Alton Moore's Wind Power Page

Here is a page I have written to do wind-related calculations.

The graphics on this page will take a little bit to load; please forgive me.

Wind Turbine Overview

I'm finally getting around to tackling one of my larger projects, which is to make wind turbines. To that end, I've been reading on the internet for a while and collecting information on things I don't know about. I've run into several areas that I haven't seen well explained on the internet, so I thought I'd explain what I know about some of those areas here.

The nature of wind energy is important to take into account when you're planning to capture and utilize it. Too small a unit won't capture enough to do a lot of good, and too large a unit is too expensive to make sense: you would be better off investing the money and paying your electric bill with the interest. :-)

Because wind power is not particularly reliable over the short term, the storage/use of the power has a lot to do with how much good you'll get out of it. Your situation will determine what best to do with your wind power.

First let's see about actually capturing some energy.

Mechanical Matters

There are a few useful facts to keep in mind when capturing wind energy.

The amount of energy in the wind is proportional to the cube of the speed. You can check wind maps for the U.S. or your area of the world to see how much energy you're likely to get out of the wind in your area. Try here, here, and here. High winds are great; low winds mean that you'll need a larger prop, since the larger the prop, the lower the windspeed it will work well with.

The amount of energy your prop gets is proportional to the area which is covers when it rotates. This is proportional to the square of its length.

You may ask why you shouldn't make as large a prop as you possibly could. The limits on the size of the prop are (1) how it is constructed (since larger ones will want to fly apart), (2) how large a generator/alternator you can afford to hang off of it, (3) how you're going to regulate the speed of it in excessive winds, and (4) how high you can mount it. Let's take each point in turn, since you probably want to build as large a unit as you can without running into these limitations.

Point 1: How are you going to make the blades?

You can buy sets of prop blades for less then $100 if you prefer, and most of these come in sets of 3. Of course, if you're going to buy parts, you might as well buy entire wind units, complete, for about $500. :-) But seriously, these are blades which you know will develop rated power, and are usually well made; it couldn't hurt to have a set around to go by at least when making your own.

Smaller to medium sized props can be made with wood if you have the appropriate tools. Larger ones tend to be made of fiberglass, and the largest are carbon composites.

Here's a picture of how I mounted my prop onto a 1" shaft. I welded 1" collars on rectangular plates and put one on each side of the prop and they seem to do a good job.

There are many good pages on the internet discussing how to make blades, so I won't attempt to duplicate all of that information here. Let me just give some useful general figures and facts, and suggest that you visit my calculations page, found at the end of this page, when you're ready.

The faster the prop spins, the more energy it can collect from the wind. As a practical matter, though, you probably want to shoot for a TSR (tip-to-speed ratio) of 5 or 6. This is achieved by the outer half of the prop having about 5 degrees of "attack" from the plane of the prop. This means that the flat side of the prop has this angle; of course this angle becomes greater (usually up to the maximum attainable for your particular thickness of wood) near the hub of the prop, within reason. The hub is greatly stressed and it's preferable to leave a little extra material here than to try to use the little bit of wind that this area of the prop covers.

If you want 5 degrees of angle in your blade then you will have a slope of 1:11. If you merely take a 1"x4" plank of wood and make the flat side of the blade run from one corner to the opposite (diagonal) corner then you'll end up with a 12 degree angle, which is a fairly slow-turning and inefficient prop. In any event, the slope is determined by the tangent of the angle you'd like to achieve. tan(5) = .087, let's say .09, and 11 of those will fit in 1, so this gives a 1:11 ratio. Using our 1"x4" plank example (and the true dimensions of a 1"x4"), .75 / 3.5 = .214, which is about the tangent of 12 degrees.

Here are a few rules of thumb for the shape of the airfoil.

The thickest part of the airfoil should occur 1/4 of the way back from the leading edge of the blade. The thickness of the blade at this point should be 17% of its width at high angles of attack (like near the root) and 12% at low angles of attack (like near the tips). The width (chord) of the blade should taper from the root to about 1/2 that amount at the tips. However, if you are making a prop which really doesn't have enough blades to capture the wind fully (the blades should cover about 10% of the swept area) then I wouldn't give the prop this taper.

The bottom of the airfoil (the side that faces the wind) should be more or less flat, with a twist. At the root the angle should be as great as possible (up to 30 degrees) given the thickness of the blade, with the outer half of the prop generally having an angle of 5 degrees (vary according to position of course). The leading edge should be rounded so that the point farthest forward is 25-35% "high" from the flat bottom of the blade toward the thickest point.

If you have more time than money you can maybe cut your own prop with hand tools. I happen to have a few tools around, some courtesy of my father, and I found it possible to use a table saw to take off most of the material from the blades, then use a planer (power table-type) to do most of the shaping. A hand-held belt sander finished things off and the prop worked pretty well for a first effort. Due to a knothole near the hub, I hung it up on the wall instead of trying to use it for the long term.

Taking one table off of the planer made for fairly easy going, and I was able to do without the table-saw setup, which was a bit difficult to control. I made 2 props, an 8-footer and a 6-footer, each taking about 2 hours. The first step was to taper the chord, and although I used the planer, a saw could have done most of the work. In any event, next came the forward (flat) surfaces, with their associated concave cuts near the hub. Lastly was the rounding off of the "tops" of the blades.

I removed one of the tables from the planer so I could make the concave cuts near the hub of the blade.

This hand-held power planer is great; it leaves wood quite smooth and is easy to use.

In my meager experiences building props, I have found that, in general, my errors have been along the lines of giving the blades too much angle and leaving them too thick. A small 2 foot diameter prop I made for a small permanent magnet motor turned quite pitifully, for example, until I removed most of the thickness I'd left on it, after which it turned about 4 times as quickly. It's certainly tempting to leave lots of angle, to get balky devices turning in low winds, or to leave too much thickness, to achieve strength, but you can see how these defeat the purpose of the prop in the end.

Point 2: How large a generator/alternator can you afford/make?

The size of the generator/alternator needs to be more or less matched to the size of the prop. Usually we measure the size in Watts, which is voltage times amperage. If an alternator is too small then we waste power and can't use the load on the alternator to regulate the speed of the prop. If an alternator is too large then the prop will have a difficult time getting it started and/or running it at the rated RPM because of friction losses. Most alternators (or motors run as alternators) work best at their labeled RPM.

Look at page 7 of this file, or this page, for a nice table giving a guide to alternator size as a function of prop size, at "reasonable" wind speeds. There is another important table, on the same page, which gives the rough angles the blade should have to give an appropriate speed of rotation versus wind speed (called TSR, the tip-to-speed ratio). As a rough guide (tables exist for this, too) a 6-foot prop should turn at about 500 RPM and a 9-foot prop should turn about 300 RPM. This will give you some idea what you're up against when coupling various alternators to your blade.

Point 3: How to regulate speed in excessive winds?

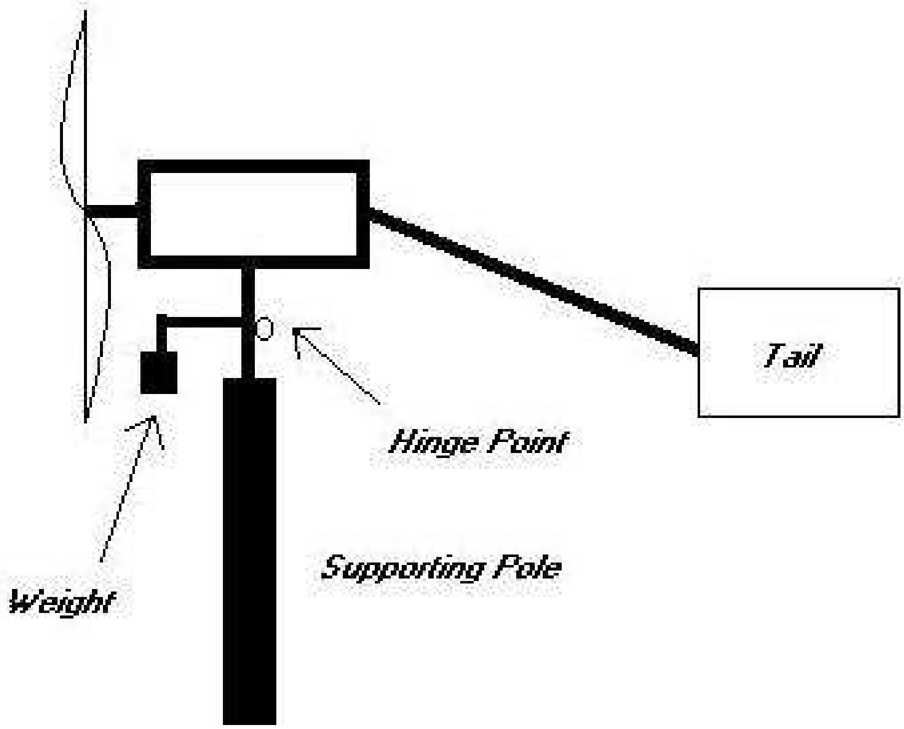
This may seem like a trivial point -- but the fact remains that your unit will almost certainly fly apart, literally, when exposed to unusually high winds. The amount of energy contained in 40-50 mph winds is great; it's too bad the winds aren't always that strong! :-)

A common way to slow the blades down that you'll often see mentioned is to load them down with the alternator. If your alternator is too small for your blades, all this will do is burn your alternator out. But with reasonable matching, this can be a good way to prevent overspeeding. Often a simple wind-speed switch of some sort will turn on a relay or the like which will connect a normal electric space heater (or equivalent) to the alternator, which is enough of a load to slow down the average runaway wind turbine.

Changing blade pitch is great if you're working at that scale; many very large wind turbines have adjustable pitches to take the best advantage of varying wind speeds. But most small wind turbine builders will not opt for such a complication in the design, because the payback at small scales is not great enough.

A popular method of speed regulation is to turn the blades out of the wind. This can be done manually, or, preferably, automatically. Manual tasks can occasionally not get done at crucial times, though, so I'd recommend at least some forethought about how to make this automatic. :-)

Automatic turning has been done cleverly in several ways. One way which strikes me as being simple is that the entire unit is hinged somewhere and held in place by its own weight or by springs. When the wind presses too much upon the front of the assembly, it "gives" at the hinge point. This might require a bit of experimentation with hinges and springs when you're testing your unit out, but I like this idea and think that it's fairly simple and reliable. It's better to avoid putting the extra power into the whole system to begin with than to accept the power in and try to dissipate it later. The down side of this is that the gyroscopic forces upon the blades and the rest of the unit can be quite significant, since the wind is trying to change the plane of the prop at just the time that the prop is spinning its fastest. Maybe an old car shock absorber would help here?



The "furling tail" arrangement consists of mounting the prop a bit to the side of the vertical axis of the mounting pole, say a few inches. This produces a bit of a turning force on the whole unit, but of course the tail is mounted in the normal manner, aimed just a bit to the other side if necessary, producing the same amount of force the other way.

The key is to make the tail boom "break away" when enough of a turning force is present on the unit because of high winds. The prop then turns to the side of the vertical mounting pole which it pivots on and no longer faces the wind straight on. The tail also turns and the effect is to fold the prop and the tail together.

Some sort of hinge and spring arrangement would probably suffice. You can also mount the hinges at an angle off of vertical, say 30 degrees, so that whenever the tail moves to the side it also moves up at that angle. That makes the weight of the tail itself provide the "springing" action. Of course the angle has to be adjusted depending on the weight of the tail, offset of the prop axis, etc., but this is doable and reliable.

Point 4: How high can you mount your wind turbine?

I have heard of fairly good-sized units (10-15KW) mounted on 2 sections of 2" diameter tubing, guyed in 2 places of course. The problem I have with these mountings is that they are too dangerous to climb for normal maintenance tasks. On the other hand, they're fairly non-permanent and inexpensive. You're supposed to tilt them down when it's time to do repairs and maintenance. I think I'd prefer a good-sized phone pole (about a dollar per foot used and somewhat more new) as this is something you can screw steps into and climb safely with a climbing belt. Believe me, if you can't get to your unit fairly easily then you're going to have trouble keeping it going sooner or later and just give up on it.

I myself prefer real towers, to allow for plenty of fooling around and regular maintenance. You can put a fairly large wind generator on even the smallest tower. A 60-foot tower is easy enough to put up with a bit of work and a few bags of concrete. Of course, at $100 per 10-foot section, even small towers are expensive when new; I get mine used by asking around and taking them down myself. "Real" towers are safe, useful, and a joy to own. See my towers page for more information on towers.

I installed anchor bolts from the local home supply store into a regular phone pole and plan to put a turbine up there. This one is about 25 feet high. Next to it is the "test stand". I've hung a car alternator off of the 8-foot blade with a 12" pulley I made myself out of a couple of pieces of plywood. The winds are 25mph today and so the unit is really whirring away! However, to tell you the truth, this prop doesn't usually get this alternator turning very well, and should probably have 3 or 4 blades. However, there is the advantage of being made out of single piece of wood (the 2" x 6" plank) and the prop is therefore quite strong. I have let it turn freely in 30-35mph winds and it hasn't come apart yet! Of course, all the energy is dissipated into noise.

I have made a wind turbine out of a ceiling fan and have just made a mounting for it. Hopefully I can see how it works soon. It's the typical ceiling fan motor, which is an inside-out induction motor. As with most induction motors, it should require a larger capacitor than is already present to behave well as a generator. I am hopeful that this approach will work well, since these motors have many poles and usually operate from 500-1000 RPM, and should therefore generate electricity at around these speeds with a prop directly attached.

The results? So far I have never managed to turn the electric meter backwards. Either it's something about being on the "slow" setting or not having a large enough capacitor; I haven't figured that out yet. I'll keep you posted.

You may have seen many references to wind turbines designed around a "brake drum". I think that Hugh Piggott is famous for this type of setup. You may not have seen a couple of the reasons why these car parts make good turbine parts.

From a mechanical standpoint, the type of front wheel spindle which appears to be ended by a flat plate (which is bolted to car suspension parts) is quite convenient. You can bolt the spindle to anything you please, and of course it's going to be solid; it was a critical part of a car! Moreover, this sort of spindle will take end loads (because of the tapered roller bearings inside), and so it works like a thrust bearing. This is in contrast to most (non-tapered) bearings which you encounter, which may quickly wear when exposed to end loads, depending on the bearings. Remember, we want a design that will work for hopefully years without too much intervention.

The other nice thing about this sort of spindle, complete with brake drum, is that the drum itself makes a nice place, magnetically and mechanically, to mount high-powered magnets and make your own alternator. The magnets are epoxied to the (cleaned) inside edge of the drum, some coils are wound and affixed where the magnets will excite them, and you have a setup with very few moving parts. Centrifugal force doesn't try to throw the magnets off of their mounting surface either, but rather presses them against it, so they can be simply stuck on with epoxy with no worries.

It's probably worth a trip to the junkyard to see about some front end parts like these if you plan to make your own alternator. My only advice would be to get parts from a car which you can still buy bearings for without too much trouble. After you've spent so much time building around a particular spindle, you don't want to find out that you can't find bearings for it later.

I have taken the off-the-shelf approach, with a 1" shaft and a couple of pillow-block bearings, with the idea being that the parts I use can be bought anywhere. Therefore, it's easier to convey what they are over the internet, and it's also easier when it comes to looking for a replacement bearing or whatever.

Generating Electricity

Electricity is so useful! It would be nice if we could just make as much as possible, store it, and use it for everything. Too bad that's not practical. But if we're going to make any electricity at all with our wind power, we might as well do it as well as we can.

Ratings

If you have a generator, then that's good; you already know what the output rating is. However, if you're driving a motor and expecting it to work as a generator or alternator, there are a couple of small things to know about the ratings.

If you're turning an induction motor, then it will need to be turned just above its rated speed to work properly. You may also need to adjust the capacitance (most of them have external capacitors) so that they generate appropriately. I hear that the speed range of these motors can be narrow, so don't expect to turn one of these at, say, half its rated speed and get great results. Besides losing a good deal of the generation capacity, they may not generate at all, and probably won't.

Permanent magnet DC motors will indeed generate at almost any RPM. The question is how much power you will get out, of course. If you are trying to charge a 12V battery and you're turning the motor only fast enough to generate 10V, then of course you won't get anything useful. So the question becomes how the motor ratings affect what you can get out.

If you have, say, a 90V DC motor (some treadmills have these) rated at 3600 RPM and 6 amps, then the rules of thumb will be that the voltage will be proportional to the RPMs you turn it at, and that you can never exceed the amperage rating. This last point is the most important, and usually determines how much sense it will make to use a particular motor.

90V at 6 amps is 450 watts, and if you turned the motor at 3600 RPM and could use 90V then you'd have a suitable generator. However, if you can only use 14V and/or can only turn the motor fast enough to get 14V out, then your output will be limited to 14V x 6A, or 84 watts. You may be losing half that much to friction, though, and that's why people don't use overly large or mismatched motors a lot. It would probably be a better idea to go ahead and generate the higher voltage (90V) and then step it down with a switching power supply circuit, which has an efficieny of around 90%. This way you can get out the 14V at around 29 amps.

The key point here is that the amperage rating should not be exceeded on any sort of motor. Wires with too many amps passing through them get hot, and that's all there is to it. This is one of the reasons that success in wind generation is determined by matching, matching, matching! Wind speeds combined with desired outputs result in propellor sizes and coverages. Propellor RPMs and power plus desired output result in the kind of generator -- and possibly gearing and control -- that's appropriate.

Low Voltages

If you want to charge 12V batteries and run things off of them (see my battery page) you might go with a homemade or other permanent magnet alternator (with an efficiency of around 70%) or a car alternator (although I hear these need to be turned at about 1800 RPM) with an efficiency of about 50% (plus the loss from the belts or whatever needed to turn it at 1800 RPM, plus the loss needed to run the field coils, about 40 watts). I have pretty decent average winds here and my 8-foot 2-bladed prop has trouble getting an alternator started (with a 5:1 pulley) so beware of the alternator approach. I have also heard that Delco single-wire (called "self-exciting") alternators cut in at much lower RPMs and could be useful for wind generators.

Another item I have heard of is surplus computer tape drive motors, available for about $35 over the internet. These have brushes, so there is a little bit more than just bearings to wear out, but they'll make good power for a long time for a reasonable price. I have looked around the internet a bit, though, and these don't seem to be _readily_ available.

Some small engine starters have permanent magnets and would probably make suitable direct-drive generators. These have the advantage of being common and repairable. I'm not sure what RPM most of them would work well at, though, so they would require a little bit of experimentation. Look for ones with bearings instead of bushings... which might be a bit rare. The starters with bushings won't do well under continuous duty.

If you're going to generate 12V at the wind generator, you're certainly going to lose some power if you run that 12V a very long way without some very large wires. If you have free large wire, then more power to you, but keep in mind how much loss running your 12V a mere 100 feet can engender and plan accordingly.

High Voltages

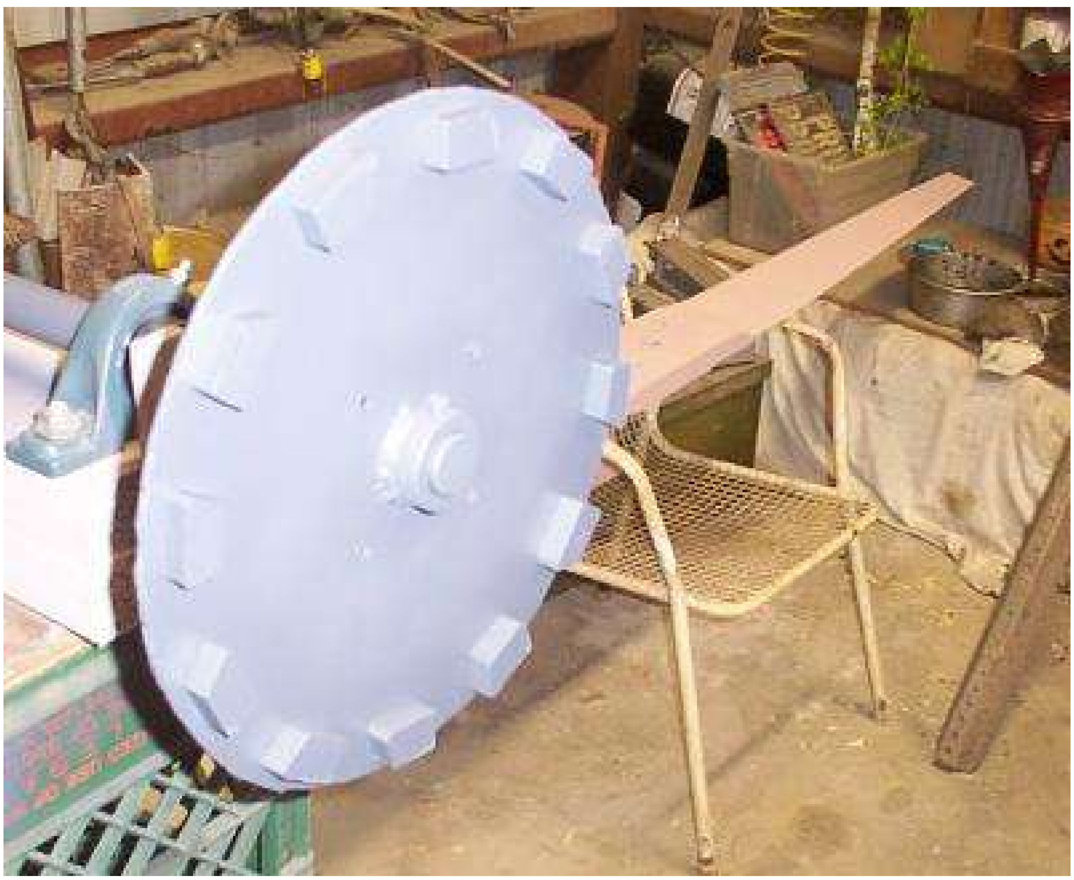
If you want to create higher voltages, you may have good luck turning an AC induction motor at just over its rated speed. These popular motors are distinguishable by the fact that they have no connections to the armature -- no brushes, slip runs, nothing. The question is what to do with power from these sources. It's the 110VAC that we can use for many things, but it's not reliable enough to use directly for most devices. Also, the RPM range for generation is narrow, so these units will generally come up to power with increasing wind speed, make a given amount of power (which depends on the prop size, gearing, etc.), and make no more power as the wind blows harder.

At least the amperage is fairly low, and we can run it along long (and inexpensive) small wires without very much loss at all. At the other end, if we can use it directly in this form, that's good; otherwise we will probably incur another 10% loss by using a transformer to change it to a lower voltage, say for battery charging again.

Keep in mind that if you're going to use one of these setups, there must be almost no load on the motor until it self-excites and starts making juice. A small relay would probably be suitable to detect this; the coil will not present much of a load to the motor and it should excite ok, thus making electricity and closing the contacts to the load. Of course, if you are doing net metering (feeding power back to the utility system) then the utility power will provide the excitation and you need another system of determining when to make the connection.

Configuration Of Magnets/Coils

To begin with, keep in mind that the voltage a coil puts out is proportional to the rate of change of the magnetic field you are influencing it with. Therefore, for a given number of magnets, the farther you put them from the shaft, the more voltage is produced. Of course, since this voltage is produced more intermittently, the lower the amperage will be overall, but this is the usual tradeoff and not a problem; the same power is available even if it is harder to filter.



My favorite configuration is a set of steel disks with matching magnets facing each other, and the coil(s) in the middle. Here you are guaranteeing that the magnetic field completes, largely through the coil in question, and that it is quite strong. The drawback, of course, is that this requires twice as many of these expensive magnets.

There is no rule requiring a certain number of magnets or a certain number of coils. If you have even one magnet passing by one coil, you're going to make power of some sort. Assuming that we're going to have a number of poles, what number to choose?

As with all things power-related, it's helpful if you create the electricity at roughly the voltage you need it. Of course, you can always put all of your coils in series to create the highest voltage, and if you have a distance to go from the turbine to the load, that might be the best thing to do (assuming single phase). If you're finding that your unit is producing ridiculously high voltages on a regular basis, ones you can't efficiently use, you may wish to parallel some of your coils.

Let's take an example with 12 magnets and 12 coils, all evenly spaced. All of the magnets are passing by all of the coils at the same time, so if they're all in series, you get the greatest voltage. Now take 2 sets of 6 coils each, in parallel, and you have half the voltage and twice the amperage. 3 sets of 4 and 4 sets of 3 work similarly of course. Of course I like the number 12 because it's easy to factor in this manner. :-) But I also think it's a reasonable number to work with insofar as size and cost go, for the home-made wind turbine.

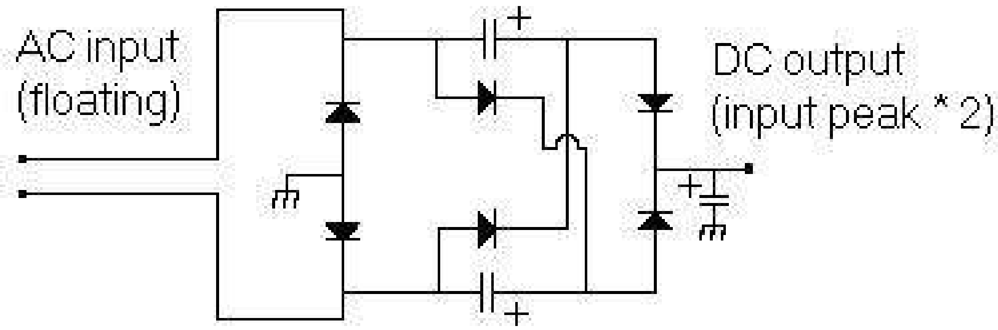
Using a single 4-pole, double-throw relay, it would be easy to change, say, from 12 coils in series to 2 sets of 6 coils in parallel, depending on wind speed. I might prefer less mechanical and more electronic implementations, but the low-tech approach has the benefit of simplicity and ease of maintenance. Of course, this could be taken to extremes, and I don't suggest a whole bank of relays clicking about trying to do voltage regulation, as reliability might suffer.

There is no rule saying that you must have the same amount of magnets as you do coils. Almost any configuration will do, as long as any given set of coils are simultaneously actuated. It's not going to do much good to run a magnet by a coil if the next coil in the chain is not similarly actuated; you can see the sense in that. Similarly, don't have one string of 6 magnets actuated and another string of 6 connected in parallel with it unactuated. To keep power from "bouncing around" we need to use it or accumulate it in some manner right after making it.

Making 3-phase power is popular because 3 single phases add up well together and are therefore easier to rectify into purer DC. 6 magnets spinning past 18 coils would make 3-phase power, for example, where every third coil is connected in series to form one of the phases. I am not a great fan of 3-phase power generation in wind turbines because it is more difficult to run through transformers and the like. I like to play around with electronics, however, and if you merely want to generate power and immediately rectify it to DC then 3-phase is just fine.

The number of phases you generate also has something to do with the amount of vibration your unit is going to produce and subject itself to. If you are generating single-phase power, then all of the coils are generating electricity, and being subjected to pull, at the same time. This creates more vibration in the unit as a whole than if the power generation, and vibration, were divided up into thirds for example.

One possibility that you might investigate when implementing your own alternator is a voltage doubling circuit. This is a simple configuration which will change, say, 12V AC into 24V DC. Using this setup, you can always bump up your low-voltage AC to useful levels, and it's a lot simpler and probably just as efficient as, say, rewinding your wind generator. Of course, the current loading will be doubled, but if your alternator has sufficiently heavy wire this is not a problem. In any case, this is probably the sort of circuit you would switch in at low wind speeds to get some semblance of charging and you won't be putting much power through it.



Component values will depend on what you have kicking around or what you can afford. Usually it's safe to choose, for diodes, ones which will handle the desired current and at double the highest voltage expected. For the capacitors, ones rated at the highest voltage expected will do in this case, and the uf rating needs to be larger as the current drawn gets larger. What I'm saying is that these values aren't critical.

AC voltages can also be tripled, quadrupled, etc. with a similar sort of circuit. Search the internet for "voltage doubler" and "voltage tripler" to see this sort of circuit.

I need to put in a word for magnetsource.com, where I got my neodymium magnets. They had a pretty good deal on some poorly plated magnets and I figure I can paint them myself when things are all put together.

Magnetic Tidbits

You may have read about eddy currents that occur inside of transformers and alternators. These can have serious effects upon the efficiencies of these devices. Why do they happen and what do you do to avoid them?

Eddy currents can occur in any "largish" piece of metal which is subjected to rapidly changing magnetic fields. Certainly the core of an alternator winding qualifies for this; the whole idea is to rapidly change the polarity of the magnetism at one end (or both) of the coil, and of course the core is the main conduit for this magnetism.

If you don't have magnets on both sides of an alternator coil, then it behooves you to at least place appropriate metal close to the unexcited end to act as a conduit to complete the magnetic field. It's important to realize that, because the magnetic field is also always changing in this piece (say, a ring) of metal, it too must be constructed in such as manner as to minimize eddy currents.

Most transformers are constructed with thin metal plates (laminations) which are enameled to insulate them electrically from each other. Since they are well intertwined, they still conduct magnetism just fine.

Unless you happen to want to cut and enamel your own laminations, you might go with a popular and widely available solution: pieces of enameled clothes hangar wire. This wire is already insulated with enamel, or at least paint most of the time, and is of the appropriate hardness already. I use coat hangar wire for everything else; why not for alternator coil cores? :-)

You may have read about "cogging", which is meant to describe the condition where the magnets attract the metal cores of the coils so strongly that it's hard to get the prop turning! Although metal cores improve the efficiency of coils (by acting as a conduit for the magnetic flux and coaxing more of it through the middle of the coil), this may not help if your turbine requires a blowing gale to start! If your prop has a smallish diameter or you know that your particular area is not blessed with high wind speeds, I'd leave the metal cores out so that the turbine can spin in low winds and at least have the possibility of making useful power.

Net Metering In Texas

Here's some information for those of you fortunate to live here in Texas with your author. :-) Texas law provides for "net metering", which means that you can pay off your electricity bill by sending energy back through your meter. If you turn your meter backwards, then your bill is lowered by the amount you would have paid the electricity, of course. Now, if you generate more electricity than you used within a "billing period", then you don't get paid at the same rate, but rather get paid what is roughly equivalent to the fuel cost. For me that's about 1/3 of the retail cost of electricity. Obviously you're not going to get rich selling excess electricity to the company, but the idea of paying down/off your bill is attractive!

I have spoken with the "distributed generation designated contact person" for my electric company, a very knowledgable fellow. The parameters for interconnection are that you must detect certain degrees of over and under voltage and over and under frequency at the interconnection point, along with some reasonable safeguards (breakers, disconnect switch accessible, etc.). They would also like to get the impression that your safety equipment will function correctly and continue to function after they test it and leave. If you have "certified" interconnection equipment then there is almost no testing at all, since the law says they basically have to approve it forthwith.

The local "retail provider" of electricity is clueless about net metering, but I've got an inquiry in and hopefully they're learning a bit more about it. If I actually have a working system ready to go, the law states that they must get me approved and connected within a certain time period, 30-90 days, I forget exactly. I am not submitting an application to start that process, however, without a bit more progress on this end.

I had an old electric meter kicking around, the mechanical kind that will spin backwards, and hooked it up to an extension cord for testing purposes. Turning a 1200 RPM induction motor geared up 2:1 by pulleys (yuck) with my 6' prop and decent winds, the meter did spin backwards -- not quite like a top, but power was certainly going in that direction. I guess a clamp-on ammeter might give a better real-time indication of how much power I was making. However, the 6' prop needed pretty good winds to get going because of the friction of the pulleys and the belt. The 8' prop did better but needed the same higher winds to turn quickly enough to make any juice. You can't win for losing! :-) I probably need to try a chain drive or something more sensible on this particular unit.

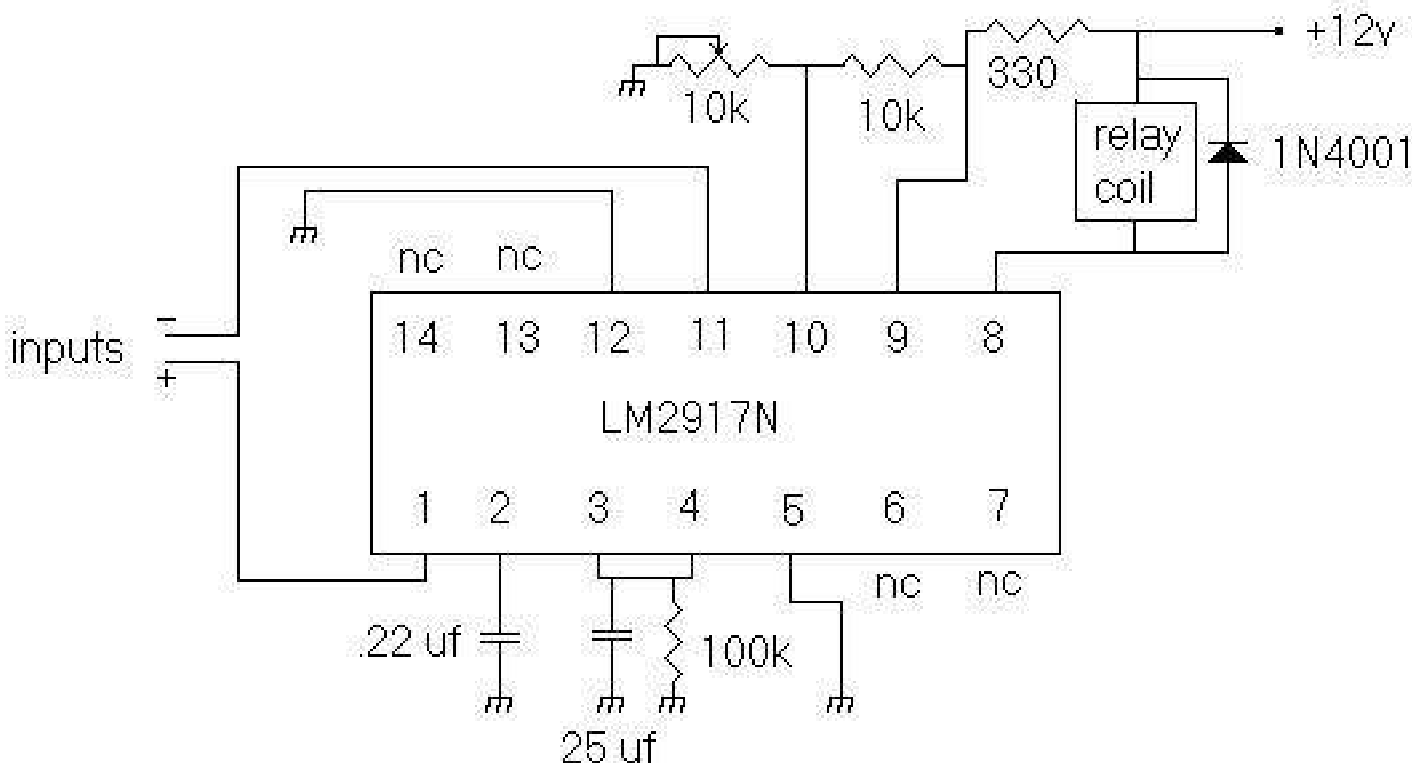
If you have 3-phase power at your place, or can arrange to get it connected, then you'll get a couple of benefits insofar as using induction motors as generators goes. Not only does your power company prefer that you generate 3-phase power, but 3-phase motors are generally more efficient. Also, because there is no capacitor or set of starting coils or the like, there is nothing to change or experiment with. You don't have to worry about bypassing starting switches or fooling with capacitor values.

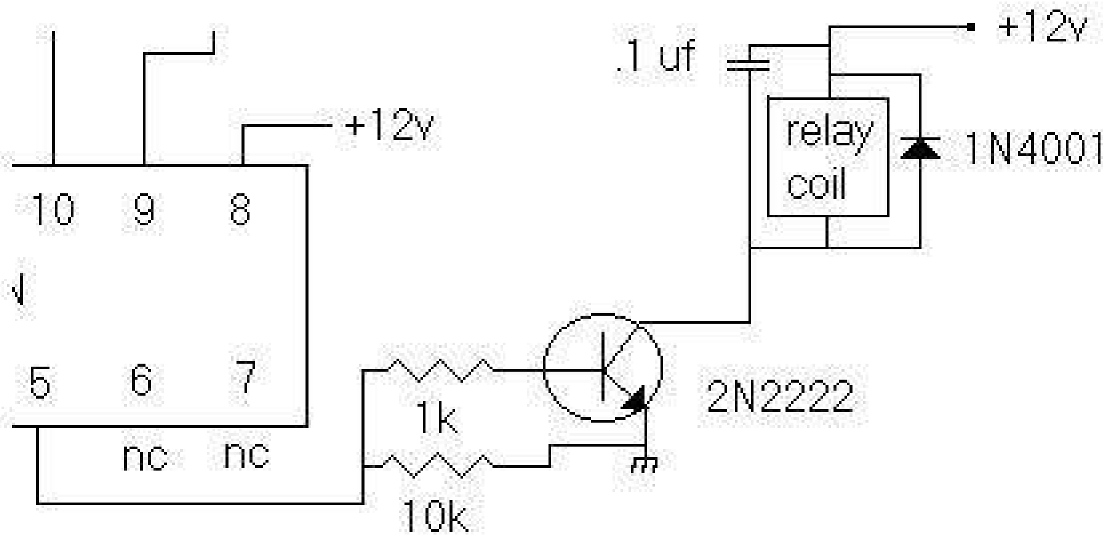
3-phase motors can be easily reversed, usually by just reversing two of the wires, and that can be an important advantage. I wanted to mount my single-phase induction motor differently, and so changed the wiring like the plate on it said so it would run the other way. Well, it ran the other way as a motor... but I could never get it to generate in that direction! I'm not sure why, and was kinda curious... but I know that motor winding is a complicated subject, and possibly something about it escapes me.

Finally, three-phase motors are cheaper for some reason, especially when you get into the larger sizes. I bought a 2hp and a 5hp for $20 each recently, and had a new 1hp outright given to me. If they run when you connect them, then about the most you might have to do it replace the bearings to have good units. Also, I a fairly sure that they can be put to good use even if you don't have 3-phase power connections at your place. They can be run as motors off of single-phase power if you start them spinning manually, or attach the appropriate capacitors (they're somewhat derated, of course) and I'm fairly sure that means they'll generate fine too, although this may require using delta rather than wye connections. I'll check on this, or you can email me if you know more about it than I do. Meanwhile, you can look around on the internet for this sort of information.

You can find most of the Texas net metering laws in this PUC index if you know what you're looking for. Try 25.211 and 25.212 for starters.

Texas law even specifically addresses/allows induction motors as a generation facility. You'd need a circuit to make the connection to the electric lines at the proper RPM, and it would have to be fairly accurate if you didn't want the thing using electricity instead of making it! Cutting in right at rated (1200, in this case) RPM would probably be acceptable, although 10-20 RPM more might be better. Here's a schematic for this sort of circuit, based on the LM2917N chip:





You want to measure the RPM of the induction motor directly, not the prop, and so for this I rigged up a magnetic pickup by taping a 1/4" chip of an old tape drive magnet to the flat part of the motor's shaft with a bit of electrical tape, then wound about 50 turns of smallish wire on the end of a 1/8" welding rod. The rod is bendable and easy to screw/bolt to something near the shaft, and each turn of wire generates about a millivolt at the RPMs we're dealing with here. The LM2917 chip requires about 30mv to properly actuate, and of course the more the better, to fight noise, but this pickup is not complicated and you can always fool with it. The voltage the pickup creates can be checked with any good meter.

You may ask youself why we don't just turn on a transistor or op amp at the proper speed by comparing the voltage the pickup generates with a reference. The problem with this is that it's not very accurate over extremes of temperature and the like, whereas the LM2917 chip, properly configured, is counting frequency itself and gives an accuracy of .3%, which should be good enough for our purposes. Use reasonably good components and you can expect adequate accuracy; probably the variable resistor will be the hardest component to keep stable.

The .22 uf capacitor can be experimented with so that your unit cuts in somewhere in the middle of your variable resistor's range. If you experience any chattering right at cut-in and cut-out, then increase the value of the 25 uf capacitor; the only down side of this is that the unit takes longer to cut in and out, so be reasonable.

The LM2917's output transistor can source or sink 50ma of current. If you have a larger relay you may wish to use the alternative output circuit described. It provides an output that goes positive upon actuation, instead of negative, and of course you could run whatever you wanted with it.

Some sort of feedback is usually desirable to produce some hysteresis in the operation, which will help cut down on chatter. Of course, you don't want too much of this, since your circuit can cut in at a fine RPM for making electricity, but fail to cut out when the RPM drops and begin to run as a motor, thus using electricity instead. Try connecting a 1 megohm variable resistor between pins 8 and 10 of the circuit described (4 and 5 for the second version) and experimenting with the amount of hysteresis appropriate for your setup.

Here is the datasheet for these chips. The 330 ohm resistor was chosen to keep a voltage of 7.56 at pin 9 with my particular power supply; usually 470 ohms is suitable. If you find your pin 9 voltage is significantly lower than 7.56 then drop this resistor's value a bit or bridge it with a 1k resistor and see what happens.

Other Uses For Wind Power

Remember that every time you convert energy from one form to another, there is a bit of loss. Belt drives, chain drives, gears, inverters, and the like all have losses in the range of 10-15%. You can tell that interposing many of these intermediate steps between the prop and the end use of the energy will greatly reduce the useful power you get out. Although it's tempting to just create electricity, store it, and use it to do everything, sometimes it's not practical.

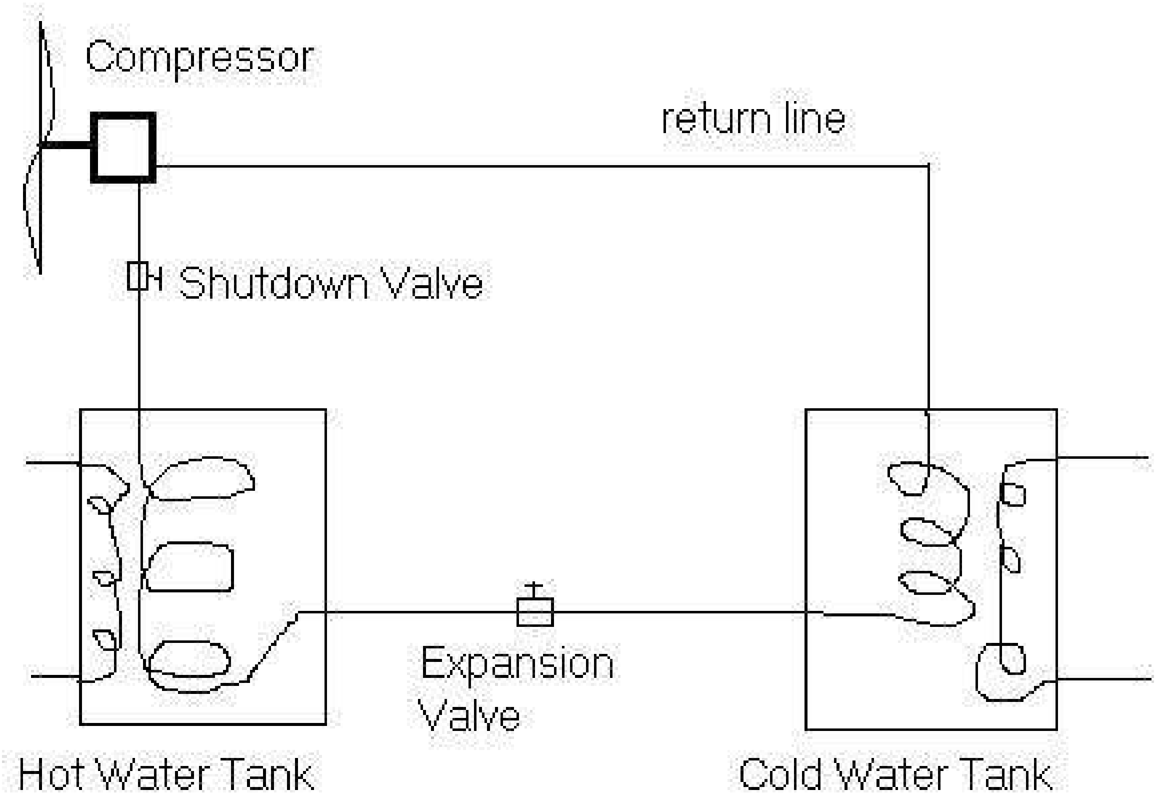
Most of the time that energy storage is mentioned, what's being referred to is the storage of electricity. It's important to think of what other uses you might come up with for the power though. I myself plan to run my electric hot water heater with a windmill. This is an ideal use, since over the course of a day, there is usually enough wind to heat the water up, hopefully by shower time! Since the heater has 2 elements, I can leave one connected to the utility power and turn it on when necessary; the second element is available to us. The point is that here we have a useful storage medium. Since my water heater costs me $35 per month or so to run, I figure it would be a real benefit to run it with wind power when possible, which is most of the time around here.

Old-style windmills use wind power directly to pump water up out of the ground; a rod moves up and down and pulls the water up directly. This is a fairly direct use of the wind power and is pretty efficient. I myself have the idea of using wind power to mechanically agitate a large tank of water; this should result in the heating of the water directly, without any intervening steps. In all of my searches of the internet, I've only seen this mentioned in one other place, probably because it would be difficult to agitate a pressurized tank. I've been thinking of elevating a tank somewhat and agitating that with a prop mounted above it -- maybe!

A company called Bowjon mounts small air compressors on windmills and runs the compressed air down into water wells. When the air bubbles out at the right depth, into the right diameter of pipe, it makes a pretty good water pump, and there are no moving parts to mention except for the air compressor! I like this idea, and as I am working on a cable tool rig for drilling my own water wells, I hope to actually get this setup going. Someone even gave me an original Bowjon compressor and the literature, although it seems like any air compressor would work.

Another idea is to use the wind power to directly run a small air conditioning compressor. Nowadays most small A/C compressors are sealed units, with only the tubes and wires protruding, but the sort we're talking about looks like a small air compressor which is run by a belt. A friend of mine also says that old Delco car A/C compressors will work fine and are very durable.

Since compressors "generate" both heat and cold at the same time, a small compressor could, for example, heat a large tank of water and cool another large tank, so this heat and cold would be available when needed.



Please excuse the poor drawing of the coils in the tanks. :-) In any case, insulated tanks of some sort filled with water would probably do the trick. Filling them with bricks would store more heat/cold. The key accomplishment here is the generation of "cold" from wind power in the most direct manner possible, so that we avoid multiple conversion losses.

This is about the best way of getting cold out of a wind turbine that I can think of. Generating electricity, with which to run an air conditioner, is not likely to be practical. Can you imagine the size of the generator, batteries, and inverters it would take to run an air conditioner? :-)

Good Links

OtherPower has a pretty good all-around page right here.
I am working on a page that does wind-related calculations here.
I found a Windows program that does calculations here.

Alton's Propeller Carving And Power Calculator

Prop diameter in meters: 2.5

Prop tip/speed ratio: 7

Prop number of blades: 2

Prop efficiency: .3 Most props are between .25 and .35

Number of stations to calculate: 10

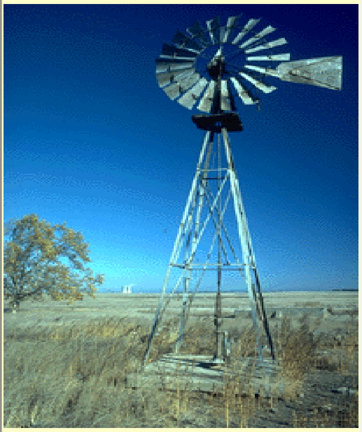
Coefficient of lift: .8 This is typically .8

Angle of attack: 4 This is typically 4 (degrees)

Do calculations

My wind turbines page

My home page



Wind Power

A Clean, Renewable, Form of Energy

Wind Energy

Wind power, or wind energy, is a renewable resource; it is from the sun. The intensity of solar radiation differs across the globe. Some areas receive intense amounts of sunlight, while others receive much less. The result is a temperature gradient; a gradient which is mediated by the flow of air to and from areas of dissimilar temperatures and pressure systems in our atmosphere. Uneven heating of the earth's atmosphere, in addition to irregularities on the earth's surface and the rotation of the earth create wind. Terrain, water bodies, and vegetation then shape flow patterns.

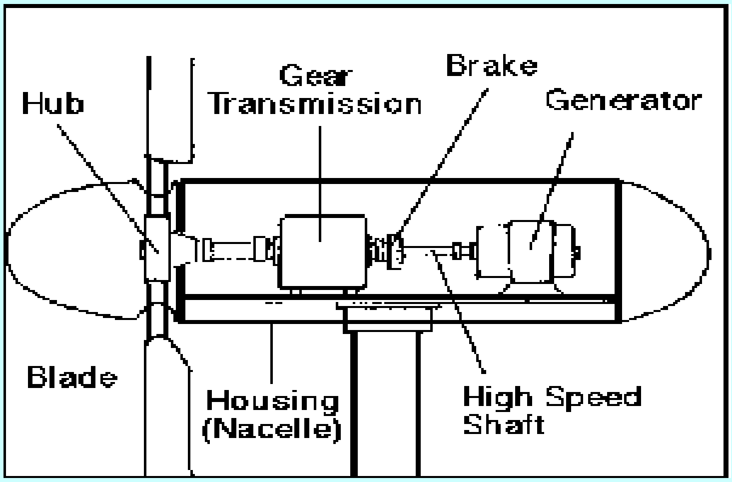
History of Wind Power

The recent history of wind power in the United States has a similar impetus to that of alternative fuel sources in general-- it was an idea borne from the 1970's Oil Crisis. It does, however, have a more extensive history reaching back into to late 19th century in the colonization of the American West; millions of windmills were erected for irrigation and cattle purposes to facilitate the growing number of farms and ranches. 1900 but soon feel into disrepair as inexpensive energy sources became more widespread and grid power extended its reach into rural areas used small electric wind systems.

Outside of the US, however, wind power has a broader history. In fact, there was evidence that boats were propelled along the Nile as early as 5000BC via wind energy. China used wind for pumping water several millennium ago.

Wind Power-harnessing wind energy for power purposes

Wind is harnessed to make mechanical power or electricity. The kinetic energy from the wind is converted through various different processes to create mechanical energy that can be used in lieu of fossil fuels. Although there exists some variety in the size and shape of the turbines, they perform the same function as illustrated in the following diagram:



- Wind turbines-similar to propeller blades-are erected in areas of high wind flow.

- Movement of the turbine powers an electric generator. The power is fed through a transmission before being released into the generator. The transmission keeps the generator operating efficiently during different ranges of wind speed. This allows energy generation at all times, even when winds are slight. The result of this process is an electrical current.

- This energy is either stored for later use, used directly.

There are two types of modern turbines-horizontal and vertical axis, both of which work similar to one another and as decried above. Between the two types, they come in an array of sizes from small 100 watt units for single homes to much larger or ones (with a blade diameter greater than 50m). These larger turbines can generate 1 MW of electricity.

The most common used today are  horizontal axis turbines with three blades (15-30m in diameter) and produce approximately 50-350 kW of electricity. Often times wind turbines are grouped together; the arrangement in called a wind farm that provides energy to an electrical grid.

Vertical axis turbines are more efficient in areas with vast amount of lands and moderate wind speeds. Current technology is looking to develop different turbine types for different areas of wind speed given the amount of land available for farms.

General Advantages of Wind Power

The advantages of Wind power are many, including practical, environmental as well as economic.

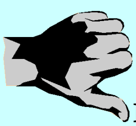
Worldwide, the total kinetic energy contained in wind is more than 80 times that of human energy consumption. While only a fraction of this can be used for electricity purposes, the potential-given future technological developments-is great.

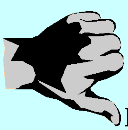
**Environmental Advantages** Renewable source of energy Clean, nonpolluting source of energy Curb the demand and use of fossil fuels Emit no air pollution of greenhouse gasses In CA, wind plants have offset the emission of than 2.5 billion pounds of carbon dioxide, and 15 million pounds of other pollutants

**Economic Advantages**--Wind energy is free! The cost of installation and maintenance has dramatically decreased in recent years. Future technology ensures only a continual decrease in the prices. No fuel to purchase and low operating costs. As a result, the lifetime investment is much lower than most fossil-fuel systems. Under the 1978 PURPA, individuals can install a wind mill and the local energy company must buy the excess power produced.

General Disadvantages

One of the primary disadvantages to wind power is the natural variability of wind in any given locale. Indeed there are certain areas with extremely high average wind speeds, but in most places, wind exposure is quite variable. Wind energy can only be stored with a battery, otherwise it is not. In the latter case, not all energy demands can be met through the natural timing of winds. For these reasons, it may not be a viable option for some. One other disadvantage is the competition for other -more highly valued and profit generating-land uses.

**Economic Disadvantages** The initial investment is often higher than fossil fuel systems. The higher costs is mostly due to the machinery which is involves. Other costs include site preparation and installation.

**Environmental drawbacks** The primary environmental drawbacks to wind power are as follows:· Noise pollution via the rotor blades Aesthetic impacts ("visual pollution")· Bird deaths

It is important to keep in mind that many of these problems have been resolved with increasing technology. Avian mortality, however, is still being studied.

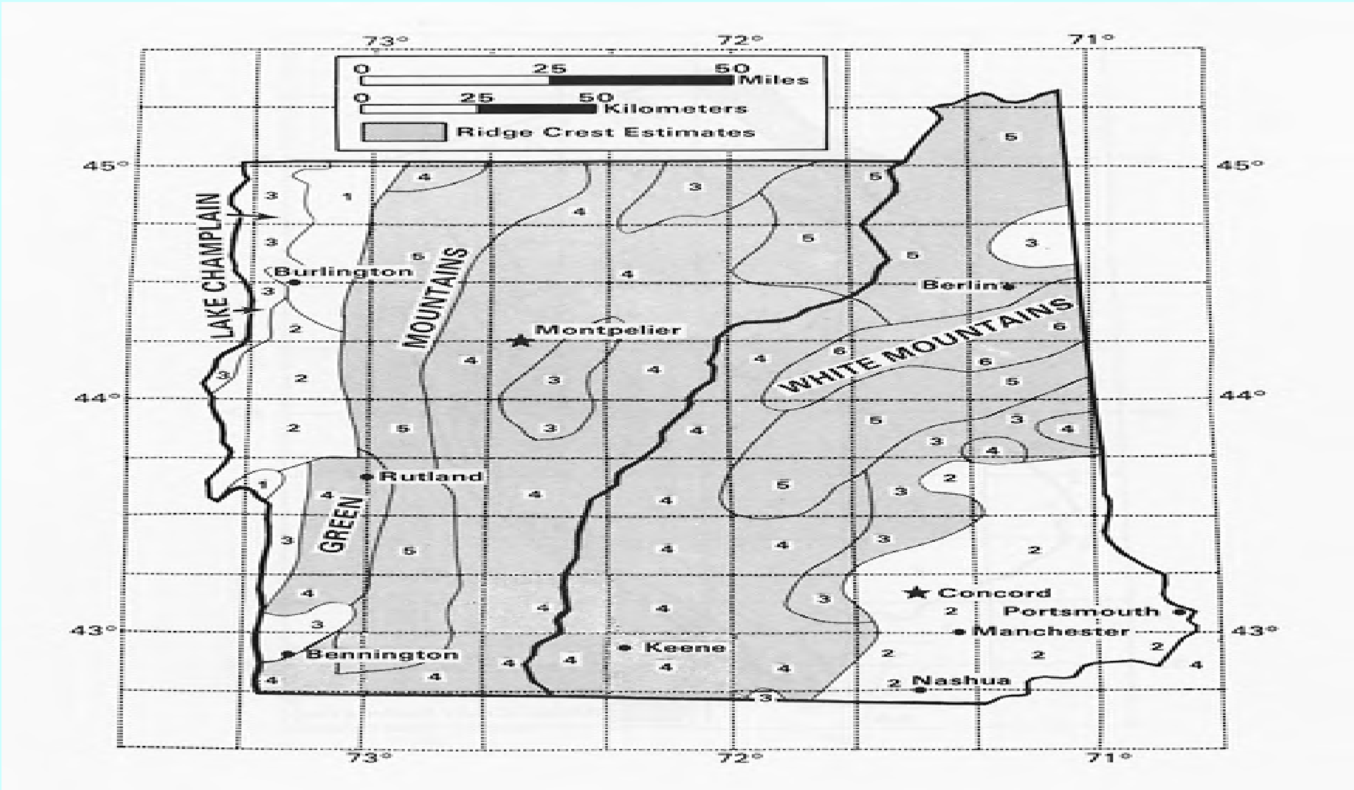
A Homeowners Guide to Wind Power

How do you know if wind energy is an option for you?

Wind resources a categorized by wind-power density classes, wherein 1 is the lowest and 7 is the highest. Good wind resources generally fall above a class 3 level, with an average annual wind speed of at least 13 mph. These areas are located in the Pacific Northwest, the Great Plains, the Appalachian Mountain Chain, and various different locations along the east coast and elsewhere.

What about Vermont? Is wind energy feasible in the Green Mountain State, and more specifically in and around Addison County?

· The DOE provides mapping of the United States for potential users of wind energy:



The Northeast Region

The Northeast region consists of Connecticut, Massachusetts, Rhode Island, Maine, New Hampshire, Vermont, New Jersey, New York, and Pennsylvania. The region's total population in 1980 of 49,136,000 represents approximately one-fourth of the nation's population. A large percentage of the people in the Northeast live in the corridor between Boston and Philadelphia, while large areas of northern Maine and upstate New York are quite sparsely populated. The major cities, rivers, lakes, and mountain ranges are shown in Map 3-20.

The topography varies dramatically throughout the Northeast. The Appalachian Mountains extend in a bank from northern Maine beyond the southern border of Pennsylvania. To the east of the mountains lie piedmont and coastal plain regions. West of the mountains the land becomes flatter as one approaches the Great Lakes. A large portion of the land area of the Northeast is composed of either hills or mountains or open hills and mountains, while large areas of Massachusetts, Rhode Island, Maine, and New York are plains containing hills. The only area of tablelands in the Northeast extends in an arc from the Hudson River valley, across central New York, and into northwestern Pennsylvania. Central and southern New Jersey contains the only true plains in the region.

Areas of class 3 or higher wind energy potential occur throughout much of the Northeast region. The primary areas of good wind energy resource are the Atlantic coast, the Great Lakes, and exposed hilltops, ridge crests, and mountain summits from Pennsylvania to Maine. Areas of highest wind energy potential (class 5 and 6) are the outer coastal areas such as Cape Cod and Nantucket Island, offshore areas of Lake Ontario and Lake Erie, and the higher mountain summits of the Appalachians. Winter is the season of maximum wind power throughout the Northeast region. During this season, all except the most sheltered areas have class 3 or better wind resource, and exposed coastal areas and mountain summits can expect class 6 or 7 wind resource. In summer, the season of minimum wind power, class 3 wind resource can be found only on the outer coastal areas and highest mountain summits.

Major areas of wind resource in the Northeast region are described below. Maps of annual average wind power are presented in Maps 3-21 through 3-26 for Connecticut, Massachusetts and Rhode Island (displayed on one map), Maine, New Hampshire and Vermont (displayed on one map), New Jersey, New York, and Pennsylvania.

**This a map showing annual average wind power greater than 3 all along Vermont's eastern and middle regions. The range is from 3 to 5- indicating that wind power is indeed possible in Middlebury.

Another point made about wind power is that a wind farm or even a few turbines can share agricultural land uses. Grazing, for example, can continue to take place in the presence of a wind farm.

Small Wind Energy systems can be used in connection with (i.e./ supplementing the energy grid) or as stand-alone applications which are independent of the energy grid. One can choose between these two options based on the following criteria provided by http://www.eren.doe.gov/wind/homeowner.html

Conditions for stand-alone systems

· You live in an area with average annual wind speeds of at least 4.0 meters per second (9 miles per hour)

· A grid connection is not available or can only be made through an expensive extension. The cost of running a power line to a remote site to connect with the utility grid can be prohibitive, ranging from $15,000 to more than $50,000 per mile, depending on terrain.

· You have an interest in gaining energy independence from the utility

· You would like to reduce the environmental impact of electricity production

· You acknowledge the intermittent nature of wind power and have a strategy for using intermittent resources to meet your power needs

Conditions for grid-connected systems

· You live in an area with average annual wind speeds of at least 4.5 meters per second (10 miles per hour).

· Utility-supplied electricity is expensive in your area (about 10 to 15 cents per kilowatt-hour).

· The utility's requirements for connecting your system to its grid are not prohibitively expensive.

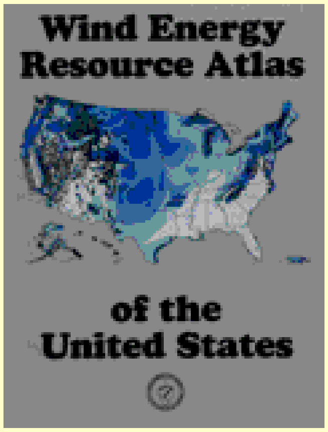
· Local building codes or covenants allow you to legally erect a wind turbine on your property.

· You are comfortable with long-term investments.

Before one decides on wind power, one must do a series of site specific spots. Even within the same property, there can be better places to harness the wind than others can.

Go Back To Alternative Energy

Home.



Wind Energy Resource Atlas of the United States

Table of Contents

List of Maps

Analyzed Annual and Seasonal Average Wind Resource Maps

Gridded Wind Resource, Certainty Rating, and Areal Distribution Maps

Regional summaries of wind resource estimates

Northwest Region

North Central Region

Great Lakes Region

Northeast Region

East Central Region

Southeast Region

South Central Region

Southern Rocky Mountain Region

Southwest Region

Alaska

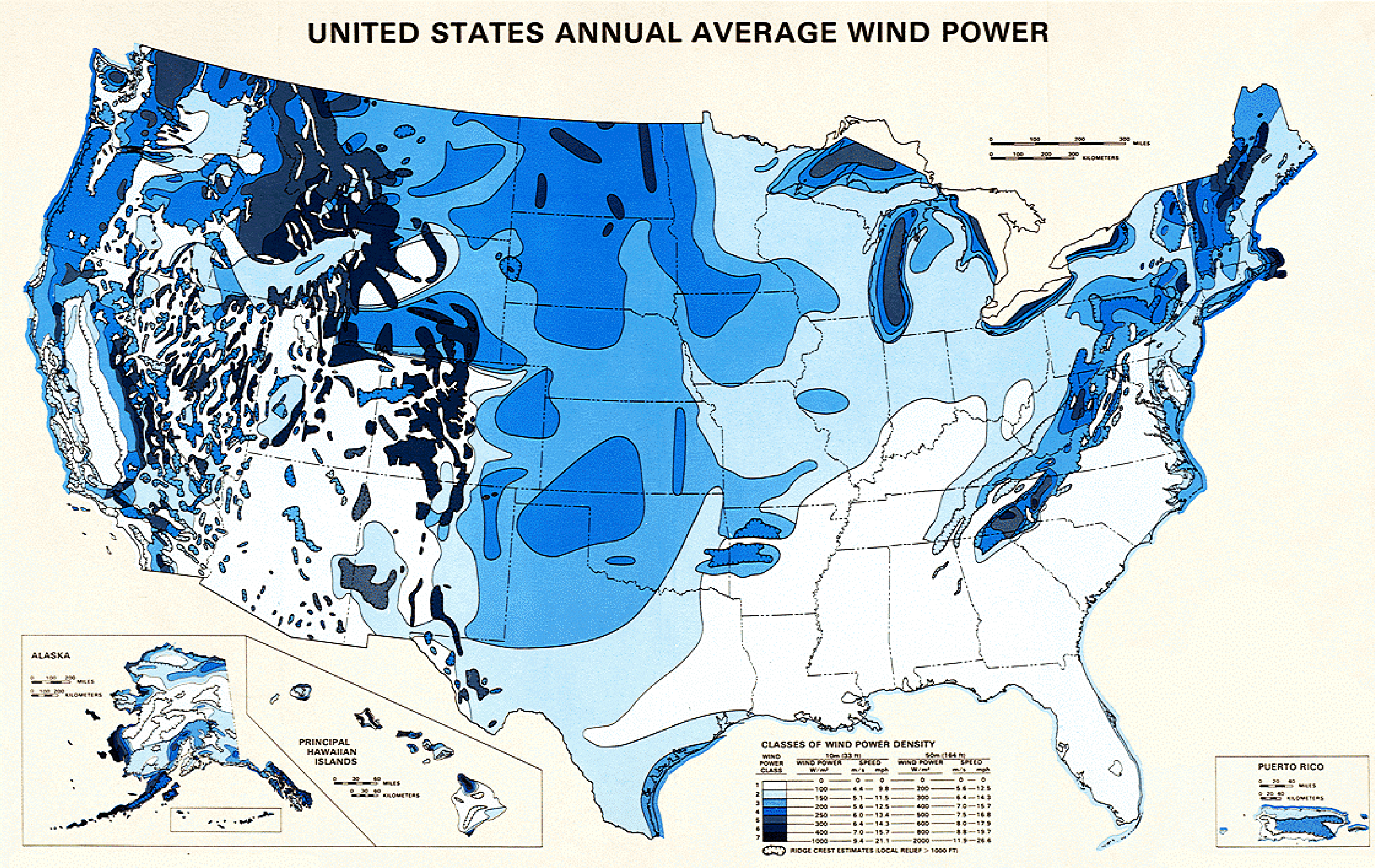
Hawaii and the Pacific Islands

Puerto Rico and the Virgin Islands

Appendices

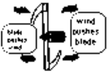
Table of Contents

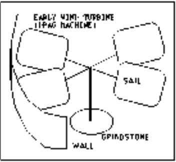
Return to RReDC Homepage *(http://rredc.nrel.gov)*


UNITED STATES ANNUAL AVERAGE WIND POWER
ALASKA
PRINCIPAL HAWAIIAN ISLANDS
PUERTO RICO
CLASSES OF WIND POWER DENSITY
WIND POWER CLASS
WIND POWER
SPEED
RIDGE CREST ESTIMATES (LOCAL RELIEF > 1000 FT)

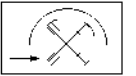
Wind turbine rotor blades take power from the wind by slowing it down

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





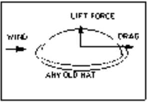
Objects in the path of a stream of air experience a 'downwind' force called drag.

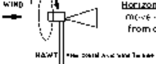


The drag force was used by the earliest wind turbines. It is easy to understand how this force causes the blades to turn, but such rotors are very slow and the blades which are moving up-wind actually slow the rotor down.

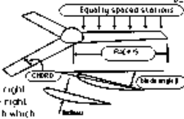
Drag is the force of wind pushing straight downwind.

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



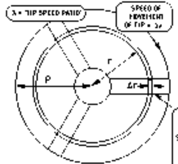


Horizontal axis wind turbine blades never move downwind, so they can get no help from drag forces. Instead they use lift.



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

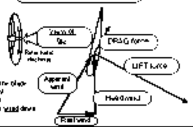
THE BIT OF THE BLADE AT RADIUS r SWEEPS A FRACTION OF THE TOTAL SWEPT AREA AND HAS THE JOB OF SLOWING THIS BIT OF WIND DOWN BY THE RIGHT AMOUNT TO SATISFY THE BETZ CRITERION

THE AREA OF WIND IT SWEEPS WILL BE $2\pi r \delta r$

ITS HEADWIND WILL BE ...
WHERE ... 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

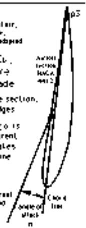
$$LIFT = C_L (\rho/2) A V_a^2$$
$$DRAG = C_D (\rho/2) A V_a^2$$

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



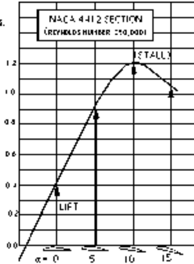
You cannot calculate the lift and drag coefficients

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

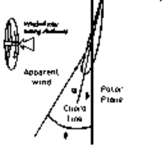


When designing a wind turbine rotor, the angle α will depend on the angle of the apparent wind φ, and the blade angle β

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 drag is minimised

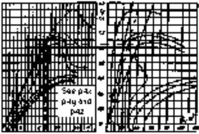
So we have to choose a section and an angle of attack, where the lift/drag ratio is high



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

Finding the exact best angle α can be an involved process, because the lift and drag coefficients depend on both the section and the Reynolds number (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

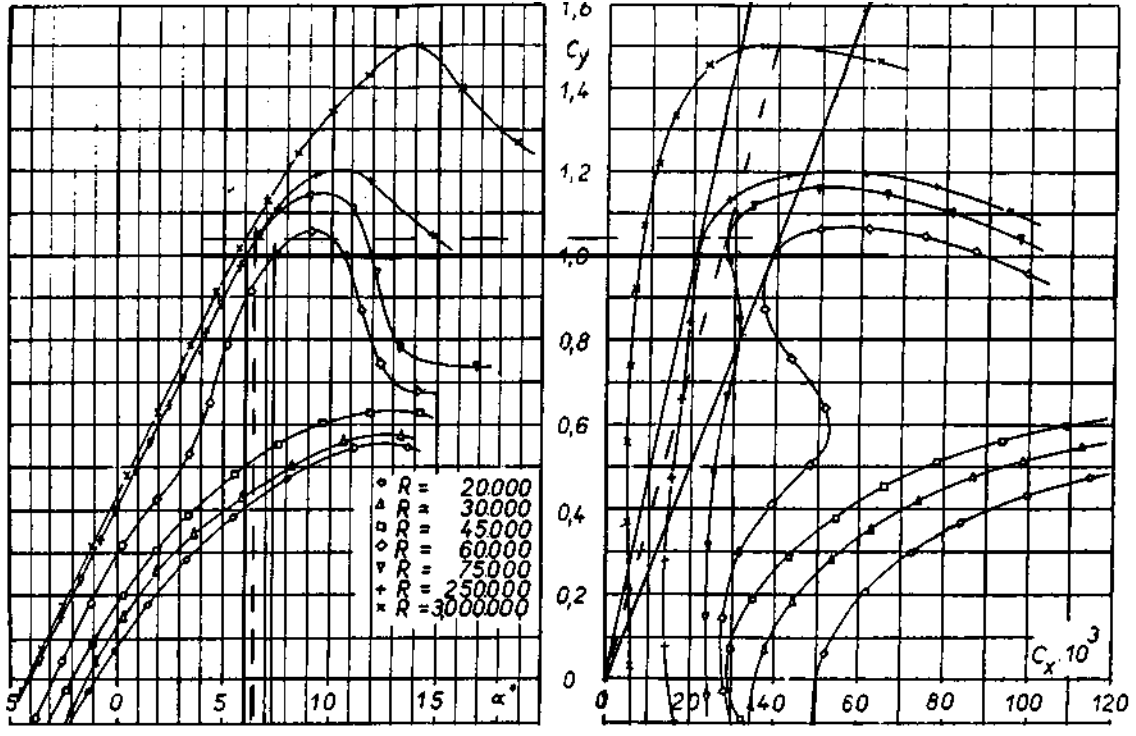


On the left is a pair of graphs which again relate to the NACA 4412 section for several different Reynolds numbers.
The lefthand graph shows lift/α.
The righthand one shows lift/drag.
The straight lines through zero, represent particular lift/drag ratios.
Best lift/drag ratio for a given Reynolds number 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 [illegible] and [illegible]) which have better performance than the NACA 4412 at low Reynolds numbers.

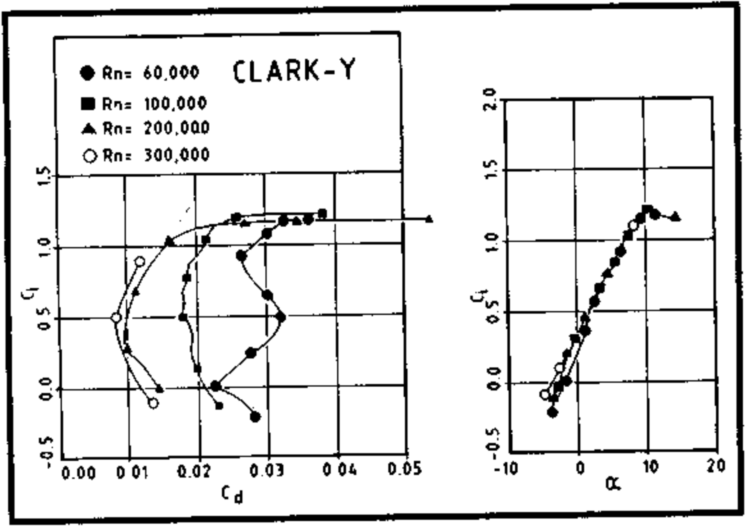
In practice, most sections will produce their best lift/drag at an angle of attack around 5 degrees, so as a general rule, where detailed data is not available, we can say that the blade angle β should be set to give this angle of attack, thus

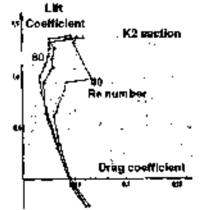
$$\beta = \phi - 5$$



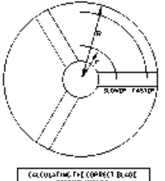
c_y
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0
5
0
5
10
15
α°
0
20
40
60
80
100
120
$c_x \cdot 10^3$
○ R = 20.000
△ R = 30.000
□ R = 45.000
◇ R = 60.000
▽ R = 75.000
+ R = 250.000
× R = 3.000.000

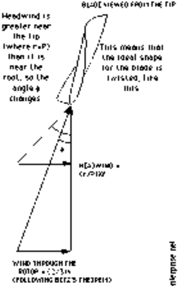
WIND TUNNEL TEST POLARS




Lift
Coefficient
K2 section
80
80
Re number
Drag coefficient

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





CALCULATING THE CORRECT BLADE SETTING ANGLE β

$\beta = \phi - \alpha$

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

SO THE BLADE ANGLE β IS

$\beta = ATAN(2R/3xr) - \alpha$

WHERE α IS USUALLY AROUND 5 DEGREES

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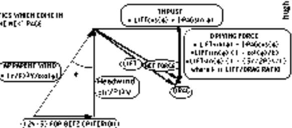
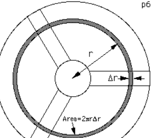
MORE MATHEMATICS WHICH COME IN USEFUL ON THE NEXT PAGE

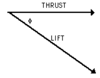




Having worked out β we still need to work out the <u>Chord width</u>. Here is the logic:

Each blade element has a certain <u>band</u> 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 = $CL(\rho/2)BC\Delta r(\text{APPARENT WIND})^2$

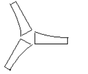
$$=CL(\rho/2)BC\Delta r(\lambda V(r/R)/\cos(\Phi))^2$$

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.
$BC\Delta r$ is the area of blade used to produce lift at radius r.

THIS LEADS TO A ROUGH EXPRESSION FOR THE <u>CHORD WIDTH C</u> 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 $\cos(\phi)$ ARE BOTH ABOUT =1.
THIS EQUATION WORKS BEST FOR THE OUTER PART OF THE BLADE ONLY.



<u>CONCLUSIONS</u>

C IS INVERSELY PROPORTIONAL TO <u>RADIUS</u> r.
so the blade shape should be tapered

C IS INVERSELY PROPORTIONAL TO BLADE <u>NUMBER</u> B
so fewer blades will be wider blades

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

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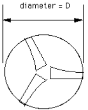
Back of envelope blade design:-

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

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

3. Decide how many blades B to use

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

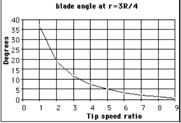
4. The width of the blade C in the outer portion, will be :

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

For example if D=2m, and tip speed ratio = 7 and B=2, then C = 4x2/49x2= 0.08m (or 8cm).

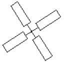
The outer part is the most important, but the inner part should be made wider, to help with starting torque.

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

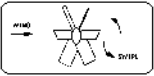
STRONGER BLADE ROOT

Factors affecting the power coefficient

(Where the lost energy goes)

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

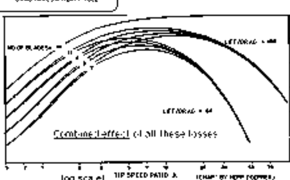
Loss 2 is the lost power in the swirl created by high torque rotors. Glauert figured out that this is worst at low tip speed ratios



Loss 3 is due to the fact that we are not able to be everywhere at once. Where 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 Tip loss.

DRAG FORCE
= [illegible]
[illegible]
SO LIFT/DRAG MUST INCREASE WITH INCREASING TIP SPEED RATIO OR DRAG TAKES A HEAVY TOLL

Loss 5 is drag loss, 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

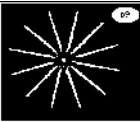


So what is the <u>best design</u> for a wind turbine rotor?

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 (or both), to satisfy the Betz condition.

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

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



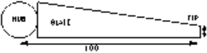
Source: Windmission

HERE IS A 12-BLADED WINDFLOWER ROTOR DESIGNED FOR TIP SPEED RATIO λ = 5.6 (APPROX). 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 = (7/100)R, 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</u> λ –

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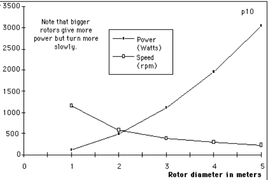
High speed blades

(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

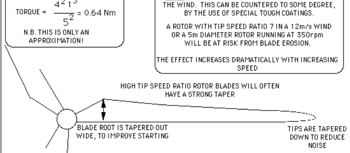
$$\text{TORQUE} = \frac{4^2 1^3}{5^2} = 0.64 \text{ Nm}$$

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



Hugh Piggott's Homepage

Website relocation

I have moved my web site to a new server,
which means that any pages you have bookmarked with my old server homepage address
homepages.enterprise.net will expire in due course and cease to work.

If in doubt, go to
www.scoraigwind.co.uk

hugh@scoraigwind.co.uk

Towers (The "Real" Kind)

I'll talk a bit about how to raise/lower guyed steel lattice-type towers. These towers are not difficult to work with and are good for antennas, cameras, and wind turbines.

For more information from Rohn, one of the most well-known tower manufacturers, try their site. Here you will find all of the official data on their towers, which are pretty much the industry standard. I myself have a good deal of Rohn 25(G?) tower.

One bit of advice I'd like to give before going much further is that, as much as I'd trust my life to my tower, I don't know that I'd want it to endure a 24-hour-per-day regime of shaking and vibration. I'd be very careful putting a wind turbine on top of a tower without making sure it's well balanced and easy to stop in case of emergency. Climbing towers in the wind is already no fun, and climbing one to stop a runaway wind turbine might not be the smartest thing you ever did. :-)

Let me first discuss the only special tools that you need to work on towers. The first is a safety belt of some sort. I'm not talking about a rope tied through your belt loops, either, but rather something that you'll be comfortable and confident hanging off of the tower with for long stretches of time. I have my father's tower-climbing belt, and also one from Mike Hales (RIP). I have them specially outfitted with chains and very large spring-loaded hooks. 2 long chains are each about 3 feet long, for going all the way around the tower, and one short one is about half that long, for attaching to tower braces in various situations or for carrying things with. Most tower-climbing belts have only one leather strap that goes around the tower, but you're unprotected when going around guy wires and I like more security than that.

I have seen industrial safety belts at garage sales and stores and they look pretty substantial to me. I'd probably use one myself on a tower, but I'm not necessarily recommending that you do so yourself. Also, remember that climbing to the top of a tower and flipping your belt over the top is surprisingly common and easy to do by mistake, and a good way to die. That's one of the reasons I have the short extra chain on my belt. :-)

The second tool is popularly called a gin pole. This is the device (basically a pipe) which clamps onto an installed tower section and allows you to install one above it (or remove the one above it). It consists of a pipe about as long as one tower section, 2 "clamps", and a pulley. About the only thing special about the pole is, surprisingly, not the pulley, but rather the clamps. The pipe itself can be a nice aluminium pipe, or, as I use, a regular piece of galvanized 1 1/4" water pipe.

The third tool is what I call a "jacker". It's easy to make out of a couple of pieces of flat steel stock about 1" wide and a bolt. Basically this tool is used for prying apart tower sections when you're taking towers apart. The normal way to employ it is to pry at each tower joint, going around all 3 legs while your helper carefully pulls on the rope a bit. Sometimes you can just pry one leg and shake the tower, which is quite a bit faster and can be fairly exciting! :-)

Here are pics of the tools mentioned.

Tower sections don't weigh much; I have carried 2 sections of Rohn 25 in each hand with no problem. But a gin pole is going to need to hold one tower section quite securely, as you don't need it falling down on your helpers, or, worse yet, on the guy wires that are holding you up in the air! Therefore it behooves you to buy or make the proper clamps for holding your pole.

The little pulley at the top of the gin pole doesn't have to be anything very special, but I'd recommend against using cheap steel stamped or tack-welded pulleys. The one I have is an idler pulley off of a Ride King lawnmower, about 2" in diameter (avoid smaller pulleys) with a bearing in the middle ready to accept a 5/16" bolt. To each side of the pulley I have some 3/16" thick flat steel bar, with another bolt at the top. A 5/16" hook is hung into the top of the gin pole, a couple of links of chain run from that to the top bolt in the pulley assembly, and a few more links are run back up and fed into the top of the pole, where a bolt through the pipe holds the chain in.

The idea here is to have a solid pulley with no sharp edges, with enough radius to avoid bending the rope too sharply (which breaks the fibers on the "outside" side of the rope). The pulley should be as close to the top of the pole as practical while still leaving one or two chain links for a bit of swiveling action, which is often useful. With this setup you can also unhook the hook from the top of the pole and hang the gin pole on the tower when necessary.

You need about twice as much rope as your tower is high. Again, tower sections aren't that heavy, so you don't need to break the bank here, but then again, your life is on the line, so buy a reasonable quality of rope and take good care of it (I store mine in a 5-gallon pail). I have black 1/2" nylon rope and it seems to be more than adequate for Rohn 25 towers. INSPECT ALL OF YOUR ROPE BEFORE EACH USE.

The placement of the 2 clamps in the gin pole is important for a reason that's not immediately obvious. Of course you don't want them too close together, as that doesn't give a very strong connection. Having them too far apart, of course, uses up too much of the pole, and we need our pulley to hang at least 1/2 the length of a tower section above the top of the tower.

However, you'll want to install the clamps so that one is at the bottom end of the pole (say 1" away) and the second one is the distance between 2 of the horizontal braces of your particular tower type. The reason? You'll find the the shape of the clamps allows you to wedge both of them into the Vs formed by the tower braces, and this is almost a necessity when working with the pole, especially when raising it above the top of the tower. See this picture:

If you loosen the side of the clamp which attaches to the tower sufficiently so that one side will come off (you'll see which side is the right one to take totally off) then the entire gin pole can be wedged into the "V" between the tower braces and the pipe in such a manner that the bolts are around the pipe. Of course you don't want to put a load on the gin pole like this, but it is secure enough so that you can clamp the pole snugly to the tower, then raise it up as high as it will go (until the clamps touch the next higher set of braces), then tighten the clamps somewhat. Don't put a killer torque on these clamps, as you are only lifting 25 pounds or so. It would certainly be better to have the pole slide down a bit than to have one of the clamps' bolts break and drop a tower section, possibly on the guy wires below you that are holding you up! Use common sense here.

Your help must be trustworthy. As these tower sections don't weigh very much, I have even been helped by a female or two in the past, and in fact, you can put up or take down a whole tower by yourself if you don't mind the extra climbing up and down that this would entail. In any event, it probably isn't safe to be up there alone; have someone around please.

One very important thing your help must be good at doing is tying the knot which holds the tower section while you're lifting it. I suggest fixing up the end of your rope by passing it through a 1/2" drive socket (mine is a 1 1/8" socket) and then tying an overhand knot in the rope and cramming that into the business end of the socket, with a couple of inches of rope past the knot hanging out of the socket for safety. If the socket's edges aren't too sharp this will serve for a long time, and the socket's weight will help out a bit when you're lowering the end of the rope from the top of the tower.

With the end of the rope suitably prepared, it is easy to tie it to the tower section (always tie to the middle of a section) with a clove hitch knot (search the internet for this). The size of the socket guarantees that the clove hitch won't come apart. A couple of extra (loose) half hitches couldn't hurt either, although for extra security, I usually request that two clove hitch knots be tied, one on one tower leg and another on the next. Again, tower sections don't weigh very much, but we do want security. One good thing about clove hitch knots is that they don't put sharp bends in the rope which wear it out or weaken it. They are also easy to untie, and the last thing you want while you're up hanging off of a tower is trouble untying a rope.

To keep the tower section from hanging horizontally while you're lifting it, and therefore bouncing off of guy wires and the like and possibly getting caught, twist a loop in the rope near one of the end of the tower section and loop it around one of the legs. As always, don't twist the rope any more than is necessary. You'll see how to go about it. Now when you lift the tower section it will be easier to move around guy wires and the like by manipulating the rope from the top (your job :-).

As far as the mechanics of supporting and guying a tower go, I'd have to suggest that you to go the Rohn web site for the official word. I myself have seen a free-standing 50-foot Rohn 25 tower sitting in 2 feet of concrete in the ground, held up by 3 1/4" nylon ropes tied to this guy's fences! This didn't look safe, but made it through a hurricane somehow. When it came time to take this tower down we just dug around the base a bit, stood on the house, and lowered it down with one or two of the ropes. I sure wasn't going to climb that darned tower! :-)

I put my towers in a hole dug with post-hole diggers a couple of feet deep, just a bit bigger than the tower itself. You want to fill the bottom of the hole with some bricks to hold up the open ends of the pipes away from the dirt, and probably throw some gravel or the like in there too. The goal is to keep the pipes' ends free of dirt and concrete so that any (unlikely) accumulation of water in there can drain out.

The hole in the ground isn't going to hold the tower up anyway; the guy wires are. They should be about every 30 feet (3 sections), at the very top of the section. I have seen towers with much greater spacing and for these frightening beauties I usually add in my own guy wires made out of 1/8" galvanized fence wire. After all, who knows how long some of these towers have been standing? It's scary enough when you're 100 feet up and unhooking the wires from the end of a 30-foot length of tower! I wouldn't push my luck.

The three guying points (where the guy wires go into the ground) need to be fairly solid, although I have seen some pretty flimsy ones hold up. You'll certainly want them out of the way, where they can't be hit by cars or large lawnmowers or the like. I wonder sometimes if one of my cows will panic and run into one and knock my tower over. :-) In any case, I usually dig a cone-shaped hole with post hole diggers, with the large end toward the bottom, and place large pieces of angle iron and/or stainless steel in there, with reinforcing wire of some sort binding everything. Pour the concrete and add enough to stick above the ground a few inches, then taper the top away from the embedded steel so that water doesn't puddle next to it and rust it over time. A failure here could be pretty bad for the health of your tower -- or you, for that matter!

If you're going to take down a tower of unknown quality then you'll first climb it to at least check out the condition. If the outside looks fine then about the only other thing to check is the bolts which join the sections together. If they look bad then replace them as you go up the tower. It's not that difficult, as even a whole tower doesn't weigh that much, and it's not all sitting on each bolt of course. Remove the nut, and then try to punch the bolt out with a center punch or a smaller bolt. If there's a good deal of weight on a particular bolt, then use the "jacker" tool described above to relieve the weight and get the bolt out. Immediately put a new bolt in, of course. I always use friction nuts when replacing these bolts.

The things I'd check before climbing old towers are:

1. the tower itself. If it's rusty to the point that it has holes in it, then don't bother with it at all, unless it's to knock it down.

2. the bolts that hold the sections together. The tower is not really that heavy, and you shouldn't have much trouble jacking up the tower at the joints (use a tool like the one I describe and show on my site) and checking both the bolts and the metal of the tower that way. If the tower is fine but the bolts are bad, then replace the bolts as you climb up it the first time.

3. the guy wires. If they're bad then just get some 1/8" galvanized wire from the hardware store (it's cheaper than dying) and make new guy wires for the tower as you climb it, one set at a time. The guy wires don't have to be any more than hand tight, to tell you the truth, and that wire is easy to work with. Get some of the small u-clamps if you buy this wire.

As far as the tower being tilted goes, that's not a very big deal. If everything else is ok I wouldn't worry about it that much. However, if you replace the guy wires, make sure that you leave enough spare wire on the ground ends so that you can straighten the tower (bit by bit) while you're safely on the ground.

Don't take any shortcuts.

Hugh Piggott's Homepage

Website relocation

I have moved my web site to a new server,

which means that any pages you have bookmarked with my old server homepage address

homepages.enterprise.net will expire in due course and cease to work.

If in doubt, go to

www.scoraigwind.co.uk

hugh@scoraigwind.co.uk

Lead-Acid Battery Information

To visit my home page, click here.

General Battery Information

Have you ever had one of those maintenance-free batteries that worked fine for a couple of years... then one day you go out to start the car and it's "dead" as a doornail? What's happened is that the fluid level has dropped in the battery, because the charging systems in cars aren't perfect and often overcharge your battery a bit. Charging doesn't cause "gassing" (when water is split up into hydrogen and oxygen and escapes as gas). Overcharging does.

So the fluid level has been slowly dropping in your supposedly maintenance free battery, but you've never noticed a loss of power. That's because it hasn't dropped significantly below the level of the tops of the plates, where the power is made. But here is an often-forgotten fact about battery construction: the lead bars that connect to the plates and run between the cells are just above that level. If the fluid level should fall below these bars and expose them to air, the darned things start corroding for some reason, especially if the car sits for a while and the fluid doesn't slosh up on the lead and keep it wet. After corroding a while, the darned bars don't work, and sometimes even make a spark which blows up the battery!

The lesson here is that maintenance free batteries... aren't. If you're like me and you lose the battery receipts after a couple of years, then find out how to open those batteries up and make sure you top them off with distilled water. Usually you can peel off the label or something like that and there are some caps under there.

If you've ever charged a battery until it gassed, you should check the fluid level in it. Never add anything but distilled water! Adding acid is not going to "freshen" the battery; it will usually ruin it. Adding dirty water is going to make minerals settle out and accumulate in the bottom of the battery, which often shorts out the plates, or other untoward things could happen with impure water. I use only reverse osmosis water; don't use "baby mineral water" or the like from the store. Sufficiently distilled water is fine.

Reviving Batteries

The most convenient way to revive tired batteries is to overcharge them. This doesn't necessarily mean charging them at a high rate, however! Most work with batteries should be done slowly.

If the battery will hardly take a charge at all, then it's "sulfated"; there is an insulating layer of sulfate on the plates. This happens to any battery that sits around in a discharged condition. A battery that is heavily sulfated is going to be difficult to revive by just charging it. There are electronic and chemical ways to get the sulfate off, though.

Sending pulses of high voltage/current through a battery will slowly knock sulfates off of the plates. I have had pretty decent luck with batteries as long as they're mechanically sound (the plates aren't broken, shorted, etc.). The schematic for desulfators can be found either here or here. If you build one, remember the error in the original article about the capacitor having the wrong value printed: the .022uf should be .0022uf instead. If the plates look black, crumbly, and ugly, then the desulfating isn't going to work very well, but if there's an obvious layer of white sulfate on the plates, you'll probably have good luck.

Tetrasodium EDTA (about $15 per pound, plus shipping, from www.bostick-sullivan.com) is a chemical way to remove sulfates. Some people just dump it into the battery (it's in powder form) but that gives the sulfates a chance to precipitate out of solution and settle in the bottom of the battery. I'd prefer to get those nasty sulfates out of the battery totally.

I mix a solution of 1 tablespoon to one quart of water. Empty the acid from the battery; I usually turn the battery upside down in a sufficiently large pail or 5-gallon bucket. Try to keep the acid clean, as you'll probably want to reuse it. Rinsing the battery out with distilled water can't hurt either. Please note that fluid/acid/water will "stick" between the battery plates, especially when that space is filled up with sulfates, and it can be difficult to get all of it out! A bit of shaking is sometimes warranted, or maybe several rinses with distilled water.

I refill the battery with the EDTA solution and leave it overnight. This is a fairly weak solution, and you may wish to double the strength for this purpose. Also, keep the solution away from light so it won't break down.

The next day the solution should look milky when you pour it out of the battery. You've made progress! I don't think this "used" solution is good for anything, but if I think of something I'll post it here. Anyway, repeat the process until the battery is noticably cleaner (the white sulfate on the plates should be disappearing). Sometimes one cell will be much more sulfated than others, and you may wish to treat that cell only. Heat will speed up the process, although I wouldn't get too carried away trying to heat up your batteries!

When the process is done, put the old acid back in, unless you happen to have new acid kicking around. If you do have new acid, then make sure it's properly mixed with water. Buy a hygrometer (Wal-Mart has cool ones for $1 lately) so you know for sure what's going on.

Another trick I've heard of for reviving batteries is to drain/save the acid, fill them with distilled water, and charge them (overnight, at low current). Do this 2-3 times and it might take some sulfates off of the plates. I'll check into this as it might not be very effective.

I think the most reasonable approach for heavily sulfated batteries will be to treat them chemically, then leave them pulsing with the electronic device for a while.

Keeping Batteries Alive

Most motorcycle batteries seem to be of pretty poor quality. Maybe it's just the cheap ones that I buy at Wal-Mart. As Norm McDonald says, "Wal-Mart sells crap!". But I have one motorcycle with a Yuasa battery in it which absolutely refuses to die. What makes this battery so good?

I've heard that lots of batteries come with EDTA in them now. Doubtless there are other chemical tricks/processes which can make a battery perform well. But the EDTA trick is easy enough for the common man to implement. Adding a small amount of EDTA to each cell is supposed to do the battery a world of good over the long run. It doesn't dissolve well in battery acid, so mixing in a little water couldn't hurt -- but even just dropping the powder in works as a preventative measure, and I'm sure it dissolves just fine over time. Search the internet for suggested dosages; it doesn't take much.

The electronic desulfator presents a very small load to the battery and really doesn't have any undesirable effects that I know of. Probably the more that you can run these devices, the better, at least on batteries that are used only occasionally and more likely to develop sulfates.

You need to keep your batteries charged... but you don't want to overcharge them. There are automatic chargers which do a pretty good job of detecting battery charge and keeping them at the right level. Keep in mind that small "tickle chargers" are not in any way "automatic" and you can certainly overcharge a battery with one of these if you leave it on long enough.

My Setup

I have a couple of buildings between which I have run a #8 wire. Each end is terminated with a 2"x8" board with 2 strips of aluminium, and each strip has about 10 screws (with washers) going through into the wood. This allows me to connect batteries, or cables running to my vehicles, at each end. I can keep the batteries more or less charged this way, even on vehicles which are used infrequently like the tractor, and those batteries provide useful storage capacity for the wind generator system.

Not all lead-acid batteries have exactly the same voltage curve, but 12V batteries should be close enough so that they work well paralleled. There will be some resistance due to wire lengths/sizes in a system such as this, of course, but you can certainly expect the batteries to stay reasonably charged over the long wire, and if you want to pull a heavy load from one end or another, just make sure that you have batteries on that end for that purpose.

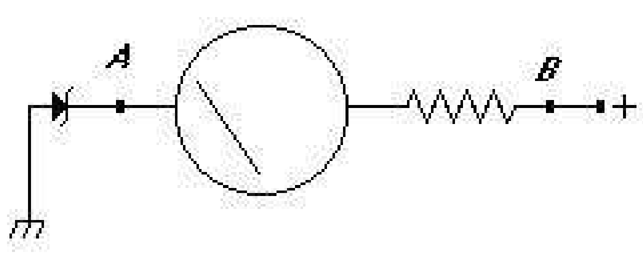
It's useful to have a good digital meter to check your battery voltages with, but you can't usually leave your digital meter hooked up and turned on all the time. Analog meters can be a bit inaccurate, though, since the range of voltages you want to read (10-15 volts) will be 1/3 or less of the meter's scale. We can improve upon the accuracy and usefulness of such a meter by dispensing with the lower range of voltages (up to 9-10 volts) and displaying only the range we're interested in.

Here is a schematic for a meter which starts reading at 9 volts. You can get a 9V zener diode at Radio Shack for a dollar or so. The resistor on the right will depend on your meter movement. Many movements have the full-scale current written on them somewhere, and you can figure out an appropriate value based upon Ohm's law. Try something around 100k to start with if you're clueless about your meter's sensitivity.

This circuit will also work with a regular voltmeter (of any sensitivity) if you simply replace the meter movement and resistor in the below circuit with the meter in question.

If your meter is too sensitive (it's possible) then the zener diode will not reach rated voltage. If the circuit doesn't read correctly, then add a 10k or so resistor between points A and B. Calibrate the meter by comparing readings with a digital meter and choosing an appropriate resistor for the full-scale voltage you want (around 15V seems fine). After you have an appropriate resistor, make marks on your meter with a felt-tip or piece of tape or something.

This circuit will draw a small current from your batteries, and so we're assuming that you want to install it on a working system, one which maintains the charge of the batteries somehow, and one on which you need to check the voltage on a regular basis.



This is a pretty darned basic schematic, and I'll try to add some more schematics here soon. I guess I oughta find one of those schematic-drawing programs on the internet!

If you'd like to chat, enter a nickname and hit "Connect".

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Substantive Rules - Chapter 25
Applicable to Electric Service Providers

Download Complete set of Chapter 25 Rules **(Word doc)**

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Rule	Description/Explanatory Information	Download	Effective
25 TOC *	Table of Contents	25toc.doc	10/03/05
Subchapter A	**General Provisions**		
§ 25.1	Purpose and Scope of Rules	25.1.doc	03/12/03
§ 25.2	Cross-Reference Reference Transition.	25.2.doc	05/07/98
§ 25.3	Severability Clause.	25.3.doc	03/12/03
§ 25.4 *	Statement of Nondiscrimination.	25.4.doc	03/12/03
§ 25.5 *	Definitions.	25.5.doc	05/19/04
§ 25.6	Cost of Copies of Public Information.	25.6.doc	05/27/99
§ 25.7	Relief for Victims of Hurricanes Katrina and Rita.	25.7.doc	12/01/05
Subchapter B	**Customer Service and Protection**		
§ 25.21	General Provisions of Customer Service and Protection Rules.	25.21.doc	05/06/99
§ 25.22	Request for Service.	25.22.doc	05/06/99
§ 25.23	Refusal of Service.	25.23.doc	05/06/99
§ 25.24	Credit Requirements and Deposits.	25.24.doc	05/06/99
§ 25.25	Issuance and Format of Bills.	25.25.doc	05/06/99
§ 25.26	Spanish Language Requirements.	25.26.doc	05/06/99
§ 25.27*	Retail Electric Service Switchovers.	25.27.doc	03/02/99
§ 25.28 *	Bill Payment and Adjustments.	25.28.doc	05/06/99

§ 25.85 *	Report of Workforce Diversity and Other Business Practices.	25.85.doc	07/30/00
§ 25.87	Distribution Unbundling Reports.	25.87.doc	09/16/98
§ 25.88 *	Retail Market Performance Measure Reporting	25.88.doc	05/11/03
§ 25.89 *	Report of Loads and Resources.	25.89.doc	06/28/00
§ 25.90 *	Market Power Mitigation Plans	25.90.doc	08/31/00
§ 25.91 *	Generating Capacity Reports	25.91.doc	08/31/00
§ 25.93 *	Quarterly Wholesale Electricity Transaction Reports.	25.93.doc	09/19/04
Subchapter E	**Certification, Licensing and Registration**		
§ 25.101*	Certification Criteria.	25.101.doc	01/01/03
§ 25.102	Coastal Management Program.	25.102.doc	01/01/03
§ 25.105 *	Registration and Reporting by Power Marketers.	25.105.doc	06/28/00
§ 25.107 *	Certification of Retail Electric Providers (REPs).	25.107.doc	08/15/00
§ 25.108 *	Financial Standards for Retail Electric Providers Regarding the Billing and Collection of Transition Charges.	25.108.doc	08/15/00
§ 25.109 *	Registration of Power Generation Companies and Self-Generators.	25.109.doc	06/28/00
§ 25.111 *	Registration of Aggregators.	25.111.doc	06/28/00
§ 25.113 *	Municipal Registration of Retail Electric Providers (REPs)	25.113.doc	01/12/03
Subchapter F	**Metering**		
§ 25.121	Meter Requirements.	25.121.doc	06/11/98
§ 25.122	Meter Records.	25.122.doc	06/11/98
§ 25.123	Meter Readings.	25.123.doc	06/11/98
§ 25.124	Meter Testing.	25.124.doc	06/11/98
§ 25.125	Adjustments Due to Meter Errors.	25.125.doc	06/11/98
§ 25.126	Meter Tampering.	25.126.doc	06/11/98
§ 25.127	Generating Station Meters, Instruments, and Records.	25.127.doc	06/11/98

§ 25.484 *	Texas Electric No-Call List.	25.484.doc	09/27/04
§ 25.485 *	Customer Access and Complaint Handling.	25.485.doc	06/01/04
§ 25.487 *	Obligations Related to Move-In Transactions	25.487.doc	08/04/03
§ 25.488 *	Procedures for a Premise with No Service Agreement	25.488.doc	08/04/03
§ 25.489 *	Treatment of Premises with No Retail Electric Provider of Record	25.489.doc	08/04/03
§ 25.490 *	Moratorium on Disconnection on Move-Out	25.490.doc	08/04/03
§ 25.491 *	Record Retention and Reporting Requirements.	25.491.doc	06/01/04
§ 25.492 *	Non-Compliance with Rules or Orders; Enforcement by the Commission.	25.492.doc	01/15/01
§ 25.493 *	Acquisition and Transfer of Customers from one Retail Electric Provider to Another.	25.493.doc	06/01/04
§ 25.495 *	Unauthorized Change of Retail Electric Provider.	25.495.doc	06/01/04
§ 25.497 *	Critical Care Customers.	25.497.doc	06/01/04
Subchapter S	**Wholesale Markets**		
§ 25.501 *	Wholesale Market Design for the Electric Reliability Council of Texas.	25.501.doc	11/18/04
§ 25.502 *	Pricing Safeguards in Markets Operated by the Electric Reliability Council of Texas	25.502.doc	01/09/05
§ 25.503 *	Oversight of Wholesale Market Participants	25.503.doc	02/29/04
Appendices			
Appendix I *	Cross Reference: Location of Rule Section in Chapter 23 to New Location in Chapter 25 or Chapter 26.	apendix1.doc	01/22/01
Appendix II *	Electric Commonly Used Acronyms.	appII.doc	01/13/03
Appendix III *	Records, Reports, and Other Information that May be Required.	appIII.doc	10/26/04

Last Updated: 12/02/05

* PDF files require the use of the Adobe Acrobat Reader. Down load a free copy here.

National Semiconductor

May 2003

LM2907/LM2917 Frequency to Voltage Converter

General Description

The LM2907, LM2917 series are monolithic frequency to voltage converters with a high gain op amp/comparator designed to operate a relay, lamp, or other load when the input frequency reaches or exceeds a selected rate. The tachometer uses a charge pump technique and offers frequency doubling for low ripple, full input protection in two versions (LM2907-8, LM2917-8) and its output swings to ground for a zero frequency input.

The op amp/comparator is fully compatible with the tachometer and has a floating transistor as its output. This feature allows either a ground or supply referred load of up to 50 mA. The collector may be taken above V_{CC} up to a maximum V_{CE} of 28V.

The two basic configurations offered include an 8-pin device with a *ground referenced tachometer* input and an internal connection between the tachometer output and the op amp non-inverting input. This version is well suited for single speed or frequency switching or fully buffered frequency to voltage conversion applications.

The more versatile configurations provide differential tachometer input and uncommitted op amp inputs. With this version the tachometer input may be floated and the op amp becomes suitable for active filter conditioning of the tachometer output.

Both of these configurations are available with an active shunt regulator connected across the power leads. The regulator clamps the supply such that stable frequency to voltage and frequency to current operations are possible with any supply voltage and a suitable resistor.

Advantages

- Output swings to ground for zero frequency input
- Easy to use; $V_{OUT} = f_{IN} \times V_{CC} \times R1 \times C1$
- Only one RC network provides frequency doubling
- Zener regulator on chip allows accurate and stable frequency to voltage or current conversion (LM2917)

Features

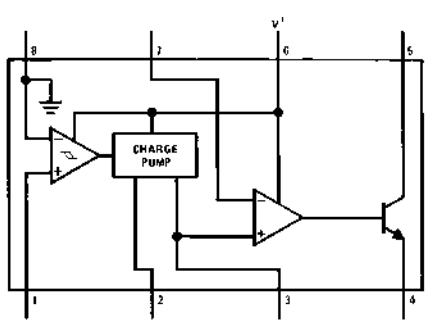
- Ground referenced tachometer input interfaces directly with variable reluctance magnetic pickups
- Op amp/comparator has floating transistor output
- 50 mA sink or source to operate relays, solenoids, meters, or LEDs
- Frequency doubling for low ripple
- Tachometer has built-in hysteresis with either differential input or ground referenced input
- Built-in zener on LM2917
- ±0.3% linearity typical
- Ground referenced tachometer is fully protected from damage due to swings above V_{CC} and below ground

Applications

- Over/under speed sensing
- Frequency to voltage conversion (tachometer)
- Speedometers
- Breaker point dwell meters
- Hand-held tachometer
- Speed governors
- Cruise control
- Automotive door lock control
- Clutch control
- Horn control
- Touch or sound switches

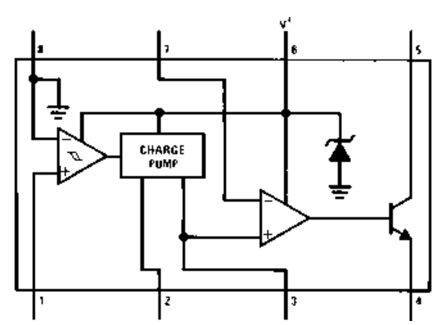
Block and Connection Diagrams

Dual-In-Line and Small Outline Packages, Top Views



00794201

Order Number LM2907M-8 or LM2907N-8
See NS Package Number M08A or N08E

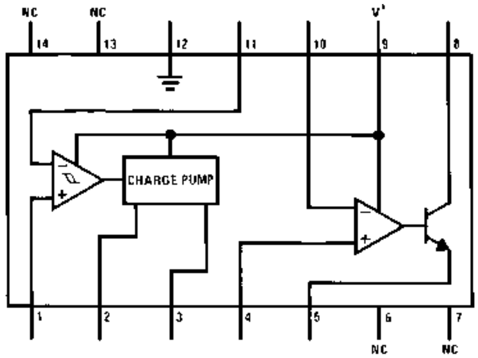


00794202

Order Number LM2917M-8 or LM2917N-8
See NS Package Number M08A or N08E

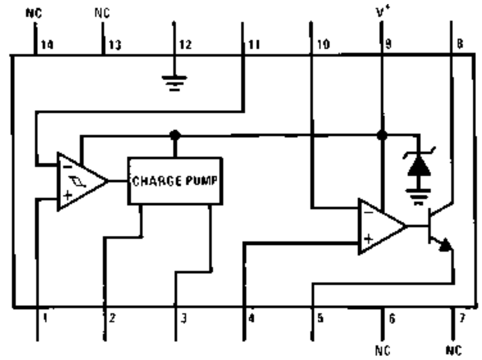
 DS007942

Block and Connection Diagrams Dual-In-Line and Small Outline Packages, Top Views (Continued)



00794203

Order Number LM2907M or LM2907N
See NS Package Number M14A or N14A



00794204

Order Number LM2917M or LM2917N
See NS Package Number M14A or N14A

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Supply Voltage	28V
Supply Current (Zener Options)	25 mA
Collector Voltage	28V
Differential Input Voltage	
Tachometer	28V
Op Amp/Comparator	28V
Input Voltage Range	
Tachometer	
LM2907-8, LM2917-8	±28V
LM2907, LM2917	0.0V to +28V
Op Amp/Comparator	0.0V to +28V
Power Dissipation	
LM2907-8, LM2917-8	1200 mW
LM2907-14, LM2917-14	1580 mW
See (Note 1)	
Operating Temperature Range	−40˚C to +85˚C
Storage Temperature Range	−65˚C to +150˚C
Soldering Information	
Dual-In-Line Package	
Soldering (10 seconds)	260˚C
Small Outline Package	
Vapor Phase (60 seconds)	215˚C
Infrared (15 seconds)	220˚C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

Electrical Characteristics

V_{CC} = 12 V_{DC}, T_A = 25˚C, see test circuit

Symbol	Parameter	Conditions	Min	Typ	Max	Units
TACHOMETER						
	Input Thresholds	V_{IN} = 250 mVp-p @ 1 kHz (Note 2)	±10	±25	±40	mV
	Hysteresis	V_{IN} = 250 mVp-p @ 1 kHz (Note 2)		30		mV
	Offset Voltage	V_{IN} = 250 mVp-p @ 1 kHz (Note 2)				
	LM2907/LM2917			3.5	10	mV
	LM2907-8/LM2917-8			5	15	mV
	Input Bias Current	V_{IN} = ±50 mV_{DC}		0.1	1	µA
V_{OH}	Pin 2	V_{IN} = +125 mV_{DC} (Note 3)		8.3		V
V_{OL}	Pin 2	V_{IN} = −125 mV_{DC} (Note 3)		2.3		V
I_2, I_3	Output Current	V2 = V3 = 6.0V (Note 4)	140	180	240	µA
I_3	Leakage Current	I2 = 0, V3 = 0			0.1	µA
K	Gain Constant	(Note 3)	0.9	1.0	1.1	
	Linearity	f_{IN} = 1 kHz, 5 kHz, 10 kHz (Note 5)	−1.0	0.3	+1.0	%
OP/AMP COMPARATOR						
V_{OS}		V_{IN} = 6.0V		3	10	mV
I_{BIAS}		V_{IN} = 6.0V		50	500	nA
	Input Common-Mode Voltage		0		V_{CC}−1.5V	V
	Voltage Gain			200		V/mV
	Output Sink Current	V_C = 1.0	40	50		mA
	Output Source Current	V_E = V_{CC} −2.0		10		mA
	Saturation Voltage	I_{SINK} = 5 mA		0.1	0.5	V
		I_{SINK} = 20 mA			1.0	V
		I_{SINK} = 50 mA		1.0	1.5	V
ZENER REGULATOR						
	Regulator Voltage	R_{DROP} = 470Ω		7.56		V
	Series Resistance			10.5	15	Ω
	Temperature Stability			+1		mV/˚C
	TOTAL SUPPLY CURRENT			3.8	6	mA

Note 1: For operation in ambient temperatures above 25˚C, the device must be derated based on a 150˚C maximum junction temperature and a thermal resistance of 101˚C/W junction to ambient for LM2907-8 and LM2917-8, and 79˚C/W junction to ambient for LM2907-14 and LM2917-14.

Note 2: Hysteresis is the sum $+V_{TH} - (-V_{TH})$, offset voltage is their difference. See test circuit.

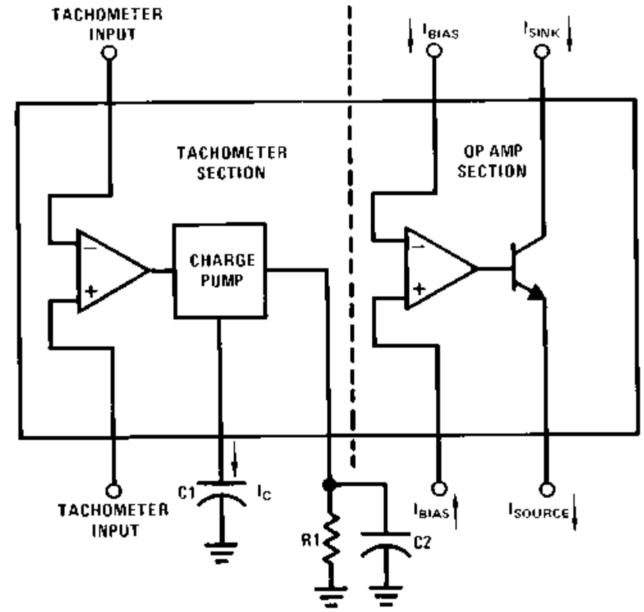
Note 3: V_{OH} is equal to ¾ x V_{CC} − 1 V_{BE}, V_{OL} is equal to ¼ x V_{CC} − 1 V_{BE} therefore $V_{OH} - V_{OL} = V_{CC}/2$. The difference, $V_{OH} - V_{OL}$, and the mirror gain, I_2/I_3, are the two factors that cause the tachometer gain constant to vary from 1.0.

Note 4: Be sure when choosing the time constant R1 x C1 that R1 is such that the maximum anticipated output voltage at pin 3 can be reached with I_3 x R1. The maximum value for R1 is limited by the output resistance of pin 3 which is greater than 10 MΩ typically.

Electrical Characteristics (Continued)

Note 5: Nonlinearity is defined as the deviation of V_{OUT} (@ pin 3) for f_{IN} = 5 kHz from a straight line defined by the V_{OUT} @ 1 kHz and V_{OUT} @ 10 kHz. C1 = 1000 pF, R1 = 68k and C2 = 0.22 mFd.

Test Circuit and Waveform



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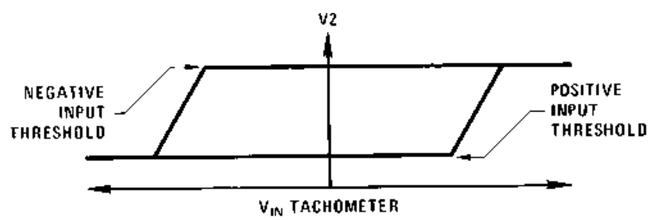
Tachometer Input Threshold Measurement



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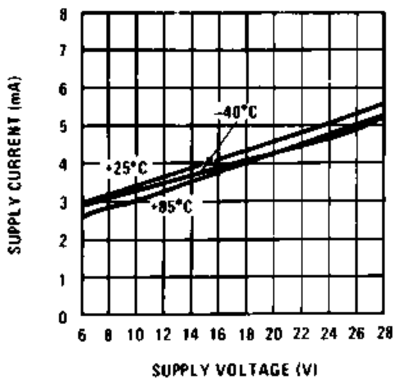
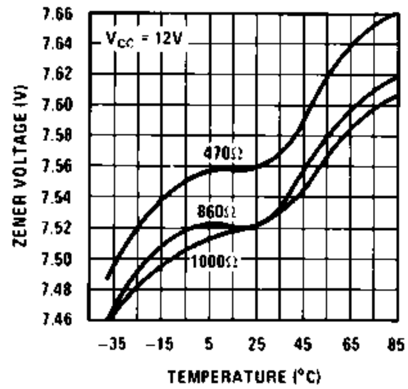
Typical Performance Characteristics

Total Supply Current



00794240

Zener Voltage vs Temperature



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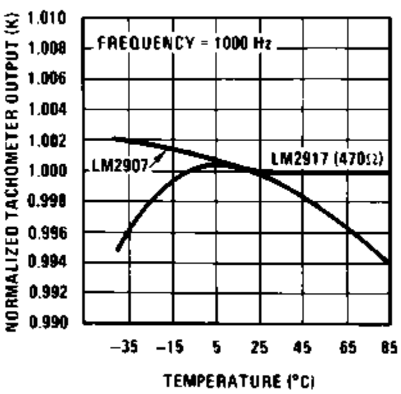
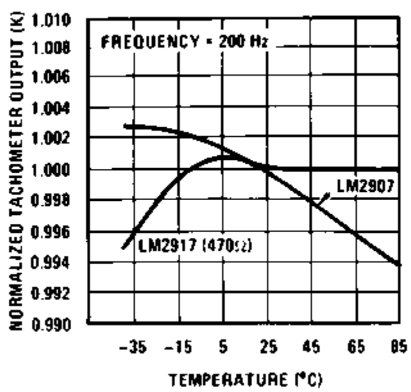
Normalized Tachometer Output vs Temperature



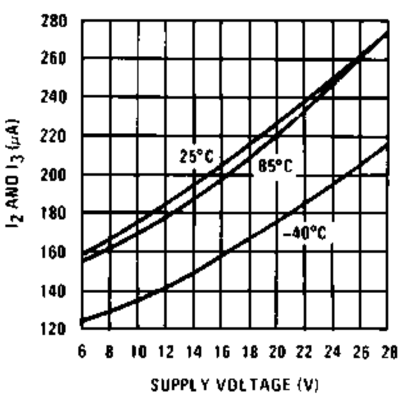
00794242

Normalized Tachometer Output vs Temperature



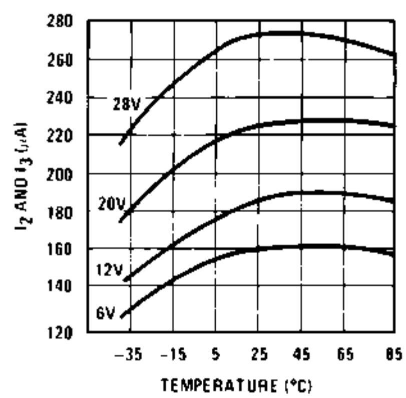
00794243

Tachometer Currents I_2 and I_3 vs Supply Voltage



00794244

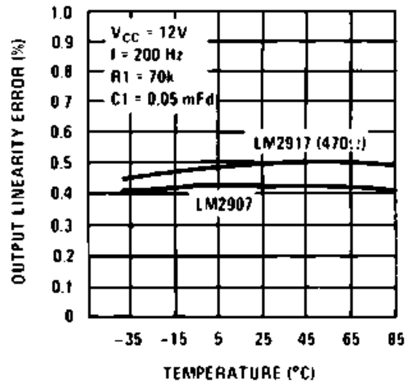
Tachometer Currents I_2 and I_3 vs Temperature



00794245

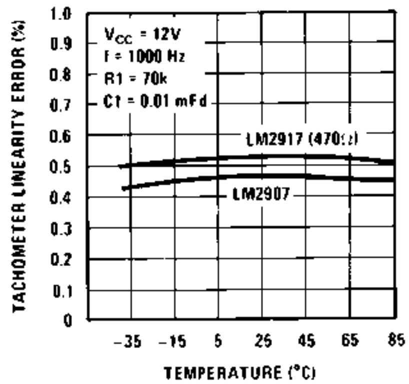
Typical Performance Characteristics (Continued)

Tachometer Linearity vs Temperature



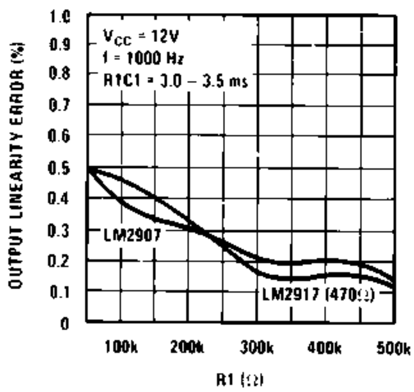
00794246

Tachometer Linearity vs Temperature



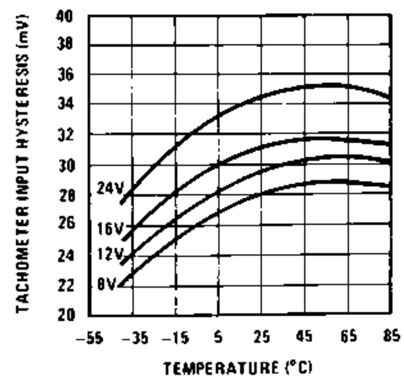
00794247

Tachometer Linearity vs R1



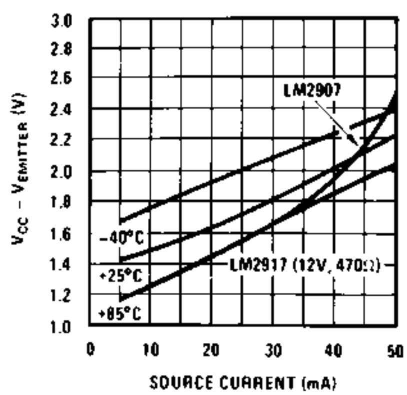
00794248

Tachometer Input Hysteresis vs Temperature



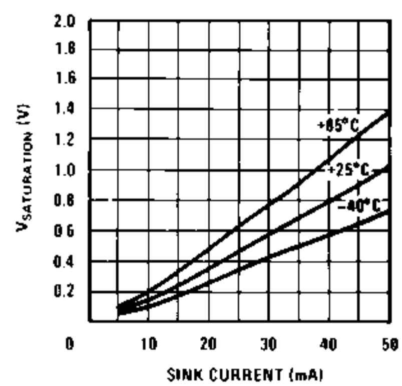
00794249

Op Amp Output Transistor Characteristics



00794250

Op Amp Output Transistor Characteristics



00794251

Applications Information

The LM2907 series of tachometer circuits is designed for minimum external part count applications and maximum versatility. In order to fully exploit its features and advantages let's examine its theory of operation. The first stage of operation is a differential amplifier driving a positive feedback flip-flop circuit. The input threshold voltage is the amount of differential input voltage at which the output of this stage changes state. Two options (LM2907-8, LM2917-8) have one input internally grounded so that an input signal must swing above and below ground and exceed the input thresholds to produce an output. This is offered specifically for magnetic variable reluctance pickups which typically provide a single-ended ac output. This single input is also fully protected against voltage swings to ±28V, which are easily attained with these types of pickups.

The differential input options (LM2907, LM2917) give the user the option of setting his own input switching level and still have the hysteresis around that level for excellent noise rejection in any application. Of course in order to allow the inputs to attain common-mode voltages above ground, input protection is removed and neither input should be taken outside the limits of the supply voltage being used. It is very important that an input not go below ground without some resistance in its lead to limit the current that will then flow in the epi-substrate diode.

Following the input stage is the charge pump where the input frequency is converted to a dc voltage. To do this requires one timing capacitor, one output resistor, and an integrating or filter capacitor. When the input stage changes state (due to a suitable zero crossing or differential voltage on the input) the timing capacitor is either charged or discharged linearly between two voltages whose difference is $V_{CC}/2$. Then in one half cycle of the input frequency or a time equal to 1/2 f_{IN} the change in charge on the timing capacitor is equal to $V_{CC}/2$ x C1. The average amount of current pumped into or out of the capacitor then is:

$$\frac{\Delta Q}{T} = i_{c(AVG)} = C1 \times \frac{V_{CC}}{2} \times (2f_{IN}) = V_{CC} \times f_{IN} \times C1$$

The output circuit mirrors this current very accurately into the load resistor R1, connected to ground, such that if the pulses of current are integrated with a filter capacitor, then $V_O = i_c \times R1$, and the total conversion equation becomes:

$$V_O = V_{CC} \times f_{IN} \times C1 \times R1 \times K$$

Where K is the gain constant—typically 1.0.

The size of C2 is dependent only on the amount of ripple voltage allowable and the required response time.

CHOOSING R1 AND C1

There are some limitations on the choice of R1 and C1 which should be considered for optimum performance. The timing capacitor also provides internal compensation for the charge pump and should be kept larger than 500 pF for very accurate operation. Smaller values can cause an error current on R1, especially at low temperatures. Several considerations must be met when choosing R1. The output current at pin 3 is internally fixed and therefore V_O/R1 must be less than or equal to this value. If R1 is too large, it can become a significant fraction of the output impedance at pin 3 which degrades linearity. Also output ripple voltage must be considered and the size of C2 is affected by R1. An expression that describes the ripple content on pin 3 for a single R1C2 combination is:

$$V_{RIPPLE} = \frac{V_{CC}}{2} \times \frac{C1}{C2} \times \left(1 - \frac{V_{CC} \times f_{IN} \times C1}{I_2}\right) \text{pk-pk}$$

It appears R1 can be chosen independent of ripple, however response time, or the time it takes V_{OUT} to stabilize at a new voltage increases as the size of C2 increases, so a compromise between ripple, response time, and linearity must be chosen carefully.

As a final consideration, the maximum attainable input frequency is determined by V_{CC}, C1 and I_2:

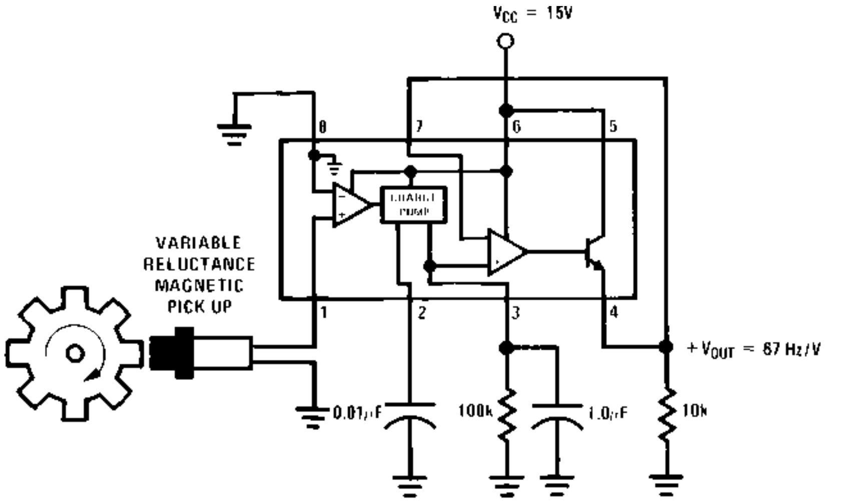
$$f_{MAX} = \frac{I_2}{C1 \times V_{CC}}$$

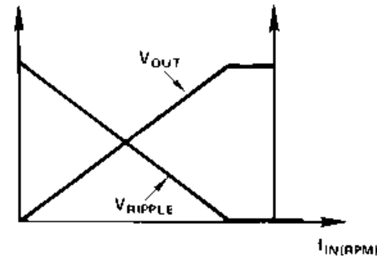
USING ZENER REGULATED OPTIONS (LM2917)

For those applications where an output voltage or current must be obtained independent of supply voltage variations, the LM2917 is offered. The most important consideration in choosing a dropping resistor from the unregulated supply to the device is that the tachometer and op amp circuitry alone require about 3 mA at the voltage level provided by the zener. At low supply voltages there must be some current flowing in the resistor above the 3 mA circuit current to operate the regulator. As an example, if the raw supply varies from 9V to 16V, a resistance of 470Ω will minimize the zener voltage variation to 160 mV. If the resistance goes under 400Ω or over 600Ω the zener variation quickly rises above 200 mV for the same input variation.

Typical Applications

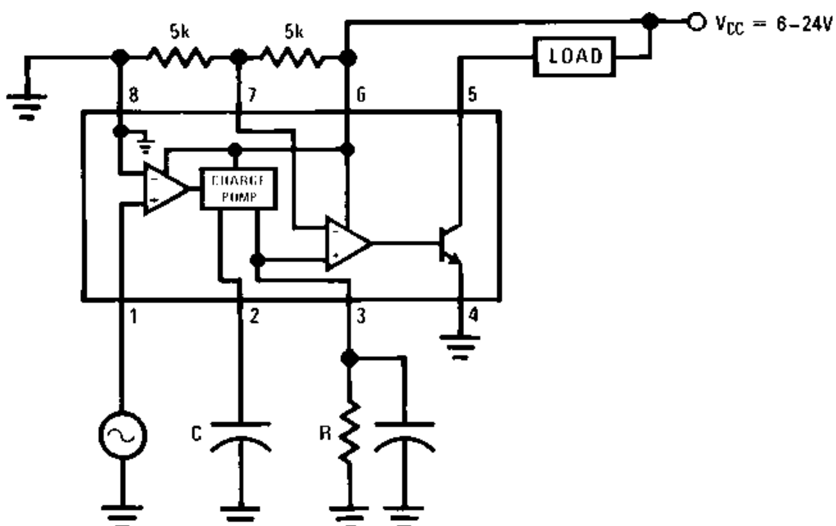
Minimum Component Tachometer





00794208

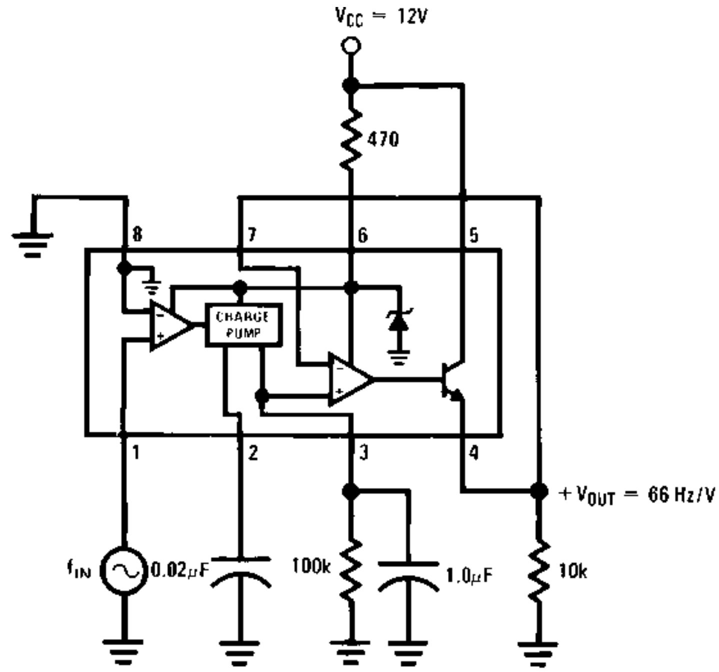
"Speed Switch" Load is Energized When $f_{IN} \geq \frac{1}{2RC}$



00794209

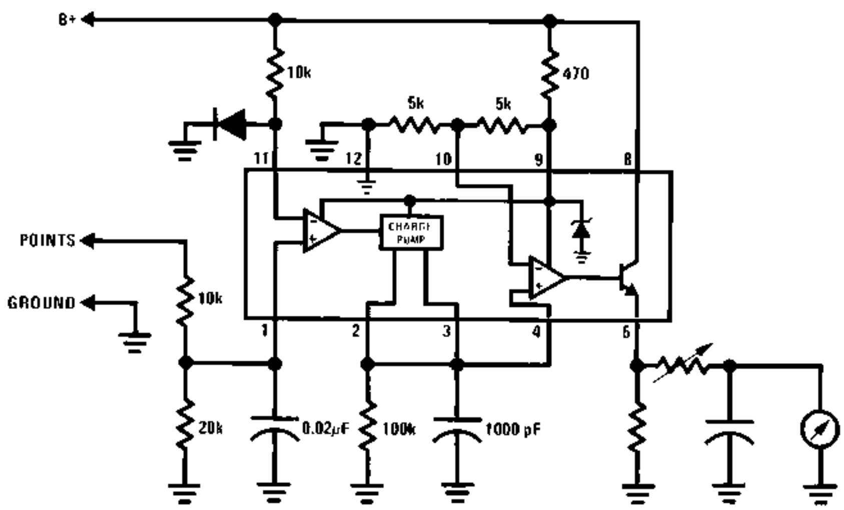
Typical Applications (Continued)

Zener Regulated Frequency to Voltage Converter



00794210

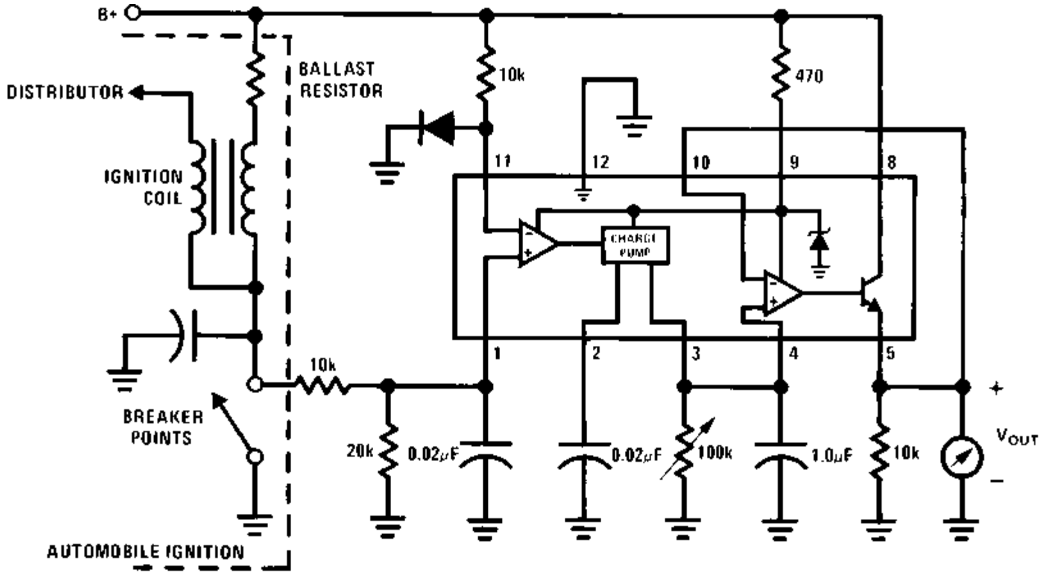
Breaker Point Dwell Meter



00794211

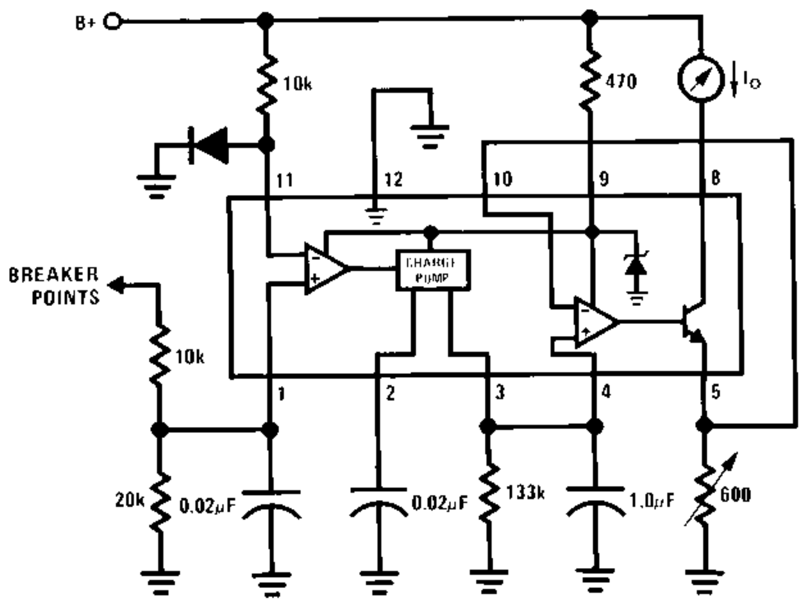
Typical Applications (Continued)

Voltage Driven Meter Indicating Engine RPM
V_O = 6V @ 400 Hz or 6000 ERPM (8 Cylinder Engine)



00794212

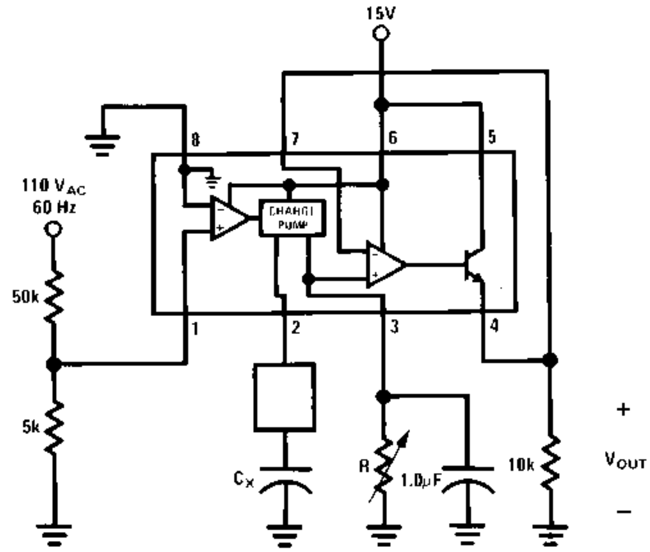
Current Driven Meter Indicating Engine RPM
I_O = 10 mA @ 300 Hz or 6000 ERPM (6 Cylinder Engine)



00794213

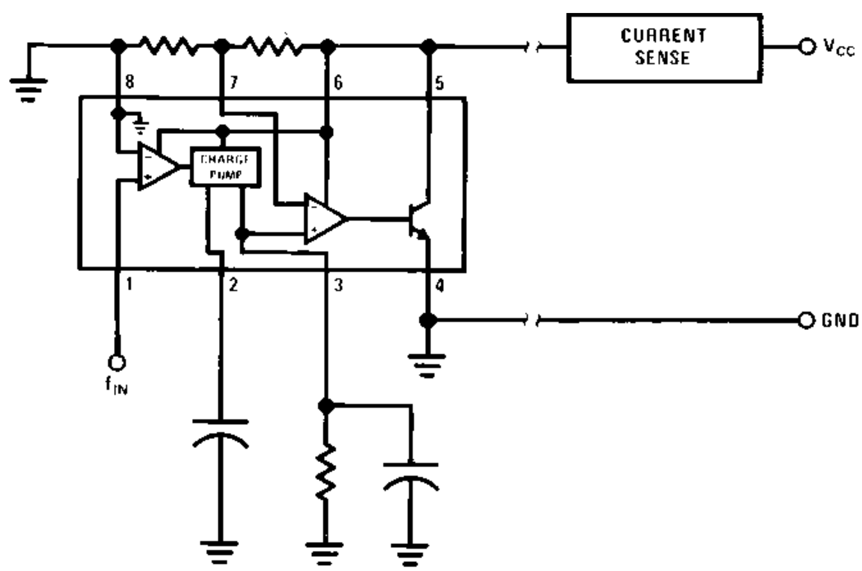
Typical Applications (Continued)

Capacitance Meter
V_{OUT} = 1V–10V for C_X = 0.01 to 0.1 mFd
(R = 111k)



00794214

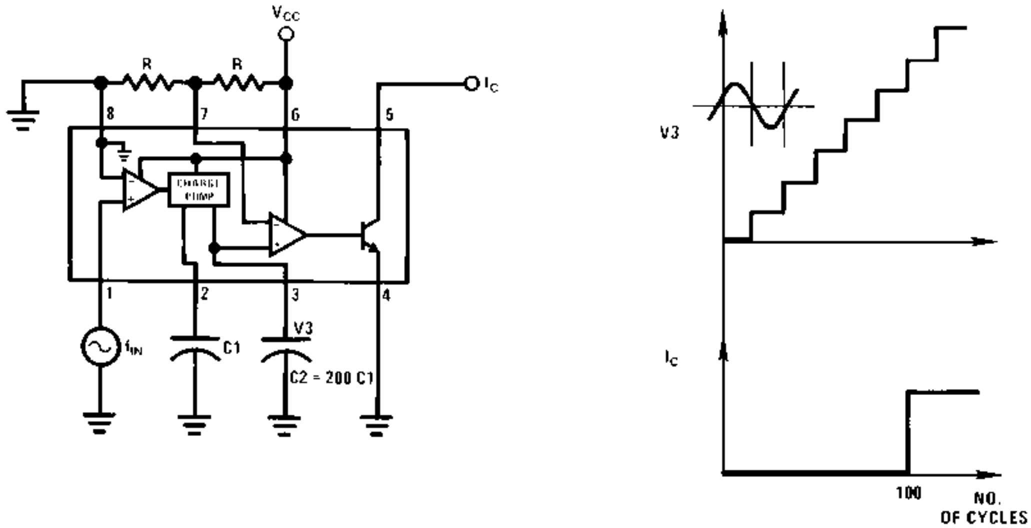
Two-Wire Remote Speed Switch



00794215

Typical Applications (Continued)

100 Cycle Delay Switch



00794216

V3 steps up in voltage by the amount $\frac{V_{CC} \times C1}{C2}$

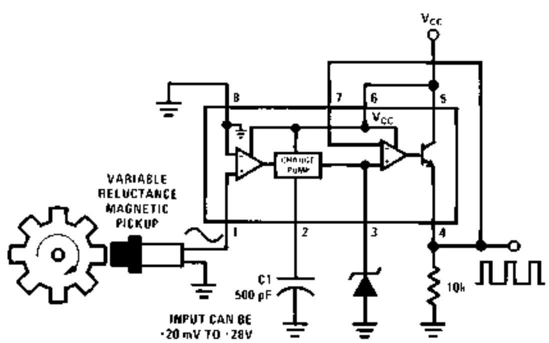
for each complete input cycle (2 zero crossings)

Example:

if C2 = 200 C1 after 100 consecutive input cycles.

V3 = 1/2 V_{CC}

Variable Reluctance Magnetic Pickup Buffer Circuits



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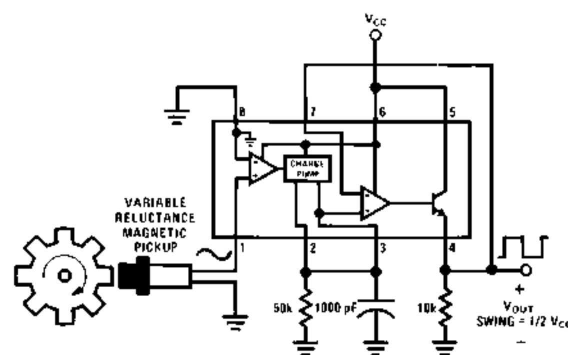


00794217

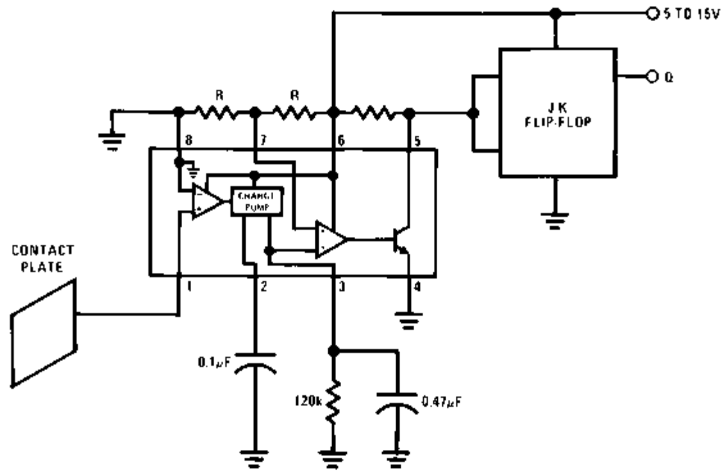
Precision two-shot output frequency equals twice input frequency.

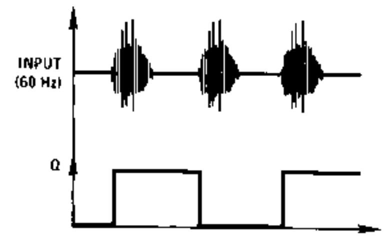
$$\text{Pulse width} = \frac{V_{CC}}{2} \frac{C1}{I2}$$

Pulse height = V_{ZENER}

Typical Applications (Continued)

Finger Touch or Contact Switch





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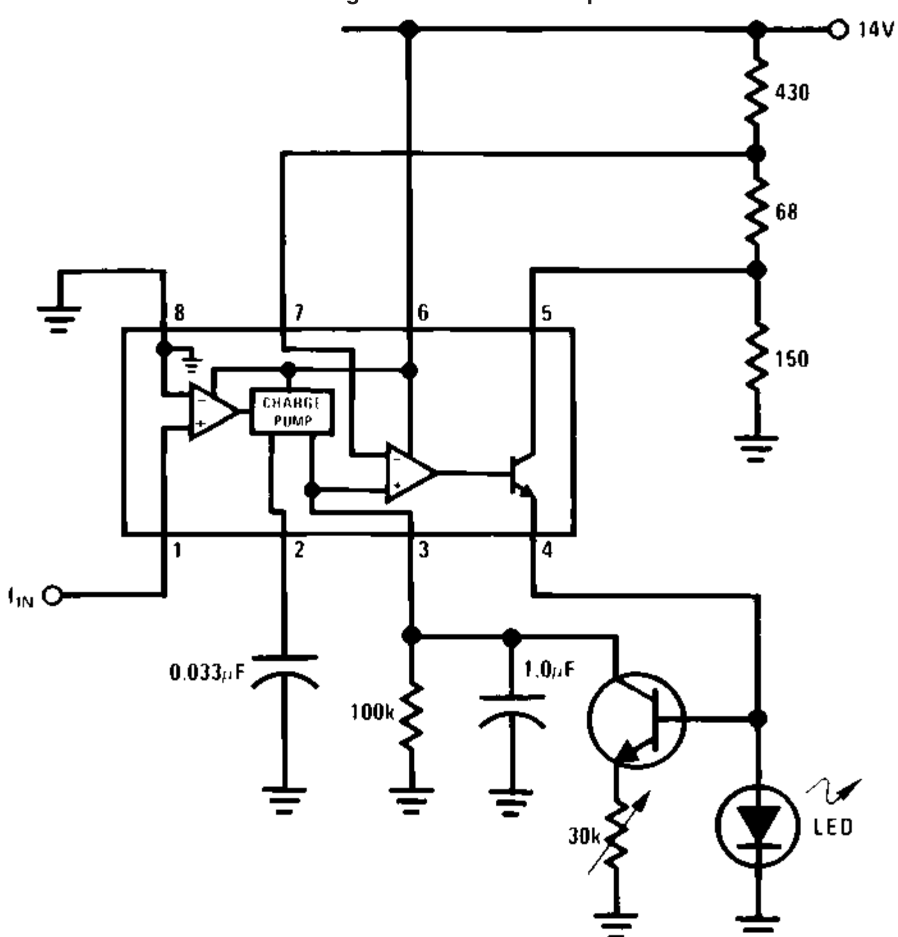
00794218

Flashing LED Indicates Overspeed

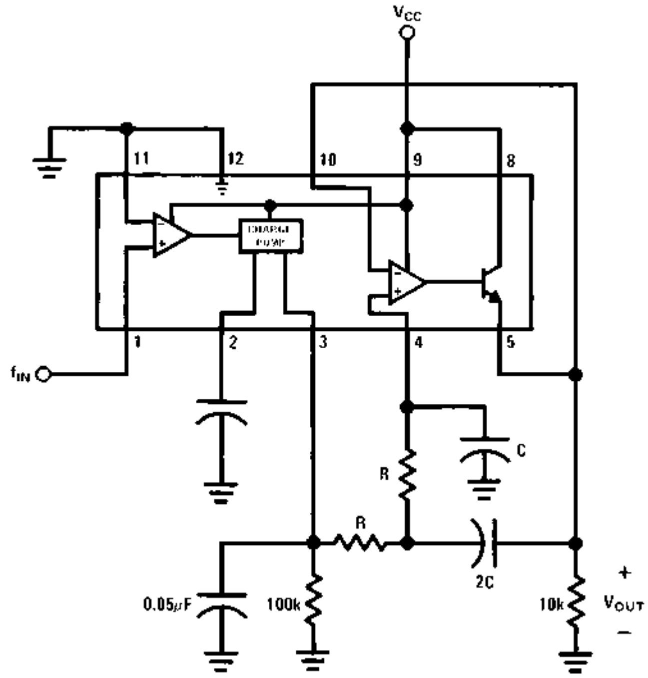


00794220

Flashing begins when $f_{IN} \geq 100$ Hz.
Flash rate increases with input frequency
increase beyond trip point.

Typical Applications (Continued)

Frequency to Voltage Converter with 2 Pole Butterworth Filter to Reduce Ripple

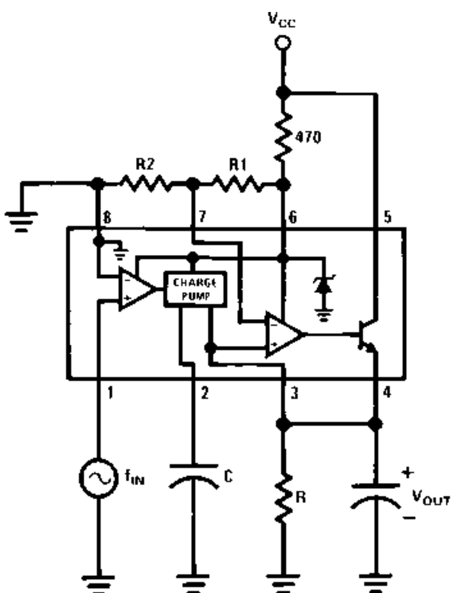


00794221

$$f_{POLE} = \frac{0.707}{2\pi RC}$$

$$\tau_{RESPONSE} = \frac{2.57}{2\pi f_{POLE}}$$

Overspeed Latch



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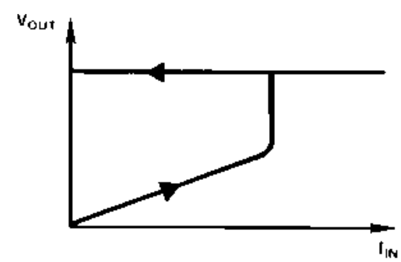


00794223

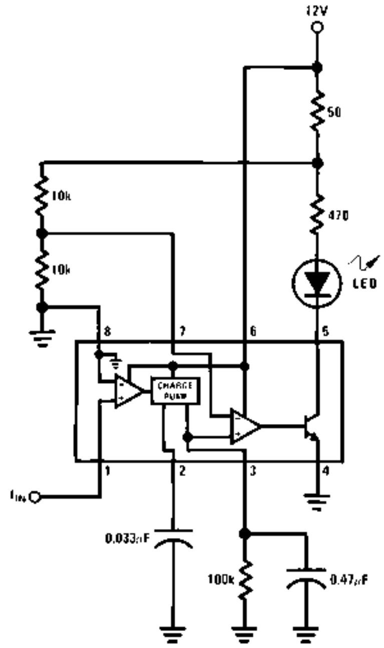
Output latches when

$$f_{IN} = \frac{R2}{R1 + R2}\frac{1}{RC}$$

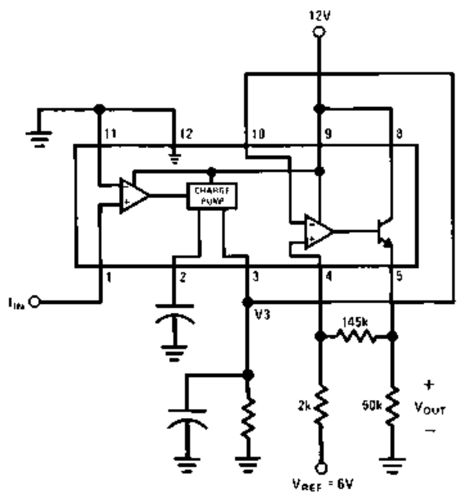
Reset by removing V_{CC}.

Typical Applications (Continued)

Some Frequency Switch Applications May Require Hysteresis in the Comparator Function Which can be Implemented in Several Ways:



00794224



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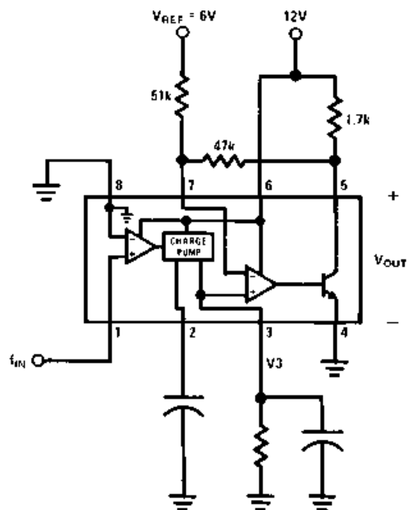

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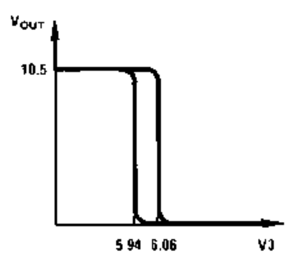

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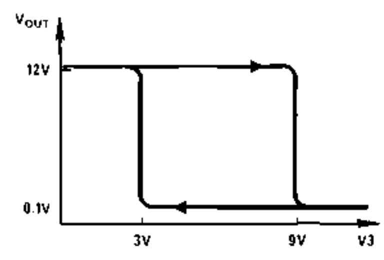
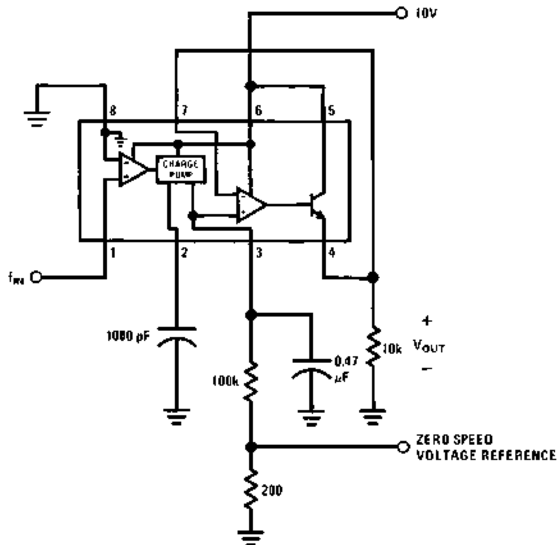


00794228

Typical Applications (Continued)

Changing the Output Voltage for an Input Frequency of Zero



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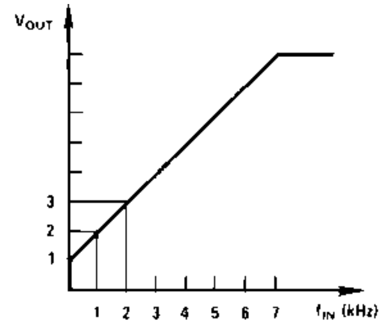
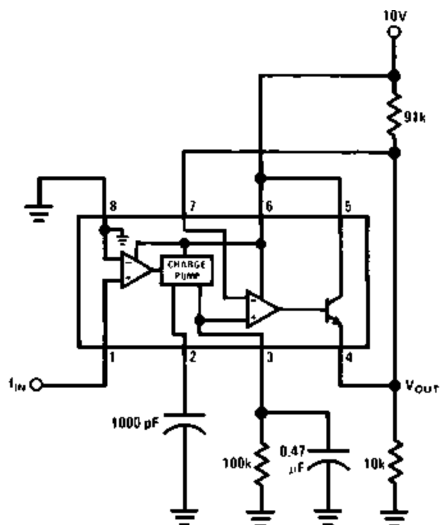


00794230

Changing Tachometer Gain Curve or Clamping the Minimum Output Voltage



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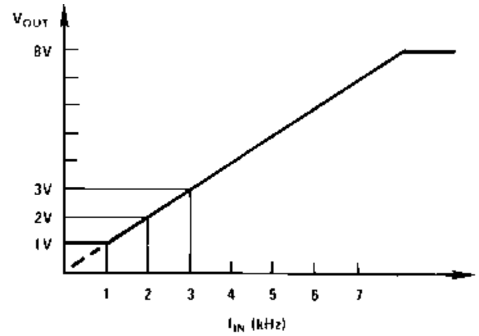
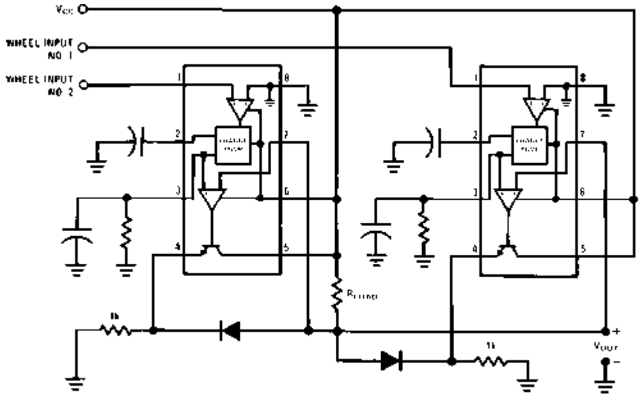


00794232

Anti-Skid Circuit Functions

"Select-Low" Circuit



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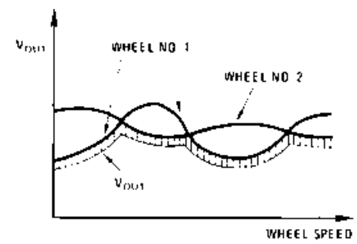
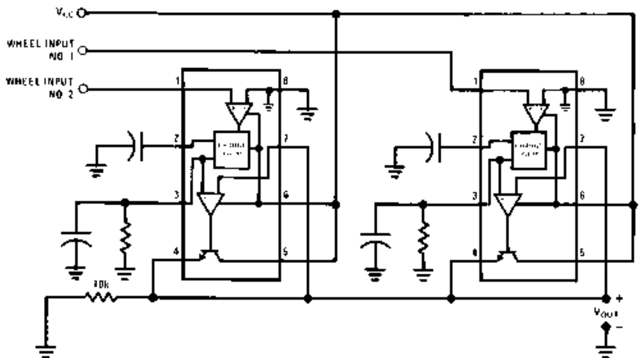


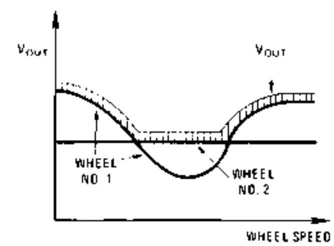
00794234

V_{OUT} is proportional to the lower of the two input wheel speeds.

"Select-High" Circuit



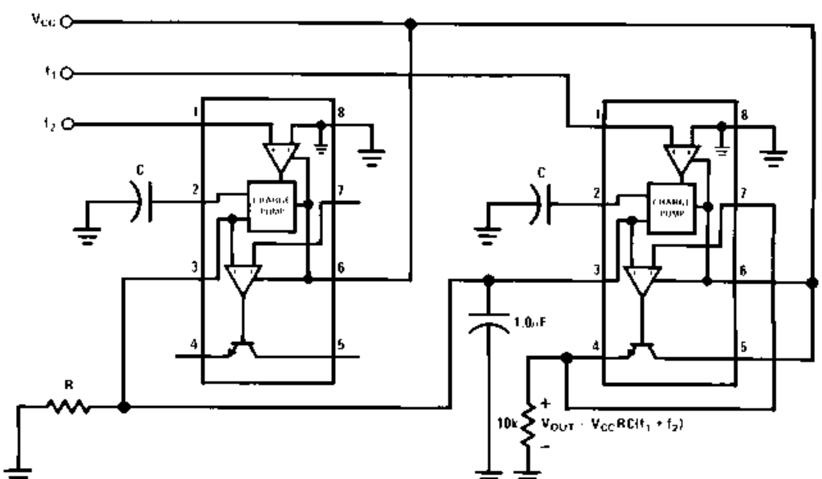
00794235



00794236

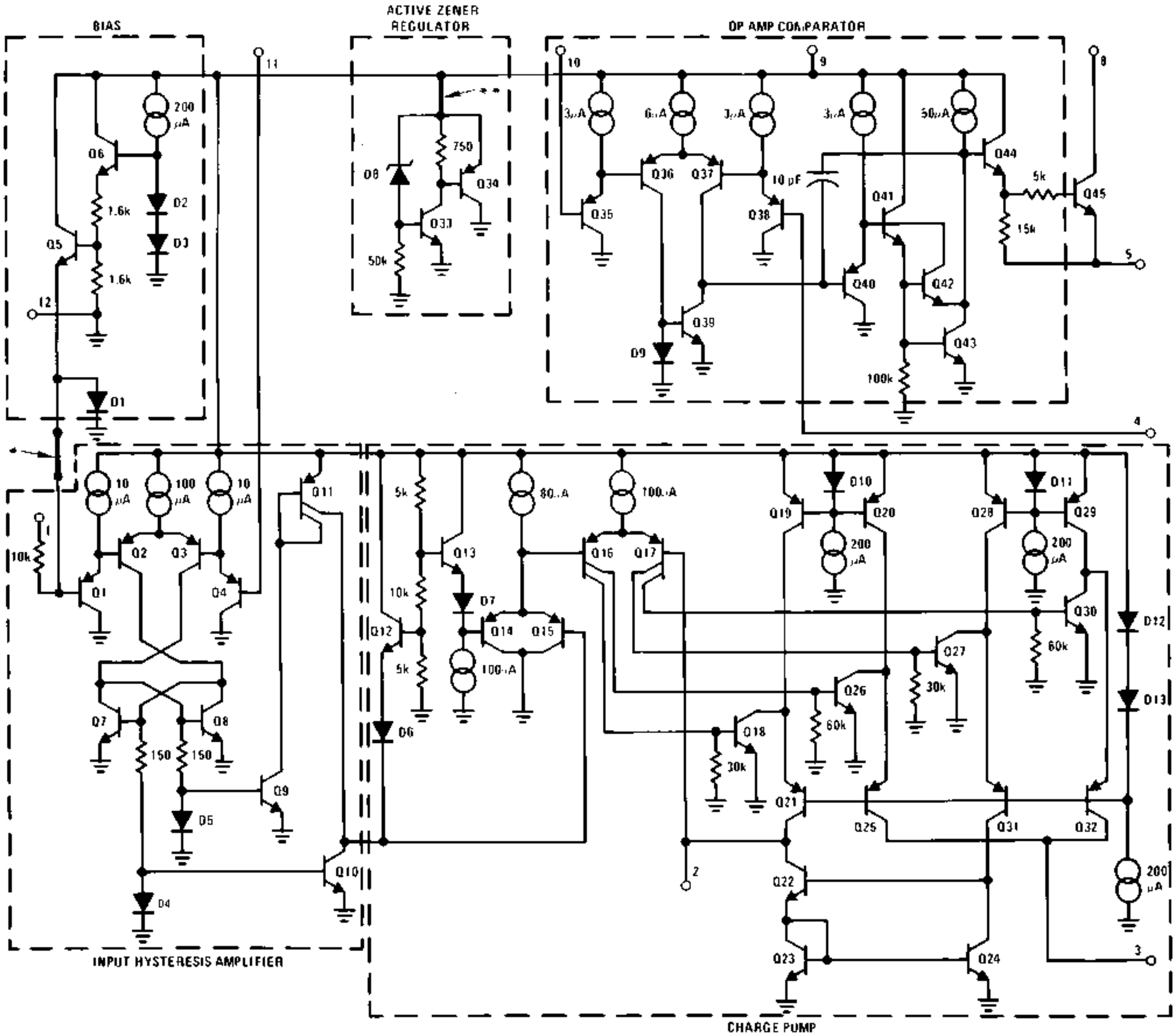
V_{OUT} is proportional to the higher of the two input wheel speeds.

"Select-Average" Circuit



00794237

Equivalent Schematic Diagram

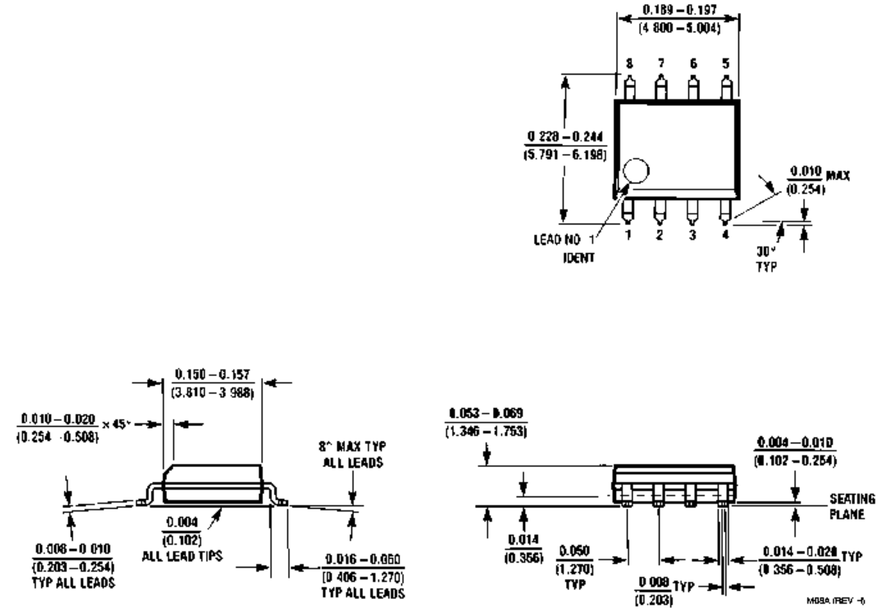


00794238

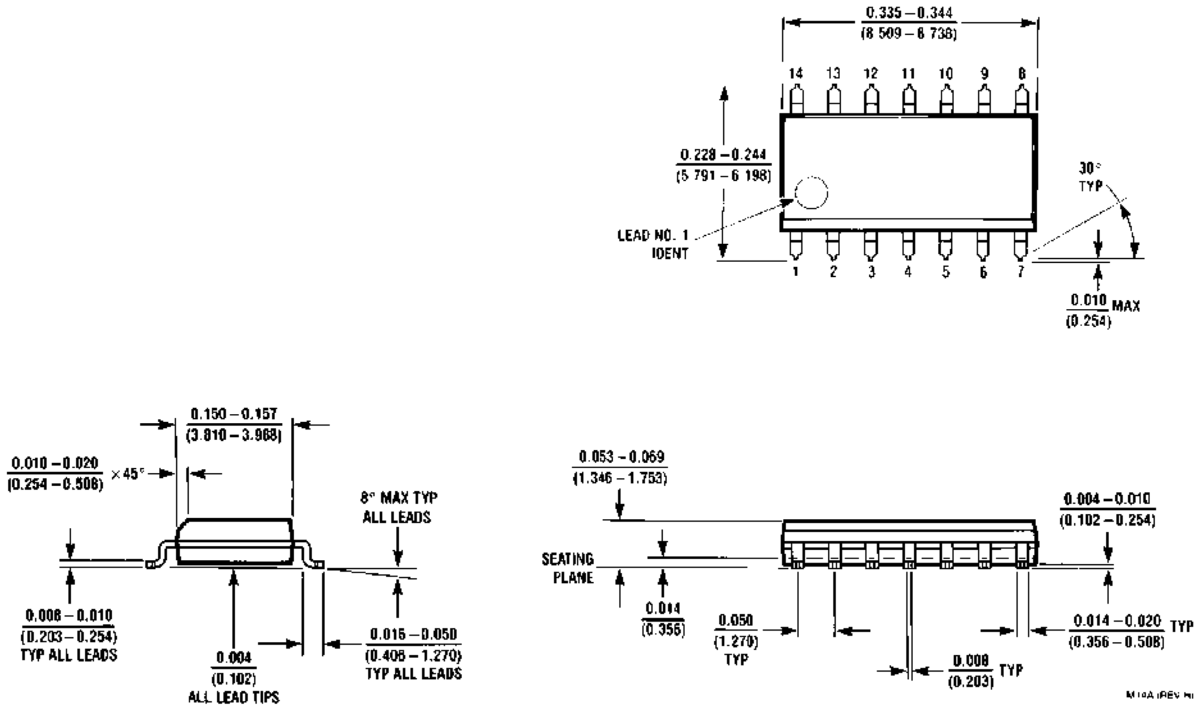
*This connection made on LM2907-8 and LM2917-8 only.

**This connection made on LM2917 and LM2917-8 only.

Physical Dimensions inches (millimeters) unless otherwise noted

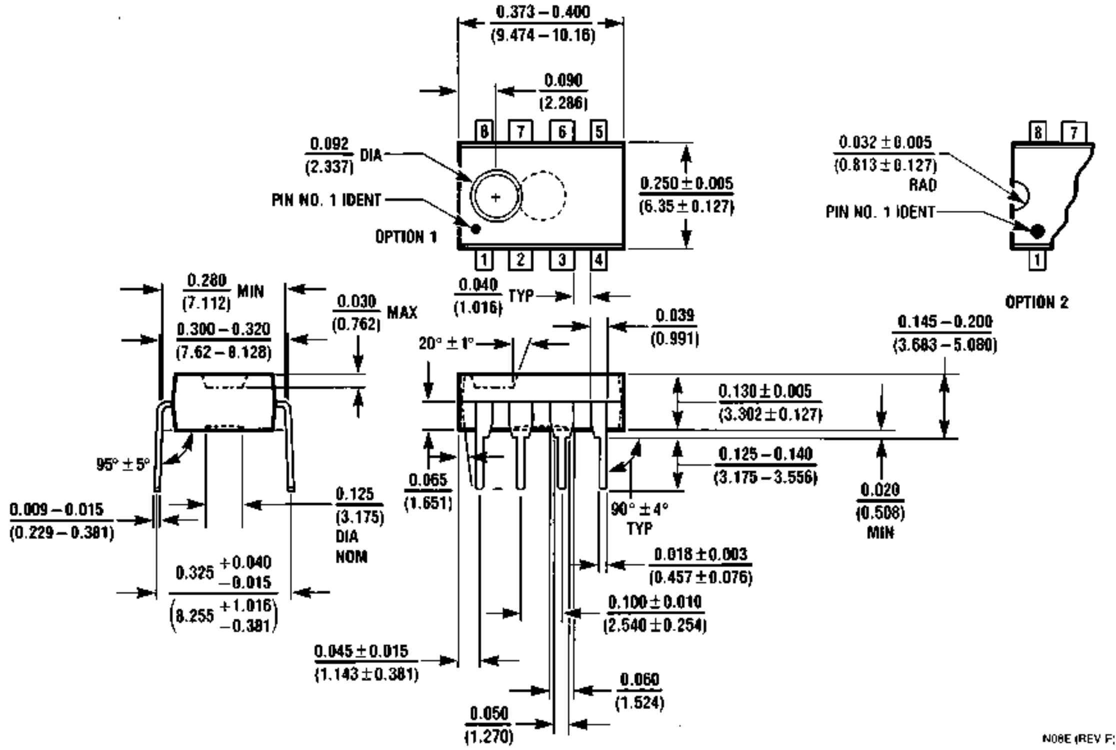


8-Lead (0.150" Wide) Molded Small Outline Package, JEDEC
Order Number LM2907M-8 or LM2917M-8
NS Package Number M08A

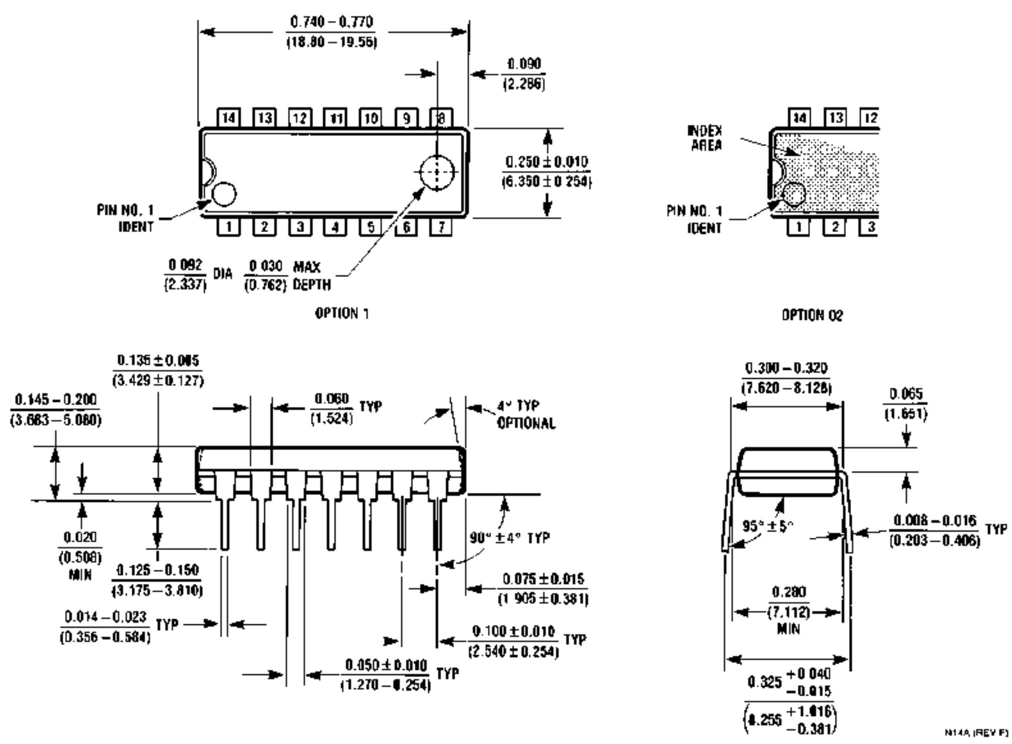


Molded SO Package (M)
Order Number LM2907M or LM2917M
NS Package Number M14A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Molded Dual-In-Line Package (N)
Order Number LM2907N-8 or LM2917N-8
NS Package Number N08E



Molded Dual-In-Line Package (N)
Order Number LM2907N or LM2917N
NS Package Number N14A

Notes

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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Tips for Designing, Building, and Flying Wind Generators

Raising a wind machine and watching it produce power is an exhilharating experience. And if it does fly apart during a gale, the show is often worth the price of admission--plus you've obtained more knowledge for the next try!

| Site | Tower | Anemometers | Generators & Alternators | Cut-In Speed | Alternator Design |
| Rotor Design & Carving | Furling & Shutdown | Regulation | Slip Rings |

Where do you start???

First, do your homework! Why re-invent the wheel when you can learn from others' successes and failures? There are many useful books, websites and plans available. Check our recommended reading list HERE.

First, figure out how big a wind generator you are willing to tackle, either commercial or home-brewed. There is really only one important measure of windmill size...the *swept area.* That's how many square feet (or meters, if you are into that sort of thing) of area the windmill's blades cover during a rotation. The formula for swept area is Pi r^2, where Pi is 3.1415 and r is the radius of your prop. The available power from the wind increases dramatically with the swept area...but so do the stresses on your blades, tower, bearings, tail. More stress means stronger engineering and materials are required, and a much larger, more complicated and expensive project. Windmills with props of 4 feet diameter and under are fairly easy to design, build and handle. Once you get into the 7-8 foot range, everything must be very strong and rock-solid. At 10 feet and above, your materials and engineering need to be top-notch! We have learned this from the experience of watching windmills blow up, and we highly recommend building a smaller windmill like our 4 foot diameter Wood A-X or the 4-foot model in Hugh Piggott's Axial Flux Alternator Windmill Plans before trying a large windmill.

Here's some of our advice and ramblings about various aspects of designing, flying, building and destroying wind generators.

Site

- **Location--**First, figure out the direction from which the prevailing winds in your area usually come. You can determine this by observation during wind storms, and by looking at the trees near your site. Trees that are all leaning the same direction and that have branches mostly on one side of the trunk are a good indication of prevailing wind speed and direction. Local airports and weather stations can sometimes provide you with this information. The National Renewable Energy Laboratory in Golden, CO publishes an excellent Wind Energy Resource Atlas of the United States on the internet, for free. A Logging anemometer that also records wind direction can be useful here too, though expensive.
- **Height:** Flying a wind generator close to the ground is like mounting solar panels in the shade! Your wind generator should be located at least 30 feet above any obstruction within 400 feet -- many sources recommend even more. Of course, this may be impractical, so just keep in mind that turbulance caused by obstructions will rob you of huge amounts of potential power, and cause extra stress on all components of your wind machine. A higher tower is usually MUCH easier on your machine! At least make sure there are no obstructions between your windmill and the direction from which the wind usually blows. Remember that even an obstacle that's behind or to the side of your turbine in the prevailing wind will cause turbulance, rob you of power, and beat up your machine.
- **Distance:** The distance between your wind generator and your batteries can also be a problem--the closer the better, to avoid losses in long wires and to keep the wire size required down to a reasonable thickness and cost. 12 volt systems are the worst for power transmission losses--you end up needing very thick wire. A 24v or 48v battery bank can save you big money on wire! Transformers can be used to keep the voltage high for long distances, but they cause added complexity and losses.

Tower

Check out our TOWERS page for some home-brewed solutions that are cheap and easy to fabricate, plus lots of details and pictures. There's also lots of tower information, discussion and pictures available by Searching the Otherpower discussion board for 'towers'.

- Your tower must be *extremely* sturdy, well-anchored, and tall enough to get above obstructions. We've seen 1.5 inch steel pipe bend like a pipe cleaner in 50 mph winds, underneath a wind machine with only an 8-foot prop. Some wind energy guidelines tell you to plan on spending at LEAST as much on your tower and power wiring as on the wind generator itself!
- **Do you like to climb?** The two basic kinds of tower are the Tilt-Up and Stationary. A stationary tower is the most sturdy and trouble-free, but you have to climb it to install, maintain or remove the wind machine. A crane is often used for installation, an expensive proposition--though you can do it yourself by climbing the tower and moving a gin pole up it as you add each new section. If

climbing towers disagrees with you, go for a tilt-up. Then all maintenence can be performed while standing safely on solid ground.

- **Roof mount?** We strongly recommend against mounting a wind generator on your roof. Though the manufacturer of the AIR 403 says it works, we have observed first-hand the vibration and noise during a windstorm in two different roof installations...it is VERY noticable and irritating. And keep in mind that the AIR 403 is a very small unit (only a 1.3 meter prop) that makes very little power...a larger mill would be unbearable, and possibly dangerous to your house itself. Most commercial and homemade wind generators don't make much physical noise, but some vibration is unavoidable due to the nature of permanent magnet alternators. Listen to the vibration of Ward's 7 foot diameter windmill (12 second .WAV file, 140K) and hear why we don't recommend roof mounts! Ward's mill is actually very quiet; this audio clip was taken with the microphone pressed against the steel mast to give an idea of the vibration that would be transmitted into your house with a roof mount. The buzzing sound is the vibration of magnets spinning past coils; the clanking is from the sectional tower itself. The windmill rotor itself makes very little noise.

Anemometers

- It is essential to know the real windspeed in any wind generator installation, commercial or homemade. This allows you to see if the machine is performing correctly, and extremely high windspeeds might be a clue that you should shut the mill down for the duration of the storm. If you plan on investing significant money in wind power, a logging anemometer might help you decide if your local wind resource is worth the investment. Commercial anemometers and weather stations are very expensive, but can be found with a quick Google search...you can also try one of the homebrew options below.
- **Build your own anemometer:** We built an accurate anemometer for under $10 using plastic Easter eggs. See it here! It counts frequency with a simple circuit, and can be adapted to use with computer data acquisition equipment. Another option uses a pre-fabricated cup assembly and a bicycle speedometer, you can see our page about it HERE.
- **Logging anemometer kit:** This ingenious kit is from Australia and costs less than $100 US, including shipping. It tracks wind speed and direction, and logs data to its own memory, including average and peak readings. And, it interfaces directly to a PC...your wind data can import live right into a spreadsheet! See it here.

Generators and Alternators

- **Terms--**On our site, we try to use the term *Generator* to describe a machine that produces Direct Current (DC), and use the term *Alternator* to describe a machine that produces Alternating Current (AC). However, the term Generator is also used generically to describe any machine that produces electricity when the shaft is spun.
- **Options--**The alternator or generator is the heart of your wind machine, and it must be both properly sized to match your swept area, and produce the right type and voltage of power to match

your application. Options include commercial and homemade permanent magnet (PM) alternators, PM converted induction motors, DC generators, DC brushless PM motors, vehicle alternators, and induction motors.

We cover the different types extensively on our Alternator and Generator Comparison page.

- **Application--**Wind-generated electricity can be used for battery charging, heating, and for connection with the power grid. All of our designs and information are about battery charging, as we heat with wood and the nearest power line is 12 miles away from Otherpower.com headquarters.
- **Single Phase vs. Three Phase--**3 phase offers some advantages over single phase in most alternators. Most small commercial wind turbines use 3 phase alternators, and then rectify the output to DC (direct current) for charging batteries. When building an alternator from scratch, single phase seems attractive because it is simple and easy to understand. 3 phase is not really any more difficult. For some details, look at some of our later wind turbine experiments vs some of the earlier ones. Going 3 phase allows for squeezing more power from a smaller alternator. It significantly reduces line loss, and it runs with less vibration. Older single phase alternators we made vibrate much more (and make more noise) than 3 phase machines.
- **Speed--**The shaft speed is a very crucial factor in all types of alternator and generator. The unit needs to make higher voltages at lower rpms, otherwise it is not suited for wind power use. This goes for all power units...even motors used as generators and alternators should be rated for low rpms. This is also why vehicle alternators are not suited for wind power use, see our Alternator and Generator Comparison page for more details.
- **Start-Up Speed--**This is the windspeed at which the rotor starts turning. It should spin smoothly and easily when you turn it by hand, and keep spinning for a few seconds. Designs that 'cog' from magnetic force or that use gears or pulleys to increase shaft speed will be poor at start up. A good design can start spinning in 5 mph winds and cut in at 7 mph.
- **Cut-In Speed--**A wind generator does not start pushing power into the battery bank until the generator or alternator voltage gets higher than the battery bank voltage. Higher shaft speed means higher voltage in all generators and alternators, and you want to try and get the highest shaft speed possible in low winds--without sacrificing high-wind performance. Most commercial wind generators cut in at 8-12 mph. The generator's low-speed voltage performance, the design of the rotor (the blades and hub), and the wind behavior all factor into where cut-in will occur.
- **Voltage Regulation--**With battery-charging windmills, voltage control is not generally needed--until the batteries fill up. Even if your alternator is producing an open-circuit voltage of 90 volts, the battery bank will hold the system voltage down to its own level. Once the betteries are full, you'll need to send the windmill's output to a 'dump load' such as a heating element. This regulation can be done manually by simple turning on an electric heater, stereo, or lights. Automatic systems can be built or purchased too.
- **Battery Bank Voltage--**In addition to having less line loss, 24v and 48v power systems give other significant advantages in wind alternator systems. An alternator that cuts in at 300 rpm into a 12v battery bank will not cut in until 600 rpm into a 24v battery bank. However, the same machine may produce half again as much power at higher speeds into a 24v battery than into a 12v one.

This is because of...

- **Inefficiency--**Every generator has a certain speed at which it runs most efficiently. But since the wind is not constant, we must try to design to a happy medium. As the wind speed rises, the raw power coming into the generator from the wind becomes more than the generator can effectively use, and it gets more and more inefficient. This power is wasted as heat in the stator coils. Alternators with wound fields can adjust the magnetic flux inside to run most efficiently, but PM alternators cannot. An alternator that uses many windings of thin wire will have better low-speed performance than one that uses fewer windings of thicker wire, but higher internal resistance. This means it will become inefficient more quickly when producing higher amperage as wind speeds and power output rise. The formula used to calculate power wasted from inefficiency is AMPS^2 * RESISTANCE = Power wasted as heat in the alternator windings (in watts).
- **What does this mean in practice?** Compare the performance of our Volvo Disk Brake Alternator to that of our Induction Motor PM Conversion Alternator. The Volvo alternator internal resistance is 1/4 ohm, while the converted motor's resistance is 4 ohms. The conversion alternator reaches 12 volts at very low rpms for cut-in, but look what happens at 10 amps of output: 400 watts being used as heat while charging the batteries at 130 watts. With the Volvo alternator at 10 amps, only 25 watts are used up as heat, and at 50 amps it is wasting 625 watts while charging at 600 watts...and therefore is starting to become inefficient.

Alternator Design

- **Factors--**Making PM alternators from scratch is sort of a "black art"--there are many factors that enter in to it, we try to discuss some of them below. And then, you must add in another important factor, the design of the blades. We discuss that below also. We didn't start building windmills and alternators by doing a bunch of math...we just jumped right in, made lots of mistakes, and eventually wound up with a satisfactory design by observing performance and changing one variable at a time!
- **Bearings--**The operative word here is STRONG. Besides having to withstand vibration and high rotation speed, there is a significant amount of thrust back on the bearings from the wind, and it increases geometrically as the prop size increases. That's why we've moved to using automobile wheel bearings in our designs, they are tapered and designed to take the thrust loads. The front bearings in our converted AC induction motors have so far held up well, but they are not designed for that kind of load. DC tape drive motors are especially vulnerable--the front bearing will eventually fail dramatically in high winds if extra bearings are not added.
- **Air Gap--**This is the distance between the magnets and the laminates in a single magnet rotor design, or between two magnets in a dual magnet rotor design. The smaller the distance, the better the alternator performs. This means it's important to keep the coils as flat as possible, and to make the armature fit very precisely near the stator...if it is not perfectly square, the air gap will be larger on one side of the alternator than the other, and performance will be compromised. Halving the airgap gives 4 times as much magnetic flux.
- **Number of Poles--**A 'pole' is either the North or South pole of a magnet. Generally when building an alternator we need a seperate magnet for each pole. The faster that alternating north and south

magnets poles pass the coils, the more voltage and current are produced. But surface area is important as well. If we have a very narrow magnet (required for using many poles), the field strength would be much weaker over a distance than a wider magnet. So like all things with making wind turbines, there is a compromise to be made. We choose a number of poles that allows for reasonably sized coils and a good strong magnetic field through whatever airgap we wind up with. It must always be an even number. If it's to be a single phase machine, we can have either the same number, or twice the number of poles as we do coils. If it's a 3 phase machine we like 4 poles for every 3 coils, although there are certainly other very feasable options. In most cases, for a 3 phase machine we'd have somewhere between 8 and 16 poles (magnets) unless perhaps the machine were to be very large.

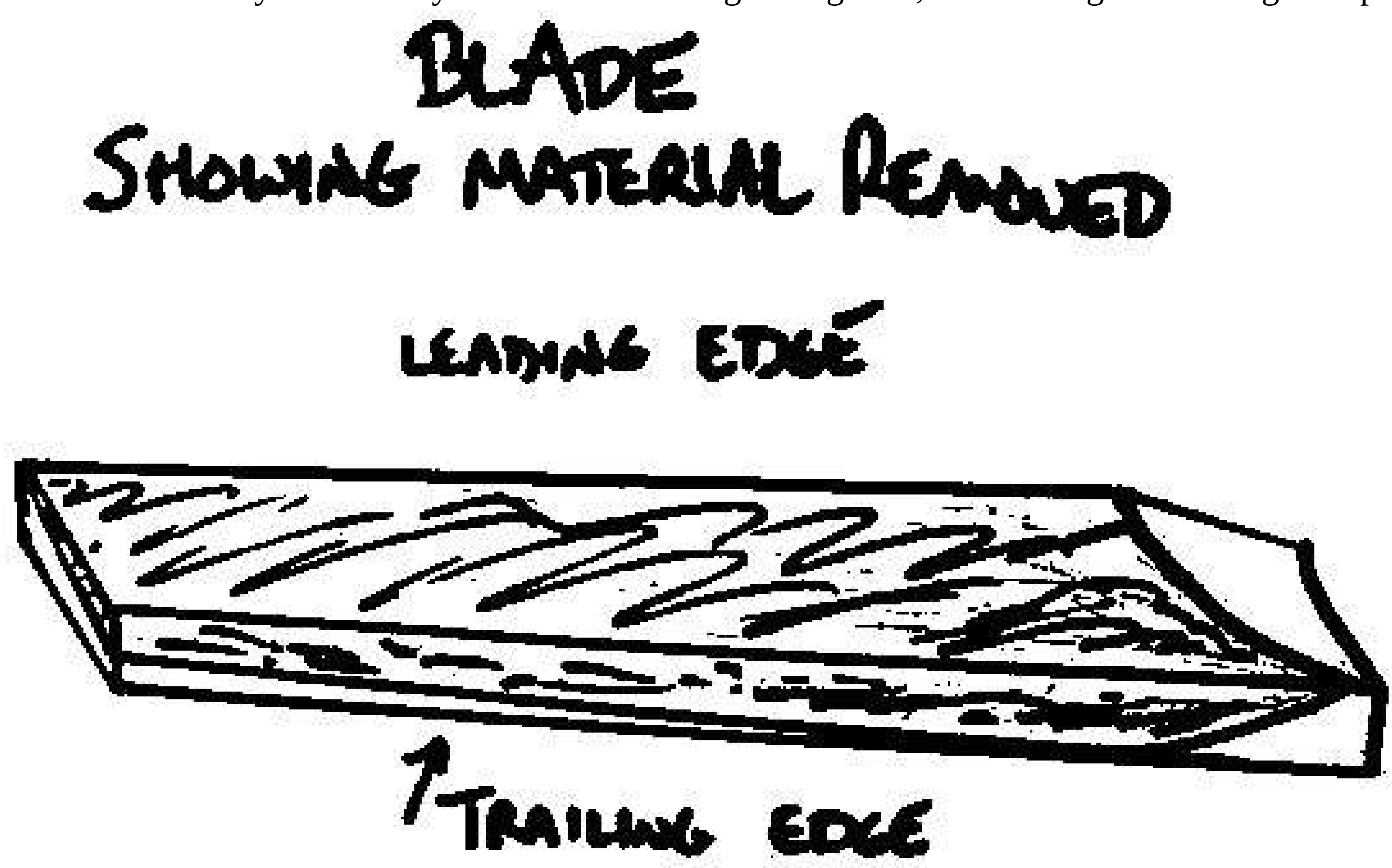
- **Series or Parallel? Star or Delta?**When coils are connected in series, the voltage increases and so does resistance. When connected in parallel, voltage stays the same but amperage increases and resistance decreases. Also, parallel connections in an alternator can cause current to flow where you don't want it to, called 'parasitic losses.' The correct configuration for your project depends on many factors. Windstuff now's 3-Phase Basics Page has some great diagrams that explain 3-phase, star and delta.
- **Magnets--**The stronger, the better. The larger and stronger your magnets are, the more power you can produce in a smaller alternator. Neodymium-Iron-Boron ("rare earth", NdFeB) are by far the strongest permanent magnets known to man, and are ideal for building permanent magnet alterantors. Many older designs call for strong ceramic magnets, this was mainly because of price. We do sell large, high-grade ceramic magnets that are suitable for alternator use, but in practice NdFeB magnets will give over 4 times as much power in the same space than ceramics. Plus, prices on large NdFeB magnets have dropped dramatically since they were first invented in the 1980s. We have a big selection of them on our web Shopping Cart, including quantity discounts on sets of large magnets for building alternators. **WARNING! Large NdFeB magnets are EXTREMELY powerful, and can cause serious injury. Read our Magnet Safety Warnings before handling large magnets.**
- **Wire--**Enamelled magnet wire is always used for winding the stator, because the insulation is very thin and heat-resistant. This allows for more turns of wire per coil. It is very difficult to strip, use a razor knife or sandpaper, and be sure to strip each lead thoroughly! Choosing the gauge of wire is yet another trade off--thinner gauge wire allows for more turns per coil and thus better voltage for low-speed cut-in, but using longer, thinner wire gives higher resistance and therefore the unit becomes inefficient faster at high speeds. Our larger alternators use 10-16 gauge wire, the smaller ones 18-22 gauge.
- **Magnetic Circuit--**Picture a magnet to be almost like a battery. The lines of force from a magnet are said to originate at one pole and return to the other, just like a battery. Air is a poor conductor, both for electricy and for magnetic lines of force. In order to make best use of a magnet (and our copper wire) in an alternator, we need to have the strongest possible magnetic field. Just like copper is a good conductor of electricity, steel is a good conductor of magnetic fields. A good magnetic circuit involves steel between the poles with a gap (the airgap) where we need to utilize the field. In an alternator, our wires should occupy the airgap, it should be no wider than necessary, and every other part of the magnetic circuit should be of steel. We can either use steel laminates (laminated steel reduces eddy currents) or we can have magnets on each side of the

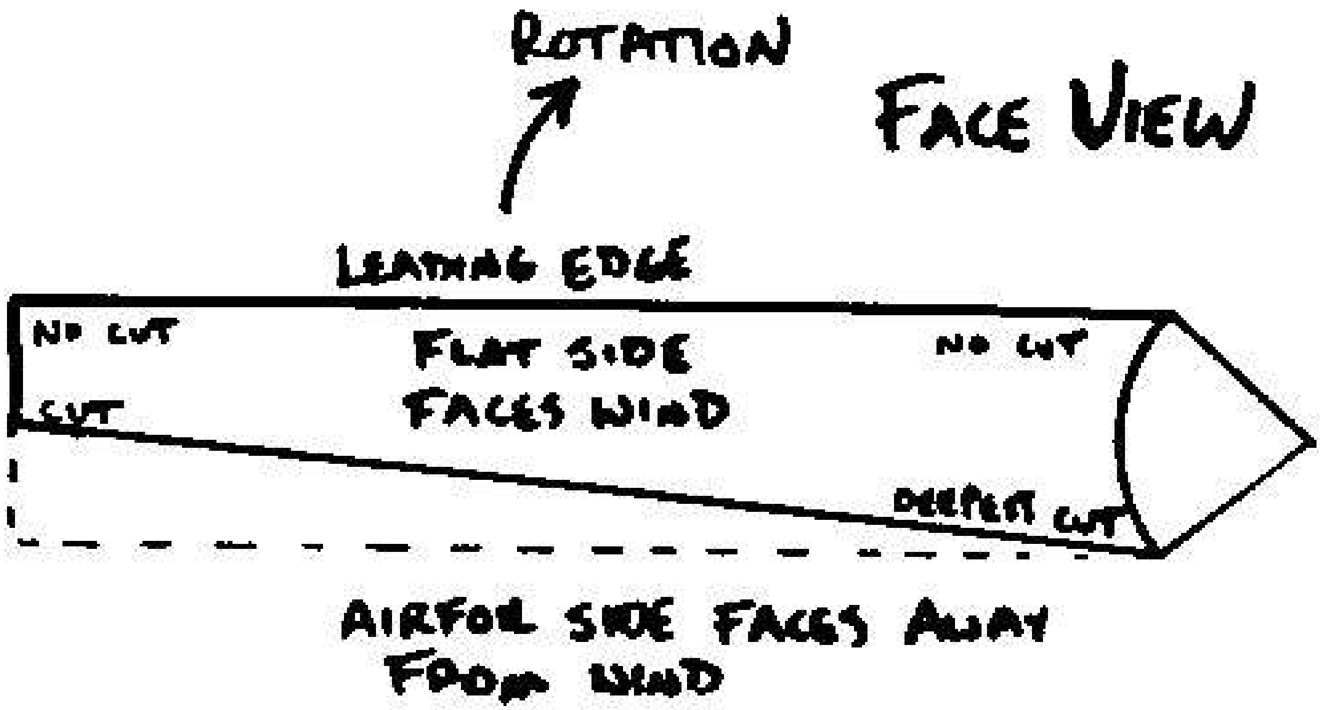
coil(s) moving together with steel behind them. Again, look at our various wind turbine experiments to see. It should be said that some of them, like the wooden alternator and the all wooden windmill have very poor magnetic circuits.

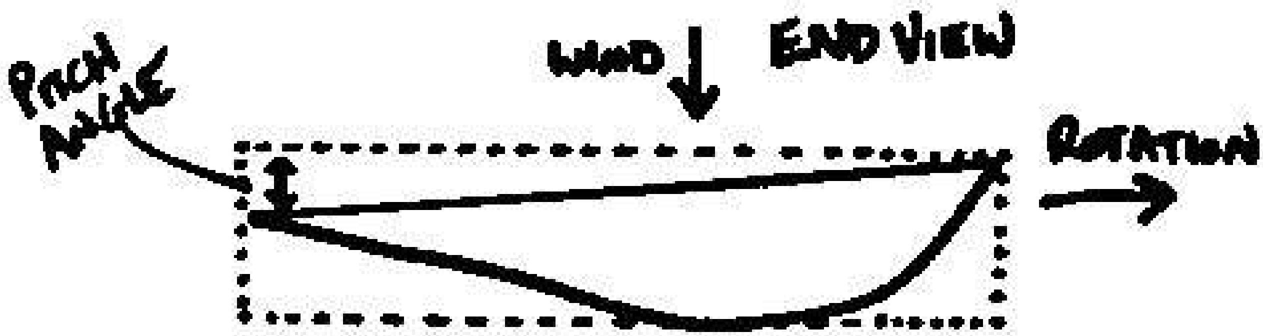
Rotor

- A wind generator gets its power from slowing down the wind. The blades slow it down, and the alternator collects the power. BOTH must be correctly designed to work together and do this efficiently. We are not experts at blade design...we sort of started in the middle with a functioning design, and made changes from there. Really, you could make a simple set of blades with a straight 5 degree pitch down the entire length and they would work JUST FINE! But to really tune in the performance of your wind generator, it's important to pay attention to a few factors. ALSO--please forgive us when we slip up and refer to the rotor as a "prop" or "propellor"--it doesn't propel anything! Rotor is the proper term, not to be confused with the rotor of an armature. But we slip up sometimes...
- **Some REALLY GOOD rotor design information** can be found on Hugh Piggott's Website. Another excellent resource is WindStuffNow.com, with good information and low cost blade design software.
- **Blade Material--**Wood is really an ideal material for blades. It is very strong for its weight, easy to carve, inexpensive, and is resistant to fatigue cracking. Choose the best, straightest, most knot-free lumber you can find; pine and spruce are excellent. Hardwoods are generally too heavy. Steel and aluminum blades are much too heavy and prone to fatigue cracking; sheet metal would be a poor choice, and extremely dangerous...check out the photo of fatigue cracks on a sheet metal windmill TAIL in Ward's Prop Gallery and imagine what the vibration would do to sheet metal blades! Cast reinforced Fiberglas® blades are very strong, and are common on commercial windmills--but the moldmaking process would take longer than carving a complete set of blades from wood, and there would be little or no gain in strength.
- **Diameter--**Blades that are too short attached to a large alternator will not be able to get it moving fast enough to make good power. Blades that are too large for a small alternator will overpower and burn it up, or overspeed to the point of destruction in high winds--there's not enough of an alternator available to collect the energy coming in from the wind.
- **Number of Blades--**The ideal wind generator has an infinite number of infinitely thin blades. In the real world, more blades give more torque, but slower speed, and most alternators need fairly good speed to cut in. 2 bladed designs are very fast (and therefore perform very well) and easy to build, but can suffer from a chattering phenomenon while yawing due to imbalanced forces on the blades. 3 bladed designs are very common and are usually a very good choice, but are harder to build than 2-bladed designs. Going to more than 3 blades results in many complications, such as material strength problems with very thin blades. Even one-bladed designs with a counterweight are possible.
- **Tip Speed Ratio (TSR)--**This number defines how much faster than the windspeed the tips of your blades are designed to travel. Your blades will perform best at this speed, but will actually work well over a range of speeds. The ideal tip speed ratio depends on rotor diameter, blade width, blade pitch, RPM needed by the alternator, and wind speed. Higher TSRs are better for alternators and generators that require high rpms--but the windspeed characteristics at your particular site will make a big difference also. If in doubt, start in the middle and change your blade design depending on measured performance.

- **Taper--**Generally, wind generator blades are wider at the base and narrower at the tips, since the area swept by the inner portion of blades is relatively small. The taper also adds strength to the blade root where stress is highest, gives an added boost in startup from the wider root, and is slightly more efficient. The ideal taper can be calculated, and it varies depending on the number of blades and the tip speed ratio desired. Hugh Piggott's Windpower Workshop book and his free Blade Design Notes contain the relevant formulas, and WindStuffNow.com's blade design software will help you with this too. Honestly, though...if you simply take a look at a picture of a functioning small-scale wind generator's blades and estimate the taper by the eyeball method, you will come very close to meeting the criteria and have a very functional blade. The calculation is done by balancing the thrust from lift with the energy needed for Betz's momentum change and Newton's Laws (whew).
- **Pitch and Twist--**As we've said before, a simple wind generator blade with a straight 5 degree pitch down the whole length would give adequate performance. There are advantages to having a twist, though--like with taper, having more pitch at the blade root improves startup and efficiency, and less pitch at the tips improves high-speed performance. The wind hits different parts of the moving blade 's leading edge at different angles, hence designing in some twist. One of our common blade designs that's right in the middle for design parameters is to build an even twist of 10 degrees at the root and 5 degrees at the tip--but the ideal solution will also depend on your alternator cut-in speed, efficiency and local wind patterns.
- **Carving--**Our layout and carving process is very simple...after marking the cut depth at the trailing edge at both the root and tip, the two depths are connected with a pencil line. DanF likes to use a hand saw to make layout cuts into the blade every couple inches along the length before firing up the electric planer...when the saw kerfs disappear, the pitch is correct. DanB prefers to hack into it with a planer right from the start. In case you are fuzzy about how this all goes together, the drawings below might help.







- **Airfoil--**There are great lengths that you can go to for designing an airfoil...NASA has some great information and calculations out there on the net. But all an airfoil needs to do is maximize lift and minimize drag. You will do fine if you do like we did--find a likely looking airfoil cross section from a working wind generator blade, and copy it. A power planer makes quick work of carving it, and a drawknife is great for carving too, especially with the deep cuts near the blade root.
- **Balancing--**The blades must be very well balanced to prevent vibration. This is more easily accomplished with a 2-blade rotor than a 3 bladed one. But generally, we simply use a homemade spring scale to make sure that each blade weighs exactly the same, and that each has the same center of balance. A simple balancing jig for any rotor configuration can be made with an upright spike that sticks into a dimple punched at the exact center of the hub. Excess material from the heavy areas can be removed quickly with a power planer. You'll also need to balance the blade in place on the alternator. It's weight distribution can be adjusted by attaching lead strips to the blade root.

Furling and Shutdown Systems

- **Furling Systems--**We use the term "furling system" to describe a mechanism that turns the wind generator rotor at an angle out of the wind, either horizontally or vertically, to protect the machine from damage during high winds. Ideally it will keep power output levels near the maximum even when fully furled. Our early wind turbine designs didn't use furling systems, and we feel fortunate that some of them are still flying. A wind turbine that furls is also much more gentle on your tower and guy wires--the force on an overspeeding wind turbine increases as the wind gets stringer.. There are a variety of furling system designs:

- **Variable Pitch--** An ideal but extremely complicated solution is to use blades which change pitch depending on the wind speed....these also have the advantage of keeping power output at the most efficient point for the current windspeed. During low winds, the blades are pitched for best startup. In higher winds, they rotate and adjust shaft speed to the ideal RPMs for the generator. In extreme winds, they turn the blades even further to protect the unit from damage. The problem is the complexity of making a system work reliably...but it can be done! Large commercial wind generators use this system exclusively, as do antique and modern Jacobs turbines, and some old WinChargers.
- **Tilt-Back--**In these designs, the generator body is hinged just behind the nacelle. When wind speed gets too high, the entire nacelle, hub and blade assembly tilts back out of the wind to nearly vertical. As the wind slows down, it returns to normal horizontal operating position by either springs, wind action on a tilted tail, or a counterweight. Commerical wind generators that use this method are the old Whisper models (from before the buyout), the Windstream, and many homemade designs.
- **Furling Tail--**The generator is mounted off-center horizontallly from the yaw bearing. The tail is also angled in this axis. The tail is also angled in the vertical axis, and hinged. When the wind force back on the rotor is strong enough to overcome the off-axis generator making it want to yaw and the angled tail trying to keep it from yawing, the tail folds up and turns the alternator away from the wind direction, forcing the wind turbine to yaw out of the wind. When wind speeds drops, the tail is returned to normal operating position by gravity, or springs. Many commercial and homemade designs (including ours) use this system, and it has proven to be very reliable.
- **Folding Vane--**Similar to the furling tail, but the tail boom is fixed, with a hinged vane underneath. Used on some older Winchargers and homemade designs, the disadvantage is that tail and vane are more highly stressed from wind force during furling, as they still are sticking out there in the gale.
- **Flexible Blades--**The theory is that the blades flex both back toward the tower and around their main axis, and therefore protect themselves from overspeeding. It does work if the materials and details are correct...for example, the blades must not flex back far enough to hit the pole, and they must withstand flexing during cold weather too. The popular Air 403 and new Air X from SouthWest Windpower use this system for furling. One problem is that it is noisy....in fact the Air 403 is noisy even in gentle 15 mph winds, BEFORE it starts producing power. The Air X has some fancy electronic circuitry to reduce noise.
- **Air Brakes--**Noisy and full of vibration, but they do work. Older WinChargers used this system. Metal cups extend from the hub from centripetal force during high winds, and noisily slow the machine down; they retract back into the hub when the wind slows.

- **Shutdown Systems--**This is a manual control that completely shuts the wind generator down. It is not allowed to spin at all, and should be able to survive extremely violent winds in this condition. It can be electrical or mechanical.

- **Electrical Shutdown--**With permanent magnet alternator machines, simply shorting the main AC power output leads together should effectively shut down the wind turbine. The problem is that when the machine is spinning at high RPMs during a windstorm, the shutdown may be either impossible electrically (the turbine is performing too inefficiently for shorting the output to have any effect), or too damaging to the alternator (the heat produced in the stator coils by shutdown at high speeds turns the coils into molten slag.) Our normal method is to simply wait for a space between high wind gusts to short the mill with a switch. We have successfully shut down Ward's turbine while it was putting 30 amps into 12vdc...numerous shutdowns at 10-20 amps of output have caused no vibration or problems. You can use a manual switch, or simply a shorting plug to do this. Our homebrew deisgns have never had problems with refusing to stop in high winds when shorted.
- **Mechanical Shutdown--**These systems physically brake the wind generator, or force it out of the wind by turning the tail parallel to the blades. Even the mighty Bergey Excel 10kW wind turbine has a mechanical crank for emergency shutdown. Generally, a cable is attached to a hinged tail, with a small hand winch located at the bottom of the tower for the operator.

Regulation

- With battery-charging wind generators, regulation of the incoming voltage is accomplished by the battery bank itself, *until* it is fully charged. Though a PM alternator or DC generator's open-circuit voltage might be 100 volts, the battery bank keeps the wind generator circuit voltage at its own level. Once the battery bank fills, system voltage will rise rapidly and something must be done with the uneeded incoming power. Simply disconnecting the windmill is *not* an option--a windmill allowed to 'freewheel' will quickly blow itself up from overspeed. The power must be diverted into some sort of load.
- **Turn on Some Lights! --**This is the oldest, simplest and most reliable method of regulation. Problem is, you have to be there to do it. But by turning on house lights, heaters, etc. that more or less equal the extra power coming in, you prevent the batteries from overcharging, keep a load on the windmill and keep your system voltage in the normal range.
- **Shunt Regulation--**These systems simply sense the battery voltage and divert all or part of the incoming wind power into heating elements (known as a 'dump load'), thus keeping a load on the windmill while ceasing to charge the batteries. The very simplest solution is a manually thrown switch that disconnects the incoming power from the batteries and connects it to some heating elements...just keep in mind the voltage requirements of the heaters must be a good match to the alternator for braking to occur. Simple systems that divert all the incoming power at once can be built using Trace C-series charge controllers or relays and voltage sensors. More complicated systems use power transistors or pulse width modulation to divert only part of the incoming power, or the entire amount, as charging needs require. Both Home Power Magazine and Hugh

Piggott's Website have plans and schematics for building shunt regulators. Some commercial solar charge controllers can be set to function as dump load controllers, like the Trace C40. A controller intended only for solar power will NOT function with a wind turbine, nor will an automotive voltage regulator.
- **Diodes--**A permanent magnet DC generator (such as a surplus tape drive motor) does need a diode in the line--otherwise, the battery bank will simply spin it as a motor. The diode should be rated for higher amperage than the maximum output of the motor, and must be well heat-sinked.
- **Bridge Rectifiers--**Since alternators make AC power and batteries need to charge with DC power, conversion is needed. This is accomplished with bridge rectifiers, which are simply an array of diodes. For single-phase alternators, standard bridges with 4 diodes are used. The biggest bridge that's commonly available at a reasonable cost is 35 amps--for larger wind generators multiple 35 amp bridges can be hooked in parallel to give greater power handling capacity. The bridges must be well heat-sinked to a large piece of finned aluminum or steel. Three-phase alternators need rectifiers that use 6 diodes in an array...these can be scavenged from old car alternators, or built using 6 large barrel diodes. We sell both on our web Shopping Cart.

Slip Rings

The power produced by the generator must be transferred down the tower to your power system. Since the actual wind generator must yaw to keep pointed into the wind, the main power wires must be able to handle this. There are 2 options...

- **Pendant Cable--**Our personal experience up here in Colorado is that it is much easier to simply use a length of flexible cable and a steel safety cable instead of slip rings. Use the highest quality stranded, flexible cable you can find and attach it in a loose loop from the wind generator power terminals to where your feed wire comes up the pole. Use a length of wire that allows about 3 or 4 wraps around the pole. Or, run the wire down the center of the tower pipe and let it twist inside. Our experience is that while the cord can eventually wind itself around the pole, it will also eventually unwind itself. Some of our models have flown for years with this kind of system and required no maintenance. With a properly designed wind turbine and furling system, you should hardly ever see the mill make a 360 degree yaw. We simple use a power plug and socket at the bottom of the tower and unplug it once or twice a year to untwist the wire. We've seen commercial turbines on 120 foot towers that successfully use the pendant cable system.
- **Make or Convert Slip Rings--**Slip rings can be salvaged from old car alternators and converted to wind generator use, or built from scratch using copper pipe, PVC pipe and graphite brushes. Home Power Magazine has had articles in the past about both methods. We have never felt the need to use them and they make for another potential failure point, so we have not experimented with it.

Recommended reading list for your 'homework':

- Homebrew wind power articles here on Otherpower.com:
  - Tips on designing, building and flying wind generators.
  - Choosing alternators/generators for wind power.
  - Designing and building towers for wind turbines.
  - Glossary of wind power terms.
- Wind power information from homebrew wind power guru Hugh Piggott's website. We've learned a BUNCH from Hugh.
- Hugh Piggott's book Windpower Workshop is an indispensable reference for anyone that's thinking about building a wind turbine. His Axial Flux Alternator Windmill Plans are very detailed and highly recommended.
- Homebrew wind power infomation from Ed Lenz's Windstuffnow.com, a highly informative website.
- Read the Renewable energy FAQs on the Otherpower discussion board, and Search the Otherpower.com discussion board. It's highly active and populated by windpower experts and hobbyists worldwide. If you still can't find and answer, by all means please join the board and ask your question there!
- Join the AWEA mailing list for more discussion with wind power experts worldwide.
- Explore other wind power websites from worldwide on our Links page.

Questions or comments? Click here to send us an email at

our new email address.!

This page last modified 1/5/2004

We encourage you to evaluate this test version and send us your feedback. Simply download this file and run the installation program. Last updated 11/13/05

Wind Energy Engineering Toolbox of Mini-Codes

Version 1.01

Summary Description of Beta Test Version
November 8, 1999

Introduction

In conjunction with the development of the Wind Energy Engineering course notes a number of computer codes have been assembled and made accessible from a simple graphical user interface. In most cases, the codes apply methods that are discussed in the course notes. In some cases the codes embody techniques that are beyond the scope of the notes, but they are included because they might nonetheless be of use to the student or practicing engineer.

The codes were written in Microsoft Visual Basic, Ver. 3.0. They can be used on any computer using Windows.

The codes are presented in six main groups:

i) Data analysis,
ii) Data synthesis,
iii) Rotor aerodynamics,
iv) Electrical,
v) Dynamics, and
vi) Turbine/System Performance.

The Data Analysis group includes 7 codes:

i) Statistics of a file,
ii) Histogram of a file,
iii) Weibull parameters from a wind file,
iv) Autocorrelation of a file,
v) Crosscorrelation of 2 files,
vi) Block averaging of a file,
vii) Power spectral density of a file

The Data Synthesis group includes 6 codes:

i) Normally distributed time series generator (using auto regressive moving average)
ii) Markov process transition probability matrix (TPM) generator,
iii) Use of Markov process TPM to generate data,
iv) Hourly wind speed generator (using synthetic TPM), including diurnal scaling,
v) Hourly load generator (using synthetic TPM), including diurnal scaling,
vi) Turbulent wind generator (Shinozuka method)

The Rotor Aerodynamics group includes 3 codes:

i) Optimum rotor design,
ii) Rotor analysis/linearized method,
iii) Rotor analysis using blade element momentum theory.

The Electrical group includes 3 codes:

i) Complex arithmetic calculator,
ii) Induction generator model,
iii) Synchronous generator model

The Dynamics group includes 5 codes:

i) Vibration of a uniform beam (Euler method),
ii) Vibration of non-uniform, possibly rotating, beam (Myklestad method),
iii) Hinge-spring blade rotor flapping dynamics (Eggleston and Stoddard),
iv) Rotating system dynamics (Holzer),
v) Rainflow cycle counting

The Turbine/System Performance group includes 6 codes:

i) Power curve estimation,
ii) Average power from a turbine (from statistics or data),
iii) Life cycle costing economics,
iv) Simple wind/diesel system, with or without storage,
v) Battery discharge capacity,
vi) Noise estimation

Using the Codes

Use of the codes is largely self-explanatory. Click an option button to choose the code to be used, then click "Do It". When through using a code click "OK". To cancel click the cancel button. In many cases the input text boxes already have values in them. These are there for test purposes and can be replaced.

Description of Codes

Below are summaries of the capabilities of each of the codes. Each summary gives an overview of the purpose and function of the code and describes the form of the inputs and outputs. A brief description of the methods employed underlying algorithms is also included. Finally, some tests for verifying the accuracy codes are discussed.

Data Analysis

Statistics of a file

Function

This procedure may be used to find the basic statistical characteristics of a data file. These include mean, standard deviation, maximum, minimum and number of points. Inputs The input is a text file, with one point per line. Outputs The output appears in text boxes on the screen.

Methods

The algorithms may be found in any text on basic statistics. They are also discussed, with reference to wind data, in Chapter 2.

Validation

Any file of known characteristics can be used as input. The appropriate values will appear in the text boxes. For example, file based of an integral number of sine waves should yield a mean of zero, and standard deviation of 0.707, a maximum of 1 and a minimum of -1.

Histogram of a file

Function

This procedure generates a histogram from a time series data file.

Inputs

The input is a text file, with one point per line.

Outputs

The output is normalized to correspond to probabilities. The output is displayed on the screen and may be written to a file.

Methods

The methods used are described in Chapter 2.

Validation

Select a bin width and create a file for which the number of occurrences in each bin over the range of the file may be readily determined. The output should show the same results.

Weibull parameters from a wind file

Function

This procedure facilitates the calculation of the Weibull c and k parameters from mean and standard deviation of a data set.

Inputs

The input is a text file (typically of wind speed data), with one point per line.

Outputs

The output values of c and k are displayed on the screen

Methods

The methods used are described in Chapter 2.

Validation

Hand calculations of the c and k values using techniques of Chapter 2 should give the same results as the code. A probability density function may be generated using the output values and superimposed upon a normalized histogram of the input file. The match should be fairly close.

Autocorrelation of a file

Function

This routine may be used to perform an autocorrelation analysis of time series data. The average is removed from the data before the analysis.

Inputs

The input is a text file, with 1 data point per line. The maximum number of lags should be specified.

Outputs

The output is written to the screen and a comma delimited text file. The first value on each line is the lag number. The second is the autocorrelation.

Methods

The method used is based on the basic definition of the autocorrelation, which is described in detail in Bendat and Piersol (1986) and is summarized in Chapter 2.

Validation

A file of known autocorrelation can be generated and used as input. For example, a sine wave with multiple cycles at 20 points per cycle should have an autocorrelation of 1 at 0 lags, -1 at 10 lags, 1.0 at 20 lags, etc.

Crosscorrelation of 2 files

Function

This routine may be used to perform a crosscorrelation analysis between two time series data files. The averages are removed from the data before the analysis. Crosscorrelation analysis is often used to when comparing wind data taken at two different locations.

Inputs

The inputs are two text files, with 1 data point per line. The maximum number of lags need to be specified.

Outputs

The output is to the screen or a comma delimited text file. In the case of a file, the output file includes the lag number and crosscorrelation on each line.

Methods T

he method used is based on the basic definition of the crosscorrelation, which is described in detail in Bendat and Piersol (1986) and in most basic statistics books.

Validation

A simple test involves using identical files for both inputs. The results should be the same as the autocorrelation of one of the files.

Block averaging of a file

Function

This procedure is used to block average a data file, thereby increasing the effective averaging time and decreasing the total number of points. For example, a typical application is to reduce a data set of 1 minute averages of wind speed to hourly averages.

Inputs

The input is a text file, with one point per line. The original time step and desired time step of the data must be entered on the screen (in the same units).

Outputs

The output is text file, with one point per line. The number of points is reduced from that of the original by the ratio of the original time step divided by the desired time step.

Methods

The method used relies on the basic arithmetic of averages.

Validation

A simple test involves comparing the average of a block averaged output data file with an input file. The averages should be the same. The standard deviation is generally somewhat smaller. Comparing histograms should result in similar histograms, with generally less spread.

Power spectral density of a file

Function

This procedure is used to derive a one sided power spectral density of a time series data set.

Inputs

The input data is a text file, with one point per line. There should ideally be 2n points in the file, where n is an integer. Data sets which are not 2n long are truncated to the nearest appropriate value. Two types of "windowing" are available, the rectangle and the Hanning window. Windowing used to reduce the effective of aliasing of the data. The data set may also be broken into shorter segments for analysis. The segment length may be specified on the screen.

Outputs

The output is to a comma delimited text file, 2 points per line: frequency and power spectral density (units squared)/frequency unit. The number of lines will be equal to the segment length divided by two.

Methods

The algorithms used employ the Fast Fourier Transform method, and conversion of the Fourier Transform to the one side power spectral density. Details are provided in Bendat and Piersol (1986).

Validation

A simple test is to generate a sine wave consisting of multiple cycles. A peak should appear at frequencies close to the frequency of the sine wave. The sum of all the psd terms, times the difference between any two frequencies, should equal the variance of the input file.

Data Synthesis

Auto regressive moving average, normally distributed time series

Function

This routine may be used to synthesize a normally distributed time series data set, with an exponentially decreasing autocorrelation.

Inputs

The inputs are the number of points, mean of the time series, standard deviation, and the autocorrelation at a lag of 1.

Outputs

The output is written to a text file, one point per line.

Methods

The algorithm uses a first order autoregressive moving average method, which is described in most statistics text books.

Validation

A synthesized file of can be tested with the Statistics of File, the Histogram of a File, and the Autocorrelation. The results should confirm that the file has the desired characteristics.

Markov process transition probability matrix (TPM) generator

Function

This procedure may be used to derive a Markov process Transition Probability Matrix from a data time series. This matrix can then be used (see below) to generate a time series with the same mean, standard deviation, and probability density function as that of the original data. The autocorrelation will be decrease exponentially, but will be close to that of the original data for low lag numbers.

Inputs

The input data is a text file, with one point per line. The number of bins, N, into which the data is to be grouped, must be entered on the screen.

Outputs

The output is saved to a comma delimited text file, representing a square matrix of size N x N, augmented by a column at the front which specifies the mean of the bin. Subsequent entries in each row indicate the probability of making a transition from the bin corresponding to the row to the bin (bin N) corresponding to the column (bin N-1).

Methods

Use of Markov processes with wind speed data are provided in Kaminsky et al (1990) and Manwell et al (1999).

Validation

The TPM may be checked indirectly, by first using it to synthesize a data file, as described below. The synthesized file can be tested with the Statistics of File, the Histogram of a File, and the Autocorrelation. The results should confirm that the file has the expected characteristics.

Use of TPM to generate data

Function

This procedure uses a Markov process Transition Probability Matrix to generate time series data

Inputs

The input TPM is read from a file, with a matrix format of N x N+1. The format is the same as that of the TPM produced in the previous procedure,

Outputs

The output is saved to a text file, one point per line.

Methods

Use of Markov processes with wind speed data are provided in Kaminsky et al (1990) and Manwell et al (1999).

Validation

The validation method is the same as that described in the previous procedure.

Hourly wind speed generator (using synthetic TPM), including diurnal scaling

Function

This procedure can be used to generate synthetic hourly wind speed data. It uses a Markov process method that results in a time series with a specified mean, standard deviation, probability density function (Rayleigh or Weibull), and autocorrelation. A diurnal sinusoidal variation, starting at a specified hour, may also be imposed.

Inputs

The inputs are made on the screen. They include the desired mean, standard deviation, type of probability density function (Rayleigh or Weibull), autocorrelation and corresponding lag. The diurnal characteristics are input by specifying i) the ratio between the maximum diurnal value and the average value and ii) the time of the maximum.

Outputs

The output is saved to a file, one point per line.

Methods

Use of Markov processes with wind speed data are provided in Kaminsky et al (1990) and Manwell et al (1999).

Validation

The method can be tested by first synthesizing a time series. The synthesized file can be tested with the Statistics of File, the Histogram of a File, and the Autocorrelation. The results should confirm that the file has the desired characteristics.

Hourly load generator (using synthetic TPM), including diurnal scaling

Function

This procedure can be used to generate synthetic hourly load data. It uses a Markov process method that results in a time series with a specified mean, standard deviation, probability density function (shifted Rayleigh), and autocorrelation. A diurnal sinusoidal variation, starting at a specified hour, may also be imposed.

Inputs

The inputs are made on the screen. They include the desired mean, standard deviation, autocorrelation and corresponding lag. The diurnal characteristics are input by specifying the ratio between the minimum and maximum diurnal average and the time of the maximum.

Outputs

The output is saved to a text file, one point per line.

Methods

Use of Markov processes with load data is discussed in Manwell et al (1994). A shifted Rayleigh distribution is one whose lowest value is not equal to 0. The mean of the data will be the mean of the non-shifted distribution plus an offset.

Validation

The method can be tested by first synthesizing a time series. The synthesized file can be tested with the Statistics of File, the Histogram of a File, and the Autocorrelation. The results should confirm that the file has the desired characteristics.

Turbulent wind generator (Shinozuka method)

Function

This routine is used to generate synthetic turbulent wind speed data, with a specified mean and standard deviation. The power spectral density function for the data approximates the von Karman spectrum

Inputs

The inputs (to the screen) include the desired mean, standard deviation, and integral length scale of the data. The desired number of points, the range of frequencies (as determined by the length of the longest cycle and shortest cycle) and the number of frequencies must also be entered. (Note that when the number of desired points exceeds the number of frequencies, the time series will begin to repeat itself).

Outputs

Output is to a text file, one point per line.

Methods

The Shinozuka method (with no jitter) is used to generate turbulent wind data. It uses the von Karman spectrum as a target. A sine wave is generated at each frequency of the PSD. The sine waves are all scaled by the square root of the psd at that frequency. A random phase angle is used of each sine wave as well. The sum of all the sine waves results in the output. Note that the time series will repeat (alternately with a sine reversal) when the number of frequencies is less than the number of points in the data file being generated. More details on the Shinozuka method are given in Jeffries et al (1991).

Validation

The resulting file can be checked by the Statistics of File and Power Spectral Density Procedures. A graph of the PSD should correspond fairly close to a graph of the von Karman model of the psd. The Autocorrelation will indicate if the time series is repeating.

Rotor Aerodynamics

Optimum rotor design

Function

This procedure is used to illustrate an optimum wind turbine of a specified size and tip speed ratio.

Inputs

The airfoil lift coefficient at the intended angle attack as well as other basic rotor parameters must be specified. The required rotor parameters are the design tip speed ratio total radius, hub radius, number of blades, and number of sections for the analysis.

Outputs

Output is to the screen or a comma delimited text file. In the case of a text file, there are three points per line, corresponding to blade station, chord, and twist.

Methods

The methods used are described in Chapter 3.

Validation

Applying blade element momentum theory (see next two procedures) to the resulting rotor shape should result in a power coefficient very close to that expected for the corresponding tip speed ratio.

Rotor analysis/linear method

Function

This routine utilizes a linear approximation of the lift curve to estimate the performance of a wind turbine rotor.

Inputs

Input may be from a file: fractional radius, chord, twist on each line.

Outputs

The output is to a comma delimited text file. It includes the radius, tip loss factor, angle of attack, angle of relative wind, lift coefficient, drag coefficient, axial induction factor, angular induction factor, and local power coefficient.

Methods

The methods used are described in Chapter 3.

Validation

The output of the linear model should be similar to that of the full rotor model for small angles of attack. The overall power coefficient of an ideal rotor should be close to the values given in Chapter 3 for the corresponding tip speed ratios. Results should be similar to that of the PROPPC code (q.v.) if the entire rotor is unstalled.

Rotor analysis/full method

Function

This procedure is used to analyze a wind turbine rotor. It can use non-linear curves for lift and drag.

Inputs

Blade and airfoil data may be from either the screen or a file. The blade data includes fractional radius, chord, twist on each line. The airfoil lift data includes angle of attack and lift coefficient. The airfoil drag data includes angle of attack and drag coefficient.

Outputs

Summary outputs displayed on the screen. Detailed results may be printed to a comma delimited text file. It includes the radius, tip loss factor, angle of attack, angle of relative wind, lift coefficient, drag coefficient, axial induction factor, angular induction factor, and local power coefficient.

Methods

The methods used are described in Chapter 3. Tip losses are modelled using the de Vries method. A turbulent wake model is also included.

Validation

The output of the full model should be similar to that of the simplified one, for small angles of attack. The overall power coefficient of an ideal rotor should be close to the values given in Chapter 3 for the corresponding tip speed ratios. Results should be similar to that of the PROPPC code.

Electrical

Complex arithmetic

Function

This procedure can be used to perform complex arithmetic as is useful for analysis of AC power.

Inputs

Inputs are made at the screen. They can be in either polar (magnitude/angle) or rectangular form.

Outputs

Outputs are in both polar and rectangular form.

Methods

The methods are described in Chapter 5.

Validation

Calculations from the code should correspond to calculations done by hand, using the definitions given in Chapter 5.

Induction generator model

Function

This procedure is used to analyze an induction generator/motor.

Inputs

Inputs are made on the screen. They include the rotor and stator leakage resistances and reactances as well as the mutual inductance. The input parameters are normally obtained from test data or the machine's manufacturer. For cases where input parameters are not available, an approximate method for estimating them is also included.

Outputs

Output is to the screen or to a comma delimited text file. The output includes slip, power in, power out, current, torque, power factor and efficiency. Generated power is assumed to be positive. Windage losses and other mechanical inefficiencies are not included.

Methods

The conventional induction machine equivalent circuit model is used as the basis of the analysis. The method is described in Chapter 5.

Validation

The program can be checked by comparing it with results from a known case. For example, the results are consistent with those of Example 3.3 in Brown and Hamilton (1984).

Synchronous generator model

Function

This procedure is used to analyze a round rotor synchronous generator. It assumes the presence of an ideal voltage regulator to keep the terminal voltage constant.

Inputs

Inputs are made on the screen. Machine parameters include the terminal voltage, the synchronous reactance and the armature resistance. Operating parameters include either the load resistance and reactance or the output kVA and power factor.

Outputs

Output is to the screen. The output includes power out, power angle, power factor, internal voltage (voltage per phase times the square root of 3), and current. Windage losses and other mechanical inefficiencies are not included.

Methods

The conventional synchronous machine equivalent circuit model, including armature resistance, is used as the basis of the analysis. The method is described in Chapter 5.

Validation

The program can be checked by comparing it with results from a known case. For example, the results are consistent with those of Problem 6.9 in Nasar (1981).

Dynamics

Vibration of uniform beam (Euler method)

Function
: This procedure is used to estimate the natural frequencies of a uniform, vibrating cantilevered beam such as a simplified model of wind turbine blade or free standing tower. It is assumed that the same material is used throughout.

Inputs
: The inputs (all to the screen) include the length of the beam, the beam's area moment of inertia, its length density (mass per unit length), and the modulus of elasticity for the material. The range and frequency step for the analysis must also be specified. By clicking on the button calculations for subsequent modes may be made.

Outputs
: The outputs are to the screen. They include the mode, the natural frequency for the mode, and the term "beta," which is a parameter used in the calculations. The first natural frequency in the range is shown first. Subsequent ones are shown when "Next Mode" is clicked.

Methods
: The Euler method, which is described in Chapter 4, is used in these calculations.

Validation
: The program can be checked by comparing it with results from a known case. For example, the results are consistent with those of Example 7.4-1 in Thomson (1981) when appropriate constants are substituted into the resulting equation.

Vibration of non-uniform, possibly rotating, beam (Myklestad method)

Function
: This procedure is used to estimate the natural frequencies of a non-uniform, vibrating cantilevered beam such as a wind turbine blade or free standing tower. It is assumed that the same material is used throughout.

Inputs
: Data may be input from the screen or a file. In either case, the length of the beam, the beam's area moment of inertia, its density (mass per unit volume), and the modulus of elasticity for the material must be specified. When using the file input, each line must include three numbers: x/L, area, and moment of inertia. The values in the file should begin at the free end. The input file should be comma delimited. The screen input for a tapered beam is simplified, in that only the width and depth of each end of the beam, together with the number of sections, must be specified. The range and frequency step for the analysis must also be specified. If the beam is rotating, as in the case of a wind turbine blade, the speed of rotation must be entered as well.

Outputs
: The outputs are to the screen. They include the mode and the natural frequency for the mode. The first natural frequency in the range is shown first. Subsequent ones are shown when "Next

Mode" is clicked.

Methods

The Myklestad method, which is described in Chapter 4, is used in these calculations.

Validation

This code can be checked by making an example equivalent to the one used in the Euler method. The results should be essentially the same, differing only due to approximation error.

Hinge-spring blade rotor flapping dynamics

Function

This procedure analyzes a flapping blade of wind turbine rotor using the simplified model of Eggleston and Stoddard. The method assumes a blade can be considered to be rigid but connected to the hub via a hinge and spring. The effects of wind shear, gravity, cross flow, and yaw rate are considered. Sinusoidal motions are predicted.

Inputs

Inputs are made at the screen. The rotor parameters include the number of blades, the rotor radius, the blade chord, the airfoil lift curve slope (radians), the blade pitch angle, the blades non-rotating natural frequency and rotating natural frequency, the blade mass, and the offset of the blade from the rotor's axis of rotation. Operating inputs include the rotational speed, tip speed ratio, wind shear coefficient, cross flow, yaw rate, and air density.

Outputs

The outputs are the magnitude of collective flapping angle, cosine term, and the sine term.

Methods

The method used is described in Chapter 4. More details are provided in Eggleston and Stoddard (1987).

Validation

The predictions of the code can be validated by comparing them to hand calculations.

Rotating system dynamics (Holzer)

Function

This routine is used to find the natural frequency of a rotating system, such as a wind turbine drive train. The system is assumed to be comprised of lumped inertias, separated by shafts of specified stiffness. Both ends are assumed to be free.

Inputs

Input is made on the screen. The user must specify the number of nodes, the inertias of each of them, and the stiffnesses of the connecting shafts. There will always be one fewer stiffness than inertias. The starting frequency, ending frequency, and frequency step of the calculations must also be entered.

Outputs

The output is to the screen. The output consists of the mode numbers and natural frequencies for all the modes in the range of the calculations.

Methods

Calculation is done via the Holzer method, which is described in Chapter 4.

Validation

The program can be checked by comparing it with results from a known case. For example, the results are consistent with those of Example 10.1-1 in Thomson (1981).

Rainflow cycle counting

Function
This routine may be used to perform a cycle counting analysis of time series data. It uses the rainflow method to do so.
Inputs
Input is from a text file, one data point per line. The method uses a fixed number (twenty) of bins.
Outputs
Output is to the screen. The output includes the bin number, the midpoint of the bin and the number of occurrences.
Methods
The algorithms used are discussed briefly in Chapter 6. More details are provided in Downing, S.D. and Socie (1982) and Manwell et al. (1999.) Cycles smaller than 3% of the maximum are ignored.
Validation
A simple test consists of generating a file of sine waves, whose cycles can be easily identified. The code should give the same results.

Turbine / System Performance

Power curve estimation

Function
This procedure is used to derive a wind turbine power curve from test data. The input data may be block averaged to a longer time step before the analysis is done.
Inputs
Input is from 2 files, one for wind speed, the other for power (one data point per line.) The two input files are assumed to have been generated simultaneously, and must have the same averaging time. The block averaging time must be input as well.
Outputs
Output is to the screen and to a comma delimited text file. The outputs on each line are: integer wind speed, power.
Methods
The method of bins is used. For each pair of wind speed and power data points, the bin number correspond to the integer of the wind speed is found. The power is summed into then bin, then averaged with the other powers in that bin to obtain the average power.
Validation
A set of wind speed and power data with a known simple relation can be generated. The code should confirm the relation.

Average power from a turbine (from statistics or data)

Function

This procedure may be used to estimate the average power produced by a wind turbine.

Inputs

A wind turbine power curve may be input on the screen or from a data file (1 data point per line.) The wind regime may be characterized by a mean and standard deviation, using a Weibull distribution, or from time series wind data. The wind data may be scaled up or down by scale factor input by the user. The output calculations may be reduced by an "availability" scale factor, which should be equal or less than 1.0. The rated power must also be input. It is used as the basis of the capacity factor calculation.

Outputs

The outputs are to the screen. They include the average power, the capacity factor, and the annual energy generated.

Methods

The methods used here are described in Chapter 2.

Validation

The method can be validated by using a simple power curve together with constant or simple wind data. The results from the code should be the same as can be obtained by hand.

Life cycle costing

Function

This procedure performs life cycle costing analysis of a wind energy or hybrid power system. Parameters that may be varied include a variety of system and economic terms.

Inputs

Inputs are to the screen. They include:

- System installed cost, $
- Annual energy generation, kWh/year
- Maintenance cost, fraction of system cost per year
- Fuel consumed, units/year
- Cost of fuel, $/year
- Value of energy, $/year
- Down payment, fraction of system installed cost
- Loan period, years
- Economic life, years
- Interest rate, fraction/year
- Energy inflation rate, fraction/year
- General inflation rate, fraction/year
- Discount rate, fraction/year

Outputs

Outputs are to the screen. They include:

- Present value of all costs, $
- Levelized cost of energy, $/kWh
- Net present value of savings, $
- Simple payback period, years

Methods

The algorithm uses a closed form life cycle costing method that assumes interest rates, inflation, etc. are constant over the life of the project. The method is described in Chapter 9.

Validation

Simple calculations can be done by hand. The code should give the same results.

Simple wind/diesel system, with or without storage

Function

These procedures allow the performance of a simple wind diesel system to be estimated. The system is comprised of a single wind turbine and a single diesel, possibly with storage. The wind turbine is characterized by a conventional power vs. wind speed curve. The diesel is characterized by a linear fuel vs. power curve. It is assumed that the diesel is off whenever the wind power exceeds the load. There is no diesel minimum power level. Storage may or may not be included. When storage is included it is assumed to be ideal. That is, there are no losses associated with charging and discharging, and there is no limit to the rate of charging or discharging. Short term fluctuations of wind or load are not considered.

Inputs

The user must input a wind turbine power curve, either on the screen or with a comma delimited text file. The text file must include a wind speed and corresponding power on each line. For the diesel generator, the user must enter the rated power, the no load fuel consumption, and the full load fuel consumption. The user must then select whether or not storage is to be considered. If storage is to be used, an appropriate amount, in kWh, must be entered. For the no storage case, wind speed and load may be input as either long term average and standard deviations, or hourly time series may be used. For systems with storage, data must be input as time series. If time series are used, the data must be in a text file, with one data point per line. When no time series data are available, synthetic load and wind can be generated using a Markov process method (See Data Synthesis.)

Outputs

The outputs are all shown on the screen. They include:

Average wind turbine power, kW
Average diesel power, kW
Average diesel fuel use, fuel units/hr
Average dump load power, kW A
verage unmet load, kW

Methods

Calculations for the no-storage case are done using statistical methods, described in Manwell and McGowan (1993). Calculations for the storage case are done using a time series, power balance method. More discussion of modeling wind/diesel and other hybrid power systems is given in Chapter 8.

Validation

The wind turbine power calculations may be checked against Average Power from a Wind Turbine procedure. For cases with small wind turbines relative to the load, all the wind turbine power should be used to reduce the load on the diesels, so the diesel power should equal the load less the wind power. If storage is used, there should be little benefit shown if the wind turbine is small compared to the load. The effect should increase as the ratio of the average wind power to average load increases. The storage cases should give results very similar to the no storage cases when small amounts of storage are used.

Battery discharge capacity

Function

This procedure is used to illustrate the capacity of a battery as a function of current, using the Kinetic Battery Model.

Inputs

Inputs include maximum capacity, the capacity ratio, c, and the rate constant, k as well as the current.

Outputs

The output is the battery capacity at the specified current.

Methods

The procedure uses the capacity part of Kinetic Battery Model. This is summarized in Chapter 8.

Validation

The results of the code can be compared with hand calculations, following the methods described in Chapter 8.

Noise estimation

Function

This procedure is used to estimate the noise (sound pressure level) of one or more wind turbines at a given distance away from the turbine(s), based on the noise emitted (sound power level). The sound power level itself is calculated from test data or according to generic "rules of thumb."

Inputs

Data input is at the screen. First the sound power level needs to be estimated. When test data is used, the input data must include the measured sound pressure level at a specified distance. Three simple rules are available for estimating sound power level.

When rated power is used, only the rated power needs to be input.

When rotor diameter is used, only the diameter needs to be input.

When rotor speed is used, both the diameter and the rotational speed (rpm) need to be input.

Calculation of sound pressure level at a certain distance from the turbine(s) requires specifying the number of turbines and the distance.

Outputs

Data output is to the screen. Output consists, first of all, of the sound power level at the turbine. It then includes the sound pressure level at the specified distance.

Methods

The sound level algorithm assumes a hemispherical propagation of the noise. The basis of this is described in Chapter 10. The rules of thumb apply to 3 blade, upwind turbines and are very approximate. They are also described in Chapter 10.

Validation

The predictions from this code may be checked by comparing the results with hand calculations, using the equations presented in Chapter 10.

References

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