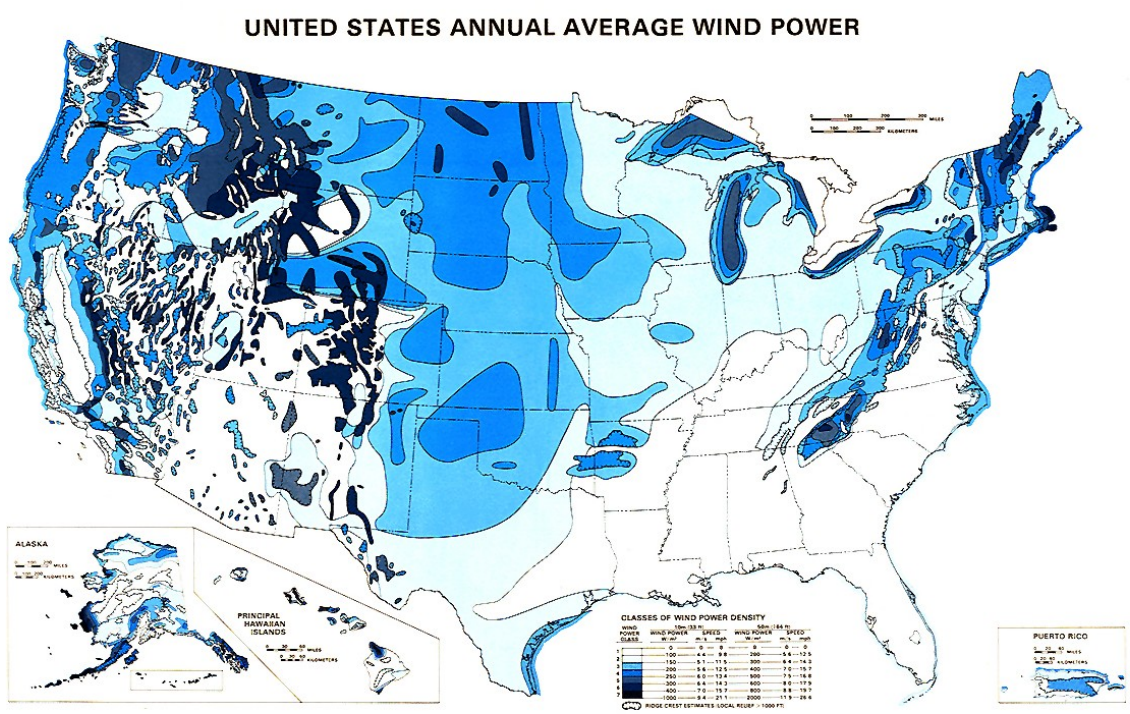
A new spin on an old twist. My take on the Savonius rotor, a Vertical Axis Wind Turbine or VAWT. Here I will share the information that I used to develop my wind power generating unit. I hope the information is of value to you.

Today, (February 2007), I read in the ABC news that wind is being seriously considered for off shore power generation. "Offshore wind turbines could produce enough electricity to power nine states, plus the District of Columbia, with a surplus of 50 percent for future growth, according to the study. At the same time, carbon dioxide emissions would be reduced by 68 percent, and all greenhouse gases would be reduced by 57 percent, according to the study, published in the Jan. 24 issue of Geophysical Research Letters." Imagine if everyone in this country in a good wind area put up a home size wind generator system, we could have a positive impact on the environment while saving lots of money in the long run. There is no reason to put off a project of this type.

Before you begin, you will want to make sure you are in an area that has enough wind to make this a worthy endeavor. Here is a wind map of the U.S. It was obtained from the following website address: http://en.wikipedia.org/wiki/Wind_power



Since the chart is not really legible, let me just say that if you are in a white zone, this may not be a project for you. The darker the color, the more steady wind and at higher average speed is recorded for the area. If you appear to be in a white zone, you can always buy an anemometer to measure wind speed and keep a log over time to know if you live in an area that is an exception. This map is very general. You can also research average wind speed with your local weather service. Another more detailed website on wind speed is as follows:

http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_maps.asp

According to my reading, the "good air" is about 20 feet or higher above the ground. This is also something to consider. You want air flow to hit your windmill without a lot of turbulence from structures. Local city and or community ordinance may not allow you to have anything above a certain height other than a tree.

Another thing to consider is wind gusts, wind energy potential increases very rapidly with increasing wind speed. In fact, if wind speed doubles, the energy content goes up by a factor of eight. So even if you have relatively calm wind with regular gusts, you may want to "catch" some of that energy. Remember, the savonius rotor doesn't mind gusts or even what direction they come from. This unique attitude of the savonius rotor allows you to take full advantage of varying and gusty winds.

From: "The Journal of Solar Energy Engineering" – Feb 1989 Vol 111/71

On the Performance of the Savonius Wind Turbine

An extensive wind tunnel test program is described which assesses the relative influence of system parameters on the Savonius rotor performance. The parametric study leads to an optimum configuration with an increase in efficiency by around 100 percent compared to the reported efficiency of ≈ 12-15 percent. Of particular interest is the blockage correction procedure which is vital for application of the wind tunnel results to a prototype design, and facilitates comparison of data obtained by other investigators. Next, using the concept of a central vortex, substantiated by a flow visualization study, a semi empirical approach to predict the rotor performance using measured stationary blade pressure data is developed. The simple approach promises to be quite effective in predicting the rotor performance, even in the presence of blockage, and should prove useful at least in the preliminary design stages.

Introduction

The Savonius rotor concept never became popular, until recently, probably because of its low efficiency. However, it has the following advantages over the other conventional wind turbines:

- *simple and cheap construction;*
- *acceptance of wind from any direction thus eliminating the need for reorientation;*
- *high starting torque;*
- *relatively low operating speed (rpm).*

The above advantages may not outweigh its low efficiency and make it an ideal economical source to meet small scale power requirements, especially in the rural parts of developing countries. ----- The concept of the Savonius rotor was based on the principle developed by Flettner. Savonius used a rotor which was formed by cutting the Flettner cylinder into two halves along the central plane and *then moving the two semicylindrical surfaces sideways along the cutting plane so that the cross-section resembled the letter "S." -----*

The following are some rules for construction of a Savonius rotor.

a. The size of the end plates, to which are mounted the buckets, should be about 5% larger than the diameter of the rotor.
b. The central shaft should be mounted to the end plates only, and not through the buckets. By keeping the shaft to the end plates, the air space is not blocked. For example, a central shaft of about 20% of the rotor diameter reduces the power coefficient by about 8%.
c. The aspect ratio, height to diameter, 6 to 8 gives a better performance. However, an aspect ratio of about 2 is desirable from the economic point of view.
d. Use only two buckets, as a higher number reduces the efficiency.
e. The use of augmentation devices such as concentrators or diffusers or combination of the two result in increased power coefficient. Again, the increased costs of such devices should be weighed against the increased capital cost and complexities.

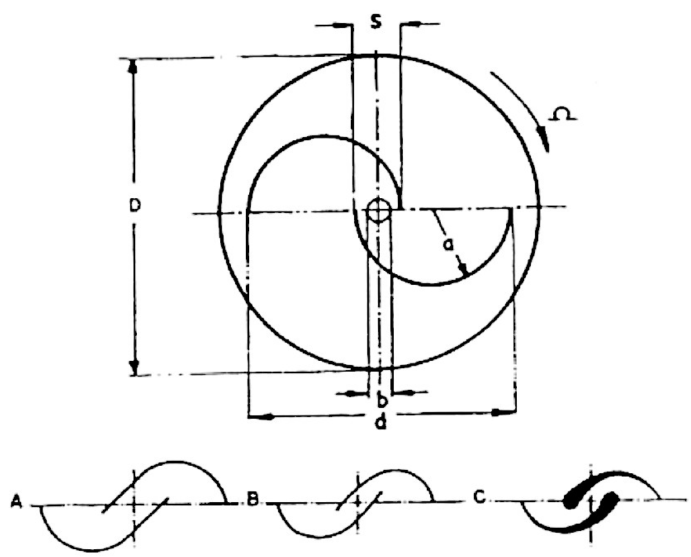


Figure 7. Cross section of Savonius rotor and blades.

55 gallon Drum Savonious Rotor *for water pumping applications remote from other energy sources. This wind conversion system is not economic where other, larger scale sources are available.*

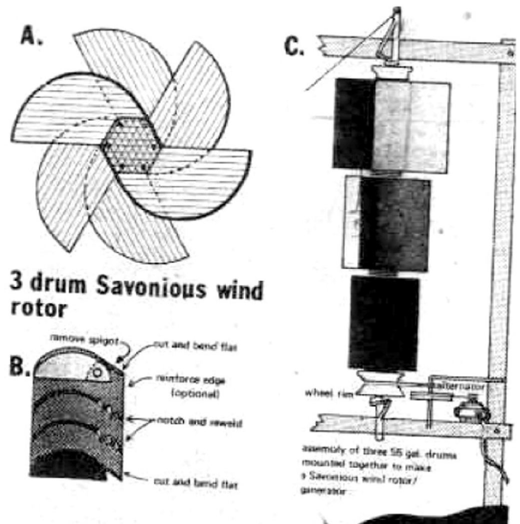
Take a 55 gallon drum and cut it in half lengthwise. Make one of the side cuts along the seam, and measure the other cut line with a cable that stretches around the drum and is marked in the center.

If it is a used drum, be sure to fill it with water before you make the cuts. Welding on an empty drum could very easily cause an explosion. Don't listen to anyone's assurances that the drum has only held water. Somewhere back in its far distant past someone may have put in some gasoline which has permeated the metal. In an enclosed chamber it doesn't take much to cause an explosion.

If you cut the drum along the sides and top, the bottom of the drum will simply break in a straight line when you bend it open. This will save your lungs and the cutting tip the indelicacy of having to cut through the gunk of the ages that has collected at the bottom of the drum.

If you had cut along the seam of the drum, the two tapped spigot openings should be near the edge of the cut. These holes mark the inside of the rotor. Leaving the rim attached to the side of each drum half, make a 6" cut along the rim and a second cut to remove the small triangle that includes the spigot openings (diagram B). Make the same 6" cut along the bottom rim (directly below the triangle where the spigots were removed) but this time don't remove any metal.

Now 6" of the inside of the drum is hanging free, but it still maintains its shape because of the top of the bottom rim, and the two ridges that go all the way around the drum. Cut three notches in these ridges (as shown in Diagram B) and heat up e top and bottom rims so you can straighten out this panel. it a template out of plywood to guarantee an even bend.



This article was both inspirational and insightful. This was the only article I found that put the whole Savonius design on paper in summary form. The study of information once collected was surprisingly short. This is not rocket science. It is however a science, and a very old one at that.

Since ancient times, man has harnessed the power of the wind to provide power for work. Also, the technique of grinding grain between stones to produce flour is similarly ancient, and widespread. Where and when these two came together in the first windmill is unknown, but a general consensus suggests a Persian origin, from where (tradition has it) the knowledge spread back into Northern Europe as a result of the Crusades. However, since the Persian mills were quite unlike the early European designs it is just as likely that the adaptation of wind as a power source was independently discovered in Europe at a later date. (Of course wind was not the first non-human power source applied to the task of grinding corn - it was preceded by animal power, and probably, water power).

According to a document used in the UK education system,
the windmill was invented in 634 A.D. for a Persian caliph and was used to grind corn and draw up water for irrigation. In the vast deserts of Arabia, when the seasonal streams ran dry, the only source of power was the wind which blew

steadily from one direction for months. Mills had six or 12 sails covered in fabric or palm leaves. It was 500 years before the first windmill was seen in Europe.

Another source, the illustrated history of the windmill says the following:

The first windmills were developed to automate the tasks of grain-grinding and water-pumping and ***the earliest-known design is the vertical axis system*** *developed in Persia about 500-900 A.D. The first use was apparently water pumping, but the exact method of water transport is not known because no drawings or designs -- only verbal accounts -- are available. The first known documented design is also of a Persian windmill, this one with vertical sails made of bundles of reeds or wood which were attached to the central vertical shaft by horizontal struts (see Figure 1a).*

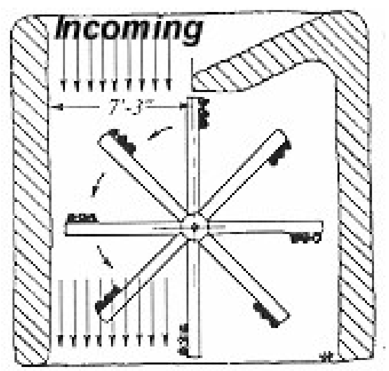


Figure 1a. Maximum efficiency of a "drag" device is obtained when the collector is pushed away from the wind, as is a simple, drag-type sail boat. In this Persian panemone design, the rotor can only harvest half of the wind striking the collection area. The panemone is one of the least efficient, but most commonly reinvented (and patented) wind turbine concepts.

To visit the website and read more history, go to:
http://www.telosnet.com/wind/early.html

Once you have designed and built your rotor, you will need to get energy from it. After all, this is not an art project. So, your rotor will either hook directly to a mechanism like a water pump or an alternator of some type to generate electricity. Generating electricity is the purpose for mine and also my intent to cover later in this document.

When it comes to alternators, (any device that generates alternating current, AKA AC), there is a lot of information. In my experience the information was presented very technically and did not spend any time explaining the basics. I'm a stick to basics kind of guy when it comes to a project like this, especially the first one. After the first one, if successful, I like to learn more and refine designs while advancing performance.

This portion of the article describes exactly how to wire your coils that make up the stator of your alternator and why you may want to choose one pattern over another. The author refers to his alternator as a motor/generator because that was what he was building. We are calling it an alternator because ours is an alternating current generator. We will come in on step 5 because that is most relevant for our purpose:

The following insertion is taken from
http://www.stanford.edu/~hydrobay/lookat/pmg.html

5. Decide how many phases you want to use in your polyphase motor/generator. Most everyone on the planet chooses three, and, I'm going to choose 3 for this discussion, so you might as well, too. You don't have to choose three phases, but at least choose an odd number. (To show this technique does generalize I'll diagram hooking up a five-phase motor/generator after the 3-phase discussion.)

6. Calculate the number of coils required:
For a given number of phases, N, you need N coils per magnet pair in your N-phase motor/generator. For a count of M magnets (often referred to as poles), with M an even number, we have M/2 magnet pairs. So, for an N-phase motor/generator with M poles the number of coils required, C, is: C = N(M/2). I found 8 magnets in my junk box when I set out to write this. So, for a 3-phase motor/generator the number of coils we want to wind is: 3*8/2 = 12.*

7. Calculate the number of coils per phase:
For C coils and N phases, the number of coils per phase is C/N. Here, for our 8 pole, 3-phase motor/generator we get 12/3 = 4 coils per phase. This means you will be connecting three groups of 4 coils each in your motor/generator.

8. Select the motor/generator wiring configuration:
For a 3-phase system, there are two primary types of polyphase motor/generator connections, Delta, and Y (also know as a Star connection). For a Delta connection, the phases are connected in a triangular configuration. In a Y connection the phases are connected in 3-armed, or "Y" shaped configuration. The Delta configuration is more efficient for low rpm operation, and we'll choose that for now. The Y configuration will be covered in the details discussion that follows these rote instructions and formulas.

9. Diagram the phase connections:
Using the previously described diagramming technique (figure 1), each of the four coils in the 3 phase groups is connected in series just as in the single-phase motor/generator so there is proper current flow through the group. Draw lines so they connect (+) to (+) and (-) to (-) polarity coil connections for each of the phase coil groups (figure 4). You can use the "follow the arrow" method with each phase group the same as described in step (6) for the series connection of all coils in the single-phase motor/generator. Note carefully how the B phase starts on phase coil B2, not coil B1. This is because the first B phase coil who's current direction matches the current direction of the first coils in the A and C phase coil groups is B2, not B1.

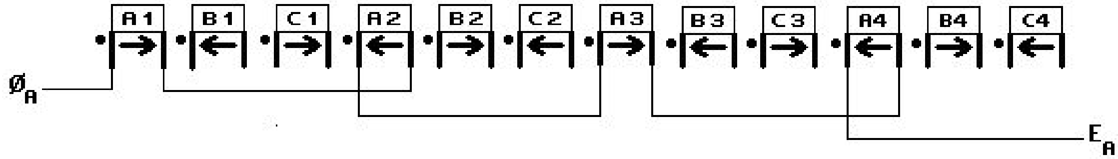


FIGURE 4A: Wiring diagram for the A phase coil group of an 8-pole, 3-phase motor/generator.

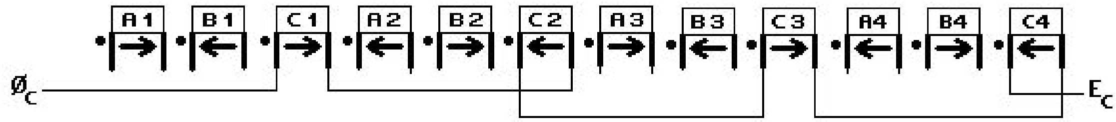


FIGURE 4B: Wiring diagram for the C phase coil group of and 8-pole, 3-phase motor/generator.

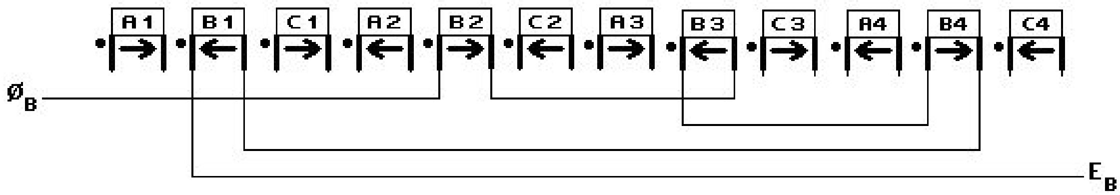


FIGURE 4C: Wiring diagram for the B phase coil group of an 8-pole, 3-phase motor/generator Note the start is on coil B2 to match the current direction with phases A and C.

Once the A,B, and C, phase coil groups are connected, then the groups are connected to form the chosen Delta or Y configuration. For a three-phase Delta connection the end lead of the A phase coil group is connect to the starting lead of the C phase coil group, the end lead of the C phase coil group is connected to the start lead of the B phase coil group, and the end lead of the B phase coil group is connected to the start lead of the A phase coil group, as diagrammed in figure 5. Again, as pointed out in step (9) above, note the starting lead for the B phase coil group comes from coil B2, not coil B1.

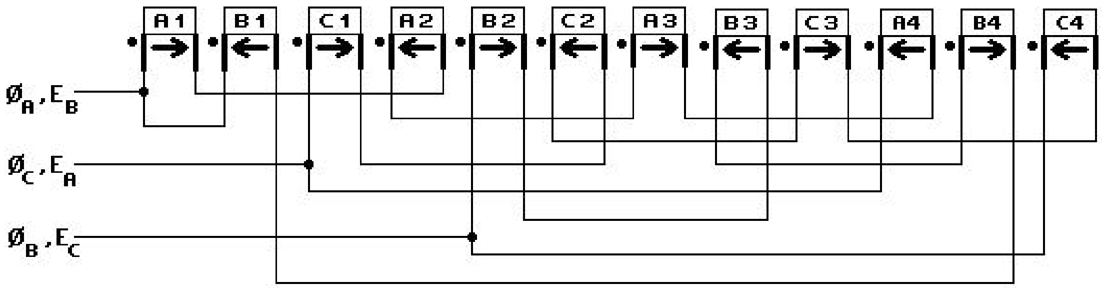


FIGURE 5A: Armature connection diagram for an 8-pole, 12-coil, 3-phase, delta connected motor/generator. Dots near each coil's left lower corner indicate a coil's positive (+) polarity lead. A dot on a wire crossing indicates the wires are connected. The arrows indicate alternating current (AC) flow direction through the coils when the motor/generator is operating. Note how the B phase coil group starts with coil B2 to match that group's first coil AC current direction with the current direction of the first coils in the A and C phase groups.

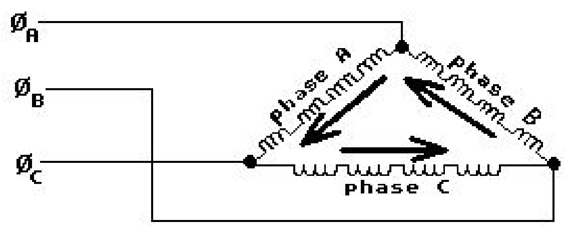


FIGURE 5B: Schematic representation of the 3-phase delta connection diagrammed in figure 5A.

10. Build it. Figure 6 shows an example physical diagram for a three-phase, 8-pole, 12-coil, Delta connected motor/generator.

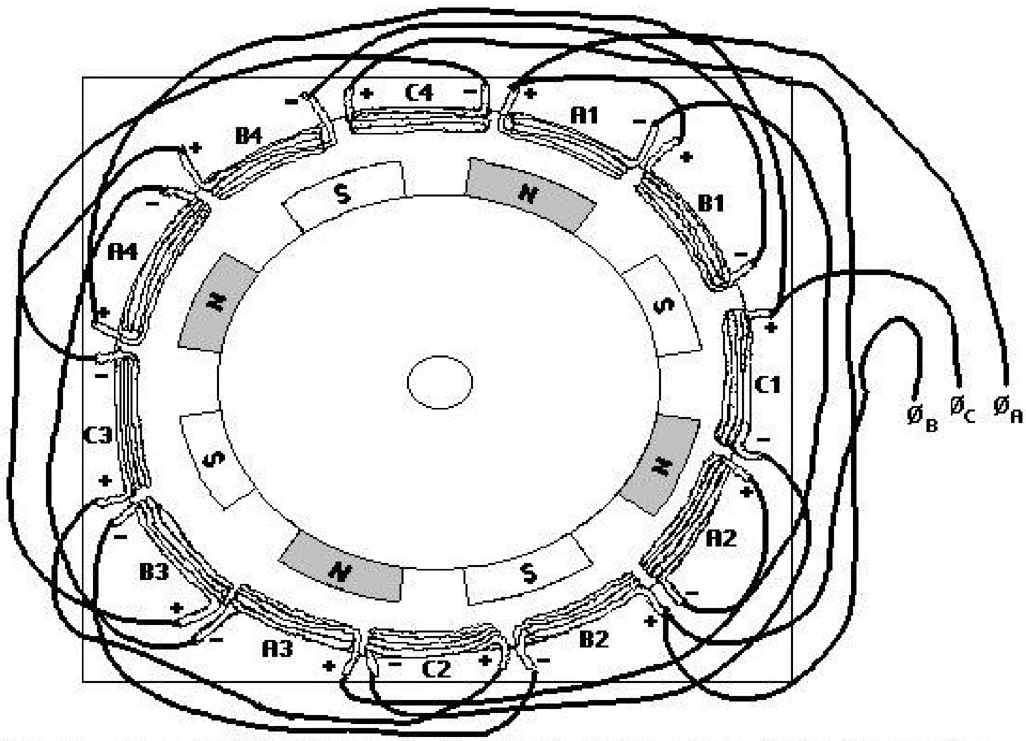


FIGURE 6: Basic construction of an 8-pole, three-phase motor/generator. Cut a circle from the center of a block. Trim the circle to allow magents and coils to clear. Mount coils in the block and wire as shown. Mount magnets on the circle, alternating poles. Mount axle so circle spins in block. Use.

If you use your motor/generator in motor mode and want it to spin in the opposite direction from what you will find with the motor/generator design given here, you can reverse any two of the input phase connections, and the motor will run in reverse. We'll see why that is later. (And, of course, you could also physically turn the motor around 180 degrees so that the end of the shaft facing you becomes the end of the shaft pointing away from you.) There is no issue with self starting of polyphase motors. Connect three-phase power to a 3-phase motor/generator and it will run as a motor without any of the startup connection tricks required for a self starting single-phase motor to be discussed later.

Of magnets and wires and such:

Getting into the spin:

First thing, magnets. Most everyone has played with magnets at one time or another. Point the opposite poles of two magnets at each other, north to south, and they attract. Point the same poles at each other (north to north, or south to south) and they repel. Interaction of the magnetic fields produced by the magnets is what causes the attraction and repulsion effects observed for a pair of magnets.

The same as it is for the magnetic field of the earth, the magnetic field of a simple bar magnet is described as lines of magnetic flux which extend from a magnet's *north pole to its south pole (figure 7). (It might be good to note here that the north geographic pole of the earth is actually a south magnetic pole. Which explains why the north pole of the magnet in a compass points toward the earth's geographic north pole.)*

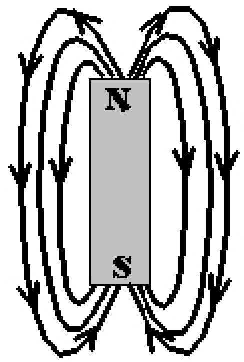


FIGURE 7: Magnetic flux lines emanate from N to S.

Considering the magnet flux lines as drawn in figure 7, magnetic attraction and repulsion can be viewed as the interaction of the arrows (or vectors) giving the direction of the flux lines from north pole to south pole. When two north or two south poles are brought next to each other, the arrows from one magnet's pole point in the opposite direction of those from the other magnet's pole, and, hence, "collide," pushing each other away, causing the repulsion effect. But, when a north pole and a south pole are brought together, the arrows point in the same direction, and one set "sucks" the other set along, much like two streams of water flowing in the same direction, which causes the attraction effect. (This is, of course, just a description for visualization purposes.)

Magnetic repulsion and attraction are the basis of operation for an electric motor. By proper alignment and timing of magnetic fields, the parts of an electric motor can be made to push and pull on each other so that a smooth continuous motion is obtained. Besides having a magnet handy, another way to generate a magnetic field is to run an electric current through a piece of wire. The flow of current through a wire produces lines of magnetic flux around the wire just like the lines of magnetic flux produced by a magnet. The lines of flux are produced such that when you point your left thumb along the wire in the direction of current flow through the wire, your left fingers will curl around the wire in the same direction as the lines of flux around the wire, i.e., your finger tips will point in the same direction as the arrows seen in a diagram of the flux lines (figure 8).

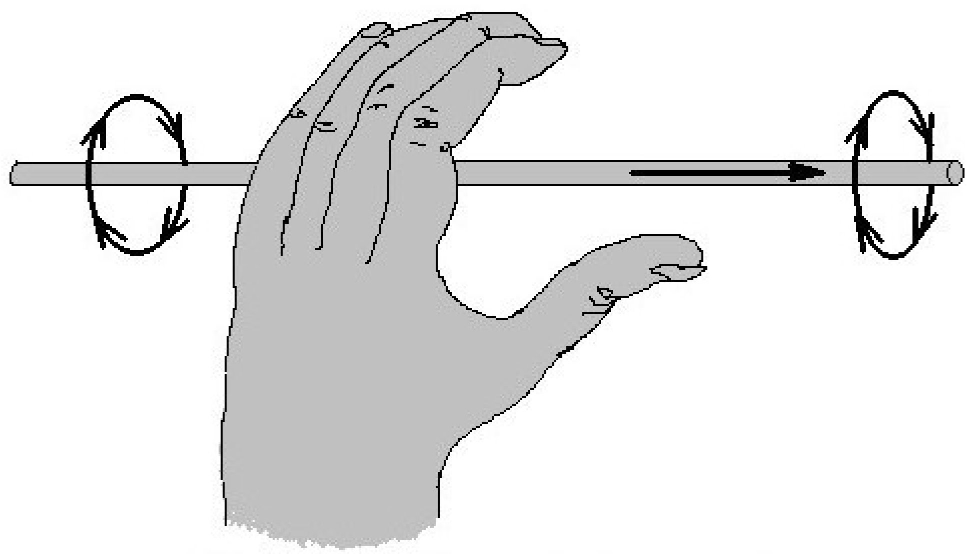


FIGURE 8: Left hand rule for current flow through a wire generating magnetic flux lines.

Obviously, if the direction of current through the wire is reversed, then you have to point your left thumb in the opposite direction, and, as shown by the curve of your fingers, the lines of flux around the wire will be in the opposite direction, effectively changing the polarity of the magnetic field around the wire.

We aren't going to get deeply into what constitutes the "real" direction of current flow in a wire. As has been pointed out above, consistency is what counts. Make your favorite assumption, use it without fail, and all will be well.

Here we'll consistently consider current flow to be from the negative terminal of a power supply to the positive terminal of a power supply. That means we're looking at electron flow, and not current flow as it was originally assigned to be from positive to negative for the first electric batteries, (a concept based on Benjamin Franklin's earlier description of two types of electricity, "positive" and "negative," which, well, frankly, some would say he got backwards). Engineers and physicists can argue about what is really going on all they want, and we'll just get on with the task at hand. Symmetry, which we'll talk about more a bit later, is the key to why, for practical purposes, the initial choice doesn't really matter. In fact, if you are more comfortable considering current flow to be from positive to negative then consistently use that idea, and instead of using the left-hand rule as described above, just use your right hand to apply the right-hand rule. Then following the curve to your right finger tips will get you the same results as we've seen for the left-hand rule. That's symmetry!

Now, the nature of magnetic poles around a straight piece of wire with current flowing through it isn't immediately obvious. But, if you turn the wire into a loop, *the orientation of magnetic poles relative to the wire becomes more clear. As shown in figure 9, with current flow from left to right and the loop directed into the page, the flux lines circulate into the top of the loop and out of the bottom. Comparing this to the flux lines seen for the magnet in figure 7, we can see this implies the north pole of the loop's magnetic field is at the bottom, and its south pole is at the top.*

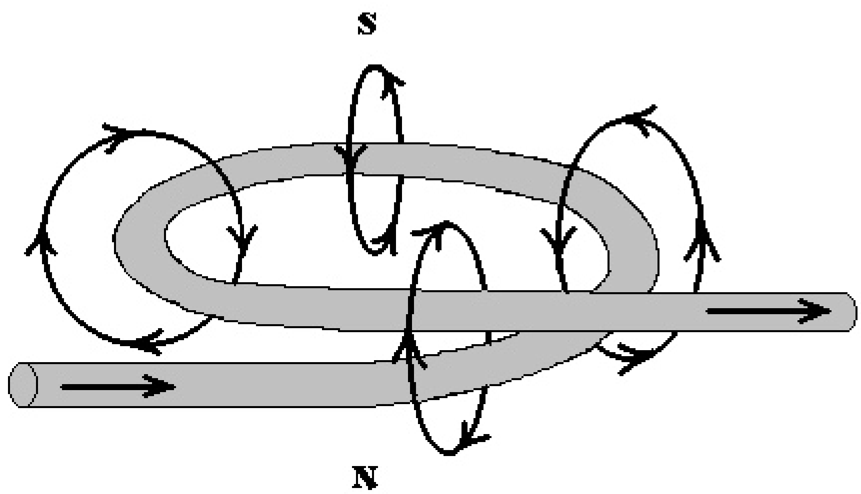


FIGURE 9: Magnet flux lines following the left hand rule for a loop of wire. Note the orientation of the implied north and south poles.

The effect becomes more clear when there are multiple loops stacked on top of each other to form a coil.

Since the flux lines produced by each loop combine in the same direction they produce a larger (and stronger) magnetic field (figure 10). This is why more turns in the coil of an electromagnet make for a stronger electromagnet.

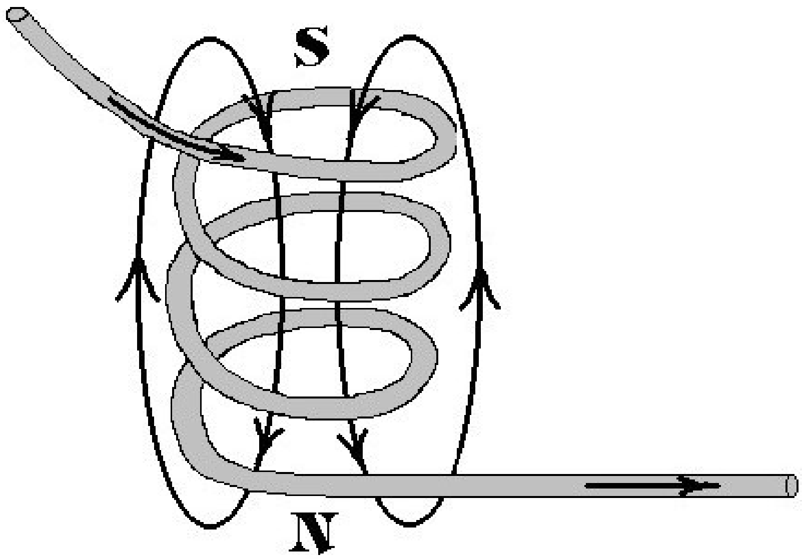


FIGURE 10: Magnetic flux lines for a multi loop coil.

As can be seen in figure 10, the same repulsion and attraction of flux lines can be had from the coil as from a real magnet. By reversing the direction of current through the coil the orientation of its north and south poles is reversed. And, by taking this action in to account, simple electric motors can be devised.

For example, with proper timing of the change in direction of current through two coils, a magnet on an axle can be made to rotate between the coils (figure 11).

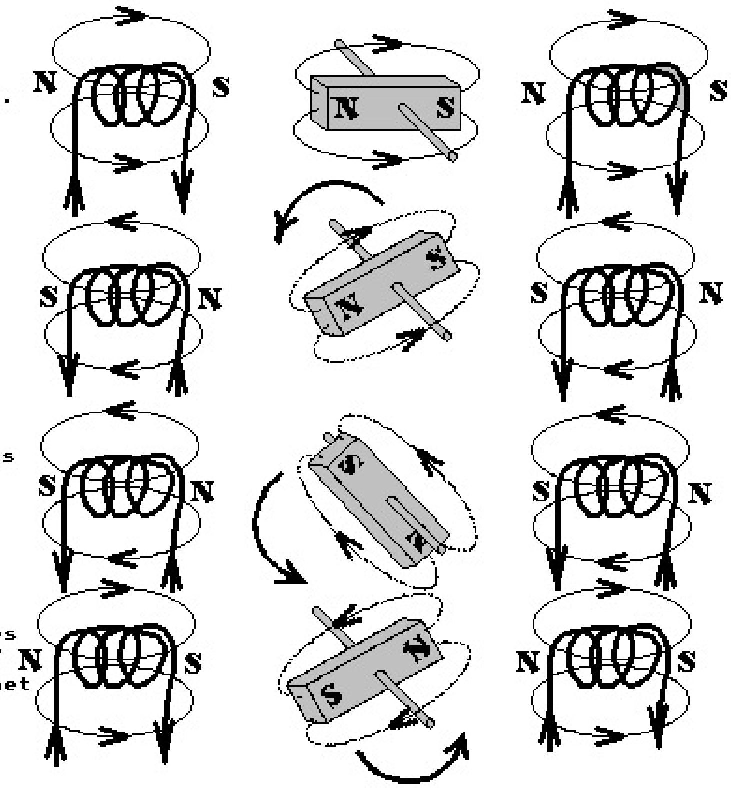


FIGURE 11A: Magnet and coil fields attract. Magnet locked in place.

FIGURE 11B: Reverse coil currents. Fields repel to start magnet rotating on axle.

FIGURE 11C: Magnet rotates past vertical. Fields attract to continue rotation of magnet on axle.

FIGURE 11D: Magnet rotates to horizontal. Reverse coil currents. Fields repel to continue magnet rotation on axle.

Going the other way:
OK, in the last section we made it as far as a good idea of how to make a simple electric motor. A lot of details need to be filled in yet. Like, in particular, how to control switching and timing of the magnetic fields, but it's a definite start. And, with the information we put together there about magnets and wires and such, we are in good shape to move ahead with an initial description of how electric generators work.

As mentioned before, the aspects of physics we're looking at are symmetric. So, just as running a current through a wire creates a magnetic field, moving a magnet near a wire creates an electric current in the wire (figure 12).

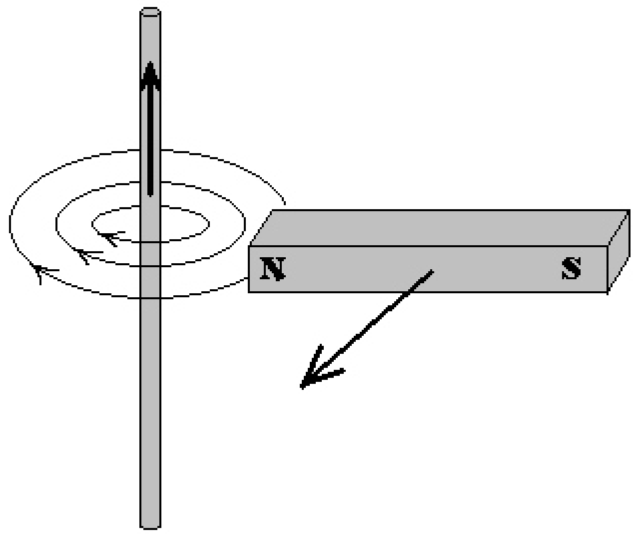


FIGURE 12: Moving a magnet past a wire generates an elecrical current in the wire.

Of course, the more wires a moving magnetic field crosses, the more currents that are generated, one for each wire (figure 13). And, when a wire is wound in a coil, the effect is the same for each loop in the coil, except, because the coils are connected, the multiple currents created as the magnetic field passes over the coil windings add together. So, the more windings in the coil, the more current generated as the magnetic field passes by (figure 14). This is the basic idea behind an electric generator.

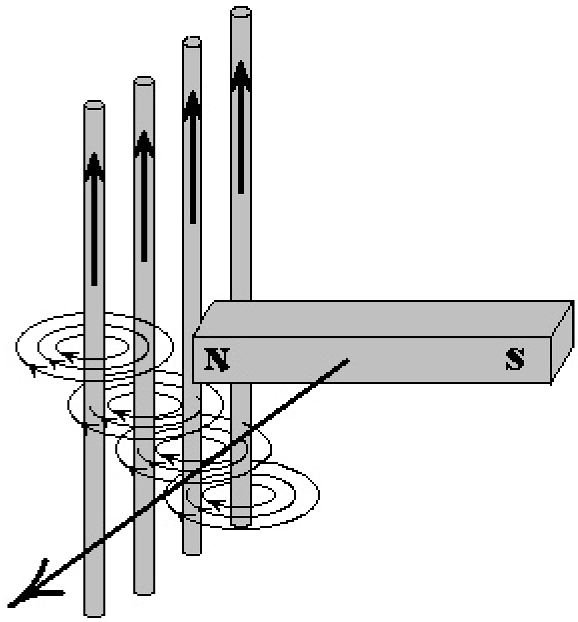


FIGURE 13: Moving a magnet past several wires generates an idential elecrical current in each wire.

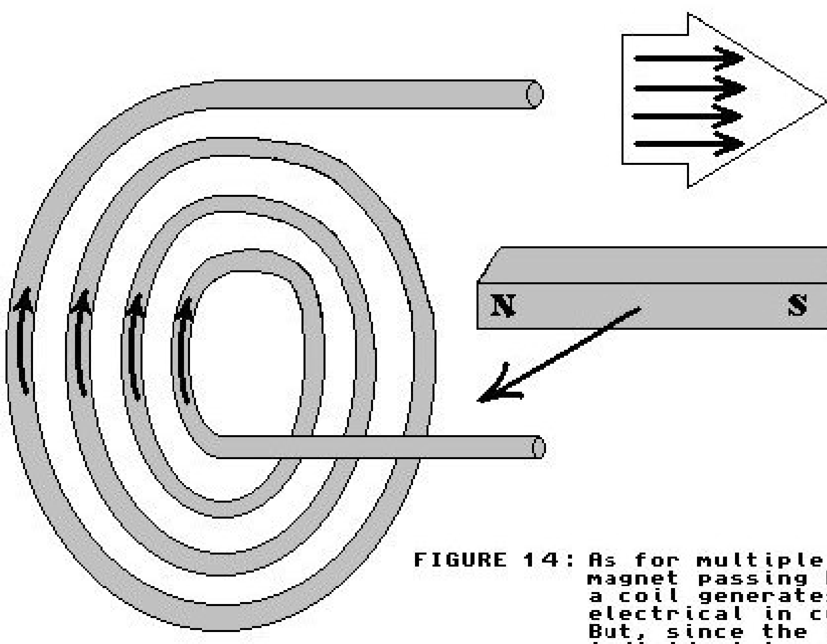


FIGURE 14: As for multiple single wires, a magnet passing by the loops in a coil generates an identical electrical in current each loop. But, since the loops connect, individual loop currents add up to equal the current in one loop times the number of loops in the coil.

Also, the stronger the moving magnetic field, the more current generated in any wire it moves by. So, either by putting more turns in its coils, or by using stronger *magnetic fields, or both, the more power that can be produced from a generator or utilized from a motor.*

We've already see examples of making simple permanent magnet generators in the coil count and connection sections above. So, let's continue on and investigate a few more details that will lead us to an understanding of why we make the connections we do as previously described for single-phase and three-phase delta motor/generators, and also how to define connections for other than single and three phase systems.

Pick a phase, any phase:

OK, so what does "phase" mean, anyway? Well, it's another one of those words that changes meaning with context. Regarding polyphase motor/generators, it is often used interchangeably to describe two main features. It can mean one of the multiple leads (or the lead's associated electrical waveform) in a polyphase system, or it can mean the difference (measured in degrees) between the peaks seen in the waveforms found in any two leads in a polyphase system. For the second case that difference is more correctly referred to as the "phase angle," which, here, is a term that relates to the notion of a rotating magnetic field. The rotating magnetic field concept is at the heart of any motor/generator system, be it single or polyphase.

That we are dealing with rotating magnetic fields seems easy enough to accept. The devices we've been discussing have magnets that spin on an axle. So, there it is, rotating magnetic fields. Pretty unavoidable, that. Of course, as always, the devil is in the details.

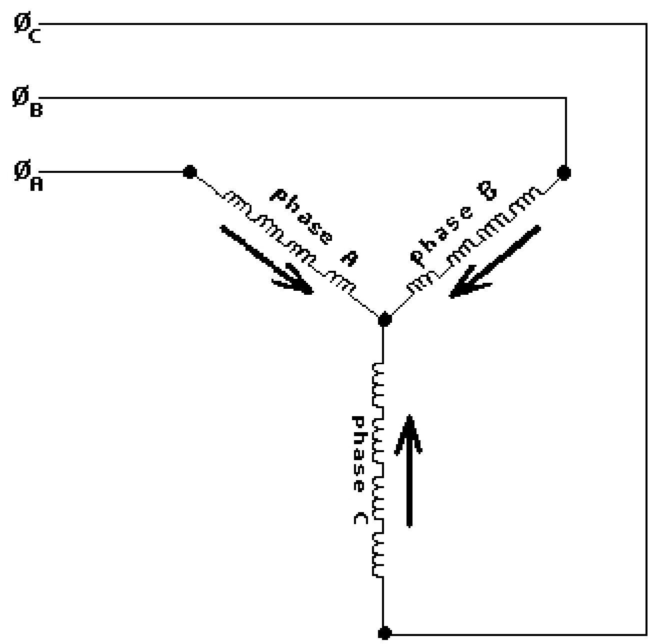


FIGURE 21: Schematic representation of the 3-phase Y connection.

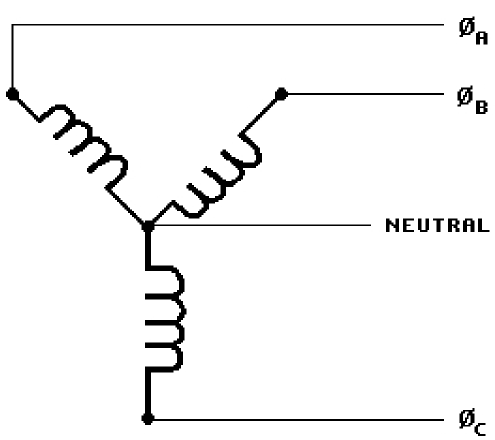


FIGURE 23A: 3-phase, 4-wire, Y

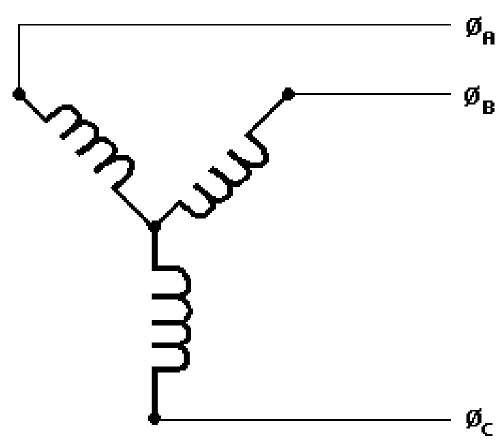


FIGURE 23B: 3-phase, 3-wire, Y

Taking what I learned from this article and applying it to my project I concluded that I want to build a Y circuit alternator. The reason is simple. VAWT's, vertical axis wind turbins, don't spin at very high RPM's. Even with design changes, we will want the highest voltage at the lowest RPM. Remember, in order to charge a battery, your charge source must be higher voltage than the battery being charged. The "Y" circuit attains the voltage sooner but at lower amps. Still, this trade off helps ensure the low RPM VAWT will put in a lot more time charging batteries than it would otherwise, besides it looks like the "Flux Capacitor" doesn't it?

The low RPM of a VAWT is seen as a problem by most wind generator enthusiasts. I know cost of production weighs heavily against any loss of efficiency. VAWT's are cheap to build.

In all of my research, most designs include some type of gearing with pulley wheels or even a truck differential! I kept picturing in my mind the photo of the giant VAWT with a differential mounted below it. Here it is for you to enjoy.

The reason I am sharing this particular image and thought with you is simple. Compared to a propeller style windmill, these things have enormous torque! We are always looking for an efficient way to convert the torque and low RPM into a lower torque high speed rotation to get electricity. Remember, speed directly affects the amount of current generated.

My dad always told me from the time I was small that simpler designs are usually better. I kept thinking there must be a way to simplify the design. There were too many conversions, (each conversion creates a small loss of energy as well as something else to go wrong). My mental mission was to remove excess components from existing designs I had read about. It seemed that all of the well documented alternator designs with stable results were very similar and usually included old brake rotors, magnets doubled up on the coils
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I keep reading that there are too many mechanical conversions for a VAWT to be really effective. I also kept reading that the enthusiasts of VAWT's are die hard. Was I becoming one, even though I have read about 100 times the efficiency differences between the designs for electricity production? **Yes**. I enter the realm of "VAWT die hard" knowingly. I also realize what I need to do to the design to enhance performance. I've come up with a simple answer to the problem. Best of all, I have not seen it done anywhere.

Every design seems to have a modular approach. There is nothing wrong with this. I used to program computers and I watched software grow in size exponentially while function grew in a more linear fashion. I know this was caused by modular programming practices. An entire module of code would be pasted to the software to only use one or two features when that script may actually have 10 or 20 features coded in it.

With the windmills, there was always the windmill itself and then the alternator is hooked or built on to it. They are separate. There is always a connection issue, whether it is gearing, or straight coupling on a propeller type.

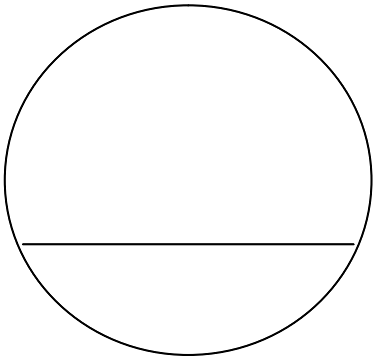
With a fresh look at a VAWT, I realized that the rotor itself could be part of the alternator. After this revelation, another one hit me. The bearing and speed problem was also solved in the same step. By using the outer most edge of the rotor as the permanent magnets, (armature), of the alternator and presenting the coils to it, the passing speed of the magnet would be greatly increased relative to the center hub conventional turbines use due to their designs! The next question was math. Will the diameter of the rotor vs. the standard set to match the increase of speed necessary?

A traditional propeller type windmill is rated on 12MPH winds or better and about 400RPM to generate optimum electricity. A VAWT won’t usually turn nearly as fast, because half of its surface is always fighting the wind. On my planned size, the speed the magnet would move past the coil would be increased about 3x from the standard design. Now my VAWT only needs to turn 1/3 the speed to attain the same power. Although this is still just academic, will it work in real life? Also, now my rotor is the only moving part of this design. There are no gears, no couplers, no shaft mechanisms etc… I only have two points of friction, the top center and the bottom center where the rotor is supported.

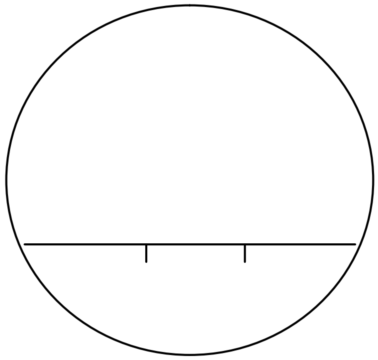
This reduces maintenance too!

Well, after all that talk and all of my research I decided it was time to act. So with a great idea from my dad to use stove pipe, (because it is already split and won't require cutting), as well as a couple of pre-fab (almost rounds), this is what I did.

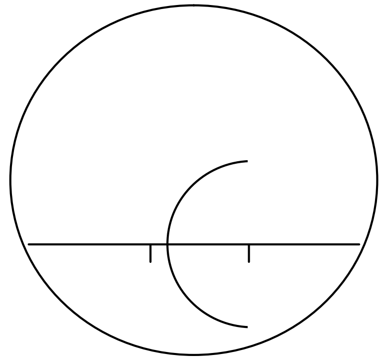
1st, I had to find the center of the circles. One, run a line across any portion with marks the same number of inches in from each side. Two circle portions with those marks as the center for the compass. The intersects create a line through the center. Repeat for an intersect at the center, or just measure to the middle. Next I had to figure my 20% overlap and create a circle in the middle to represent that. Last, draw the two half circles based on the over lap and the finished dia. That is one carefully marked piece of wood. See the diagram below:



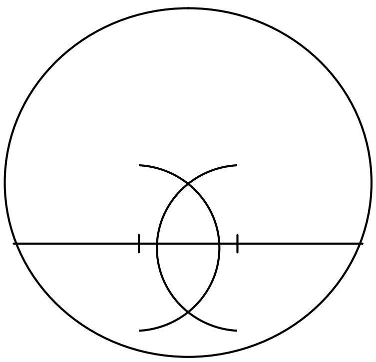
First, run a line across the circle. Preferably off center a fair amount.



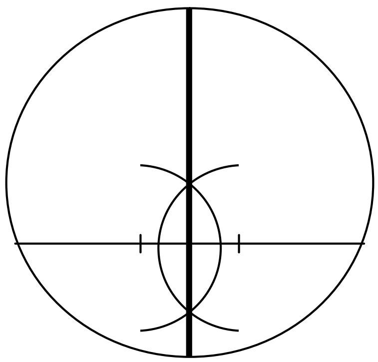
Next, measure in from edge the same amount from each side. This is arbitrary, but I recommend a whole # about 1/3 from outside.



Next, put your compass on one of the marks and draw about ½ circle as shown above.

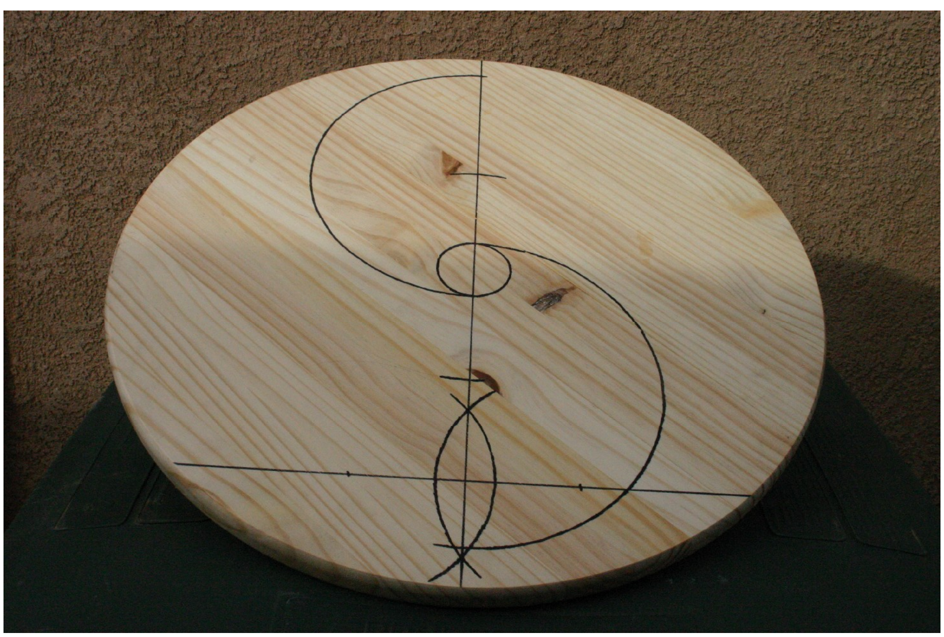


Next, repeat from opposite mark so that the half circles overlap as shown above.



Last, draw line through the intersects of the half circles. This line is now through the true center of the circle.

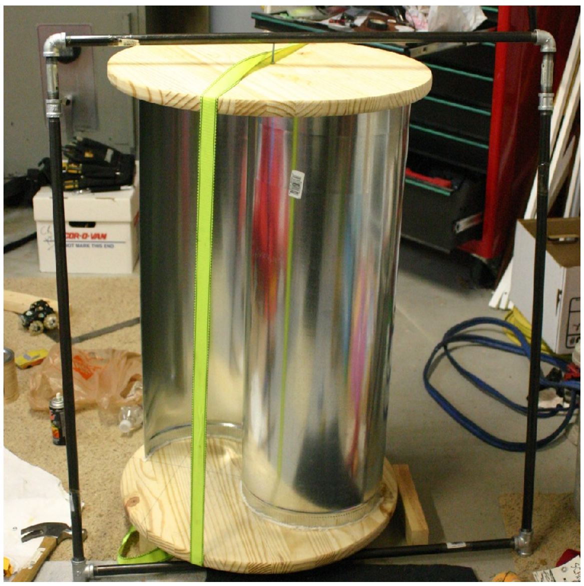
Repeat the whole process using your new center line as your starting point to create the intersection at the center of the circle. You could always just measure if you know the diameter now that you have a line through true center.



My Pine (almost Round). This is the finished marked piece.

My Pine almost rounds are 24” diameter. My stove pipe is the 6” diameter variety and 3’ long. When the stove pipe is opened to half circle it is ½ of a 12” diameter circle and you will have two of them for 24” diameter. Then you will mark overlap of 20%, a circle in the middle of about 1 ¾” and you get the same arrangement I have in the photo. Mark with your compass the two half circles so that they allow overlap to line up with the center circle like my photo depicts.

2nd, use plunge router to create a channel for the pipe to set in. I set my router for about ½” depth and cut the two half circles only. Mark the other end with the half circles reversed, remember the two rounds will be facing each other and will need to be mirror images of each other.



3rd, Dry fit pipe, (mostly for practice run, it’s not easy to get it all into place at the same time). Fill channels with glue and insert pipe. Strap together while glue dries for at least 24hrs.

4th, build the temporary pipe support structure while first section of glue dries. Pipe is not cheap. This is however a fast easy way to build a very strong frame for my prototype. I used 2 elbows, 4x 3 foot nipples, 2x 3” nipples, 2x female to female connectors and 2 T’s. The T’s allow another length of pipe to attach and or some rebar to slip up into the legs. The rebar allows me to stake the holder to the ground easily and still slip the whole thing right up and off without any great effort until I am ready to mount it permanently.

5th, mount unit in pipe structure. A simple fit is to simply drill a hole half way through the pipe frame for the bottom and all the way through at the top. The top will act as a guide for rotation while the bottom will be a seat with a guide. Add some oil. A bearing is your best bet, however this gets you started.

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8th, Start weather treating everything. More is better. So now is the time to get a good first coat of outdoor polyurethane on the wood surfaces.

9th, time for electricity! After several experiments with wire winding and starting with theories already tried and true, I have found that there is one simple goal; Get the most windings exposed to the magnetic field at every pass and still be heavy gauge enough to carry the Amps. A very tightly wound coil helps concentrate wire into a smaller area. A coil wound semi flat and in the shape of the magnet helps take advantage of the magnetic field without over explanation. Basically if you're using the magnets I am, make your coils about 1"x2"x1/2". Remember, wire comes wound. You may find that simply cutting one end of the plastic spool off and sliding the entire coil off and simply pinching it to shape can be a great time saver. Like every do it yourselfer, you will probably try a few different winding schemes. With electricity, everything is a trade off of Amps, Volts, and Watts. More windings means higher voltage earlier but there is only so much energy in the wind, so some amperage will be lost because you will not develop as high a speed when there is a load on your circuit as you will with fewer windings. Your goal plain and simple is to charge batteries as fast as you can with as little wind as possible. This means a machine with few moving parts, few friction points, good aero dynamic properties for catching wind and a good well thought out stator,(group of coils wired together strategically) and rectifier circuit (converts AC to DC for battery charging). Because it is important when wiring the stator, keep track of your leads off the coils. Mark or tape the lead from either the center of the coil or the outer edge, but do it consistently so you know what they are.

10th, locate and lock in the coils around the rotor.

It is very important that the coils be held at spacing equal to the magnet spacing and that clearance or air space be tween coils and magnet face is minimal. The relationship of energy produced to air gap seems to be geometric. Get these as close as you can without touching for maximum energ y production.

11th, wire the stator circuit into a "Y" or "Delta" electrical pathway.

Remember I said I was going with the "Y" circuit because it reaches higher voltage faster than the "Delta" configuration. I will now mark my coils into 3 groups evenly spaced from each other so that every 3rd coil belongs to the same group. Remember I told you to mark your leads so you could be consistent when wiring, now is when it counts. Working with one group at a time, connect inner coil lead to outer coil lead creating a chain of coils connected in series. Leave two ends open, not connected to each other so that they may be wired into the "Y" circuit. Repeat the process for the other two groups.

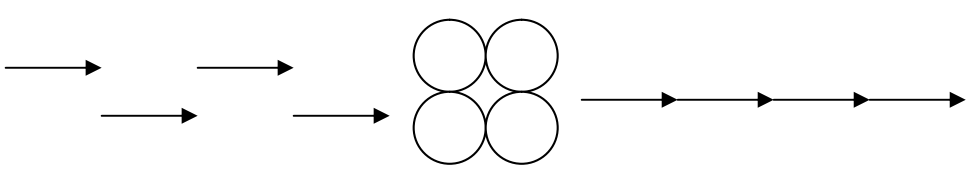
Now you have 3 groups of coils wired in series. Each group is now called a Phase. These are now ready to be wired into the "Y" configuration as shown in the previous diagrams.

Take three leads all coming from either the inner or the outer coil leads and connect them together. All three leads must be the same, inner or outer coil leads, not mix and match. This point is now your Neutral in the AC current. The remaining three leads are all hot and ready to be rectified. If you are wondering how I know which your hot is, I don't actually know except that the characteristics of the current flow are dictated by orientation of the "Y" wiring, not the direction the coils are wound. Remember AC means alternating current, switching back and fourth depending on weather the north or south pole of the magnet is currently passing a coil. This changes every time a magnet passes because we alternated the poles of the magnets in our alternator.

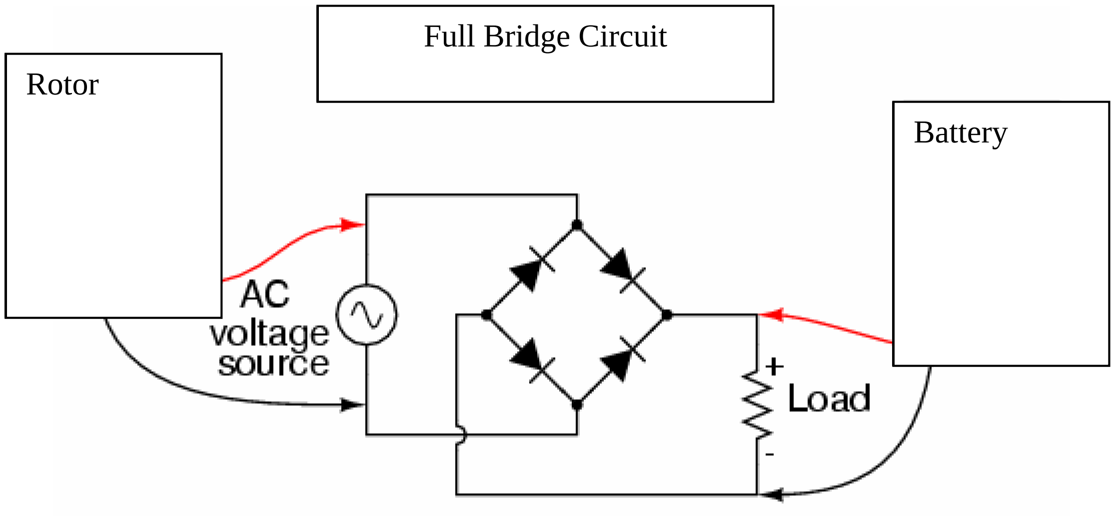
12th, build or buy a rectifier.

What is a rectifier? This is a circuit that puts the alternating current into a re-oriented direct current. By using diodes or gates, the electricity is sorted and released again in a uniform manner rather than an alternating manner.

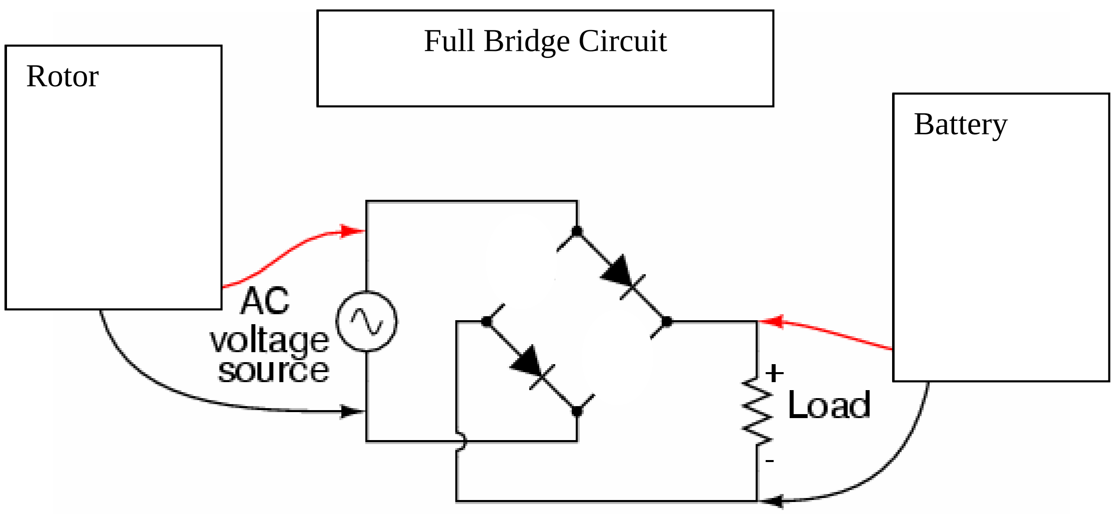
Over simplified diagram below:



The broken lines are alternating current and the circles are diodes with the direct current represented on the right.



A diode is like a one way gate for electricity. When you look at the diagram above, you see four diodes depicted with an arrow in the direction of current flow and a line representing the stop meaning that current can not go back. This symbol is standard in electrical schematics.



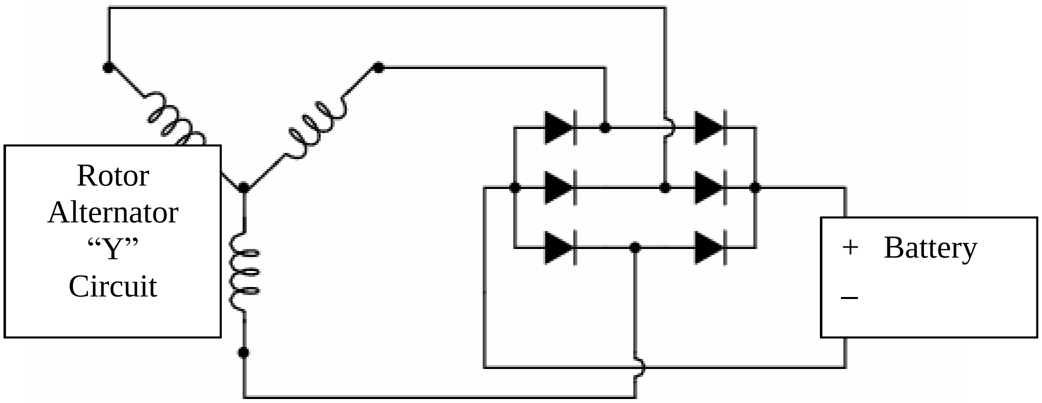
The diagram above shows a half cycle path for the current. On the other half of the cycle the diodes displayed would be reversed.

Make sure your diodes are up to the level of current you expect from your rotor. You may need a fuse before your rectifier or may need to double up on diodes.

If you choose to buy a rectifier, you may want to buy the used variety from an auto wrecker. Auto alternators have built in rectifiers for charging the car battery. You will have to research this on your own. I'm building my rectifier.

13th, wire current leads from stator through a rectifier.

My wiring will be similar to the following diagram:

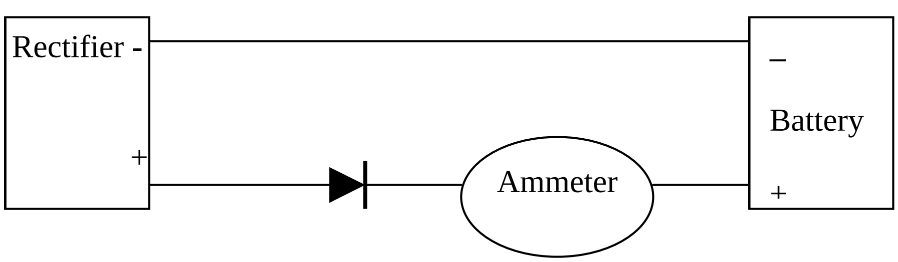


I don’t think the diagram requires a lot of explanation. Simply wire as depicted except for the battery. We don’t actually want the battery hooked up directly like this. We want a charge controller between the new direct current and the battery.

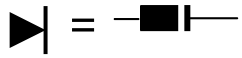
Charge controllers are a big subject. I will let you research that on your own. There are sites with circuit diagrams and sites that will sell them. To prevent battery damage, you want one. Charge controllers also help ensure your battery is getting the most from the energy without giving any up in the process.

If you must start charging your batteries, beware of overcharging, and use the following information:

A very simple charge circuit uses a diode and an ammeter. To charge a battery just connect the + and - terminals of the circuit to the corresponding terminals of the battery. When the battery is not charged, the ammeter reading shows 1-3 amps. When the battery is fully charged the ammeter reads Zero or nearly zero, after which the battery should be removed from the charger. Care should be taken NOT to reverse the + and - terminals while connecting it to the battery.

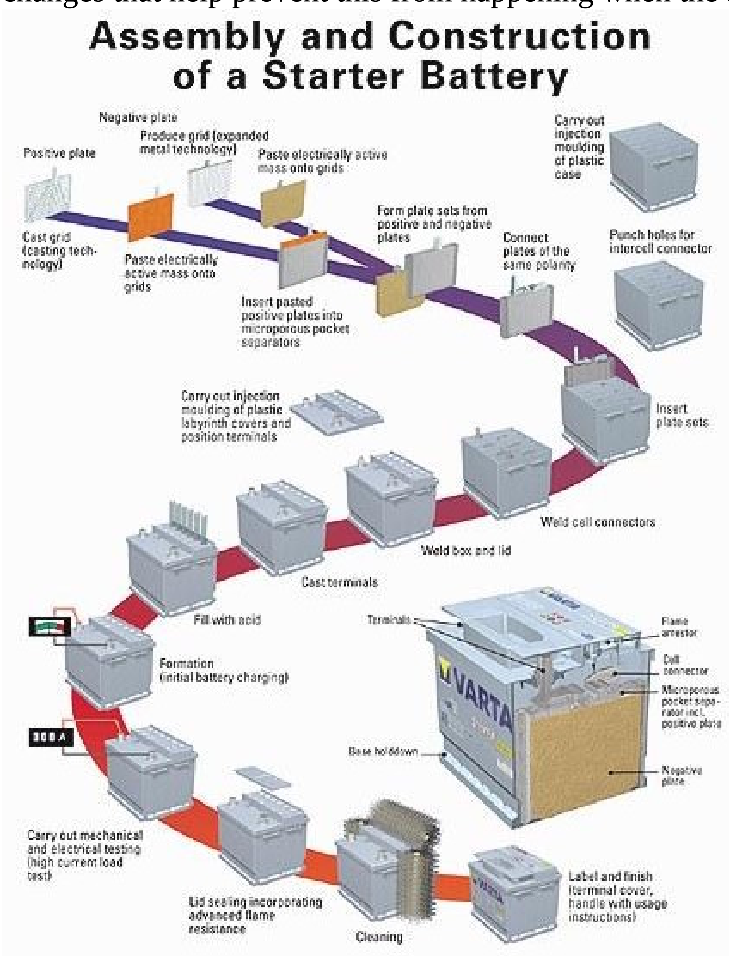


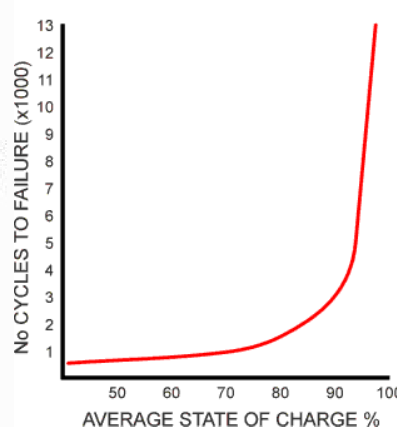
To improve on this, add a diode on the negative side. The diode should have a rating of 5A or better also known as a rectifier diode. For those of you who are novices with diodes, on the diode the colored stripe indicates which way the current flows. The power flows from the end without the stripe to the end with the stripe. The stripe is referred to as the cathode band.



14th, wire from rectifier to charge controller to your batteries, you do have deep cycle batteries right?

There are some fundamental differences between a starter battery on a vehicle and a deep cycle battery. A starter battery like the one in your car is put together as shown in the next diagram and is designed for high output for a short burst. This design also does not like to drain very much before causing deterioration. Over draining accelerates the batteries demise. Deep cycle batteries are assembled the same way with some material changes that help prevent this from happening when the battery is drained.





The chart on the right shows that a car battery lasts longest when it is never allowed to drain to a state less than 95% of full charge. A deep cycle battery will be run down to 20% charge regularly.

The following two definitions and size chart are taken from www.windsun.com.

Deep cycle batteries are designed to be discharged down as much as 80% time after time, and have much thicker plates. The major difference between a **true deep cycle battery** and others is that the plates are **SOLID Lead plates** - not sponge. Unfortunately, it is often impossible to tell what you are really buying in some of the discount stores or places that specialize in automotive batteries. The popular golf cart battery is generally a "semi" deep cycle - better than any starting battery, better than most marine, but not as good as a true deep cycle solid Lead plate, such the L-16 or industrial type. However, because the golf cart (T-105, US-2200, GC-4 etc) batteries are so common, they are usually quite economical for a small to medium system.

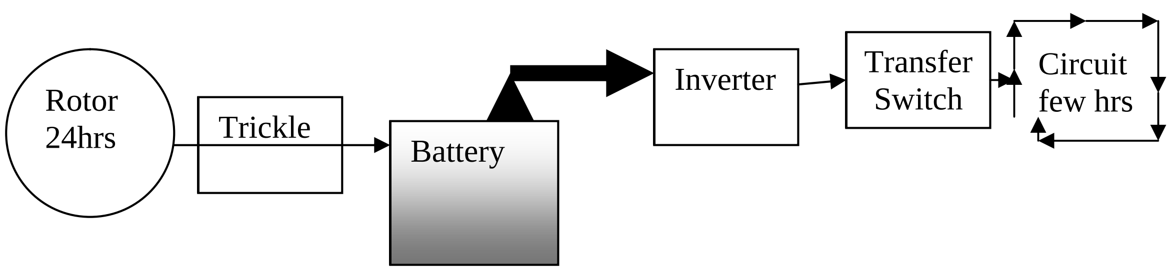
All deep cycle batteries are rated in amp-hours. An amp-hour is one amp for one hour, or 10 amps for 1/10 of an hour and so forth. It is **amps x hours**. If you have something that pulls 20 amps, and you use it for 20 minutes, then the amp-hours used would be 20 (amps) x .333 (hours), or 6.67 AH. The accepted AH rating time period for batteries used in solar electric and backup power systems (and for nearly all deep cycle batteries) is the "**20 hour rate**". This means that it is discharged down to 10.5 volts over a 20 hour period while the total actual amp-hours it supplies is measured. Sometimes ratings at the **6 hour rate** and **100 hour rate** are also given for comparison and for different applications. The 6-hour rate is often used for industrial batteries, as that is a typical daily duty cycle. Sometimes the 100 hour rate is given just to make the battery look better than it really is, but it is also useful for figuring battery capacity for long-term backup amp-hour requirements.

Marine batteries are usually a "hybrid", and fall between the starting and deep-cycle batteries, while a few (Rolls-Surrette and Concorde, for example) are true deep cycle. In the hybrid, the plates may be composed of Lead sponge, but it is coarser and heavier than that used in starting batteries. It is often hard to tell what you are getting in a "marine" battery, but most are a hybrid. "Hybrid" types should not be discharged more than 50%. Starting batteries are usually rated at "CCA", or cold cranking amps, or "MCA", Marine cranking amps - the same as "CA". Any battery with the capacity shown in CA or MCA may not be a true deep-cycle battery. It is sometimes hard to tell, as the terms marine and deep cycle are sometimes overused. CA and MCA ratings are at 32 degrees F, while CCA is at zero degree F. Unfortunately, the only positive way to tell with some batteries is to buy one and cut it open - not much of an option.

Some common battery size codes used are: (ratings are approximate)

U1	34 to 40 Amp hours	12 volts
Group 24	70-85 Amp hours	12 volts
Group 27	85-105 Amp hours	12 volts
Group 31	95-125 Amp hours	12 volts
4-D	180-215 Amp hours	12 volts
8-D	225-255 Amp hours	12 volts
Golf cart & T-105	180 to 220 Amp hours	6 volts
L-16	340 to 415 Amp hours	6 volts

All of this information is important because your wind power will not be enough to actually run very much. What it will do is trickle charge your batteries. While you sleep, while you are at work, while you are home, your system will be trickle charging. You primarily use energy during a few hours of the 24 each day. The process here is to fill the batteries all the time and then use what you need during a short period so the whole thing can start again the next day. If you need more power or time, add rotors with alternators and or batteries.



If this is still unclear, imagine a wheelbarrow. You are transporting something in it, usually dirt. You shovel dirt in small chunks or shovels full until the wheelbarrow reaches capacity. Then you deliver the load, return and start again. The wheelbarrow is like the battery and the shovel is like the rotor.

15th, Select an inverter.

Inverters are a huge subject of their own. The basics are like this; You have square wave, modified square wave and sine wave. Each of these types have particular characteristics. Any of them can kill you. These will all generate real Amps and should be treated with the respect you give wall power regardless of the Watt rating the unit has.

The square wave is furthest from utility style power and is the cheapest and oldest technology. Square wave will also create hum in your audio equipment, and sometimes lines on a T.V. and will even damage some electric motors or sensitive electronics.

Modified square wave is currently most common and sometimes called modified sine wave in advertisements I've seen. This type uses a tapering process to "round" off the corners of the square wave to more closely emulate a sine wave. This is a cheap fix to the issues created by square waves but does not completely eliminate them. Most compact single computer battery backup units have this type of power when in backup mode.

True sine wave is the same or better than what the electric company provides. The sine wave from these units is very stable because of the stable nature of a battery as the power source. True sine wave units cost a lot more than modified square wave.

Lets talk WATTS. This is confusing as well. Remember, electricity is measured in Watts, Amps and Volts. This is a balancing act or perpetual trade off as you relate these to each other. Many of the less expensive inverters are rated as #### Watts. Take note, many devices have a start load and an operational load which will be rated in Amps! Because of inherent loss when converting energy and the relationship between Watts and Amps, you can estimate that 1200 Watts is 10 Amps at the rated output voltage of 110 Volts. Remember that AC current is called 110 because it used to be less steady and 110 was the target voltage. If you check your utility provided AC, you will find it is more like 118 or 120 Volts. Also note that newer appliances are labeled to run on 120 Volts. This means a 12 Amp vacuum cleaner is 12 Amps at 120 Volts. Your inverter will probably output 110 Volts. What happened to the relative Amps? The Amps are closer to 13! The Amps and Voltage requirements may not be met unless the inverter is rated considerably higher than the appliance lists as its functioning Amperage. Also, remember that the inverter only puts out the full rated Amps if the battery is at full charge and as the battery drains, the voltage drops. I recommend that your inverter be rated for at least 50% higher Watts than the additive value of the things you will be plugging in to it. Appliances rated for 120 Volts will run on 110 Volts, but the Amp draw will probably be higher depending on the nature of the appliance. The formula for the raw calculation is Watts = Volts x Amps.

Inverters also use power when they are turned on and nothing is plugged in to them. This is another problem to consider when making your purchase. Some of the more expensive units will sense a load and only turn on when a demand is present. Many of the inexpensive units use fans for cooling and these make audible noise.

For more information on inverters, do a search on the internet. There are many websites dedicated to inverters and some even have nice little charts of common appliances and their typical Amp draw.

A favorite in my research for an inverter:

http://www.donrowe.com/inverters/inverter_faq.html

16th, consider a Transfer Switch. If you plan to wire this power onto a circuit in your home or any dwelling, you absolutely must have a transfer switch if there is another power source at the site. A transfer switch prevents back feeding and potential for two sources to be hooked up at the same time on the same circuit. A basic mechanical one can even be purchased in the electrical department of home improvement stores.

You now have 110 Volt electricity from wind! What will you do with it? No matter what you decide to run with your new power, you will be doing the environment a favor and helping pave the way for a greener future.

Best of luck,

- Brad   brad@homesopen.com

P.S. For the 6th, 7th, and 10th steps, please donate $1.00 or write me a very sincere request with a description of where you are in the country and how you plan to use your wind power as well as promise to share your results. These steps are my personal recipe for the alternator which is currently on the side of my house about 1 foot off the ground and generating 25 to 28 volts in about 6MPH wind. I'm just looking for the donation to further fund this project and look for even more efficient ways to implement the alternator and the savonius rotor. This is an ongoing project. I will also include more photos of the unit with close ups of the coils which are currently mounted in a very temporary fashion.

Tools List (the tools I used, others may be substituted)
Pliers
Hammer
Plunge router
Caulk Gun
Battery Powered Drill
Drill Bits
Compass (for marking wood with half circles)
Sharp permanent marker
Goggles
Ratcheting strap
Clamps (mine are 3' but I really only used them at about 6 or 8 inches)
Drill guide for making perfectly perpendicular holes in center of wood rounds
Pencil
Skill Saw for cutting miscellaneous wood for platform

Materials List

2 – pine rounds 24"
2 – 6" x 3' stove pipe
1 – tube of construction adhesive (outdoor rated)
1 – tube of liquid nails small project (indoor outdoor rated)
4 – 36" pipe threaded at both ends (Optional for temporary rotor mount)
2 – elbows for pipe (Optional for temporary rotor mount)
2 – "T's" for pipe (Optional for temporary rotor mount)
2 – pipe couplers (Optional for temporary rotor mount)
2 – 4" pipe nipples (threaded at both ends) (Optional for temporary rotor mount)
9 – spools of magnet wire (one for each coil worked for me, you could order bulk)
http://www.forcefieldmagnets.com/catalog/product_info.php?products_id=113
16 – neodymium 2"x1"x1/2" magnets charged through thickness
http://www.forcefieldmagnets.com/catalog/product_info.php?products_id=30
1 – roll electrical tape
3 – rectifiers – full bridge (NTE5324 12.5Amp works pretty good and was only $10)
1 – Diode for optional charging circuit (NTE5812 is a 6A and cost me $0.99)
NTE Electronics is at www.nteinc.com or 800-631-1250
2 – bolts at least 3" long
2 – nuts for the bolts
4 – washers for the bolts
2 – lock washers for the bolts
1 – quart of outdoor grade urethane to weather protect everything
2 – disposable 2" paint brushes (a few of these are always good to have around)
Paint of your choice (I'm going for camouflage on mine)
Lumber for platform and misc
3 lead outdoor electrical wire (rated for burial to suit your needs for a run from rotor to charging and inverter station)

Glossary

- **Application—**refers to how you will use the power generated.
- **Single Phase vs. Three Phase—**How your stator (wire coils) are connected to each other for generating electricity. If you have 9 coils and wire them into 3 groups of 3 coils, and then wire them up as 3 groups, you have a 3 phase alternator. The breakdown of this is described in the body text of this document.
- **Speed--**The shaft speed is a very important factor in all types of alternators and generators. The unit needs to make higher voltages at lower rpms, otherwise it is not good for wind power use. This is also why vehicle alternators are not good for wind power use.
- **Start-Up Speed--**This is the wind speed 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—**the speed of wind required to start the windmill turning. In some references, this refers to the alternator speed at which the charging process engages.
- **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 batteries 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.
- **Air Gap--**This is the distance between the magnets and the coils in the rotor design, or between two magnets in a dual magnet rotor design. The smaller the distance, the better the alternator performs. Halving the air gap gives 4 times as much magnetic flux. Flux here is electricity later.
- **Number of Poles--**A 'pole' is either the North or South pole of a magnet. Generally when building an alternator we need a separate 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.
- **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. Keep this in mind and examine the diagrams of the Y and Delta configurations.

- **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 alternators.
- **Wire--**Enameled 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.
- **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.
- **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.
- **Tip Speed Ratio (TSR)--**This number defines how much faster than the wind speed 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.
- **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.
- **Pitch and Twist--** 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.
- **Carving—**The act of cutting material into the shape required for your windmill blades.