I've been playing with wind generators for two or three years now, and along the way I have also purchased and re-sold three commercial units. Here's what I've come up with for my homebuilt, the writeup being copied from a posting I made to the small-scale-windpower email list.

Let's talk about three main aspects - the generator, the blades, and the support structure.

THE GENERATOR

For someone into this as a hobby, I think using a permanent-magnet DC 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.

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:

$$12 + (5)(1.24) = 18.2 \text{ volts}$$

and the rpm required is:

$$(18.2)(26.5) = 482.3 \text{ rpm}$$

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.

In my application, I only need to generate 5 to 10 amps, which is in the range of the motor's operating current under some mechanical 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".

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. 1-800-488-3407.

Weight is about 10 pounds (my guess).

A benefit 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 you wanted to power communications equipment, this would probably be a good choice.

There are several inconveniences to using a commutated PM motor as a generator. Like the PM alternator, an external regulator must be implemented unless you are using a fairly large storage battery or direct-driving a load that is not voltage-sensitive.

Also, if you don't have anything else between the battery and the generator, you need a series 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. High-current Schottky diodes are available on the surplus market for one or two dollars each. I use a diode rated at 50 amps in order to minimize forward voltage drop in my 10-amp application. My local source for high-current Schottky diodes is Tanner Electronics in Dallas, Texas.

If you build your own shunt regulator, wire the controller and dump loads on the generator side of the diode. I recommend this in the interest of fail-safe operation; the diode will prevent the controller from "dumping" your battery in the event of a regulator failure or malfunction.

Regarding long-term mechanical reliability, keep in mind that these motors are not generally intended to operate with high thrust loads on the shaft. For a semi-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. While I have not noticed significant brush wear in the PM motor I've been using, my application involves temporary setups of only a few days at a time.

THE BLADES

Making blades is an interesting proposition. I went through several phases of blade manufacture. My first was a Cessna airfoil design, no taper or twist, and a hub whose pitch I could vary by shimming the blades at the root. In other words, a flat-bottom blade that resembled a long slender airplane wing. Later, I purchased a spare set of commercial blades from SW windpower and had a chance to see the performance improvement. Somewhere in between, I purchased all of Hugh Piggot's pamphlets as well as read everything in my library on rotor design. Of course, my first set of blades would have been much different had I done all the research first.

My experience is (1) darn near anything can be made to work if it is reasonably close to the right size, has some sort of airfoil, and you are free to play with the setting angle, (2) following this "cut and try" approach will yield you about half the results of following a proven formula, and (3) making "real" blades, from wood, with both twist and taper, requires a lot of forethought.

Bottom line - Read everything you can get your hands on first, then decide how fancy you want to get with the blade-carving. Paul Gipe's book will discourage you from homebuilding anything, but has good information and should be read. Hugh Piggot is the "anti-Gipe", he builds everything! He's also very conservative in his designs (ie no transmissions, no slip rings, etc), but then most of his projects are apparently for permanent long-term low-maintenance installations. He's also one of the most resourceful "use-what-you-can-get" types I found, and his blade-carving procedure is pretty straightforward. If you're going to make your own blades from wood, buy Hugh's instructions.

There's a lot of knowlege out there on this list - it's well-populated by engineer/hobbyists (like me), "real" users (like Ian Woofenden), and experienced builder/installers (like Hugh). There seem to be very few "pretenders" on here. Out in the newsgroups, I have seen several "pretenders" spreading stories about what they've built, that obviously don't hold up under scrutiny. It's great being able to toss ideas around with the experienced people on this list.

So anyway, my first set of wooden blades were constructed using Cessna airfoil patterns (from an aeronautics textbook) and trial-and-error hub-pitch settings. It worked fine, but now I'm using a spare set of AIR303 blades. These are high-tech carbon-fiber construction, designed for a 300-watt machine with 45-inch rotor diameter. You can buy them as spares for $25 each from Southwest Windpower in Flagstaff, AZ. Even though these blades were obviously designed for a substantially different machine, they work great driving my generator. I suspect I could have gotten by with only two of them, and saved myself $25.

THE TOWER

Here's how I built a temporary tower for weekend trips to the lake, using cheap materials. I went to my local "Home Depot" building-materials store, electrical department, and found a 10-foot piece of metal EMT (conduit) that looked strong enough. It was about 2 inches in diameter. I then walked over to the fencing department and found an 8-foot piece of gatepost that is a slip fit over the outside of the EMT. I don't remember exact figures, but total cost of materials was around $10.

At home, I cut two six-inch pieces from the gatepost, and cut the EMT to about 8 feet long. I then used a hacksaw to "slit" the six-inch pieces for about 2 or 3 inches, cutting six slits, such that I could bend out three tabs. I then drilled a hole in each of the tabs. Do this before sawing and it's easier. The six-inch pieces form "collars" on the EMT, and the drilled tabs are attachment points for the six guy ropes.

BTW, I don't have slip rings in my design - if the wind changes too many times over the course of a day, I could presumably wind up with the wires twisted around the pole. This has never happened yet, probably won't.

I slipped one six-inch "collar" onto the EMT, slid it about 1-1/2 feet from the end, and welded it in place. I then welded the other six-inch piece in about the middle of the EMT. When the EMT is slid inside the gatepost, the first "collar" stops it when it slides in about 1-1/2 feet, defining the amount of overlap. This collar and the one above it each receive 3 guy ropes.

To erect and secure the structure. I follow this procedure:

1. Drive a piece of 1" steel water pipe into the ground, to a depth of about 1 foot, leaving about 4 inches above ground. Slide the "base" over this. The "base" is nothing but a square piece of 1-inch plywood with a hole cut in the middle for the water pipe. The base keeps the mast from pushing into the ground, which would allow the guy ropes to become slack.

2. Assemble the two halves of the mast, and attach all 6 guy ropes.

3. Install the generator on the mast (prop the mast on a handy stump, pack, or other object to keep it off the ground), and tie or tape the wires to the side of the mast.

4. I use four people to erect the mast. One person lifts the mast from the "top" end while another makes certain that the "bottom" end goes over the stub of water pipe. Two others pull on two of the guy ropes to lift the pole. The first person then grabs a third guy rope as soon as the pole is lifted out of his reach. His rope serves to make sure that the other two folks don't pull the tower over too far forward. Once these three folks have the pole more or less vertical and under control, the person who was manning the base goes around and helps them stake out their ropes, and provides feedback on leveling. Then they tighten and stake the other three ropes. The water-pipe stub prevents the bottom of the mast from sliding sideways, without requiring that the mast be imbedded in the dirt.

5. For power testing the wind generator in the bed of my pickup truck, I used only the top section of the mast. I made a wooden frame that held a metal stub in the center of the truck bed, and I used four guy ropes (two on one tab and one each on the other two tabs).

Hope this gets you started.

Eric,

I'll answer as best I can, although I'm not sure about how
to find similar motors in Mexico.

> From ejohnson Tue Oct 13 15:12:19 1998
>
> Thanks for the file Marty,
>
> I like this and think it's just what would work for my current
> purposes. A few questions if you don't mind:
>
> > 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 mounting pattern, and is totally enclosed. I use
> > it to produce about 100 watts at 15 volts in a moderate wind.
> >
> I am a medioignoramus when it comes to motors and electricity - I
> know enough to be dangerous and that's about it. Can you give me some
> more details about this kind of motor so that I could figure out if
> it's possible to find something like this here in Mexico where I
> live? Where and in what kind of application are these kinds of motors
> used?

The "servo motor" is generally a low-RPM permanent-magnet DC motor
with a large number of poles, therefore a large-diameter commutator
with many subdivisions. The servo motors are generally used in
robotic and machinery-control applications where good torque
at low RPM combined with a linear torque-current characteristic and
a very "smooth" power delivery (very little "cogging") are required.

These features also lend themselves to small-wind applications
because the same features (mainly large number of poles) that make
for smooth power delivery also make for easy starting of a wind generator.
If you load the terminals of a pm motor and try to spin the shaft, you will
feel distinct "bumps" as each pole passes the magnets. Overcoming these
"bumps" at low speed is one thing that makes the generator require a
higher wind to start from a standstill. A motor, such as a servo motor,
with a large number of poles will have more "bumps", spaced closer
together, and they will be less prominent, making for a smoother and
easier startup.

More poles also means that the DC output from the generator will
have lower ripple and harmonic content, therefore will require less
filtering to produce a given quality of DC in applications where the
generated voltage is used to directly drive loads instead of charge
batteries.

As far as a physical description of the servo motors, so that you can
recognize them in a catalog - They are generally cylindrical in shape,
about four inches in diameter by seven inches long, completely enclosed,
and have two brushes which are externally replaceable by removing plugs

in the side of the case. Most I have seen also have four threaded holes
in the front face for mounting purposes. Shaft diameters are generally
quite large for such a low-power motor. Most I have seen are either 5/8"
or 3/4" in diameter. They are fairly heavy for their power rating, being
designed for smoothness, linearity, and precision rather than high power.

All the forementioned features, particularly the large number of poles,
large-diameter shafts, rigid case, and low-rpm design, make these servo
motors well-suited to direct drive by a wind turbine. And their common
industrial application makes them easy and cheap to find on the surplus
market.

>
> >
> > 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.
>
> Do they have an email address or do you have a phone number in case I
> choose to buy one from them? I may just ask someone coming down
> here to get one and bring it down.
>

They do have a phone number, but I'm not aware of an email address. I'm
sorry I don't have the phone # handy, but you can get it from directory
assistance. I think they are located on West "O" street in Lincoln, NE.
As an alternative, you can inquire on the rec.crafts.metalworking
newsgroup. Many of the guys I know on there use Surplus Center as a
source for motors that they use to drive or automate their machine tools.
When you get the number, call and have them put you on their mailing
list for free catalogs.   Posting the number to this list might be a
good idea also. I've seen it posted here several times in the past,
but we're probably ready for a refresher.

> > So anyway, my first set of wooden blades were constructed using Cessna
> >airfoil
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> > settings.
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> > designed
> > for a substantially different machine, they work great driving my
> > generator.
> > I suspect I could have gotten by with only two of them, and saved myself
> > $25.
> >
>
> This sounds like my kind of solution for the blades as I don't have
> lots of time to invent. Is it very hard to make the plywood hub like
> you did? How sure are you that only two blades would do the trick?

Yes, I went to more trouble making the plywood hub than the ones I can make now, because I didn't have a lathe at the time! Since you asked I'll describe what I did, but if I didn't own a lathe and had to do it again, I'd just buy a 4" or 5" pulley that fit the shaft perfectly and make a flange from that. I had that idea about a week after I finished doing it the hard way :)

The hard way: What I did was buy a stub of steel water pipe, already threaded, and screwed it into a "floor flange". This gave me a short hollow stub with a flat front on it. This would appear to be a hub in itself, but the problem is that the fit of the stub and flange are not precise enough to run true. In other words, the flange will not be absolutely perpendicular to the pipe stub, which means if blades were attached to the flange they would wobble severely. Since I didn't have a lathe to true up the flange surface and make it perpendicular to the stub, I added a plywood hub to the flange so that I could "machine" the surface with tools I already had.

So I made myself a "custom" piece of very tough plywood by epoxying several layers of thin plywood together. Then I cut out a circular hub using a jigsaw, and screwed/epoxied it to the flange on the end of the pipe stub. Now here's where I had to get a little tricky - lacking a lathe, I just went ahead and mounted the metal/plywood hub on my generator, strapped the generator down to my workbench, and hooked a power supply to the generator. Running it as a motor, I now had a "lathe" spinning the plywood hub. I then used a rotary file in my electric hand drill to machine the front surface of the plywood as it spun. The result was a nice true mounting surface for the blades.

BTW, the inside diameter of the water pipe was larger than the motor shaft, so I needed a precise-fitting bushing to go inside the pipe and accept the shaft. With a lathe, one could just make a bushing with the proper inside and outside diameters. Since I had no lathe, what I had to do was search and search until I found something that had the correct wall thickness, but was actually too large. I took a section of this thinwall aluminum tubing and slotted it so that, when forced into the water pipe, the result was now a good fit on the motor shaft. The final result still wobbled a small amount, but as long as I reinstalled it in the exact same mounting configuration as when trueing it, it worked OK.

Pretty involved, wasn't it? Too bad I didn't think of the pulley idea first, as it could have eliminated most of the hassle of trueing the surface and getting a good fit on the shaft. If you try the pulley, let me know how it works out.

That particular motor had a flat on the shaft that did not go to the end, so I was able to hold the hub on with a screw and not worry too much about it coming off the end if it loosened a little. Otherwise, I would have drilled through the motor shaft and used a pin. Of course, my application doesn't involve leaving the generator in the wind more than a few days at a time.

To answer your other question, note that I said I "suspect" I could have gotten by with two blades. I confess I have not actually tried this. But the generator starts very easily with three when configured in a battery-charging application, so I suspect two would also do the trick. Because a blocking diode is required in a battery-charging system with the PM motor, there is essentially no electrical load at standstill or low RPM, which means the shaft spins freely until it's going fast enough to begin charging. If the application was something like directly powering a resistive heater, it would not start as easily and the extra blade would be more likely to make a difference.

I may copy this to the list, since I didn't include the information in my original wind generator plans.

best regards,

Marty