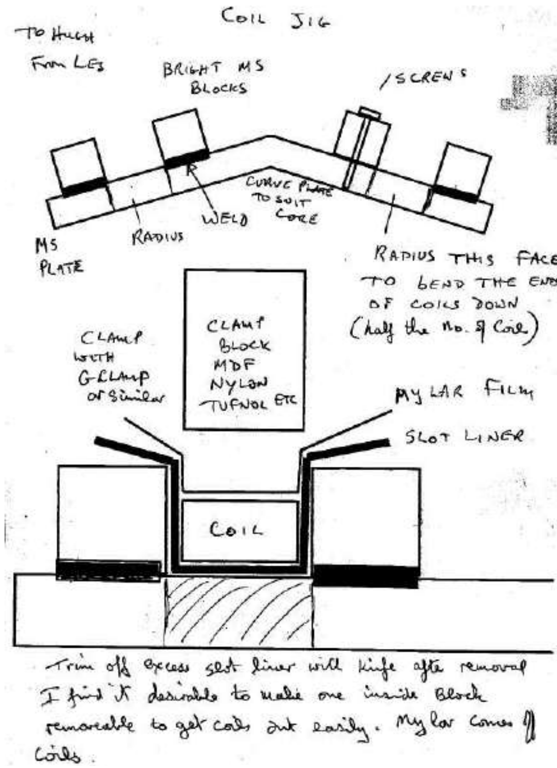
Pictures from 'the Homebuilt Dynamo'
by Alfred T. Forbes - sorry about the quality

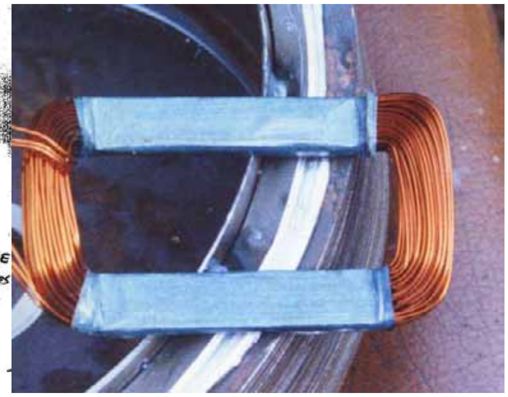
Thomas uses 20 neodymium magnets for his brakedrum rotor.

"The Neodymium magnets I used are 46mm x 30mm x 10mm. I got them from MAGNA Co. Ltd. JAPAN. I paid $100. Thier Email address is. sales@magna-tokyo.com"

From: "thomas moar" <thomasmoar@xtra.co.nz>
To: "hugh piggott" hugh@scoraigwind.co.uk
Subject: Re: Neo alternator tests
Date: Sat, 10 Nov 2001 13:38:07 +1300
Thanks Hugh,
I happened to have a 1000watt Radiator rod, This is a round ceramic rod overwound with resistance wire.
After connecting this to the DC output I got the following results.
At 55rpm = 26v DC. 157rpm = 75v DC. 172rpm = 81v DC. 212rpm = 97v DC. 282rpm = 132v DC. 471rpm = 214v DC. At this point the Radiator rod is red hot so I guess that I have pretty close to 1000watts.
With my test set up I am able to put my finger on the coils of the alternator, after a few minutes I can feel no heating, Maybe I should let it run longer? Thomas.

Les Vincent <les@vincent7288.freeserve.co.uk> has built a very nice machine using very similar techniques of his own. He first sets the legs of the coils in epoxy resin using a former which presses them into the right shape:



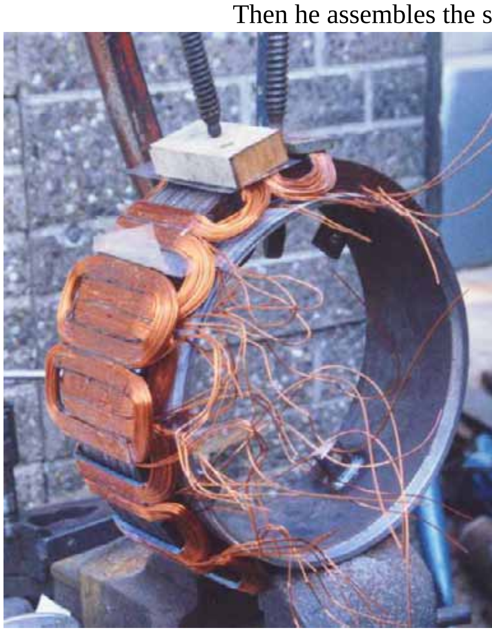


Les writes: "The blue stuff round the coil is a cheap slot liner material, elephantide with a polyester layer bonded on. I just have lots of it. The ideal material would be un callendared nomex but could be difficult to get in small quantities. Ordinary Nomex would do, from R.S. but is stiff to work.

The elephantide is only a class E (120 degree) insulation, but I used the SP wood glue that you use and I have no idea of it's temperature limits. I wouldn't trust it above 100 degrees.

"I wind the coils on a simple split former as you do. I then clamp them inÝanother former and set them in resin. The slot liner material acts as the release agent and provides the insulation from the core and also interphase."

Then he assembles the stator in the same general way as Thomas:




The 20 magnets Les used are also neodymium ones, with a rather unsuitable curve on them, but they are nicely fitted to the rotor by painstaking machining.

This 20 pole machine can produce over 1kW at 320 rpm with approximately 70% efficiency.

Hello Hugh,

This is Michael O'Brien in Australia.

Hi. Is it OK to put your message and my replies onto my web page http://www.scoraigwind.co.uk/brakeupdate ?

I recently purchased your book, Brakedrum Windmill Plans and have been reading it with interest. Thank you for writing it and making it available.

It was a pleasure.

If it's okay, I'd like to ask you a few questions please...

1. How did you attach the laminated core inside the brakedrum? (Unless I missed it, it doesn't seem to be covered in your book.)

check the web page above for more detail. I agree it is poorly covered.

2. You made your design to be most efficient in low winds, but your book talks about your site being so windy that other wind turbines have failed. This is a bit confusing. What is the normal wind speed in your area?

Average windspeed is about 6m/s (13mph). We get some very high winds, but at those times the batteries are usually full. What matters to me is to get good power output in low winds so that the power supply is more consistent. And to survive the gales. In high winds it is easy to get plenty of power at low efficiency, but in low winds there is very little to be had so that is when the machine needs to be very efficient.

3. How can I relate the RPM to the wind speed? (Eg. You say it cuts in at 200rpm with 24v, but how much wind does it take to reach 200rpm?)

The rotor tip speed ratio is designed to be around 6, I think. But at cut-in it will be unloaded and therefore run at a higher speed say 7.5. To work out the windspeed at which it can do 200 rpm, first work out the tip speed at 200 rpm and then divide by 7.5 (or so).

Tip speed is 200/60 revs per sec x 2.1 x 3.14 metres per rev = 22m/sec cut in speed will therefor be about 22/7.5 = 3 metres per second wind.

Finally, and this may be the most difficult to answer... I'm also trying to design and build an alternative style wind turbine: One with vertical wings rotating around a vertical axis. From what I've read, this will rotate faster than other types - with the potential to produce more power from the same amount of wind.

there is a lot written about vertical axis but they are not so successful in reality. There are serious fatigue problems and the performance is not that great. I do not recommend this approach.

Once I have tested the design to determine its normal rpm for our wind conditions, how do I translate that into a suitable alternator design?...
Is it best to find as big an electric motor as I can find - and a brakedrum to suite - or just wire the one you suggest for your turbine differently?

a bigger one will give more power at lower speed.

Thank you very much for your help.

Kind regards,

Michael O'Brien
(Tasmania, Australia)

you are welcome.

Tail furling system

To: ilcarrascosa@fatronik.com

From: hugh piggott hugh@scoraigwind.co.uk
Subject: Re: Last question

At 11:38 pm +0200 7/4/02, ilcarrascosa wrote:
Thanks for your answer,Mr Piggott.

Anyway, I understand yet the movement and the angles of the tail vane and boom (15º to allow the vane go up in a cone-way, and 45º to allow the vane to turn 90º). But I still not understand how the lift and the weight could be balanced. I mean that the tail-vane weight is a vertical force, and the lift and the thrust are horizontal, doesn´t they?

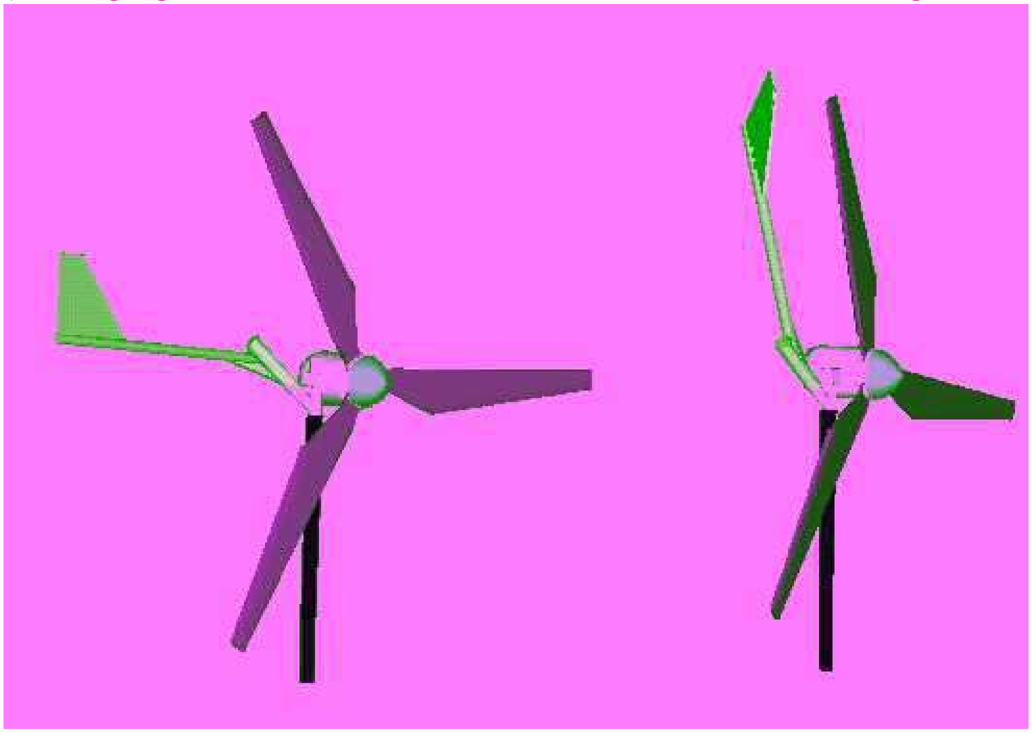
If you have a cart on a ramp you can use a horizontal force to push it up the ramp. It moves vertically. The weight of the cart will oppose the movement. When you stop pushing, the cart will run down, and move you horizontally if it has to.

From: "ilcarrascosa" <ilcarrascosa@fatronik.com>
To: hugh@scoraigwind.co.uk
Subject: Thanks

Hello again Mr Piggott.

I decided to draw the machanism on 3D to understand on the space the movement of the tail-vane, and finally I've seen right that the the relative turning around the axis wich conects the boom and the rotor is the main reason (this 15º).ÝWhen I saw on your book I couldn't imagine exactly how could the tail-vane get upwards, but once drawed and gived movement to the mechanism I've understand.

I send you two drawings of the mechanism. This is only a basic scheme, and the tail, tower and nacelle dimensions are not the right ones (now I'm going to start with the calculations of the real dimensions, and also thinking on re-designing the furling mechanism).

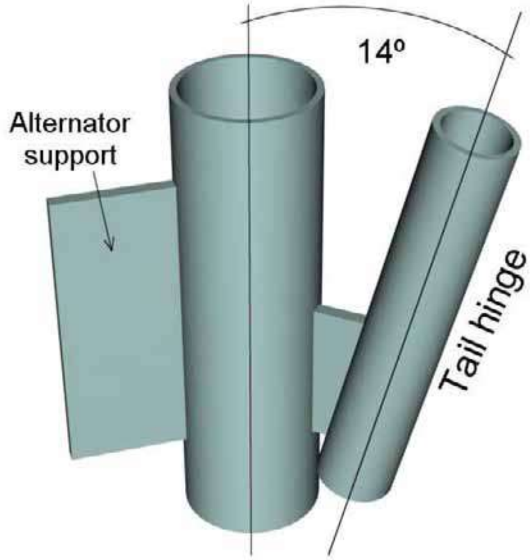


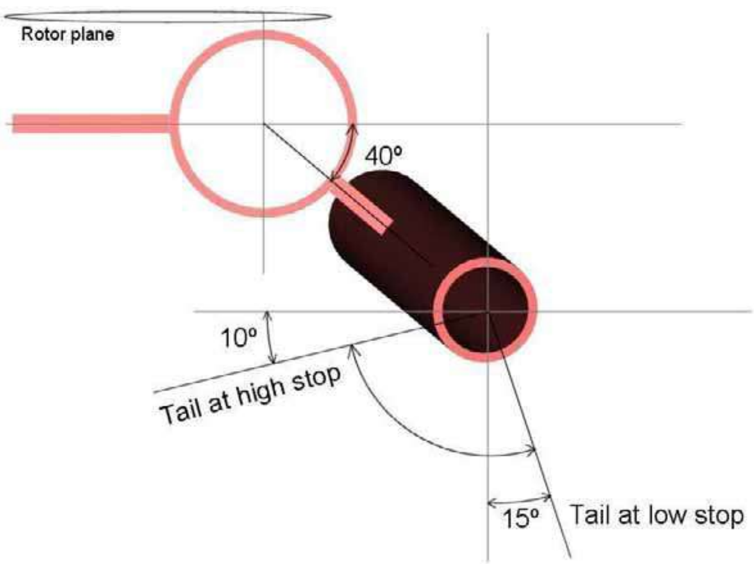
It goes without saying that if anytime you need help with drawings or something else, please tell me and I will be very proud to help you.

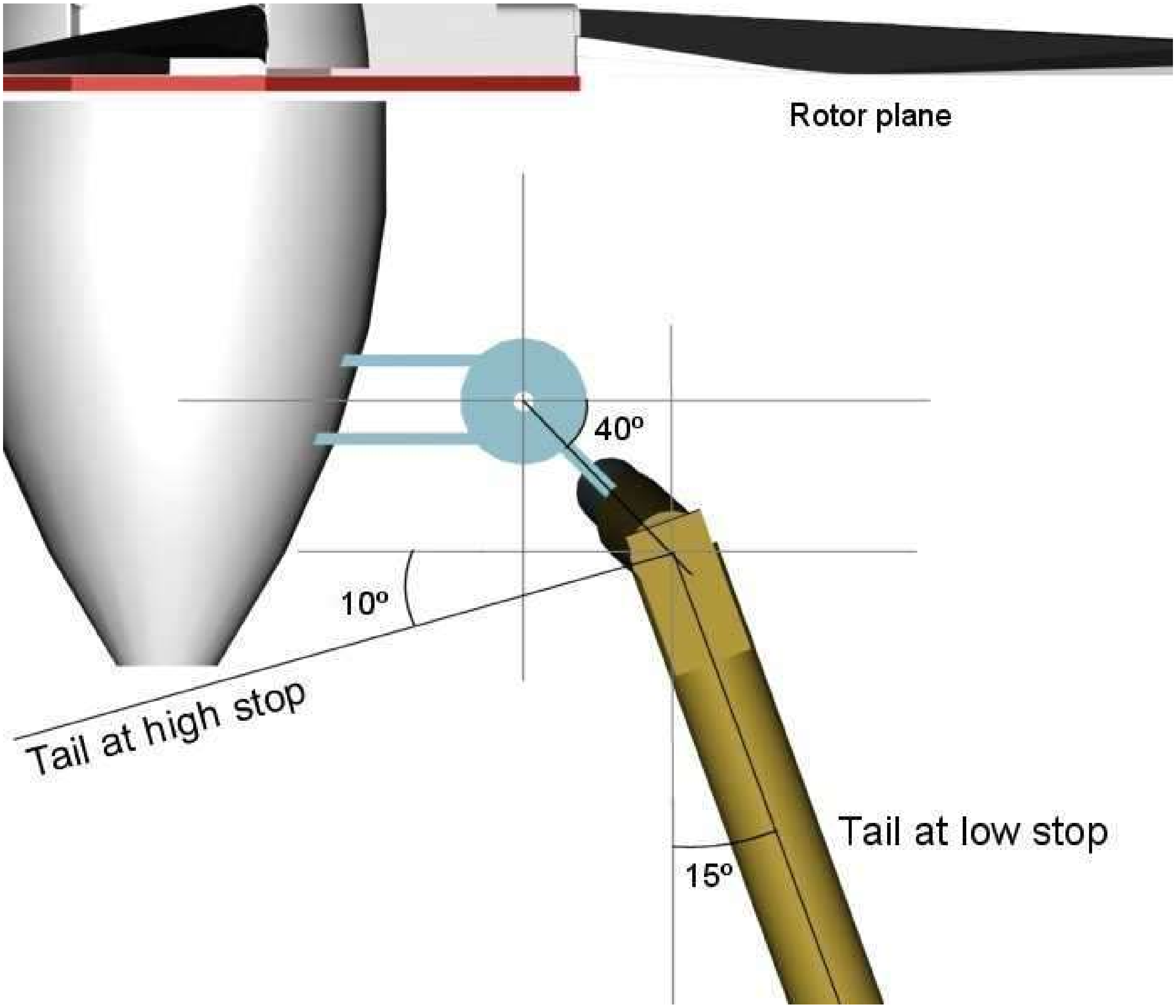
Best regards, Mr Piggott.

NOTE: The vane on the above windmill seems to be at a funny angle - I would expect it to appear to the left of the boom, in the right hand drawing above. - HUGH

"José Galán" <eng@bornay.com> or 'pepe' has also made some nice drawings of the tail furling system (see below). Note that the angle is different from the ones published in the plans. This will work just the same, but you need a heavier tail. I now prefer hinge angles about 18 degrees. The angle in these drawings is 14 degrees off vertical.


14º
Alternator support
Tail hinge


Rotor plane
40º
10º
Tail at high stop
15º
Tail at low stop



From: "josephturrisi" <jturrisi@hotmail.com>
Mailing-List: list awea-wind-home@yahoogroups.com; contact awea-wind-home-owner@yahoogroups.com
Date: Sun, 05 May 2002 03:25:49 -0000
Subject: [a-w-h] Re: Axle bearings in brake drum

The best way to find out if the bearings are full floating is to look at the axle. If it is a full floating design you will be able to remove the axle from the rear end housing without taking the wheel off. The most common axle of this design in the USA is the Dana 60. It can be found in most 1 ton pickups and some 3/4 ton pickups. Again you will be able to remove the axle shaft from the housing without having to take off the wheel. These axles also have a 8 lug bolt pattern that holds the wheel/tire on.

--- In awea-wind-home@y..., Daniel Day <gamshara@T...> wrote:
> Hello all,
> I have a question for Hugh Piggott and the mechanics in the
> list about Hugh's specification of the type of support
> between the drum and axle in his brakedrum windmill plans:
>
> 'You need "fully floating" bearings on the hub, i.e. the hub
> must be supported by two bearing races, even after the half

> shaft is removed.'
>
> Is there a way to find out if the bearings are fully
> floating aside from cold-calling auto mechanics (I hate to
> be a pest) or looking the truck model up in auto-repair
> books in the library (I did, but no books had this
> information)? Also, if the brake drum is large and
> bell-shaped, rather than cylindrical, and is mounted on a
> pickup truck, can we assume that the bearings are this type?
>
> I found a large brake drum on a Chevy Scottsdale at a local
> junkyard. The OD was over 14" and the length of the exterior
> at the largest-diameter portion of the drum, corresponding
> to the section where the brake pads are applied inside the
> drum, was about 4". As long as the bearings are the right
> configuration, this drum looks like a good prospect.
>
> Can anyone give any pointers here? Thanks much in advance.
>
> Dan Day
> Corbett, Oregon

More pictures of the job in progress (click here)
Build your own windmill courses in 2001
contact me at hugh@scoraigwind.co.uk

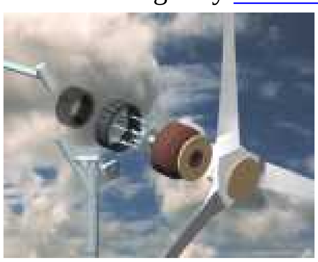
Plans for building wind turbines from brakedrums are now available in 2 flavours:
UK and "North American"

 --- 

The UK version is available from me and also from Picoturbine in the USA

It includes information suitable for North american readers. This page is to clarify the differences and similarities

The "N American" version is taught by Robert Budd at workshops in Ontario.



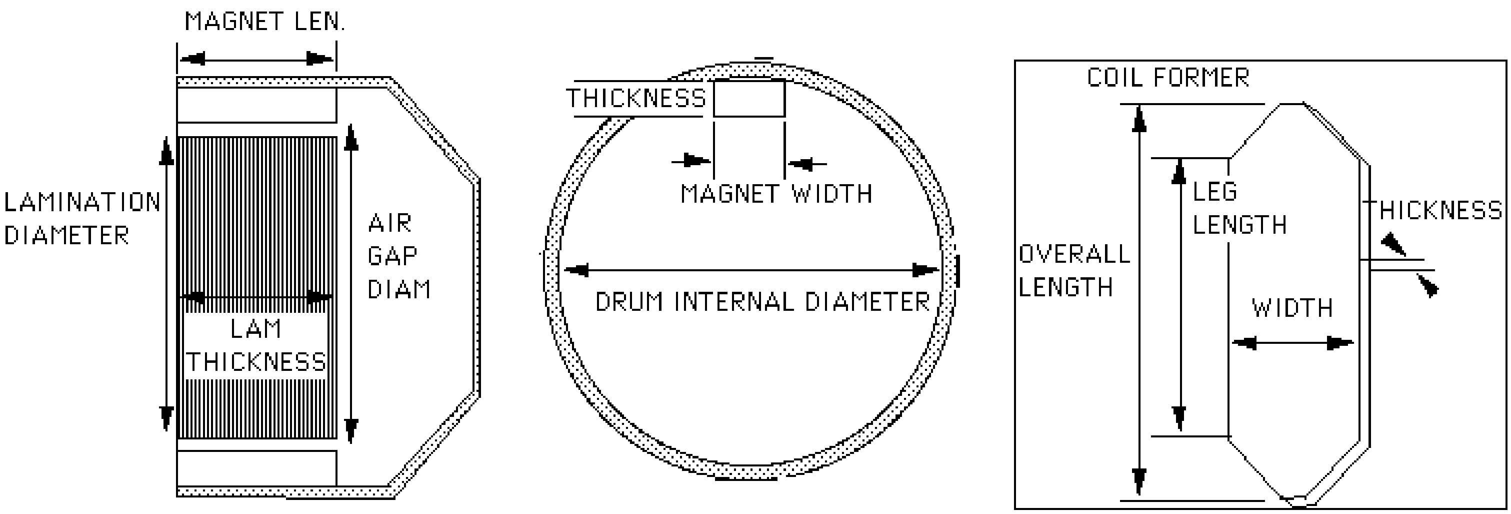
and is based on the UK plans, modified for a larger brakedrum.

Here are some basic dimensions for the two versions.

There are diagrams below to help you identify what the dimensions mean.

	UK version	N. American	
Vehicle	Transit van	Ford 3/4 ton truck	
	(long wheelbase)	E or F 250 or 350	
Internal diameter	254mm [10"]	306mm [12"]	
number of magnets	20	16	
Magnet length	64mm [2.5"]	76mm [3"]	
width	32mm [1.25"]	51mm [2"]	
thickness	20mm [3/4"]	25mm [1"]	
Air gap diameter	212mm [8 5/16"]	251mm [9 7/8"]	
lamination diameter	204mm [8"]	245mm [9 5/8"]	
thickness	64mm [2.5"]	76mm [3""]	
Coil former leg length	76mm [3"]	76mm [3"]	

overall length	96mm [3.75"]	90mm [3.5"]	
width	22mm [7/8"]	33mm [1 9/32"]	
thickness	2.5mm [3/32"]	2.5mm [3/32"]	
no. coils/ phase & total	10 & 30	8 & 24	
Wire size	0.8mm diameter	0.7mm diameter	
	20awg	21	
wire turns per coil	24	36	
nominal voltage delta	12V	12V	
star	24V	36V	



There are also two different designs for the blades. The "N American" blades are larger.

HOME

WHERE TO GET PERMANENT MAGNETS

FOR THE BRAKEDRUM DESIGN, YOU NEED FERRITE MAGNET, CERAMIC OR SINTERED - NOT BONDED - GRADE 3 (OR 8 WILL DO). IF YOU CANNOT FIND THE EXACT CORRECT SIZE, ASK THEM TO CUT THEM, OR BUY SEVERAL AND STACK THEM.

NEODYMIUM MAGNETS (NdFeB) ARE LIGHTER AND MORE POWERFUL AND CAN BE USED INSTEAD, BUT YOU WILL HAVE TO CONTACT ME PERSONALLY FOR HELP WITH CHOOSING A SIZE TO TRY.

IN THE UK TRY CERMAG 0114 244 6136 AND ASK FOR DEREK FOX

OR TRY SHAWS

Mail order magnets from Tokyo at **Magna** These guys are very efficient.

THERE IS A HUGE AMOUNT OF INFORMATION ON THE WEB ABOUT MAGNETS! I HAVE ONLY SPENT A SHORT TIME EXPLORING TO GET THE LIST BELOW.

HERE IS A SITE WITH LOADS OF LINKS (IF IT STILL EXISTS FOR YOU)

MAGNETWEB HAS DIRECTORIES OF SUPPLIERS (INCOMPLETE), AND LOADS OF OTHER USEFUL STUFF. THE DESIGN PAGES ARE PRETTY MATHEMATICAL.

GOOD JAPANSE SOURCE AT MAGNA

DOWNLOADABLE CATALOGUES IN PDF FORMAT

- HITACHI
- ARNOLDS
- BONDED MAGNETS
- MAGNET SALES

SANMU (CHINA)

USA
WONDERMAGNET HAVE LOADS OF CHEAP DEALS, MOSTLY IN NEODYMIUM- they also sell grade 8 ferrite blocks for my brakedrum design at $5 each (you need 20 pieces).

MAGNET SALES A VERY GOOD ALL ROUND GOOD SITE WITH A TOOLKIT OF DESIGN CALCULATION TOOLS ON-LINE.
BUNTING MAGNETICS OFFER PRICES AND SHOPPING CARTS ONLINE
DURAMAG HAVE GOOD ONLINE PRESENTATION TOO, AND WILL SUPPLY SMALL ORDERS
ARNOLD ALSO HAVE SOME NICE ON-LINE MATHEMATICAL MODELS YOU CAN USE IT PREDICT FLUX NEAR MAGNET BLOCKS.

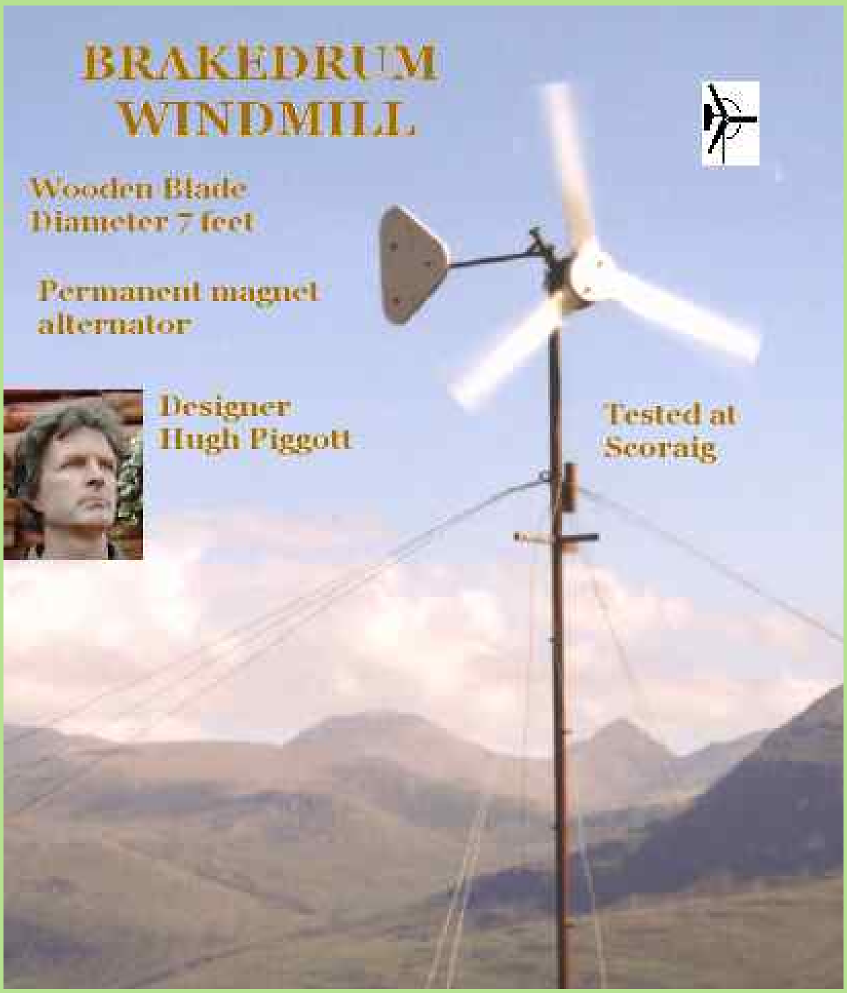
CHINESE MAGNETS
SANMU HAVE A GOOD DESIGN GUIDE PAGE
YUXIANG (GOOD SITE WITH DOCUMENTATION OF CHINESE GRADES)
CADEE
NINGBO
HUAKANG
I HAVE TO SAY I KNOW NOTHING ABOUT THE SITES ABOVE AND YOU USE THEM AT YOUR OWN RISK.

Brakedrum Windmill Course at Green Loops

May 2000

Green Loops invited me down to Liverpool from 24th - 26th May 2000,
to teach a course
for 15 people and to help them build a Brakedrum windmill, following my published plans.

<<<<   This page is still slowly under construction .>>>>



Plans are available in the USA from PicoTurbine

Click on these images below to load a larger picture in its own window.
These are digital pics I took in the available light and they may not show the technicalities very well,
but they may convey some of the atmosphere of enthusiasm.
Green Loops have a warehouse in central Liverpool with space and some tools.
We were working in there until ten pm each night.

Building wind turbines is not easy, and it takes time and care, which is what these guys had plenty of. I was surprised how far we got toward completion of the machine, and I look forward to news of further progress.

 .

Most of the time was taken up with hands-on work. The blade carving was the most popular task.

There is a description of the blade carving process for a similar blade here.

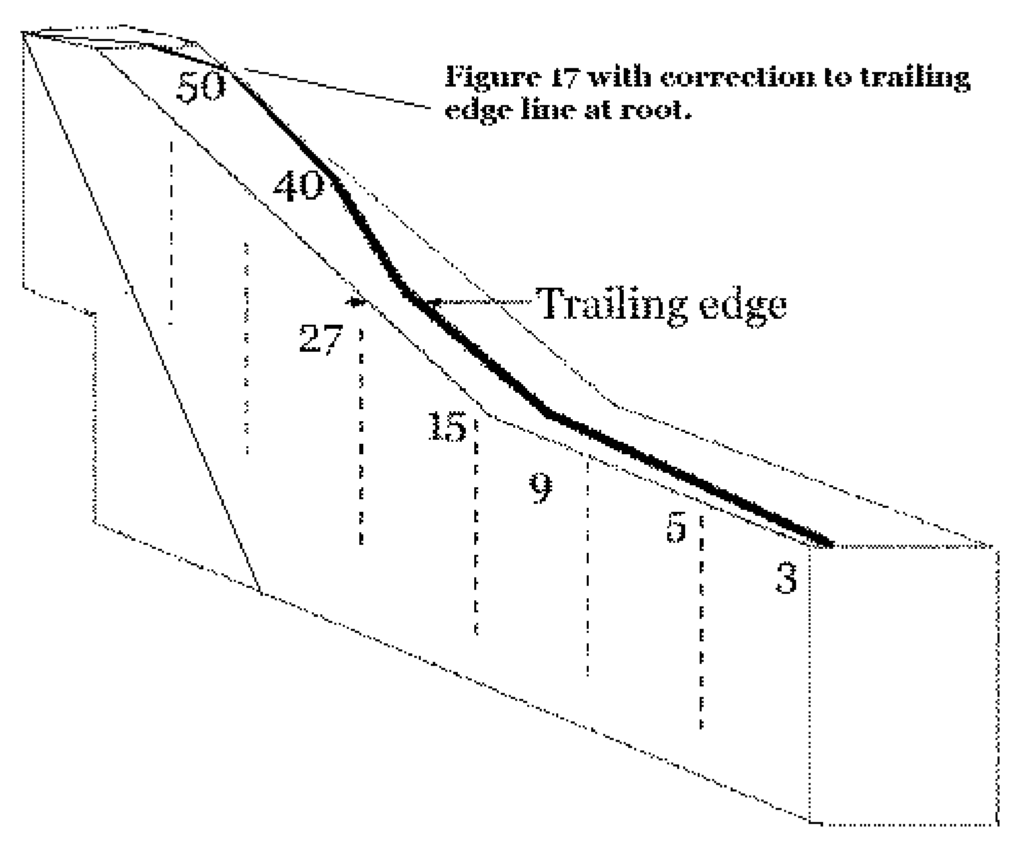
Greenloops had found some very nice lightweight hardwood - probably Meranti - which was tough to work, compared to pine, but came out beautifully. The grain was smooth and sleek. Beginners are slow at carving work, because they are too cautious to dig deep into the wood, so I had to be patient..

Clamping up pieces. the rotor blades are each made from two pieces of wood glued together. It is also quite possible to use a single piece of 6x2 timber. It pays to be adaptable, because you never know what you are going to find.

Putting a twist on the windward face (right). The next few shots are all taken during this process. The idea is to carve away all the wood above the leading and trailing edges, so that you can place a straight edge on the wood and it will (practically) touch both edges.

You can see the stator in the background.

Some people were puzzled by figure 17 which does not show the leading edge line exactly right. Here is an ammended version




Everyone has a go at it.


Blades turned over for thicknessing


tapering the trailing edge

.  and finishing the airfoil shape.

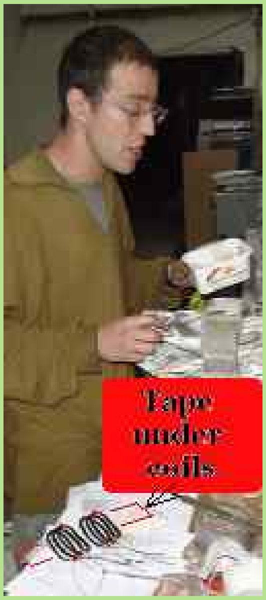
Winding the coils has a certain mesmerising quality too.

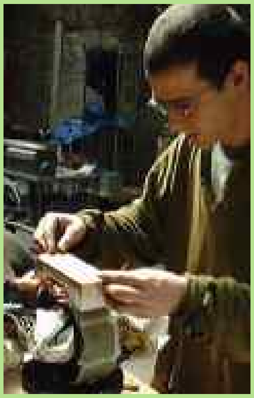
 . 

Balancing the coils on the
laminations can test the patience..

 .  .

Richie found out that a bit of masking tape helps.



.  . 

The coil clamping former was not perfectly flat so the stator is a little oversized.

 . 

 . .  . 

 . 

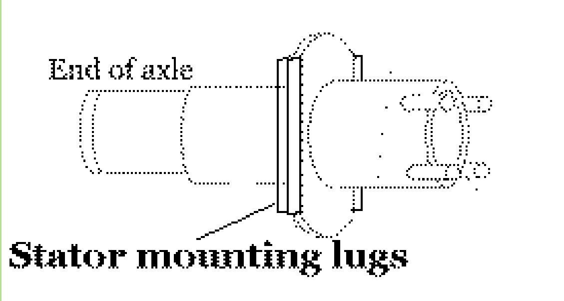
the shape of drum was slightly different from the standard

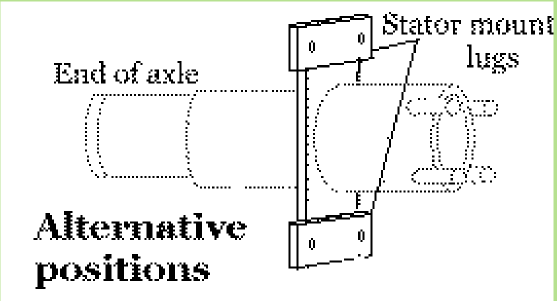
 in the plans

At greenloops they had a bearing stub in front of the brakedrum hub like this

but there was no problem with this. It just called for a slight modification to the rotor blade mounting bolt arrangement. We decided to unscrew the shaft studs, and then drill and tap 3 of the holes M12 to fit blade studs.

Depending on the internal size of the laminations it may be better to weld the stator mounting lugs on the side or the back of the brake plate, and not on the front as in figure 26 of the plans. In Liverpool we decided to put them on the sides.





It's important to be flexible. The plans cannot cover every possible mis-match of materials, and there will always be different ways to do things.

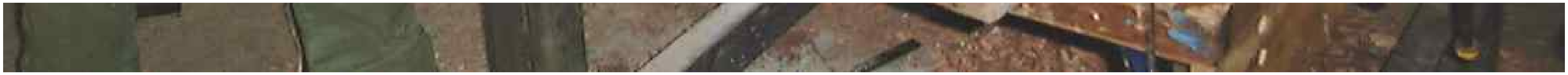
to be continued.. (?)

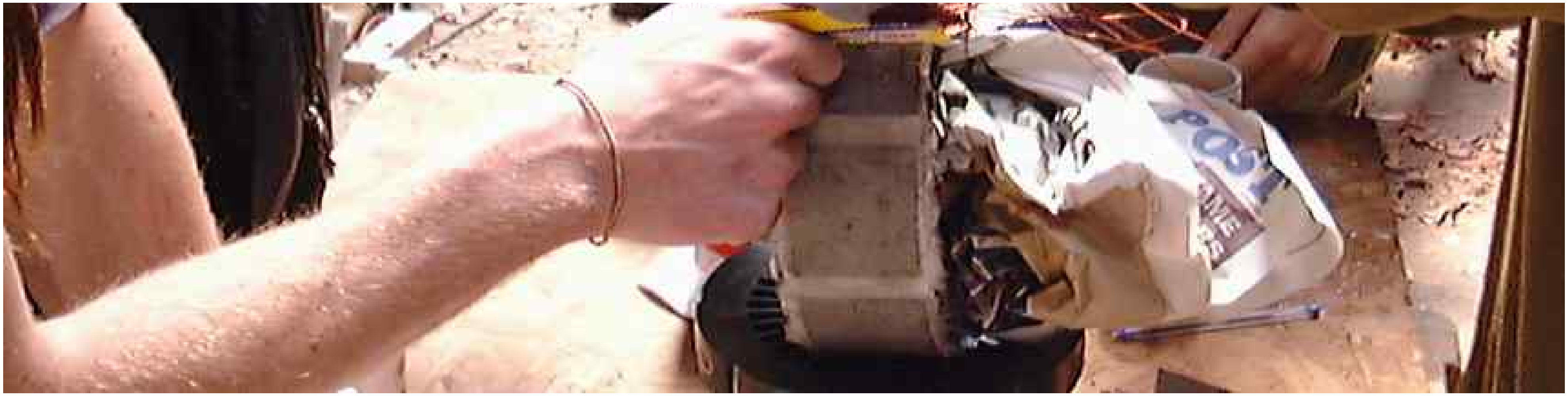

VEGGIE GRILL
STOP
THE BILL
RESISTANCE
IS
FERTILE


VEGGIE GRILL
STOP
THE BILL
RESISTANCE
IS
FERTILE

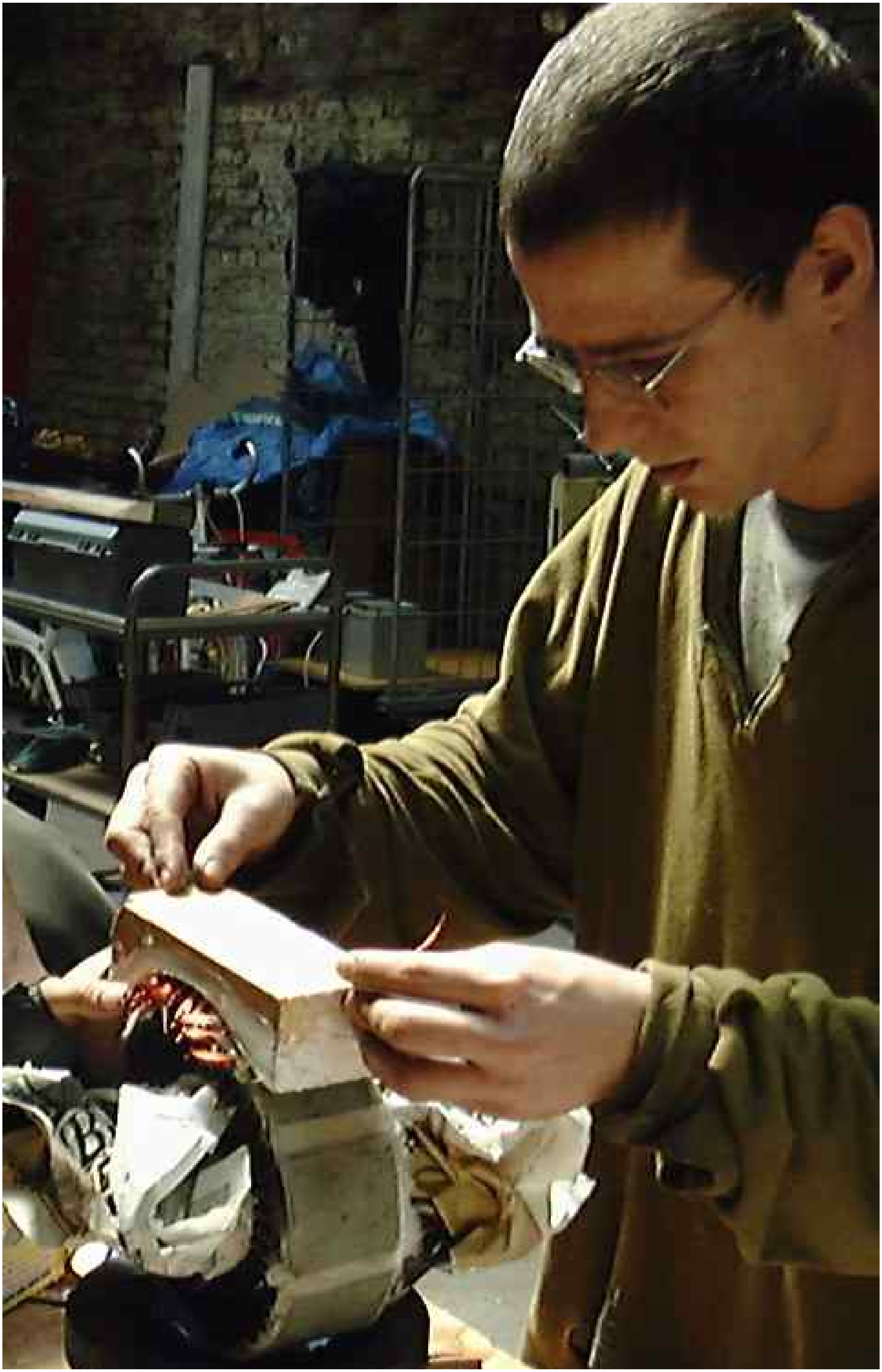

RESISTANCE
IS
FERTILE

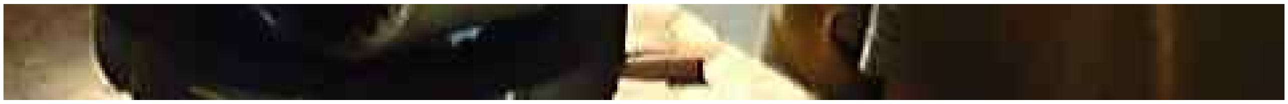

SCREAM






Sunflower



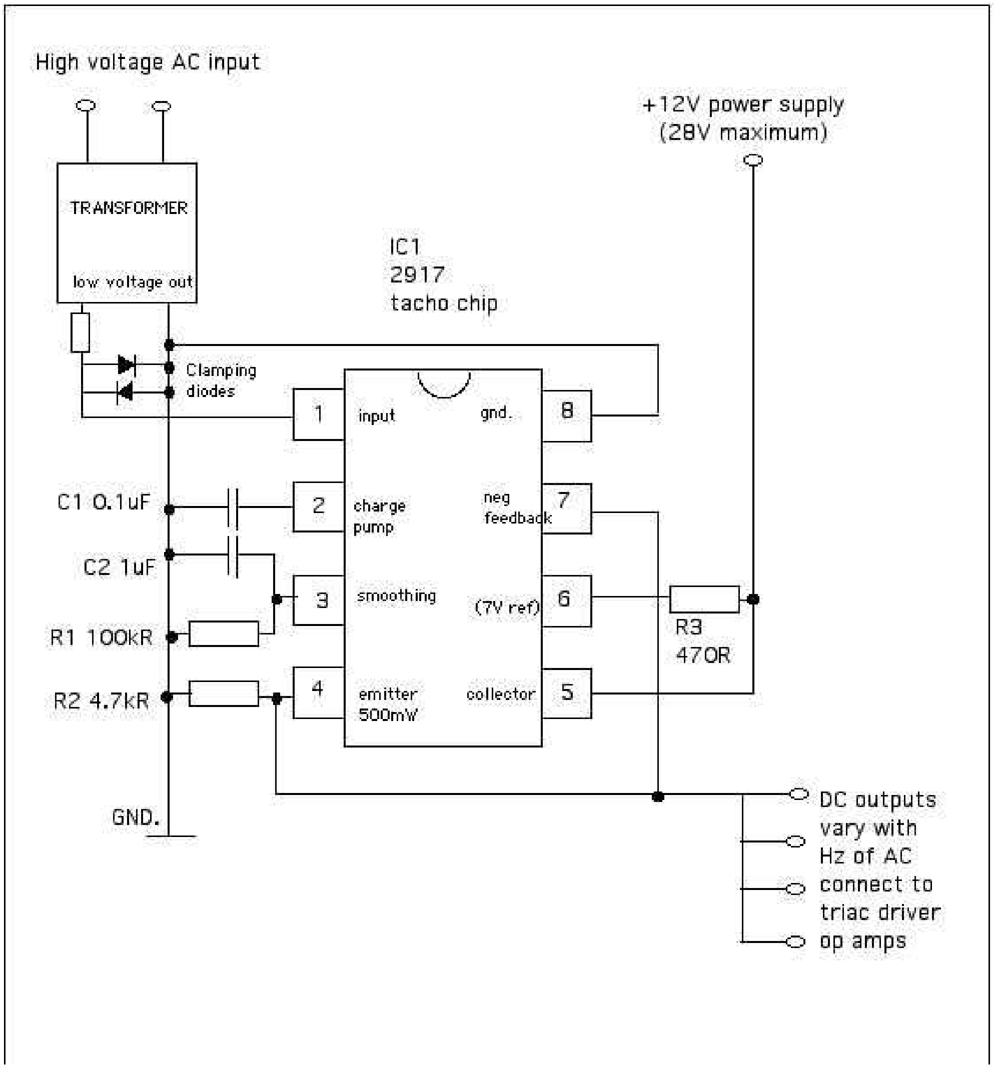


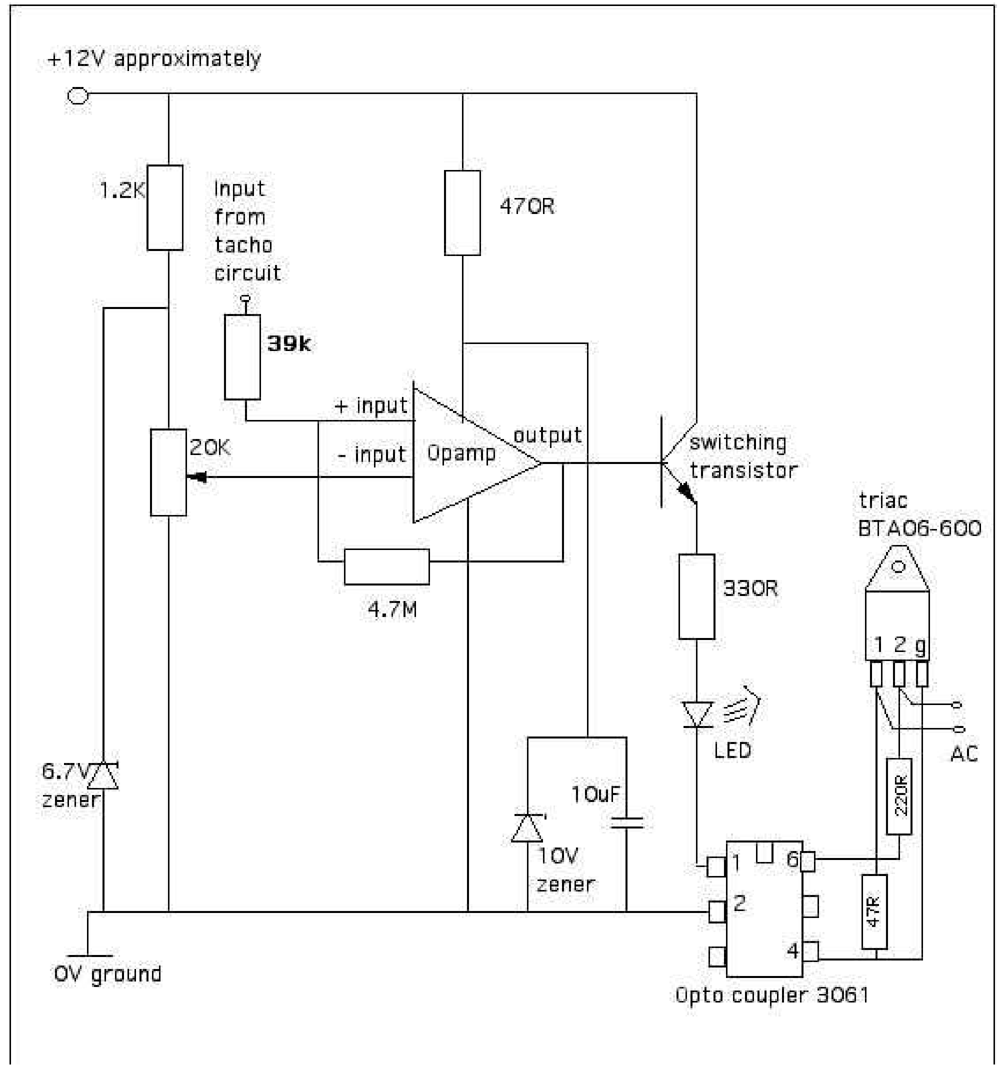

110
SELMAR

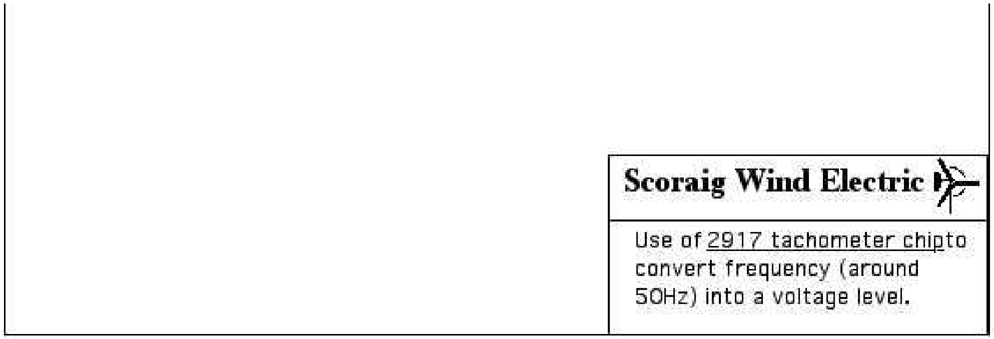
load control circuits

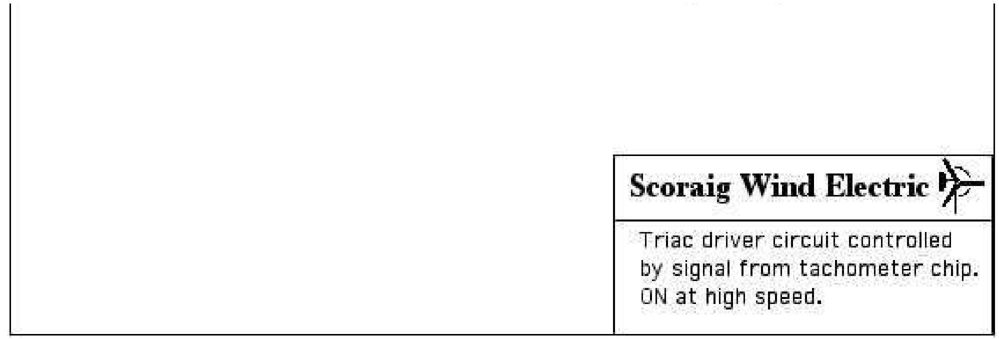
Here is a circuit for controlling heating loads on a wind turbine. It is intended for switching multiple small heating loads on and off. The circuit has various sections:

- A tachometer circuit which takes input from the AC from the wind turbine and converts t to a DC level which represents the rpm. see left hand diagram below.
- A number of Op-amp comparator circuits (can be one or two quad-op-amp chips) which compare this voltage (rpm indicator) to a reference and switch loads on at particular speeds. This circuit include feedback to increase its stability - it turns on at one rpm and then off at a lower one. This is achieved by a feedback resistor from the op-amp output to the positive input of the op-amp. Without this the load will switch on and off rapidly and cause some rumbling noises. The op-amp and an optocoupler circuit is shown below right.
- Finally you need the power circuitry which actually handles the loads. It is possible to switch the loads onto individual phases of the wind turbine using a single triac driven by an op-amp comparator (as shown). But this results in unbalanced loading and hence some vibration in the wind turbine. A better solution is to use two triacs for each comparator (connect their two opto couplers in series) and put them in two of the feeds to a 3 phase bridge rectifier. Each load runs on the output from its 3-phase bridge (on DC). This is not shown in the diagram.









X-Sender: hugh.piggott@enterprise.net
X-Apparently-To: awea-wind-home@yahoogroups.com
Date: Mon, 2 Jul 2001 07:45:24 +0100
Subject: Re: [a-w-h] load control circuitry

At 5:30 pm -0600 1/7/01, Laurie Forbes wrote:

>. what voltage range does the input xformer for the f/v circuit need
>to supply?

Hardly anything. The chip just has to smell the frequency.

>. at what voltage do the clamping diodes need to cut in?

these are ordinary IN4001 diodes. They clamp the voltage at about 0.7 volts peak.

>. what wattage are the resistors?

say 1/4 watt.

>
>. on the triac driver circuit, does the 20K pot govern the frequency
>at which the triac is fully "on" or something else?

it sets the frequency at which it switches on. This happens fully at once, not gradually. This circuit switches on fully at one frequency and then off fully at a slightly lower one.

>. what is the initial cut-in frequency for this circuit?

that's what you set with the 20k pot.

>. part numbers for the op amp and switching transistor?

op amp can be a 741. any old transistor.

>. what purpose does the LED serve?

indicates that the load is on.

>. above you mention each triac control circuit switches two triacs
>for each load but only a single triac is shown on the circuit?

put the two opto-couplers' inputs in series with the led. They are
leds too, so you then have 3 leds in series altogether.

>. does the triac simply connect in series between the gen phase and the load?

yes it is like an AC switch.

>. what is approximate current consumption of each circuit (@ 12 V)?

20mA? something like that.

X-Sender: hugh.piggott@enterprise.net
X-Apparently-To: awea-wind-home@yahoogroups.com
To: awea-wind-home@yahoogroups.com
Date: Tue, 3 Jul 2001 17:52:06 +0100
Subject: Re: [a-w-h] TACHOMETER CIRCUIT

>Hugh:
>
>Could you, please, give the complete value of the 2917 Tacho Chip

LM2917N from National Semiconductor (scottish nationalists? or not)

In the US you can get the 8 pin or 14 pin part from DigiKey

http://www.digikey.com/scripts/US/DKSUS.dll?Criteria?Ref=35036&Cat=18022921

> and who
>manufactures it.
>Same thing for the Opto Coupler 3061

MOC3061 triac driver optocoupler from Quality Technologies

there are many others which would do the job.

--
Hugh

http://www.ScoraigWind.co.uk

From: Laurie Forbes <lforbes@cadvision.com>
Date: Thu, 05 Jul 2001 20:11:47 -0600
Subject: [a-w-h] National Semi LM2917 Tacho chip

Had a look at National Semiconductor's web site and their 2917 tach chip (used in Hugh's load control circuit). It appears this chip is a combination tach *and* op/amp comparator + switching transistor which, with addition of a couple of resistors to Hugh's tach circuit, can be used to switch a relay etc. at a selectable input frequency thus apparently eliminating the requirement for a separate op/amp switching circuit (or so it appears to me). The chip also apparently has built-in hysteresis although that does not appear to be adjustable.

I wonder what's missing here - this solution is considerably simpler than two separate circuits but, may have disadvantages.

The URL for specs on this chip is:

http://www.national.com/ads-cgi/viewer.pl/ds/LM/LM2907.pdf

Laurie Forbes

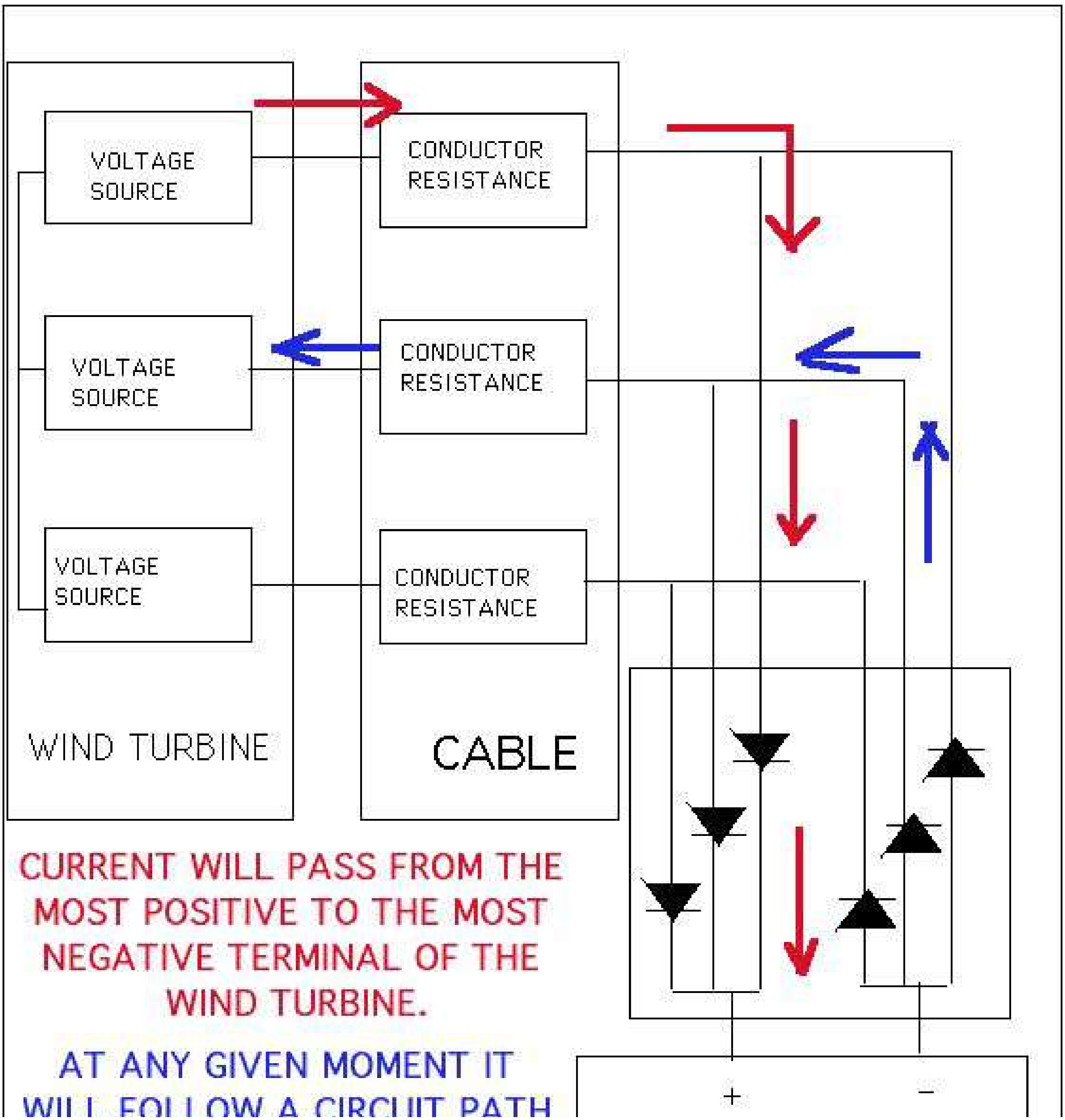
============================

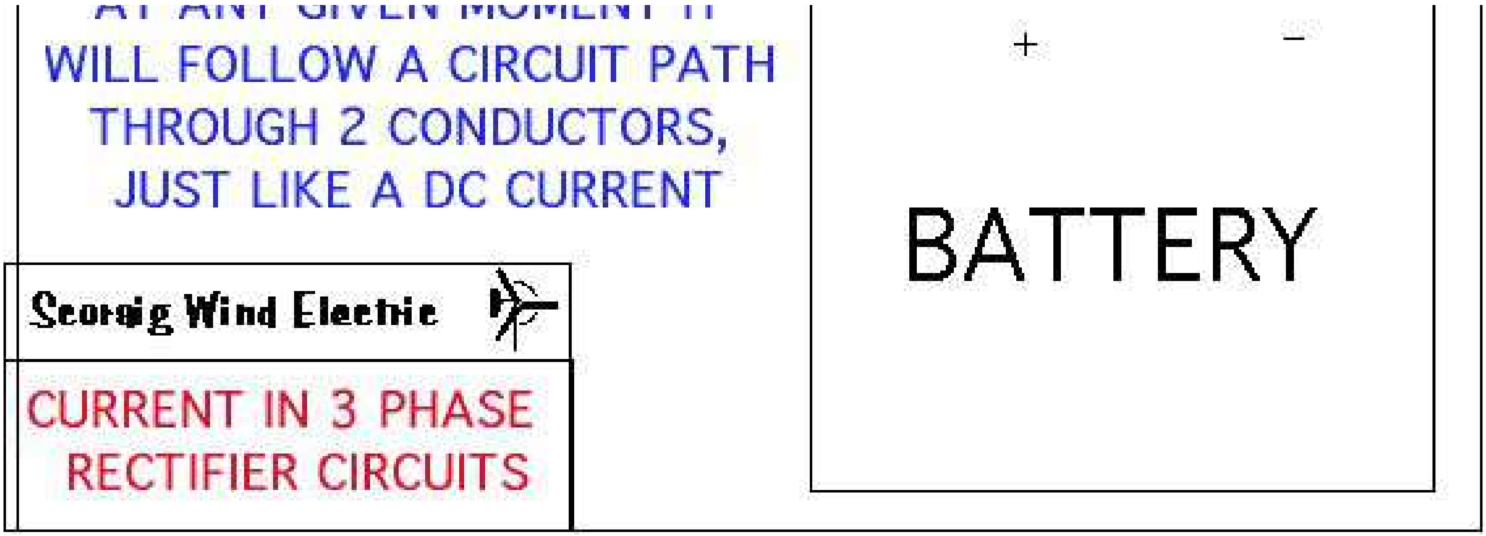
(this would switch one load only - Hugh)

Wiring loss in 3 phase wind systems.

There is some confusion about how to calculate losses in the cables of a 3 phase wind system. If the 3 wires are feeding a rectifier, charging a battery, then the current in the cables is dominated by the need to supply DC at battery voltage to the load.

The cables may change, but the current tends to remain constant.





Paul Gipe's question

What is the power lost in conductors from a 850 Watt permanent-magnet, three-phase alternator feeding a diode bridge rectifier delivering a nominal 24 VDC to a battery bank. The rpm, voltage, and current of the three-phase alternator varies with wind speed. There are three cables (conductors) between the wind turbine's alternator and the diode bridge. There are two conductors from the diode bridge to the batteries. The conductors are #8 AWG with an AC resistance of 0.78 Ohms/1000 feet. There is 150 feet from the wind turbine to the diode bridge, and an insignificant distance from the diode bridge to the batteries.

The DC current is found by dividing watts by volts. this gives 850/24 = 35 amps.

If you want to analyse situtation **mathematically**, current in each conductor is 35 amps for 2/3 of the time. The rms current in each conductor is therefore (2/3)^.5=0.82 times 35 amps = 29 amps (rms).
Resistance of **each** conductor is 0.78 times the cable run of 150/1000 feet, giving 0.117 ohms.
Power loss is I^2*0.117
which is 2/3*35^2*0.117
which is 1/3*35^2*.234 for each conductor
which is 35^2*.234=287W in total.

This is a 34% loss!

An easier way to analyse the situation (which also give the same answer) is to say that at any given instant the DC current 35 amps is flowing around a circuit path with resistance equal to 0.78*(cable run in feet/1000). Cable run is 300 feet for the full circuit.

Finally I should point out that the above is strictly only true if the internal loss is small. As loss increases, the situation becomes much more complex, since more than 2 wires will start to conduct at once during the changeover. But the above answer will be accurate enough for practical purposes, given that we are arguing about such large differences in our answers.

Hugh

October 1999

Paul Gipe has allowed me to put his recent articles on my site with the graphics :- Power curve tests and Noise Tests

AirX Fails Power Curve Tests

January 29, 2003

Tests during 2002 at the Wulf Test Field demonstrate that the AirX fails to meet the manufacturer's power curve by a wide margin.

Key words: AirX, Air 403, Southwest Windpower, Small wind turbine testing.

Disclosure: The three versions of the AirX tested as well as a Whisper H40 were provided by Southwest Windpower at no charge in lieu of noise measurement services provided by Paul Gipe.

Beginning in early 2002 I began measuring the noise emissions from a preproduction version of the AirX at the request of Southwest Windpower. As part of these measurements I also monitored the AirX's power curve. (My report on the noise emissions from the AirX will be posted separately.)

During these tests I noted that the AirX was not meeting its power curve. Previous measurements of the Air 303h and 403 indicated that these turbines also failed to meet their advertised power curves. However, the AirX failed by a much wider margin.

In cooperation with Southwest Windpower I've tested three versions. These I call AirX.1, AirX.2, and AirX.3 respectively for lack of a better description. For the most part the difference between the versions is programming on the chip that controls the AirX's operation.

None of the AirXs tested met or even approached the power curves in Southwest Windpower's owner's manual.

Power was measured with a watt transducer and average during 1-minute periods. Wind speed was recorded on the tower with the turbine. The turbine was tested at an elevation of 4700 feet (1430 meters) in the Tehachapi Pass. Data was corrected to sea level, 15 C conditions. For more details on the test technique, altitude and temperature correction, averaging period, and possible losses in the conductors see http://www.chelseagreen.com/Wind/articles/PowerCurves.htm .

While the performance of the three versions differed, sometimes markedly, from one another, the overall performance fell far below that of the Air 403 and that of the manufacturer's proffered power curves.

Southwest Windpower clearly, and fairly state on page 28 of the AirX Owner's manual that the manufacturer's power curve represents "instantaneous wind speed". This is a significant improvement over previous power curves for the Air 303 and 403 that were not so identified. Nevertheless, purchasers will expect that the turbine produces the advertised power on a consistent basis, which it does not.

The AirX will briefly reach rated power but begin to regulate. When it does so, the average power produced is well below rated. For example, if the AirX reaches rated power and begins to regulate, the turbine may be braked for as much as half a minute. When it does so the average power is half that of rated, or 200 W. Actual performance is even less that this.

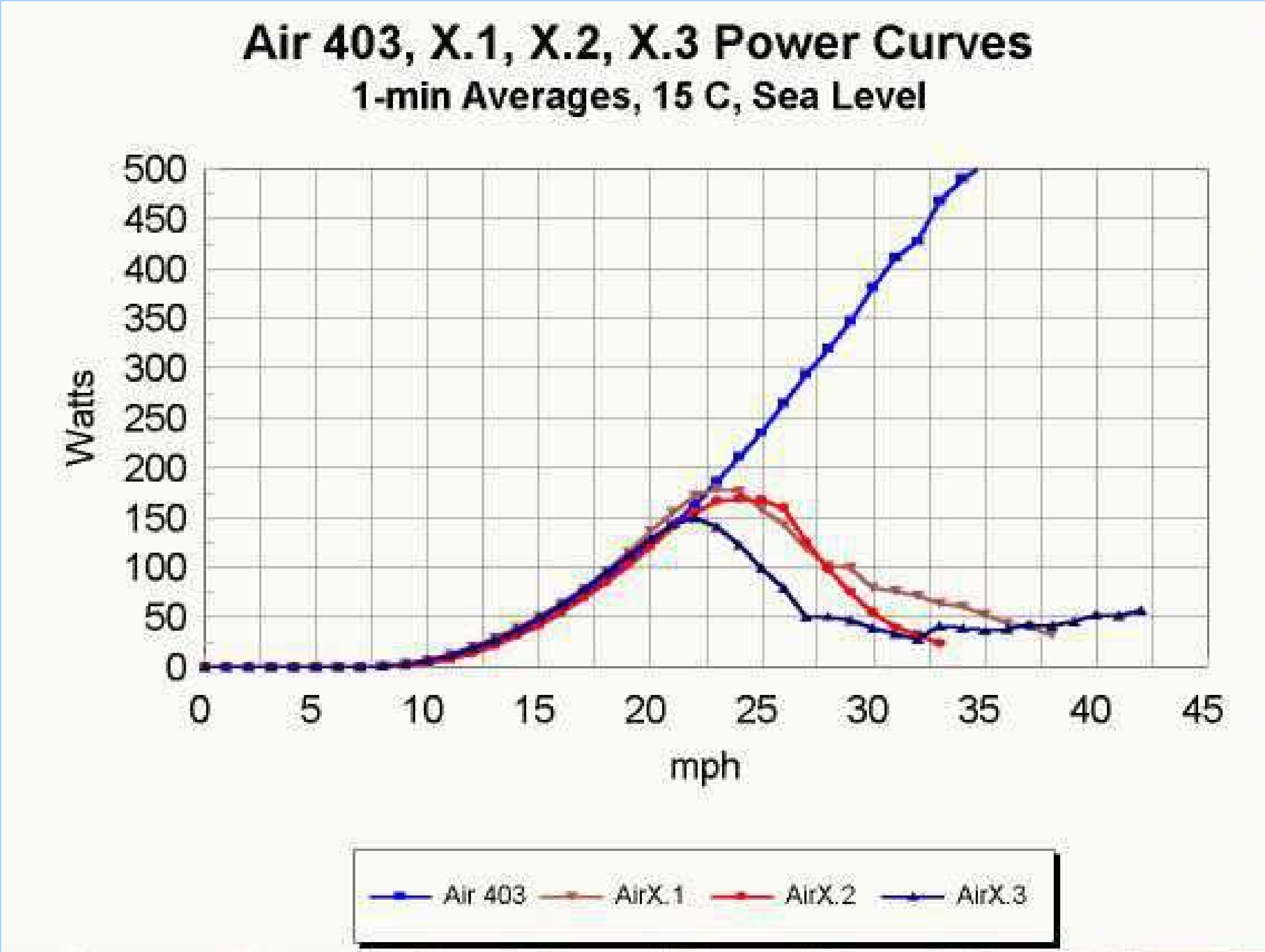
The AirX compares well with the Air 403 and meets the more conservative of the company's two power curves up to 23 mph (10 m/s).

At rated wind speed the AirX delivers only 103 W 99 W, and 51 W respectively, not the 400-525 W advertised. In the worst case, the AirX.3, the turbine only produces 10% of the advertised instantaneous power claimed. This is probably a record of some sort.

As Michael Klemen points out, this isn't the whole story. Energy production is reduced by a lower than expected power curve, but the energy generation lost is not quite so dramatic.

In a 12 mph (_5 m/s) wind regime with a Raleigh distribution, the AirX.2 and AirX.3 will generate 80% of the 388 kWh/yr produced by an Air 403. In a 14 mph (_6 m/s) wind regime with a Raleigh distribution the AirX.2 and AirX.3 will generate 65% of the 612 kWh/yr produced by an Air 403.

The AirX is both subjectively and quantitatively quieter than the Air 303 and Air 403. However, this is accomplished at a significant sacrifice of performance.


Air 403, X.1, X.2, X.3 Power Curves
1-min Averages, 15 C, Sea Level
Watts
500
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
45
mph
Air 403
AirX.1
AirX.2
AirX.3

AirX Power Curve Summary
Wulf Test Field
C:\MyFiles\Winsite\dat\airxpcmeasuredsummary.wb3
Corrected

Rated power 400 W at 28 mph

Wind Speed (mph)	Air 403 Power at 15 C Sea Level W	AirX 1 Power at 15 C Sea Level W	AirX 2 Power at 15 C Sea Level W	AirX 3 Power at 15 C Sea Level W
Begins	06/04/00	04/22/02	05/17/02	12/12/02
Days	12	11	11	22
0	0.0	0.0	0.0	0.0
1	0.1	0.1	0.1	0.3
2	0.1	0.1	0.1	0.1
3	0.1	0.1	0.1	0.1
4	0.1	0.1	0.1	0.1
5	0.1	0.1	0.1	0.1
6	0.1	0.1	0.1	0.1
7	0.1	0.3	0.1	0.5
8	0.4	1.2	0.6	1.4
9	1.3	3.5	1.7	3.5
10	3.7	7.3	4.2	7.2
11	8.6	13.3	8.3	12.3
12	15.5	20.4	14.0	18.8
13	24.4	28.9	21.2	26.9
14	35.1	39.4	31.3	37.3
15	47.0	51.0	42.2	49.2
16	60.3	64.2	55.0	63.3
17	74.4	79.0	69.2	78.2
18	89.5	96.4	84.7	95.3
19	105.4	115.1	102.4	112.4
20	123.4	136.5	120.9	128.6
21	142.9	155.4	140.9	144.0
22	163.4	172.3	156.0	150.0
23	186.8	179.2	166.5	141.4
24	211.4	176.7	169.9	122.9
25	235.6	158.5	169.2	99.7
26	264.9	143.1	160.0	79.5
27	294.2	119.7	126.2	50.4
28	**320.3**	**102.5**	**98.6**	**51.3**
29	348.0	99.6	75.5	47.5
30	381.6	79.3	55.4	39.7
31	411.2	75.9	40.2	33.3
32	427.8	71.9	32.6	28.8
33	468.3	64.2	23.9	41.4
34	491.1	61.4		39.7
35	505.0	52.4		36.6
36	530.4	44.2		38.0
37	530.6	40.4		43.2
38	533.2	32.3		41.8
39				45.7
40				52.4
41				51.6
42				57.6
43				
44				
45				

AirX Noise Emission Measurements

January 30, 2003

Both versions of the AirX monitored at the Wulf Test were qualitatively and quantitatively quieter than the Air 403.

Disclosure: All AirXs tested and a Whisper H40 were provided by Southwest Windpower in lieu of payment for noise measurements by Paul Gipe.

Background

Southwest Windpower's Air 403 was notoriously noisy. While not the noisiest wind turbine ever made, its widespread distribution caused an unusual number of noise complaints.

In late 2001 Southwest Windpower asked me to measure the noise from a preproduction version of the AirX. Beginning in 2002 and through the first half of 2002, I conducted a series of noise measurements on two versions of the AirX. For lack of a better descriptor I called them AirX.1 and AirX.2. I also measured the power curve on a third version, the AirX.3 but I have not made any noise measurements on this unit.

I've withheld publishing the data collected until now for several reasons. First, I had other obligations. Second, I considered the versions I tested defective products and returned them to the manufacture for correction. They were defective because they failed to meet the manufacturer's power curve. While the noise measurements on these units were complete, the fact that the product would likely be modified by the manufacturer to correct the power curve defect suggested that the final production version would not be represented by my tests.

The final version I received, the AirX.3, operated similarly to the AirX.2 and the noise emissions are likely comparable. Further, Southwest Windpower has been shipping various versions of the AirX for more than one year. I have no idea how my versions compare with current production.

For a complete description of the rationale for testing, the methods employed, the terminology used, and my test equipment, see http://www.chelseagreen.com/Wind/articles/noiseswt.htm .

Critical to understanding the following data is the difference between sound pressure levels of ambient noise, and noise with the turbine operating. It is the difference between ambient and the turbine noise plus ambient that determines the noisiness of the wind turbine. The difference determines the noise from the turbine at a specified distance from the turbine. This calculation in sound pressure level is then used to arrive at the source emission strength in sound power level (LWA). The latter is the noise at the source, the wind turbine. This value can be used to project noise at varying distances from the turbine and can be used to compare one wind turbine with another.

Air 403

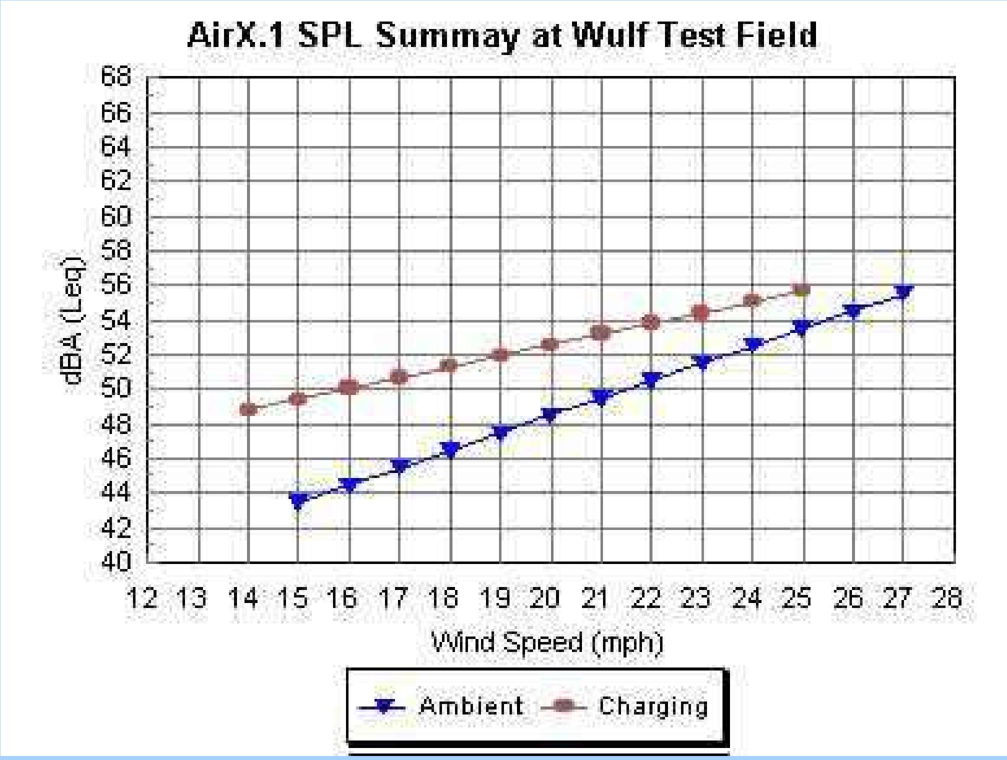
To recapitulate earlier results on the Air 403, in winds from 8-10 m/s (18-22 mph), the Air 403 would emit an annoying "buzz" most of the time. The Air 403 sound power level or emission source strength (LWA) was 88 dBA at 8 m/s and 91 dBA at 10 m/s.

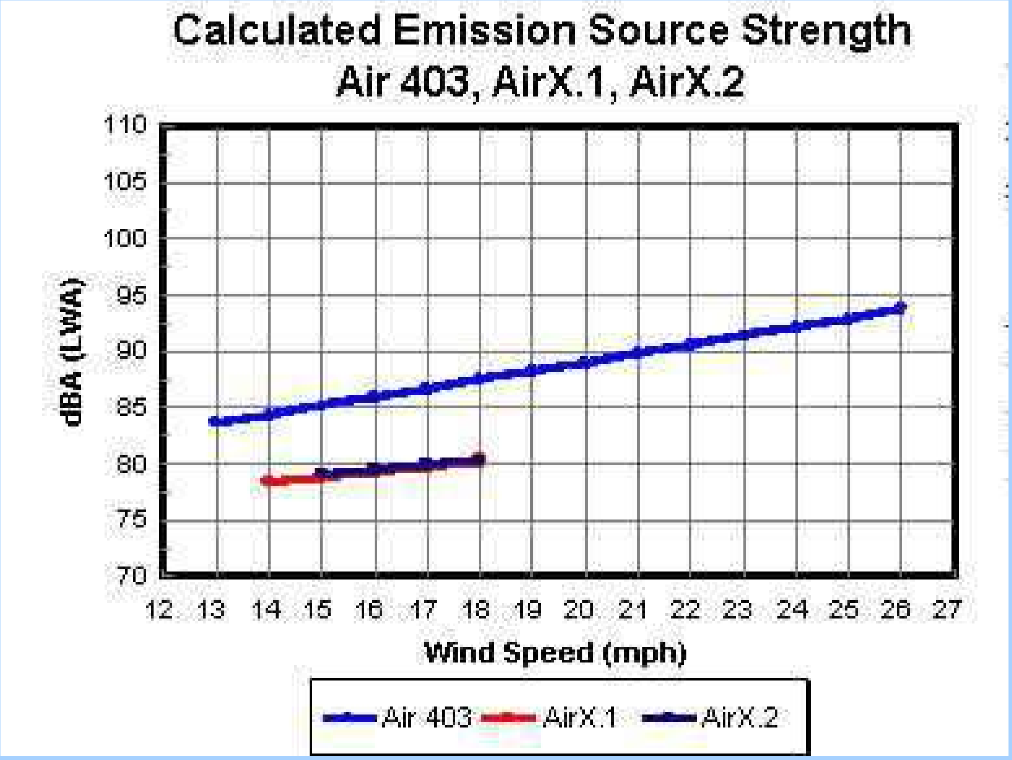
AirX

The AirX is so significantly quieter than the Air 403 that it was difficult to measure a sufficient difference between ambient and turbine plus ambient in wind speeds greater than 18 mph (8 m/s) to calculate valid values for sound power levels above this speed. In the accompanying chart for the SPL Summary for the AirX.1, the ambient noise can be seen rising steeply with increasing wind speed (wind noise in nearby willows) while the noise from the AirX rises less rapidly.

As seen in the second chart, Calculated Emission Source Strength, both the AirX.1 and the AirX.2 emitted about the same amount of noise. The sound power level for the AirX.1 and AirX.2 at 8 m/s (18 mph) is 80 dBA or 8 dBA quieter than the Air 403.

The AirX accomplishes this by stalling the rotor or turning the turbine off so the blades don't begin to flutter. This is a very effective method for reducing the noise emitted by the AirX, but it does so at a cost. The AirX fails to meet its power curve by a wide margin.


AirX.1 SPL Summay at Wulf Test Field
dBA (Leq)
68
66
64
62
60
58
56
54
52
50
48
46
44
42
40
12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Wind Speed (mph)
Ambient
Charging


Calculated Emission Source Strength
Air 403, AirX.1, AirX.2
dBA (LWA)
110
105
100
95
90
85
80
75
70
12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
Wind Speed (mph)
Air 403
AirX.1
AirX.2

How to Build a Wind Turbine - Scoraig May 2003

hugh@scoraigwind.co.uk

Once again we assembled to build a small wind machine.

Brian Faley of Shoreline Power Design came from Washington State USA to help teach.
Julius Tangka came from Cameroon in Africa.
Uwe and **Stephan** came from Germany (different cities).
John came from Denmark (John was also on the CAT 2002 course).
Giuseppe came from Rome.
Demian came from Edinburgh.

A number of other folk booked in for the course and then later cancelled.
This is the smallest course I have done.
Here you will find some familiar pictures because the activities are much the same as we always do, but there are always some new ideas.

Notes from this course are now for sale at this link.

Captions for the pictures below were written by Stephan Gilbert - Thanks, Stephan!

Stephan has also prepared a small site with pictures of the course.

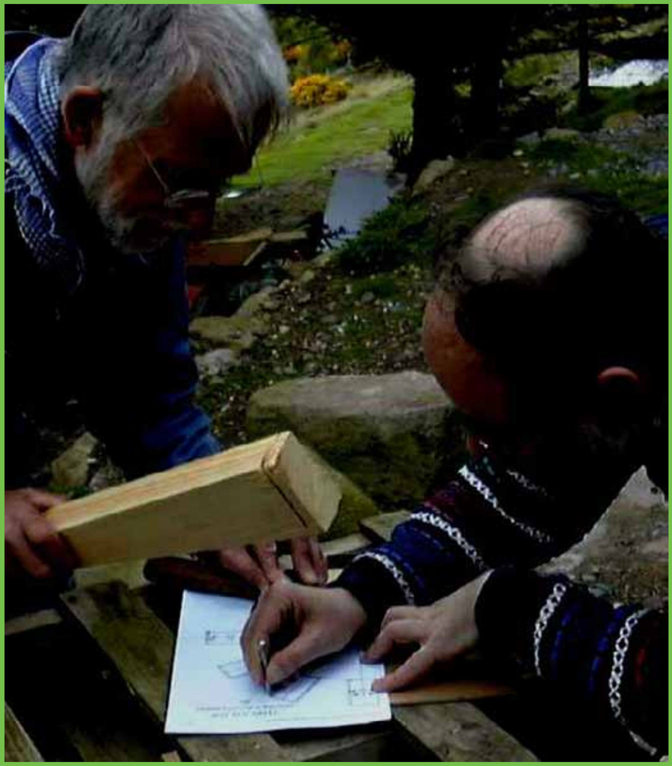
Pic 1: actually a very nice way to start the course, becoming familiar with the manual with Hugh's help by building the coil winding tool and the different pieces of plywood for the the rotor and stator moulds, it's perfect to start feeling comfortable with the tools available in the workshop.
(Here we see Julius Tangka, Uwe and John, with Brian behind - Hugh)

Pic 2: quite challenging to convert drawings into real size shapes, where do you draw and where do you cut? Also learning to use perhaps unfamiliar aids. With one precise angle on a piece of ply between two cuts all other lines and dimensions can be drawn using a simple angle and ruler. The beauty of the design as we found out during the course lies in the generous error margins allowed and required when working mostly with generally available hand tools.
(Here we see Brian, Demian and Stephan - Hugh)

Pic 3: The jigsaw seems the perfect starter-power-tool. One can control the direction and speed precisely. At the beginning it seems affording some time and patience but the results are more than rewarding. For long and straight cuts we mostly used a circular saw.

(Personally I would not recommend using the jig saw here because it is slow and hard to steer - Hugh).

Pic 4: The magnet jig needs to be fabricated with high accuracy. During the placement of the extremely powerful Neodymium magnets on the the steel disks we noticed that the positioning errors of the strong magnets would have been difficult to reverse by trying to remove them before reworking the jig.
(John holds the improvised mallet, and Uwe the punch - Hugh)



Pic 5: The drawknife gives you a lot of control, coarse and fine. The grain of the wood tells you in which direction to work, it's what one needs to watch for very closely especially around knots. The blade takes on shape rapidly and precisely ready for finer work with other tools. Learning to work in harmony with the wood feels very rewarding and natural.
(Stephan himself is at the handles of the knife.)

Pic 6: The winding of coils generated a lot of questions. How can you make sure to correctly count all the turns? What tension should the wire have while winding? How can we make sure the coils all have the same number of turns?
Well, the best measure is weight and a scale came in just handy. After winding the coils we compared the weights to make sure the person winding used the right amount of wire. But induction is proportional to the number of turns, would the number of turns be the same even though the weight is within tolerances? By the way, we wound 24 V coils. Since the coils will not be paralleled before rectification, differences in the number of turns are not so critical. Again, design tolerance where it's needed.

Pic 7: the hub looks like new after having been treated to a prolonged workout with an angle grinder. Unfortunately most hubs one will find at scrap yards will have worn races, with the help of inexpensive new ones our problems where solved after gently packing them with just the right amount of grease.
(Here Brian is using the old bearing race, split on one side, as a drift to knock in the new one. - Hugh)

Pic 8: The beautifully laser cut extra thick steel rotor plates are drilled with the help of an often used self aligning technique. One hole is drilled through both plates and the hub for alignment (you can see the bolt holding everything in place). After aligning all three pieces, the 3 remaining holes are drilled.

Pic 9/10: First one is impressed by the force and speed (and noise) of these very powerful tools, but after trying the hack saw on impressive 6 mm steel bars (and not having to start up the petrol powered generator) the choice is clear: the hack saw wins!

Pic 11: Fully protected Julius Tangka really is a fine welder but not without the help of John though! A few parts have already been assembled, the two "L" shaped brackets have been welded to became a "U" shape one (which will hold the alternator), the cylinder to turn on top of the pole and the top ring piece (which Julius Tangka is getting ready to weld) will prevent the wind turbine from sliding down the pole, oups!

Pic 12: Demian also proved to be a talented welder. These little gas powered generators can become real life savers when everything else fails. A litre or less of petrol and you can do all the welding, cutting, lighting, you name it!

(My poor, neglected welding engine is over ten years old and it's always a miracle when it does the job!

Pic 13: Uwe showed a lot of endurance in polishing the stator disks, belts were replaced more than once. The disks finally lost the self-oxidizing layer which could impair the magnetic flux and the belt sander gave up its life. (We remove the oxide layer to improve adhesion. The sander works well if you press down hard. I finally wrecked the sander myself by hitting a sharp edge and tearing the belt. The belt then tore up the rubber roller. - Hugh)

Pic 14: The metal tools were attracted by the magnets creating a force pressing the moulds together. The 2 rotor moulds are in the front, the stator mould behind. To help curing the resin we installed two heating lamps in William's winter garden. A beautiful tour of Scoraig's wind turbines was scheduled for the next day to give the resin more time to harden.

Pic 16: The reusable stator moulds have been opened, it turned out just perfect. After pouring the resin it is important to vibrate the moulds so air bubbles can rise to the top. Neodymium magnets will deteriorate when exposed to harsh environments, the resin not only prevents the magnets from flying away but also from aging. (Neodymium magnets suffer deterioration if water manages to penetrate the protective coating. Embedding them in resin seems a good idea. - Hugh)

Pic 17: What great weather we had to explore all the different wind turbines on the peninsula... Julius Tangka is showing off his pole climbing skills, Giuseppe followed just after. We truly enjoyed meeting original "Scoraigians" and were impressed to see that wind turbines - self-built, restored and commercial ones - were in full use to meet power needs from small dwellings to school houses. At the end of our visit, Allan Bush welcomed us in his unique home and offered us refreshing tea.

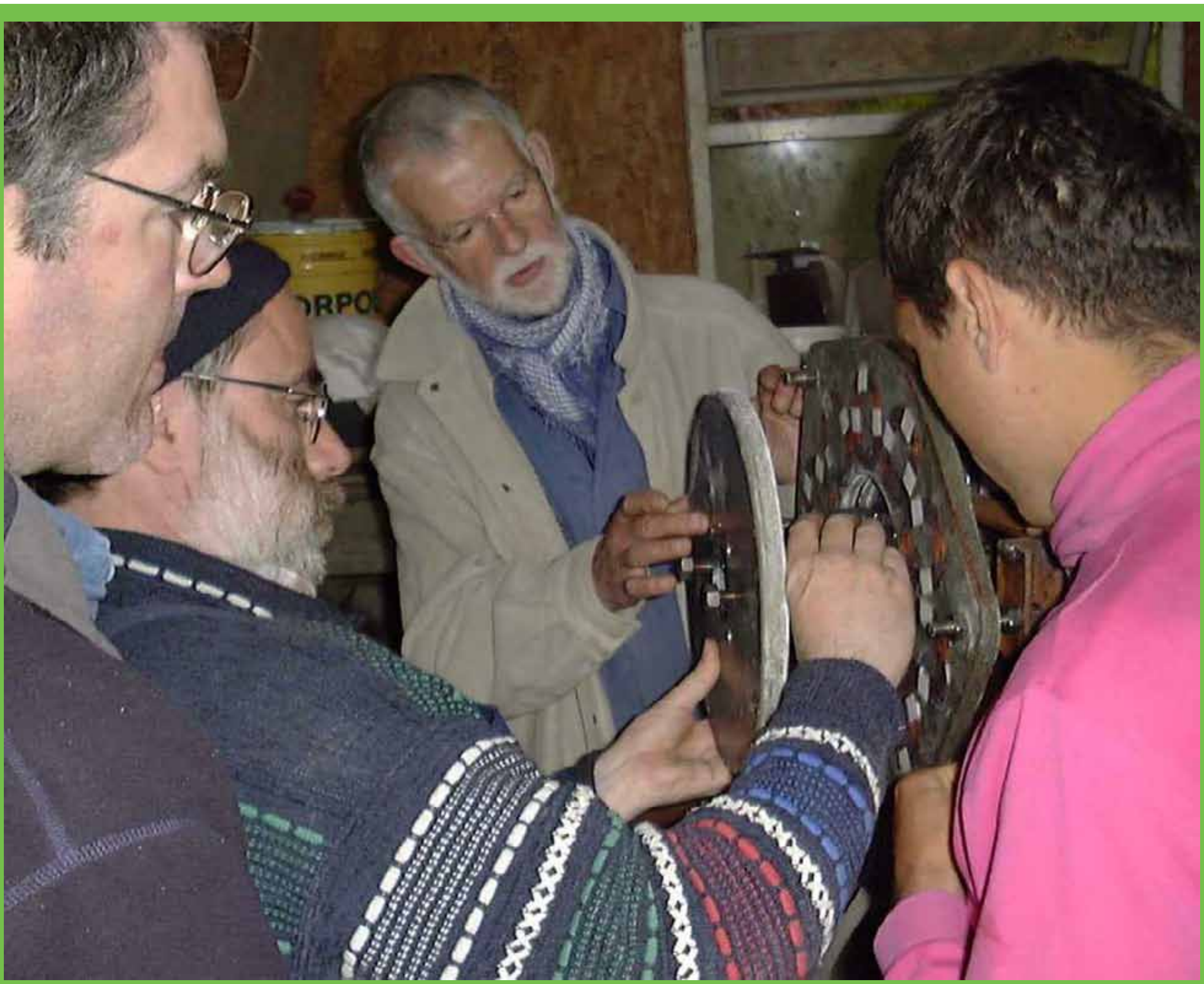
Pic 18: The correct amount of grease keeps the friction in the bearings low.

Pic 19: The wooden stator cut out comes in really handy when drilling the mounting holes. Demian and John are standing at a right angle to each other to help Uwe align the power drill vertically.

Pic 20: Nice job!
(Welding the tail mount onto the yaw frame, with the frame set up at the correct angle. - Hugh)

Pic 21: Here is a nice trick how to cut along 2 lines in 3 dimensions with ease, somewhat of a mind twister when trying to visualize how you are going to saw this piece while drawing it up. A hand saw really does a great job.
(These are the blade wedges - Hugh)

Pic 22: There was quite some tension in the air when the alternator was being assembled. Strong magnetic fields attract all the tools. The accuracy of all parts now pays off. (Here we see the front magnet rotor being fitted in front of the stator - Hugh)



Pic 23: The jacking screws work wonder. Actually, the attraction of the Neodymium magnets is so strong it would be impossible to control the assembly process without them.

Pic 24: The diode voltage drop across the rectifier may be quite low, but even at 1 Volt and 5 to 10 Amps it starts dissipating quite some heat (5 - 10 Watts each).
(Twin heat sinks for the rectifiers. - Hugh)

Pic 25: While Julius Tangka is trying to "rip off" the insulation, John and Stephan are checking the tail movement. We had to weld a small additional piece of steel to prevent the tail from hitting the hinge pipe weld.

Pic 26: Lots of hands were needed to safely assemble the finished blades. It took some time to equalize the tip-to-tip distances while holding the centers together before we could clamp everything down and start drilling the mounting screw holes.

Pic 27: Can you smell the hydrogen?

Pic 28: The completely assembled turbine in the workshop awaits static balancing.

Pic 29: Oops, a fuse blew. It is and was good advice to always use fuses with battery circuits, discharging currents can be huge. Julius Tangka flipped the polarity of the alternator wires and everything was OK then - after we used a new fuse.

Pic 30: The last touch, tightening the blade assembly onto the alternator before raising the previously tested pole configuration, carefully of course.

Pic 31: Here are some very happy and proud wind turbine scholars! Everything is in place, the anemometer reads

5-7 m/s winds, let's go.

Pic 32: Julius Tangka is operating the winch while John and Uwe use the ladder to guide the cable. Note that the tail is in full furling position. Some rain clouds were approaching and we hoped to see some gusts, but....

Pic 33: We were all looking - somewhat in awe - at the wind turbine we started building from scratch just 5 days ago actually generating electricity. What a rewarding moment!(We had an anemometer to check the windspeed. It was mostly around 3-5 m/s (7-11 mph)
Output was around 20-100 watts. Hugh)

Pic 34: After the mill being up and running smoothly, no imbalance or vibration could be noticed. The blade carvers must have done a good job. Time to drink a toast! - Uwe

A few drops of very pure Scoraig rain water falling into our drams released all the remaining flavors of an outstanding single malt Brian offered. - Stephan

All too soon, it was time to take it down again....

All were happy to know that
Julius Tangka was going to arrange for transportation back to Cameroon and that our wind turbine would help people in their quest to teach and develop independent energy projects.

The next course at Scoraig will be on 8-15th May 2004

"Thanks again for the wonderful course. It really demystified wind turbine technology." Julius Tangka

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"This course showed me what a small number of enthusiasts are able to achieve." Uwe Hinz

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There is a lot of exciting new stuff going on at the Otherpower discussion board where Dan is extending the design and using old Volvo parts to do it. Dan has put his latest wind machine project on this page.

Windmills of Scoraig

An informal tour, by Hugh Piggott year 2000
This tour is always out of date :-)
things change too fast

Back to Hugh's homepage

This is an very brief guide to the windmills which provide electricity to households on a small peninsula with no road access or power lines (called Scoraig). I hope I don't step on too many toes by telling it like it is and describing our experiences of various commercial makes, old and new.

Links to machines below:- Ampair, AIR, LMW, Proven, Survivor, winco, chinese
My own designs, including also the African AWP3.6 and the ITDG alternator

Here is some text to read, while you wait for the pictures to load

Intro Hugh Piggott

Windpower fanatic. Born Scotland 1952, educated Edinburgh and Cambridge. After graduation, went back to the land in NW Scotland where I remain. For 4-5 years I did without electricity except what I could rob off 12V vehicle systems on rare shopping expeditions, by connecting an elderly car battery to bits of loose wire. This ran my cassette tape machine.

In 1978 I got seriously bitten by windpower and have been partly or totally obsessed with it ever since. This is a windy place and very dark in winter, so there is a strong sense of victory when you can harvest energy from a crashing gale and swamp the house in dazzling light. Lots of bits would drop off my windmill(s) but I persevered and ended up making windmills for most of my neighbours. They still ring me up when they need the windmill fixed. There are about 30 windpower systems within a few minutes' walk of my house.

In the late 1980s I decided to broaden my perspective and I started working on windmills built by others. I was amazed to find that bits drop off them too (I thought it was just me). In fact it turned out that I was pretty good at fixing windmills by then and so I did some work with manufacturers, testing and developing machines, in the demanding conditions we have here. I also wrote up some of my ideas and helped teaching courses at the Centre for Alternative Technology in Wales. Stopped milking a cow and bought a fax machine.

More recently I have designed a windmill for manufacture in Africa and also installed some direct AC hydro systems. I find hydro very exciting because it provides much more energy at lower cost (on a good site) and you do not need batteries. I hate batteries.

In 1999 and 2000 I have worked as consultant to a TV company, designing and installing a wind/hydro system for castaways on an island.. I have also been doing another developing world project for ITDG, culminating in a permanent magnet alternator design you can download for free.

Ancient History

When I moved here in 1974, most people used oil lamps for lighting, because this was simpler than running a diesel generator. There is not a lot of money around on Scoraig, but the atmosphere is generally quite relaxed. Planning and discussion are favorite occupations. The working day is often curtailed by bad weather, so there is no point in being in a hurry.

One neighbour had an old battery charging 'Freelite' made by Lucas.
I would take my tape machine 12 volt battery along to him for charging, but I also messed around trying to build a windmill myself. The first attempt was a bicycle-hub dynamo which I sat on the rooftop. It worked, but it was really noisy in the house. In those days I was a 'back to the land' hippie type, and my resources were pretty thin.

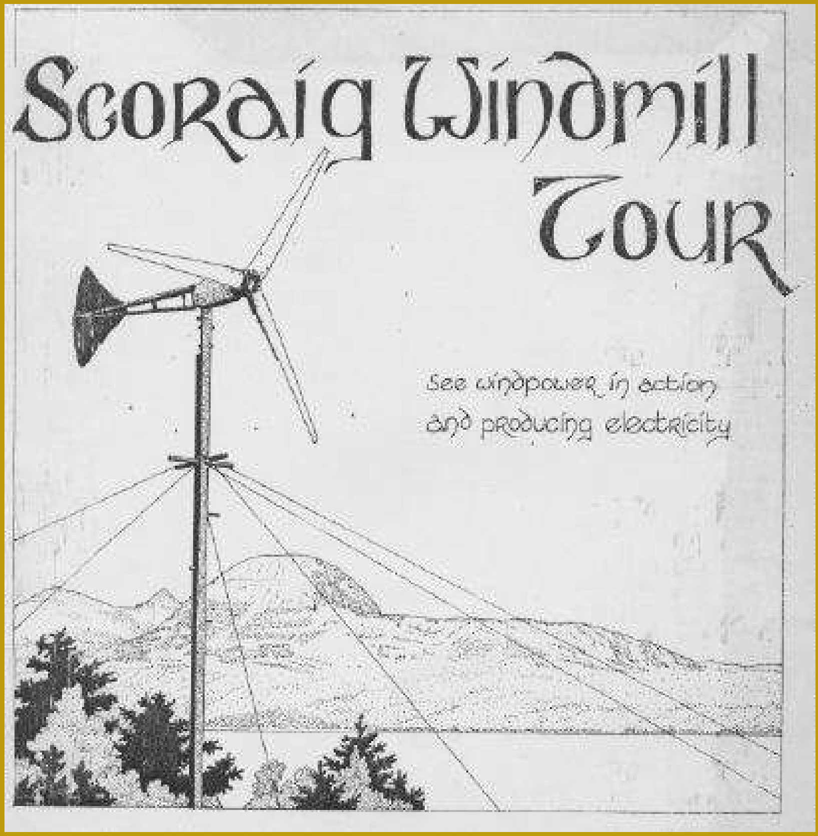
 .  . 

I struggled for a long time to build something workable, but that's another story. We had a lot of fun finding out what worked and what didn't. This single bladed machine for example (built by my cousin, Topher Dawson) worked after a fashion but the pitch control system never quite got perfected.

I had a lot of help from friends like Alan Bush, Alan Beavitt, and countless others, and I read some books. Around 1980, I made quite a number of 2-bladed windmills based on 24volt dynamos from Austin Champ Jeeps. Many of them are still in use today, although they have been repaired and modified a few times over the 20 years.. Output is around 300 watts from a 6 foot diameter rotor.

and as the trees have grown, I have had to increase the heights of them.

Here is an old **Winco** being moved to a new site by a tractor, complete with its tower. Sadly this machine is no longer working today. The linkages wore out and the commutator gave constant problems.



Year 2k

During the 1990s a number of windmills were imported to Scoraig, and I learned a lot more about the art of wind turbine mechanics. Much of what I have done has been repair work, because I was using secondhand parts, or fixing up something which fell apart unexpectedly. I developed some designs of my own at the same time, and published some stuff about how to build small wind turbines.

What follows is a guide to the ones which are around in year 2000 (I am struggling to update it in places too), and what stuff has happened getting to here. Awful things do happen to small wind turbines, as you will see, but remember - these machines are working, and bringing joy and light to their owners. Being a mechanic I mainly see the breakdowns.

Links to machines below:- Ampair, AIR, LMW, Proven, Survivor, winco, chinese
My own designs, including also the African AWP3.6 and the ITDG alternator

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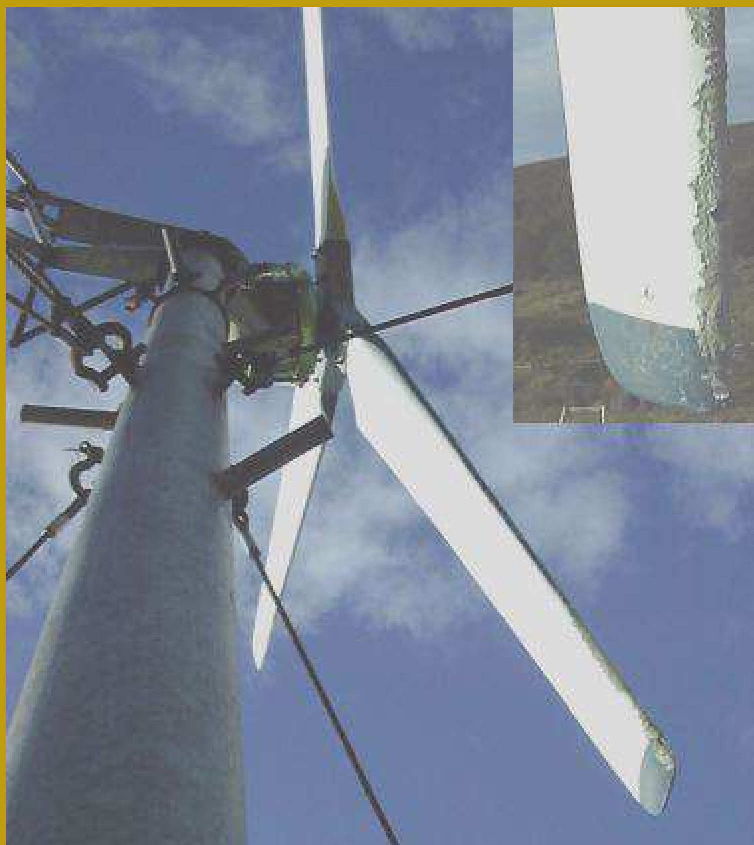
Here is the **LMW3600** which was installed here, to heat the Primary school, in 1990.


the view is southeast, up the loch.

This machine taught me that I was not the only person who had problems producing a good design of windmill. We had a lot of problems with the LMW during the first few years.
It makes a very loud humming noise which swells and reverberates.
The tail furling system didn't work properly, and it ran too fast, which wore out the blade edges.
This in turn caused vibration, fatigue and failure of vital parts such as the tail, and the alternator mounts.
In other words it fell apart, repeatedly.

I have modified the tail so that it furls at about 2kW and it has now gone for several years without problems. We have gradually grown used to the noise and we don't notice it these days.


some blade erosion in this picture.

Ultimately, this has been a successful installation, and it keeps the school supplied with ample electricity, although it never could have provided sufficient heat. The average output is under 1kW - not enough to heat a building of that size. But the rotor diameter is large (5m. 16') and so it catches plenty of power in low winds, to keep the school supplied with light, and power for computers, vacuum cleaner, photocopier, etc.. And in windy weather it does produce enough surplus to heat one room to a very nice temperature.

Not many small windmills are built to give good service in very windy conditions.
They work OK on other sites, where there is less wind, but in an exposed coastal location like ours the problems show up early.

Some of my neighbours have owned **AIR** machines from Southwest Windpower (Arizona), but their life expectancy has been about 2 weeks. Commonest failures are burned out electronics and broken blades.
After-sales service has been absolutely brilliant. Spare parts and replacement machines have been supplied promptly and without quibbles. On one site the machine was upgraded to an 'industrial' (very expensive) version free of charge, and this has lasted almost for a whole year on one occasion.

Here is a picture of the site. 

The owners live in the little house on the right. We had to fix a piece of sheet metal to the tail after the yaw bearing started to seize up. It's quite a powerful machine for its size, given a good wind. But we all know about it when it is running - it's almost as noisy as the LMW in normal conditions, and when it hits full power it's louder than a chainsaw.

The other family who had an AIR machine were lucky enough to be given an old **Marlec FM1800** as a replacement. This is a sturdy machine,even though the electrics are horribly complicated.

We have now moved this machine up the hill to get away from the trees.

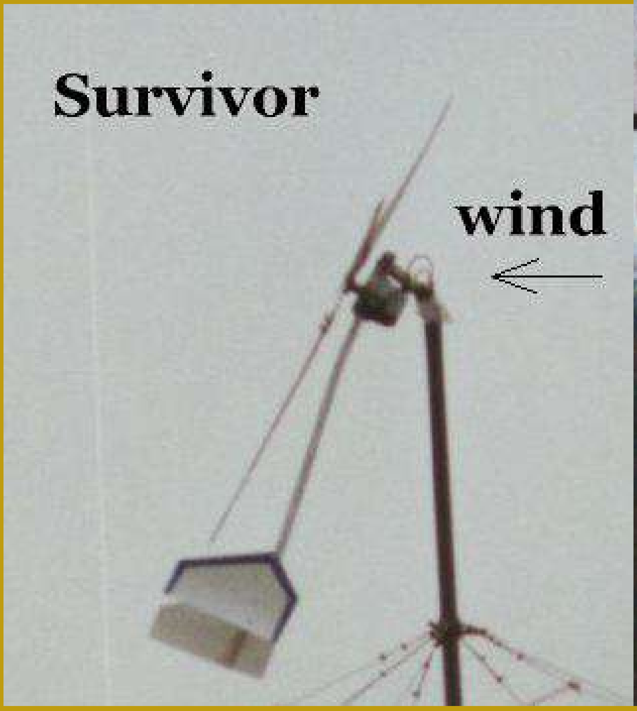
We tried **Marlec** Rutland72 watt machines for a few years, but the stators would normally fail after about one year, and you can only replace the stator a few times before the bearings work loose, and then you need a new alternator. Marlec gave up making spare stators for their older models, and I began to lose interest in Marlec. Especially since they 'upgraded' the fm1800 by giving it only 2 blades.

One machine which gets full marks is the **Ampair Hawk**

.

It only produces 100 watts but at least it goes on doing it through outrageous storms, and years of service with little or no attention. The only thing which has been a real problem is the regulator. These tend to burn out. Brushes can also give problems but this is rare/unknown on Scoraig.

For 2 years I ran a **Survivor S3000** wind turbine, which I had bought ex-demonstration. It was rather out of date, and is now badged 'Synergy' instead. I believe they have also put sliprings on it. I never had problems with cable twist, but I did have problems with rain running into the yaw bearings, so that they fell apart and the machine flew off the tower top. I also had a blade root failure (see picture) where the mounting plate cracked across. It ran for a few hours with 2 blades. This type of cracking has happened to me before, with a Whisper 1000 'spring plate'. Seems like a highly stressed piece of plate.

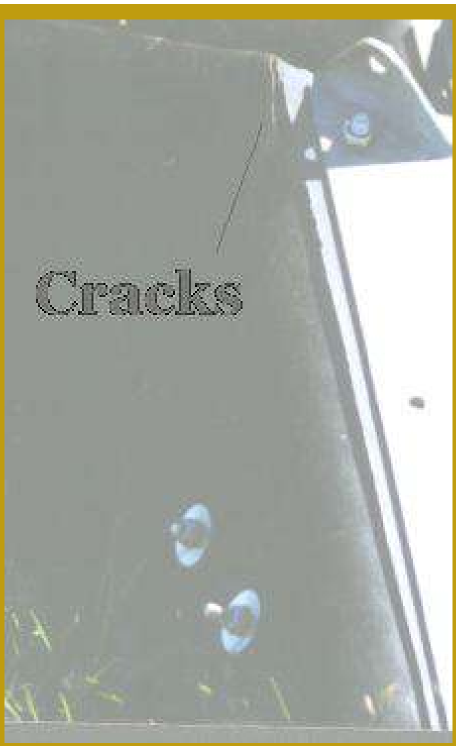


The furling system is fascinating, based on a hinge at the topmost point, from which the windmill hangs. High winds blow it upwards until the tail and blades are horizontal.

Another 'downwind' machine, which has fared much better here is the **Proven**.

Here is the 2.5kW machine at Scoraig. I did some development work with it around 1995, leading to the use of double springs in the governing system. This windmill does not furl by turning away from the wind as most others do. It governs its blade speed accurately using centrifugal force to alter the pitch of the blades.

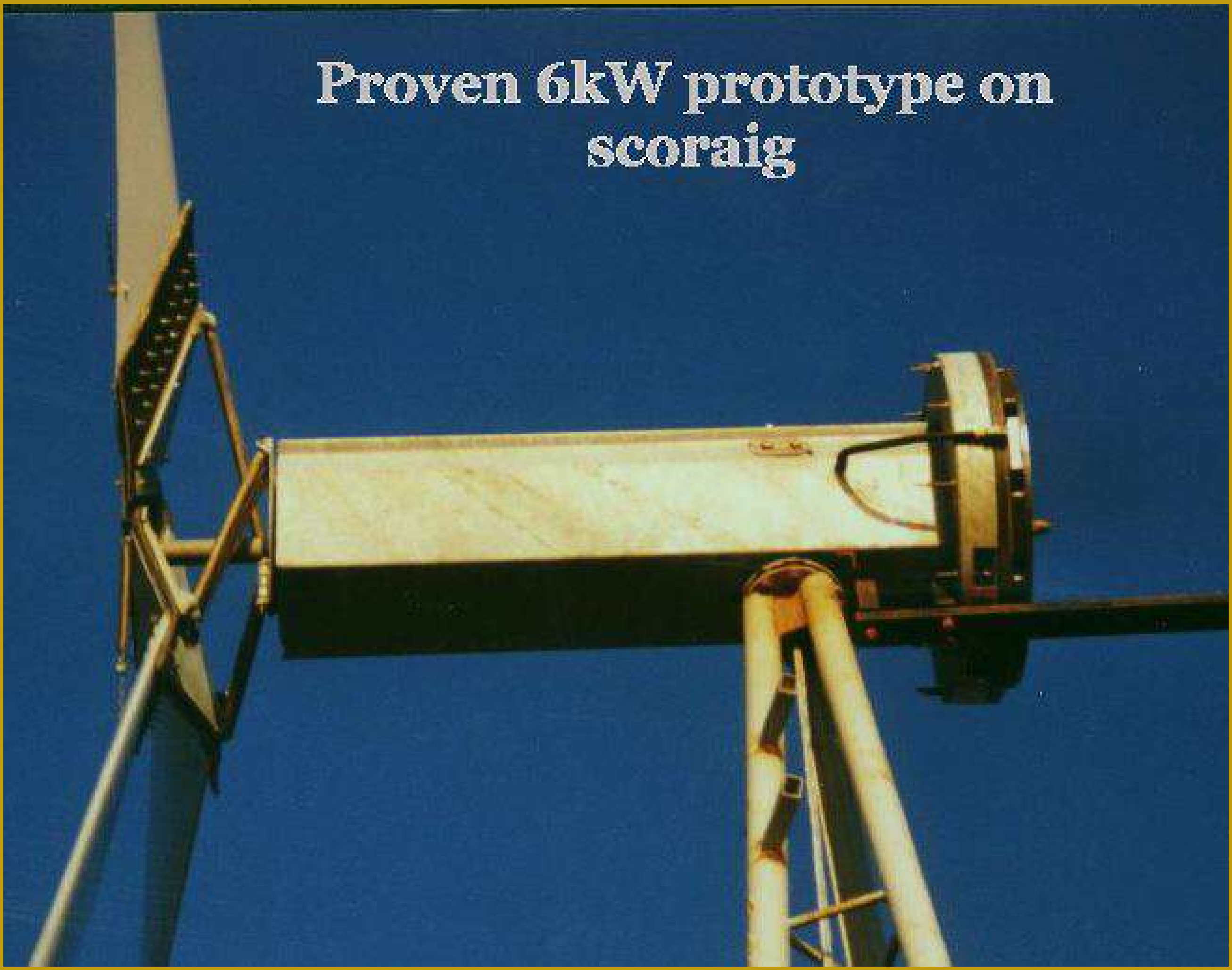
The system puts quite a high stress onto the blades and springs, which have sometimes cracked, and failed. For example the blades on the Castaway machine at Taransay have just failed after very nearly two years of high wind duty. One blade disappeared entirely.



Cracks in the polypropylene blades occur at the hinge points.

Proven have recently introduced Polyurethane hinges for their blade roots and these are proving to be much more robust.

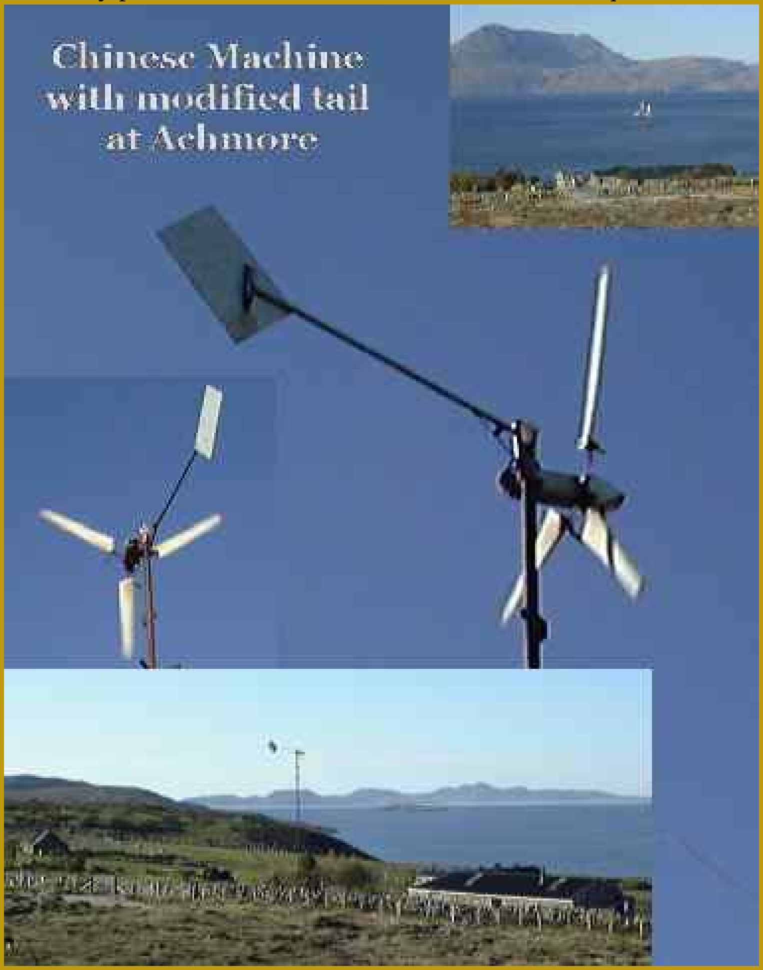
Scoraig is also the home of the prototype **Proven 6kW machine** which is owned by my cousin Topher Dawson (boatbuilder and wind turbine blade fabricator).



No more machines were built in this 'monocoque' style. The beam on the right is for a balance weight, which is also unique to this prototype. This windmill has worked well for about 3 years, with some nursing from its owner. Unfortunately, the production versions still have some problems to be worked through, but as usual, Proven Engineering are working on solutions!

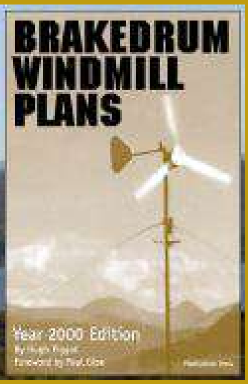
In this picture you can see the magnet rotor inside the alternator.
The cover was removed to improve cooling, and it looks nice too, wheeling along.

Here's a picture of a chinese wind turbine which I have been testing. As supplied there were problems with its balance and its furling system. After some early problems in 1998, it has settled down to be quite a nice reliable machine .



PS we did have a blade fly off during the winter 2000-2001 and I have now put the blades from the survivor on it. this is typical of the sort of 'swift and grotty' repairs which keep scoraig windmills going on a shoe-string long after they would have been abandoned on other sites.

We also have some machines of **my own design** here, for example the brakedrum windmill
(as written up in the Plans available from Picoturbine.com)



and the **African 36**

(see this link too)

This wind turbine powers our home.

and now another one power Scoraig Secondary School

And one for william at Rhireavach..

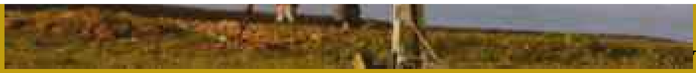
another is located at Badrallach on the tarmac road, 10 miles from Dundonnell:-

Here is another one on Scoraig, installed sumer of 2000 for Bill Burstall

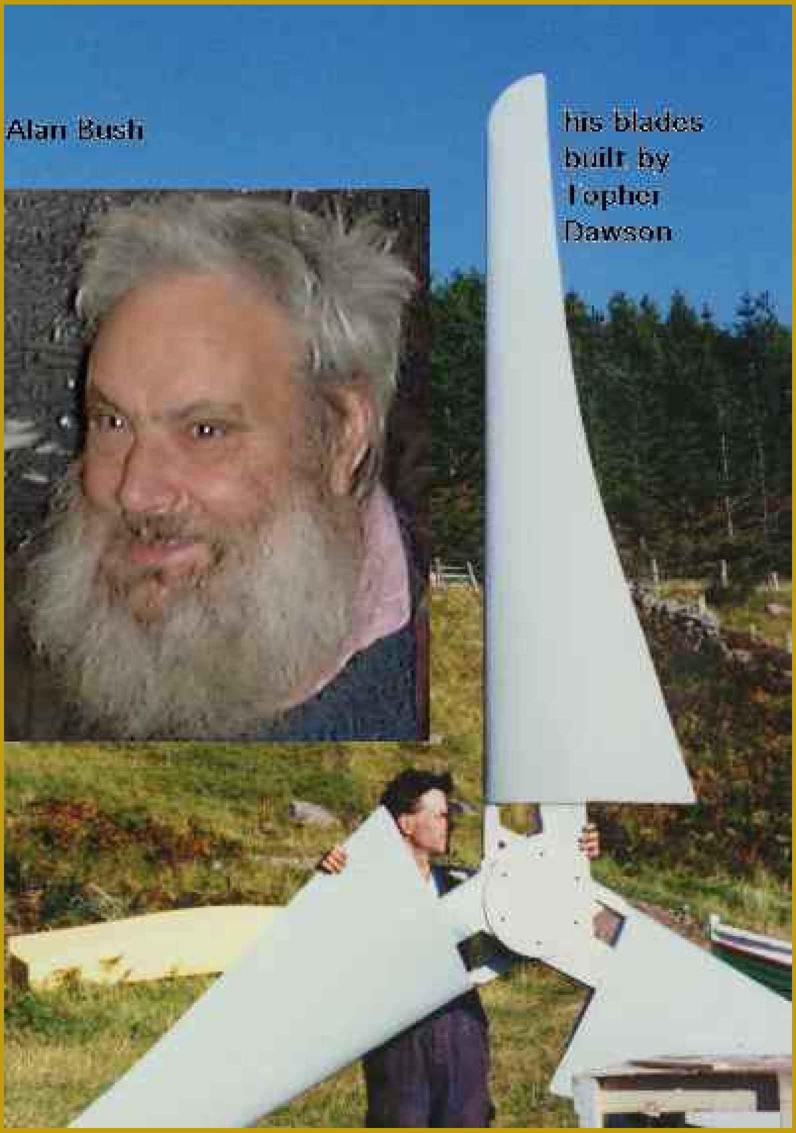
In this one you can see 3 AWP machines out of the 7 which are now up and running in this area.

We have had some early problems related to manufacturing quality of the alternator shaft, and cracks in the fibreglass blades, but there are no real technical challenges remaining for this machine. It works. It just remains to get on and install them.

Another one to shout about is the 4kW heating machine I built with help from Alan Bush and African Windpower in Zimbabwe (who made the stator for me). African Windpower are working on a production version.



The blades were made on Scoraig by [Topher Dawson](#).

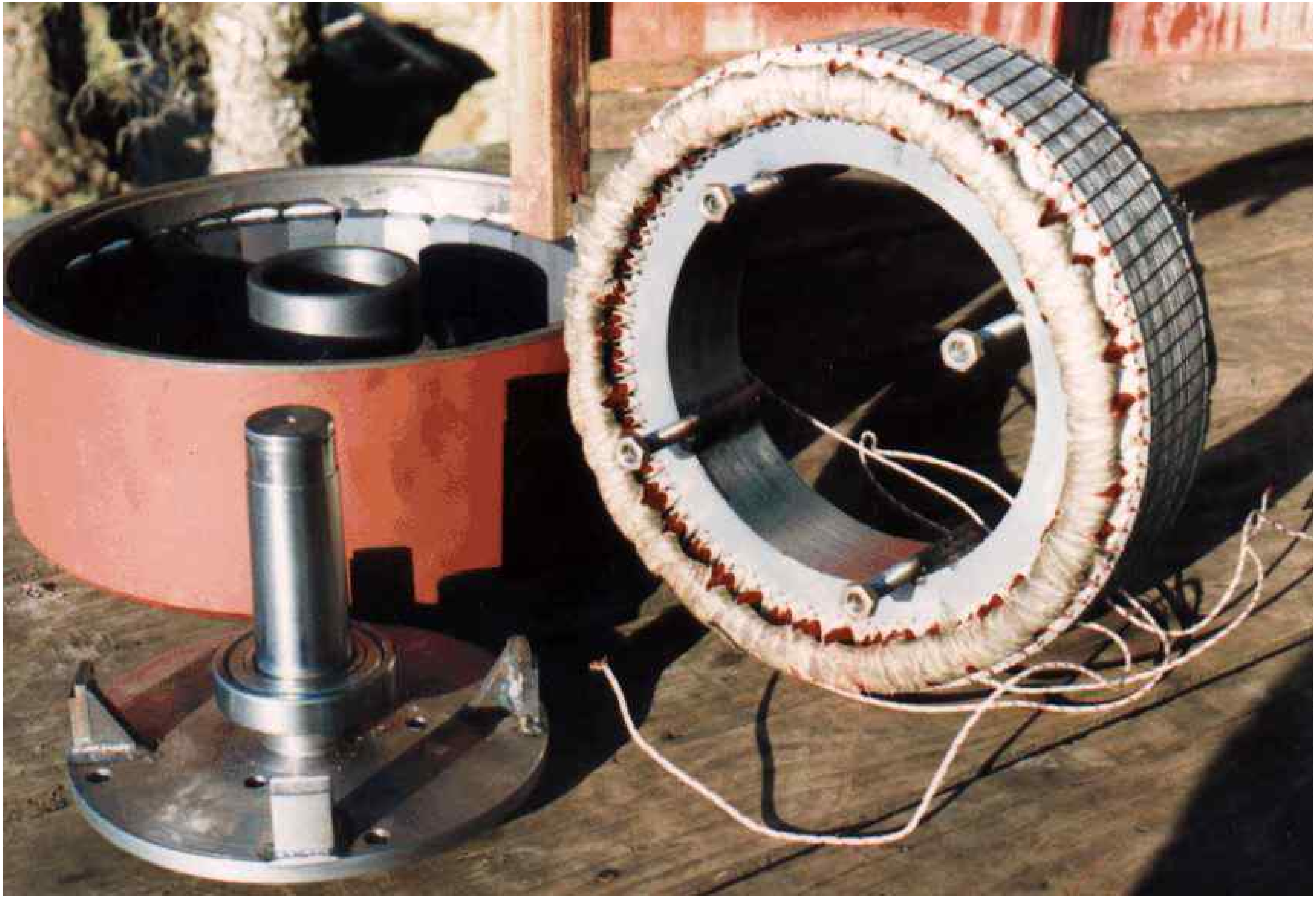


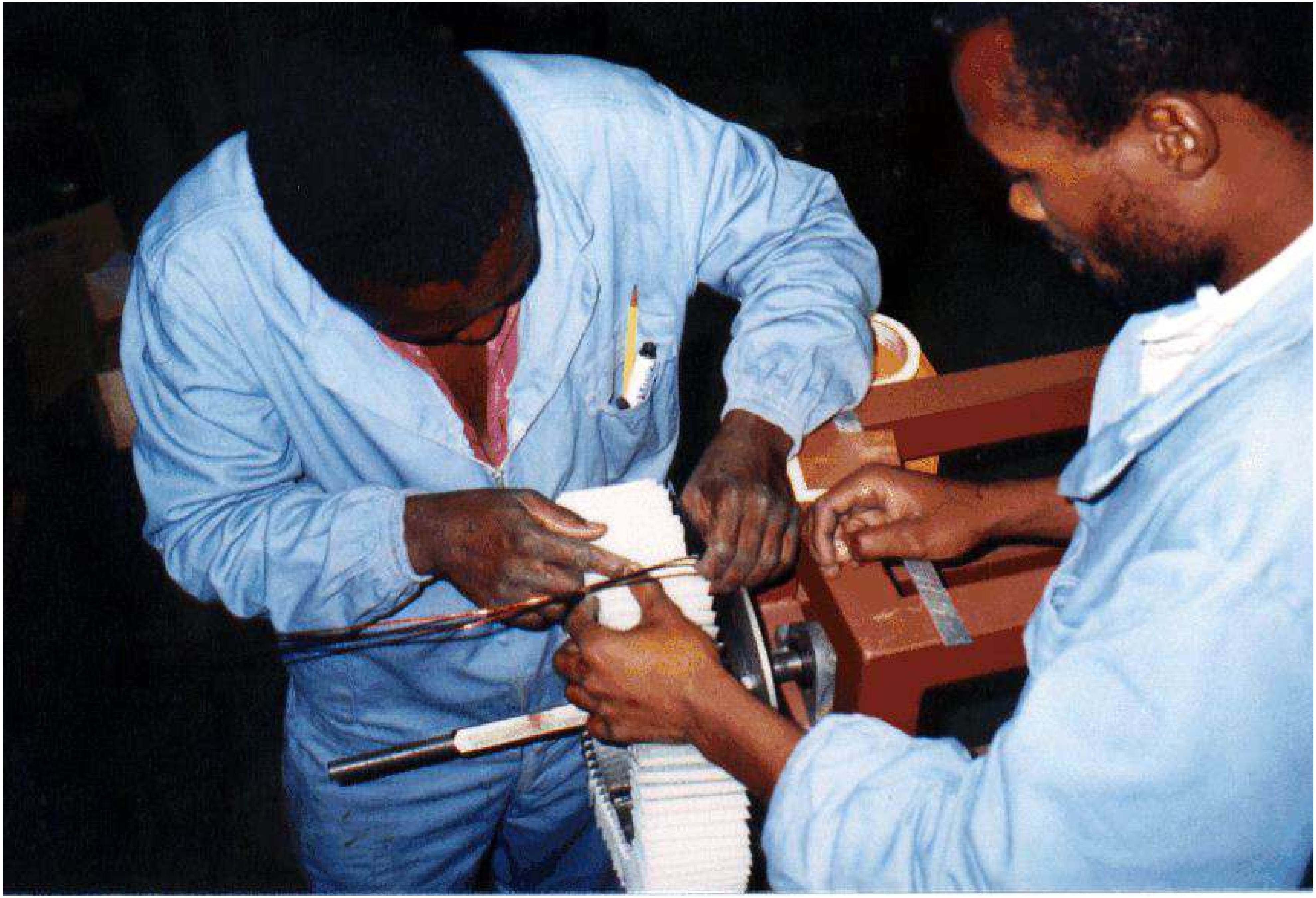
In the next picture you can see it being lowered for repair in June 2000.
It does have occasional problems, with rotor balance, stator insulation, and suchlike, but it has run pretty consistently for nearly three years.

Here are a couple of pictures of locally produced prototypes using the alternator I have designed for ITDG for local manufacture in sri lanka and peru. see also this link for details of the alternator and how to build one.

[Back to Hugh's homepage]


1 KiloWatt Powervision
Wind Turbine
Turbine Blade





PROVEN

PROVEN ENERGY

Proven Improved Blade System ñ PU Zebedee Hinge

Prepared: BR
To: Hugh Piggott
Date: 5/12/01

Background

ÝProven decided to improve blade lifetime on our WT2500 and WT600 wind turbines by going to a higher performance blade hinge material back in late 1998.ÝÝÝÝ The blades at that time featured zebedee hinge material the same as that of the blade (polypropylene).ÝÝÝ

This had a working life of 3-5 years depending on site severity and average wind speed.ÝÝÝ While replacement costs were low (~£200 if metal fixing plates from old blades were recycled) often machines in the field are in difficult locations and many Proven machines are not maintained as per manufacturers recommendation!ÝÝÝ The development of a blade hinge with a higher lifetime was started.

The Solution

After extensive bench and field testing the Proven PU blade hinge was introduced to all 3 turbines in the Proven range in early 2000.

It features a specially formulated polyurethane (PU) hinge with integral nylon rope strengthening.ÝÝÝ The rope patterns are wrapped around the fixing bolt locations at either end of the hinge.

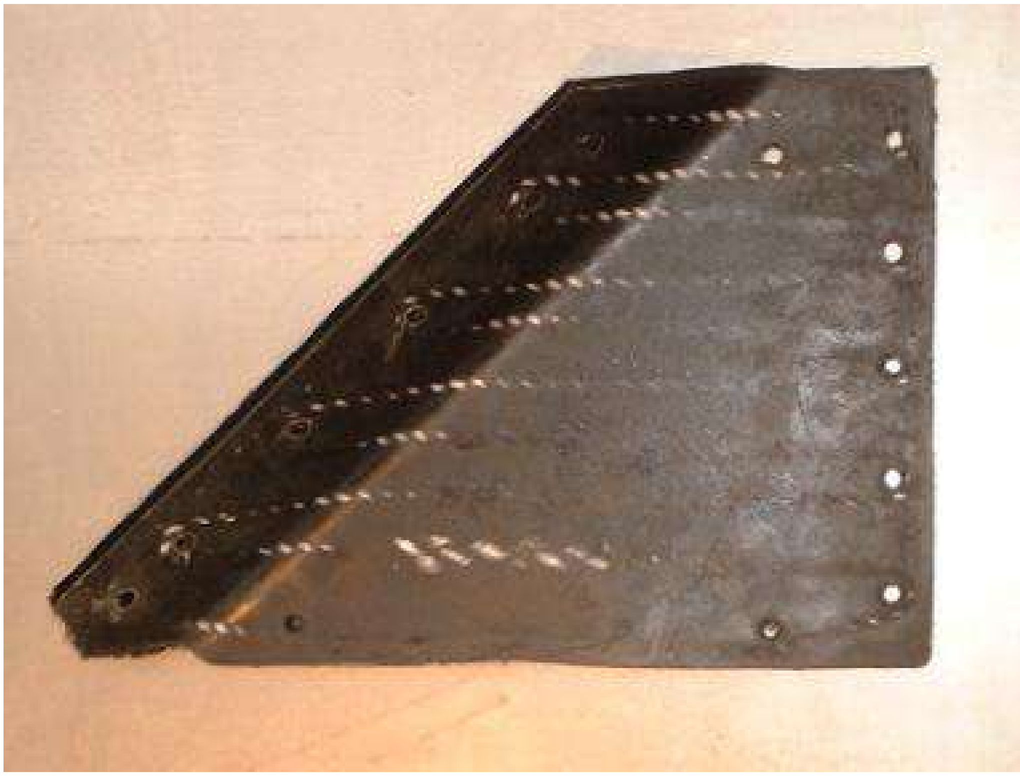


Figure 1: Proven WT2500 Blade PU Hinge

Figure 2: PU Hinge separate and integrated into the blade root.

Thermal Performance

Another element built into the PU selected for the hinge was excellent performance over a wide temperature range from ñ40 to +50 deg C.ÝÝ This makes the turbine suitable for operation in more extreme climates.

PU hinge lifetime

We have to a fair no. of years before finding out!ÝÝÝÝ From the testing we have done we are confident of 10-15 years for the PU hinge.ÝÝÝ We have had no problems with any of the PU blades in operation so far.ÝÝÝÝ This has effectively removed this maintenance issue.ÝÝ When the PU hinge does wear out then just this small section of the blade will need to be replaced.ÝÝ This will typically be a field retro-fit.

Retro-fitting Blades

Sets of PU blades are available for retrofit to existing wind turbines ñ all fixing points for the blades are unchanged from the previous polypropylene versions.

Spare Parts No.s

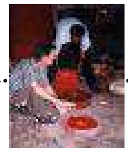
PU2501 (1 set of PU blades) replaces the BL2501 (1 set standard polypropylene blades)
PU601 replaces BL601
PU6001 replaces BL6001

In July I got back from a trip to sri lanka, part holiday part windpower consultancy job. It was a lot of fun and very interesting so I am going to give you a brief acount.

The job is with Intermediate Technology (IT) sometimes known as IT development group (ITDG) who have offices in many countries including UK, peru, sri lanka, zimbabwe, nepal... they operate on ethical principles, centred around Schumacher's 'Buddhist economics' whereby local solutions are found for local problems, and 'small is beautiful'. Nice people to work for, in other words.

In this project they are developing a small wind turbine for battery charging (100 or 200 watts rating) which will be manufactured in Sri Lanka (and also Peru..). I am designing the alternator, and helping with other aspects. I produced a design and built a prototype, took it out there and taught Udaya in his small workshop how to build it. He built it and we tested it. It worked fine and he was very enthusiastic to build many more. The blades etc are still at the design stage. I understand from itdg that the whole project will be put in the public domain when finished so that anyone can share it. The funds come from UK government DFID.

Here is a picture of Udaya Electricals in Colombo. The alternator prototype alternator is on the left. Centre is Sunith Fernando, who is Mr Windpower in Sri Lanka, and designer of the turbine. Udaya Hettigoda is on the right.

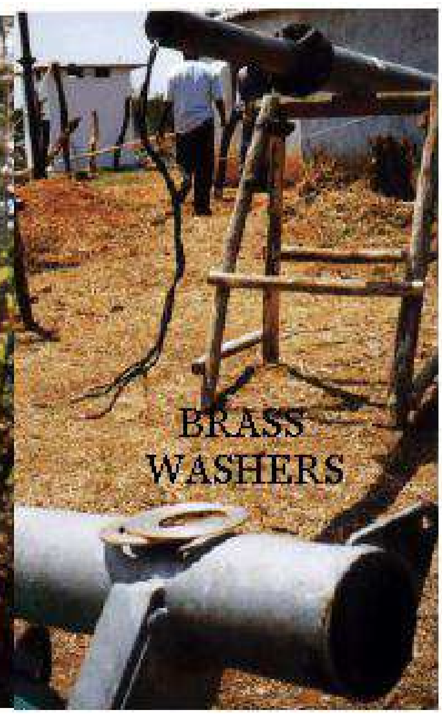
.click..on..pic.
.for full size.

ITDG Sri Lanka have done a number of successful small hydros for village electrification, using induction motors and peltons in most cases.
Udaya Hettigoda, who I was teaching, had worked on 80 (or could he have said 18?) of such projects, and in some cases done the whole thing himself, from site assessment to designing/welding the manifold, building the electronic controller and commissioning the system. Now he is keen to build wind turbines.

Wind in SL is quite good in places but very seasonal. Between monsoons are killer calm periods which cause a headache for system design. What to do for power in these periods? Windpower is potentially very cheap, but if a back up source is needed this can ruin the economics. If the back up is PV, and sized to meet the load then it can run the load all year (no need for windpower). Engine back-up is expensive.

IT took me to a site where they had a wind/Biogas system in operation. It's an interesting country to drive around in, to say the least.

The wind turbine was a 2kW unit from LMW in Holland. I know LMW well from years gone by, so I was able to give some helpful practical advice. The machine was working quite well (to my surprise) on this site.



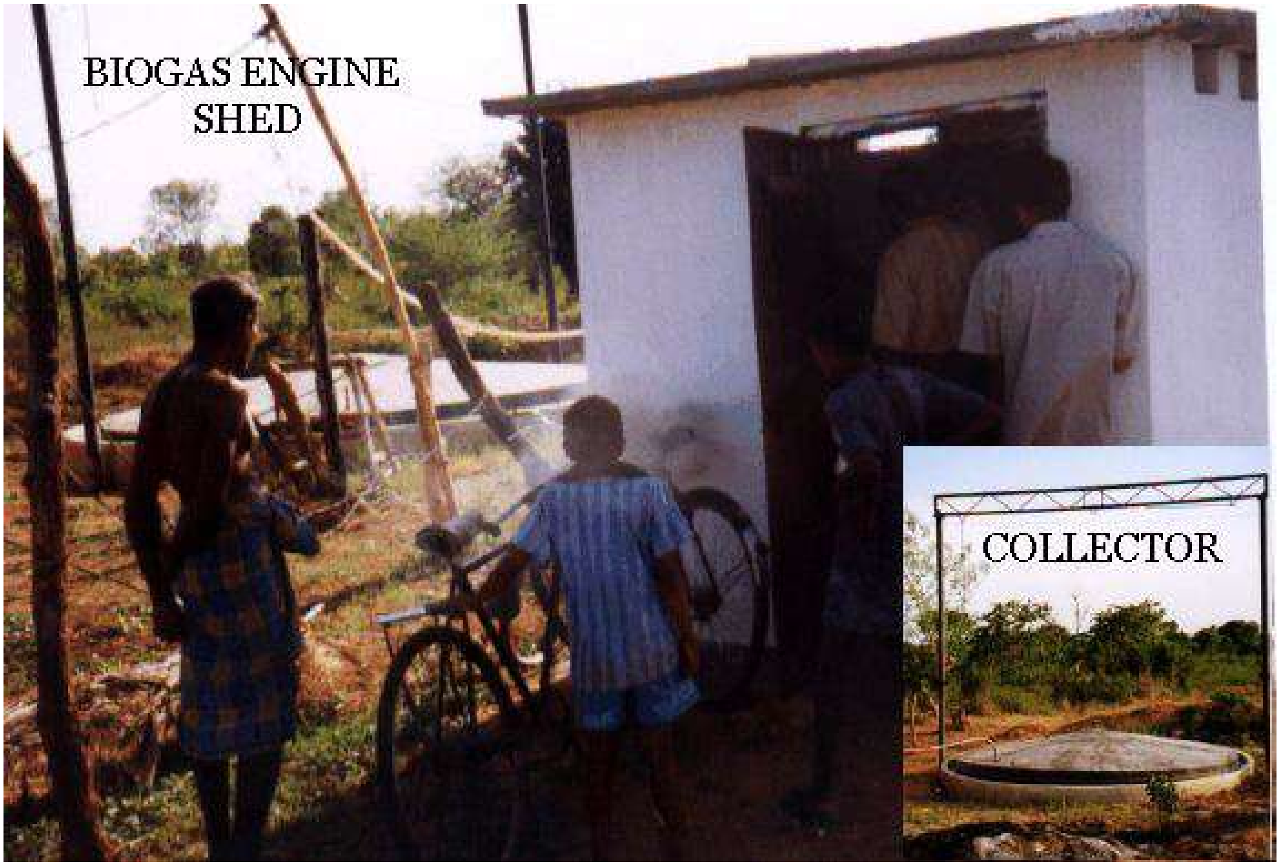
We took it down for some minor repairs and adjustments.

The thrust bush in the yaw head had worn out (nylon) and we replaced it with 3 brass washers, 100mm in diameter. This was fascinating mission, in a small agricultural town.

First we visited the machine shop but they had no brass stock large enough (100mm diameter). Then we found some irrigation fittings in the scrap dealer which were almost big enough. I was happy but the IT guys decided to check out the local store, and (miraculously) found a piece of brass stock of the right size. You can buy anything at Embilipitya Stores!

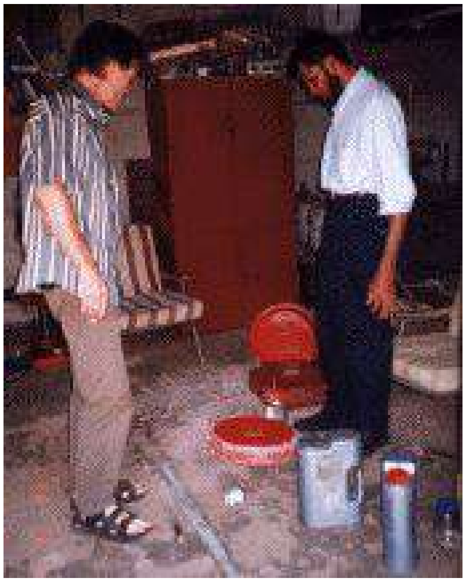
But it cost 20,000 rupis (US$35ish) . A small fortune! In SL you can buy a 4 hour train ticket for under a dollar, and raise a family on about US$50 per month. Anyway we negotiated the price down by returning the surplus, and had the washer machined. 2 hours skilled lathe work cost only US$3.

The biogas plant is a huge hole in the ground full of rice husk and manure which lasts for 6 months. A big bell of steel captures the gas. There was a small problem with the airfilter, so they were running the engine on dead dynasaurs instead when I came. I hope they get that fixed. Biogas is worth looking at for hybrid systems, but this system was very expensive, so there is a way to go yet.



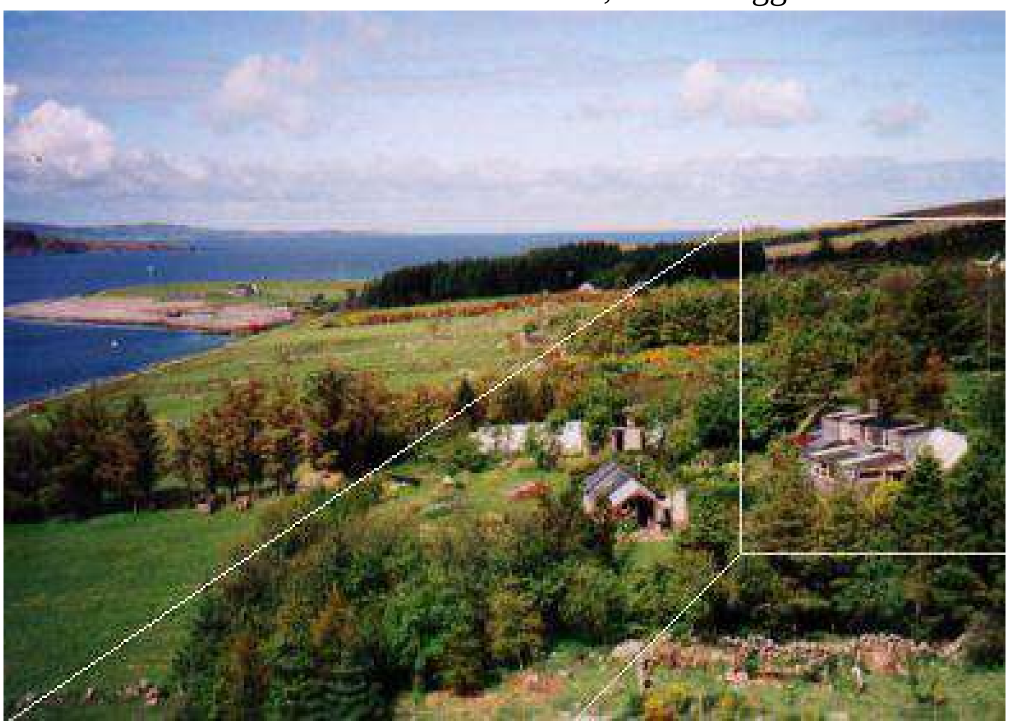
Sri Lanka people are very friendly, always smiling, and a joy to be among. There is an understandable desire to share the money which westerners bring into the country. (Suddenly you find that you are fabulously rich compared to the locals) and some are over-eager to provide you with services which you may not need, but with good humour this need not be a problem. When they rock their heads from side to side and say 'Ow ow' they mean 'yes', which is rather hard to get used to, but very charming. I am looking forward to going back next year if our plans materialise.

Hugh



The picture above shows the end of the Scoraig peninsula, as seen from the top of Ben Ghobhlach (our nearest mountain). See map at bottom of this page.

The box on the left is where we live, shown bigger below.



There are a lot of trees around our house, so it's not nearly as windy as when I first moved into it in 1975.

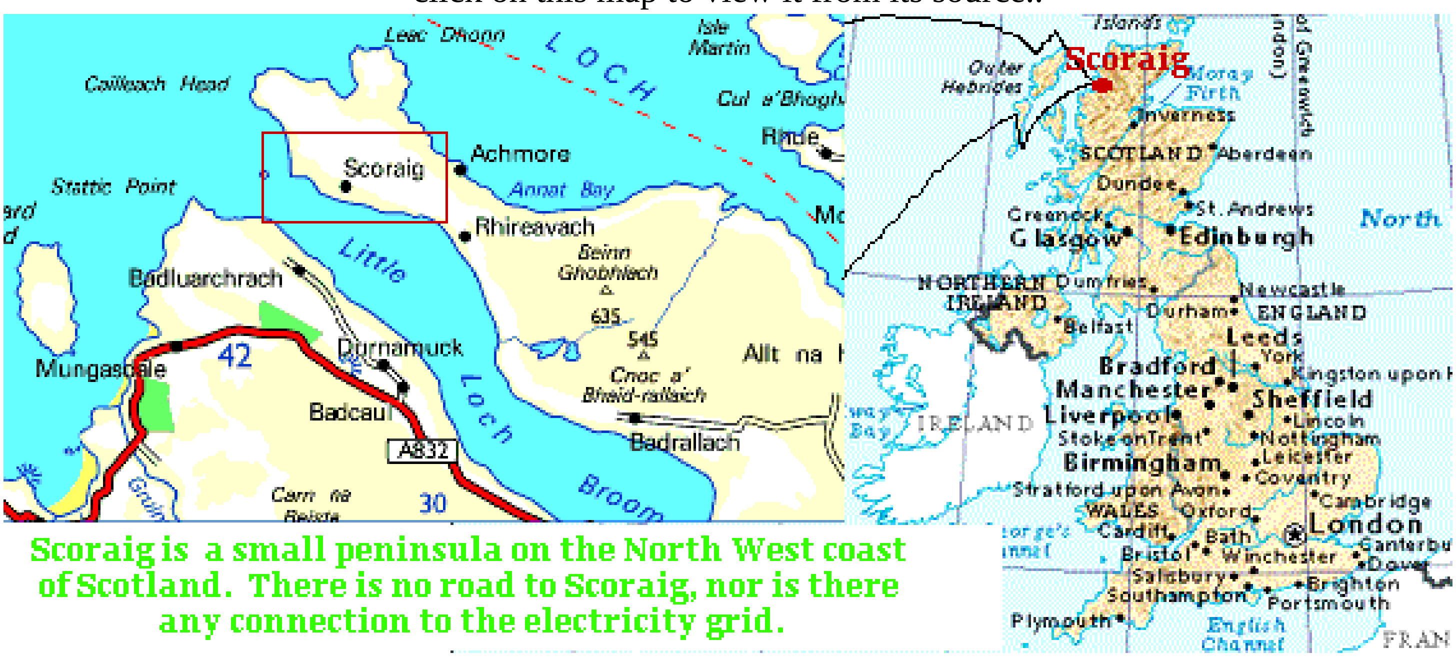
The next picture is a closer zoom again.

The house has also grown since 1975 - I've added bits every couple of years.

Now you can see our growing array of pv panels, for charging my 12V battery on calm sunny days.
There are 525Wp of solar, in seven 75W BP panels..
You can also can see my little windmill (but not the big one - that's where I took this from).
The little windmill is 2.3m diameter Windkit typ.
You can see a picture of my big windmill among my african pics. - because that's where it came from.
Now it's on a 20metres tower near the house.

My wife Jytte is brilliant at growing flowers, so the whole place is covered in flowers.

Here is where Scoraig is on the map.
click on this map to view it from its source..



[Back to my homepage.]

Information about Hugh Piggott

Windpower fanatic. Born Scotland 1952, educated Edinburgh and Cambridge. After graduation in 1974, went 'back to the land' at Scoraig in NW Scotland where I remain. For 4-5 years I did without electricity. Married with children (now grown up). Built my own house. Grew vegetables and kept cattle.

In 1978 I got seriously bitten by windpower. I have used wind and solar power for my own electricity ever since that time. I have designed, built and sold small wind turbines in sizes from 3 feet to 15 feet in diameter. These supply electricity to the population of Scoraig (about 100 people) and beyond. I had to learn the essentials of aerodynamics, electrical engineering and all other aspects of small wind turbine design.

During the early 1980s I started to write up my experiences and published some booklets. Took guided tour parties around the small wind systems of Scoraig. In 1986, helped to found a secondary school here, and gained experience in teaching physics, mathematics and computer skills.

In the late 1980s I decided to broaden my perspective, and I started to do some work with wind turbine manufacturers, testing and developing machines, in the demanding conditions we have here. Built up a connection with the Centre for Alternative Technology in Wales, teaching windpower at their four day courses twice each year. Stopped milking a cow and bought a fax machine.

In 1995 I was hired (as part of an aid project) to design a wind turbine for local manufacture in Zimbabwe. The design prototype was successful and has lead to a company 'African Windpower'

being set up to manufacture the wind turbine. Good design was important in this process, but equally important was the ability to provide clear drawings and instructions, and to train personnel in Africa during my short visits to the country. More recently (1999-2000) I have travelled to Sri Lanka and Peru, on another aid project for a different organisation 'Intermediate Technology'. In both countries I have successfully trained local people to build alternators for small wind turbines. The project is ongoing, involving preparation of a manual for construction. Another phase of dissemination to more countries is planned.

I have also installed several direct AC hydro systems in recent years, mostly on the island of Eigg. I find hydro very exciting because it provides much more energy at lower cost (on a good site) than wind power, and you do not always need batteries. I hate batteries.

In 1999 and 2000 I was chosen as the renewable energy consultant to the BBC's Castaway 2000 program. I designed and installed a wind and hydro system which kept the castaways supplied with electricity throughout the year. I am also training Scoraig people to help build small wind turbines.

Authorship

I have written a number of short books about building small wind turbines, culminating in a longer one 'Windpower Workshop' (CAT publications 1997) which has sold over 6,000 copies, and is becoming increasingly popular. I have also published plans for a specific small wind turbine design, based on the brakedrum of a truck. This is currently selling at approximately one thousand copies per year. See www.picoturbine.com Others have been inspired by this particular design, for example Robert Budd in Canada who teaches workshops in windmill construction in Ontario.

see my web page for more information

Renewable energy systems

from Castaway 2000 TV program

NOTE: I designed and installed this system with some labour input from the 'castaways' themselves. This page was orignally written as a description of the equipment for sale at the end of the project. The castaway renewable energy systems are no longer on the market. But I am leaving the details here on the web in case they are of general interest.

The castaways' electricity came from two renewable sources: wind and hydro turbines. Energy was stored in a battery, and then converted to 230 volts mains power by two inverters - one for normal use, and one for backup. These are Trace SW series inverters, with many sophisticated software functions built in - including the ability to automatically start a generator (not used on Taransay, where the generator was hand started if necessary). The backup inverter was also used to feed surplus power to heaters and prevent the battery from overcharging. There is a changeover switch to allow easy transfer of the load between inverters and also (in the worst case) to a backup generator. This switch was never needed. The inverters synchronised with the generator automatically (when it was started up), and use it to charge the battery when necessary.

The wind turbine is a 2.5kW 'Proven' with 48 volt output, on a 6.5 metre free standing tower (see bottom of page for detailed pics of tower). The tower comes complete with a Tirfor rope hoist for easy erection. There is a kit of spares for the turbine, including blades and springs. Heavy armoured cable takes the power down to the battery room. Adjacent to the battery room is a plant room, with the 'controller' for the wind turbine. This converts the 3 phase AC power form the wind turbine to DC, and monitors the battery voltage. If voltage indicates that the battery has reached its maximum optimum charging rate, then surplus current is diverted to a special (multiple element) immersion heater.

The battery comprises 8 quantity, 12 volt units, each with 230 amphour capacity (at the 20 hour rate), giving a total of 460 amphours at 48 volts nominal. This represents about 15-20kh units of usable electricity storage. Battery charge level is displayed as a % on an amphour meter panel, for easy interpretation by the castaways.

The hydro turbine is a 'stream engine' from Energy Systems and Design <http://www.microhydropower.com/> It has two nozzles which can be used to control water usage.

At present it has 440m of 5 inch pipe (MDPE which could be re-used with new fittings) and a mile of high voltage cable (6mm 3-core steel wire armoured). There is a 3-phase transformer at the battery, to step the voltage down to 48 volts for battery charging. The existing site has 30m head (drop from intake to outlet). It functions with between 1 and 8 litres of water per second, as available.

This turbine would supply all the electrical needs of a typical home, from a stream one mile away, producing up to 1kW charge rate into a 48 volt battery, (depending on the available water),

Here is a rough guide to the NEW costs of the above items

battery 2320
immersion heaters 105
amphour meter 205
Switch boxes 168
Inverter 3.3kW 2361
inverter 4.5kW 2697

wind turbine 3385
tower 1580
Tirfor 360
Cable 259
Spares 521
controller 855
hydro and transformer 2400
Pipe 2500
cable 1530

Liz (a castaway) reports to me on the state of the system on 6th December 2000 as follows:

The hydro & windmill have worked fantastically well throughout the year (apart from the lack of water during the summer).

- windmill - great no problems whatsoever

- hydro - started working again when the water levels rose in September. Have got 13 amps continuously from it since then. fuses blew once on the hydro, not sure why - maybe the unit got wet - but replaced them with new ones and it has been fine since.

Diesel - used hardly at all except for the odd windless day during the summer & when the fuses went on the above for a couple of days. The diesel supply we started with has lasted all year.

So all in all the system's worked brilliantly.

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wind turbine tower details:


Proven 2.5kW installation
Western Isles of Scotland
December 1999

Renewable Energy Equipment

Trading as Scoraig Wind Electric I sell and install wind, hydro and pv equipment along with batteries and inverters for stand-alone systems. I am happy to spend time on the phone or by e-mail (not so happy with letters) discussing your requirements. I often have to persuade people not to buy a wind turbines, which is hard, but necessary if they have very little wind or they think they can save money off their mains electricity bill. I try to limit my sales to successful systems.
Government grants are coming in this year to assist with installation of small renewable energy systems. They offer a 30% grant on systems installed by an approved contractor.

Wind turbines

I sell the Ampair Hawk, which is probably the most robust wind turbine I have ever come across. The Hawk is suitable for a very small bothy or holiday home in a windy spot. It can deliver about 15kWh of electricity a month. The cost is £466 plus VAT.
There are more pictures of Hawk installations I have done on the Ampair page under galleries > Isle of Eigg. Most of these pictures were actually taken on Scoraig. It also shows a twin turbine installation on the Isle of Eigg.

The ampair is a battery-charging wind turbine with 12 and 24 volt options. It is usually necessary to buy a separate regulator to control the battery charge rate.

I import the African Windpower AWP36 machine from Zimbabwe in batches every couple of years. I am fond of this machine because I designed it myself. It is very cost-effective but availability is not so good because of the shipping and the situation in Zimbabwe.
Rotor diameter is 3.6 metres so the AWP can catch plenty of energy in light winds.

"Nothing tells you more about a wind turbine's potential than rotor diameter."
- Paul Gipe
-Wind Energy basics, Chelsea Green 1999

I use it for powering my own house and it produces about 200kWh per month on average. I also use 500 watts of photovoltaics to keep my system going during the calmer months. My last batch of AWP turbines sold at £2000 each plus VAT.

I recommend and sell the Proven range of wind turbines because I know from experience that they are very robust and durable. Prices range from £1845 for the 600 watt machine to £7765 for the 6kW. I prefer the 2.5kW machine (£3655) because of its track record.

I act as an agent for Wind and Sun, the UK agents for Trace. I can therefore sell inverters, solar panels, charge controllers etc. at the same list price as Wind and Sun (including the 10% discount on Trace SW inverters). For smaller systems the range of Studer sine wave inverters are often a good choice.

Hydro turbines are usually the best option if you have a suitable site. I sell the north american battery charging turbines from Energy Systems and Design, and Harris hydroelectric.

Photo: Paul Cunningham of Energy Systems and Design, Canada

I am also looking into the idea of importing Platypus turbines from Australia, as a substitute for building larger hydro turbines myself. With a good flow of water and a reasonable gradient, you can produce enough power to make a direct AC supply to the house without batteries.

SCOTTISH EXECUTIVE

Energy Saving Trust

Scottish Community Renewables Initiative (SCRI) – Households Grants

One quarter of all the UK's emissions of carbon dioxide (the key climate change gas) comes from household use of fossil fuels. Scottish householders have a vital role to play in lowering our greenhouse gas emissions, and in helping to reach Scotland's target of 40% of electricity from renewable sources by 2020.

There are many small-scale renewable energy technologies suitable for residential premises. They can provide electricity to run appliances, heat water and provide heat for space heating. To help Scottish householders play their part in protecting the environment, and to help build a thriving renewable energy industry in Scotland, the SCRI provides financial support for a range of eligible technologies, for both individual households and community groups. The Energy Saving Trust (EST) is managing the household component of the SCRI on behalf of the Scottish Executive. The Energy Saving Trust and the Highlands and Island Enterprise are managing the community component of the SCRI.

Funding available under the household scheme

- Funding is set at 30% of the installed cost
- The maximum grant is £4,000. Any capital cost up to £13,300 will attract funding. The householder can spend more money than this and still be eligible, but expenditure over £13,300 will not attract additional grant
- Match funding from other public sources for the same system will **not** be allowed. This is to ensure the efficient use of public sector funds

What technologies apply?

Technologies eligible under the Scheme include:

- micro hydro-electric
- micro wind
- solar water and space heating
- ground-source heat pumps (powered by renewable electricity)
- automated wood fuel heating systems
- solar PV (photovoltaic) in dwellings not connected to the electricity grid

The scheme will **not** fund:

- PV installations that are eligible to apply for funding under the DTI Major Photovoltaic Demonstration Programme
- Non-automated wood burning stoves. This is a mature technology with a well-established market which does not require pump-priming support

Installations that are connected to the main electricity grid, stand-alone, or connected to a mini-grid are equally applicable.

Eligibility

The main criteria are:

- SCRI grants are open only for owner-occupied residential dwellings in Scotland
- The renewable energy system must supply a residential building or a permanently sited mobile home
- The system must be designed, installed and commissioned by an approved installer, and must use components approved by the DTI/Scottish Executive or their agents as conforming to relevant standards
- A maximum of two grants per property are available, each covering different technologies
- To maximise the carbon dioxide savings, applicants should consider measures to save energy through energy efficiency, at the same time as switching from damaging fossil fuel technology to renewable energy. All applicants will be offered a DIY Home Energy Check by their local Energy Efficiency Advice Centre as part of the grant award process

Application process

- SCRI – Household Stream will use a fast track application pre-approval process (full details will be provided with the application forms)

- Two quotes must be obtained per system, unless suitable evidence can be provided as to why this was not possible (for example, lack of local suppliers, remote locations)

Suppliers and installers

Under SCRI, only systems installed by accredited installers are eligible for grant. SCRI will rely on the accreditation process being developed for the *Clear Skies* programme (the equivalent England/Wales/Northern Ireland scheme). Installers should contact the Clear Skies programme on 08702 430 930 or visit the website **www.clear-skies.org**.

More information

The application forms and procedures for the SCRI are currently being developed by the Energy Saving Trust and are expected to be available from early February. If you would like more information on the operation of the SCRI, contact the SCRI Hotline on **0800 138 8858** (Monday - Friday 9am – 5pm**)**.

Correct as at 15 January 2003

SUSTAINABLE ELECTRICITY SUPPLIES FOR THE ISLE OF EIGG

This page provides supporting material for the report.

Scoraig Wind Electric site
Isle of Eigg site

The report is available for download or viewing here

The pdf file is 900kB in size
To download the report, right click on the word 'here' and choose 'download link to disk'

Software used to model renewable energy sources

Wind power The database of windspeeds over the UK can be downloaded free of charge from the British Wind Energy Assocaitation website .

Hydro power HydrA is a software package developed (and sold) by the Centre for Ecology & Hydrology at Wallingford. The National River Flow Archive provides useful data free of charge.

Solar (photovoltaic) power software from Retscreen in canada is available from free download.

The new grants available under the Scottish Community Renewables Initiative

contacts:-

HIE's community energy unit

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Factsheet on Community grants in pdf format

WEB LINKS FOR EQUIPMENT

-- These are useful links, but no claim is made that they are complete or up to date!

Manufacturers Wind Turbines (UK)

Proven Engineering Products (also hydro turbines) Kilmarnock, Scotland

Ampair Hampshire

Marlec Engineering Co. Northamptonshire

LVM Ltd Bedfordshire

Iskra UK

Supplers of wind turbines (UK)

Windsund Energy Systems Tyne and Wear

Scoraig Wind Electric Ross shire

Galeforce Northern Ireland (good web site)

Suppliers of wind turbines, solar panels and inverters (UK)

Wind and Sun Ltd. Herefordshire

Sundog Cumbria

Solar Energy Alliance Suffolk

Dulas in Wales (pv and small hydro systems plus consultancy on many issues)

Manufacturers of wind turbines overseas

African Windpower AWP Zimbabwe

Bergey Windpower Oklahoma USA

South West Windpower Arizona USA

Manufacturers of inverters Overseas

Power Solutions Australia Australia

Xantrex (Trace) USA

Manufacturers of hydro turbines Overseas

Platypus Australia

Harris USA

Energy Systems and Design Canada

Katmendu Metal Industries Nepal

Critical comment on wind turbines

Ocean Solar USA

Paul Gipe USA

User magazine Home Power also for sale in UK from Wind and Sun Ltd

CENTRE FOR ALTERNATIVE TECHNOLOGY WALES

SUSTAINABLE ELECTRICITY SUPPLIES FOR THE ISLE OF EIGG

A report by Hugh Piggott, Scoraig Wind Electric
For The Isle of Eigg Heritage Trust
February 2003

TABLE OF CONTENTS

Overview

This report for the Isle of Eigg Heritage Trust seeks to identify the best strategy for meeting the electrical needs of the island in a sustainable way. Additional resources, links and software can be found at the web address printed in the footer of the page.

Section 1. Pros and cons of renewable energy

Renewable energy sources (energy from wind, water and sunshine) are the only energy sources that can ultimately provide electricity in a sustainable way. We shall assess the practical implications of maximising renewable energy use on the small scale.

Section 2 : Questionnaire

Popular support, and community involvement, are both key issues for successful development of renewable resources in the UK. A questionnaire was used to gather information on present electricity usage, and future preferences among Eigg residents. Several options emerged, including diesel generator power, small hydro turbines, wind and solar power.

Opinion on the island favoured the continued use of diesel power as a backup source, while exploiting the abundant renewable resources of the island for the bulk of the energy required. Reliability is also an important consideration, and most islanders would like to have uninterrupted power delivered to them. Some islanders desire a connection to the mains electricity grid, because of its reliability.

Section 3: . Electricity supply requirements

The first step in designing any electricity supply is to estimate the demand. Demand is described in two ways: the peak (instant) power demand and the total demand for energy over a given period. Power (kW) is the rate of consumption of energy at one instant, whereas energy (kWh) is the accumulation of electricity consumed over a period.

We can assume that demand will increase over time until all of the affordable energy is used. This process is typical of our consumer society, which is intrinsically unsustainable. A sustainable strategy will instead use energy conservation measures, to improve our enjoyment of the benefits of electricity while reducing our actual demand for energy.

Section 4: The renewable energy resources of the island

Hydro and wind turbines are already in use on the island, as are solar 'PV' panels. In section 2 we look at the scale of the available resources, and the best sites where their use can be expanded.

There is very little hard data for water run-off, windspeed or insolation (solar energy) on the island. Instead this report relies on computer software packages to predict the energy capture of different types of renewable energy equipment.

Experience has shown that reality is different from software predictions in most cases, but the software gives us a starting point for planning an overall strategy. It would be prudent to monitor the renewable resources (windspeeds, water flows, etc) at several sites and to data-log the daily production of pilot installations so as to verify the conclusions of the computer models.

Section 5: The suggested model for electricity supply

In view of the high cost of grid connection, this report favours independent power supplies based on a variety of renewable sources, some of which will be communally operated. Stand-alone electricity systems consist of more than just turbines and solar panels. Energy has to be gathered, stored and converted for use as required. We propose that each house should have its own core system, based on a battery and a back up generator.

A network of wind and hydro turbines can be used to provide the bulk of the energy required, supplemented by solar 'PV' arrays at each building. A pilot project using a centralised hydro to feed several battery systems is under construction at Kildonnan on the island. Similar schemes could be developed to form a network of independent cells covering the whole island.

1. Pros and cons of renewable energy

Why we need renewable energy

Renewable energy is plentifully available all around us every day, and there are no particular technical obstacles to harnessing it. Wind and water power have been in use long before the invention of combustion engines, and it seems likely that they will be the chosen technology in the future, when we shall have to reduce our unsustainable reliance on fossil fuels. Renewable energy production causes no CO2 emissions nor does it consume fuel resources, after the initial manufacture and installation of the turbines, solar panels and infrastructure required. Using renewable energy frees us from dependence on imported fuels, and sets an example for developing countries. Most of the world's population could not possibly use fuels resources on the scale they are used in the west. If the entire world tried to live the lives we live now in the UK, then the planet would immediately choke to death.

Problems with renewable energy

The biggest problem with renewable energy is the high capital cost.

The energy is diffuse and demands large structures to collect and convert it. The equipment is expensive and comes with a large amount of infrastructure. There is an 'energy cost' associated with manufacturing renewable energy equipment. This investment has to be redeemed before it can be said to produce a net energy output. The time required to pay back the energy cost of manufacture is generally quite small in terms of the life expectancy of the system (often less than one year) but it can be longer in the case of small systems.

Environmental impact is the next big problem.

Wind turbines for example are visually prominent by nature, and will change the character of the landscape to an extent. Some people like to see them, and others do not. Hydro systems divert water from its natural course into pipes and through turbines. This will have some impact on the ecology and amenity of the watercourse. These impacts must be weighed up against the impacts of alternative 'conventional' energy sources, if a rational decision is to be made. We need energy to fulfil our aspirations for lifestyle and survival. Environmental impact of some sort is inevitable.

A third problem with renewable energy is its intermittency.

Unlike fossil fuel, the source cannot be controlled to match demand. The energy is not available all the time, and may not even be easy to predict. To match supply to demand, it may be necessary to store energy, or to reschedule our use of energy, or to use a mixture of different energy sources. This consideration in itself increases the cost and the environmental impacts of the energy we ultimately use at our convenience. On the small scale (domestic electricity systems), we can use batteries to store the energy for later use. A device called an 'inverter' delivers mains voltage power from the batteries on demand.

Household scale, Area grid or National grid systems?

It has been pointed out that small renewable energy equipment (less than 10 kW, say) is inefficient compared with 'utility scale' windfarms, or even the intermediate scale turbines which supply the neighbouring island of Muck. There are several arguments for using small-scale renewables on this island:

Larger scale systems require very expensive distribution networks

The cost of a grid connection cable to Eigg has been estimated at over £2 million. While this is less than the cost of the unpopular pier development, it is not clear that anyone will pay for it. In any case it is arguable that the money could be better spent on renewable energy equipment. This year, the Scottish Executive is launching grants to support the development of small renewables. It will be more cost-effective to site these renewable sources at the point of use than to install an undersea cable. And small renewables can actually deliver the required energy at lower capital cost than the cost of the transmission cable alone.

An electricity network could be attractive, especially for those who would like to obtain a 'turnkey' connection, but again the cost is a consideration. The cost of an island-wide distribution network has been estimated at over £300,000 (Scottish Power, April 2000). Many islanders have expressed a willingness to undertake maintenance and repair of community based energy systems (see part 2, question 4g). It should not be necessary for any unwilling individual to get his/her hands dirty.

The self-reliant lifestyle of the island is part of its appeal

Visitors are a substantial part of the island's economy. They come for many reasons, including the wild life, scenery, fresh air and cultural events.

But part of the attraction is the island lifestyle, including the difficult access and the unconventional electricity supplies. Small renewable energy systems are something to be proud of, and an added bonus for visitors.

Human-scale, community-based renewable energy systems literally place the power in the hands of the local people. Or at least that is how it can be perceived.

2. Questionnaire

The questionnaire was distributed during the winter 2001-2. 30 forms were returned, and most were fully completed. This section includes the original questions, and some analysis of the results.

Replies represented approximately 40 islanders, but the opinions expressed may have been those of the person who filled in the form rather than the household. In one case, two forms were returned with very different opinions, from the same house.

While imperfect, the results must nevertheless help to reflect the views of those decision-makers who would wish to see improved electricity supply options on the island.

The questionnaire began with the following introductory passage.

INTRODUCTION (by Hugh Piggott for Eigg Trust)

I am very pleased to have been asked to prepare a report on the options for sustainable electricity supplies on the Island. The best first step is to gather wisdom from you, the residents, so that I can put forward proposals based on common sense and local knowledge. For my own part I can add some technical analysis, and projected costs.

My own preference is for small-scale, renewable energy systems using wind and hydro (free, clean energy) on a domestic scale. There are other ways to provide electricity to the island. Some options are more sustainable than others are. They range from individual diesel generator sets (as in the past) through to a connection with the national grid.

For example, Scottish Power has already proposed a scheme to power the island, from mainly renewable sources. Their scheme uses an island-wide network and would cost £900,000. In contrast, residents are about to build a smaller water powered project at Kildonnan. It is an example of a 'community' scheme, which is therefore able to attract substantial grants toward the £40,000 cost.

CONFIDENTIALITY
If you have any doubts about this questionnaire, please talk to .....
from the Eigg Trust and he/she will explain what it is about. You are (obviously) free to refuse to answer these questions. That would be a pity because your views might not be understood. Much work can be avoided if we can learn what you want now, and not have to deal with unforeseen objections later.

We hope that you will answer as many questions as you comfortably can. Please feel free to add extra comments as well. If you would like your answers to remain confidential, then we shall not reveal your name. If you are happy to make your views public, that is better still. If members of your household have various differing views, you can try to include them all here, or ask for separate forms.

Thanks for your feedback.

QUESTIONS

1. About yourselves

Would you like all of your replies to these questions to be treated as confidential information (yes/no)?

Only two respondents asked for confidentiality. Two other respondents did not give their names.

If you wish, you can tell me some details of people who live with you - their names, their ages, and how many months of each year do they spend here?

Name					
Age					
Months per year spent on Eigg					

Name					
Age					
Months per year spent on Eigg					

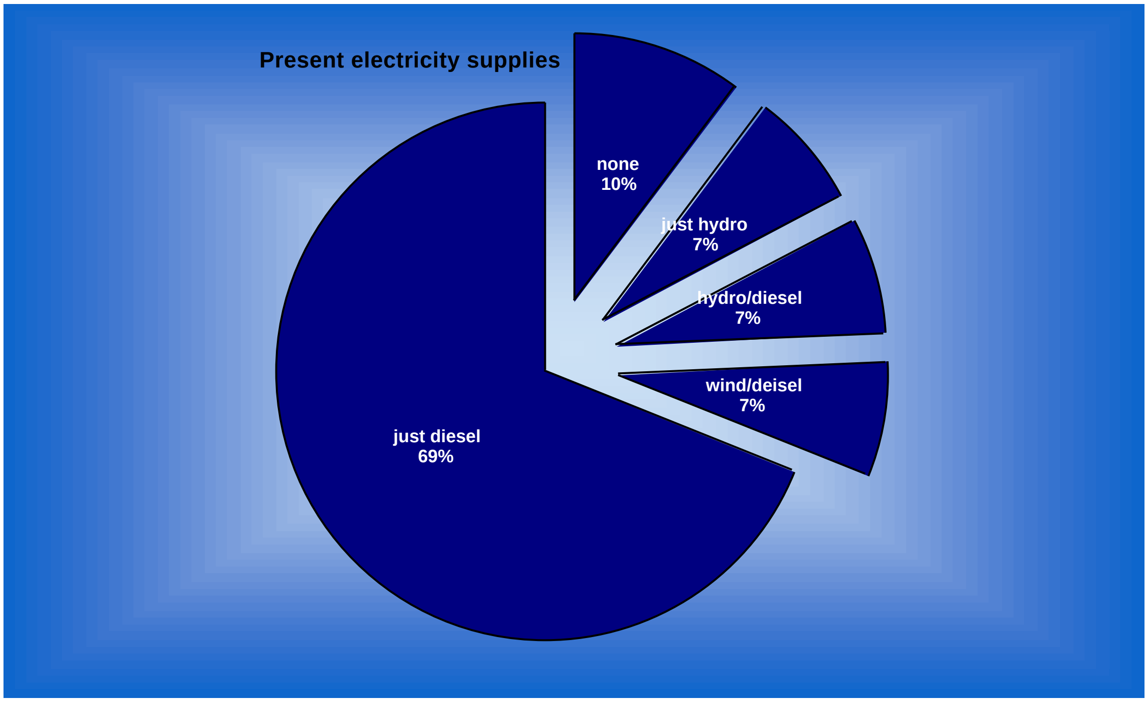
Roughly how many of the above will still be resident in ten years time (if you care to guess)?

This information was useful for determining the location and needs of the respondents. None had plans to leave the island.

2. Your existing Power Supply

a) What is your main source of electric power at present?	
b) Do you use any other sources of electricity?	
c) For about how many hours each day do you have power available?	
d) How much does it cost (roughly) each year to run this system?	
e) How reliable is your electricity supply?	
f) How happy are you with this arrangement?	

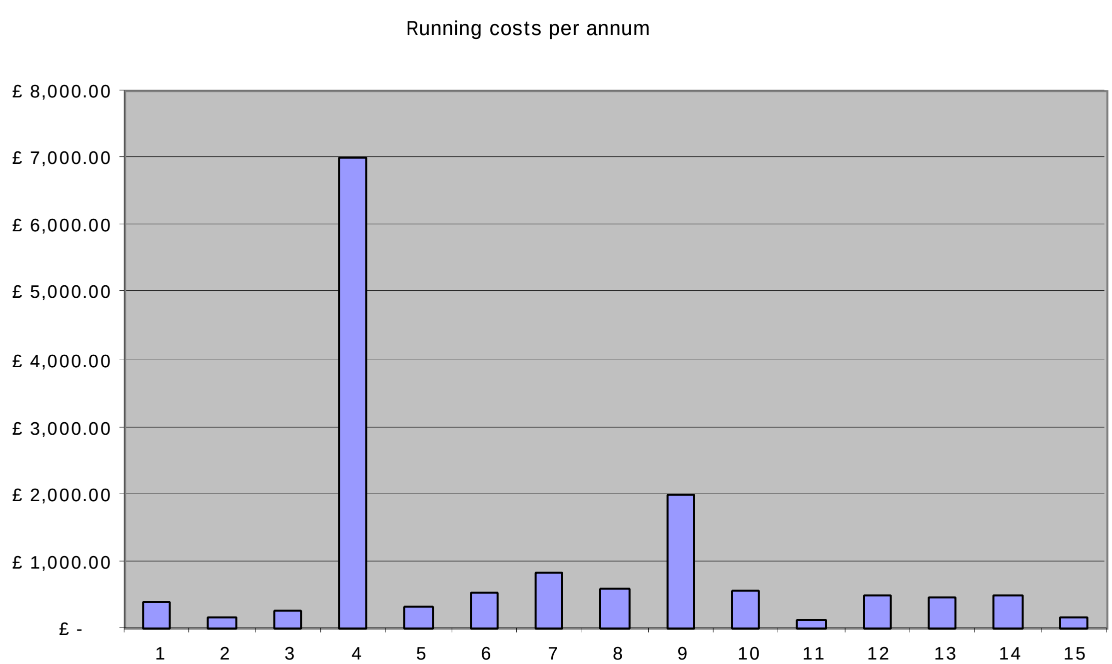
Question 2 yielded interesting statistics



Most of the respondents used diesel generation for all of their power. About half of these used batteries and inverters to maintain a 24-hour power supply.

Reported costs for running diesel generators varied from £150 to £7,000 per annum. £500 would be a typical figure for diesel running costs. Most reported fairly reliable operation.

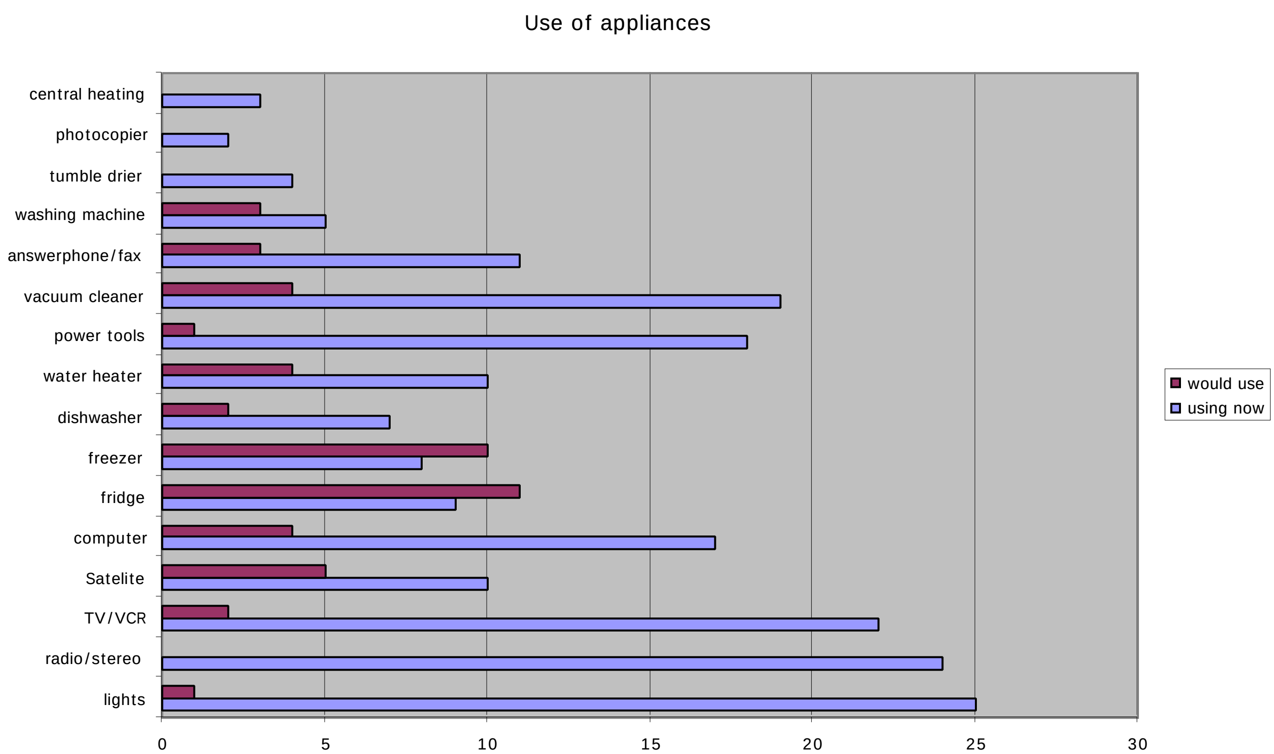
Hydro turbine users experience a higher degree of satisfaction in most cases.



3. Your appliances

Which of the following electrical appliances do you use at present, and which others would you use in future?

		At present	*In future*
Lights			
Radio/stereo			
TV / VCR			
Satellite dish system			
Computer			
Fridge			
Freezer			
Dishwasher			
Water heater			
Power tools			
Vacuum cleaner			
Telephone answering machine/fax			
Other...			



Results were as above. The 'would use' figures are for items mentioned which were not already in use. Extra items added by respondents include washing machine and central heating pump. Some users may have forgotten to add these to the list.

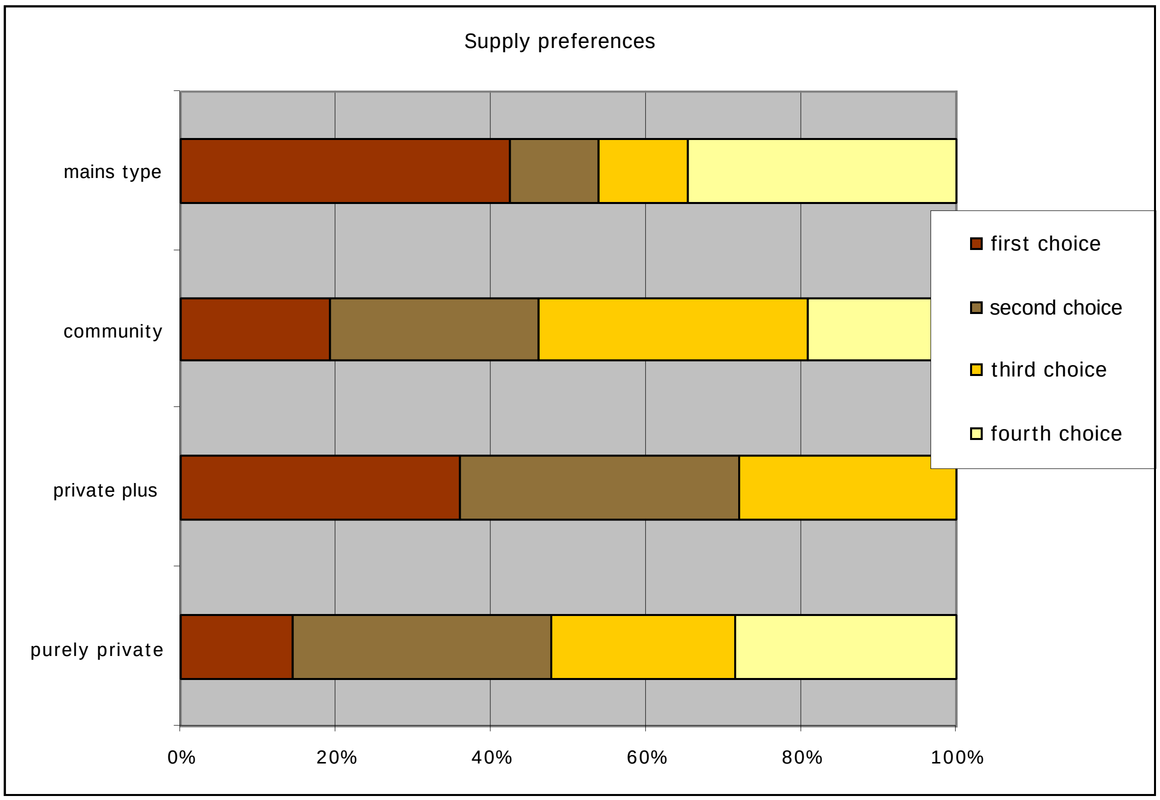
The residents do have aspirations to use more electrical appliances than they have at present, especially fridges and freezers, and these require 24-hour power.

4. Your future power supply

a) Listed below are some alternative power supply options. Please rank them in order of preference: 1,2,3 etc.

		Order of preference
A purely private supply,		
A private supply supplemented by a community scheme,		
A community based supply,		
A 'mains grid' type of supply,		
other		
(Please describe)?		

Mains electricity was a popular option, but was also many people's last choice. A private supply supplemented by a community supply was the most widely popular. The least popular option was the purely private supply. Individual power supplies are burdensome to maintain. Many would prefer to have power supplied to them.



b) Would you want to have more power available, and if so how much more?

c) Would you be willing to pay for a more expensive electricity supply?

d) Would you be willing to contribute (in cash or labour) toward the creation of a community scheme?

Most respondents felt that they could use more power, and would like 24-hour power. They would pay or contribute labour if they felt it was to their advantage. Many of the islanders have very limited financial resources.

e)Would you be willing to offer practical help with the ongoing maintenance of any electricity system?

f) Would you be interested in learning how to repair the system?

g) Would you be interested in becoming a paid caretaker on a communal system?

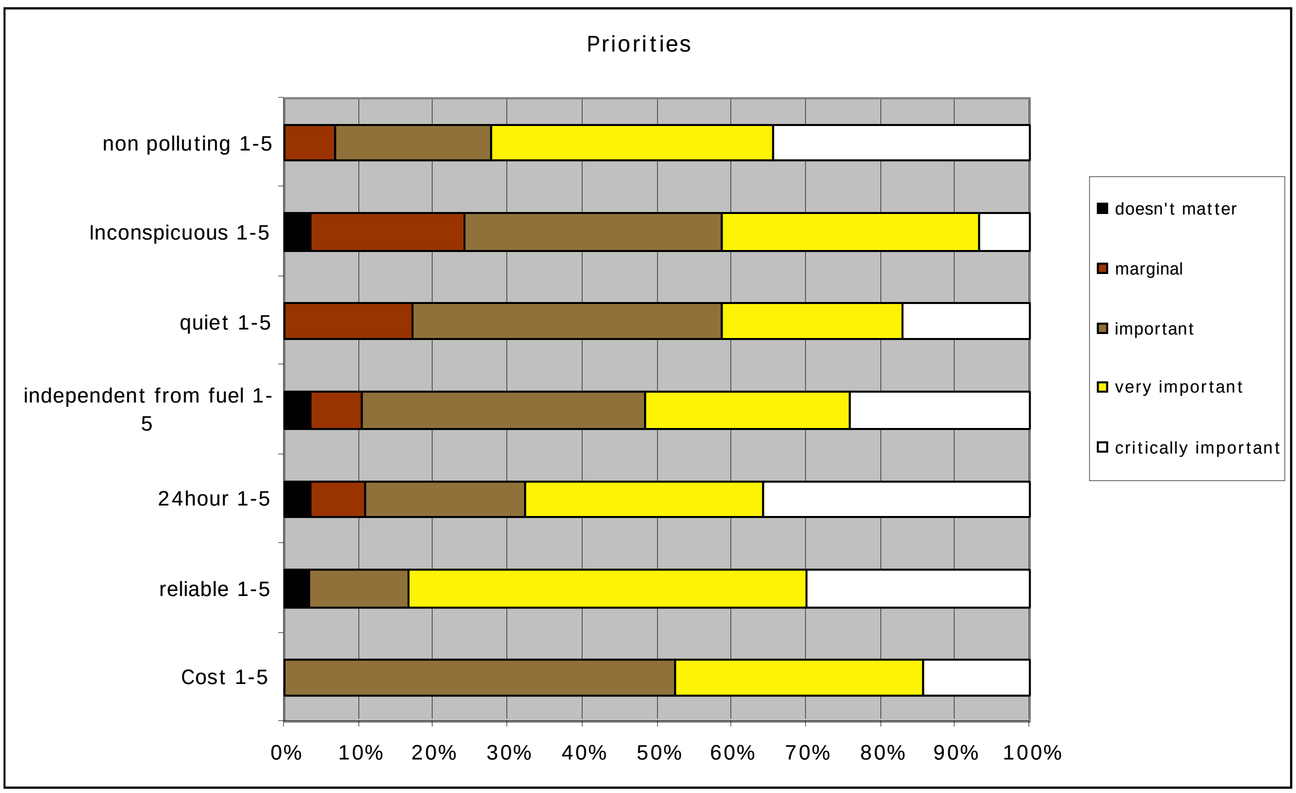
There was a good response to these questions. Approximately half of the respondents would consider becoming caretakers for a communal system.

5. Your priorities

Please say how important each of the following considerations are to you?

PLEASE TICK ONE BOX ON EACH LINE	*Doesn't matter*	*Marginal*	*Important*	*Very important*	*Critically important*
Cost of the electricity					
Reliability of the supply					
A 24 hour, un-interrupted supply					
Independence from fuel deliveries					
Quiet operation					
Inconspicuous generating equipment (sheds, pipes, masts, etc)					
Environmentally friendly, non-polluting, with no CO2 emissions					

Reliable, non-polluting, 24-hour power supplies came out most popular in these replies. These factors ranked well ahead of noise and visual impact for most respondents.



6. Your suggestions

a) Do you know of any existing opportunities for making electricity near to your home or elsewhere which you would like to see harnessed? These could be sites for water turbines, wind turbines or any other type of electricity generating equipment.

Several respondents suggested suitable sites for small hydro development (Sandavore burn and smaller sites close to houses). There was no mention of Laig.

Windpower sites were identified at Galmisdale and Kildonnan, but with reservations about the visual impact of the latter. There was also some enthusiasm for wood-chip combustion, wave and tidal power and for solar panels.

b) Do you know of any records, which have been kept of rainfall, wind or other relevant data, which could help us to assess what can be done on the island?

Donald MacLean has paper records of rainfall between 1927 and 1991 in his possession. They are in the form of monthly totals and number of dry days. In view of the uncertainties surrounding the flow duration curves for island sites, it would be more useful to collect flow information at various sites than to analyse the rainfall patterns on the island.

c) How do you feel about the appearance of electricity generating equipment on the island?

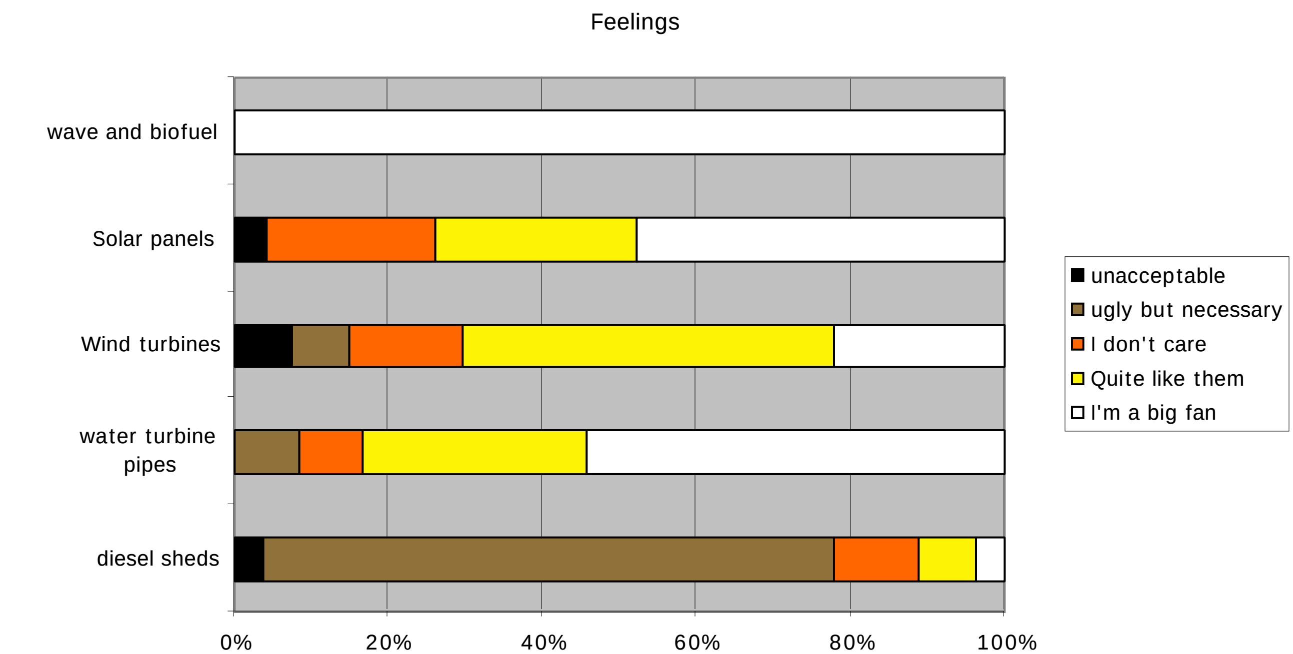
PLEASE TICK ONE BOX ON EACH LINE *OR WRITE YOUR OWN COMMENTS*	*'I find them unacceptable'*	*'They are ugly/noisy*	*'I don't care'*	*'I quite like them'*	*'I'm a big fan'*
Diesel generators in sheds					
Water turbine equipment and pipelines					
Wind turbines on masts					
Solar panels on roofs or racks					
Other (please describe)					

Water turbines and solar panels top the charts for most people, and although there is broad support for wind turbines, there are is also a small minority with strong views against them.

d) Would you have objections to the development of wind, water or other resources for producing power? Would you object to engine powered generators? If so, over which areas of the island would you object, and to which sorts of developments?

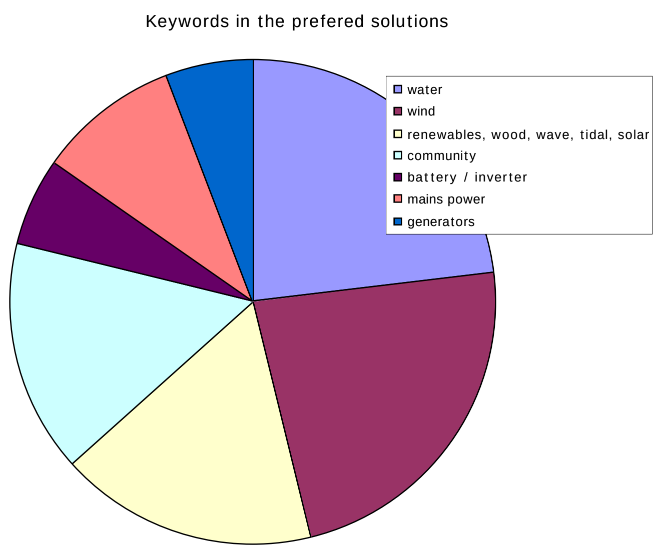
Most replies started by saying they would have no objections. Wind turbines must be sited with due sensivity, and diesels must be soundproofed.

There is a perception that wind turbines could be a hazard to birds. Some felt that renewable energy equipment would add to the character of the island. Certain special areas would not be suitable though.



	diesel sheds	water turbine pipes	Wind turbines	Solar panels	wave and biofuel
I'm a big fan	1	13	6	11	3
Quite like them	2	7	13	6	0
I don't care	3	2	4	5	0
ugly but necessary	20	2	2	0	0
unacceptable	1	0	2	1	0

e) What would be your preferred solution to supplying power to the island while respecting the environment, and also bearing in mind the limited reserves of fuel remaining on the planet? In other words, what is the sustainable option?



Water and wind power were the most popular, with other renewable energy sources popping up often too. Diesel generators would be maintained for backup purposes.

Several respondents mentioned community schemes, and it appears that the Kildonnan example referred to in the introductory text is regarded as ideal for many people. Some would like a mains grid connection, combined with use of renewables.

3. Electricity supply requirements

Planning for future electricity supplies must be based on some notion of the consumer load, in terms of energy consumption per year or similar statistics. It would be feasible to measure the existing electricity consumption at each point of use and to total this up. Previous reports have used this approach. But experience has shown that electricity consumption depends more on the availability and price than on previous habits.

Energy conservation

It is usually safe to assume that demand will increase over time until all of the affordable energy is used. This process is typical of our consumer society, which is intrinsically unsustainable. A sustainable strategy will rather use energy conservation measures so as to improve our enjoyment of the benefits of electricity, while reducing our actual demand for energy.

Consumption will vary considerably, depending on the degree of energy efficiency. For example, low-energy lighting appliances (compact fluorescents) use only 20% of the energy of conventional lamps. Modern appliances can be much more efficient than old ones. Energy efficiency costs money, but it ultimately pays for itself, even in grid-connected situations. It will be even more appropriate on Eigg, where the cost of delivering electricity is likely to be higher than on the mainland.

Electric heaters

The use of electricity for heating is an important question. Energy for heating is a larger fraction of our energy use than lighting, power and electronics. But heat energy is a lower grade of energy than electricity. If heating demand is met directly by electricity, the cost will be high compared to heating by other means such as burning fuel. A recent report has shown that the island could be self-sufficient in heating fuel from 'biomass' or firewood sources. Another feasible (but secondary) source of heat is from surplus electricity generated from renewable sources at times when demand is low, and batteries are full. It is much cheaper to store energy as heat than as electricity (in batteries).

If electricity is chosen to produce heat, then 'heat pumps' should be considered. A heat pump moves heat from the environment into a building using electricity in rather the same way as a refrigerator moves heat out of a box. Each kWh unit of electricity can be used to make 3 kWh of heat available. So the heat pump multiplies the effectiveness of the electricity.

The time factor: connecting batteries to optimise energy usage

In most electricity systems, the energy must be generated at the same rate as it is used. In other words, the generating plant must be large enough to meet the peak power demand on the system. In a renewable energy system, the energy is generated according to the weather rather than on demand. In the absence of storage, a great deal of this energy will be dumped (usually as some sort of useful heat). In order to be large enough to meet peak power demand, the turbine (or whatever) will have to be much larger than the size required to equal the average energy demand.

When generating plant is under-used in this way, we can say it has a low capacity factor. Capacity factor can be improved by charging batteries during times of low demand and then using battery power to supplement the turbine during periods of higher demand, or when there is no wind, water or sun. By adding battery storage to the system we reduce the amount of generating plant required to meet the electrical load. This comes at a price. Batteries are expensive and need to be replaced every few years. But they can make a great difference to the capacity factor of a diesel genset or a hydro turbine. And without battery storage, small wind or photovoltaic systems would be virtually useless for electricity supply.

Diversity

Much of the variation in power supply and demand can be removed by using diverse sources of power in a hybrid system (wind and solar combined for example). The greater the diversity of the system, the smaller the battery needs to be. In the same way there is an advantage to having a number of premises connected to the same supply because the diversity in their usage will even out the peaks of demand. In this case, the cost of the distribution network must be considered against the cost of the battery store. In both cases there are also energy losses to be allowed for.

Peak loads

Meeting peak loads is a challenge for stand alone power systems (where there is no mains supply). The inverter delivers mains voltage power from the battery to the load. Most inverters can deliver about three times their continuous rated power for brief periods. If overloaded they will cut out. Large inverters are expensive. Gensets are often used to help meet peak loads, so as to both save on the cost of the inverter, and also to supplement the energy supply at the same time. Peak loads have often caused reliability problems in systems where the inverter is undersized. Overloaded inverters, and glitches during genset connection, are the cause of low power quality and also loss of power on frequent occasions. To provide a reliable supply it is necessary to be generous with the inverter capacity.

Assessing the load

The potential future electrical load on the island is about as long the proverbial piece of string. A very high standard of living can be achieved with very little electricity use, if appropriate steps are taken toward energy management, efficiency, and alternative heating fuels.

Domestic electricity use of the typical UK household on the mainland grid is approximately 10-12 kWh per day (4,000kWh/year). Present consumption on Eigg is almost certainly less. This figure could be used as a ball park estimate of future energy demand for households on Eigg, while bearing in mind the above comments on ways by which demand could be reduced. Future residential energy demand can therefore be estimated as approximately 120,000 kWh based on the number of inhabited or partially inhabited dwellings.

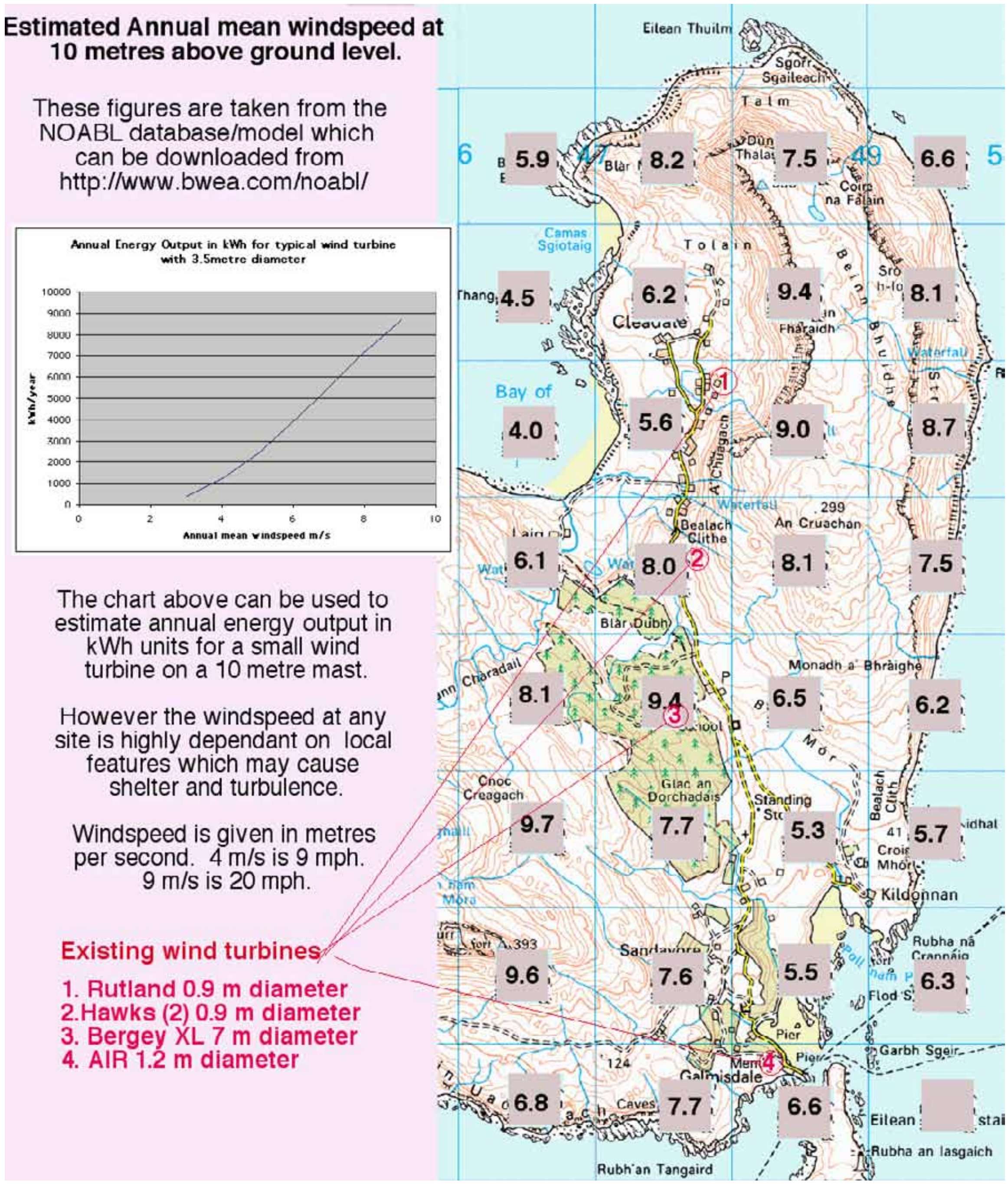
Commercial premises include the Pier Centre shops and tearoom, and several guesthouses. There is also a school, a doctor's surgery, day care centre, and telephone exchange. These additional loads could increase the overall demand to 200,000 kWh or more.

Factoring the load

To supply 200,000 kWh units of electrical energy to the user on demand, it will be necessary to generate more than this. Energy is lost at every stage: heating up transmission in cables, lost in storage batteries, discarded into heating when the battery is full, and used up during conversion from one voltage to another. To meet a demand for 200,000 kWh it would be necessary to produce 300,000 kWh and also to plan the system carefully to avoid unnecessary waste.

4. The renewable energy resources of the island.

1. Wind energy



The energy in the wind varies with the cube of the windspeed, so there is very little energy in low winds and a huge surplus in high winds. Annual mean windspeeds on the island are above average (see map), so wind energy is an option worthy of study. But the topography of the island with its many steep slopes makes the wind flow turbulent and hard to model accurately. Turbulent winds are less productive of energy and also cause premature wear and tear of the wind turbine.

There are already five small wind turbines in operation on the island, on four sites.

Table 2.1 gives estimated windspeeds and energy production for these five wind turbines.

Wind Turbine	Site 1	2 (2 turbines)	3	4
Diameter	.9 m	.9 m	7.0 m	1.2 m
Mean windspeed	5 m/s	7 m/s	8 m/s	6 m/s
Energy/year	185 kWh	370 kWh	28000 kWh	494 kWh

Site windspeeds are difficult to estimate with accuracy, even given the database figures for each kilometre square. Local conditions and height can make a huge difference to the real situation. Actual energy production may be less than the figures given in the above table.

Much could be learned from data-logging exercises, which collected windspeed data at possible future turbine sites, and also logged the energy production of existing windpower systems on the island.

Wind energy systems costs

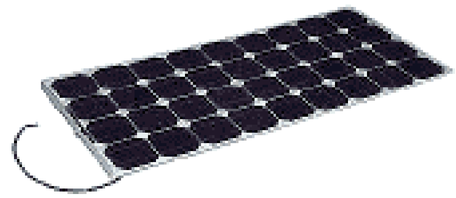
We can take as an example a 2.5kW wind turbine produced in Scotland by Proven Engineering Products of Kilmarnock. This is above average quality and weight for a small wind turbine, and would have a life expectancy of about 20 years on Eigg. During that time, some repairs and overhauls would be inevitable. On a 6 m/s site this turbine would produce approximately 4000 kWh of electricity each year - enough for one house.

Budget costs for 2.5 kW wind energy system	
2.5kW wind turbine/generator (240V output)	£ 3,655
2.5kW 240V heating controller. Volt and Ammeters 500mmHx300Wx200D	£ 660
Tilt-up self supporting wind turbine mast (6.5m) including foundation kit, plans & gin pole	£ 1,625
Tirfor winch with 20 metres wire rope + strop (suitable for WT600/WT2500)	£ 380
Estimated installation cost including 1 cu metre of concrete poured into a hole	£ 1,000
3-core amoured cable for WT2500/120	£ 500
delivery estimated	£ 400
total ex-VAT	£ 8,220

The photo shows a Proven 'WT2500' on the Scoraig peninsula, in landscape similar to that on Eigg.

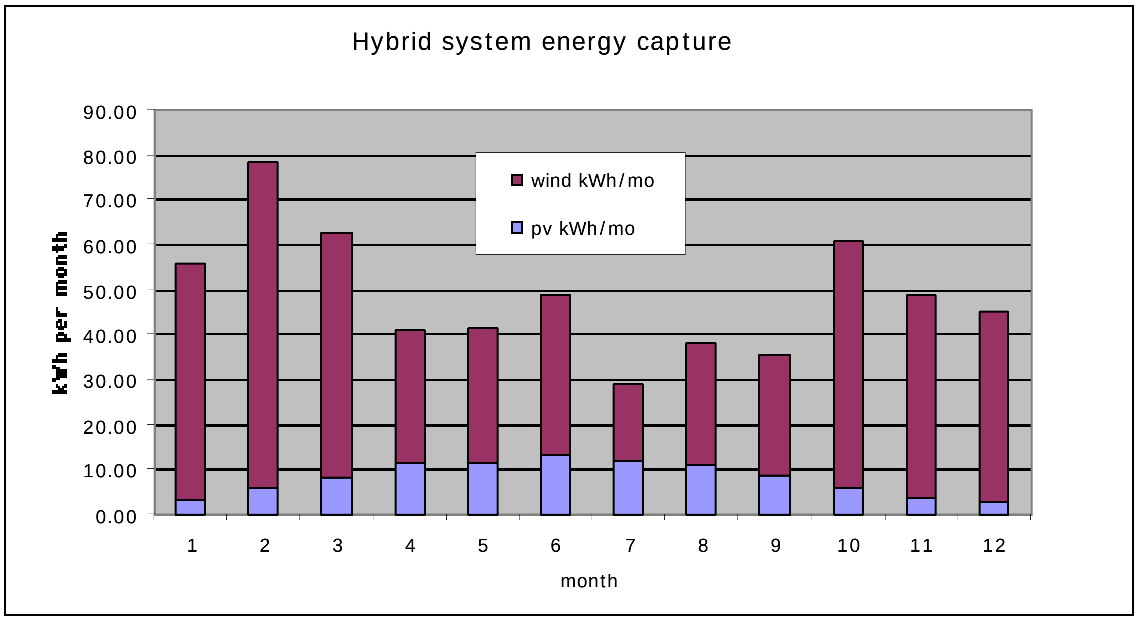
2. Solar (photovoltaic) energy

Photovoltaics or "PV" is the technology whereby solar cells are used to convert the energy of sunlight directly into electricity. The cells are assembled into panels or 'modules' (see right). Several modules are linked up to make up an 'array' (se next page) for electricity supply on any given site.



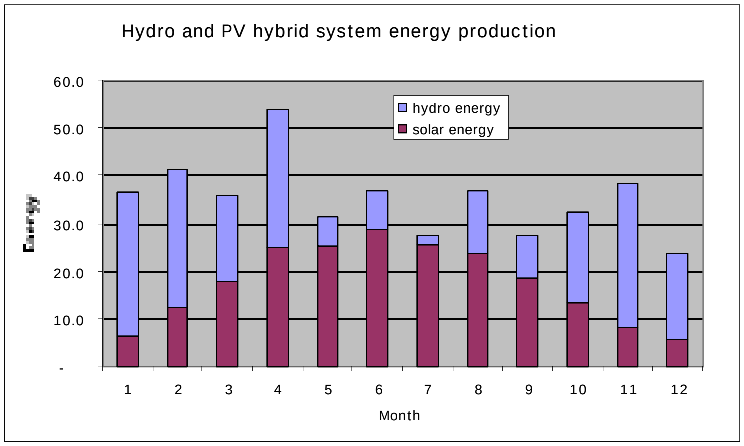
PV modules are very reliable, but expensive in terms of the energy available from the sun in Scotland. Output can be predicted with some accuracy, provided the array is sited where there is no shading.

There is a large seasonal variation in PV energy production. Consider a PV array rated at 1 kW (1000 W) nominal power output. Average annual production will be about 750 kWh each year, so the monthly average will be 62 kWh. But during the darkest months of the winter, this falls to only 12 kWh per month.



Photovoltaics are used to power the lighthouse on Castle Island. PV modules are also in use at the TV repeater station above Cuagach, alongside two small wind turbines. These wind turbines produce more energy than the PV modules per unit cost, but the mixture of wind and solar energy provides a more consistent supply. Solar energy is available in the summer when windspeed tends to be lower. This type of system, where two sources are used is termed a 'hybrid system'. The chart shows typical energy capture for a hybrid system with two 'Hawk' wind turbines and two 75W PV modules.

The second chart shows how a photovoltaic array would work alongside a hydro turbine of the sort discussed in the next section. The turbine would run for 60% of the time. The chart shows what the turbine would produce per month (data from year 2000) compared to what the PV array would produce in a typical year. (I suspect that the sun in May 2000 was actually less than average, in view of the high rainfall.) The combined energy output is very consistent over the year, indicating a suitable arrangement for a standalone system, with minimal reliance on the back-up genset.



Photovoltaic system costs

The table shows the cost of a PV system which would produce about 1350 kWh /yr

The array area is 16 square metres.

Budget costs for 2 kW Photovoltaic array	
12 no. 85 Wp photovoltaic modules	£ 8,000.00
Support framework	£ 800.00
DC cabling	£ 150.00
Charge controller with metering	£ 250.00
Fuses etc	£ 50.00
Installation estimated	£ 300.00
Total ex VAT	£9,550.00

3. Hydro energy

Hydro sites on Eigg

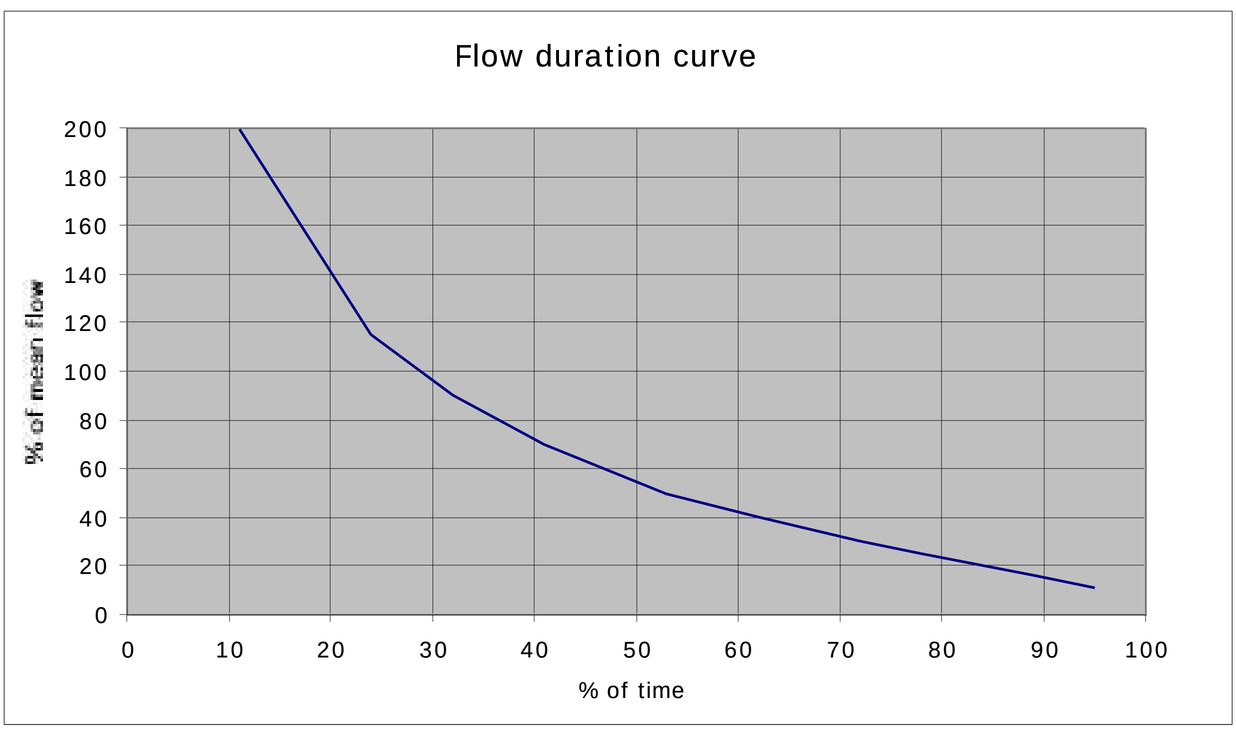
There is a long-standing tradition of using small hydro turbines to produce electricity on Eigg. A highly sophisticated 7kW turbine supplied power to the Lodge for many years before falling into disrepair. Several other sites have been developed in recent years (see map).

The hydro systems on Eigg can be termed as 'pico hydro' because they are under 10 kW in size. Modern pico hydro systems do not need dams or reservoirs. Water is collected from the stream in a small pool created by a low weir, and then returned to the stream below the turbine.

The power output depends on the flow of water, and also the head of pressure. By doubling the vertical fall between intake and turbine, we can double the power obtained from the same flow of water. The cost of this extra 'head' is a longer pipe. The pipe is a large element in the cost of the project. The bore of the pipe has to be large, so that pressure is not lost overcoming friction.

In most cases, the existing hydro systems produce AC power, which is used directly. Surplus power is diverted into heaters so as to keep a constant load on the turbine, and maintain a stable voltage. This ability to produce direct AC sets hydro turbines apart from wind and solar systems, which rely on other equipment such as batteries.

Hydro is much more consistent than wind or solar power, but it does suffer from downtime during the drier weeks of the year.



The Flow Duration Curve

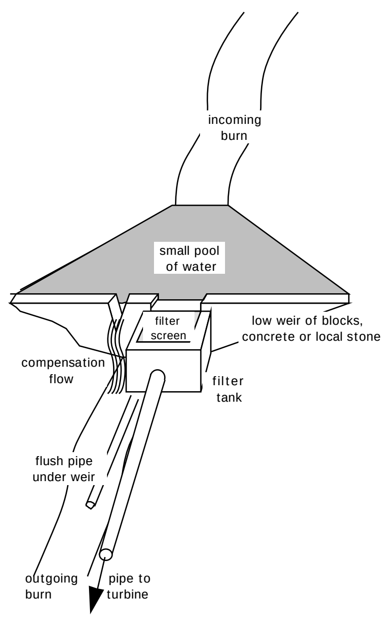
The way in which water flow varies can be expressed in terms of a 'flow duration curve' (FDC). A typical flow duration curve is shown above. It shows the percentage of the mean flow which will be exceeded for how much of the time. For example the flow which will be available for 50% of the time (also known as 'Q50') is only about 55% of the mean flow in the stream.

This idealised flow duration curve comes from computer software. It conforms to the expectations of the Environmental Protection Agency (SEPA), but the actual FDC on any given site may vary from this considerably, and will change from year to year. Actual flow measurements will greatly increase our understanding of the potential resource.

Note that the mean flow (shown as 100% on the chart) is only available for 28% of the year. Much higher flows are available for shorter periods, and much lower flows are also very common. The flow, which is available for 95% of the time, is called 'Q95'. Q95 can be estimated as typically 11% of the mean flow. This flow statistic is significant, because it is chosen by SEPA as the minimum 'compensation flow' which should remain in the water course at all times that water s being extracted. In other words, the turbine can only take water for 95% or less of the year, because it must leave a flow equal to the Q95 flow in the stream at all times, for environmental reasons. Where there is uncertainty about the FDC then the SEPA-approved compensation flow may be increased to 15% or more of the estimated mean flow.

The Water Framework Directive

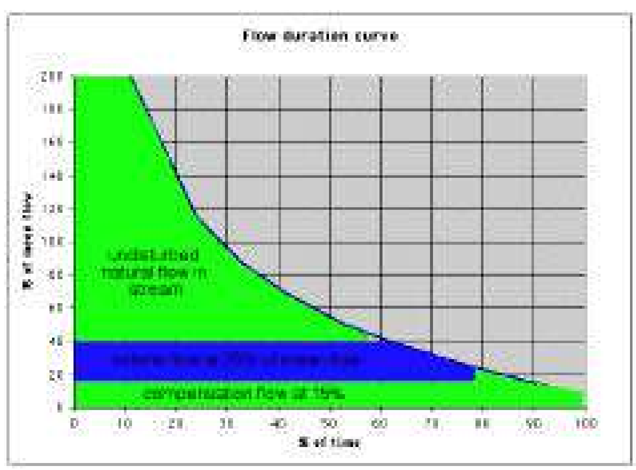
Planning applications for pico-hydro developments are subject to scrutiny by SEPA, which in turn has to bear in mind the new 'Water Framework Directive' coming out of Europe in the next few years. This will attempt to prevent **any** environmental impact by any new development on a waterway. If taken literally, this directive could simply prevent future hydropower development. However, the legislation will contain some recognition of the importance of using renewable energy to reduce the overall environmental damage we do in getting our electricity. If a hydro turbine produces benefits to the environment or community, which outweigh the (minimal) environmental damage caused, then this will be taken into account.



to

Choosing a suitable size for the turbine

We must take account of the difficulties with both varying flow and official scrutiny, in making our choice of turbine for any site. The cost of the pipe, turbine, controls and cabling will depend on the choice of flow. Traditionally, a turbine is sized to use the mean flow on the site. However this flow is only available for 28% of the time. After allowing for compensation, flow this availability is cut down still further to about 24% of the time. This is a poor capacity factor.

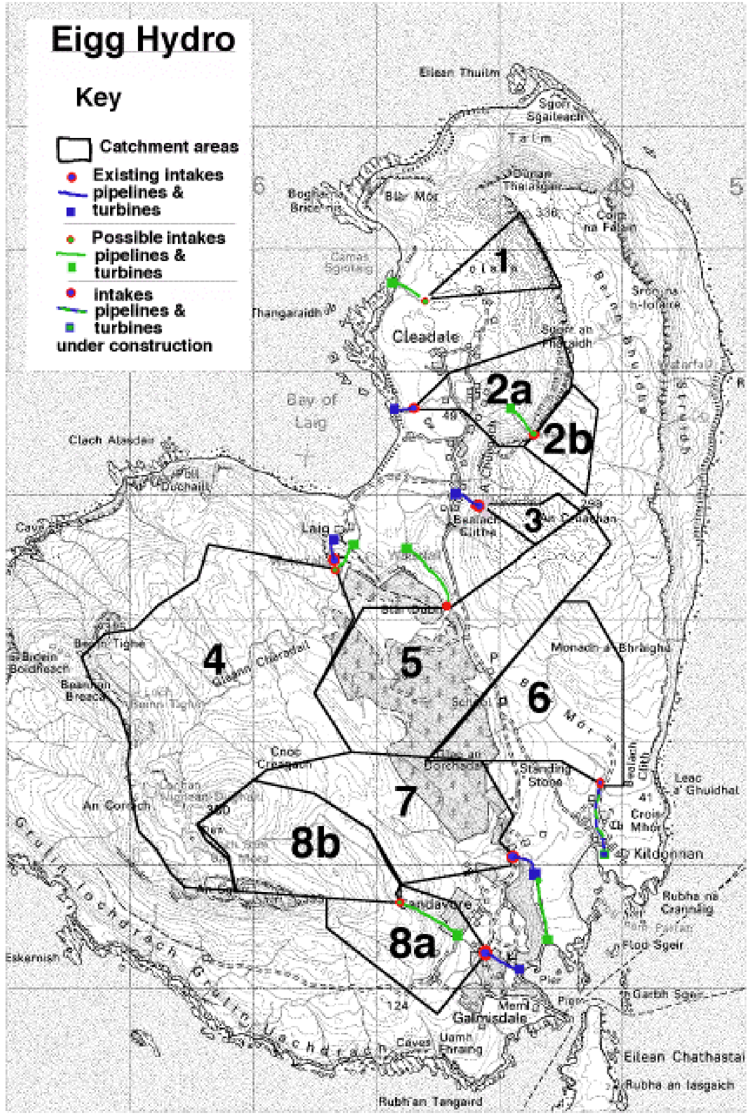


We need a consistent energy supply, with as little impact on the flow as possible. I would therefore recommend a turbine size which only uses 25% of the mean flow.

- This will cost less,

- have lower environmental impact
- and yet operate for over 60% of the time on full power.

This approach produces less energy on a given site, than the larger turbine option. But it produces the energy more consistently, rather than in big bursts during wet weather. And because it is environmentally friendly and low cost, it can be used on more sites, and over higher heads, to capture the island's full pico-hydro potential.



The potential for pico hydro development on Eigg

The map shows the island divided into catchment areas for the purpose of estimating flows at the various sites. Run off can be estimated as 1166mm per year. From this we can derive theoretical flow duration curves for each site, and thence derive specifications for turbines, pipelines and their energy production.

Several of these sites are already in use, and experience indicates that the estimated FDC is very different (better or worse) than our model predicts. Turbines existing on these sites are mostly larger than the size suggested in this report.

Physical parameters of hydro sites shown on map.

	Catchment area	Mean flow (ADF)	Gross head	Pipe length	Pipe bore	Turbine size: 60% efficient power at 25% of mean flow	Energy output (using only 25% of mean flow)
1	0.35 sqkm	13 l/sec	35	350 m	75 mm	0.7kW	3499 kWh/yr
2b	0.28 sqkm	10 l/sec	180	400 m	50 mm	2.7kW	14398 kWh/yr
2	1.25 sqkm	33 l/sec	18	150 m	105 mm	0.9kW	4628 kWh/yr
3	0.16 sqkm	6 l/sec	90	200 m	40 mm	0.8kW	4114 kWh/yr
4	3.50 sqkm	129 l/sec	30	300 m	187 mm	5.7kW	29995 kWh/yr
5	2.00 sqkm	74 l/sec	40	700 m	167 mm	4.3kW	22854 kWh/yr
6	1.34 sqkm	50 l/sec	30	550 m	144 mm	2.2kW	11484 kWh/yr
7	1.28 sqkm	47 l/sec	17	110 m	115 mm	1.2kW	6216 kWh/yr
7	1.28 sqkm	47 l/sec	30	550 m	141 mm	2.1kW	10970 kWh/yr
8b	1.05 sqkm	39 l/sec	100	600 m	104 mm	5.7kW	29995 kWh/yr
8	1.80 sqkm	67 l/sec	40	350 m	140 mm	3.9kW	20568 kWh/yr
						total	158721 kWh/yr

It is interesting to note that the theoretical energy output of the combined schemes amounts to over 150,000 kWh per year. This meets half of our energy production target as guess-timated in section 3.

The scenarios given here are not set in stone, and could be adapted in many ways. For example there are sites where a great deal more energy could be collected by extending the pipeline and increasing the head at the turbine (see for example Laig catchment 4). There are also many smaller watercourses, which could for example produce a 200-watt output, contributing perhaps 1000 kWh/year or 1/4 of a typical household demand. But some sites might prove unsuitable after further study. The scheme is offered as an illustrative example, and not a final prescription.

Estimated costs

Staying with the above examples, we can put budgetary cost figures on these developments. These costs are based on the 25% of mean flow design rule used for this exercise. Many of the existing systems use more of the flow.

Turbine costs below are based on importing Australian 'Platypus' turbines, which appear to be very competitive. Research has shown that there are also even cheaper turbines to be had from developing world countries. But these may not prove to be such a good investment long term.

Installation costs are very hard to predict, because existing sites have used the owners labour and materials, or volunteer labour. The uncertainties surrounding installation schedules and costs may become a serious obstacle to future development of renewable energy projects on the island. Available qualified and motivated people may become the most difficult resource to find.

Budget costs for hydro sites shown on map.

	Place name	Pipe estimated cost	Turbine (& controller) estimated cost	installation cost estimated	Total project cost
1	sgiotaig	£ 910.00	£ 1,550.00	£ 3,460.00	£ 5,920.00
2b	tighearna	£ 1,040.00	£ 3,000.00	£ 5,240.00	£ 9,280.00
2	cormack	£ 1,500.00	£ 1,550.00	£ 3,450.00	£ 6,500.00
3	fyffe	£ 300.00	£ 1,550.00	£ 1,885.00	£ 3,735.00
4	laig	£ 3,600.00	£ 4,000.00	£ 9,760.00	£ 17,360.00
5	cam lon	£ 7,000.00	£ 3,800.00	£ 13,840.00	£ 24,640.00
6	kildonnan	£ 4,400.00	£ 3,000.00	£ 8,200.00	£ 15,600.00
7	glebe	£ 660.00	£ 2,000.00	£ 3,780.00	£ 6,440.00
7	gurrabain	£ 4,400.00	£ 2,500.00	£ 8,220.00	£ 15,120.00
8b	sandavore	£ 4,200.00	£ 4,000.00	£ 9,580.00	£ 17,780.00
8	lodge	£ 2,800.00	£ 3,800.00	£ 7,260.00	£ 13,860.00
				total	£ 136,235.00

4. Wave and tidal energy

Wave motion can be used to generate electric power. The technology is well developed, but requires very specific site conditions, which do not exist on Eigg.

Tidal currents can be exploited by underwater turbines similar to wind turbines but smaller in size. The viability of the technology depends heavily on the speed of tidal streams. There are usable flows in the channel between Eigg and Castle Island, but they are not strong enough to make tidal power a tempting option. The need to maintain a clear channel for navigation would probably be another big obstacle to successful exploitation of the resource.

5. Biomass for electricity

Biomass would be a suitable source for renewable heating on the island. Heat can also be used to produce electricity but this usually done on a large scale, in combined heat and power (CHP) systems of several hundred kilowatts, using steam turbines. Smaller systems using Striling Engines are being developed. In both cases heat and power are produced together, so electricity is a 'spin off ' from the heating system.

5. The suggested model for electricity supply

1. The options for electricity supply are as follows:

Diesel generators. (gensets)
These are the main source at present and will likely remain a useful part of the mix in future.
Advantages: Power is available on demand. Initial cost is low. The technology is well understood, and a number of diesel sets exist.
Disadvantages: Fuel cost is an ongoing expense. The burning of diesel fuel is polluting and non-sustainable. Plant depreciation and maintenance is costly. Older diesel sets have been extremely reliable but noisy and dirty. They appear to last forever but must eventually wear out. Newer sets are less reliable, and have proved expensive to maintain when running for long periods.

Mains grid electricity.
There has never been a mains connection to the island, but a cable could be laid. This would be a popular option with some residents.
Advantages: High reliability with minimal user involvement. The ability to tap into much more efficient generating plant on the mainland. Renewable energy sources on the island could be connected to the grid, allowing surplus power to be exported, or transferred to other users on the island.
Disadvantages: A cable connection would have very high capital cost, even compared to small renewable energy installations. Electricity would still have to be generated elsewhere to meet the island's needs. This would have both financial and environmental costs, which would be ongoing. A mains connection would remove one of the island's many distinctive features, which make it attractive to visitors.

Small renewable energy systems.
Advantages: Renewable energy is abundantly available, free at source and everlasting. The environmental impacts of harnessing it are less damaging than the impacts of conventional fuel-burning plant. Small power systems fit the human-scale character of the island, which is part of its appeal.
Disadvantages: Capital cost of small renewable systems and associated infrastructure is high. The available power does not match demand very well, and additional equipment is required to regulate, store, and convert the energy for the end user. This adds to cost, and reduces the efficiency and reliability of the systems. Maintenance of the systems would fall on local residents rather than an electricity company.

2. The way forward

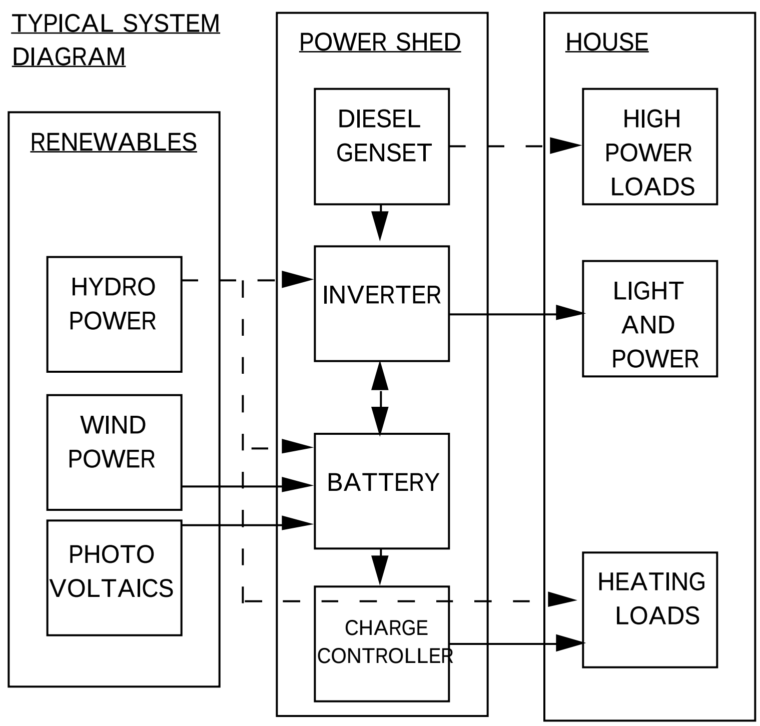
The questionnaire responses indicated a preference for reliable, non-polluting, 24-hour electricity supplies. Purely private supplies are not very popular, and many would prefer mains electricity. But the most acceptable option overall was a private supply supplemented by a community scheme.

Reliability. While grid power generally sets a high standard of reliability, it is known to be less reliable in remote places. Equal reliability can be achieved with considerably lower investment by using generously specified stand alone systems based on a more diverse supply, with generator back-up. The reliability problems of existing systems on the island typically arise from being undersized for the expanding demands of users.

Non-polluting sources were a priority for the islanders, and renewable energy is popular on the island, especially hydropower. Wind and solar power are also attractive although there is some concern about the high visibility of wind turbines.

24-hour electricity is readily available from battery/inverter systems, which store energy and make it available as AC mains-quality power on demand. Many households already operate such systems alongside their diesel generators, and benefit from increased convenience and fuel savings.

The solution which appears to best suit the majority of islanders is a semi-autonomous power system which takes most of its energy input from renewable sources, but uses a battery to maintain 24-hour power, and a diesel generator to provide backup. The diagram shows the structure of the system in its general form.



The inverter
The inverter provides 24-hour power for lights and power. The inverter is a device, which converts DC battery power into AC mains-quality power.

Some modern inverters have the facility to synchronise with an AC supply such as a genset. They can use that supply to feed the user load directly. Meanwhile the inverter actively smoothes out the load on the AC source (genset, hydro, etc) by using part of it to charge the battery when user demand is low, and by taking power from the battery during periods of high demand. This strategy makes the best use of the supply and prevents overload of the source. While this inverter operating mode is routine for a number of gensets on the island already, it has not yet been tried with a hydro turbine. The system at Kildonnan, which is shortly to be commissioned, will be a test case for this innovative approach to using hydropower.

The battery
This takes energy from such renewable sources as are available, and stores it until it is needed.

The charge controller
This monitors the state of the battery and diverts any incoming energy that the battery cannot store (due to lack of capacity) into useful heating loads in the building.

The diesel genset
This can provide power when the battery becomes discharged or the demand in the house is beyond what the inverter can meet. If the diesel generator is running, it recharges the battery at the same time as directly supplying the user demand. The inverter serves as a battery charger during this phase of the operation. On most sites there is already a genset in operation, which makes the transition to the new arrangements easier.

I have included for replacement of the existing generators in my costing below, on the assumption that there will be reliability problems with existing gensets. Reliability is a key issue. The most desirable outcome would be to have a 100% available genset power, but to use it sparsely.

Renewable energy sources
Wind and solar power may be available in the form of DC to charge the battery. Some hydro turbines produce AC mains-quality power which can be used directly. In the latter case it would be is desirable to feed hydropower through a synchronous inverter without converting it into battery power at all. Converting the power to battery voltage and back again results in some it being lost in battery-charger and inverter operating losses.

3. Stand alone system costs

Each domestic stand-alone power system will be costly because of the need for battery storage. But batteries greatly improve the capacity factor of the renewable energy sources. Without the batteries, any energy which is generated at the wrong time would have to be discarded, and replaced later with diesel generated power at times of high demand. The battery systems make renewable energy 'go further'.

Economic analysis must allow for the future replacement of batteries at approximately five year intervals. A huge battery would be required to deal with the worst case scenario. There is a good environmental case for using genset power as a very small part of the mix so as to avoid excessively sized batteries, but maintain reliability.

Location of batteries at each site enables the user to access relatively high power from the system without the need for a very expensive distribution system. PV modules can be located close to the battery, but wind and hydro turbines can be located where the wind or water supply is best. Cables carry power from the turbines to the dwelling at high voltage.

Budget costs for a stand alone domestic supply	
4.5kW inverter/charger	£ 3,000.00
15kWh battery (say 1000 amphrs at 24-volts)	£ 1,800.00
Cabling and fuses	£ 200.00
Bypass switch for generator	£ 160.00
5kW Diesel generator	£ 4,500.00
Installation	£500.00
Total ex VAT	**£10,160.00**

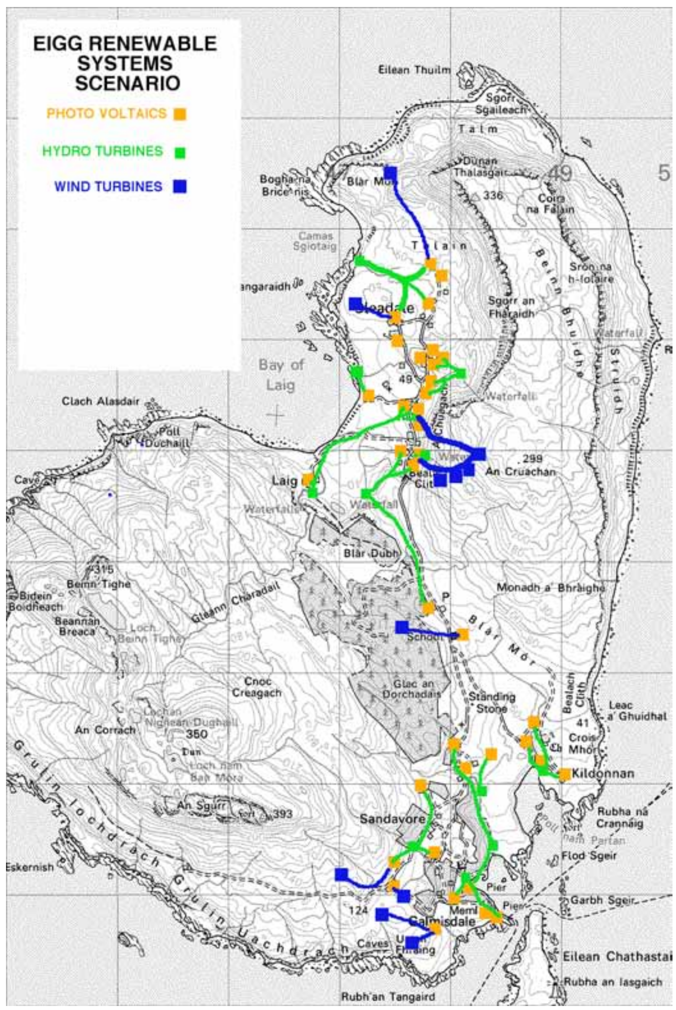
In most cases some or even all of this equipment already exists at Eigg households. But the equipment specified here is larger than existing systems. This would improve reliability, by reducing the danger of overload, which has been a frequent cause of power failure in the past. Commercial users (Shop and tearoom for example) should consider using a 10 kW inverter in place of the existing 2.5 kW.

4. Island wide system outline with costs

One possible scenario to consider...

The table below is an illustration of what could be achieved, at much lower cost than a grid connection, to power the island in a sustainable way. This is not being put forward as a final plan so much as an indication of the scope.

Budget costs for a system to meet the island's needs					
Item	Cost	Energy kWh/yr	no.	total cost	Total kWh/yr
Domestic stand-alone systems	£ 10,160	1,000	35	£ 355,600	35,000
Photovoltaic arrays 2kW each	£ 9,550	1,350	35	£ 334,250	47,250
Hydro turbines	£ 13,000	16,000	10	£ 130,000	160,000
Wind turbines	£ 8,220	4,000	16	£ 131,520	64,000
			tot:	£ 951,370	306,250



In this scenario, each house has a stand-alone system with a 2kW photovoltaic array, which provides 1350kWh of energy per year. This energy is likely to be delivered at times when water and wind energy are less plentiful.

The diesel generator might provide 1000 kWh. This represents about 4-5 hours running per average week. The generator should have a long service life on this duty.

Hydro and wind turbines at suitable sites are used to provide the bulk of the energy to meet our target of 300,000 kWh each year (see section 3). The costs of the wind and hydro systems have been adjusted to allow for long cables to reach the houses.

This is only an illustrative scenario and does not prescribe the positions of the turbines. The distribution of good sites does not match the distribution of dwellings very well. It is hard to supply the population centre in Cleadale and the area around the Glebe.

There is ample hydropower around Sandavore and Laig. There are ample sites for wind turbines west of Galmisdale, and these could be sensitively placed. It may be harder to find many other sites which are not only suitable, but acceptable, and close enough to the dwellings. Blar Mor and the slopes above Cuagach are suitable but rather inaccessible. There may possibly be inconspicuous sites near the shoreline.

Planning permission

The scenario above would be tackled in small increments, each of which would be subject to planning permission, including conditions imposed by Scottish Natural Heritage and SEPA.

There are Sites of Special Scientific Interest (SSSIs) on the island where the hazel and willow scrub and the arctic sandwort deserve special care. This duty should not be an insuperable obstacle. The whole island is a National Scenic Area. Visual impact of developments will be critical. It should be easy enough to blend the small hydro installations into the landscape, but the effects on flow in waterfalls needs to be negotiated. Small wind turbines will have to be placed where they will not cause distress. Short towers and natural colours should make this possible.

Normally residents would be classed as very sensitive to development, but since all the power will be used on the island that aspect may have to be reconsidered. Questionnaire responses indicated that noise and visual impact concerns were low on the scale of priorities for energy supply.

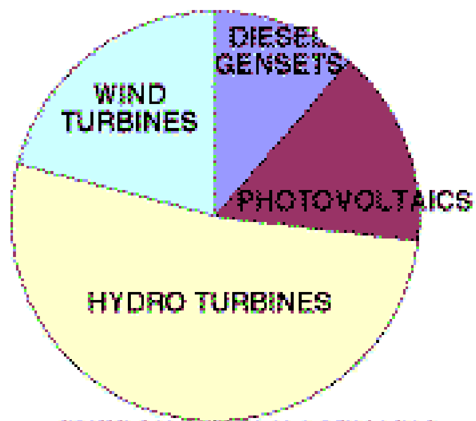
Economic analysis

The cost of the above scenario appears to be well under half of the cost of a mains cable.

90% of the energy is produced from renewable sources.

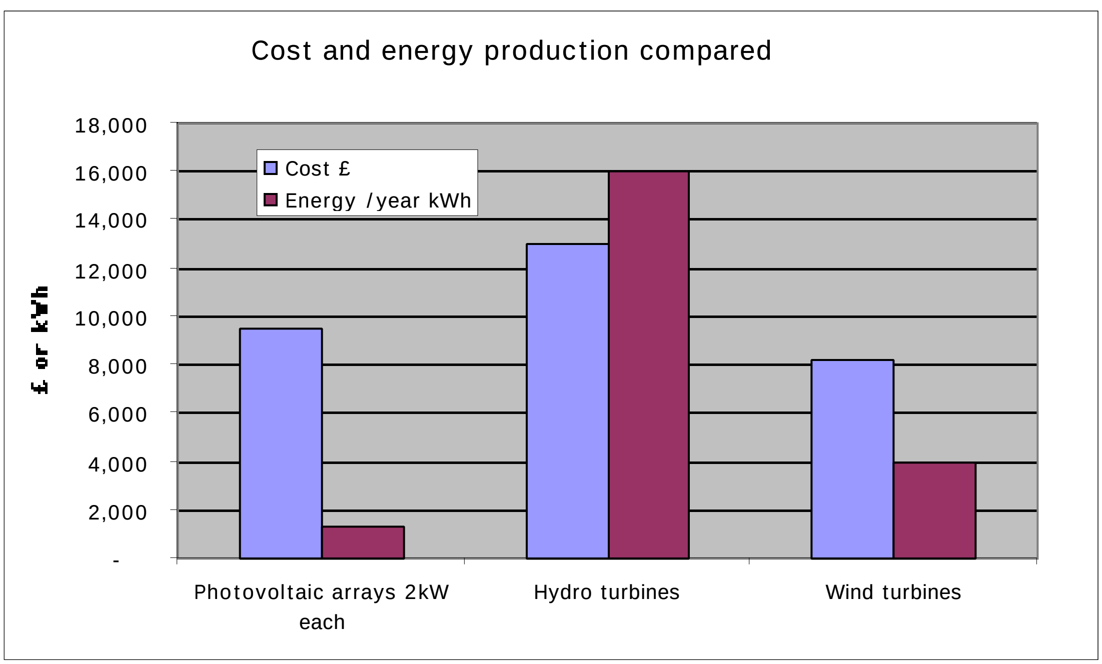
Each house would have reliable 24-hour power.

However it would be wise to be cautious with these figures until we have more accurate costs for installation work on the island. Previous installations have relied heavily on voluntary labour and have been very slow to progress. Onerous conditions which may be imposed through the planning process could multiply the cost.



ENERGY SUPPLY SCENARIO

Some energy sources are more cost-effective than others according to the above figures. But the more expensive elements play a vital role in maintaining continuity of supply.



Conclusion

Demand for electricity will probably increase on Eigg in future years, even allowing for energy efficiency measures. Residents will also expect 24-hour power, with better reliability than has been acceptable in the past. This increased expectation can be met to a very large degree from renewable energy sources. The cost would be less than the cost of grid connection. At present there are very generous grants available to assist with this type of development.

The strategy described in this report builds on the style of existing electricity supply arrangements on the island, and could be implemented gradually. Experience gained along the way would contribute to the effectiveness of later developments. Inadequately sized equipment has caused considerable problems in the past, but new community developments could take advantage of grant schemes to be more generously specified.

The process would offer sustained employment opportunities on the island in both the areas of installation and maintenance. The availability of labour could however be the main factor limiting the pace of development. In fact there is a national shortage of expertise in small renewable energy system manufacture and installation.

There is a need for more data to be collected, by manual observations or datalogging equipment. We need to know more about the energy production from existing systems, as well as the actual resources available for future development, such as windspeeds and the flows at various points in local streams. The data will help us identify the most cost-effective solutions and avoid possible environmental damage.

Eigg is an ideal situation for testing and demonstration of cost-effective small-scale renewable energy systems. Development of environmentally friendly systems could put Eigg in the forefront of electricity supply technology for the 21st century.

Hugh Piggott, February 2003

Hugh@scoraigwind.co.uk

SUSTAINABLE ELECTRICITY SUPPLIES FOR THE ISLE OF EIGG

A report by Hugh Piggott, Scoraig Wind Electric
For the Isle of Eigg Heritage Trust
January 2003

DRAFT FOR COMMENTS

Overview

This report for the Isle of Eigg Heritage Trust seeks to identify the best strategy for meeting the electrical needs of the island in a sustainable way. Additional resources, links and software can be found at the web address printed in the footer of each page.

Section 1. Pros and cons of renewable energy

Renewable energy sources (energy from wind, water and sunshine) are the only energy sources that can ultimately provide electricity in a sustainable way. We consider the practical implications of maximising renewable energy use on the small scale.

Section 2 : Questionnaire

Popular support and community involvement are key issues for successful development of renewable resources in the UK. A questionnaire was used to gather information on present electricity usage, and future preferences among Eigg residents. Several options emerged, including diesel generator power, small hydro turbines, wind and solar power.

Opinion on the island favoured the continued use of diesel power as a backup source, while exploiting the abundant renewable resources of the island for the bulk of the energy required. Reliability is also an important consideration, and most islanders would like to have uninterrupted power delivered to them. Some islanders desire a connection to the mains electricity grid, because of its reliability.

Section 3: . Electricity supply requirements

The first step in designing any electricity supply is to estimate the demand. Demand is described in two ways: the peak (instant) power demand and the total demand for energy over a given period. Power (kW) is the rate of consumption of energy at one instant, whereas energy (kWh) is the accumulation of electricity consumed over a period.

It is usually safe to assume that demand will increase over time until all of the affordable energy is used. This process is typical of our consumer society, which is intrinsically unsustainable. A sustainable strategy will instead use energy conservation measures, to improve our enjoyment of the benefits of electricity while reducing our actual demand for energy.

Section 4: The renewable energy resources of the island

Hydro and wind turbines are already in use on the island, as are solar 'PV' panels. In section 2 we look at the scale of the available resources, and the best sites where their use can be expanded.

There is very little hard data for water run-off, windspeed or insolation on the island. Instead this report relies on computer software packages to predict the energy capture of different types of renewable energy equipment.

Experience has shown that reality is different from software predictions in most cases, but the software gives us a starting point for planning an overall strategy. It would be prudent to monitor the renewable resources (windspeeds, water flows, etc) at several sites and to datalog the daily production of pilot installations so as to verify the conclusions of the computer models.

Section 5: The suggested model for electricity supply

In view of the high cost of grid connection, this report favours independent power supplies based on a variety of renewable sources, some of which will be communally operated. Stand-alone electricity systems consist of more than just turbines and solar panels. Energy has to be gathered, stored and converted for use as required. We propose that each house should have its own core system, based on a battery and a back up generator.

A network of wind and hydro turbines can be used to provide the bulk of the energy required, supplemented by solar 'PV' arrays at each building. A pilot project using a centralised hydro to feed several battery systems is under construction at Kildonnan on the island. Similar schemes could be developed to form a network of independent cells which cover the whole island.

1. Pros and cons of renewable energy

Why we need renewable energy

Renewable energy is plentifully available all around us every day, and there are no particular technical obstacles to harnessing it. Wind and water power have been in use long before the invention of combustion engines, and it seems likely that they will be the chosen technology in the future, when we shall have to reduce our unsustainable reliance on fossil fuels. Renewable energy production causes no CO2 emissions nor does it consume fuel resources, after the initial manufacture and installation of the turbines, solar panels and infrastructure required. Using renewable energy frees us from dependence on imported fuels, and sets an example for developing countries. Most of the world's population could not possibly use fuels resources on the scale they are used in the west. If the entire world tried to live the lives we live now in the UK, then the planet would immediately choke to death.

Problems with renewable energy

The biggest problem with renewable energy is the high capital cost.
The energy is diffuse and demands large structures to collect and convert it. The equipment is expensive and comes with a large amount of infrastructure. There is an 'energy cost' associated with manufacturing renewable energy equipment. This investment has to be redeemed before it can be said to produce a net energy output. The time required to pay back the energy cost of manufacture is generally quite small in terms of the life expectancy of the system (often less than one year) but it can be longer in the case of small systems.

Environmental impact is the next big problem.
Wind turbines for example are visually prominent by nature, and will change the character of the landscape to an extent. Some people like to see them, and others do not. Hydro systems divert water from its natural course into pipes and through turbines. This will have some impact on the ecology and amenity of the watercourse. These impacts must be weighed up against the impacts of alternative 'conventional' energy sources, if a rational decision is to be made. We need energy to fulfill our aspirations for lifestyle and survival, so environmental impact of some sort is inevitable.

A third problem with renewable energy is its intermittency.
Unlike fossil fuel, the source cannot be controlled to match demand. The energy is not available all the time, and may not even be easy to predict. To match supply to demand, it may be necessary to store energy, or to reschedule our use of energy, or to use a mixture of different energy sources. This consideration in itself increases the cost and environmental impacts of the energy we ultimately use at our convenience. ON the small scale, we use batteries to store the energy for later use. A device called an 'inverter' delivers mains voltage power from the batteries on demand.

Household Scale, Area Grid or National Grid systems?

It has been pointed out that small renewable energy equipment is inefficient compared with 'utility scale' windfarms, or even the intermediate scale turbines which supply the neighbouring island of Muck. There are several arguments for using small-scale renewables on this island:

Larger scale systems require very expensive distribution networks
The cost of a grid connection cable to Eigg has been estimated at £2 million. While this is less than the cost of the unpopular pier development, it is not clear that anyone will pay for it. In any case it is arguable that the money could be better spent on appropriately sized renewable energy equipment. This year, the UK government is launching grants to support the development of small renewables. It will be more cost-effective to site these renewable sources at the point of use than to install an undersea cable. And small renewables can deliver the required energy at lower capital cost than the cost of the transmission cable alone.

An electricity network could be attractive, especially for those who would like to obtain a 'turnkey' connection, but again the cost is a consideration. The cost of an island-wide distribution network has been estimated at over £300,000 (Scottish Power, April 2000). Many islanders have expressed a willingness to undertake maintenance and repair of community based energy systems (see part 2, question 4g). It should not be necessary for any unwilling individual to get his/her hands dirty.

The self-reliant lifestyle of the island is part of its appeal

Visitors are a substantial part of the island's economy. They come for many reasons, including the wild life, scenery, fresh air and cultural events. Part of the attraction is the island lifestyle, including the difficult access and the unconventional electricity supplies. Small renewable energy systems are something to be proud of and an added bonus for visitors.

Human-scale community-based renewable energy systems literally place the power in the hands of the local people. Or at least that is how it can be perceived.

2. Questionnaire

The questionnaire was distributed during the winter 2001-2. 30 forms were returned, and most were fully completed. This section includes the original questions, and some analysis of the results.

Replies represented approximately 40 islanders, but the opinions expressed may have been those of the person who filled in the form rather than the household. In one case two forms were returned with very different opinions from the same house.

While imperfect, the results must nevertheless help to reflect the views of those decision-makers who would wish to see improved electricity supply options on the island.

The questionnaire began with the following introductory passage.

INTRODUCTION (by Hugh Piggott for Eigg Trust)

I am very pleased to have been asked to prepare a report on the options for sustainable electricity supplies on the Island. The best first step is to gather wisdom from you, the residents, so that I can put forward proposals based on common sense and local knowledge. For my own part I can add some technical analysis, and projected costs.

My own preference is for small-scale, renewable energy systems using wind and hydro (free, clean energy) on a domestic scale. There are other ways to provide electricity to the island. Some options are more sustainable than others are. They range from individual diesel generator sets (as in the past) through to a connection with the national grid.

For example, Scottish Power has already proposed a scheme to power the island, from mainly renewable sources. Their scheme uses an island-wide network and would cost £900,000. In contrast, residents are about to build a smaller water powered project at Kildonnan. It is an example of a 'community' scheme, which is therefore able to attract substantial grants toward the £40,000 cost.

CONFIDENTIALITY
If you have any doubts about this questionnaire, please talk to .....
from the Eigg Trust and he/she will explain what it is about. You are (obviously) free to refuse to answer these questions. That would be a pity because your views might not be understood. Much work can be avoided if we can learn what you want now, and not have to deal with unforeseen objections later.

We hope that you will answer as many questions as you comfortably can. Please feel free to add extra comments as well. If you would like your answers to remain confidential, then we shall not reveal your name. If you are happy to make your views public, that is better still. If members of your household have various differing views, you can try to include them all here, or ask for separate forms.

Thanks for your feedback.

QUESTIONS

1. About yourselves

Would you like all of your replies to these questions to be treated as confidential information (yes/no)?

Only two respondents asked for confidentiality. Two other respondents did not give their names.

If you wish, you can tell me some details of people who live with you - their names, their ages, and how many months of each year do they spend here?

Name					
Age					
Months per year spent on Eigg					

Name					
Age					
Months per year spent on Eigg					

Roughly how many of the above will still be resident in ten years time (if you care to guess)?

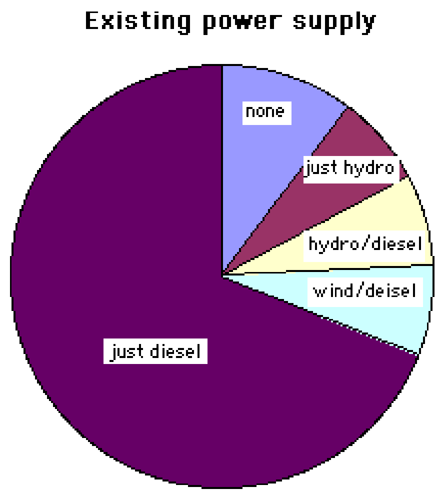
This information was useful for determining the location and needs of the respondents. None had plans to leave the island.

2. Your existing Power Supply

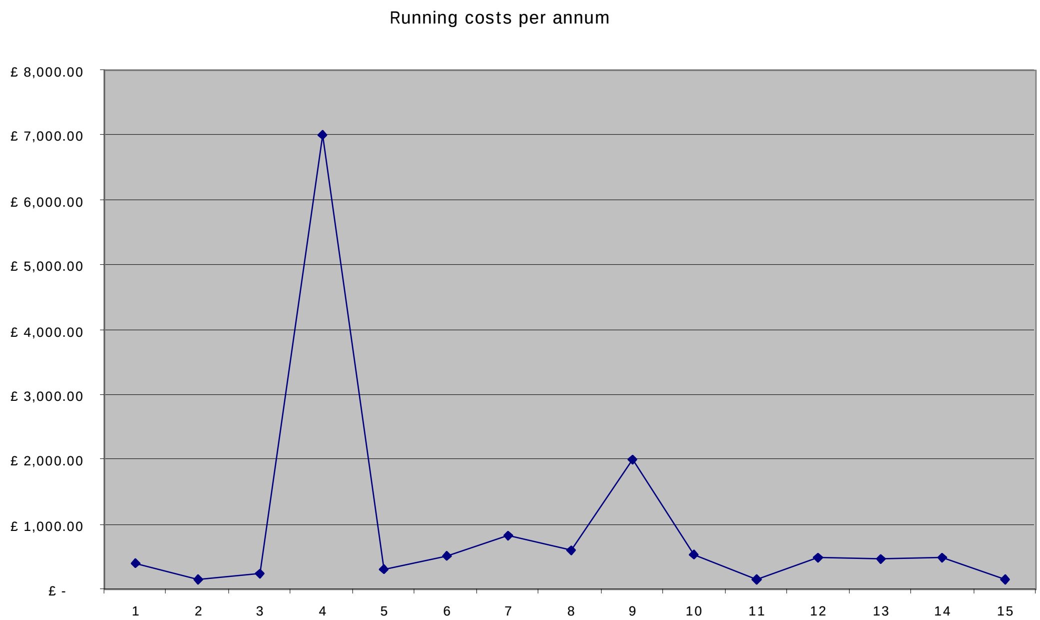
a) What is your main source of electric power at present?	
b) Do you use any other sources of electricity?	
c) For about how many hours each day do you have power available?	
d) How much does it cost (roughly) each year to run this system?	
e) How reliable is your electricity supply?	
f) How happy are you with this arrangement?	

Question 2 yielded interesting statistics

Most of the respondents used diesel generation for all of their power. About half of these used batteries/inverters to maintain a 24-hour power supply. Reported costs for running diesel generators varied from £150 to £7,000 per annum.



£500 would be a typical figure for diesel running costs. Most reported fairly reliable operation.

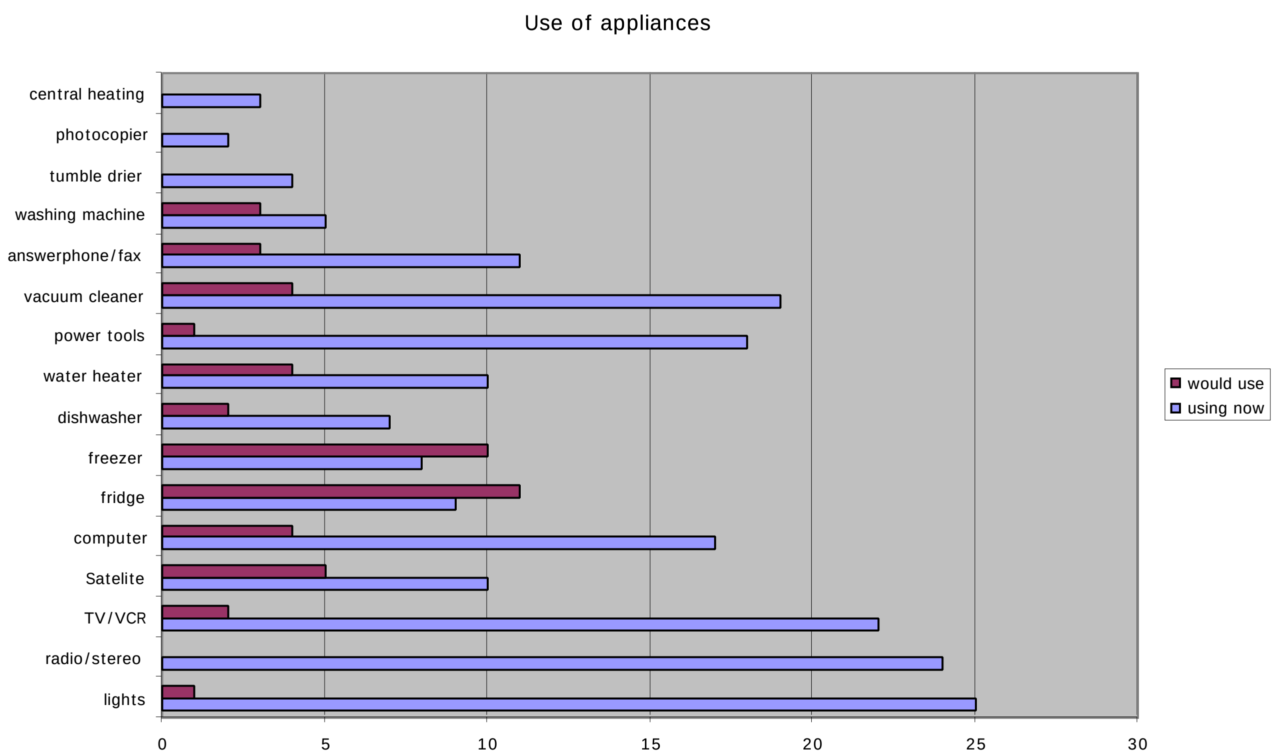


Hydro turbine users experience a higher degree of satisfaction in most cases.

3. Your appliances

Which of the following electrical appliances do you use at present, and which others would you use in future?

		At present	In future
Lights			
Radio/stereo			
TV / VCR			
Satellite dish system			
Computer			
Fridge			
Freezer			
Dishwasher			
Water heater			
Power tools			
Vacuum cleaner			
Telephone answering machine/fax			
Other...			



Results were as above. The 'would use' figures are for items mentioned which were not already in use. Extra items added by respondents include washing machine and central heating pump. Some users may have forgotten to add these to the list.

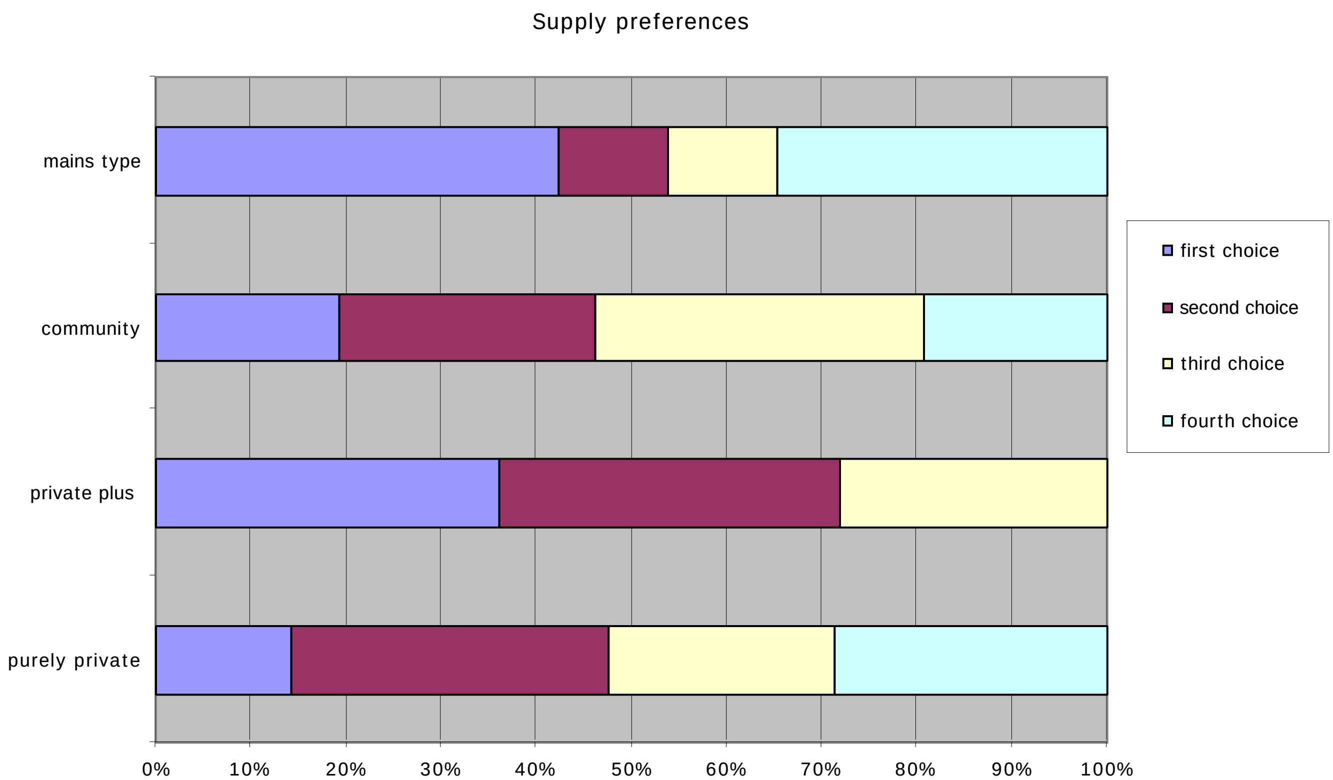
The residents do have aspirations to use more electrical appliances than they have at present, especially fridges and freezers where 24-hour power is required.

4. Your future power supply

a) Listed below are some alternative power supply options. Please rank them in order of preference: 1,2,3 etc.

		Order of preference
A purely private supply,		
A private supply supplemented by a community scheme,		
A community based supply,		
A 'mains grid' type of supply,		
other		
(Please describe)?		

Mains electricity was a popular option, but was also many people's last choice. A private supply



supplemented by a community supply was the most widely popular. The least popular option was the purely private supply. Individual power supplies are burdensome to maintain. Many would prefer to have power supplied to them.

b) Would you want to have more power available, and if so how much more?

c) Would you be willing to pay for a more expensive electricity supply?

d) Would you be willing to contribute (in cash or labour) toward the creation of a community scheme?

Most respondents felt that they could use more power, and would like 24-hour power. They would pay or contribute if they felt it was to their advantage. Many of the islanders have very limited financial resources.

e)Would you be willing to offer practical help with the ongoing maintenance of any electricity system?

f) Would you be interested in learning how to repair the system?

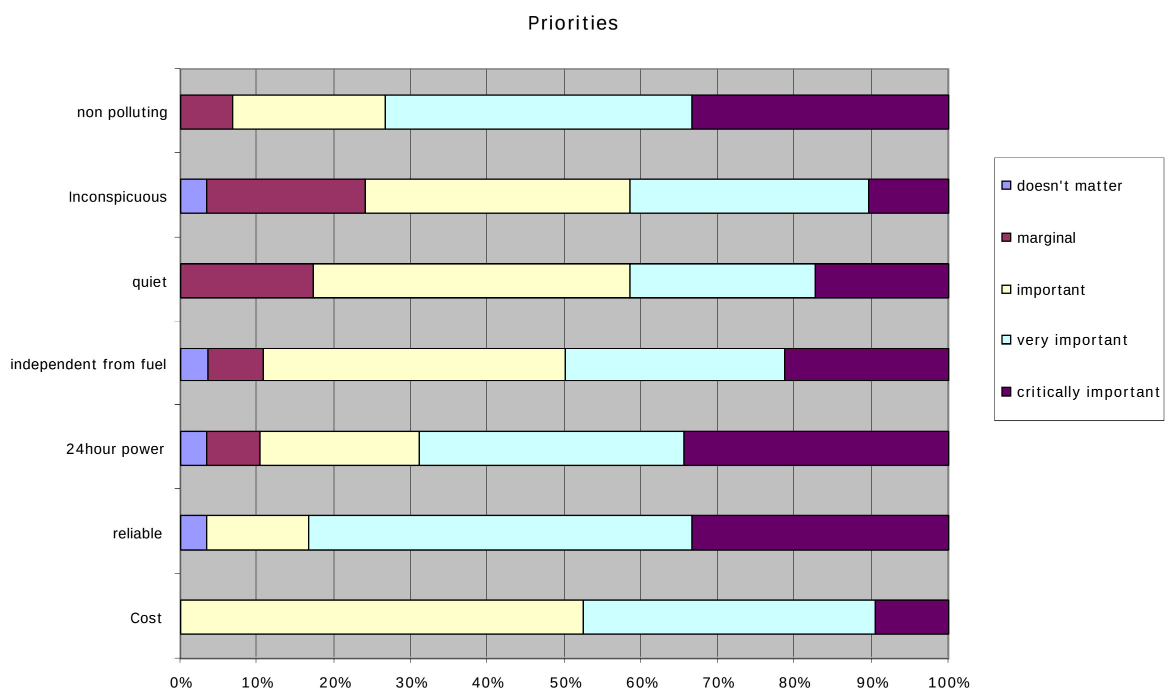
g) Would you be interested in becoming a paid caretaker on a communal system?

There was a good response to these questions. Approximately half of the respondents would consider becoming caretakers for a communal system.

5. Your priorities

Please say how important each of the following considerations are to you?

PLEASE TICK ONE BOX ON EACH LINE	*Doesn't matter*	*Marginal*	*Important*	*Very important*	*Critically important*
Cost of the electricity					
Reliability of the supply					
A 24 hour, un-interrupted supply					
Independence from fuel deliveries					
Quiet operation					
Inconspicuous generating equipment (sheds, pipes, masts, etc)					
Environmentally friendly, non-polluting, with no CO2 emissions					



Reliable, non-polluting, 24-hour power supplies came out most popular in these replies. These factors ranked well ahead of noise and visual impact for most respondents.

6. Your suggestions

a) Do you know of any existing opportunities for making electricity near to your home or elsewhere which you would like to see harnessed? These could be sites for water turbines, wind turbines or any other type of electricity generating equipment.

Several respondents suggested suitable sites for small hydro development (Sandavore burn and smaller sites close to houses). There was no mention of Laig.
Windpower sites were identified at Galmisdale and Kildonnan, but with reservations about the visual impact of the latter. There was also some enthusiasm for wood-chip combustion, wave and tidal power and for solar panels.

b) Do you know of any records, which have been kept of rainfall, wind or other relevant data, which could help us to assess what can be done on the island?

Donald MacLean has paper records of rainfall between 1927 and 1991 in his possession. They are in the form of monthly totals and number of dry days.

In view of the uncertainties surrounding the flow duration curves for island sites, it would be more useful to collect flow information at various sites than to analyse the rainfall patterns on the island.

c) How do you feel about the appearance of electricity generating equipment on the island?

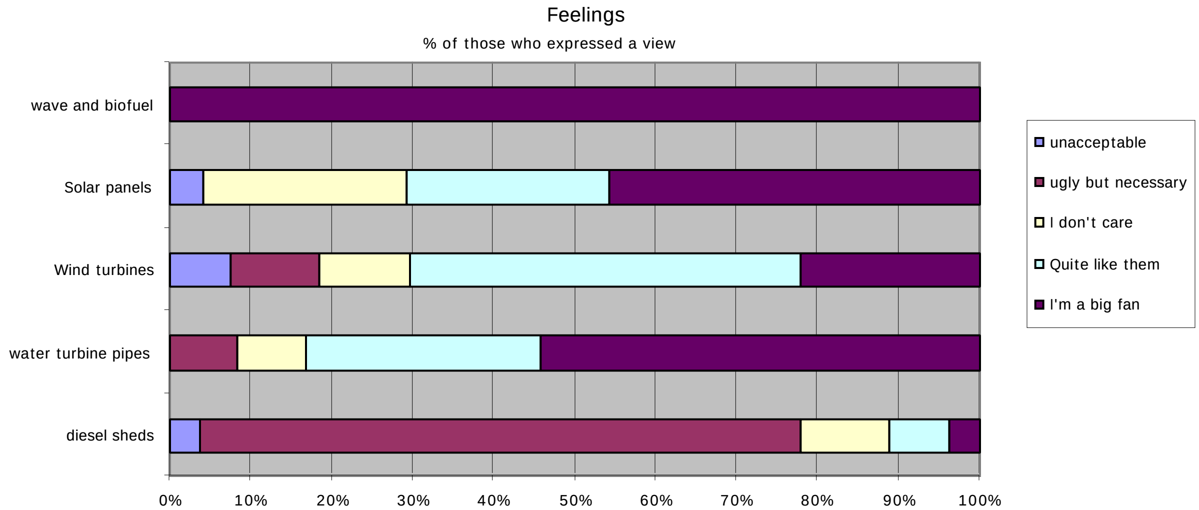
PLEASE TICK ONE BOX ON EACH LINE

OR WRITE YOUR OWN COMMENTS

	'I find them unacceptable'	*'They are ugly/noisy*	*'I don't care'*	*'I quite like them'*	*'I'm a big fan'*
Diesel generators in sheds					
Water turbine equipment and pipelines					
Wind turbines on masts					
Solar panels on roofs or racks					
Other (please describe)					

Water turbines and solar panels top the charts for most people, and although there is broad support for wind turbines, there are is also a small minority with strong views against them.

d) Would you have objections to the development of wind, water or other resources for producing power? Would you object to engine powered generators? If so, over which areas of the island would you object,



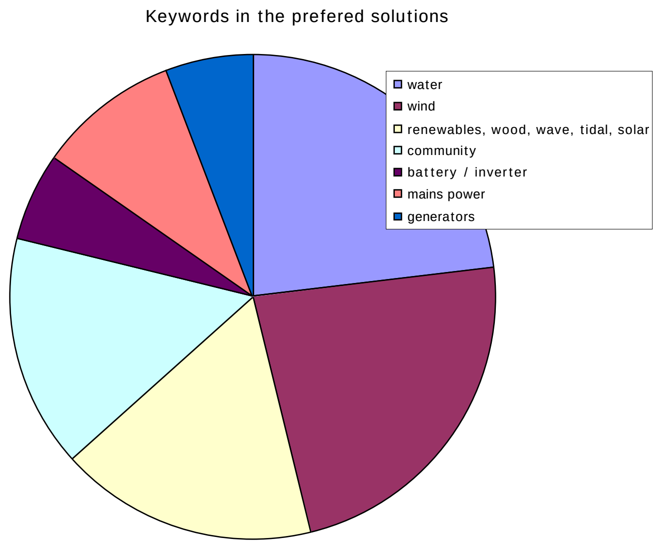
	diesel sheds	water turbine pipes	Wind turbines	Solar panels	wave and biofuel
I'm a big fan	1	13	6	11	3
Quite like them	2	7	13	6	0
I don't care	3	2	3	6	0
ugly but necessary	20	2	3	0	0
unacceptable	1	0	2	1	0

and to which sorts of developments?

Most replies started by saying they would have no objections. Wind turbines must be sited with due sensivity, and diesels must be soundproofed.

There is a perception that wind turbines could be a hazard to birds. Some felt that renewable energy equipment would add to the character of the island. Certain special areas would not be suitable though.

e) What would be your preferred solution to supplying power to the island while respecting the environment, and also bearing in mind the limited reserves of fuel remaining on the planet? In other words, what is the sustainable option?



Water and wind power were the most popular, with other renewable energy sources popping up often too. Diesel generators would be maintained for backup purposes.

Several respondents mentioned community schemes, and it appears that the Kildonnan example referred to in the introductory text is regarded as ideal for many people. Some would like a mains grid connection, combined with use of renewables.

3. Electricity supply requirements

Planning for future electricity supplies must be based on some notion of the consumer load, in terms of energy consumption per year or similar statistics. It would be feasible to measure the existing electricity consumption at each point of use and to total this up. Previous reports have used this approach. But experience has shown that electricity consumption depends more on the availability and price than on previous habits.

Energy conservation

It is usually safe to assume that demand will increase over time until all of the affordable energy is used. This process is typical of our consumer society, which is intrinsically unsustainable. In contrast, sustainable strategy will rather use energy conservation measures, to improve our enjoyment of the benefits of electricity while reducing our actual demand for energy.

Consumption will vary considerably, depending on the degree of energy efficiency. For example, low-energy lighting appliances (compact fluorescents) use only 20% of the energy of conventional lamps. Modern appliances can be much more efficient than old ones. Energy efficiency costs money, but it ultimately pays for itself in grid-connected situations, so it will be even more appropriate on Eigg, where the cost of delivering electricity is likely to be higher than on the mainland.

Electric Heaters

The use of electricity for heating is an important variable. Energy for heating is a larger fraction of our energy use than lighting, power and electronics. Where this is met directly by electricity on demand, the cost will be high compared to heating by other means such as burning fuel. A recent report has shown that the island could be self-sufficient in heating fuel from 'biomass' or firewood sources. Another feasible (but secondary) source of heat is from surplus electricity generated from renewable sources at times when demand is low, and batteries are full. It is much cheaper to store energy as heat than as electricity (in batteries).

Where electricity is required to produce heat, then 'heat pumps' should be considered. A heat pump moves heat from the environment into a building using electricity in rather the same way as a refrigerator moves heat out of a box. Each kWh unit of electricity can be used to make 3 kWh of heat available. So the heat pump multiplies the effectiveness of the electricity.

The time factor: connecting batteries to optimise energy usage

In most electricity systems, the energy must be generated at the same rate as it is used. In other words, the generating plant must be large enough to meet the peak power demand on the system. In a renewable energy system, the energy is generated according to the weather rather than on demand. In the absence of storage, a great deal of this energy will be dumped (usually as some sort of useful heat). In order to be large enough to meet peak power demand, the turbine (or whatever) will have to be much larger than the size required to equal the average energy demand.

When generating plant is underused in this way, we can say it has a low capacity factor. Capacity factor can be improved by charging batteries during times of low demand and then using battery power to supplement the turbine during periods of higher demand, or when there is no wind, water or sun. By adding battery storage to the system we reduce the amount of generating plant required to meet the electrical load. This comes at a price. Batteries are expensive and need to be replaced every few years. But they can make a great difference to the capacity factor of a diesel genset or a hydro turbine. And without battery storage, small wind or photovoltaic systems would be virtually useless for electricity supply.

Diversity

Much of the variation in power supply and demand can be removed by using diverse sources of power in a hybrid system (wind and solar combined for example). The greater the diversity of the system, the smaller the battery needs to be. In the same way there is an advantage to having a number of premises connected to the same supply because the diversity in their usage will even out the peaks of demand. In this case, the cost of the distribution network must be considered against the cost of the battery store. In both cases there are also energy losses to be allowed for.

Peak loads

Meeting peak loads is a challenge for stand alone power systems. The inverter delivers mains voltage power from the battery to the load. Most inverters can deliver about three times their continuous rated power for brief periods. If overloaded they will cut out. Large inverters are expensive. Gensets are often used to help meet peak loads, so as to both save on the cost of the inverter, and also to supplement the energy supply at the same time. Peak loads have often caused reliability problems in systems where the inverter is undersized. Overloaded inverters, and glitches during genset connection, are the cause of low power quality and also loss of power on frequent occasions. To provide a reliable supply it is necessary to be generous with the inverter capacity.

Assessing the load

The potential future electrical load on the island is about as long the proverbial piece of string. A very high standard of living can be achieved with very little electricity use, if appropriate steps are taken toward energy management, efficiency, and alternative heating fuels.

Domestic electricity use of the typical UK household on the mainland grid is approximately 10-12 kWh per day (4,000kWh/year). Present consumption on Eigg is almost certainly less. This figure could be used as a ball park estimate of future energy demand for households on Eigg, while bearing in mind the above comments on ways by which demand could be reduced. Future residential energy demand can therefore be estimated as approximately 120,000 kWh based on the number of inhabited or partially inhabited dwellings.

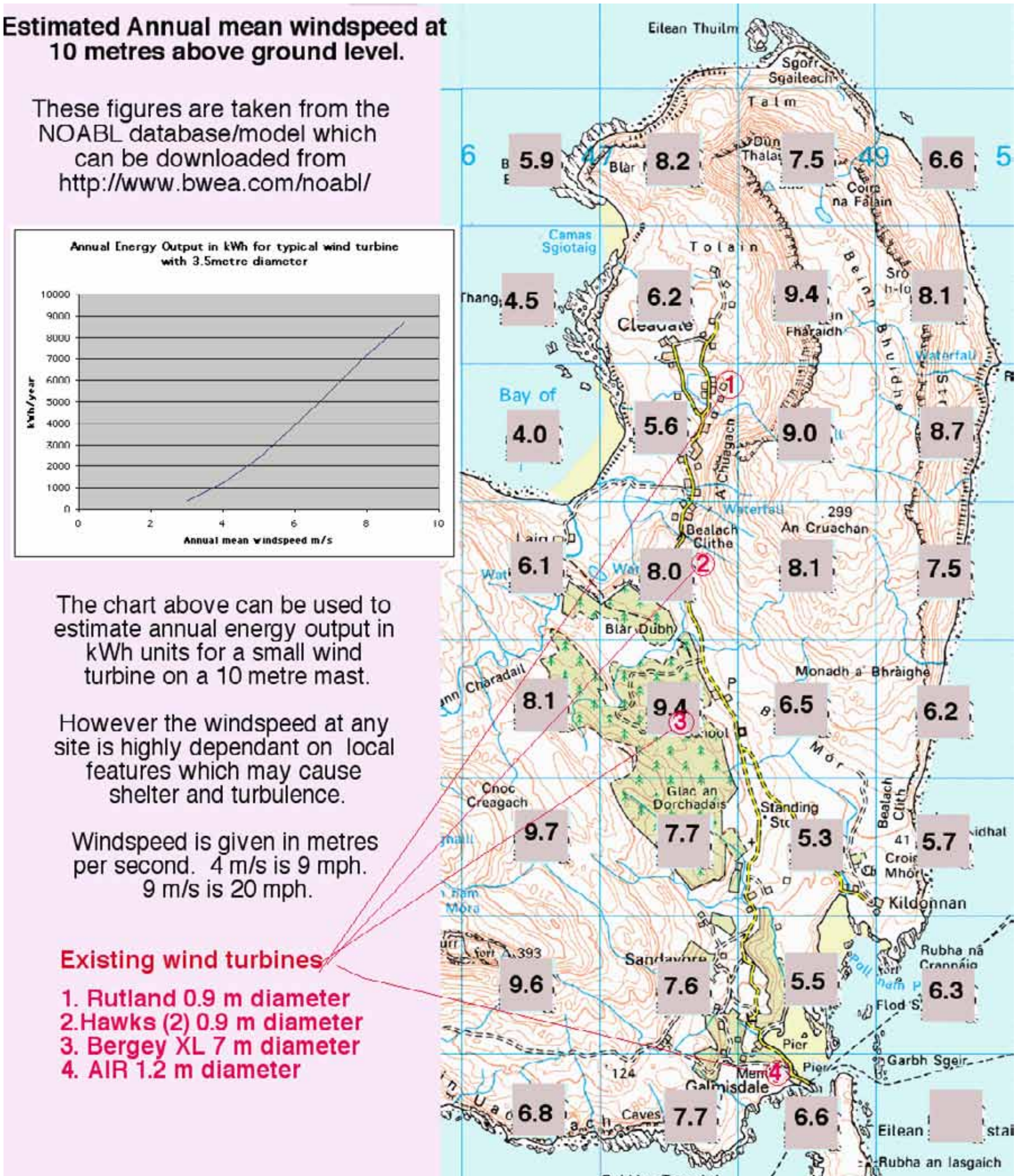
Commercial premises include the Pier Centre shops and tearoom, and several guesthouses. There is also a school, a doctor's surgery, day care centre, and telephone exchange. These additional loads could increase the overall demand to 200,000 kWh or more.

Factoring the load

To supply 200,000 kWh units of electrical energy to the user on demand, it will be necessary to generate more than this. Energy is lost at every stage: heating up transmission in cables, lost in storage batteries, discarded into heating when the battery is full, and used up during conversion from one voltage to another. To meet a demand for 200,000 kWh it would be necessary to produce 300,000 kWh and also to plan the system carefully to avoid unnecessary waste.

4. The renewable energy resources of the island.

1. Wind Energy



The energy in the wind varies with the cube of the windspeed, so there is very little energy in low winds and a huge surplus in high winds. Annual mean windspeeds on the island are above average (see map), so wind energy is an option worthy of study. But the topography of the island with its many steep slopes makes the wind flow turbulent and hard to model accurately. Turbulent winds are less productive of energy and also cause premature wear and tear of the wind turbine.

There are already five small wind turbines in operation on the island, on four sites.

Table 2.1 gives estimated windspeeds and energy production for these three wind turbines.

Wind Turbine	1	2	3	4
Diameter	.9 m	.9 m	7.0 m	1.2 m
Mean windspeed	5 m/s	7 m/s	8 m/s	6 m/s
Energy/year	185 kWh	370 kWh	28000 kWh	494 kWh

Site windspeeds are difficult to estimate with accuracy, even given the database figures for each kilometre square. Local conditions and height can make a huge difference to the real situation. Actual energy production may be less than the figures given in the above table.

Much could be learned from data-logging exercises, which collected windspeed data at possible future turbine sites, and also logged the energy production of existing windpower systems on the island.

Wind energy systems costs

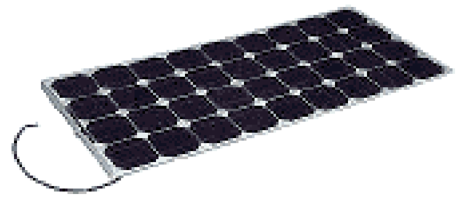
We can take as an example a 2.5kW wind turbine produced in Scotland by Proven Engineering products of Kilmarnock. This is above average quality and weight for a small wind turbine, and would have a life expectancy of about 20 years on Eigg. During that time, some repairs and overhauls would be inevitable. On a 6 m/s site this turbine would produce approximately 4000 kWh of electricity each year - enough for one house.

Budget costs for 2.5 kW wind energy system	
2.5kW wind turbine/generator (240V output)	£ 3,655
2.5kW 240V heating controller. Volt and Ammeters 500mmHx300Wx200D	£ 660
Tilt-up self supporting wind turbine mast (6.5m) including foundation kit, plans & gin pole	£ 1,625
Tirfor winch with 20 metres wire rope + strop (suitable for WT600/WT2500)	£ 380
Estimated installation cost including 1 cu metre of concrete poured into a hole	£ 1,000
3-core amoured cable for WT2500/120	£ 500
delivery estimated	£ 400
total ex-VAT	£ 8,220

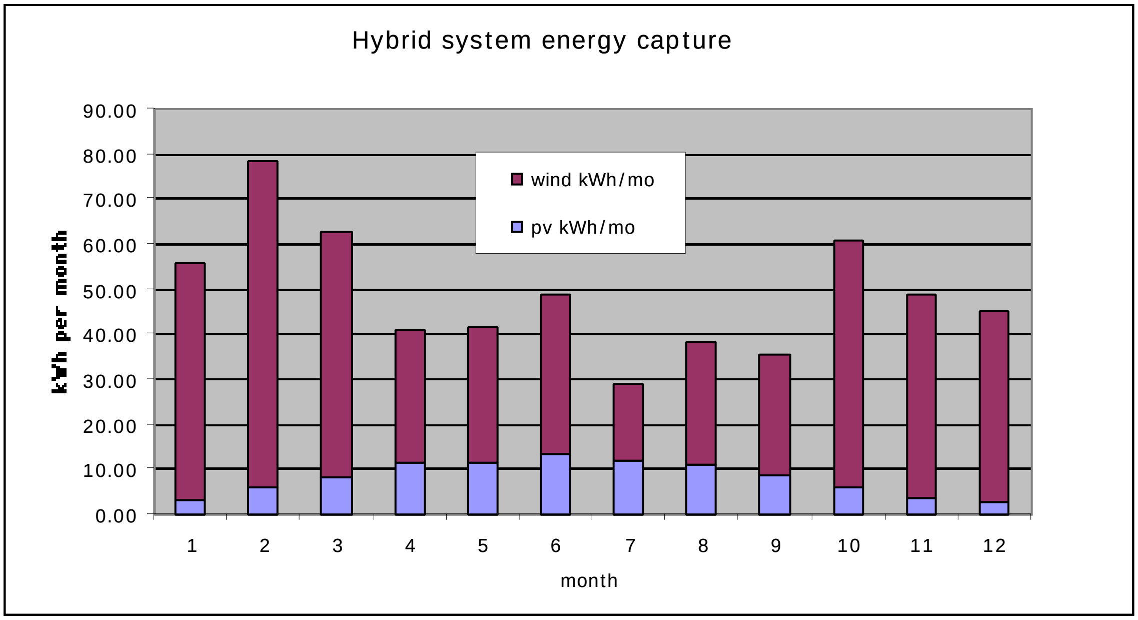
The photo shows a Proven wt2500 on the Scoraig peninsula, in landscape similar to that on Eigg.

2. Solar (Photovoltaic) Energy

Photovoltaics or "PV" is the technology whereby solar cells are used to convert the energy of sunlight directly into electricity. The cells are assembled into panels or 'modules' (see right). Several modules are linked up to make up an 'array' (se next page) for electricity supply on any given site.

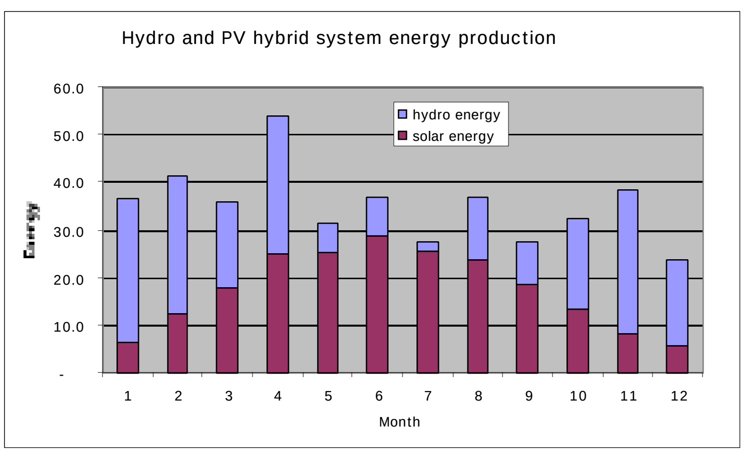


PV modules are very reliable, but expensive in terms of the energy available from the sun in Scotland. Output can be predicted with some accuracy, provided the array is sited where there is no shading.



There is a large seasonal variation in energy production. Consider a PV array rated at 1 kW (1000 W) nominal power output. Average annual production will be about 750 kWh each year, so the monthly average will be 62 kWh. But during the darkest months of the winter, this falls to only 12 kWh per month.

Photovoltaics are used to power the lighthouse on Castle Island. PV modules are also in use at the TV repeater station above Cuagach, alongside two small wind turbines. These wind turbines produce more energy than the PV modules per unit cost, but the mixture of wind and solar energy provides a more consistent supply. Solar energy is available in the summer when windspeed tends to be lower. This type of system, where two sources are used is termed a 'hybrid system'. The chart shows typical energy capture for a hybrid system with two 'Hawk' wind turbines and two 75W PV modules.



The second chart shows how a photovoltaic array would work alongside a hydro turbine of the sort discussed in the next section. The turbine would run for 60% of the time. The chart shows what the turbine would produce per month (data from year 2000) compared to what the PV array would produce in a typical year. (I suspect that the sun in May 2000 was actually less than average, in view of the high rainfall.) The combined energy output is very consistent over the year, indicating a suitable arrangement for a standalone system, with minimal reliance on the back-up genset.

Photovoltaic System costs

The table shows the cost of a PV system which would produce about 1350 kWh /yr

The array area is 16 square metres.

Budget costs for 2 kW Photovoltaic array	
12 no. 85 Wp photovoltaic modules	£ 8,000.00
Support framework	£ 800.00
DC cabling	£ 150.00
Charge controller with metering	£ 250.00
Fuses etc	£ 50.00
Installation estimated	£ 300.00
Total ex VAT	£9,550.00

3. Hydro Energy

Hydro sites on Eigg

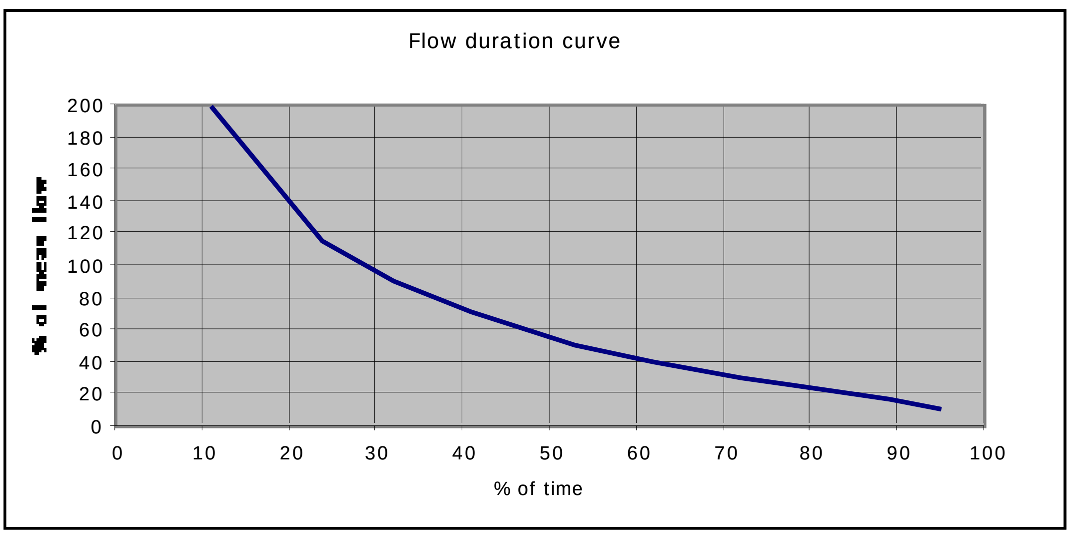
There is a long-standing tradition of using small hydro turbines to produce electricity on Eigg. A highly sophisticated 7kW turbine supplied power to the Lodge for many years before falling into disrepair. Several other sites have been developed in recent years (see map).

The hydro systems on Eigg can be termed as 'pico hydro' because they are under 10 kW in size. Modern pico hydro systems do not need dams or reservoirs. Water is collected from the stream in a small pool created by a low weir, and then returned to the stream below the turbine.

The power output depends on the flow of water, and also the head of pressure. By doubling the vertical fall between intake and turbine, we can double the power obtained from the same flow of water. The cost of this extra 'head' is a longer pipe. The pipe is a large element in the cost of the project. The bore of the pipe has to be large, so that pressure is not lost overcoming friction.

In most cases, the existing hydro systems produce AC power, which is used directly. Surplus power is diverted into heaters so as to keep a constant load on the turbine, and maintain a stable voltage. This ability to produce direct AC sets hydro turbines apart from wind and solar systems, which rely on other equipment such as batteries.

Hydro is much more consistent than wind or solar power, but it does suffer from downtime during the drier weeks of the year.

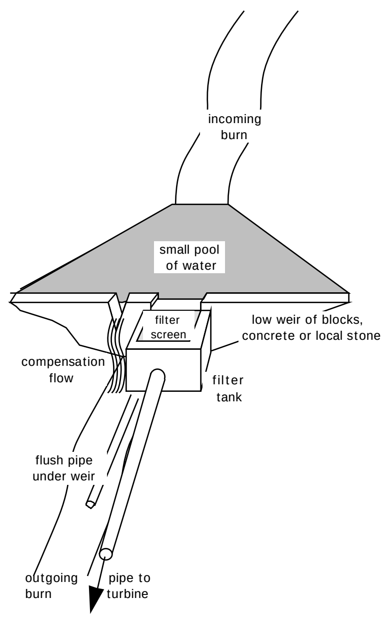


The Flow Duration Curve

The way in which water flow varies can be expressed in terms of a 'flow duration curve' (FDC). A typical flow duration curve is shown above. It shows the percentage of the mean flow which will be exceeded for ho much of the time. For example the flow which will be available for 50% of the time (also known as 'Q50') is only about 55% of the mean flow in the stream.

This idealised flow duration curve comes from computer software. It conforms to the expectations of the Environmental Protection Agency (SEPA), but the actual FDC on any given site may vary from this considerably, and will change from year to year. Actual flow measurements will greatly increase our understanding of the potential resource.

Note that the mean flow (shown as 100% on the chart) is only available for 28% of the year. Much higher flows are available for shorter periods, and much lower flows are also very common. The flow, which is available for 95% of the time, is called 'Q95'. Q95 can be estimated as typically 11% of the mean flow. This flow is significant, because it is chosen by SEPA as the minimum 'compensation flow' which should remain in the water course at all times that water s being extracted. In other words, the turbine can only take water for 95% or less of the year, because it must leave a flow equal to the Q95 flow in the stream at all times, for environmental reasons. Where there is uncertainty about the FDC then the compensation flow may be increased to 15% or more of the estimated mean flow.

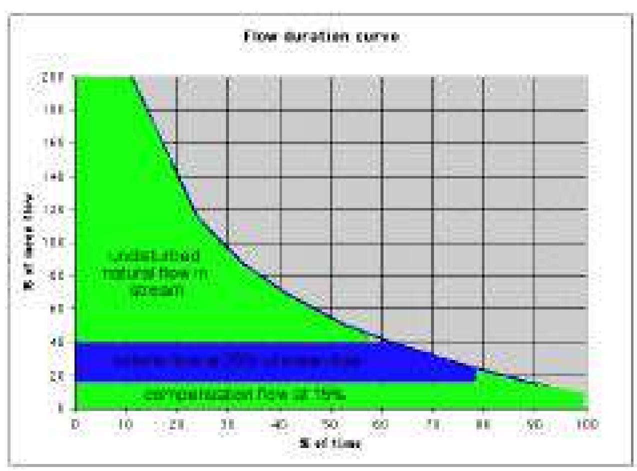


The Water Framework Directive

Planning applications for pico-hydro developments are subject to scrutiny by SEPA, which in turn has to bear in mind the new 'Water Framework Directive' coming out of Europe in the next few years. This will attempt to prevent **any** environmental impact by any new development on a waterway. If taken literally, this directive could simply prevent future hydropower development. However, the legislation will contain some recognition of the importance of using renewable energy to reduce the overall environmental damage we do, in getting our electricity. If a hydro turbine produces benefits to the environment or community, which outweigh the (minimal) environmental damage caused, then this will be taken into account.

Choosing a suitable size for the turbine

We must take account of the difficulties with both varying flow and official scrutiny, in making our choice of turbine for any site. The cost of the pipe, turbine, controls and cabling will depend on the choice of flow. Traditionally, a turbine is sized to use the mean flow on the site. However this flow is only available for 28% of the time. After removing allowing for compensation, flow this availability is cut down still further to about 24% of the time. This is a poor capacity factor.

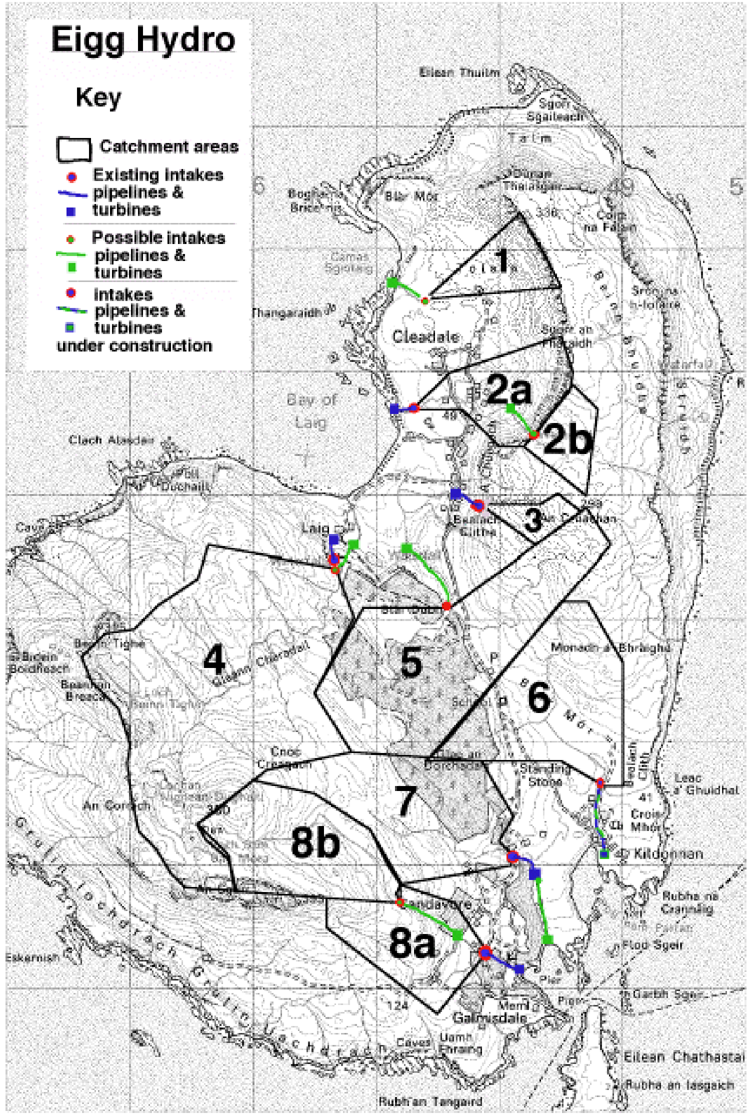


We need a consistent energy supply, with as little impact on the flow as possible. I would therefore choose a turbine which only uses 25% of the mean flow.

· This will cost less,

- have lower environmental impact
- and yet operate for over 60% of the time on full power.

This approach produces less energy on a given site, than the larger turbine option. But it produces the energy more consistently, rather than in big bursts during wet weather. And because it is environmentally friendly and low cost, it can be used on more sites, and over higher heads, to capture the island's full pico-hydro potential.



The potential for pico hydro development on Eigg

The map shows the island divided into catchment areas for the purpose of estimating flows at the various sites. Run off can be estimated as 1166mm per year. From this we can derive theoretical flow duration curves for each site, and thence derive specifications for turbines, pipelines and their energy production.

Several of these sites are already in use, and experience indicates that the estimated FDC is very different (better or worse) than the model predicts. Turbines existing on these sites are mostly larger than the size suggested in this report.

Physical parameters of hydro sites shown on map.

	Areas	mean flow (ADF)	Gross head	Pipe length	Pipe bore	Turbine size: 60% efficient power at 25% of mean flow	Energy output (using 25% of mean flow)
1	0.35 sqkm	13 l/sec	35	350 m	75 mm	0.7kW	3499 kWh/yr
2b	0.28 sqkm	10 l/sec	180	400 m	50 mm	2.7kW	14398 kWh/yr
2	1.25 sqkm	33 l/sec	18	150 m	105 mm	0.9kW	4628 kWh/yr
3	0.16 sqkm	6 l/sec	90	200 m	40 mm	0.8kW	4114 kWh/yr
4	3.50 sqkm	129 l/sec	30	300 m	187 mm	5.7kW	29995 kWh/yr
5	2.00 sqkm	74 l/sec	40	700 m	167 mm	4.3kW	22854 kWh/yr
6	1.34 sqkm	50 l/sec	30	550 m	144 mm	2.2kW	11484 kWh/yr
7	1.28 sqkm	47 l/sec	17	110 m	115 mm	1.2kW	6216 kWh/yr
7	1.28 sqkm	47 l/sec	30	550 m	141 mm	2.1kW	10970 kWh/yr
8b	1.05 sqkm	39 l/sec	100	600 m	104 mm	5.7kW	29995 kWh/yr
8	1.80 sqkm	67 l/sec	40	350 m	140 mm	3.9kW	20568 kWh/yr
						total	158721 kWh/yr

It is interesting to note that the theoretical energy output of the combined schemes amounts to over 150,000 kWh per year. This meets half of our energy production target as guess-timated in section 3.

The scenarios given here are not set in stone, and could be adapted in many ways. For example there are sites where a great deal more energy could be collected by extending the pipeline and increasing the head at the turbine (see for example Laig catchment 4). There are also many smaller watercourses, which could for example produce a 200-watt output, contributing perhaps 1000 kWh/year or 1/4 of a typical household demand.

Staying with the above examples, we can put budgetary cost figures on these developments. These costs are based on the 25% of mean flow design rule used for this exercise. Many of the existing systems use more of the flow. Turbine costs are based on importing Australian 'Platypus' turbines, which appear to be very competitive. Research has shown that there are also even cheaper turbines to be had from developing world countries. These may not prove to be such a good investment long term.

Installation costs are very hard to predict, because existing sites have used the owners labour and materials, or volunteer labour. The uncertainties surrounding installation schedules and costs may become a serious obstacle to future development of renewable energy projects on the island.

Budget costs for hydro sites shown on map.

	Place name	Pipe estimated cost	Turbine (& controller) estimated cost	installation cost estimated	Total project cost
1	sgiotaig	£ 910.00	£ 1,550.00	£ 3,460.00	£ 5,920.00
	0	£ -	£ -	£ -	£ -
2b	tighearna	£ 1,040.00	£ 3,000.00	£ 5,240.00	£ 9,280.00
2	cormack	£ 1,500.00	£ 1,550.00	£ 3,450.00	£ 6,500.00
3	fyffe	£ 300.00	£ 1,550.00	£ 1,885.00	£ 3,735.00
4	laig	£ 3,600.00	£ 4,000.00	£ 9,760.00	£ 17,360.00
5	cam lon	£ 7,000.00	£ 3,800.00	£ 13,840.00	£ 24,640.00
6	kildonnan	£ 4,400.00	£ 3,000.00	£ 8,200.00	£ 15,600.00
7	glebe	£ 660.00	£ 2,000.00	£ 3,780.00	£ 6,440.00
7	gurrabain	£ 4,400.00	£ 2,500.00	£ 8,220.00	£ 15,120.00
	0	£ -	£ -	£ -	£ -
8b	sandavore	£ 4,200.00	£ 4,000.00	£ 9,580.00	£ 17,780.00
8	lodge	£ 2,800.00	£ 3,800.00	£ 7,260.00	£ 13,860.00
				total	£ 136,235.00

4. Wave and Tidal Energy

Wave motion can be used to generate electric power. The technology is well developed, but requires very specific site conditions, which do not exist on Eigg.

Tidal currents can be exploited by underwater turbines similar to wind turbines but smaller in size. The viability of the technology depends heavily on the speed of tidal streams. There are usable flows in the channel between Eigg and Castle Island, but they are not strong enough to make tidal power a tempting option. The need to maintain a clear channel for navigation would probably be another big obstacle to successful exploitation of the resource.

5. The suggested model for electricity supply

1. The options for electricity supply are as follows:

Diesel generators. (gensets)
These are the main source at present and will likely remain a useful part of the mix in future.
Advantages: Power is available on demand. Initial cost is low. The technology is well understood, and a number of diesel sets exist.
Disadvantages: Fuel cost is an ongoing expense. The burning of diesel fuel is polluting and non-sustainable. Plant depreciation and maintenance is costly. Older diesel sets have been extremely reliable but noisy and dirty. They appear to last forever but must eventually wear out. Newer sets are less reliable, and have proved expensive to maintain.

Mains Grid Electricity.
There has never been a mains connection to the island, but a cable could be laid. This would be a popular option with some residents.
Advantages: High reliability with minimal user involvement. The ability to tap into much more efficient generating plant on the mainland. Renewable energy sources on the island could be connected to the grid, allowing surplus power to be exported, or transferred to other users on the island.
Disadvantages: A cable connection would have very high capital cost, even compared to small renewable energy installations. Electricity would still have to be generated elsewhere to meet the island's needs. This would have both financial and environmental costs, which would be ongoing. A mains connection would remove one of the island's many distinctive features, which make it attractive to visitors.

Small renewable energy systems.
Advantages: Renewable energy is abundantly available, free at source and everlasting. The environmental impacts of harnessing it are less damaging than the impacts of conventional fuel-burning plant. Small power systems fit the human-scale character of the island, which is part of its appeal.
Disadvantages: Capital cost of small renewable systems and associated infrastructure is high. The available power does not match demand very well, and additional equipment is required to regulate, store, and convert the energy for the end user. This adds to cost, and reduces the efficiency and reliability of the systems. Maintenance of the systems would fall on local residents rather than an electricity company.

2. The way forward

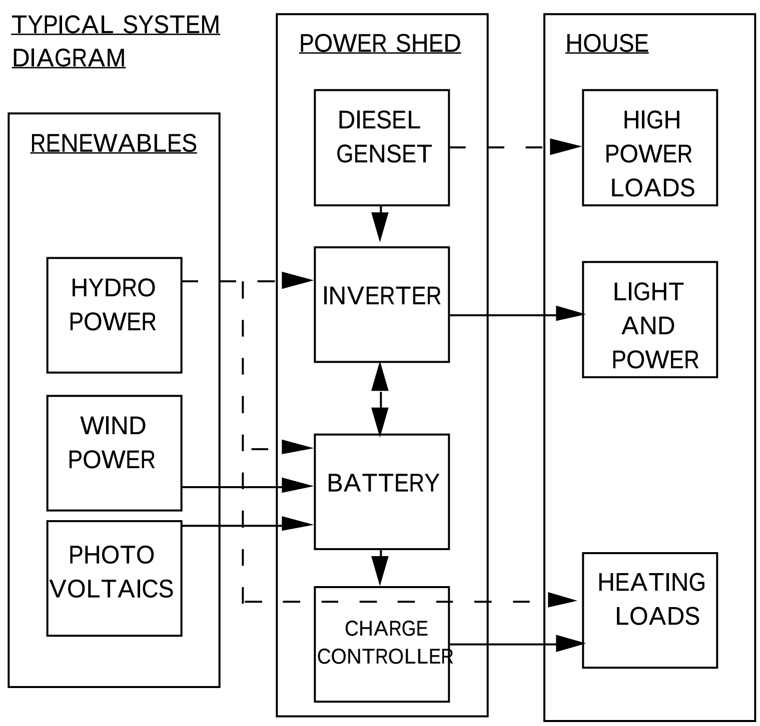
The questionnaire responses indicated a preference for reliable, non-polluting, 24-hour electricity supplies. Purely private supplies are not very popular, and many would prefer mains electricity. But the most popular option overall was a private supply supplemented by a community scheme.

Reliability. While grid power sets a high standard of reliability, this is not always the case in remote places. Greater reliability can be achieved using a diverse supply, which does not rely on one source alone.

Non-polluting sources were a priority for the islanders, and renewable energy is popular on the island, especially hydropower. Wind and solar power are also attractive although there is some concern about the high visibility of wind turbines.

24-hour electricity is readily available from battery/inverter systems, which store energy and make it available as AC mains-quality power on demand. Many households already operate such systems alongside their diesel generators, and benefit from increased convenience and fuel savings.

The solution which appears to best suit the majority of islanders is a semi-autonomous power system which takes most of its energy input from renewable sources, but uses a battery to maintain 24-hour power, and a diesel generator to provide backup. The diagram shows the structure of the system in its general form.



The inverter

The inverter provides 24-hour power for lights and power. The inverter is a device, which converts DC battery power into AC mains-quality power.

Some modern inverters have the facility to synchronise with an AC supply such as a genset, and to use that supply to feed the user load directly. Meanwhile the inverter actively smoothes out the load on the AC source (genset, hydro, etc) by using part of it to charge the battery when user demand is low, and by taking power from the battery during periods of high demand. This makes the best use of the supply and prevents overload of the source. While this inverter operating mode is routine for a number of gensets on the island already, it has not yet been tried with a hydro turbine. The system at Kildonnan, which is shortly to be commissioned, will be a test case for this innovative approach to using hydropower.

The battery

This takes energy from such renewable sources as are available, and stores it until it is needed.

The charge controller
This monitors the state of the battery and diverts any incoming energy that the battery cannot store (due to lack of capacity) into useful heating loads in the building.

The diesel genset
This provides power when the battery becomes discharged or the demand in the house is beyond what the inverter can meet. When the diesel generator is running, it recharges the battery at the same time as directly supplying the user demand. The inverter serves as a battery charger during this phase of the operation. On most sites there is already a genset in operation, which makes the transition to the new arrangements easier.

Renewable energy sources
Wind and solar power may be available in the form of DC to charge the battery. In the case of some hydro turbines, AC mains-quality power which can be used directly. In the latter case it would be is desirable to feed hydropower through a synchronous inverter without converting it into battery power at all. Converting the energy results in some it being lost as waste heat.

3. Stand alone system costs

Each domestic stand-alone power system will be costly because of the need for battery storage. But batteries greatly improve the capacity factor of the renewable energy sources. Without the batteries, any energy which is generated at the wrong time would have to be discarded, and replaced later with diesel generated power at times of high demand. The battery systems make renewable energy 'go further'. Economic analysis must allow for the future replacement of batteries at approximately five year intervals. It therefore makes sense to rely on genset backup rather than having such a huge battery that it can deal with the worst case scenario.

Location of batteries at each site enables the user to access relatively high power from the system without the need for a very expensive distribution system. PV modules can be located close to the battery, but wind and hydro turbines can be located where the wind or water supply is best. Cables carry power from the turbines to the dwelling at high voltage.

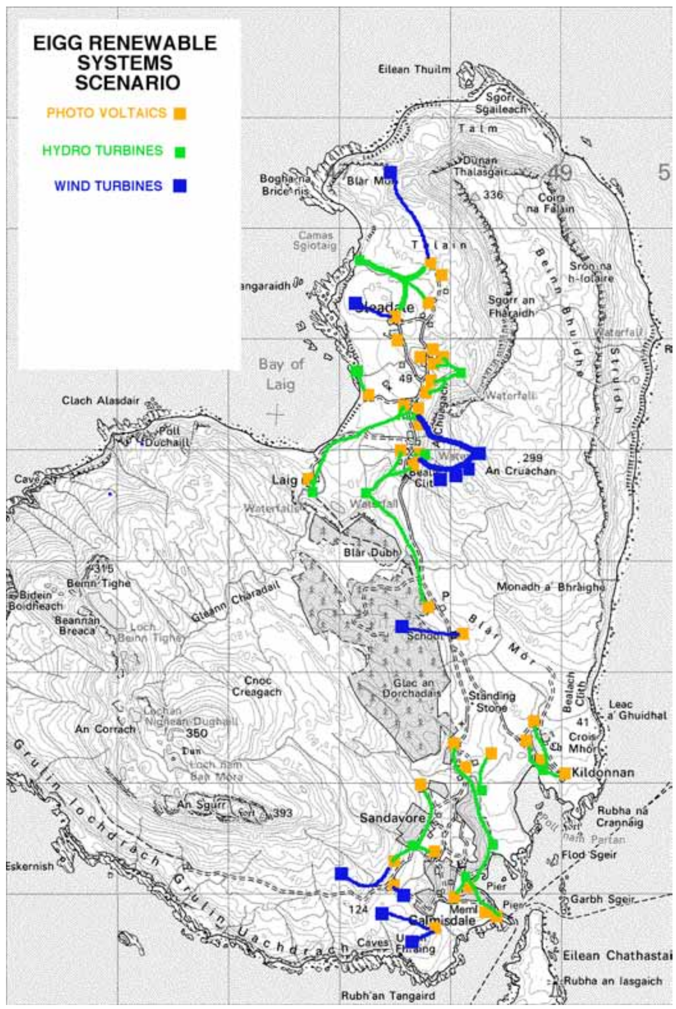
Budget costs for a stand alone domestic supply	
4.5kW inverter/charger	£ 3,000.00
15kWh battery	£ 1,800.00
Cabling and fuses	£ 200.00
Bypass switch for generator	£ 160.00
5kW Diesel generator	£ 4,500.00
Installation	£500.00
Total ex VAT	**£10,160.00**

In most cases some or even all of this equipment already exists at Eigg households. But the equipment specified here is larger than existing systems. This would improve reliability, by reducing the danger of overload, which has been a frequent cause of power failure in the past. Commercial users (Shop and tearoom for example) should consider using a 10 kW inverter in place of the existing 2.5 kW.

4. Island wide system outline with costs

One possible scenario to consider...
The table below is an illustration of what could be achieved, at lower cost than a grid connection, to power the island in a sustainable way.

Budget costs for a system to meet the island's needs					
Item	Cost	Energy kWh/yr	no.	total cost	Total kWh/yr
Domestic stand-alone systems	£ 10,160	1,000	35	£ 355,600	35,000
Photovoltaic arrays 2kW each	£ 9,550	1,350	35	£ 334,250	47,250
Hydro turbines	£ 13,000	16,000	10	£ 130,000	160,000
Wind turbines	£ 8,220	4,000	16	£ 131,520	64,000
			tot:	£ 951,370	306,250



In this scenario, each house has a stand-alone system with a 2kW photovoltaic array, which provides 1350kWh of energy per year. This energy is likely to be delivered at times when water and wind power are less plentiful.

The diesel generator might provide 1000 kWh. This represents about 4-5 hours running per average week. The generator should have a long service life on this duty.

Hydro and wind turbines at suitable sites are used to provide the bulk of the energy to meet our target of 300,000 kWh each year (see section 3). The costs of the wind and hydro systems have been adjusted to allow for long cables to reach the houses.

This is only an illustrative scenario and does not prescribe the positions of the turbines. The distribution of good sites does not match the distribution of dwellings very well. It is hard to supply the population centre in Cleadale and the area around the Glebe.

There is ample hydropower around Sandavore and Laig. There are ample sites for wind turbines west of Galmisdale, and these could be sensitively placed. It may be harder to find many other sites which are not only suitable, but acceptable, and close enough to the dwellings. Blar mor and the slopes above Cuagach are suitable but rather inaccessible.

Planning permission

The scenario above would be tackled in small increments, each of which would be subject to planning permission, including conditions imposed by Scottish Natural Heritage and SEPA.

There are Sites of Special Scientific Interest (SSSIs) on the island where the hazel and willow scrub and the arctic sandwort deserve special care. This should not be an insuperable obstacle. The whole island is a National Scenic Area. Visual impact of developments will be critical. It should be easy enough to blend the small hydro systems into the landscape, but the effects on flow in waterfalls needs to be negotiated. Small wind turbines will have to be placed where they will not be conspicuous. Short towers and natural colours should make this possible.

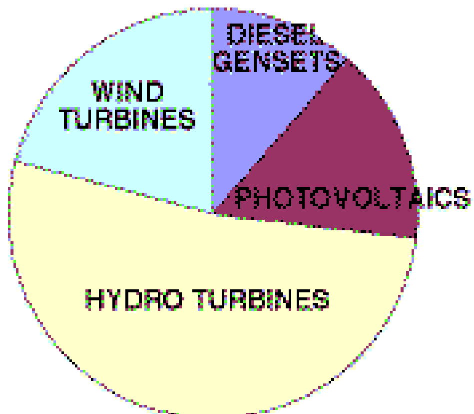
Normally residents would be classed as very sensitive to development, but since all the power will be used on the island that aspect may have to be reconsidered. Questionnaire responses indicated that noise and visual impact concerns were low on the scale of priorities for energy supply.

Economic analysis

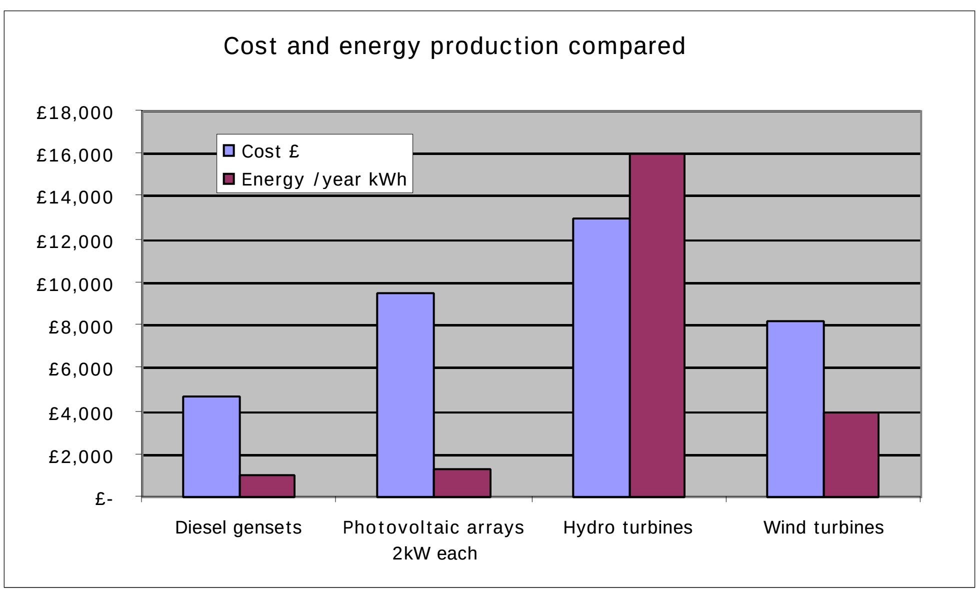
The cost of the above scenario appears to be under half of the cost of a mains cable, and 90% of the energy produced is from renewable sources. Each house has reliable 24-hour power.

However it would be wise to be cautious until we have more accurate costings for installation work on the island. Previous installations have relied heavily on voluntary labour and have been very slow to progress. Onerous conditions which may be imposed through the planning process could multiply the cost.

Some sources are more cost-effective than others according to the above figures. But the more expensive elements play a vital role in maintaining continuity of supply.



ENERGY SUPPLY SCENARIO



Conclusion

Demand for electricity will probably increase on Eigg in future years, even allowing for energy efficiency measures. Residents will also expect 24-hour power, with better reliability than has been acceptable in the past. This increased expectation can be met to a large degree from renewable energy sources. The cost would be less than the cost of grid connection. At present there are very generous grants available to assist with this type of development.

The strategy described in this report builds on the style of existing electricity supply arrangements on the island, and could be implemented gradually. Experience gained along the way would contribute to the effectiveness of later developments. Inadequately sized equipment has caused considerable problems in the past, but new developments could afford to be more generous.

The process would offer sustained employment opportunities on the island in both the areas of installation and maintenance. The availability of labour could however be the main factor limiting the pace of development. In fact there is a national shortage of expertise in small renewable energy system manufacture and installation.

There is a need for more data to be collected, by manual observations or datalogging equipment. We need to know more about the energy production from existing systems, as well as the actual resources available for future development, such as windspeeds and the flows at various points in local streams. The data will help us identify the most cost-effective solutions and avoid possible environmental damage.

Eigg is an ideal situation for testing and demonstration of cost-effective small-scale renewable energy systems. Development of environmentally friendly systems could put Eigg in the forefront of electricity supply technology for the 21^{st} century.

Hugh Piggott, Scoraig, January 2003

Scottish Community Renewables Initiative – Community Renewable Installations

Renewable energy projects offer important benefits to many Scottish communities. They generate local jobs and income, vital to the regeneration process. They help pave the way to local environmental sustainability in energy supply. They are the technologies of the future. The SCRI is a one-stop shop offering communities help at every stage of developing a renewable energy project. We give advice on project management and we provide or source expertise on renewable technologies. Financial support to contribute to part or all of the installation costs and the necessary supporting infrastructure is also available.

Local advice and project management support

There are SCRI Development Officers in each of the five Energy Efficiency Advice Centre offices in southern and eastern Scotland and at Highlands and Islands Enterprise in the north. The SCRI Development Officers work to promote local community renewables by:

- Providing expertise and developing networks to drive things forward
- Bringing interested parties, skilled advisers and funders together, to develop and implement schemes
- Signposting communities to UK and Scottish funding sources
- Advising on Scottish planning and legislative requirements

All applicants for SCRI funding for technical assistance (feasibility studies, public consultation) and for capital installation (see below) MUST involve their local SCRI Development Officer in the application process. The SCRI Development Officer will help tailor the application to ensure maximum chance of success. **You should make contact with your local SCRI Development Officer as soon as possible.**

Funding support

Communities may apply for funding for **technical assistance** and **capital grants** for renewable energy equipment installation and associated costs.

Technical assistance funding

Technical assistance funding is available to projects which are at the formative stage and which will progress no further without this support. The maximum grant is normally £10,000.

Technical assistance grants are available to:

- Pay for part or all of the costs associated with feasibility studies or community consultation
- Provide support for an organisation's staff to develop a proposal
- Pay for capacity building (renewable energy awareness raising, training and skills development)

Applicants are required to outline contributions from other sources (public or private). Applications with significant investment from other sources will be highly regarded.

Capital Grants

Capital grants pay for a contribution to the capital costs of projects, with funding of up to 100% of project costs. The maximum grant is £100,000.

100% funding will not be the norm and will only be provided in circumstances where a project demonstrates high quality environmental benefits, and particular educational and demonstration merits. In assessing applications, contributions from other funders will be highly regarded. Other funds may come from either the public sector or the private sector.

Funding is available for:

- Capital costs of installing renewable energy generation plant
- Capital costs for supporting infrastructure, such as roads
- Project management costs associated with the development and installation of generating equipment
- The costs of the community establishing a partnership with a third party such as a developer, or setting up a new company or purchasing an equity share in an existing company
- The costs of implementing regulatory or fiscal regulations designed to encourage renewable energy generation or use. These may include metering equipment , licences or costs of accessing Renewable Obligation Certificates

What technologies apply?

Technologies eligibility under SCRI include (not limited to):

- small-scale hydro-electric power
- wave power
- wind power
- solar energy (including off-grid photovoltaic, water and space heating)
- landfill and sewage gas
- biomass and energy from waste

Renewable energy technologies can generate energy in the form of electricity and/or heat – both types of technologies are acceptable. The overriding requirement is that the project must result in a decrease in greenhouse gas emissions, relative to alternative sources of power.

Applications are equally eligible for installations that are connected to the main electricity grid, stand-alone, or connected to a mini-grid. The only exception is that SCRI does not apply to PV (photovoltaic) installations that are eligible to apply for funding under the DTI Major Photovoltaic Demonstration Programme.

Assessment Criteria

Applications for assistance under the Community Stream will be assessed against a range of essential and desirable criteria. Applicants **must** meet all of the **essential** criteria. In addition, the more applicants' meet the **desirable** criteria, the higher the likelihood of the application being successful. The Energy Saving Trust, Highlands and Islands Enterprise or the SCRI Assessment Board is the ultimate arbiter in deciding if an application meets any or all of the assessment criteria (see below).

Application Process

The grant assessment and award procedure differs between applications depending on the level of funding. The application process involves the following steps:

- Applications will be receivable at any time and assessed against the established essential and desirable criteria (see below)
- All potential applicants are required to discuss proposed projects with SCRI staff who will advise on eligibility
- Applications will be made via SCRI staff who will complete the application form on behalf of the applicant
- Applications up to £20,000 will be assessed by the local SCRI Development Officer, and the Energy Saving Trust or Highlands and Islands Enterprise (as appropriate). Where necessary, technical experts will be engaged to provide advice in relation to technical or economic viability. Decisions will be made as applications are received and assessed
- Applications involving funding of more than £20,000 will be considered by an advisory group of appropriate stakeholders that will meet approximately every two months. The advisory group will make recommendations for funding to the Energy Saving Trust and Highlands and Islands Enterprise (as appropriate). Receipt of a positive feasibility assessment does not automatically mean that a project will be funded
- If an application is successful, the applicant will receive a formal offer of funding which will be open for a set period. If the applicant does not accept the offer within this time, the offer will be withdrawn
- Funding will be provided on a basis agreed with the applicant, which will generally involve the establishment of key milestones and deliverables. Up-front funding may also be provided, where it is necessary for the project to commence

Suppliers and installers

Under SCRI, only systems installed by accredited installers are eligible for grant. SCRI will rely on the accreditation process being developed for the *Clear Skies* programme (the equivalent England/Wales/Northern Ireland scheme). Installers should contact the Clear Skies programme on 08702 430 930 or visit the website **www.clear-skies.org.** In terms of technical assistance (e.g. consultants to carry out feasibility studies) an approved list of companies will be drawn-up. Interested organisations should contact the Energy Saving Trust on 0131 244 0833 for further information.

More information

The application procedures for technical assistance and capital funding under the SCRI are currently being developed and are expected to be available from early February (you will be advised when these are finalised). If you would like more information on the operation of the SCRI, contact the SCRI Hotline on **0800 138 8858** (Monday - Friday 9am – 5pm).

Correct as at 15 January 2003

CRITERIA FOR ASSESSMENT OF APPLICATIONS

Projects under the SCRI – Community stream, will be assessed against the following criteria:

Essential – eligibility (these are criteria that ***must*** *be met for a project to receive funding):*

- The scheme will be open only to applications from legally constituted, non-profit distributing organisations. Such organisations will include, but are not restricted to:
    - Local/national/voluntary, non-profit and charitable organisations
    - Local rural partnerships
    - Local authorities
    - Housing associations
    - Local enterprise companies

- Consortia of non-profit distributing organisations are acceptable. Bids in which private industrial or commercial organisations collaborate as part of consortium bids with non-profit distributing bodies will also be accepted, provided that the private organisation is not the lead applicant / beneficiary and the project itself is non-profit distributing
- All projects must be located in Scotland
- All projects must allow publication of details of their work and reasonable access to those seeking to replicate the project
- The project must entail the generation of energy from renewable means
- Projects seeking more than £10,000 in capital funding from SCRI must be accompanied by an appropriate development plan and positive feasibility study
- Projects relating to direct community ownership on behalf of the local community must demonstrate community benefit, community involvement and significant local support for the project
- The project must meet all general legal and regulatory requirements

Essential – viability

- Capital projects must be technically viable and capable of producing renewable energy within 2 years of funding being granted
- Technical assistance projects must be completed within one year of funding being awarded
- All applicants must demonstrate that the project entails the most cost-effective and appropriate means of meeting a given requirement for renewable energy
- There must be a satisfactory maintenance and management plan for the project once installed
- There must be an established and viable structure for the ongoing management of the project

Desirable (the more of these criteria that are met increases the likelihood of funding)

- Potential for replication elsewhere
- Additional sources of funding, demonstrating leverage of Scottish Executive core funding
- Amount and cost per tonne of reductions in carbon emissions as a result of the project
- Energy efficiency measures incorporated as part of the project
- A clear plan of action to maximise the project's educational potential: that is, the potential to raise awareness of renewable energy in general and /or the particular technology used

Denmark in 1999

During our family visit to Denmark, my wife and I took a few days to travel around and look at the windpower scene. Travel is expensive but the distances are small.

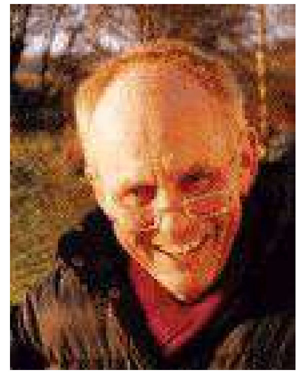
Click on the images below to see the full sized versions -

best loaded into another window.

We passed the test station at Riso, but we didn't stop this time. I have often been there before over the last couple of decades. The wind machines grow larger by a factor of about ten, every ten years. This time there was an elegant megawatt monster on the site and some smaller machines, including one 'household mill' of 22kW rated output. Back in 1980, when Vestas an Bonus made 22kW machines, they were sturdy little upwind turbines with fantail yaw drives. This was a bizarre downwind beastie, made by Genvind, based in Rold Skov near Skørping (Tlf. 70 20 80 04).

Here is a shot opf Riso from 1996.

We took public transport as far as Claus Nybroe's local town where he met us in his battered Lada. What a relief to find that not everyone in Denmark drives a brand new car!

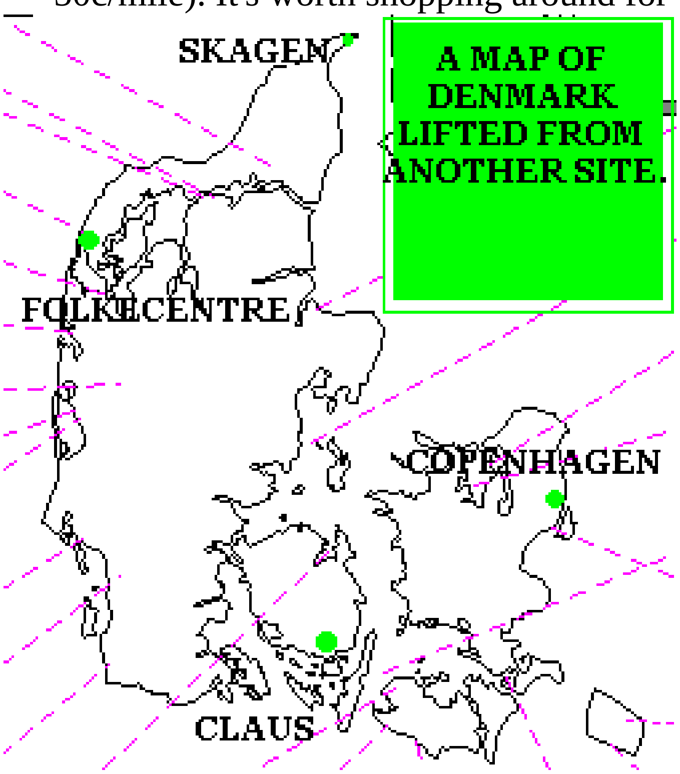
 .. 

We spent a great weekend with Claus (www.windmission.dk). It was flat calm, so the 4kW Windflower machine behind his house was not doing much.

On the Sunday we visited a neighbour who owns a 170kW Wind World turbine on his farm. On summer evenings they sometimes go up to the nacelle to admire the view.

This was no ordinary farmer though. He has built a 25kW direct drive pm alternator, and he has yummy software for visualisation of flux lines and heat conduction in the laminations (www.quickfield.dk). I wish I could afford it! Claus has started to import some smaller permanent magnet alternators from China, at very affordable prices. We bench tested some, and they look to be ideal for self-build enthusiasts, whose biggest problem is finding a suitable low speed generator.

Public transport is very efficient in Denmark (see www.dsb.dk), but we decided to hire a car for a few days so we could indulge in our favorite passtime of getting lost up the back roads. For two people, the cost is about the same as going by train/bus.. around 2DKr/km (30pence or 50c/mile). It's worth shopping around for the best deal rather then going straight to Hertz or suchlike.



On the road we admired the clusters of big wind machines which are scattered across the country. I would say that it is possible to see a 'mill' (as they call them) from most places, but I would not really say that they often dominate the landscape, even though they produce 10% of the electricity in Denmark. I am told that there are very few permissible sites left for windpower, and that the future is offshore, but I reckon they could easily find room for a few more turbines on land if they really needed to.

It was a sunny day with a good breeze. We ate some bread and spread beside the ancient stones at Jelling. A two bladed turbine caught my eye and we agreed to investigate. I must say I did not find the machine aesthetically attractive. The visual effect was busy and unsettling, but I was curious. It turned out to be another downwind household machine, and we chatted with the locals but failed to meet the owner. We spotted a few more of these, and some smaller 3-bladed versions, as we made our way on toward the northwest coast.

Our itinary was not completely random. We arrived at the Folkecenter for Renewable Energy (www.folkecenter.dk), and they made us welcome overnight for a very modest payment. I found their little collection of wind machines fascinating.

 - - 

They even had a 900watt Whisper, running very nicely (although its digital meter was defective, as usual). They had one of Claus' smallest mills, and a few household mills, and quite a few obsolete prototypes of one sort and another. The boss, a guy called Preben Maegaard, boasted that they had the biggest collection of small machines anywhere (I could not get a word in to tell him about Scoraig) and that unlike other sites, they actually tested them there. Needless to say I got quite excited about this. I met their young test engineer, Lars Christian and had an interesting chat. He had some very high spec. equipment, but did not have time or funds to test anything smaller than 22kW, and most of their recent work was with much bigger turbines. He did tell us how to find the manufacturers of the downwind machines we had been seeing - a company called Gaia Wind Energy in Viborg. It seems they are now the only active manufacturers of small machines in Denmark, apart from

Calorius-Westrup, makers of an ingenious, mechanical water heating machine, who have had very little commercial success.

Scoraig test site

The Folkecenter is a visitor centre of a sort, and also takes trainees from third world and eastern european countries. The idea is that these trainees probably have too much academic knowledge already, so they are put to work doing practical things. I hope they find this useful.. I am sure the folkecenter does. They have a brand new undergound, solar heated training centre nearing completion. I hope they will run some proper courses in there. As I was leaving, Preben gave me a lecture about how bad the UK government is at fostering renewable energy. He is right. The UK policy of pushing the cost of windpower ever downwards has done little to promote its public acceptability, or to nurture the manufacturing base. Preben believes fervently in subsidies for wind energy. He points out that all the other power producers get assistance too. Until now, the electricity companies have been paying about 0.60Dkr (=6pGB=10cUS) per kWh for wind energy (and consumers pay twice this for the power they buy), but there is a move afoot to force this subsidised price downwards. While talking, Preben photocopied and handed to me a long diatribe he had just written against this retrograde trend.

Misty rain obscured our view of Jutland as we progressed toward Skagen at the northern tip. We passed a group of 35 very handsome 600kW Vestas turbines, with some maintenance activity. By the time we had threaded our way around the access tracks, the crane was packing up - too much wind to replace the gearbox mounts. The engineers were friendly but absorbed. We were impressed by how shiny their tools and trucks were.

The blades of these big machines seem to move slowly, but in fact they aren't wasting any time, when you consider how far they have to go. There is quite a difference between these slender, willowy limbs, and the stumpy blades of the older machines from the 1980s. In fact it is quite alarming how they bend back toward the tower under load. The old 55kW machines, which seemed so big to me in 1982, now seem like kiddie's toys, with their little red-tipped 'wings' tumbling around at 60rpm. These old mills may not be so productive but they seem more personal somehow, less haughty. And many of them are still there, in farmyards and on little hillocks across the land.

_-oO*Oo-_

In Skagen, Jytte achieved her ambition of standing where the skagerrack meets the kategat (or whatever) in some pretty raw weather. The place is a tourist trap but very charming out of season. We managed to get lost, watching a long load (windmill tower) turning a corner, instead of reading the signs.

 -- 

As usual it was well worth it and we ended up at what appeared to have been the WindWorld factory. There was a huge machine there with a very swanky duck-tailed nacelle, in the back yard. How anyone could not want such a thing in their own back yard is quite beyond my comprehension.

Our final windpower detour on the way home was to visit Gaia in Viborg, a city at the exact centre of Jutland, in an area where most of the wind industry is based. The city itself is known to have been in existence at least as long ago as 2495 years after the creation of the world. Gaia had only moved in recently, to an industrial site adjacent to a very large Vestas tower facility. The director, Jens Wodstrup was kind enough to give us quite a bit of his time. He is currently building two sizes of mill, both downwind, and both grid-connected. The 5.5kW version has 7 m diameter and its three blades spin at a giddy 131rpm. It costs 106,000kr (10kUK,17k$US) installed in Denmark on a tower, but Jens recommends the larger 11kW machine with two blades which we had seen first of all. This has 13m diameter and runs at only 57 rpm, so it works much better in low winds. the price is double but the energy production is maybe three times as much. They have sold about 50 machines, mainly the larger type.

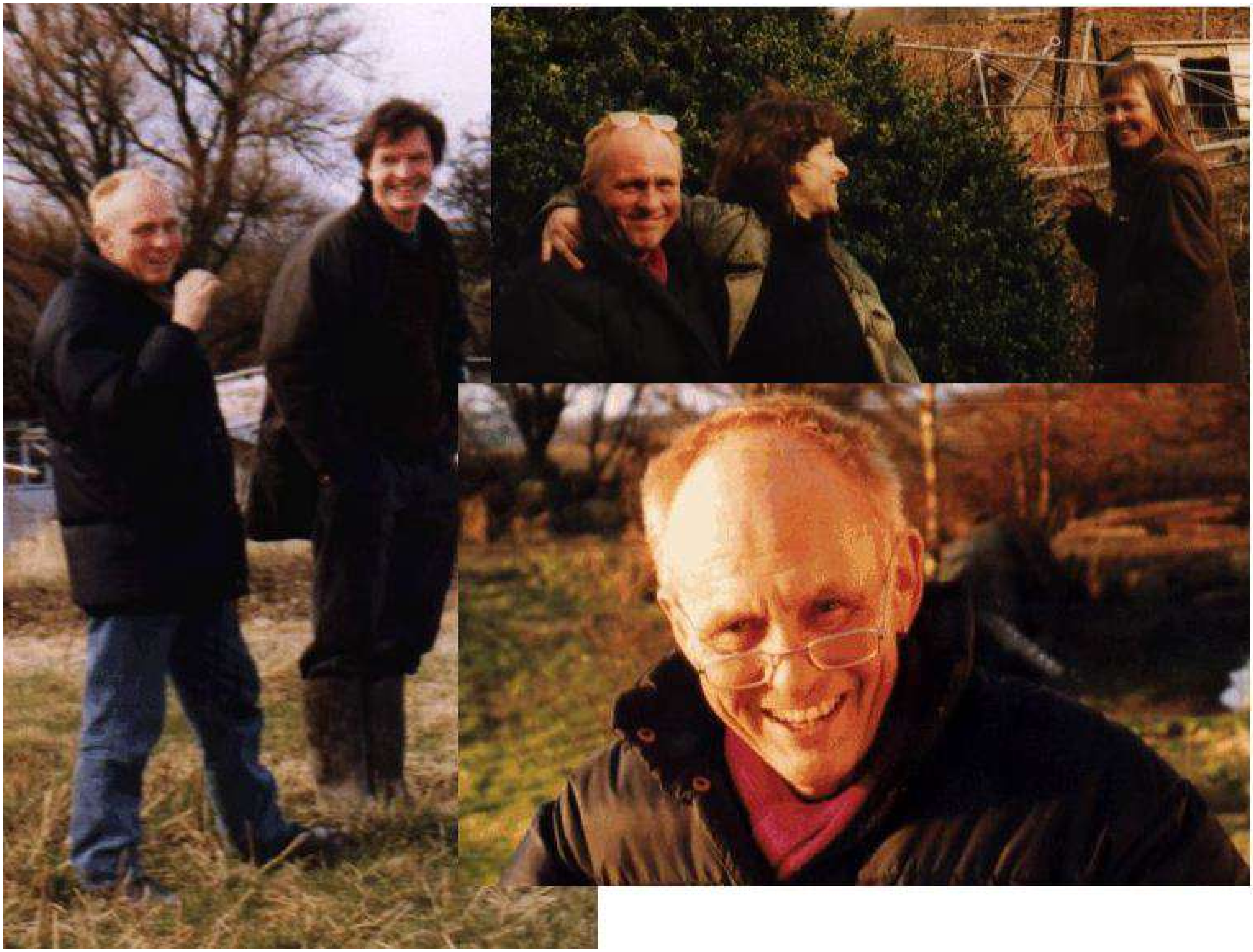
Gaia Wind, Absalonvej 1. DK-8800 Viborg, Denmark.

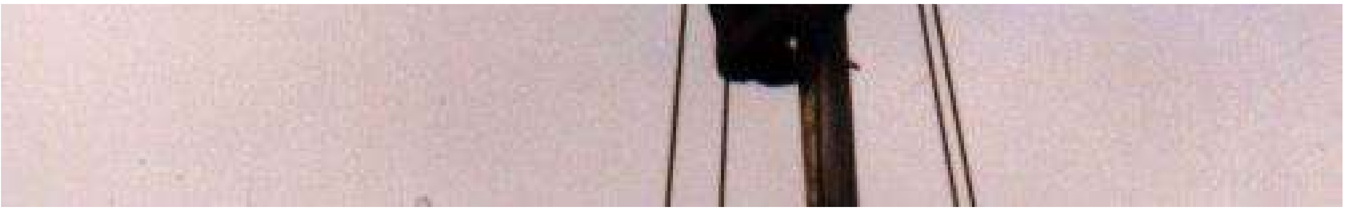
The economics of these 'household mills' are pretty marginal, even with the good buy-back tarrifs in Denmark. Jens explained that it was more important to know the tax system than the engineering even. They tax what you sell and they tax what you buy. He plans to visit the government minister and plead for net metering. There were several nacelles in the factory, and he could produce 20 per month, but sales are slow moving. Planning permission often takes a year, by which time some customer have lost interest.

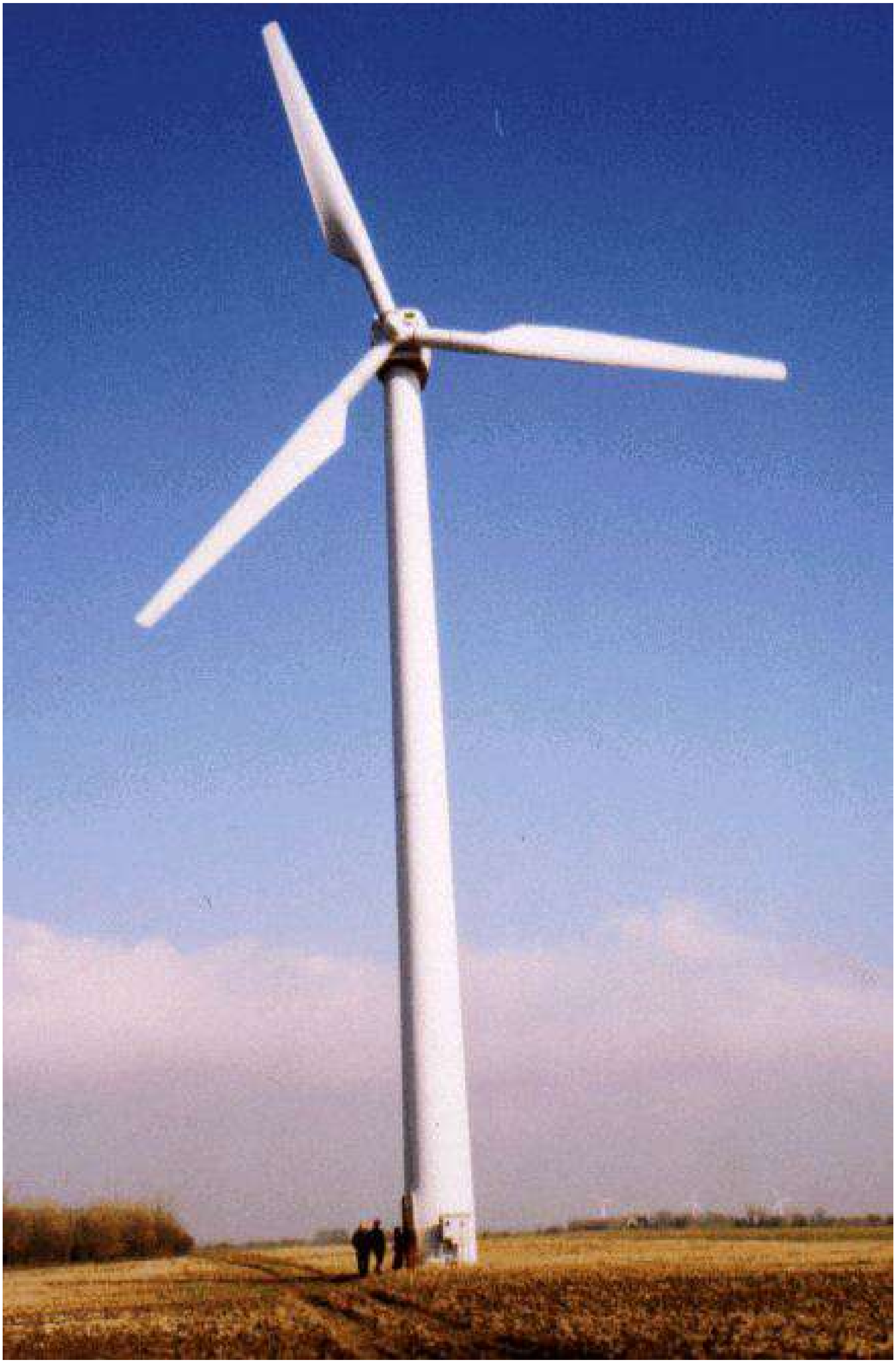
The blades of the smaller mill are built by Olsen the boatbuilder, and he makes a very tidy job, complete with wingtip brakes for overspeed control. The larger machine uses a 13m one-piece blade from LM, with a teetering hinge at the hub. I wondered if these ran smoothly (the one I saw running had rather a shake to it) but Jens pointed out that this was the most reliable of the recent generation of household mills. The others of that size had suffered intractable problems with noise and suchlike, and had mostly been withdrawn from the market. In recent years, household mill installations (up to a 13m size limit) have been elligible for a 30% grant, which helped to promote their development while the program lasted. I believe the idea was to increase the amount of windpower on the grid by exploiting the fact that small mills are more acceptable (in contradiction to the overall trend). It's a pity that the most succesful result is such a quaint object.

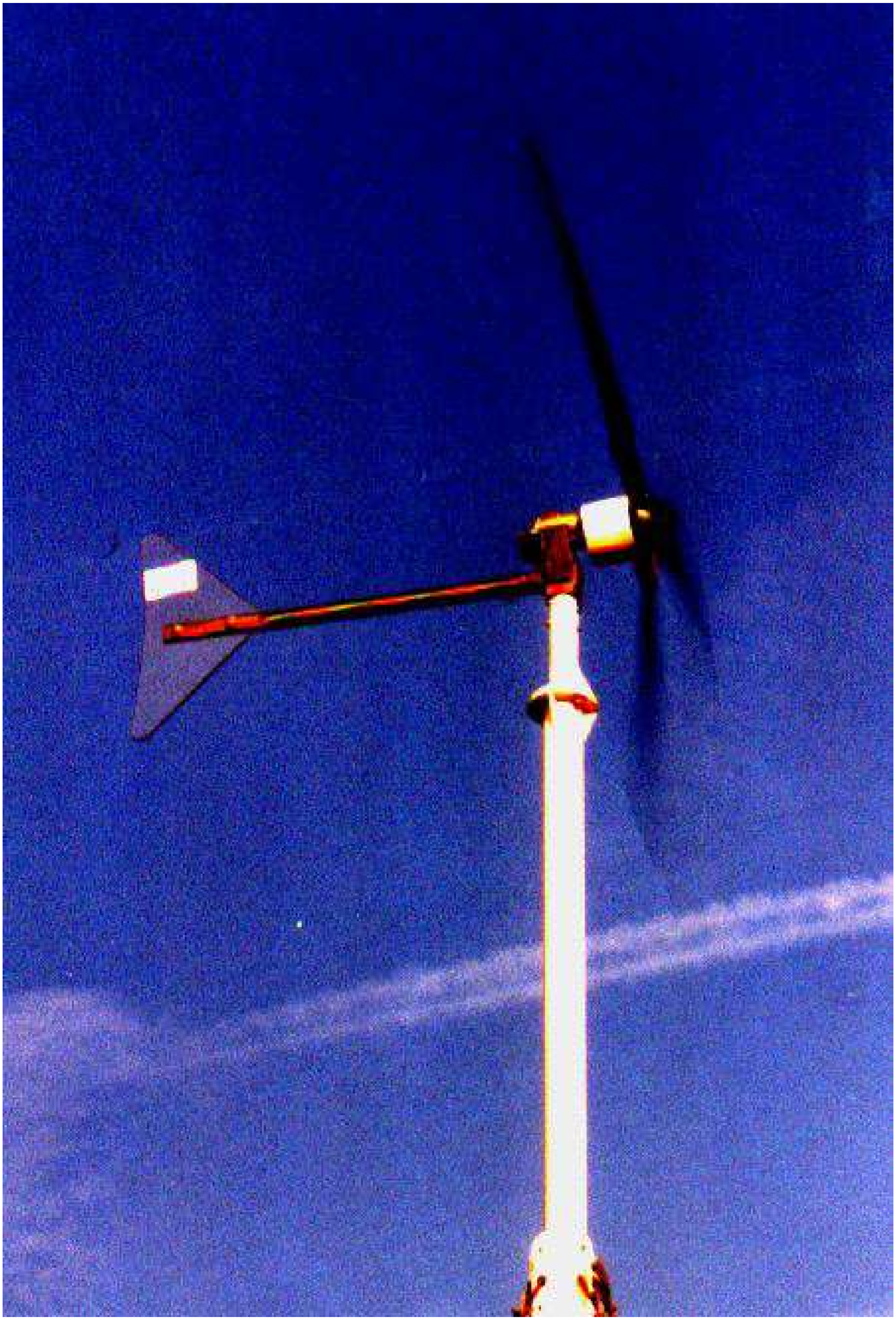
After this we returned to the Copenhagen area, for more family jollity. The Dane's have an exceptional appetite for good cheer, and it is quite normal to have a few beers in the morning. On Sunday we spotted a familiar face in the papers - our friend Preben. It seems that the european union are investigating the folkecentre for fraudulent accounting. Just another case of persecution against renewable energy, he claimed.

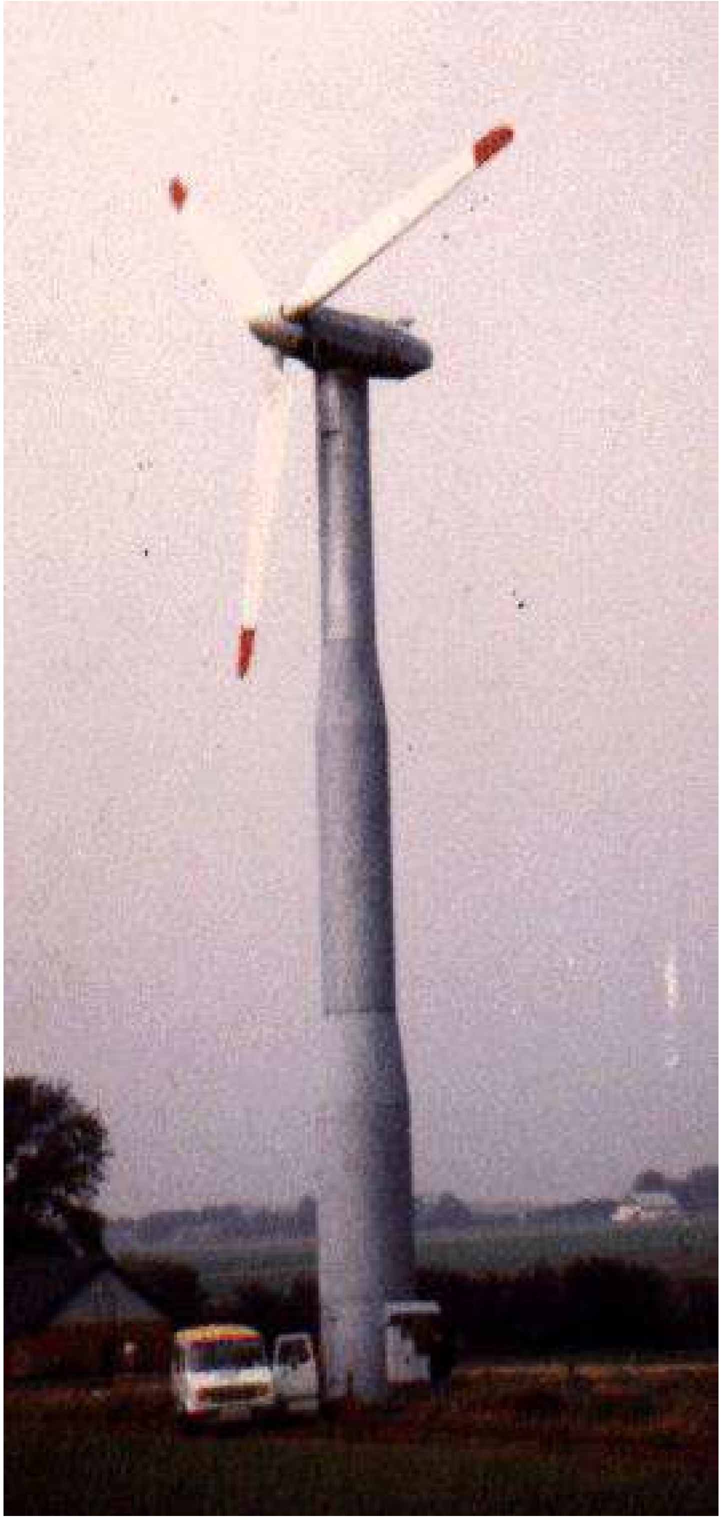
Hugh Piggott



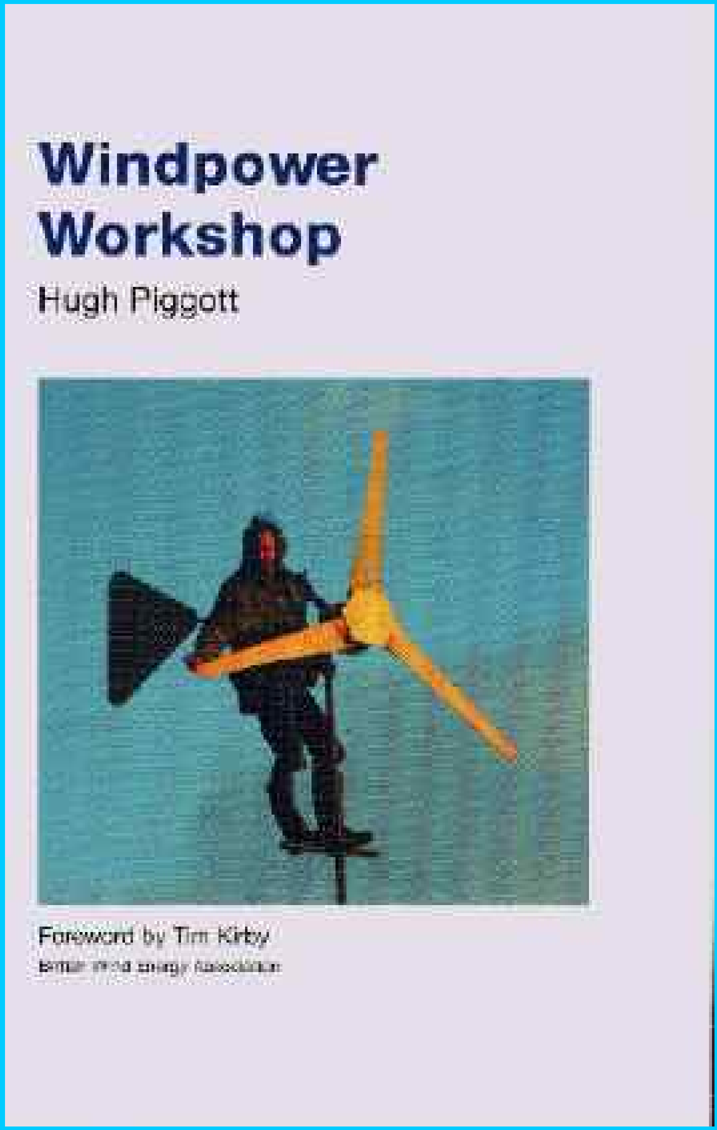








Windpower Workshop, by Hugh Piggott



A book dedicated to building your own working windmill for electricity production. Details of generator choice and design, blade construction, furling systems, towers, wiring, battery charging, heating, alternator design, modifications for car alternators and generators, and everything else you will need to know. An essential book for anyone contemplating building their own wind turbine, written by the foremost wind homebrew expert in the world.

With great interest, I have gone through the entire book within two days. I must assert that your book is the most practical and most valuable for those who want to manufacture small wind turbines. In very short, you have explained theory and practice both really vividly. Your approach of explaining the subject is really penetrating to the brain and it is highly commendable. Even a layman can understand the subject very clearly. I am sure that your book will play very important and effective role in disseminating small wind technology throughout the world.

I convey my hearty feelings and many many congratulations for writing this most valuable book. I must admit that I have never come across such a nice and practical book as WIND POWER WORKSHOP. All the 8 chapters are very nice.
V K DESAI
Managing Director
TINYTECH PLANTS - INDIA
Website www.tinytechindia.com

My name is Corey Babcock, I am 17 yrs old, and I am a GIANT wind power fan! I have built at least fifty or more wind machines since 1993 ... I have just recently purchased your new book Windpower Workshop and I think that the information in it is really great. I would like to thank you for taking the time to write this book, because there are many people out there that are like you and me who are interested in wind turbines and would like to build one *of their own.*

-Corey Babcock, AKA "The Wind Kid"

Review by Paul Gipe

Review from Amazon.com

An Absolute Must-Have For Windmill Enthusiasts, July 11, 2002

Reviewer: Bruce Boatner from Murrieta, CA USA This book contains real practicality, not just empty theory. Talk about "put your money where your mouth is" - Hugh lives on a remote spit of land in Northern Scotland that doesn't even have roads, much less access to the power grid. If necessity is the mother of invention, there's good reason why he was highly motivated to develop the kinds of simple airfoils and low speed alternator combinations that produced real power. This rudimentary experience has taken him all over the world for installations and workshops. I guess having someone like that around makes him a pretty popular guy with his neighbors.

This book covers the theory necessary to understand wind energy basics, and proceeds as a how-to manual on shaping a simple turbine out of wood. It then shows how to build a low speed alternator out of a brake drum. (There is another book by Hugh called "Brake Drum Windmill Handbook" which goes into more detail).

The challenge is building an electrical generating system that operates at the slow rotational speeds of a wind turbine (e.g. 300 - 500 RPM). Everybody wants to hook up an automobile alternator, but even if it is optimized for high output at an idle, it probably will not start producing power until it reaches 1800 RPM. (Typically the engine/alternator pulleys have a ratio of 3 or 3.5 to 1 and the engine idles @ 600 RPM).

A great little book.

CONTENTS

Windpower Workshop

by Hugh Piggott

Reviewed by Paul Gipe:

Finally, something to supplant Michael Hackleman's aging classic Wind and Windspinners. Windpower Workshop by Hugh Piggott is a welcome addition to any small wind turbine library and is a must if you want to build your own wind turbine or, as the British say, "Do It Yourself."

Windpower Workshop is a 1997 release in the Centre for Alternative Technology's series Anglicizing small wind turbine publications for a British audience. For more than twenty years CAT has been demonstrating the use of alternative technology from water power to wind turbines at their center in an abandoned slate quarry in central Wales. Windpower Workshop grew out of Hugh's lectures at CAT instructing people on how they can build their own low-cost wind machines.

The United Kingdom's foremost authority on small wind turbines, Hugh is also the author of CAT's It's a Breeze: A Guide to Choosing Windpower, as well as Scrapyard Windpower Realities. The latter, now unfortunately out of print, was a good hands-on guide to building a small wind turbine by constructing a permanent-magnet generator from a brake drum and other salvage auto parts. (Plans for the brake-drum windmill are still available directly from Hugh at Scoraig Windelectric.)

Hugh's book is a distillation of more than two decades of windpower experience most of it off-the-grid on a remote windswept peninsula in far northwestern Scotland. Many of the homes, schools, and workshops in the vicinity use windpower and Hugh has either built the turbines himself or services them.

Denizens of the electronic news group "awea.wind.home" will recognize some of Hugh's postings. One familiar discourse is his enlightening discussion of furling and furling pivot design and how this affects a turbine's performance. Some American manufacturers of small wind turbines would be well advised to read this section carefully.

I immediately liked Hugh's organization of Windpower Workshop. He's one of the few writers on wind energy that has had the guts to put a discussion of safety right up front where it counts. Hugh relates a literally hair-raising tale of an encounter between Mick Sagrillo, our own small wind turbine guru here in North America, and a whirring Jacobs generator. (Mick still can't stand the sound of velcro.)

Yanks particularly will find interesting Hugh's description of the small multi-blade micro turbines that British companies, such as Marlec, AmpAir, and LVM have developed. We haven't seen many of them yet in North America, but the durability of these rugged little machines and their low cost could offer an alternative to less robust domestic designs for off-the-grid users. There are increasing applications for these micro turbines in Europe where they have been used extensively in yachting but they are also now being found powering remote telephones and electric fences.

Some of these micro turbines, such as the Marlec, use what Hugh calls "air gap" generators. Hugh explains how these mysterious little generators work, answering questions that I've had for years.

Since I am in the process of erecting my own mini-wind turbine I found chapter 8 on towers especially useful, notably Hugh's description of the TirFor hand-operated winch. TirFor is the brand name for a grip-hoist puller or winch. There are several other brands on the market but they all pull a steel cable through the body of the winch rather than wrapping the cable around a spool. They come in a range of capacities suitable for most small wind turbine applications. Best of all, they're portable. You can carry one of these hand winches into areas where you would never get a truck or battery-operated winch.

Hugh packs his TirFor with him for trips to service wind turbines at remote Youth Hostels and railway stations in Scotland. At one of these sites you literally have to walk over the mountain on a footpath to reach the hostel and anything that Hugh can't carry gets left behind. If you have to buy any tool for your off-the-grid wind system, Hugh recommends buying the grip-hoist winch.

I've seen these grip hoists used in Denmark and I was surprised at how easy they made raising and lowering a tower with a Whisper 1500 on top. As Hugh says a grip hoist is "hard to beat for erecting tilt-up towers, because it is slow and fail-safe." Unlike using a truck or other vehicle to raise a tower, the operator of the winch has full control of the operation and there's no dependence on hand signals and the risk of missed cues or lunging.

For us here in North America there's real value in reading a book about small wind turbines by a European. We are sometimes too insular and forget that there's a big world out there. Europeans have different experiences, different wind turbines, and different ways of doing things, such as using hand-operated winches, that we can learn from. Books, such as Hugh's, can open our eyes to new possibilities.

Hugh writes in the simple, no-nonsense manner that I prefer. His illustrations are straightforward too, and he has introduced some original graphics. For example, I found his depiction of losses in a wind system both unique and informative.

Windpower Workshop includes a comprehensive list of British consultants, dealers, and manufacturers of small wind turbines, a seven-page glossary, and a useful list of equations in the appendix. What sets these formulas apart from those in other books on wind energy is their presentation. Hugh helpfully provides them in a form suitable for keying into a spreadsheet so the reader can make their own calculations. Do-It-Yourselfers will greatly appreciate that gesture.

Windpower Workshop, says Hugh, was "written for those who want to build their own windmill and for those who dream." It's books like this that keeps the dream alive.

--

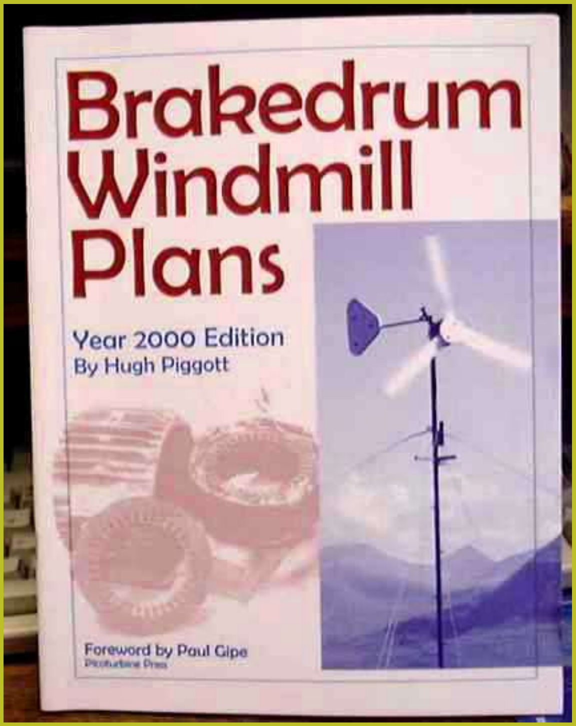
Windpower Workshop, by Hugh Piggott,
Centre for Alternative Technology

Publications, May 1997, ISBN 1-898049-13-0,
158 pages, 5-1/2 by 8-1/2 inches paperback, can be ordered for UK L7.95 from CAT Publications;

Machynlleth, Powys, Wales SY20 9AZ, United Kingdom;
phone: +44 16 54 70 24 00; fax: +44 16 54 70 27 82; email: help@catinfor.demon.co.uk;
http://www.foe.co.uk./cat.

Books by Hugh Piggott

BRAKEDRUM PERMANENT MAGNET ALTERNATOR



In 1993 I produced plans for building a windmill based on a permanent magnet alternator from the brakedrum of a van. This is an
updated edition. 34 page detailed, step by step guide to building a 300 watt windmill with 2.1metre (7 foot) diameter. I have built one and it has
worked for years on the hill near my house, producing an average output of 100 watts (at the battery). Readers may need to adapt the method to suit
their own brakedrum. It is a simple, robust and efficient windmill.

> ... congratulations on providing the most riveting reading I have seen for years. The technical content alone is worth more than most folk would imagine, and the non-technical are catered for admirably.
> -Geoffrey Remington ycl92@dial.pipex.com

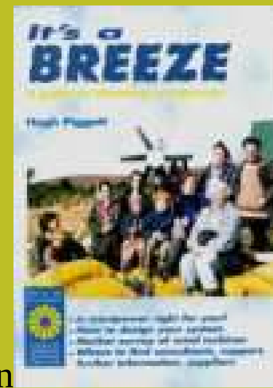
REVIEW BY PAUL GIPE

"Brakedrum Windmill includes detailed instructions for building the entire wind turbine, from carving your own blades for a 7-foot (2.1 meter)

diameter rotor to building your own permanent-magnet, direct-drive alternator capable of generating real power. By following these plans you will construct a genuine wind turbine--not just a toy--that can reliably churn out 300 to 400 watts. "

[Update page for Brakedrum builders]

[North american brakedrum plans] from Bob Budd



ITS A BREEZE (1995) now 2001 edition is packed with information for those who want to buy and install a windpower system. What size of windmill do you need? What are the options on offer (in the UK in 1995). Living with windpower, etc. 34 pages.
contents page

Brakedrum plans 2000

foreword by Paul Gipe

Hugh Piggott's plans for turning a used brakedrum into a windmill is welcome addition to the literature on small wind turbines. "Brakedrum Windmill" is especially valuable because plans for building your own wind turbine have not kept pace with the technology. Most plans date from the 1970s--or even earlier.

Better yet, the plans in this booklet are for a wind turbine that really works from someone who lives with and depends on wind energy. The brakedrum windmill is a proven design that Hugh has operated at a remote, windswept headland in northwest Scotland since 1993. His site on the Scoraig Peninsula is so windy in fact that several commercial wind turbines failed within a few years (some, unfortunately, much sooner). Hugh's prototype of the brakedrum windmill in these plans has operated so reliably that he substantially increased its output within a few years after installation. And it continues to run to this day.

The beauty of these plans can be found in Hugh's use of conveniently handy scrap yard parts. The design is based on rear brake drums used by Ford trucks widely available in both Britain (the transit van) and North America (the F250).

Another plus is Hugh's elimination of slip rings and yaw bearings. Slip rings often bedevil the design of commercial wind turbines as well as home builts. They're not necessary and seldom found on many wind turbines built in Europe. Hugh wisely avoided them, instead substituting a simple pendant cable. This greatly simplifies this design as does Hugh's use of pipe-on-pipe for a simple and hardy yaw system that allows the turbine to respond to changes in wind direction.

Hugh's brakedrum windmill also incorporates the durable "inside out" alternator design found in the popular--and successful--small wind turbines built by Bergey Windpower and World Power Technologies. With this alternator configuration there's no need to build a complicated hub that attaches the blades awkwardly to a small diameter shaft as in some other designs. Instead a simple plywood sandwich holds the blades tightly to the rotor and this assembly is mounted directly to the generator housing: the brake drum. In wind turbines it doesn't get more straight-forward than this.

And like all reliable commercial wind turbines today these plans use "self-furling" to protect the product of your labor in high winds. Hugh's an expert on this technique to limit the speed of the wind turbine's rotor and the simple design found in these plans would be helpful to not a few commercial wind turbine companies who haven't quite mastered the art.

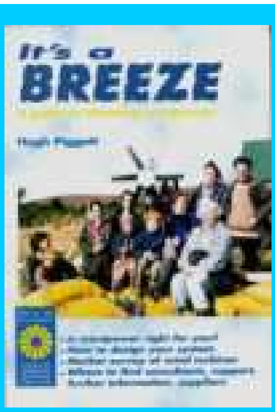
"Brakedrum Windmill" includes detailed instructions for building the entire wind turbine, from carving your own blades for a 7-foot (2.1 meter) diameter rotor to building your own permanent-magnet, direct-drive alternator capable of generating real power. By following these plans you will construct a genuine wind turbine--not just a toy--that can reliably churn out 300 to 400 watts.

"Brakedrum Windmill Plans" are a great companion to Hugh's "Windpower Workshop." Both are a valuable addition to any windmiller's library.

Paul Gipe
Wulf Ranch Test Field
Tehachapi, California
October 1999
Paul Gipe
208 S. Green St., #5; Tehachapi CA 93561-1741 USA; ph: +661 822 9150; fax: +661 822 8452; pgipe@igc.org. Wind Power for Home & Business (Chelsea Green Pub., 1993), Wind Energy Comes of Age (John Wiley & Sons, 1995), Wind Energy Basics: A Guide to Small and Micro Wind Systems (Chelsea Green Pub., 1999). <http://rotor.fb12.tu-berlin.de/personen/paul.html>

BACK

It's a Breeze! by Hugh Piggott



A booklet jam-packed with information for those who want to buy and install a windpower system. What size of windmill do you need? What are the options available? How to live with windpower, and other topics you need to understand before starting a wind project.

Mainly written with UK readers in mind, but useful to all.

CONTENTS

- Mail order form
- Other booklets in this series

SEI 'HOMEBUILT WIND GENERATORS' WORKSHOP OCTOBER 2001

SAN JUAN ISLANDS, WASHINGTON, USA

This first SEI workshop on 'how to build a wind turbine' was a success. Here are some pictures of the processes and personalities. It's a long page with over 60 pictures, so take your time :-)

THERE WILL BE ANOTHER COURSE AT THE SAME LOCATION ON 14-19 APRIL 2003 CONTACT Ian Woofenden FOR DETAILS

I am grateful to Solar Energy International, and especially to Ian Woofenden for making this happen. (Many of the pictures below are Ian's). Ian lives on Guemes island in a renewable powered home in the woods. He uses AWP36 and Whisper 1000 wind generators on 100+ foot tree-top towers as well as PV. Ian is also Senior Editor, in charge of text content at Home Power Magazine. I am also lucky to have him as a good friend.

Future workshop courses will take place in Scotland (February and May 2003), Wales (October 2002 and 2003 at CAT) and again in the USA (14-19 April 2003).

THIS PAGE CONTAINS

MAIN PAGE (YOU ARE LOOKING AT IT)
BLADE CARVING PAGE
BRAKEDRUM ALTERNATOR CONSTRUCTION PAGE
AXIAL FLUX 'PMG' ALTERNATOR CONSTRUCTION PAGE

Our target was to complete at least one wind turbine and make substantial progress with several others. The next photo shows the most of the class grouped in front of the wind machine which reached the stage of being assembled and tested. The rotor blade diameter is 8 feet (2.4 m) and it drives an axial flux 'air gap' type of alternator similar to the one described in the document at http://www.scoraigwind.co.uk/pmgbooklet/ We also worked on two brakedrum-type wind machines based on the Ford F250 brakedrum and 9 foot diameter propellers. In the background you can see Win Anderson's shop where the work took place.

Most of us stayed at Guemes Island Resort - Hugh Glass brought his own windpower from Utah.

Here is Win Anderson the shop owner giving up his valuable time to guide the students in wood carving techniques. We are most grateful to Win for the use of his spacious and well equipped wood shop, and the adjoining covered area for metal working.

Brian Faley was our plastic and electrical shop supervisor. He is a senior engineer at Trace Engineering (now part of Xantrex), and more than overqualified for the task. I for one learned a load of useful stuff working with Brian and we all appreciate his helping out.

We covered a certain minimal amount of theoretical stuff each day.

We were very fortunate to have Tod Hanley from Bergey Windpower on the workshop. He explained some tricky concepts such as 'low Reynold's Number airfoil design'. His BWC XL1 turbine is a big leap forward in small wind turbine design. Thanks for coming, Tod.

The steel components took shape under the watchful eye of local blacksmith and metalworking master Andy Gladish (left).

[Ron Richardson](#) (right) of Kettle Falls WA was a great asset in the metal shop.

Robert Preus of Abundant Renewable Energy brought an AWP36 wind turbine to show the class. He also gave us a wide ranging talk centred on the theme 'the physics of wind energy'. Robert is retailing the AWP in the USA. Below left is Robert with Ian Woofenden the workshop organiser, looking at the improved yaw frame of the latest AWP machine.

Larry Rice brought his video camera from Missouri, and gathered some footage for his TV stations (channels 25KNLJ and 24KNLC) during the workshop. On the left he interviews fellow student Brooks Tuttle, and on the right the famous author Paul Gipe. Paul came to tell us about his independent small wind turbine testing program - a heroic task which deserves all our support.

Randy Brooks of Brook Solar
came down from Chelan WA with a short tower to test and demonstrate the self-built machine on. thanks Randy!

Kelly Keilwitz of Whidbey Sun and Wind brought the necessary parts and saw his machine completed during the course, and plans to erect it at his home in Coupeville WA.

Two other students brought parts for brakedrum machines:-
Gaetan Ayotte (Ontario) and Dan Whitney (Apple farmer from WA -- thanks for the apples Dan!)

Hugh Glass and Tod Hanley are assembling Kelly's completed wind turbine.
The wiring and rectifiers go under a small aluminium weather-shield.

Hugh fits the tail. Note Andy's artistic scrollwork on the tail boom.

Below is the class erecting the machine by hand. This is not a very safe or satisfactory way to raise a wind machine, but it happened very fast, and for a very short tower it can be a fun way to do it.

Here you can see the complete machine in action. You can almost see through the air gap between the magnet rotors. We observed outputs around 100-200 watts in windspeeds around 10-15mph.

Dan Whitney later put his brakedrum machine up on a hilltop to power a radio mas. The bus headlights are the dump load.

Back to my home page

Ian Woofenden's home system

Please don't imitate this approach to erecting wind turbines
unless you are a qualified tree climber
with appropriate safety gear.

There is one AWP36 turbine (left hand tree) and one old Whisper 1000 (right hand tree, in left hand picture) powering Ian's home,
in addition to the PV panels.

The AWP is 125 feet up a ladder. The wind turbine is mounted on a pipe whcih is bolted to the tree in several places. Ian has high quality climbing gear and a fall-arrestor (Lad-Saf) which make the installation very safe to visit and work on. This type of tower is not recommended for folks without considerable climbing experience, and professional gear.

Blade Carving

I hope these pictures can convey something of the techniques we used and introduce some of the other folk at the workshop. If you want detailed guidance on step by step blade carving then look at Liselotte's page, or the self carved blade page.

Click here to see the **blade designs** we used for the rotors (propellers). We made nine foot diameter rotors for the brakedrum machines and eight foot diameter for the axial flux pmgs. Dimensions are in both inches and mm.

Below you can see the two brakedrum builders: Gaetan Ayotte (Ontario) and Dan Whitney (Apple farmer from WA, thanks for the apples Dan!) using Win's clever technique to create a smooth curve for the blade shapes with a thin wooden lath. On the right is Kelly Keilwitz of Whidbey Sun and Wind   putting his smaller blades through the bandsaw. Kelly owns the wind machine in the top photo, and plans to erect it at his home in Coupeville WA.

After the bandsaw, the next stage was to mark out the 'drop'. Here is Geoff Legg, an intern at SEI, at work.

Martye Lumpkin of Salinas CA decided to carve half sized, and even quarter sized blades to take home with her. In the central picture you can see James Edwards of Boiled Frog Trading Cooperative in Calgary Alberta. You'll have to ask James what boiled frogs have to do with renewable energy.

Above Gaetan works on his 9 foot diameter rotor. He is using 2 pieces of 1" plank glued together to make up a 2" piece. This works but there are some hassles with changes of grain. Below, Chuck Morrison works on a ten foot diameter rotor. His website is worth a visit. He has done some pioneering homebrew and we all learned some new tricks from Chuck.

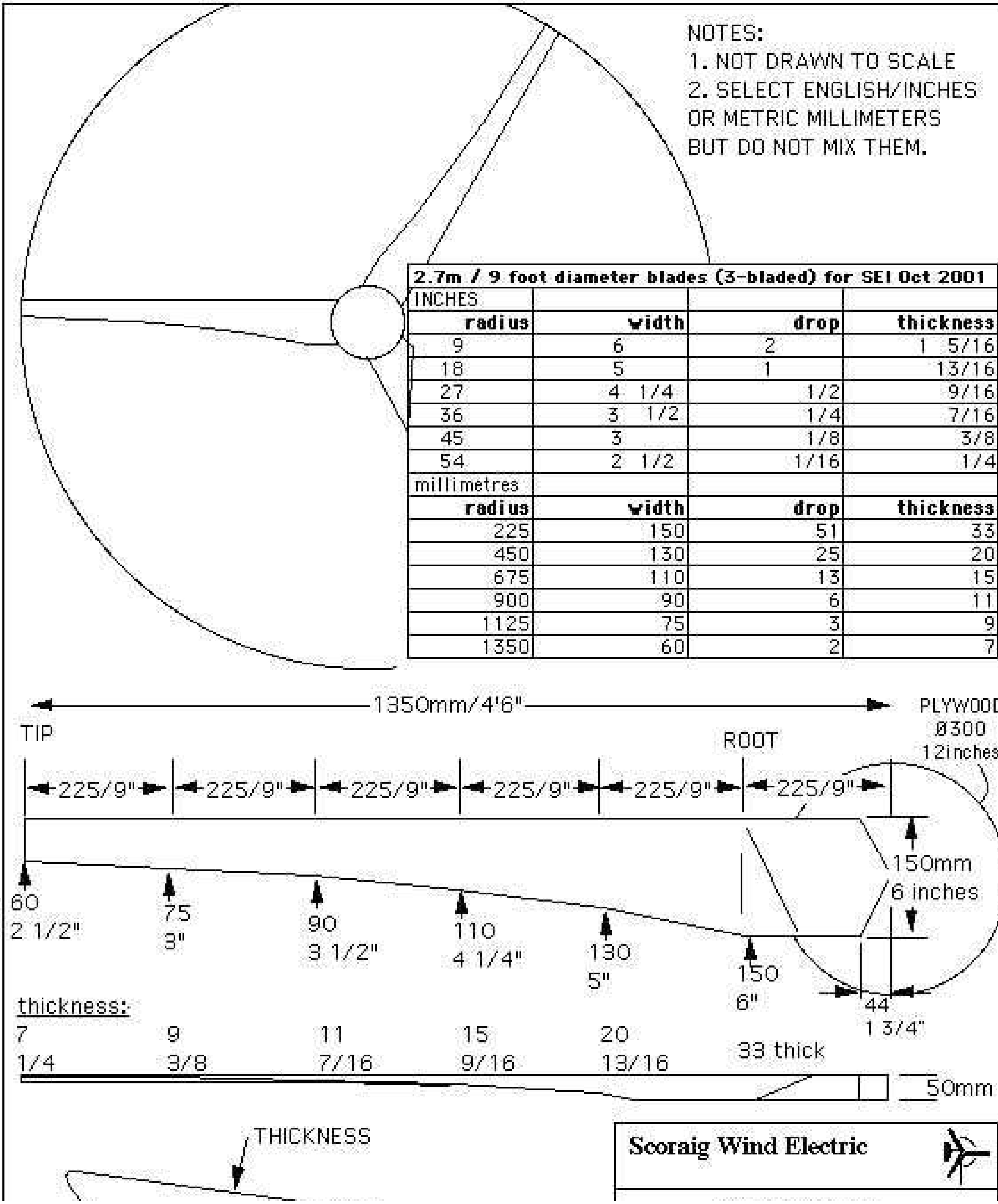
Here I am holding one of Martye's completed works (very impressed) and here is Jeff Gilbert of Chesapeake Wind & Solar holding a finished blade for Kelly's wind machine.

Kelly balanced the assembled propeller on a centre-punch in the vice, and added lead weights until it would sit exactly level. Those blades ran smoothly and quietly.

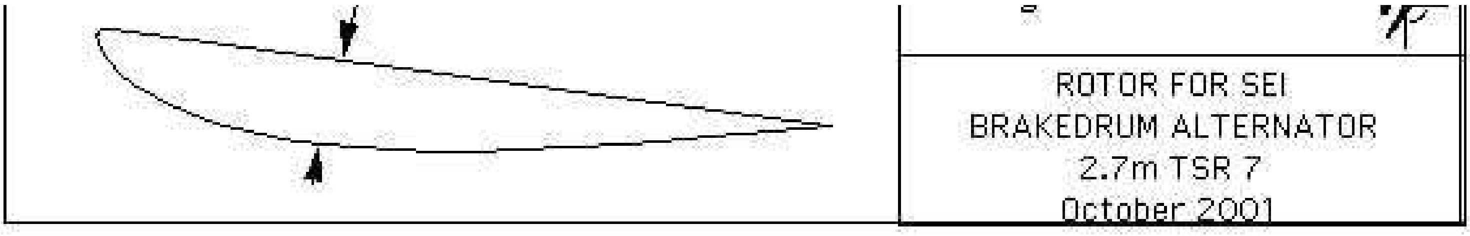
Kelly was helped out by Scott Silliman of Pittsburgh PA, and Amy Pilling of Santa Fe NM.

back to SEI workshop main page

blade designs used during the workshop:-



2.7m / 9 foot diameter blades (3-bladed) for SEI Oct 2001			
INCHES			
radius	**width**	**drop**	**thickness**
9	6	2	1 5/16
18	5	1	13/16
27	4 1/4	1/2	9/16
36	3 1/2	1/4	7/16
45	3	1/8	3/8
54	2 1/2	1/16	1/4
millimetres			
radius	**width**	**drop**	**thickness**
225	150	51	33
450	130	25	20
675	110	13	15
900	90	6	11
1125	75	3	9
1350	60	2	7



2.4m / 8 foot diameter blades (3-bladed) for SEI Oct 2001			
INCHES			
radius	**width**	**drop**	**thickness**
8	5 8/16	2 11/16	1 4/16
16	4 12/16	1	12/16
24	3 15/16	7/16	8/16
32	3 1/8	1/4	6/16
40	2 3/4	1/8	5/16
48	2 3/8	1/16	4/16
millimetres			
radius	**width**	**drop**	**thickness**
203	140	68	31
406	120	25	18
610	100	12	13
813	80	6	10
1016	70	3	8
1219	60	2	7

NOTES:

The exact shape of the blade near the root (the inner part beside the hub) is not critical. If your wood is not thick enough to achieve the listed 'drop' or thickness, you can either glue and extra piece onto it or you can simplify the design without significant loss of performance so that it fits your wood. Follow the dimensions for the outer part of the blade with care but the inner part can be adapted so long as all 3 blades are the same.

Brakedrum alternator construction

Full details of how to build a brakedrum alternator are available in my book Brakedrum Windmill Plans 2000 Edition

There is also some supplementary information on my update page

Below you can see parts for the brakedrum machines. The six tabs welded to the axle tube are mounting lugs for the stator laminations.

Here is Wally Stahle of Future Electric Energy Co., San Luis Obispo CA winding coils for the stator. On the right is the special former used for clamping the coils. It has a sheet metal liner to give a smooth surface of exactly the correct radius. The cardboard in the photo is being used to simulate the coils and create the correct radius while the liner is glued on. I am grateful to Bob Budd who taught me that trick and has an excellent video for sale,

Here is Ian's daughter Rose Woofenden with the completed former, and on the right you can see Ron helping Bob Petersen of Kankakee IL clamping the coils down in epoxy. I think Bob found my methods a little bit rough and ready compared to his own homebuilt 10kW machine, crafted with precision machine tools, but he did his best to humour me.

Below you can see the magnets going into the brakedrum. Dan Whitney had the brakedrum skimmed out to fit the magnets in advance, and chose material for the shims so that the magnets would fit neatly. The magnets are 3x2x1" ferrite blocks from wondermagnet

Below you can see the completed rotor and stator assemblies, and on the right is Brian Faley assembling them.

Below you can see the tail boom being welded to the brakedrum windmill yaw tube. It is mounted on the side rather than the top, and we took great care to angle the hinge correctly.

Dan Whitney (below) did not have the pleasure of seeing his machine fly during the course but we were able to test the alternator and figure out the best coil connection pattern for his application.


[back to the SEI workshop main page](#)

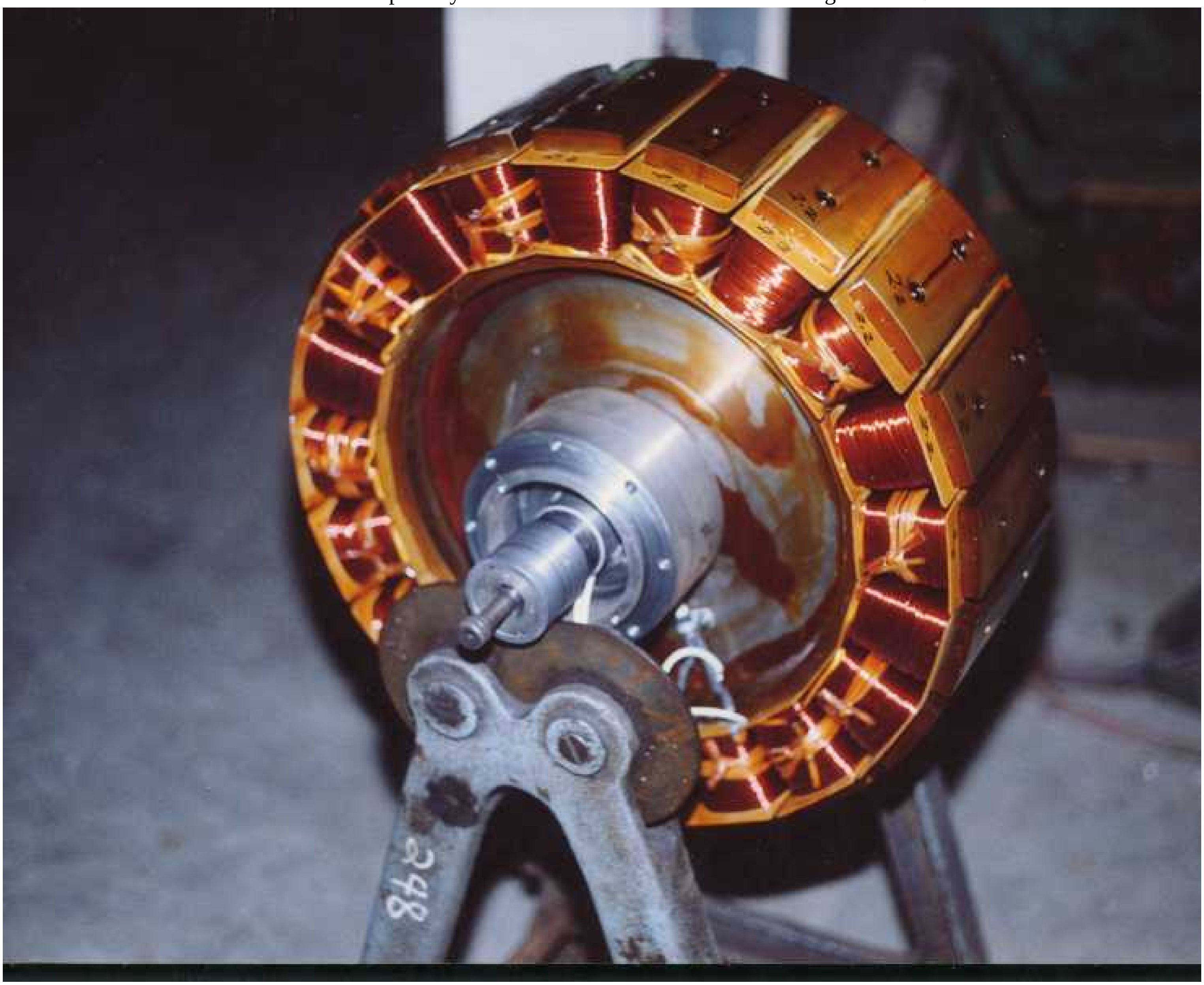
Here is Bob Petersen beside his 10 kW machine in Illinois.

He made the whole thing including the alternator (and its laminations) and the pitch controlled hub. Very impressive!

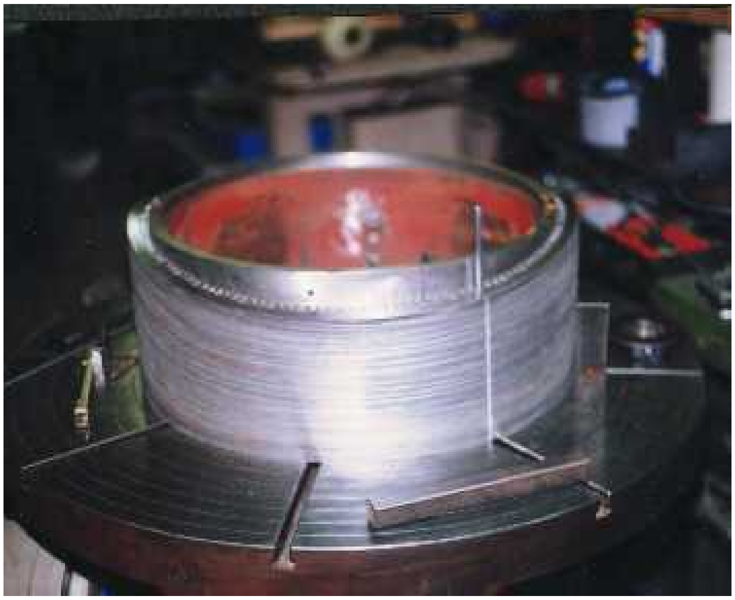



PARTICULAR
PEOPLE
PREFER
PETERSEN
PLUMBING

Here is the specially constructed rotor for the alternator being balanced.



Assembling laminations



Axial flux pmg construction

Below is the story of the other machine which did reach fruition. We start with the wheel hub, which came from a Chevy Cavalier (not a Vauxhall Cavalier but similar in size). The alternator is loosely based on the axial flux 'pmg' (permanent magnet generator) which I designed for use in the developing world. Brakedrums and laminations are not easy to find in some countries (in fact some people have problems finding them at all).

The magnets are glued to two steel disks so that they face each other. See the disks being drilled (5 holes at 1/2") to fit the hub below right. More details of the magnets later.

The **stator** for this alternator has no laminations - it is just a disk of coils which sits between the two magnet rotor disks. Here (left) is the mould for the stator (simplified from the one described in my pmgbooklet). On the right you can see the coil winding former, which is split into two parts for easy removal of the coils after winding. The coils are circular to suit the circular magnets which we chose in this case.

Nora Woofenden helped out with the coil winding.

The coils were cast in polyester, watched closely by Michael McGuiness (a local man, in the brown hat) who is also building one of this type. Michael was our 'scrounger' whose task was to find things in a big hurry when we realised we had forgot to get them before. Thanks for keeping us supplied Michael! Here we have Kelly and Brian doing the dirty work, with respirators, filling up the mould with coils and polyester.


Next day the casting was still soft. We had to heat the mould up, so as to kick the polyester into action, but after a few hours we were able to lever off the top and pry out the completed stator. Hugh Glass and Chuck Morrison inspect the final product. Much easier to produce than a laminated stator. Hugh Glass is a talented stage hand from Utah.


Now that we had the stator we were able to accurately position, and weld three supporting lugs on the yaw frame (see below). We placed the stator on a magnet rotor disk and centred it. then we fitted 3 pieces of steel angle to the stator using 1/2 inch 'all-thread' or 'threaded-rod' or 'studding'. The all-thread allows us to adjust the position of the stator so as to place it accurately centred between magnet rotors with the minimum of clearance. The right hand picture shows the yaw frame set up on a stub tower, with the tail also attached. The tail boom is welded to an inclined hinge arrangement designed by Tod Hanley and Jeff Gilbert.

Meanwhile we fitted the magnets to the rotors. For test purposes they were 'super-glued' to the steel disks, and then later we set them in polyester for extra strength. In previous designs I have used ferrite magnets, but in this machine we used neodymium ones (NeFB), which are stronger. They are also more expensive but the price is coming down all the time, so they are becoming a very attractive option. We used 12 magnets, each 1.5inches in diameter and 3/8inch thick. This works well with 9 coils for 3 phase output.

We are grateful to Wondermagnet.com for supplying the magnets. Wondermagnet's sister website Otherpower.com has a very interesting low tech alternator design using wood. Our design uses steel which makes it more efficient and also more practical for permanent duty.

Here is Kelly casting his magnet rotors in a level mould

We did a quick test of the alternator - cranking it by hand and measuring the voltage at a low rpm. It came out exactly as predicted. Using simple calculations I matched the speed of the alternator to the speed of the 8 foot diameter wind-rotor (propeller) so that it would run at or near its design tip speed ratio of 7. We were able to adjust the cut-in speed of the alternator to suit the blades by careful grouping of the coil connections.

Below I am showing Bob Peterson a design spreadsheet for matching up the rotational speeds.

return to main page for SEI workshop

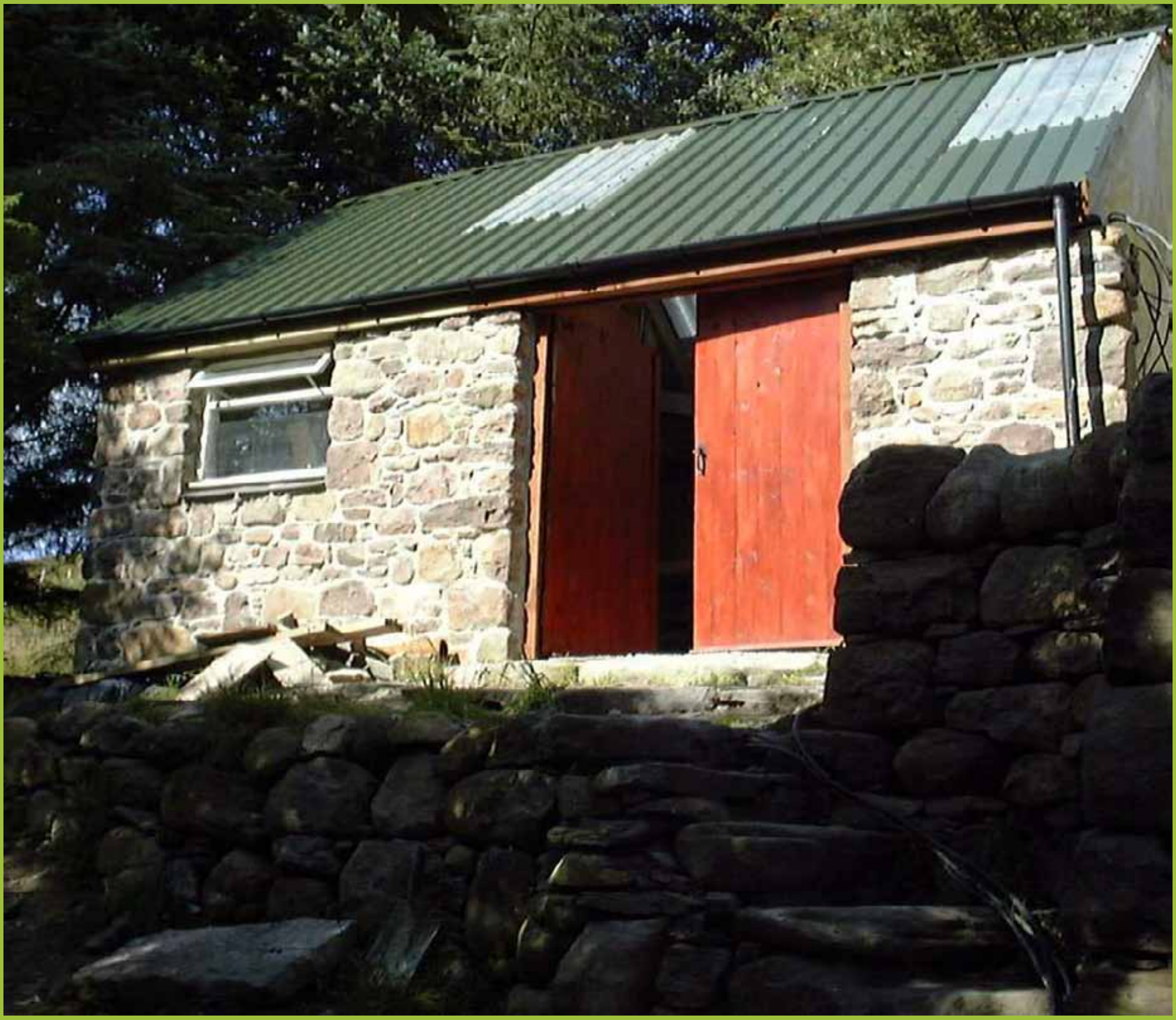
BUILD-YOUR -OWN WIND TURBINE

Workshop Scoraig August 2001

The workshop course took place from 18th to 25th August. There were 7 participants, 2 from Scoraig, 2 from England, one each from Ireland, Spain and Hong Kong. I was the only tutor. We completed a 2.4 metre (8 foot) diameter wind turbine and erected it on the last afternoon. It produced about 100 watts in about 6m/s windspeeds. Its design maximum output is about 200-300 watts. This is a low windspeed machine with a large rotor, and modest power output.

left to right John McGeady, Pepe Galan,Dave Allender, Hugh, Neil Cliff, Mike Elliott(of synergy),Michelle(of Scoraig)
also (not shown) present on the course was Brian Cooper of Shanti Griha, Scoraig.

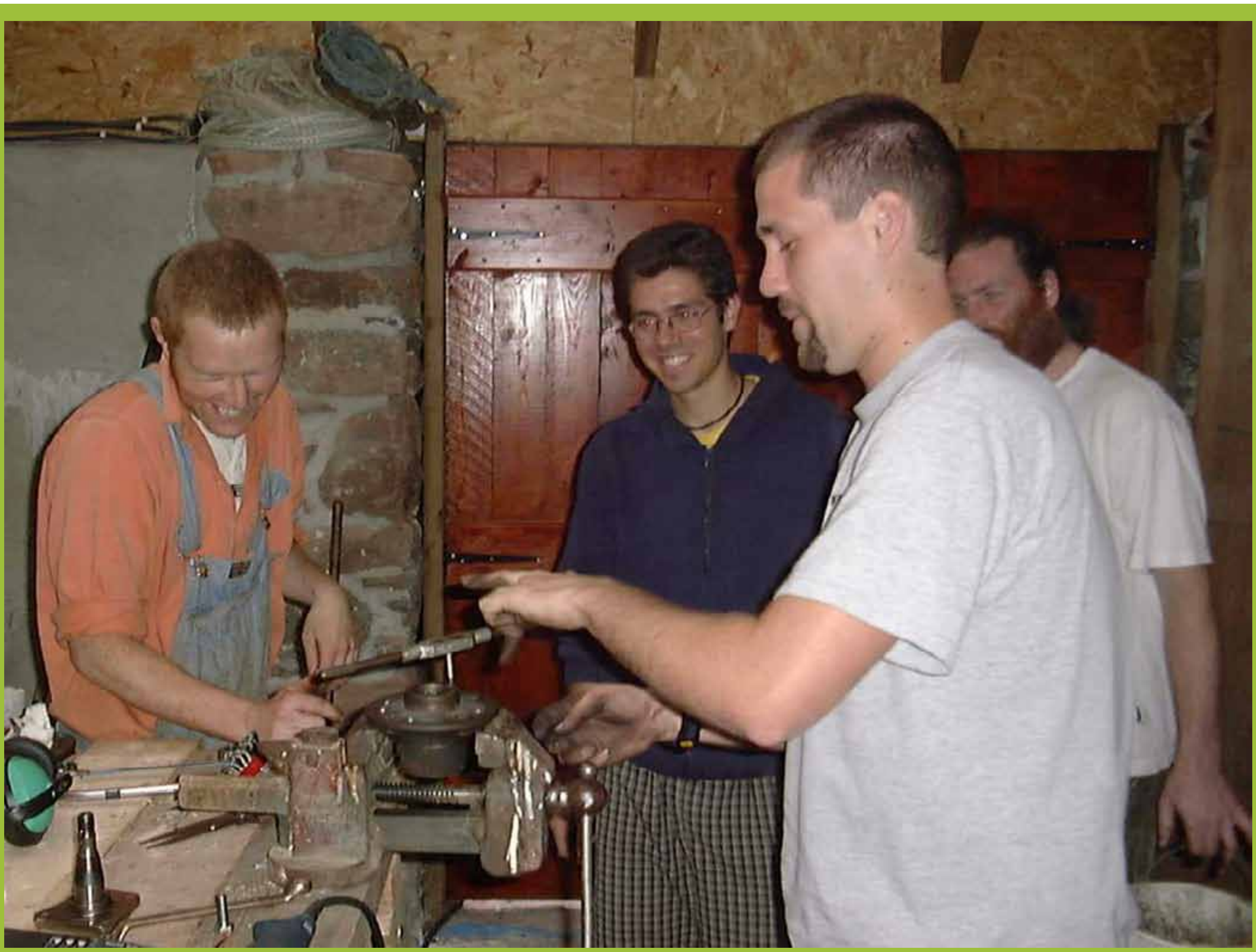
We built the machine in a smallish shed within 200 metres walk of the accommodation at Shanti Griha.



Welding and grinding took place outside in beautiful weather, with stunning views.

Apart from the welding generator, the power for the workshop was all generated from wind, via a 12 volt battery and 240 volt inverter.

Inside was a hive of activity with blade carving, coil winding and metalwork activities progressing amidst much chat and several personal projects.



Each morning I gave a lecture on theory of small turbines, followed by workshop time. Lunch was at Shanti Griha (vegetarian food).

After lunch, work continued until 5 officially, and much later for some students with their own agendas.

the pics above and below show the alternator casting and their assembly

On the WEdnesday (midway through) we took a day off to do the tour of Scoraig wind turbines and projects.

We got the wind generator completed on the last day, and erected it in low winds (3-6m/sec). The output was up to 100 watts into a 12 volt battery bank.

A similar course is scheduled to take place in Washington State USA in October (run by SEI), and further courses will take place next year, both here at Scoraig, and at CAT in Nov 2002.

Cost of this year's (2001) course on Scoraig, included full board, and there were two rates: £345 for a shared room or £395 for a private room. A deposit of £100 was payable in advance. Contact shantigriha@hotmail.com with any queries re. food and accommodation.

Back to Scoraig Wind Electric Main page

Scoraig Homebuilt Windpower Course May 2002

updated 1st June 2002

Seven guys attended this year's course, and we built a 12 volt battery charging machine with 3 bladed rotor diameter 2.4 metres (8 feet).
Cut in speed was around 150 rpm and we got 40 amps output when it furled at about 300 rpm.

Here are some pictures of the construction process. Thanks to Neil and Len for their pics!

Carving the blades
Diameter 2.4 metres and tip speed ratio 7 as in last year's SEI course 8 foot blade



Cutting the wedges and gluing to the blades near the root  

 Checking the blade angles using a spirit level and ruler.

Drilling out the bearing hub and rotor disks to 12 mm (almost 1/2 inch). This is a larger diameter hole than before, both because this alternator is more powerful, and because we were able to achieve a more accurate result by expanding the existing wheel stud holes than by drilling and tapping new 10 mm holes as in previous workshops.

Welding the steel frame of the wind turbine.  

Taping the legs of a coil before removing it from the former 

We cut out the shape of the stator from a piece of plywood, thus creating the outer part of the mould and also a dummy stator whcih was used for drilling holes in both the mounts and the actual stator.

The magnet rotor mould surround is similar but thicker

Preparing the moulds.

These moulds are simpler than the ones described in the pdf construction manual on my web site. They work well for one-off production, which is typical of homebrew applications.

The neodymium magnets are very powerful. If you aren't careful they will grab your fingers


The magnets are completely embedded in polyester resin with a layer of fibreglass on top.

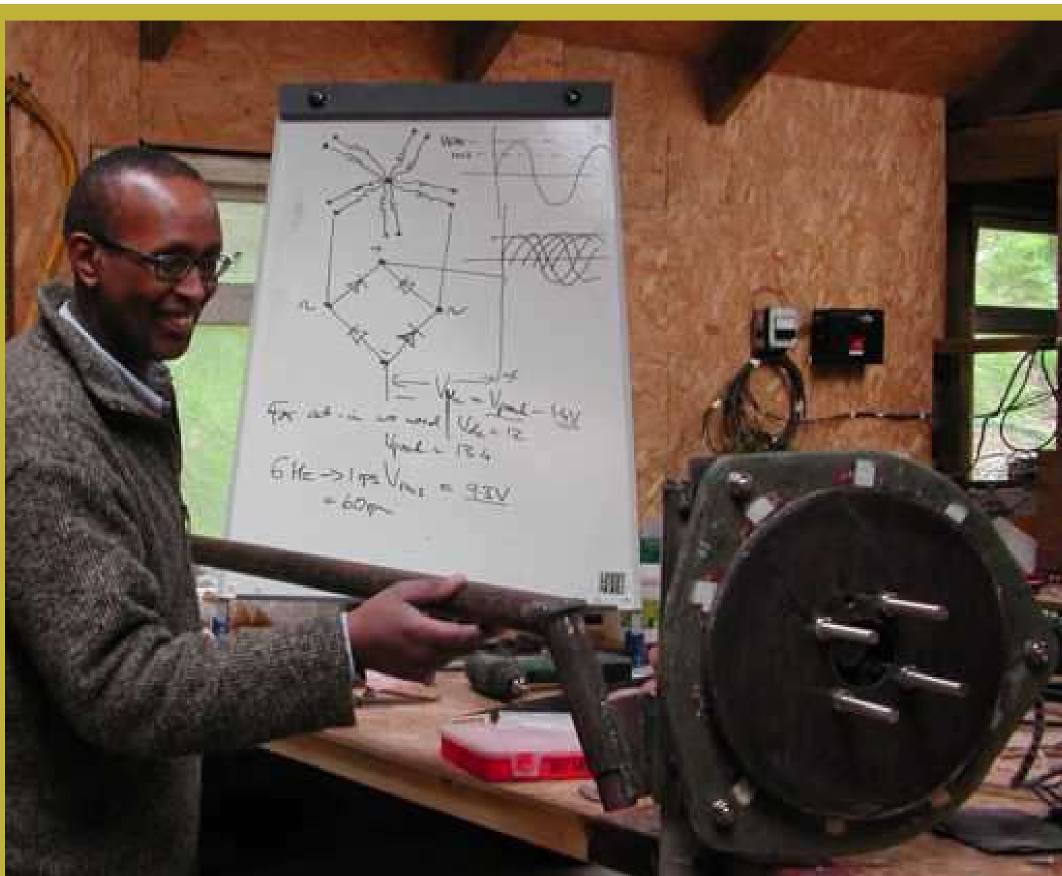
Pouring the resin onto the stator coils


Taking the castings out of the moulds is always an exciting time.

Cutting out the plywood tail vane.

Assembly of the alternator.

Here you can see the stator


The front rotor is now on and the tail is being fitted.

The tail hinge incorporates stops to allow only 90 degrees of swing


The rectifier box fits on the back.

Assembling and balancing the rotor blades.

Fetching the 20 foot (6m) length of 2" (60 mm) pipe for the mast.

Group photo before the erection.

Using a rope hoist to lift the tower

We connected it to a 12 volt system near the site of the workshop. We were lucky to have a good wind and we saw it produce 20-30 amps steadily and reach over 40 amps in gusts as the tail furled. The short circuit brake worked every time. The machine ran quietly and smoothly. We all enjoyed a well-earned beer.

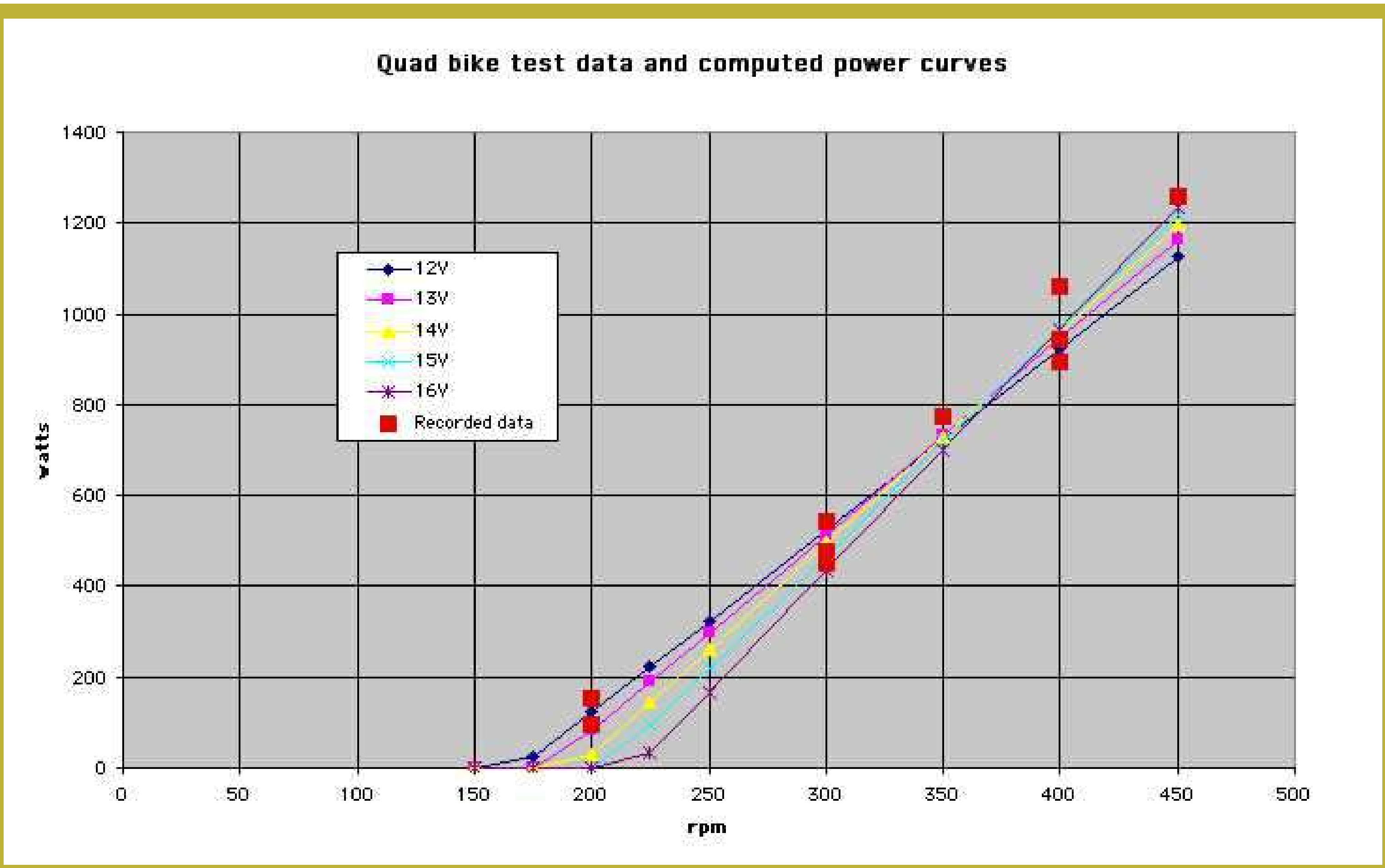
So that's it until next year! (there are more closeup pictures and some test data below)

There will be a course at CAT in Wales 6-11 October (2002) and another one in the USA 14-19 April 2003. Next year's Scoraig course will be 17-24 May 2003.

Click on the links to get e-mail addresses for more info.

On 18th June we tested the alternator using the quad bike to drive it (low speed, high torque job).

Testing the alternator on the rear wheel drive of our quad bike.


Quad bike test data and computed power curves
1400
1200
1000
800
600
400
200
0
watts
12V
13V
14V
15V
16V
Recorded data
0
50
100
150
200
250
300
350
400
450
500
rpm

2.4m / 8 foot diameter blades (3-bladed) for SEI Oct 2001			
INCHES			
radius	**width**	**drop**	**thickness**
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radius	**width**	**drop**	**thickness**
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610	100	12	13
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1016	70	3	8
1219	60	2	7

How to build a wind turbine - Workshop Course - CAT 2002

6-11 October 2002 at the Centre for Alternative Technology in Wales, UK.

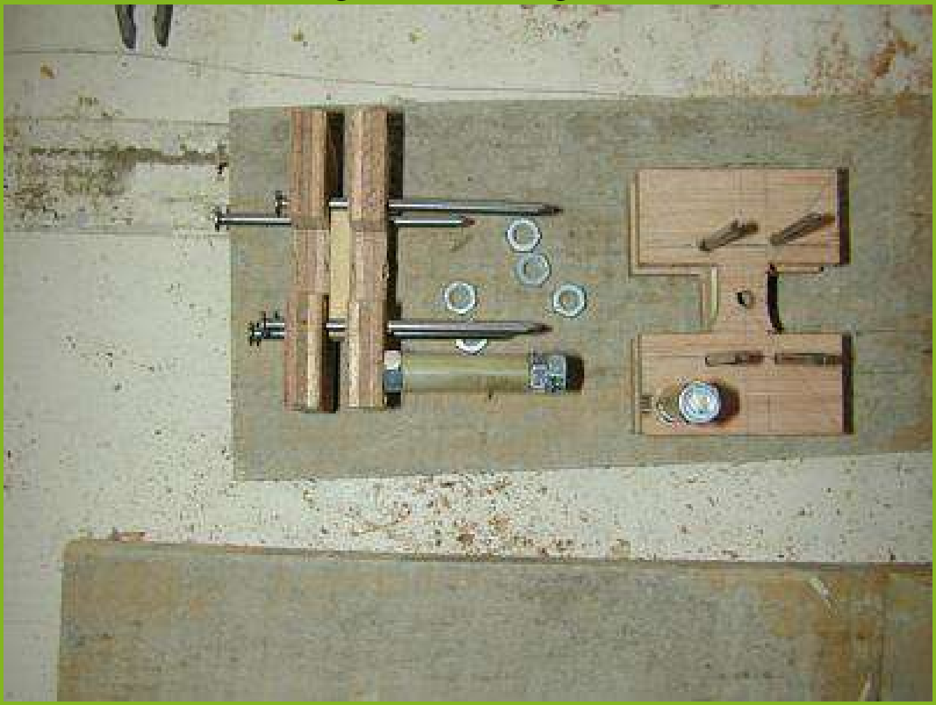
There were 17 participants from various nations and all walks of life. For example we had a small wind turbine dealer from Ireland, a vicar, an electrician from Sellafield, an architecture student, a formula one racing mechanic, a GP, a dutch group therapist, a danish energy consultant, an american engineer, a catholic church worker from Uganda, etc.... Matthew cycled all the way from milton keynes to be there.

Thanks to Katie for looking after the metal workshop.
Thanks to Mo for contributing most of these pictures.

Here is the metal workishop. Marking out the steel disks.

renewing the bearings in the wheel hub

Making the coil winding machine

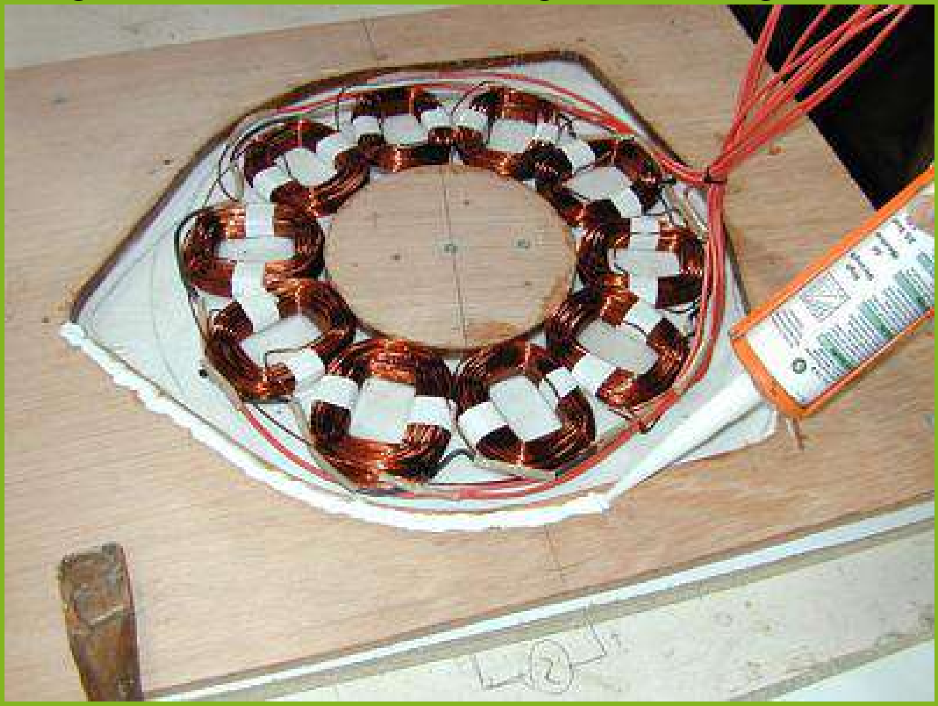


Mixing resin for the stator casting

putting resin in the statr mould

putting in some fibreglass cloth

In go the coils. Silicone around the edge to redue leakage of resin.



Putting the lid on the stator casting.

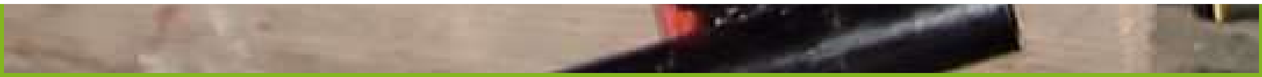
Painting the magnet disks with resin

Fitting the magnets on the disk

using various tools to compress the lid on the magnet rotor mould. The magnets pull them down tight.

A finished magnet rotor.

Assembling the alternator



Cranking it up, and testing the output.

Meanwhile the blades were being carved. This is the space we used for blade carving and resin casting.

Some of the wood had defects, so we had to develop a method to reinforce the weak place.

Fitting the blades to the alternator.

Erection on site at CAT.

Waiting for wind which never came.

The machine was then dismantled and will be shipped to Nicaragua for a village electrification project. This was the decision of the group who built it.

Down at the local pub in in Cynws.

We heard some remarkably good songs, and the notorious squirrel story.

Some pictures of the completed turbine in its new home in Nicaragua

Back to my homepage

sorry about the quality of some of these pictures - the light was very poor at times.

metalwork blades castings assembly small machine

OR JUST SCROLL DOWN...

We enjoyed the weather and the sculptures in the yard. It was alo a good place for blackboard sessions.

Drilling out the magnets disks

We centred each disk carefully by rotating it past a stationary object before drilling through the holes in the hub flange into the disk.

The alternator mounting bracket being fitted to the yaw bearing

setting the correct offset

stator mounting lugs

tail boom (oops john should have eye protection on)

Neil cutting our the blade taper on a bands

Fitting the back disk to the blades

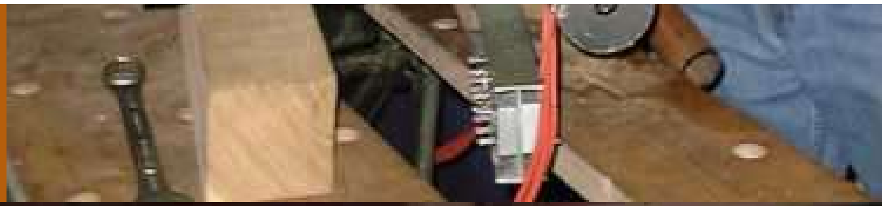
Drilling clearance holes through the blades

Cutting out the blade root wedges

Cutting very accurate circles with a router

The magnet-positioning jig

Using the jacking screws to lower the front rotor into place gently



Testing the output from the alternator

There was no wind when we erected the machine unfortunately.
NEXT COURSE IN EDINBURGH IS

15th-20th March 2004

£300.00 per place. Six day course

to book a place - e mail (click here)

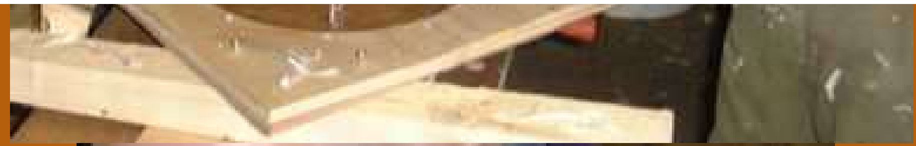
or Telephone/Fax:

0131~332~2229

We did some work on a smaller wind turbine using a

single magnet disk and casting a stator on the end of the tubular shaft.

The coils for the small machine



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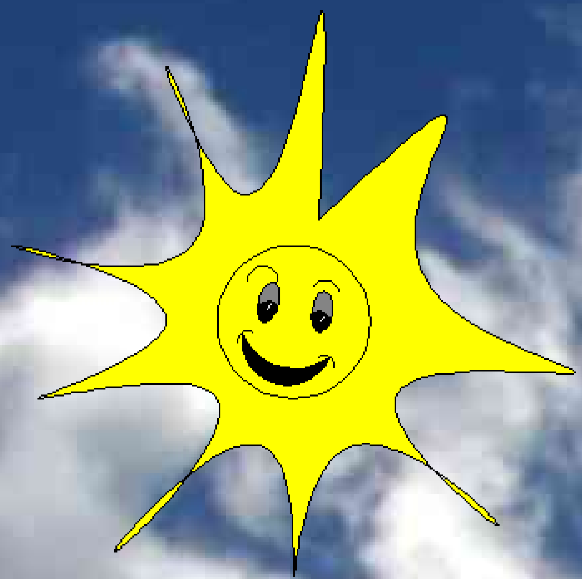
- Brændselscelle
- Designforum
- PMG - Generator
- Info og Links



SunWind Lokal

Google Search

Hjemmesiden er Designet af Monie Jacobsen
Yderligere information rettes til: Mail to Webmaster

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We offer the Stream Engine, a breakthrough in hydro technology, and we have recently introduced the LH1000, low-head propeller turbine, which operates from 1 to 3 metres of head or vertical fall of the water.

www.microhydropower.com

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- Net Metering
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- Wind Resources
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- Wind turbine manufacturers
- List of state contacts.
- Small Turbine Applications
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- SMALL WIND SYSTEMS HOME PAGE

NEW **Small Wind Success Stories**

SMALL WIND STATE-BY-STATE

These pages provide information specific to buying and installing a small wind turbine in each of the U.S. states listed on the right. Eventually, all U.S. states will be represented. In the meantime, you can find information on these states, and other states that we have yet to post, on the U.S. Department of Energy's Net Metering Web site by clicking here and following the link to "State-by-State Program Activity."

AWEA's Web site also contains general information that is helpful regardless of which state you live in. You will find the information in the links on the left. Additional general information is available from the Small Wind Home Page and in the new Windy Landowner's Factsheet.

For each state, the following specific and unique information is provided:

- **Net Metering**
- **Technical Interconnection Issues**
- **Non-Technical Requirements for Interconnection**
- **Local or State Incentive Programs for Wind Energy Investments**
- **Utility Incentives**
- **Wind Resources**
- **Additional Resources**
- **Utility Contacts**
- **Government Contacts**
- **Local Organizations Interested in Renewable Energy Issues**

Available State Pages:

- California
- "Shocked in CA?"
- Illinois
- Minnesota
- New Jersey
- New Mexico
- New York
- North Carolina
- Pennsylvania
- Rhode island
- Texas
- Vermont

SMALL WIND FAQ | AWEA HOME PAGE | SMALL WIND HOME PAGE

Updated: October 02, 2003

PicoTurbine

Welcome!

Pico (pee'ko) *very small*
Turbine (ter'bine) *a motor driven by curved vanes*

Home
PRODUCTS
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Project List
Order Form
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Hall of Fame
Rotor Simulator
Photo Gallery
INFORMATION
FAQ
Classroom Ideas
Safety Rules
Policies
Renewable Links
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We provide plans, books, videos, and kits for renewable energy education and homebrew projects. Projects are available for fifth grade through adult at this time.

We offer our projects as free, downloadable do-it-yourself plans, as well as kits that include all the materials for a modest charge. We also sell plans and kits from other vendors.

We offer hard-to-find books on homebuilt renewable energy and classic renewable energy titles.

PicoTurbine Educational Windmill Kit

Thousands have been built!

The orginal PicoTurbine has been improved yet again! This all-new version of PicoTurbine produces more voltage (2.0 to 2.5 volts) so it can directly drive more devices. The new kit is 100% complete, (requiring only common tools like scissors, a screw driver, pliers, and glue), and uses a cool bicolor LED to show the power produced. The LED flashes red and green in succession as PicoTurbine's alternating current pulses in different directions.

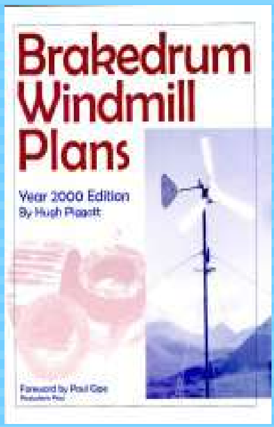
PicoTurbine is the only kit of its kind: a complete, electricity-producing wind turbine you can build yourself. And the new add-on *PicoTurbine DC Experiments Kit* allows you to learn all about AC to DC conversion techniques too! This kit has been used by major universities, government agencies, and thousands of students and hobbyists worldwide to learn about wind power. Perfect for science fairs, science reports, and just plain fun!

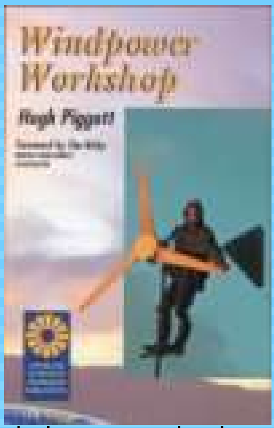
Get more information

ORDER IT!

Homemade Wind Turbine

New! Year 2000 Edition. Hugh Piggott's **Brakedrum Windmill Plans** have been built all over the world. This is a proven design that can output 300 to 500 watts of power. These plans are available in the USA only from PicoTurbine.com! (30 page booklet).



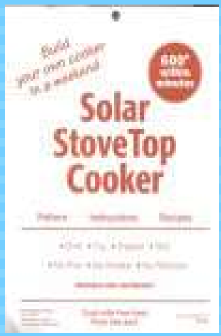


Hugh Piggott's book **Windpower Workshop** is a best seller! It gives general design principles and discusses alternator mods, choosing a surplus DC generator, wiring, towers, loads, and even design of a purpose-built alternator. A must-have reference for the DIY wind power enthusiast. (166 pages soft cover book).

[Get more information]

ORDER IT!

DIY Solar Stovetop



Build a solar stove top capable of reaching 600 degress F [300 C] in a matter of minutes! Not an oven, but rather a cook top suitable for frying. This set of plans includes a life sized pattern for the parabolic shaped parts required to reach maximum heat, no calculating to do! Serve solar burgers at your next bar-b-q and demonstrate a very practical use of solar energy.

[Get more information]

ORDER IT!

PRODUCTS: Home | Books | Project List | Videos | Coming Soon | Order Form |
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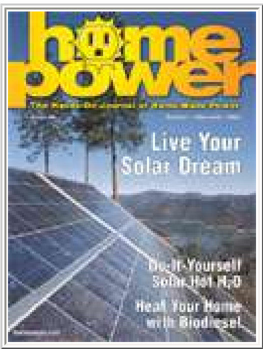
home power
The Hands-On Journal of Home-Made Power

HP Magazine

Issue #97 Contents



Download Current Issue #97

Books

Poll

For my next renewable energy project, I expect to:

- Design, purchase and install the system by myself or with friends
- Have the system entirely designed and installed by professionals
- In some way share the system design and installation

VOTE!

View Results: 111 votes

Blackout Buster
download it for FREE!

Welcome to HomePower.com!

Home Power magazine, the hands-on journal of home-made power, grew out of our passion for renewable energy (RE). We're concerned about a world that is increasingly polluted. We're concerned about the high energy use and waste of "developed" cultures. And we're concerned that people are dependent and unable to care for themselves when it comes to energy. Renewable energy gives people control over their energy future by using energy that is provided daily by nature. New to Home Power... click here to learn about us!

Feature Articles

Photovoltaic Grid-tie

I have been interested in solar electricity for many years, but the timing never seemed right for installing a system. When my union, the International Brotherhood of Electrical Workers (IBEW) joined with the National Photovoltaic Construction Partnership (NPCP), it was time to act.

Through the NPCP, union members can purchase prepackaged systems at wholesale cost. The NPCPwill even carry the California rebate for the member, lowering the out-of-pocket expense... more

Solar Water Pumping

For Butch and Linda, energy efficiency has been a priority for a long time. Before moving to their property, they lived off-grid both on land and on a boat, so they learned how to minimize their energy consumption. Since then, they have followed the

RE Directory

Need HELP? Locate an RE business in your area:

-- Select State -- Go

Successful Solar Businesses 2004!

RE Tips

Every dollar spent on efficient appliances saves three to five dollars in RE system components.

Home Power on the road!
technical advice • good deals • nice smiles
October 17-19, 2003
Bioneers Conference
San Rafael, California

Think About It...

What's the use of a fine house if you haven't got a tolerable planet to put it on?

— Henry David Thoreau

basic guidelines of avoiding electric heating and cooling, and buying efficient appliances. Water pumping was the Sagasers' biggest electrical load, until this project was completed. Although they have a shallow... more

Abundant Renewable Energy

Let us help you Spin Your Wind into Power

AWP3.6

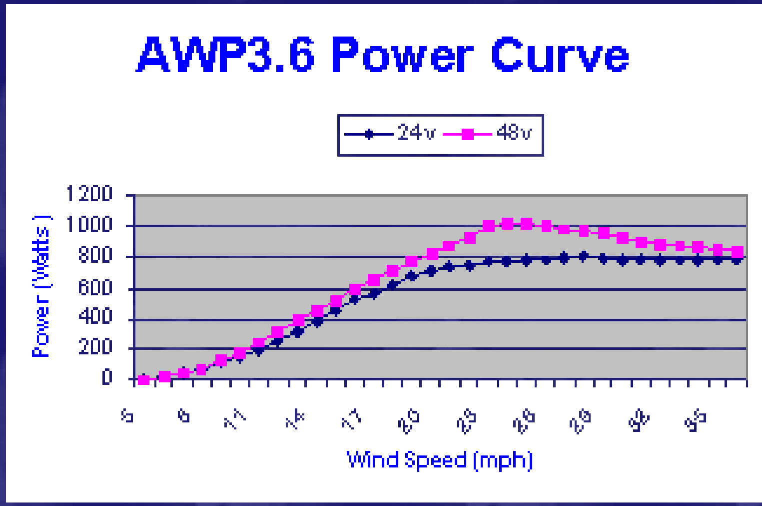
Strong as an elephant

not quite as heavy.

We have the AWP3.6 model available in various voltages. The model number refers to the rotor diameter in meters (11.8 ft), not the machine's maximum power production. The AWP3.6 has approximately a 1 kilowatt peak output. It produces more kilowatt hours of energy per rated watt than machines that have comparatively smaller rotor diameters. These machines are suited to get the most energy from low to moderate wind sites. They are simple, sturdy and dependable. They are also affordable.

Configuration:	3 blade upwind w/ gravity furling
Rated Power:	48v 1000 w
Rotor Diameter:	11.8 ft. (3.6 m)
Cut In Wind Speed:	6 mph (2.5 m/sec)
Rated Wind Speed:	25 mph (12 m/sec)
Blade Construction:	Fiberglass
Alternator:	PM, 3 phase, 0-70 Hz
Voltages:	24v, 48v, 110v, 220v
Top of Tower Weight:	250 lbs (120 Kg)
Shipping Weight:	400 lbs (180 Kg)

Shipping Dimensions:	75x21x18 inches



Pricing :

Model	Generator	Controller	Diversion Load
24 volt	$2250	$210	$105
48 volt	$2250	$195	$95
110 volt	Battery Charging System (12v, 24v, 48v)		$3,700
110 volt	Direct Grid Connect System		$5,350

The 110v Battery Charging System includes the generator, a voltage converter and a diversion load. This system can charge various voltage systems and saves money in applications with long wiring runs.

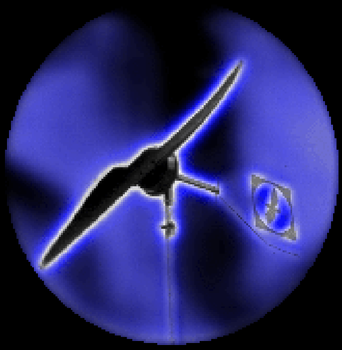
The 110v Direct Grid Connect System includes the generator, an SMA Windyboy Inverter, a voltage clamp and a diversion load.

Quote from Erhard Hermann - One of our dealers in Didsbury, Alberta

"I have been really impressed with the output of the AWP 3.6, after my experience with the Whisper H80 I pretty much thought that this area was not going to do much in the area of wind, but now I really see some good potential. Last year we were watching the flags at the police station out our front window and we could pretty much tell when the H80 was going to start producing, now we have the AWP in the same location and it starts producing much sooner and we could so far actually run totally on the AWP. Also, I have noticed that in the really low wind speeds that we generally get here, it produces about 4 to 6 times the energy that the Bergey XL 1 does. When the wind increases the Bergey does good to, but we don't get that very much here. I'm definitely impressed."

Send mail to Doug@AbundantRE.com with questions or comments about this web site.
Last modified: 09/05/03

crow electric



wind and solar power

crow wind generator | gallery | links | email

Still making wind generators but also started working with Sundance Renewables,

a renewable energy co-operative based in Wales who do feasability studies, system design and installations of wind and pv systems also solar thermal, micro hydro, biomass heating systems and CHP (Combined Heat and Power) .

WINDMISSION

Home PMG's Windflowers Projects
Workshop Crew Contact

WELCOME

Windmission is a small Danish family owned company. Over the years specialized in turbines equipped with Windflower rotors, quiet multi bladed super wind roses with a high efficiency.

A fire in 2000 stopped selling. Now focus is on developing new Windflowers, general consulting and PMG distribution. A new 1.5 kW Windflower goes up for testing in Autumn 2003. Also, a new Micro turbine design is underway.

Ampair

specialise in 12V and 24V wind, water and solar renewable energy systems for land and marine based applications. We manufacture the Ampair Pacific and Aquair ranges of wind and water powered turbines. The company also supplies low energy fridges, regulators, battery monitors and associated equipment.

The Ampair range of wind generators for maring applications can be specified to either twelve volt or twenty four volt DC systems, and are easily mounted on all yachts and cruisers. The Pacific wind generator is designed to produce 100 watt in normal coastal wind speeds (or in other words, nothing extreme!)

The generator systems are very robustly built to survive extreme conditions of wind speeds, heat or cold and can be expected to perform for many years with a minimum of maintenance.

Ampair merged with Doughty Engineering of Ringwood in early 2002, which has enabled cost savings and price reductions due to improvements in manufacturing technology throughout the range of generator systems

Wind Generators

The Ampair Pacific and Dolphin wind generators are primarily used on yachts, whereas the

Ampair Hawk is normally used for remote power to land sites. The Hawk and Pacific generators are in fact identical apart from the colour. To compare similar equipment you could also visit Rutland or Airmarine

Water Generators

The Aquair water generator is ideal for use on yachts, as the main power generation is by a towed turbine for yachts on the move. This has the advantage of producing higher charging rates than a wind powered generator. Once the yachts have anchored, the towed turbine can be hauled in and with a few minor alterations the Aquair unit can be fitted with a wind turbine, and battery charging can continue.

Solar Panels

Ampair can provide a range of photovoltaic solar panels for battery charging either for yachts, or to trickle charge systems to keep batteries healthy for irregular use, or as replacement roof tiles for complete supply to houses. They can also be combined with a water or wind powered generator system to take full advantage of the alternative energy resources available to us all.

Doughty Engineering and Ampair Combined

Associated information:

- Lube liners - low friction slip discs for articulated lorries
- Doughty Engineering: Manufacturers of theatre, tv film and studio equipment
- USA distribution centre for Doughty Engineering clamps and stands
- Doughtys range of attachments for Merlo rough terrain handlers and fork lifts

Proven Energy

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Find your way around - browse via links on the left or visit our table of contents page

Our Mission - To provide affordable and reliable small scale renewable energy systems for any location in the world. There is power everywhere you look!

Electric Citroen Berlingo and Proven WT6000 turbine

Big News.... new

WT15000 literature ready...
Video clip added ...
New 15kW turbine launched!...
We have moved!...
New grants available in UK....
more....

Company Profile

Proven Engineering Products Ltd is a family owned business based in Stewarton in south-west Scotland which manufactures and installs wind, hydro and solar photovoltaic (electric) panels. Established in 1980 with expertise in mechanical, electrical and control engineering, Proven has been manufacturing renewable energy machinery since 1991.

Proven manufacture a range of small wind turbines up to 15kW and and hydro turbines up to 25kW. We also provide consultancy, design, resource and site assessment services for small renewable systems.

Meet the people at Proven.

Contact Information

Drop in and see us at our factory near Glasgow or find how to contact us....

Members of the British Wind Energy Association. and the Scottish Renewables Forum

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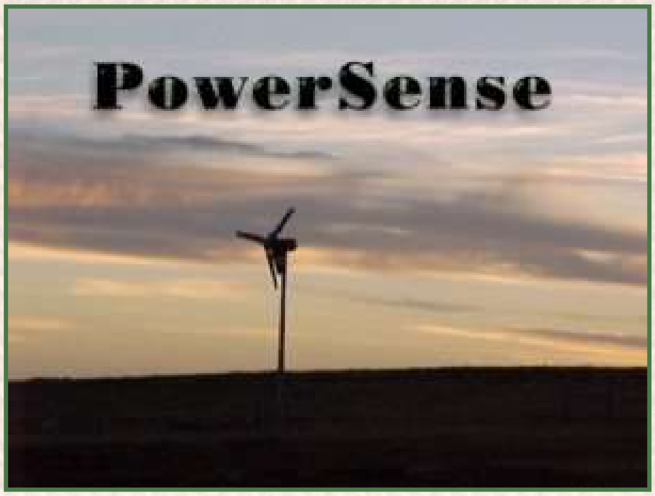
Send mail to web@provenenergy.com with questions or comments about this web site.

Last modified: September 24, 2003



Supply & installation of 24-hour power systems.

- Introduction by Clive Wilkinson

As already explained elsewhere in our website, the Falkland Islands consist of two ‘worlds’ the capital and only town, Stanley with its paved roads and main services, and Camp (the countryside, ie everywhere outside town). Many farms remain isolated, with only a distant prospect of a road link to other farms or the proposed ferry link across the Sound in the case of West Falkland farms. With dwindling wool income, the inevitable fixed costs of Camp life are becoming an increasing burden on all farmers.

Power for domestic and farm use in Camp has until recent years always been provided not from a national grid but by individual diesel generators, or occasionally a shared facility in the case of a settlement or larger farm. Solar panels are often used for fencing, and a few oldfashioned but sturdy windchargers used to provide battery-charging for radios or single lights, and still do in some cases, but not much more than this.

Use of generators inevitably mean that mains power is only available for a limited period each day, not to mention a heavy outlay on batteries, candles or other means of lighting. Many are now turning from these noisy, fuel-guzzling and ecounfriendly diesel generators to our notorious Island winds, in order to not only save on fuel importation but provide power round the clock. I am proud of PowerSense's major role in bringing about this change.

My interest in renewable energy began some years ago, on buying a Trace inverter for our own use here. Impressed by its reliability, and the sturdiness of the Chloride battery bank we purchased to go with it, I decided to offer the benefits of 24-hour power to fellow farmers and so PowerSense was born.

We tested various makes of small wind turbines here on the farm, but found few of them could survive local conditions. We have a sad collection of burned-out machines. However, the larger Proven (Scottish) turbines looked interesting.

Retired farm manager Brook Hardcastle then asked me to install a complete system for him, incorporating a Proven wind turbine, and this proved highly successful. Brook and his wife Eileen were (and still are) most impressed with their new power supply. (A full account of this installation may be read in Home Power issue #55, see Links for their URL).

The Falkland Islands Development Corporation (FIDC) in Stanley now offers Stabex-funded grants to Campers purchasing such systems, and I am kept more than busy. PowerSense standard systems - ie those eligible for grant - are designed to suit varying sizes of household or settlement. All are based on a tried and tested combination - i.e. the Trace Engineering power inverter range, Chloride Motive Power battery banks, and Proven Engineering wind turbines of 2.5 or 6kW (complete with versatile heat sinks). Other systems are designed and quoted for, based on requirements. Our own system now uses a 4.5kw Trace inverter/charger, 660Ah battery bank and 2.5kw Proven wind turbine, which is a (standard system).

Building up my business over the years, I now travel widely around the Islands, mostly using the local air service but also mudtracking overland. I'm used to working in difficult conditions, frequently battling against more than just the elements - one of my biggest headaches being the Falklands Factor i.e. sheer distance from suppliers and manufacturers. Our younger son Alistair who is a qualified electronics engineer helps me whenever possible, and is shortly to become approved as our service centre for Trace equipment. We have a base in town for use as a workshop and spares storage etc.

PowerSense is also agent for Bergey, BP Solar etc, and I offer a wide range of equipment, such as solar panels, smaller batteries, electronic equipment and spares.

I endeavour to provide a full back-up service and free advice to customers when needed. They don't hesitate to take advantage of this!! Phone calls at all hours... but I am happy to talk people through any problems they may encounter, and if a problem appears complex I will do my best to visit for a troubleshooting session - even if such visits prove unnecessary.

Wind turbines are becoming part of the Falkland Islands scenery now, with more and more being installed as time passes. See (map) for latest update!

Freighting of equipment around the Islands is normally done by sea, so in order to avoid handling impossibly heavy freight at the most awkward ports of call I now order battery banks as individual 2-volt cells for on-site assembly. Although I try to keep a reasonable range of spares on hand, the scope of such stock is limited by the capital required. Careful planning is vital. But if a manufacturer at the other end of the world omits a vital bit of equipment from the crate, some quick thinking is called for, with no electrical supplier or ironmonger just down the road... Air travel restricts the amount of spares, tools etc that I can cart around with me to sites, but I have learned the hard way what I need to keep with me for such trips.

Please note that I am willing to advise on suitable equipment for 24-hour power, demonstrate techniques or even physically assist with installations anywhere in the world. I expect no payment for this, other than travel costs plus basic bed and board. Feel free to contact me if you would like further information on this or any aspect of PowerSense, and I will do my best to help.

Contact details are:

Clive (DCW) Wilkinson
PowerSense
Dunnose Head Farm
Falkland Islands
tel +500 42202 (allow for time difference please!)
fax +500 42203 (any time)
or email me at: powersense@horizon.co.fk

Links

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awea-wind-home · Home Energy Systems Discussion

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(Already a member? Sign in to Yahoo!)

Description

Category: Energy

The Home Energy Systems Discussion list is intended for those with questions about household energy systems that include wind as a component. Questions about wind turbines, batteries, inverters, towers and other relevant equipment are welcome, and will be answered by persons with hands-on experience.

To unsubscribe from this list at any time, send a blank message to awea-wind-home-unsubscribe@yahoogroups.com

Most Recent Messages

View all Messages (11594)

Oct 2 Re: the hornet wind turbine - **hakan_falk**

I like to know also. Hakan ...

Oct 2 Re: Southwest model H80 noise - **scoraigwind**

... I recommend you have a switch that connects a dump load direct to the wind

Oct 2 Re: Proximity of Windmill, Batteries, and Load - **scoraigwind**

... Place the battery close to the load. Losses in the wind-battery cable are

Oct 2 Re: wind tubine and solar panel - **scoraigwind**

... YOu can hook them each up to the battery in parallel as if the others were

Oct 2 Re: Dutch "Turbie"/Ginny - **scoraigwind**

... http://www.core-international.nl/ the name is turby. It's a VAWT on the ro

Search Archive

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1999		81	303	150	188	208	119	234	160	76	60	151

Group Email Addresses

Post message: awea-wind-home@yahoogroups.com

Subscribe: awea-wind-home-subscribe@yahoogroups.com

Unsubscribe: awea-wind-home-unsubscribe@yahoogroups.com

List owner: awea-wind-home-owner@yahoogroups.com

Group Info

Members: **1619**

Founded: **Feb 17, 1999**

Language: **English**

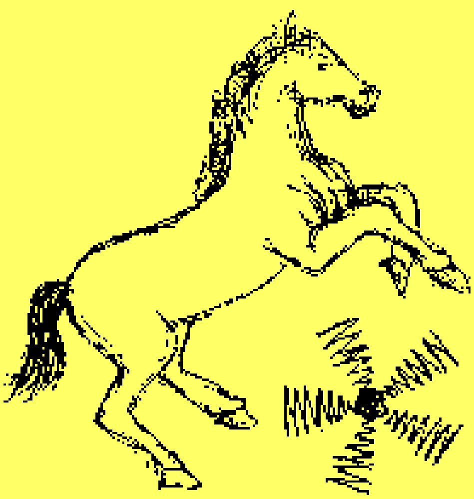
Group Settings

- Listed in directory
- Open membership
- All messages require approval
- All members may post
- Public archives
- Email attachments are not permitted

ELECTRIC HORSE

Sustainable Transport Project

Imagine a place where you could transport yourself quickly, silently and effortlessly without polluting the air we breathe, imagine a place where it would be possible to make a journey of up to 25 miles at a time for only 2 pence while travelling at speeds exceeding 30mph. It sounds like some ideal future world doesn't it? Yet such a means of personal transport does exist... Its called Electric Horse...



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