The Simple Solar and Wind Power Manual

1 notes

Throughout this book you will find a large space at the bottom reserved for notes. Please write anything you feel is necessary.

Introduction

This book is the product of two workshops given in the community of Alfred, NY in the spring of 2009. The focus of these workshops was the idea that solar power and wind power are accessible to people of all levels of education and experience. They were organized by a core group, but many people from the community contributed their knowledge and experience to the presentations. In both workshops, we began with a focussed presentation and ended with a room full of conversations between professors, students, residents of the town, and people from far away.

Our hope was not to be an authority on these issues but to share what we had learned through simple research and exploration. The workshops were a focal point for people from the area to share their experience and act as a resource for each other. This is important for two reasons: It allows people to get information from a primary source (another person) and it helps people build networks of support within the community.

Our interest lies in broader things than just solar panels and wind turbines. More generally, we ask: Where does our energy come from? How is electricity generated? How long will our current fuel sources last? What is sustainability? How does our energy use affect our surrounding environment?

A more direct way to approach these topics was to investigate our own electricity use, and learn how to generate it in different ways than usual. How can we understand how much energy we use? How can we grasp the scale at which electricity is generated? We decided to find out what was involved in unplugging from the electrical grid in order to have more control over our energy use and production.

All of the information in this manual comes from our experience of building these systems. Trying to do something unfamiliar, making mistakes, and redoing it is one of the best teachers there is. This is also the purpose of this manual: to give you a starting point to begin understanding how you can be involved in your own energy use.

Sincerely,

Sam Newman and Jenny Urfer

P.S. Please find photos from these workshops, as well as an electronic copy of this manual at: http://alfredworkshop.weebly.com

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Acknowledgements

We are indebted to a number of people who lent us their time, knowledge, encouragement, experience, and budgets. We would not have been able to produce our workshops or this document without them. Here are their names:

Barry Miller
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Stephanie McGeorge
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Thank you all for your help.

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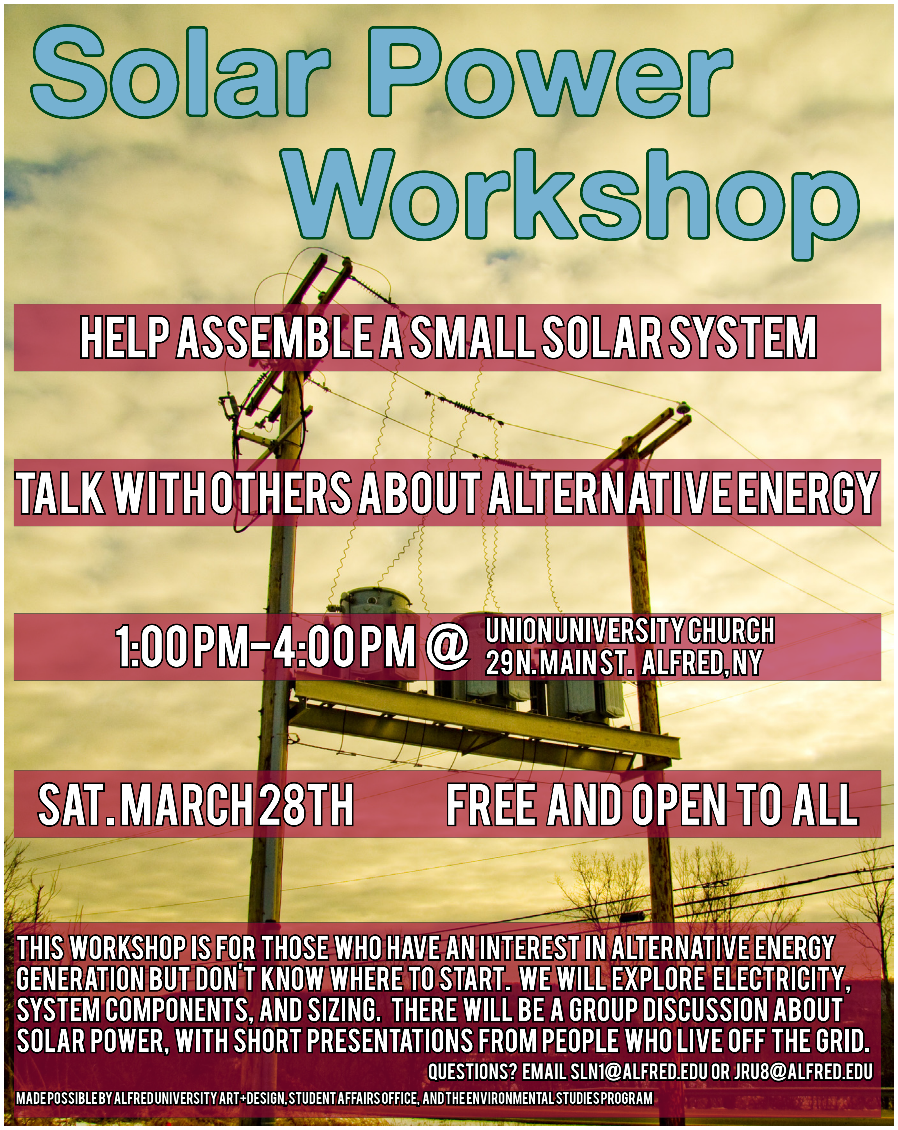
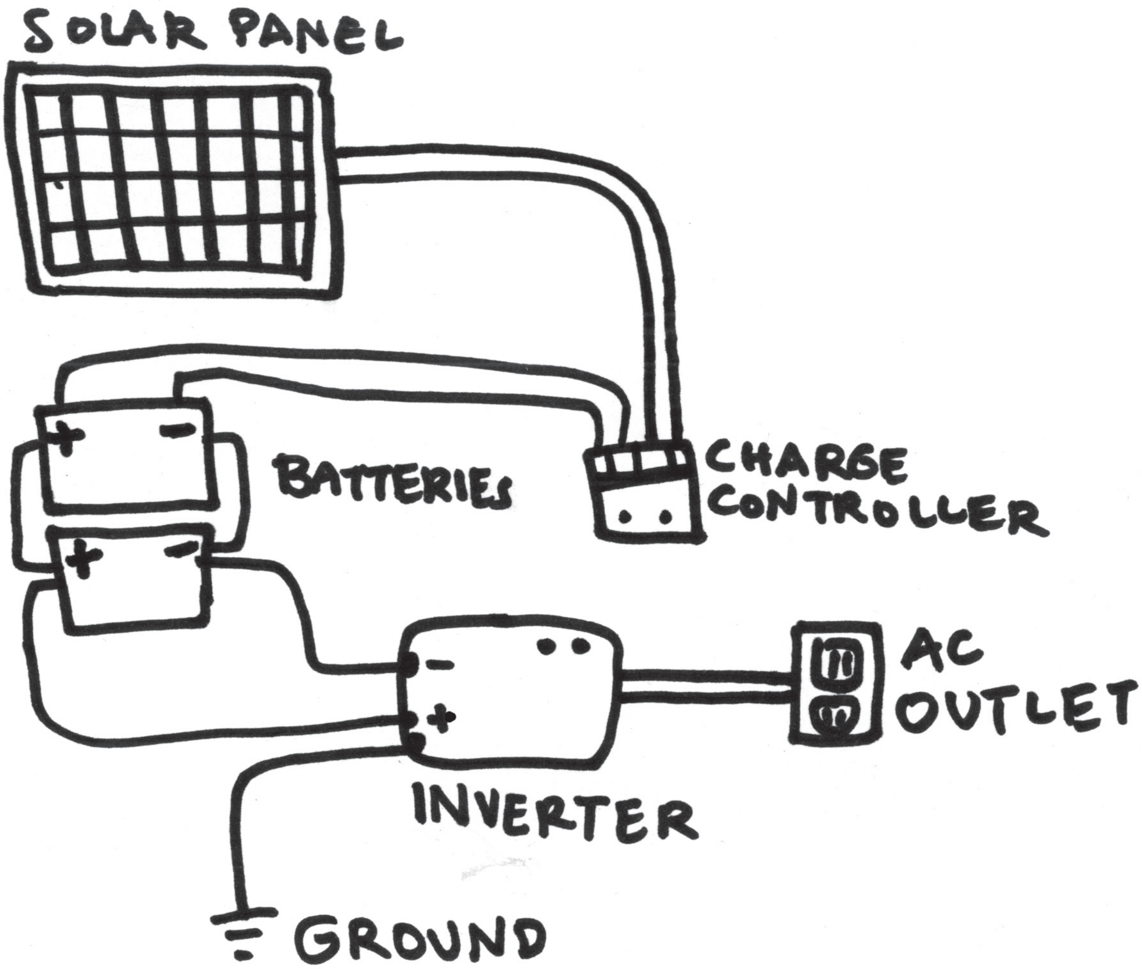

Solar Power
Workshop
HELP ASSEMBLE A SMALL SOLAR SYSTEM
TALK WITH OTHERS ABOUT ALTERNATIVE ENERGY
1:00PM-4:00PM @ UNION UNIVERSITY CHURCH
29 N. MAIN ST. ALFRED, NY
SAT. MARCH 28TH
FREE AND OPEN TO ALL
THIS WORKSHOP IS FOR THOSE WHO HAVE AN INTEREST IN ALTERNATIVE ENERGY GENERATION BUT DON'T KNOW WHERE TO START. WE WILL EXPLORE ELECTRICITY, SYSTEM COMPONENTS, AND SIZING. THERE WILL BE A GROUP DISCUSSION ABOUT SOLAR POWER, WITH SHORT PRESENTATIONS FROM PEOPLE WHO LIVE OFF THE GRID.
QUESTIONS? EMAIL SLN1@ALFRED.EDU OR JRU8@ALFRED.EDU
MADE POSSIBLE BY ALFRED UNIVERSITY ART+DESIGN, STUDENT AFFAIRS OFFICE, AND THE ENVIRONMENTAL STUDIES PROGRAM


Wind Power Workshop
Come to a workshop on wind power
Learn about alternative energy
Saturday, April 11th, 1:00PM
Union University Church
29 N. Main St, Alfred, NY
Contact JRU8@alfred.edu
or SLN1@alfred.edu
for more information
This workshop is for those who have an interest in alternative energy generation but don't know where to start. We will cover electricity, system components, and sizing, and look at some different home-built wind turbines. There will be a group discussion about wind power, with short presentations from people who live off the grid or have experience with wind generation.
Made possible by Alfred University Art+Design, Student Affairs Office, and the Environmental studies program

Overview



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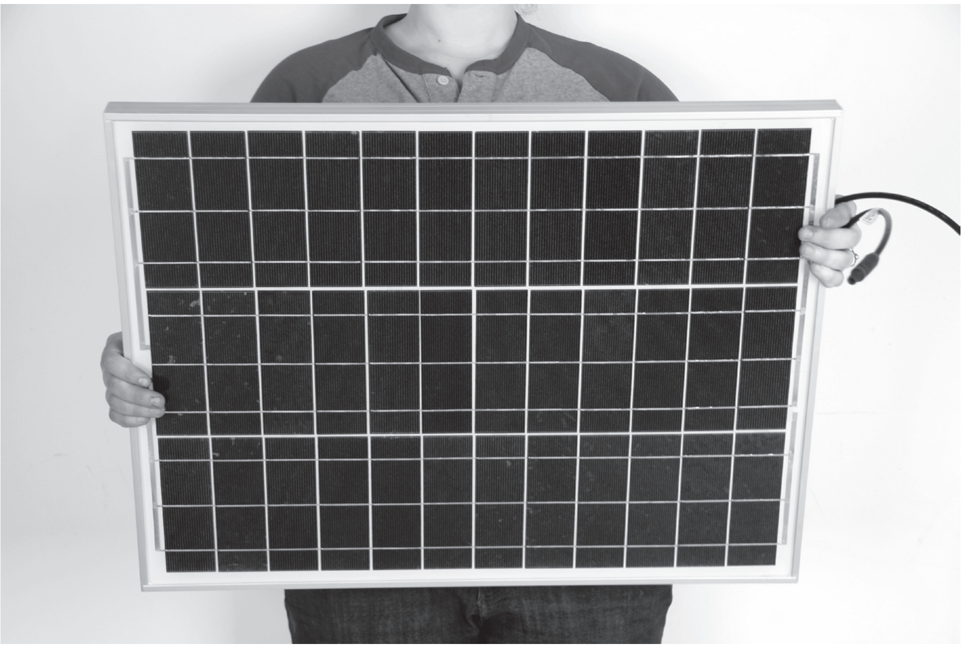
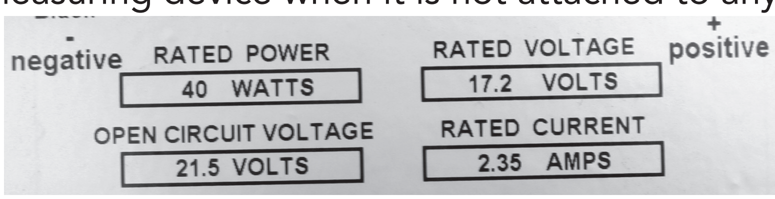
Photovoltaic System Parts



Solar Panel

This is a photovoltaic panel, also know as a PV panel or a solar panel. It produces electricity when placed in sunlight. Solar panels have a couple of different ratings, which you should find on a sticker on the back or in an owner' manual. The important things to look for are the rated voltage, rated current, and rated power. The rated voltage and current are what you can expect from it in full sunlight. The rated wattage is the rated voltage times the rated current (volts x amps = watts) and is a good way to add up your total watt-hour needs when building an array with a number of these panels. You may also find a rating for open circuit voltage. The open circuit voltage is what the panel will read on a measuring device when it is not attached to anything.



Mount

You will need a place to mount your solar panel. We welded some angle iron and rebar into a frame with holes drilled to match the holes on the panel. Your mount doesn't have to be steel. Whatever will last and keep the panel off the ground will work. If your mount is metal, you should paint it with a rust-resistant coating. You might want to consider a setup where you can adjust the angle of the panel. Solar panels are much more efficient when they are pointed directly at the sun.

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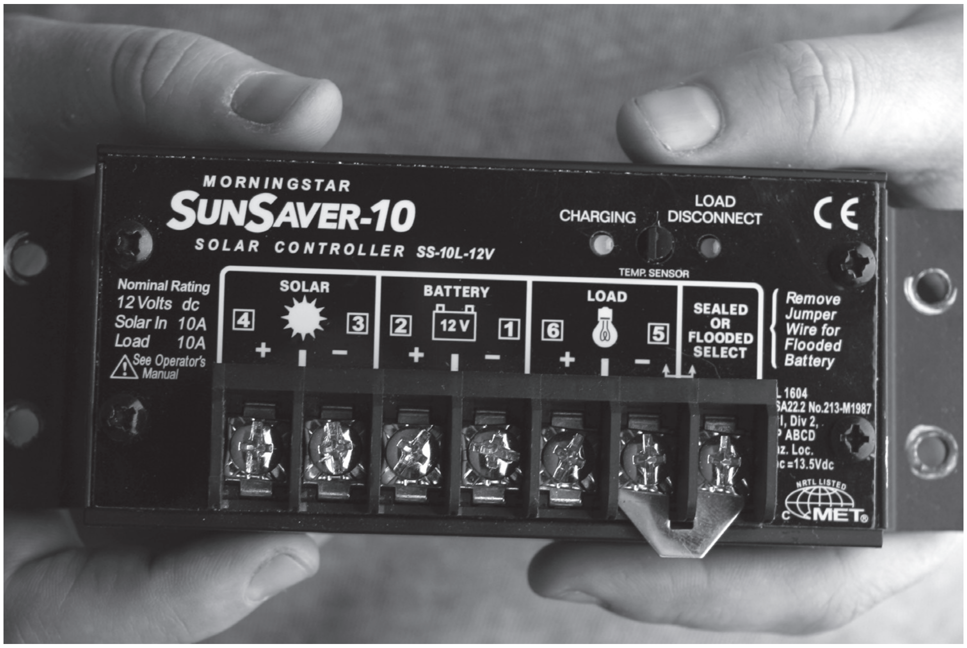

Charge Controller

This is a charge controller for PV panels. Its job is to sense the charge of the batteries. If they are low, it sends the power from a solar panel to the battery to charge it. If the batteries are fully charged, it either disconnects the panel, or it can send it directly to a DC load. Charge controllers are rated by how much power they can handle. This one is rated for 10 amps and 12 volts. The total amperage of your solar array should not exceed what your charge controller can handle. The voltage from the panels, however, will be stepped up or down to the necessary voltage to charge your batteries.

Although it is possible to connect your solar panel directly to the batteries, you would need to manually disconnect the panel when the batteries were charged to avoid overcharging the batteries. Overcharging is a very fast way to kill batteries.

It is also important to note that you need to pick a system voltage. Our system is 12 volts. The charge controller is largely what will determine your system voltage. Batteries come in 6 or 12 volts, but they can be wired into banks of 24 or 48 volts as well.

Battery

This is one of two deep-cycle batteries in our small battery bank. It is a lead acid battery, like a car battery. Unlike a car battery, it can be discharged and recharged many times because of its more robust internal structure. Batteries are rated in amp hours. This battery is a 12 volt, 40 amp-hour unit, which means that it has about 480 watt-hours. It is reasonable to use about 50 percent of a deep cycle battery's power on a regular basis and still expect a long life, so if there are 240 usable watt-hours in this battery, that could run a 10-watt fluorescent bulb for 24 hours, or a 200 watt computer for an hour.

Batteries this size have terminals with threaded holes, and they come with bolts. In order to attach wires to the terminals, you'll need special battery terminal hardware, which you can usually get from the same place you got the battery, or at a hardware store.

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Inverter

This is our inverter. The purpose of an inverter is to convert direct current (DC) into alternating current (AC). DC power has a constant direction of flow. AC power switches direction many times per second, and is the type of power that comes out of a regular wall socket.

Inverters can be big or small, expensive or cheap. This one is reasonably expensive because it produces alternating current (AC power) in a true sine wave. Cheaper inverters produce power in a modified sine wave that looks like a square wave. True sine wave AC power is important if you will be running sensitive loads, like computers, laser printers, battery chargers, or fax machines. Otherwise, it is something you probably won't need to worry about.

Inverters are rated by their continuous output in watts. This one can provide 300 watts continuously. It steps up 12 volt DC power into usable 110 volt AC power. 300 watts divided by about 100 volts is roughly 3 amps, which is the maximum current that this inverter provides. To protect it, there should be a 3 amp fuse wired between the inverter and the AC outlet.

AC Outlet

After your electricity is switched to AC, you need to send it to a wall-type socket in order to plug something in. Some inverters have a socket like this mounted in them already. Otherwise, you need to wire one yourself. These can be found at almost any hardware store. When you wire it, there are three colored screws to use. The brass screw receives the electrified wire, the silver screw receives the neutral wire, and the green screw gets the ground wire. If you're wiring this in your house, ground it like you would ground a normal outlet. If it's somewhere else (like on a portable platform), you can ground it to wherever your batteries or inverter is grounded.

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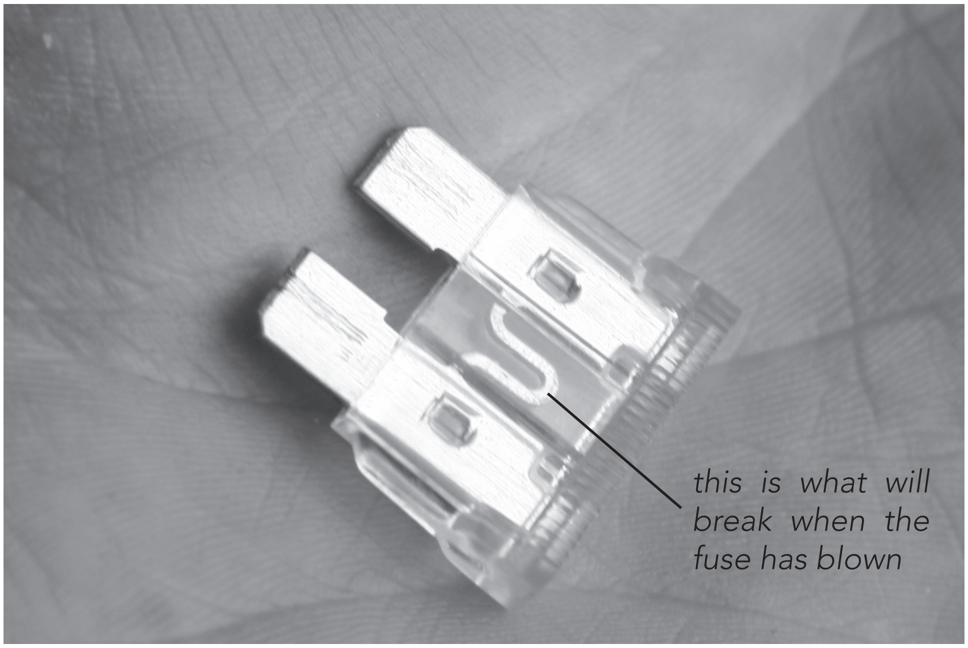

Inverter Fuse

This is a two-bladed automotive fuse. This is the kind of fuse that some inverters (like ours) use. They protect the inverter from high voltage and from reversed polarity (switching positive and negative wires). It is good to have a few extra of these around, in case you accidentally blow the fuses on your inverter. They come in different amperages, your inverter's manual should tell you which kind you need. If it doesn't, you can open up the inverter and see (make sure it isn't plugged in). When the fuse has blown, the U-shaped part in the middle will be broken, and there may be some blackening of the plastic around it.

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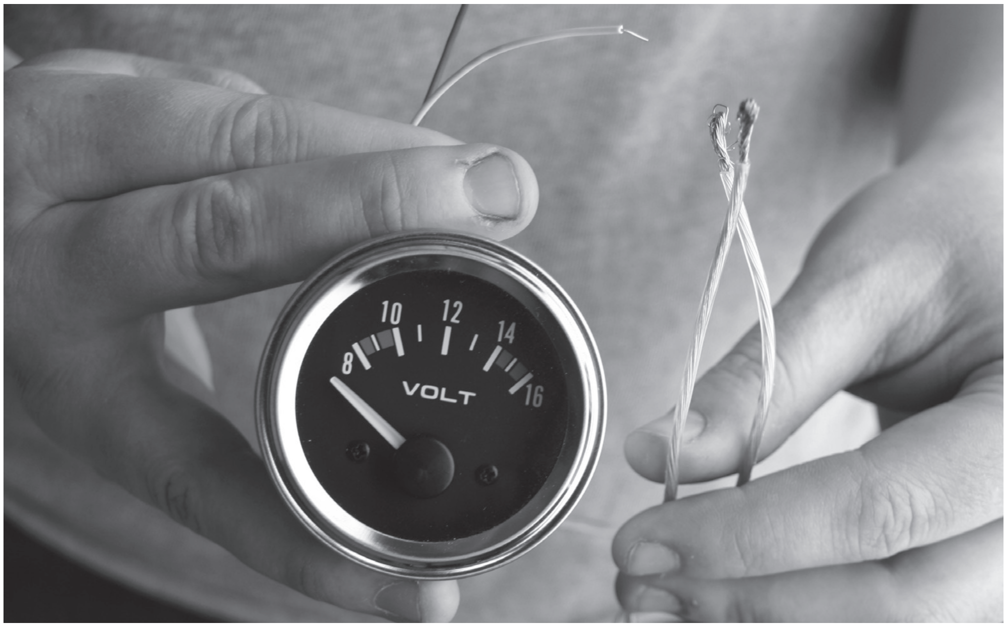
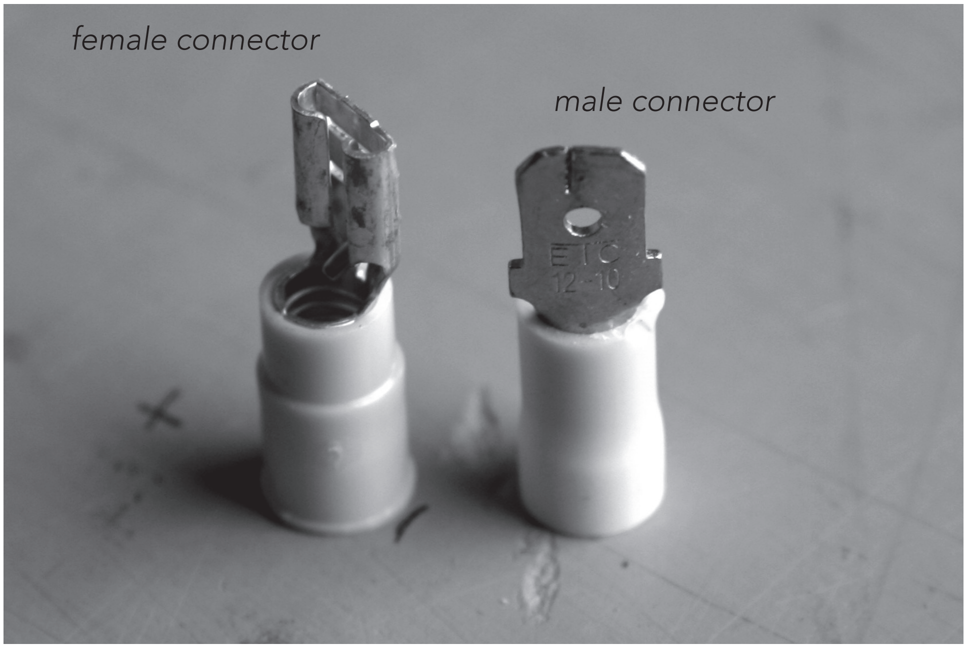


Meters

A volt meter can be wired into the system so you can read the battery or panel voltage without a multimeter. This one is from Tractor Supply Co. It is not necessary for the system, but if you include it, wire it in parallel with the batteries or the panel, whichever you want to read.

For more about wiring in series or parallel, see appendix B.



Connectors

Insulated electrical connectors make wiring a lot easier than if you were to twist all the wires together. There are a number of different kinds. These are spade connectors, there is a male and a female connector that fit into each other. The plastic part crimps closed with a pair of pliers to keep the wire from falling off.

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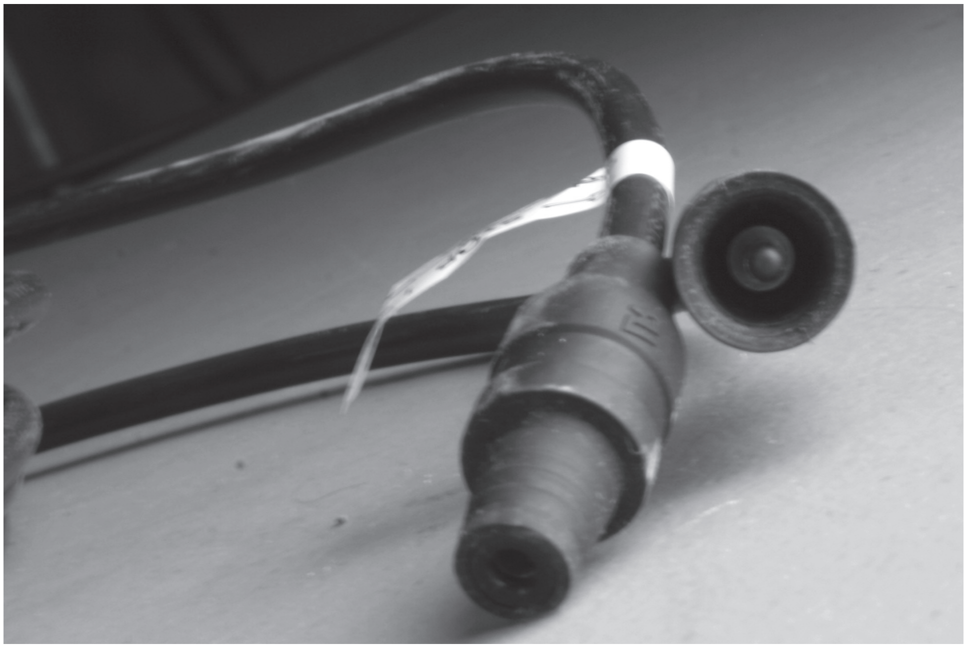

Wires

Many solar panels (including ours) have a strange type of cable coming out of the back. It is called a multi-connect (MC) cable, and is used because it is reasonably weather-proof. To get the electricity from these plugs into a charge controller, you'll need another length of the cable (twice as long as you need to span the height of your panel mount). Cut it in half, so you have two lengths of cable with either a male or female head at one end and a bare wire at the other end. As for other wiring, check the manuals for your charge controller, solar panel, and inverter to see what they reccommend. We used nothing smaller than 12 AWG wire for most connections, 6 AWG for battery and inverter connections, and 4 AWG for the ground wire.

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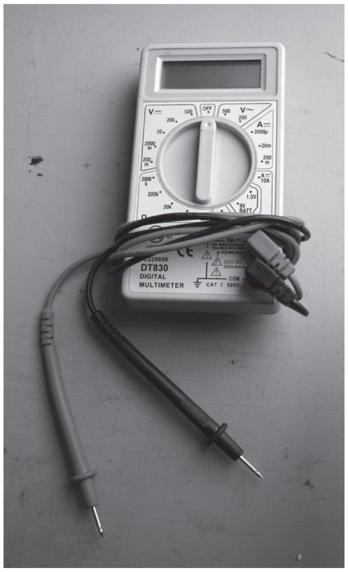
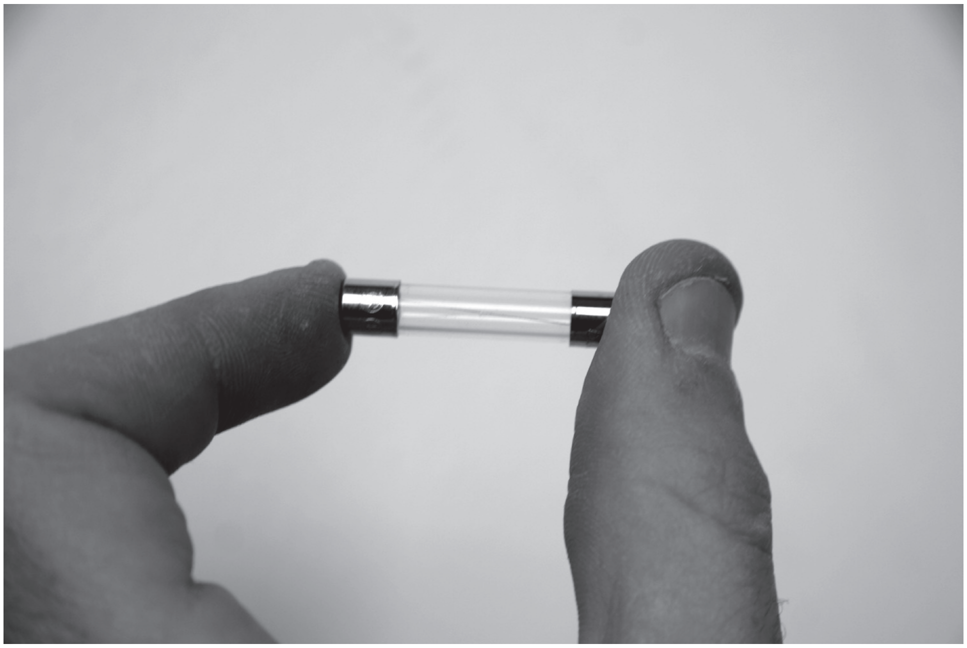


Tools

Tools and hardware you might find useful:
digital multimeter (to measure electricity)
adjustable crescent wrench
socket wrench
wire cutters/strippers
screwdriver (ours has interchangeable bits)
Electrical tape
drill/screw gun
lag screws
bolts and nuts (to secure panel to mount)

For more on how to use a multimeter, see appendix B

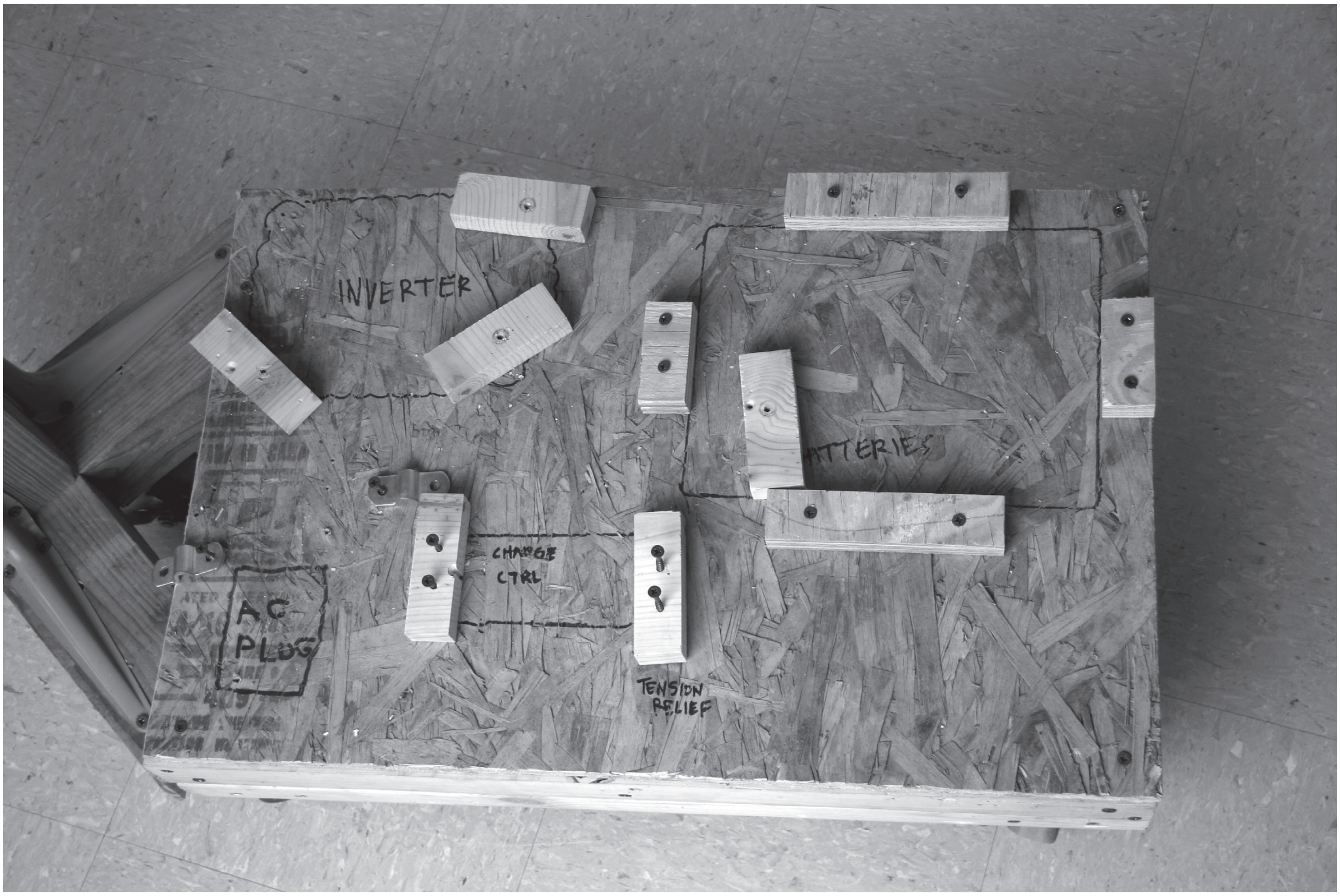


Fuse

This is a small 3 amp fuse. Fuses are good protection from electrical surges. A surge is when a large amount of electricity suddenly flows into a system. When there is too much electricity for the fuse to handle, it will blow and break the connection, so whatever is behind it will no longer be wired to the power source. To check for a blown fuse, look at the small wire inside the glass tube. If the wire is broken or you do not see a wire, the fuse has blown. The manuals for your inverter or your charge controller will tell you what kind of fuses you need and where they should go.

This is a blown fuse, notice the discoloration inside the glass part.

Assembly: Step 1



Make a place to mount everything: Batteries, charge controller, inverter, AC outlet. It can be separate from where your panel is mounted. Lay it all out and trace where everything is if you want.

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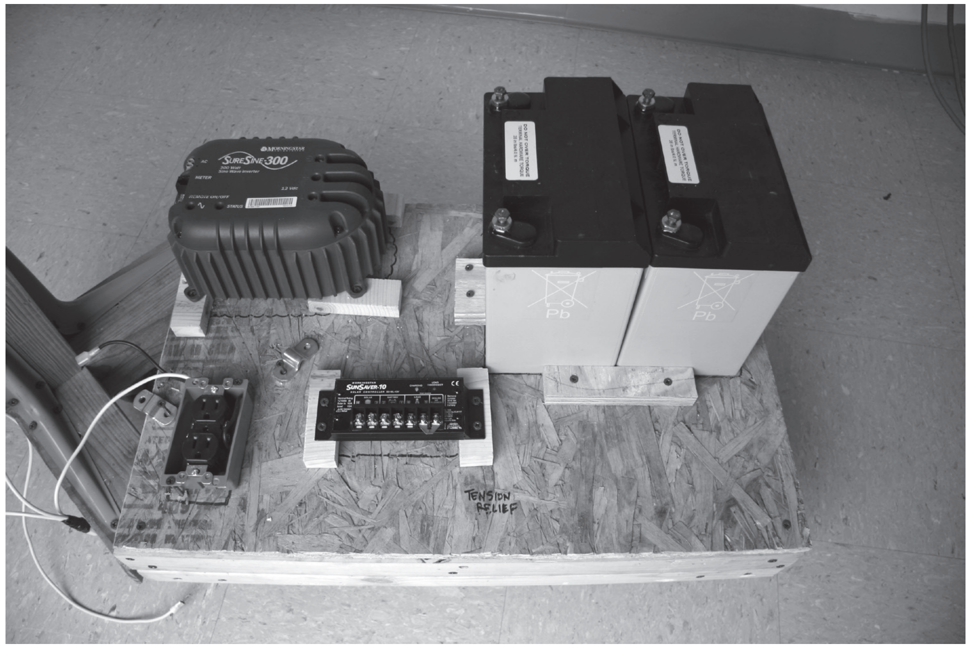
Step 2



Mount all your parts: Batteries, charge controller, inverter, and AC outlet. Everything except the batteries came with mounting holes, so we just used regular wood screws to attach everything to the base. We surrounded the batteries with blocks of wood to keep them from sliding around. Our panel mount is attached to the rest of our system so it can be portable, but yours will probably be more permanent.

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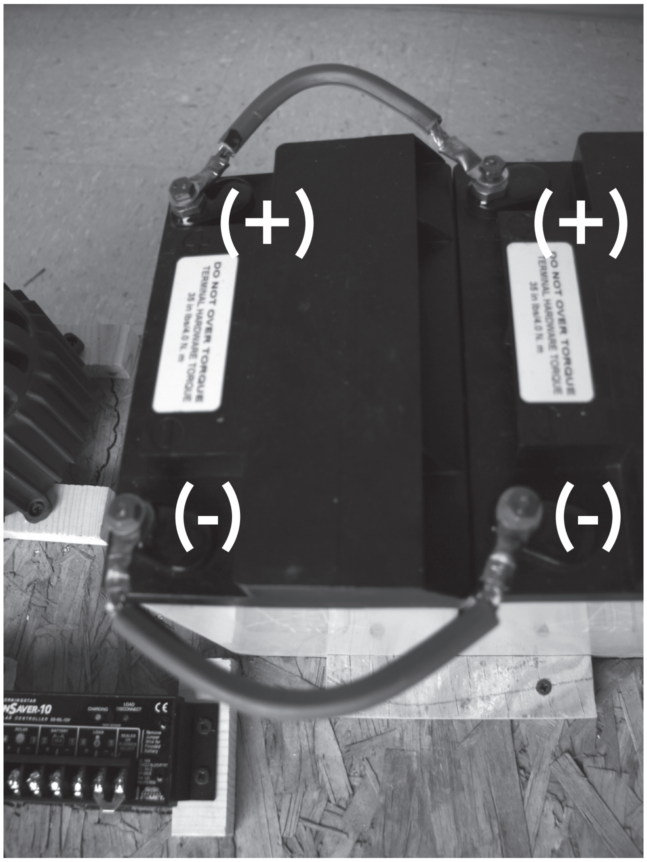
Step 3

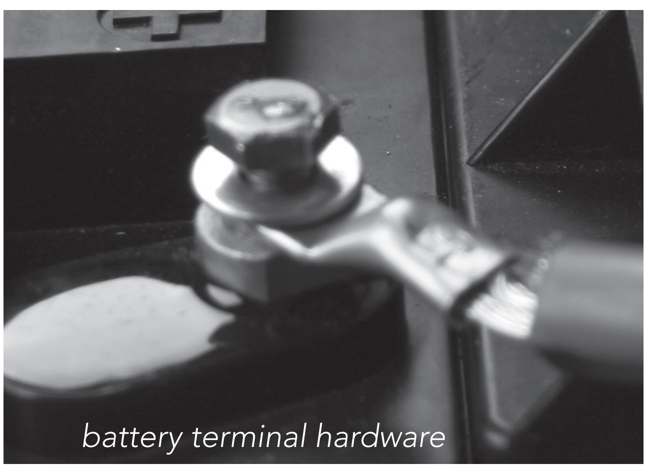


Wire your batteries together. How you do this is dependent on your system voltage. We have a 12 volt charge controller, and 12 volt batteries, so we chose to stick with a 12 volt system. Two 12 volt, 40 amp-hour batteries wired in parallel yields a 12 volt, 80 amp hour battery bank.

To wire two batteries in parallel, one wire will connect the two positive leads, and another wire will connect the two negative leads. Be careful not to touch both a positive and negative terminal at the same time, as you can get shocked.

You will need thick wire, like 4 or 6 AWG. We used wire from a 6 AWG dryer cord, but you can also get flexible welding cable at a hardware store. You will also need connectors that can accept thick wire that have a hole for the battery bolt in them.

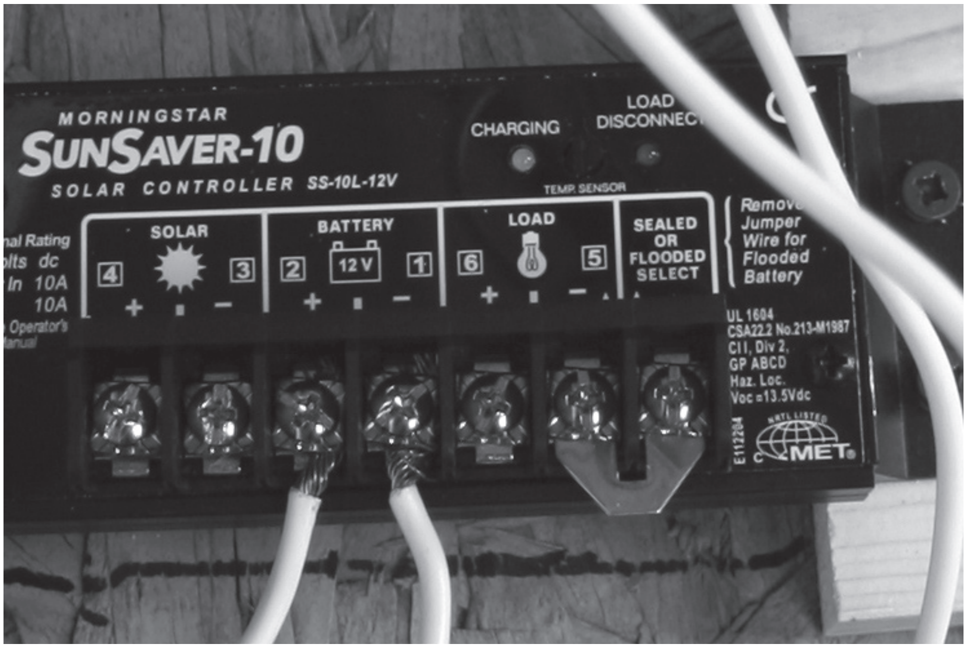
For more on battery wiring, see appendix B



battery terminal hardware

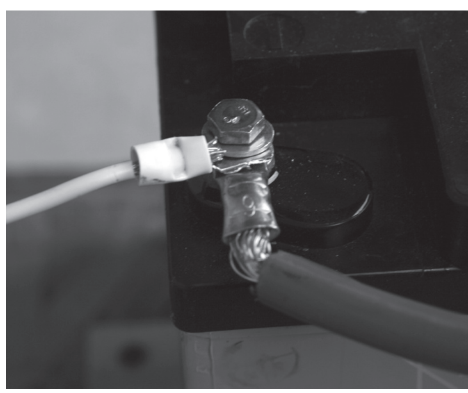
 notes

Step 4



Wire the battery terminals to the battery inputs of the charge controller. You may want to include an insulated connector in the middle of both of these wires. This way, you can wire both terminals and receptacles separately and then connect the wires without touching a metal terminal. Our charge controller has screw terminals. To insert a wire, twist the end, put it underneath the screw head, and tighten the screw.

to other charge controller



to other battery in parallel

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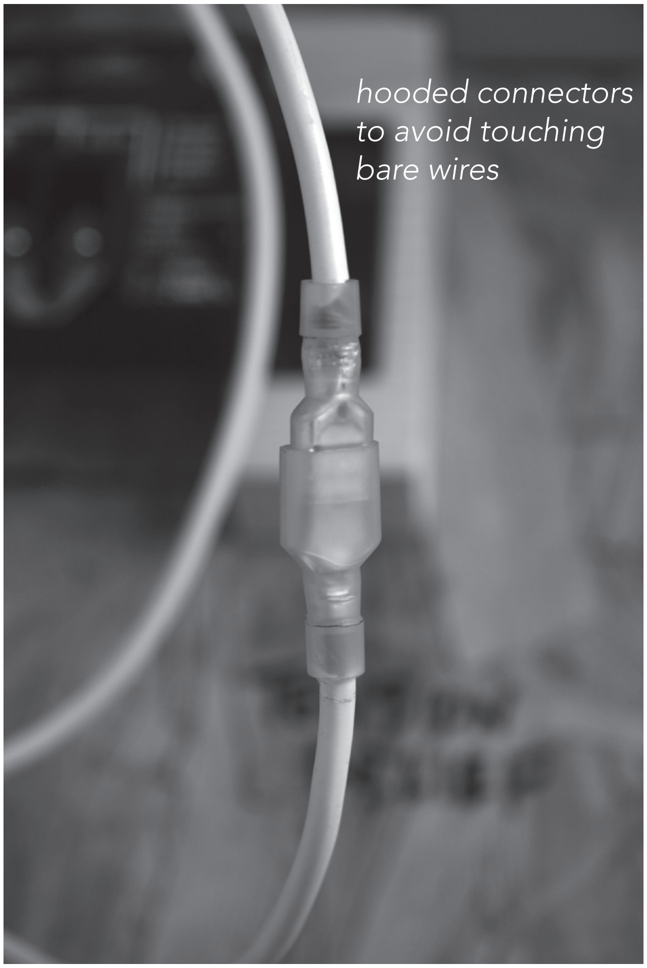
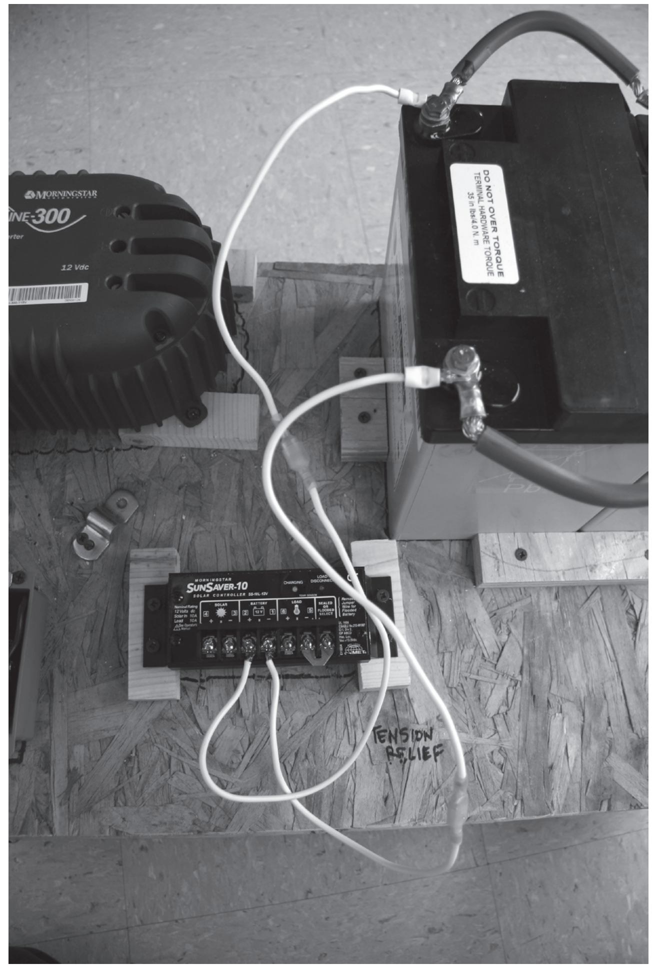
Step 5





When the wires are attached to both battery terminals and to both charge controller terminals, connect them in the middle. Be sure to wire the positive battery terminal to the positive controller receptacle, and the negative terminal to the negative receptacle.

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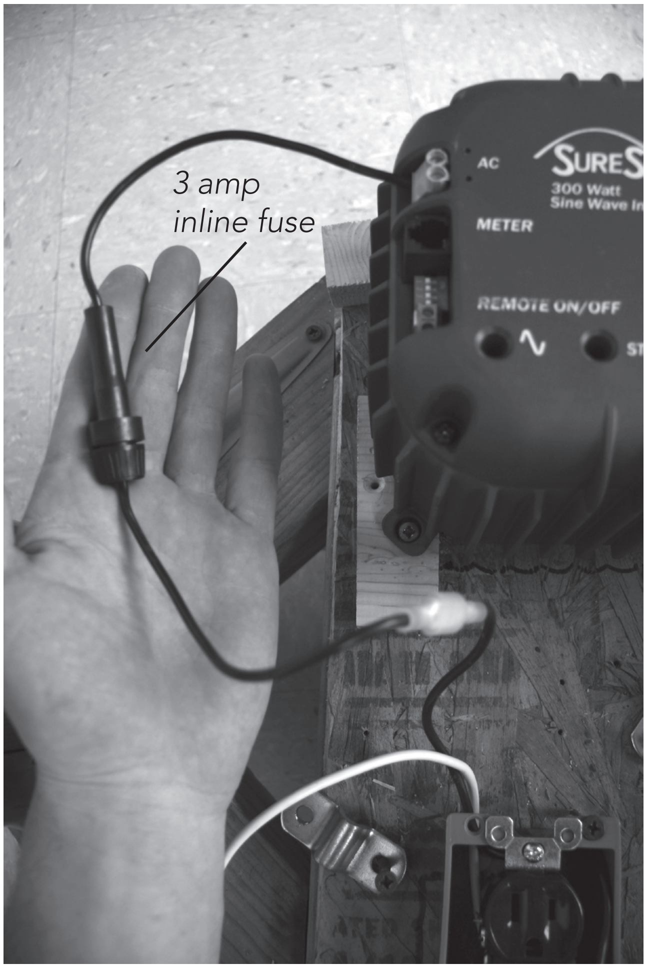
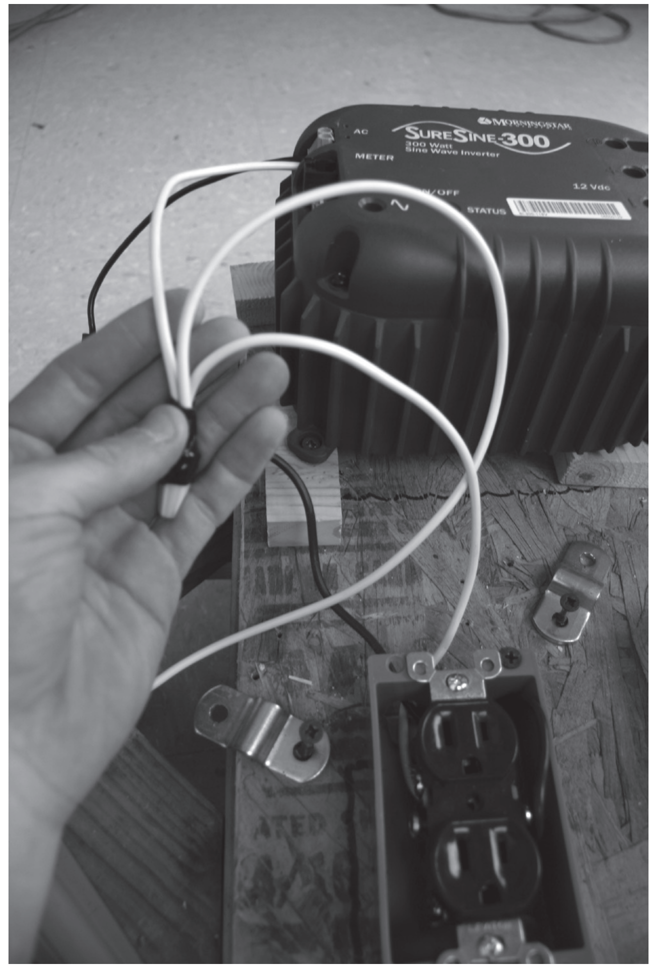
Step 6



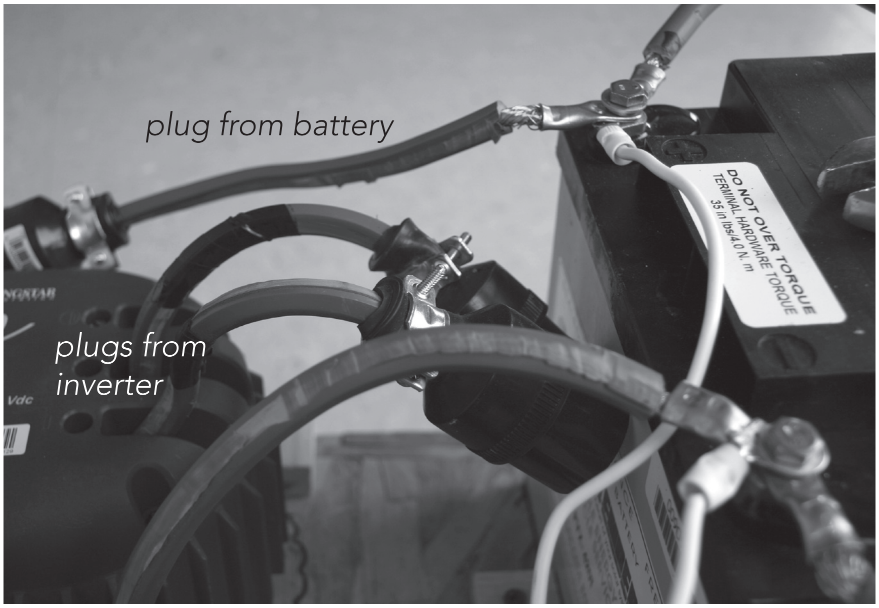


Next, wire the AC outlet to the AC output of the inverter. In these pictures, the hot, or positive wire, from the AC outlet has a 3 amp in line fuse, and the neutral wire has a third wire spliced into it. This third wire will eventually be sent to ground. If your inverter has an outlet already included in it, ignore this step.

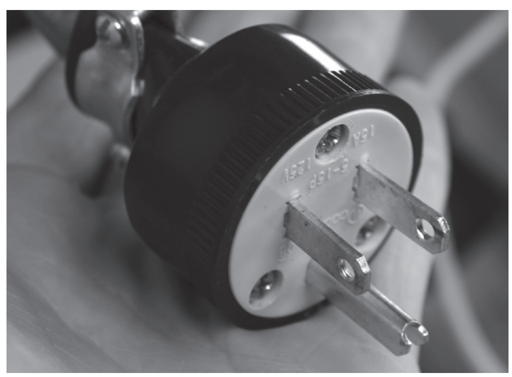
For the wiring diagram for our inverter, see appendix B

notes

Step 7

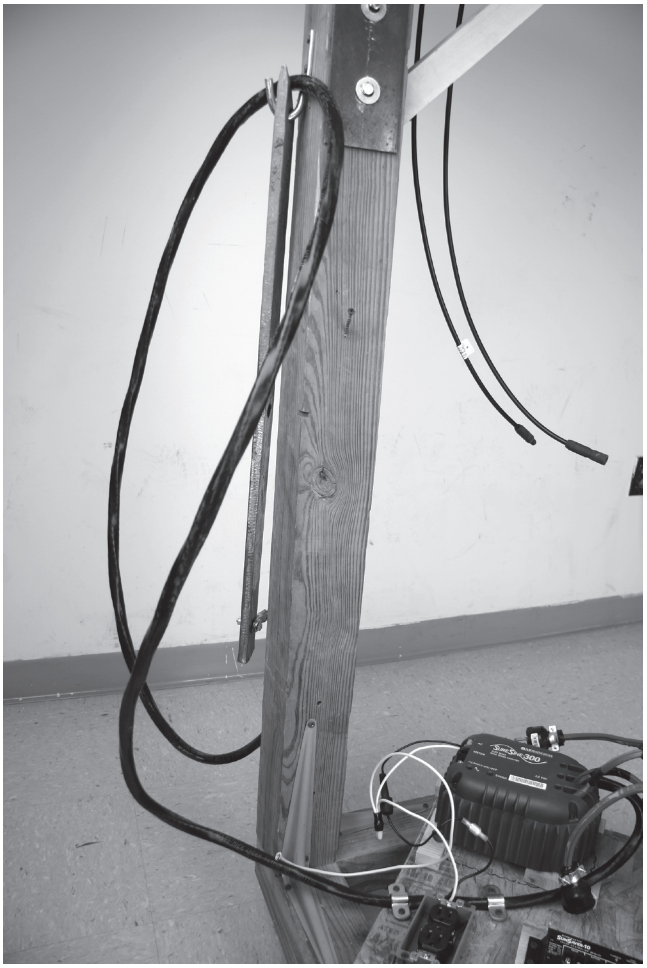


Prepare the inverter and the batteries to be connected, but do not connect them yet. They will be connected in parallel (positive to positive, negative to negative. If there is an on/off switch on the inverter, make sure it is off. When you do eventually connect the inverter, there may be a spark, and you don't want your hands touching bare wires or metal. To keep ourselves safe, we installed insulated plugs in between the inverter and the battery. That way, when we connect them, we don't need to touch either the inverter or the battery terminals.



 notes

Step 8



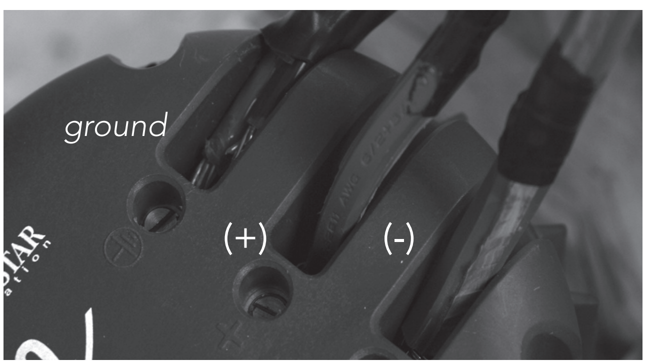
Your system should be grounded in some way. Grounding provides an easy path for fault current to travel through into the ground, rather than electrocuting you. Because we have a portable mounting system, we ground our system to the earth when we are outside.

Our inverter needed a ground, and it supplies a ground for the batteries as well. If your inverter doesn't have a ground terminal, you should ground the batteries.

The ground wire should be at least as big as the biggest conductor in the system. We used 6 AWG wire to connect the batteries, so we used 4 AWG wire to ground the inverter to the earth.

We made a three foot steel stake to pound into the ground, although if you are installing your system in a more permanent way, you can ground it to your house electrical ground.

This is a step where it would be useful to talk to an electrician to make sure you are safe.



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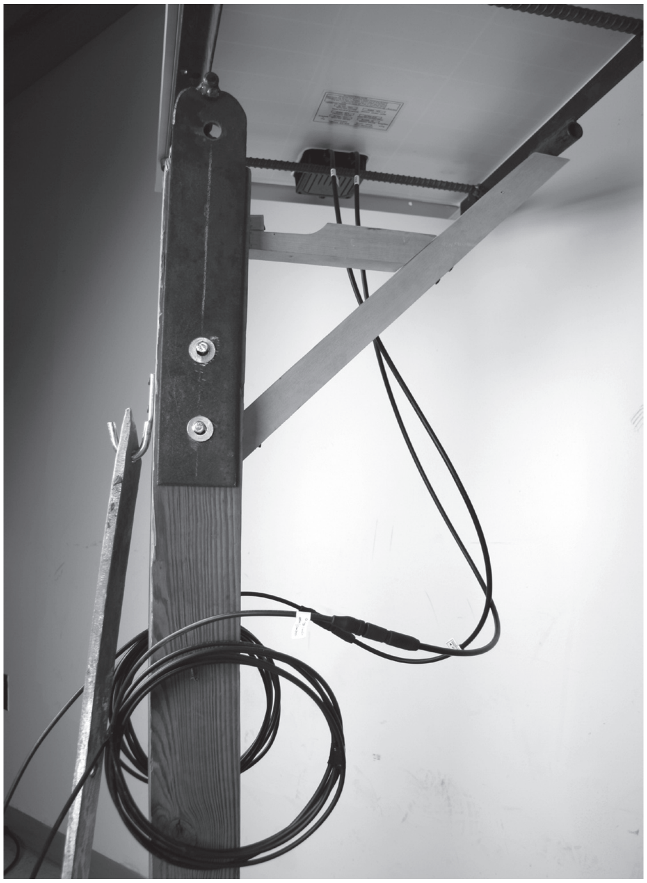
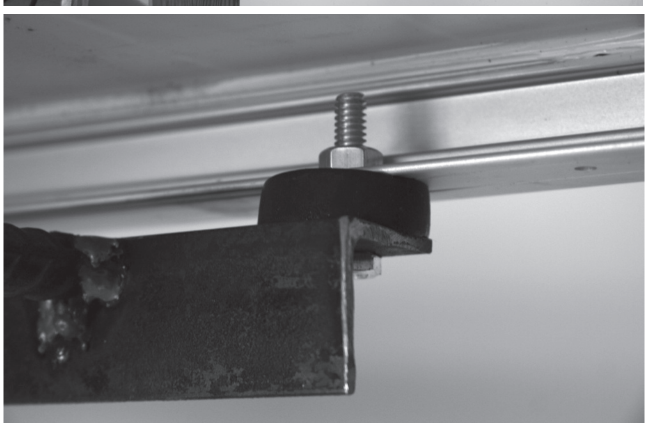
Step 9





Mount the solar panel. Make sure it is secure and that you can access the wires. We mounted it on rubber pads with locknuts so it wouldn't rattle around when we moved the system. Also check that the wires can reach wherever your charge controller is mounted.

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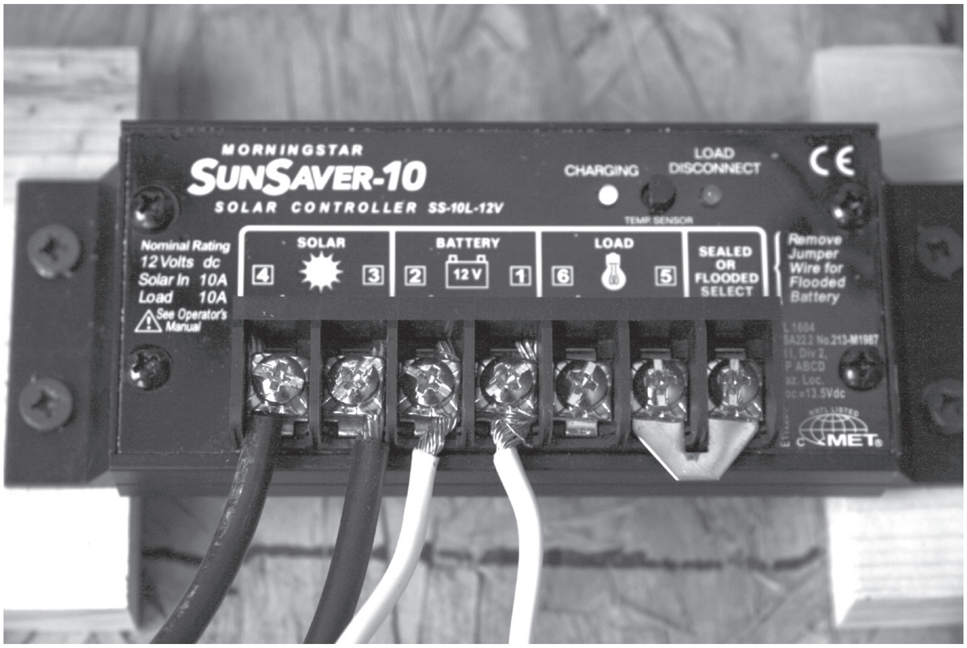
Step 10



Connect your solar panel to the charge controller. The wires should be marked (+) and (-) coming out of the panel, make sure they are connected to the correct charge controller receptacles (positive to positive, negative to negative).

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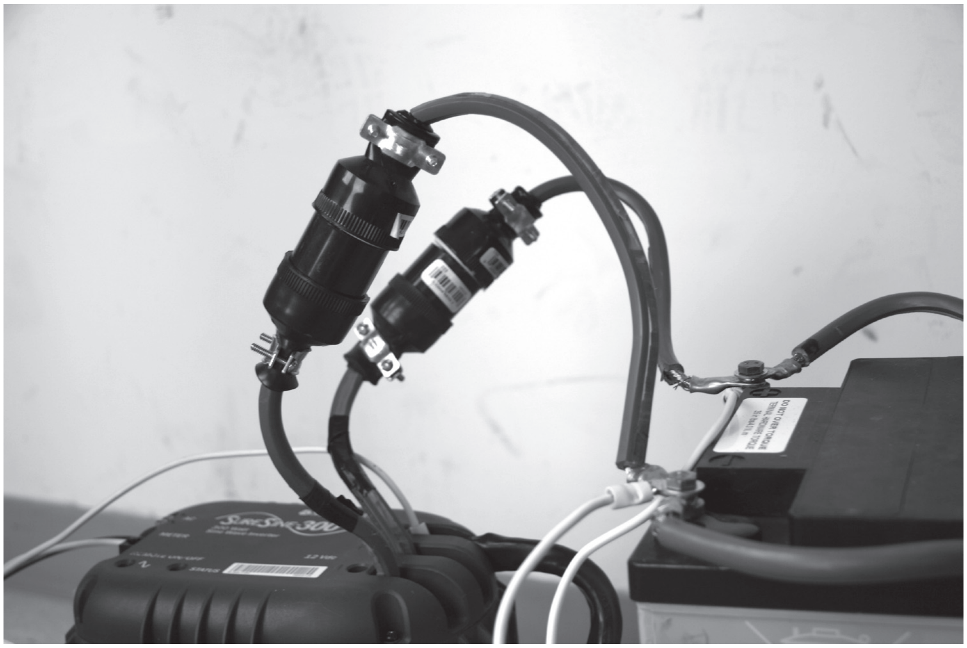
Step 11

Take the extra wire from between the AC outlet and the inverter and connect it to the large ground wire. We connected it at the inverter's ground terminal.

 notes

Step 12



Make sure all your connections are tight and double check where everything is connected. Pound your grounding stake into the ground, or if you are grounded to a building's ground, make sure it is a solid connection. Also, double check the wiring diagrams for the inverter and the charge controller. When everything looks good, connect the inverter, starting with the negative wire. Your inverter should turn on, or if there is a switch, turn it on.

Many inverters have an audible alarm for reversed polarity or low voltage. If you hear an alarm or a loud pop, disconnect the inverter and see if you have blown a fuse. Replace the fuse and check all your wiring. If your inverter comes on with no odd sounds, try plugging something into the outlet. If it works, your system is successful!

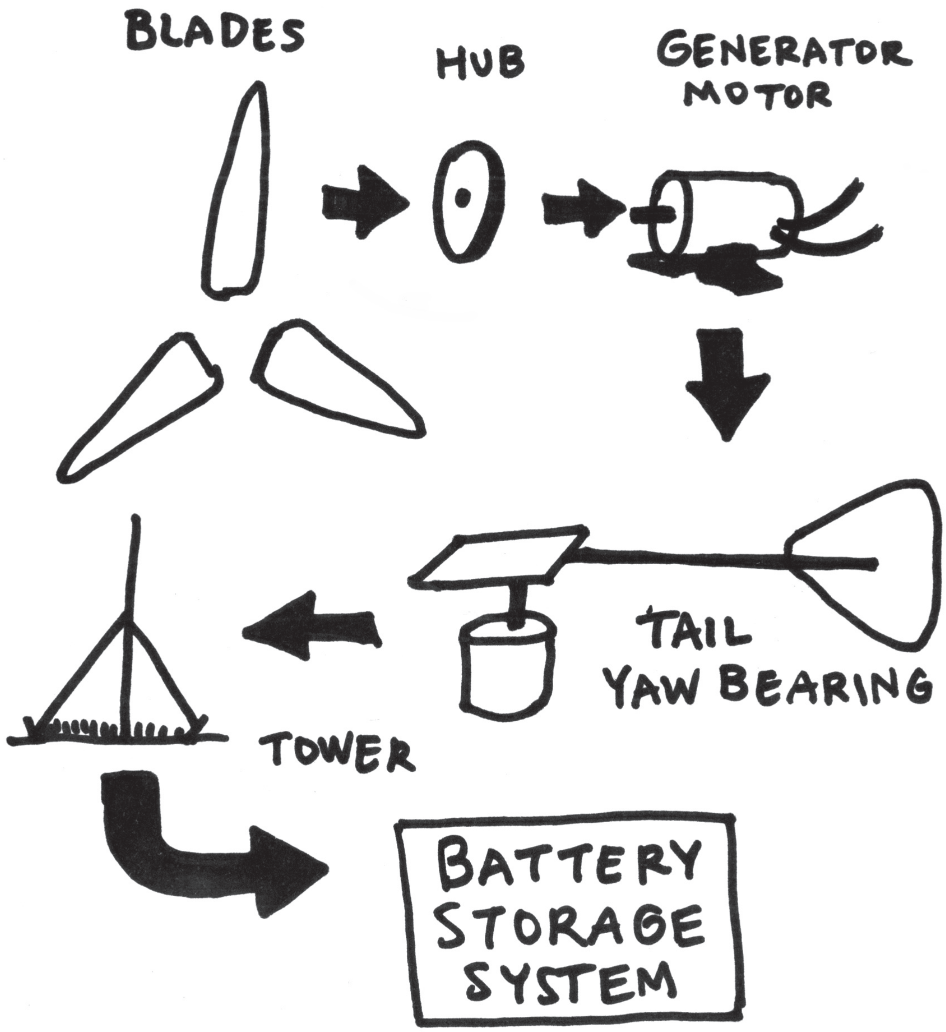
What do I do now?

Your PV system can run anything that needs electricity as long as the requirements of the device are met by what your batteries can provide. Our batteries can reasonably provide 480 watt-hours (see page 10), so we would start by finding a device we want to run and checking how much power it uses. This can usually be found on a label somewhere near the device's power cord. The wattage of a device is an instantaneous rating, so if you have a fan that is rated to use 50 watts, running this fan for one hour will use 50 watt-hours. Running the fan for two hours will use 100 watt-hours. Decide how long the device needs to run, calculate the watt-hours you will need, and see if your battery bank can handle it.

Another factor you will need to take into account is how long it will take your solar panel to charge your battery bank. If we routinely use 480 watt-hours from our batteries, and our solar panel is 40 watts, it will take about 12 hours of good sun for the panel to collect enough sunlight to recharge them (480 watt-hours / 40 watts = 12 hours). This might take two days if each day has six hours of good sunlight.

People who design whole-house systems begin with the load size rather than the panel, batteries, or anything else. We started with the front end of the system because we were experimenting. For your first system, you can do either, depending on your needs and level of experience.

Overview



Refer to the battery system diagram on page 6.

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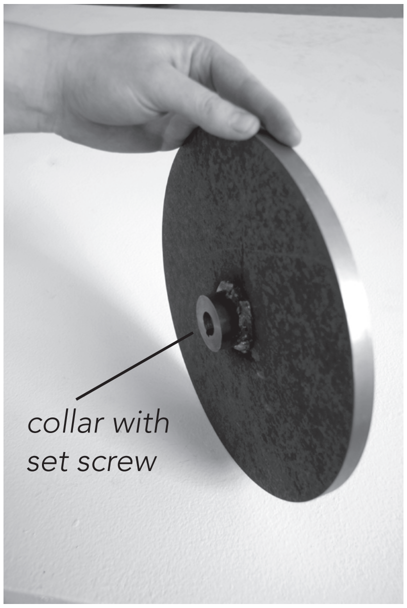
Wind Turbine Parts

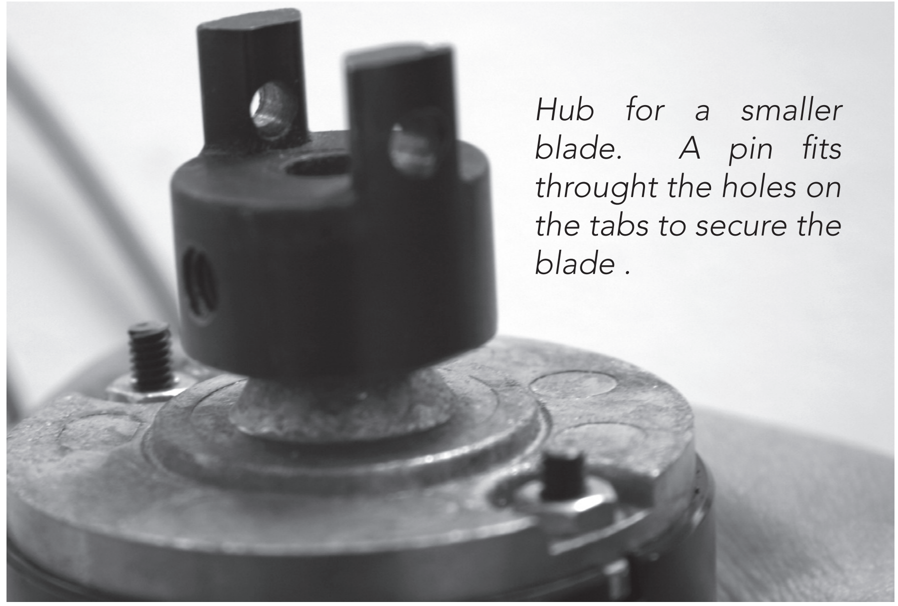
Blades

The front end of a wind turbine is the blades. We cut ours from a 10 inch diameter piece of PVC pipe. PVC is a good material for blades because it is easy to cut and shape, and because the curve of a wide pipe mimics the basic shape of an airfoil. We chose a 3 bladed design because it is one of the easiest to balance, and because you can cut three blades out of one piece of pipe by dividing the pipe into thirds lengthwise. Each blade tapers toward the tip. The blades are drilled at the bottom to be bolted into the hub, with the trailing edge flat against the hub. The leading edge is rounded and the trailing edge is sharp.

For a longer discussion on blades, see appendix C.



collar with set screw



Hub for a smaller blade. A pin fits throught the holes on the tabs to secure the blade .

Hub

The hub is the piece that attaches the blades to the generator. Our hub is a disc of 1/2" thick steel plate with a small collar with a keyway and a set screw. We had it custom made at a machine shop.

If you don't have access to a machine shop or a welder, there are other ways to make a hub. Any circular piece of sturdy metal will do. An old frying pan with the handle removed, a circular saw blade (with the sharp parts filed down), a brake rotor from a car, or pulleys and belt wheels from a hardware store can all work. The tricky part may be finding a way to attach it to the shaft of the generator. If your generator has a threaded shaft, you can probably bolt it on. If the shaft is not threaded, a heavy arbor can work. Special pulleys may already have a means of attaching to the shaft of the generator. On the right is a smaller hub for a 2-bladed turbine made from a motor shaft coupler.

pulley

arbor

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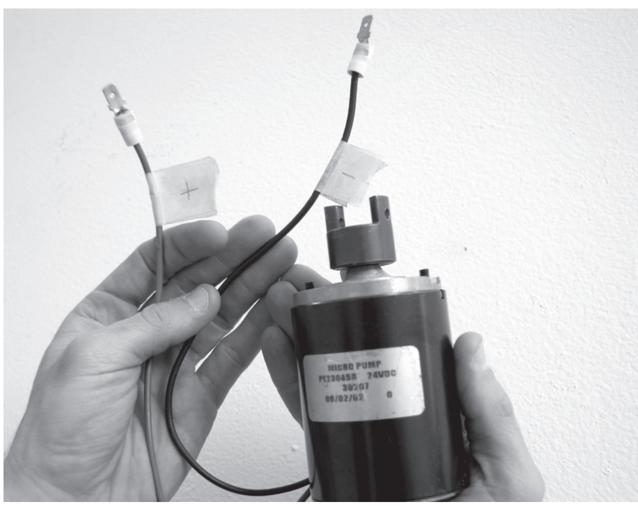
wooden belt wheel, not part of motor



Generator

The generator is the part of the wind turbine that converts the motion of the blades into electricity. One of the most available things to use for a generator is a permanent magnet DC motor. These motors, which you can find on electric pumps, treadmills, and potter's wheels, can translate electricity into motion, or motion into electricity. This quality comes from the fact that they contain a magnet inside. Other motors, which do not have magnets, will not work for this application. One way to tell is the number of wires coming out of the motor housing. A PM motor will have two, motors with four wires will likely not be permanent magnet motors.

Motors are rated in voltage, current, and RPM (rotations per minute). These specifications are very important when selecting a motor to be your generator. You want a motor that has decently high voltage and amperage while still having a relatively low RPM rating. An example of a good motor could be 12V, 5A, 1750 RPM, while an unsuitable motor might read 3V, 0.2A, 9000 RPM. Variable speed motors work well too. Ours is a variable speed 0-90V, 12A motor.

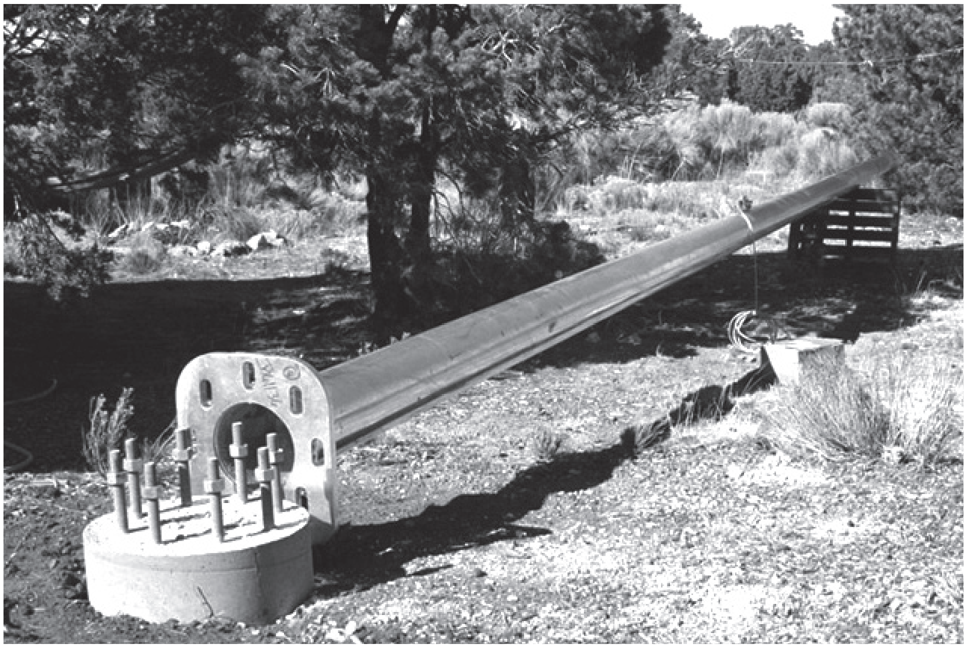
Another factor to consider is the shaft. Some motor shafts have a flat side, some have a groove, some are threaded for a nut. Take your motor to a hardware store and ask if they have anything that will fit.

Tail

The tail of your turbine should be proportional in size to your blades. There is no formula to determine tail size. Four foot blades might have a six foot tail. Two foot blades might have a two foot tail. The tail must be able to catch the wind and rotate the blades into the wind around the yaw bearing.

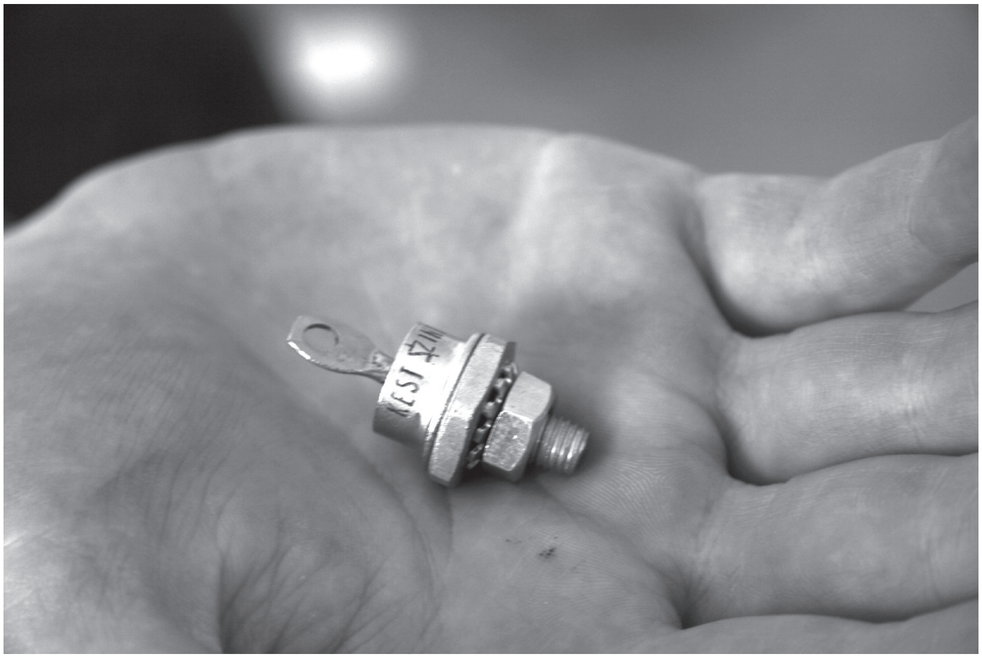
The yaw bearing is the part that allows the turbine to rotate when the wind changes direction. We found some heavy bearings in old belt-driven machinery that we used for our turbine. If you don't have access to a junk yard or scrap pile, small wheel bearings can be found at a hardware store. The tail can be mounted on a collar of pipe fittings. We found a pipe reducer coupling that fit well over the wheel bearing, allowing it to turn. The pipe extends a few inches further down from the bearing, keeping the tail assembly stable on the mounting.

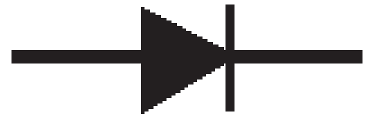
An easy way is just to have a larger piece of pipe coming off of the tail assembly that fits over a smaller piece of pipe on top of the tower. If your turbine is not too heavy, it should turn well enough that a greased bearing is not necessary.



Tower

The tower is the part of a wind system that allows the turbine to access its fuel, the wind. Putting up an adequate tower is something that is both important and beyond many people's immediate set of skills, which is why we encourage you to talk with a contractor or someone who is construction-minded. The rule of thumb with wind turbines is that the turbine should be at least 30 feet above anything within a 300 foot radius. Even if there is decent wind at ground level, wind speed increases the higher you go. Also, the power in the wind increases with the cube of the wind speed. If you equate the electricity your turbine produces with the amount of money you will save or make, it is without a doubt worth your money to put up a high tower for your turbine. We mounted our turbine on a 5 foot wooden post. Although it isn't high enough to catch good winds in most places, it is useful for testing. We took the post and the turbine up to the top of a windy hill and mounted it to see how the turbine would fare.

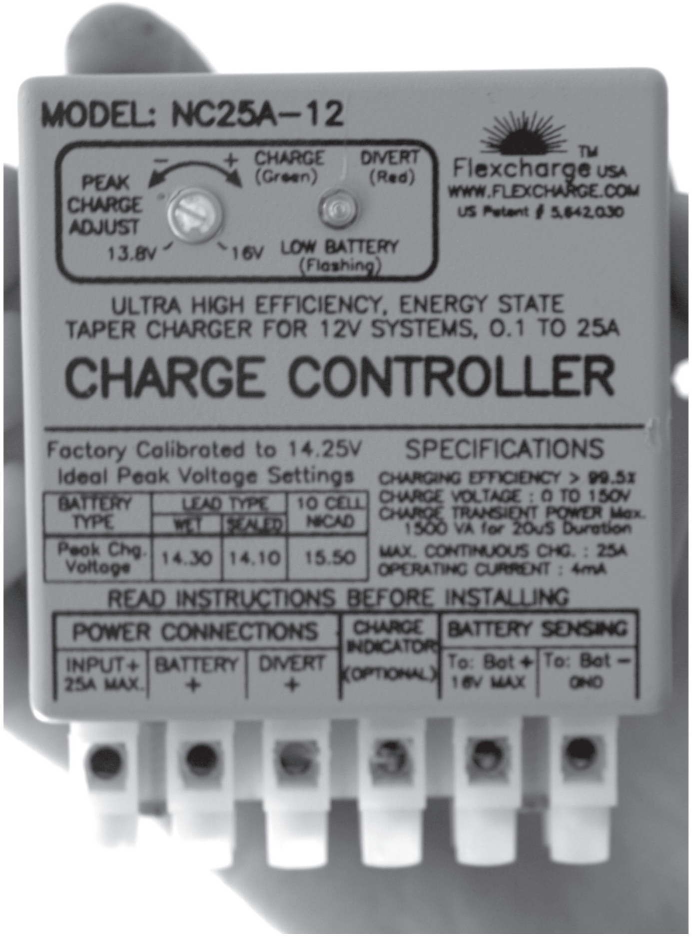




Diode

The diode is a small but important part. It is an electrical component that allows electricity to flow in only one direction, like a check valve in plumbing. This must be placed between the generator motor and the charge controller. Your generator is really a motor (made to run on electricity), so if it is connected to a battery system, just calling it a generator doesn't keep the power in the batteries from being sucked backwards and running the motor. Placing a diode in the system keeps electricity from flowing backwards, and allows your motor to become a generator.

The symbol on the diode indicates which direction it will allow electricity to flow in. Diodes are rated by how much current they can take. Your diode should be able to handle more than the maximum current that your generator can produce. If you are using a motor as your generator, look for the motor's rated current, and select a diode that has a higher rating. Our diode is rated for 40 amps. You should be able to find a suitable diode at an electronics store or from an electronics supplier on the internet.



Charge Controller

The charge controller for a wind system has the same role as the solar charge controller. It sees the electricity coming from the generator, senses the charge in the batteries, and makes sure the batteries are charged. Because a wind turbine can generate so much more current than a solar panel, disconnecting or short-circuiting the generator can be a problem. Instead, a wind charge controller diverts the power from the generator to a dump load. This can be any DC load: a heating coil, a water pump, or a bank of 12 volt light bulbs. Charge controllers come with wiring diagrams showing specifically how to hook them up. This one requires more fuses than the solar controller, but otherwise it is functionally the same.

See appendix B for wiring diagram.

 notes

Fuses

This is a 15 amp fuse in a fuse housing. We used two of these to protect the charge controller, placed between the turbine and the controller and between the battery and the controller. Check the manual for your controller to see what it needs.

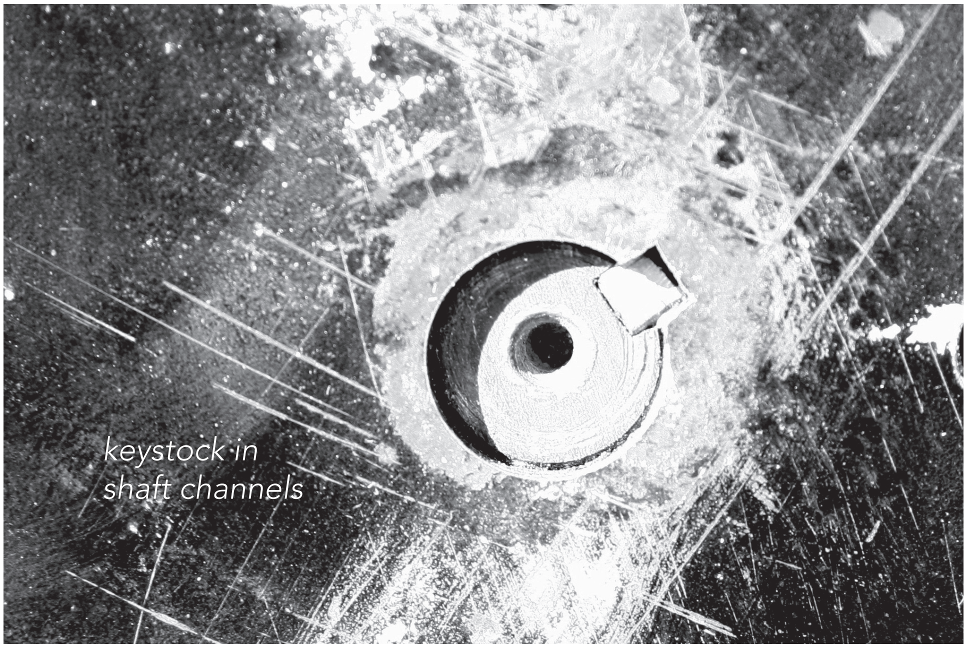
See appendix B to see how fuses are placed in our wiring diagrams

hose clamps tighten with a screw

Fasteners

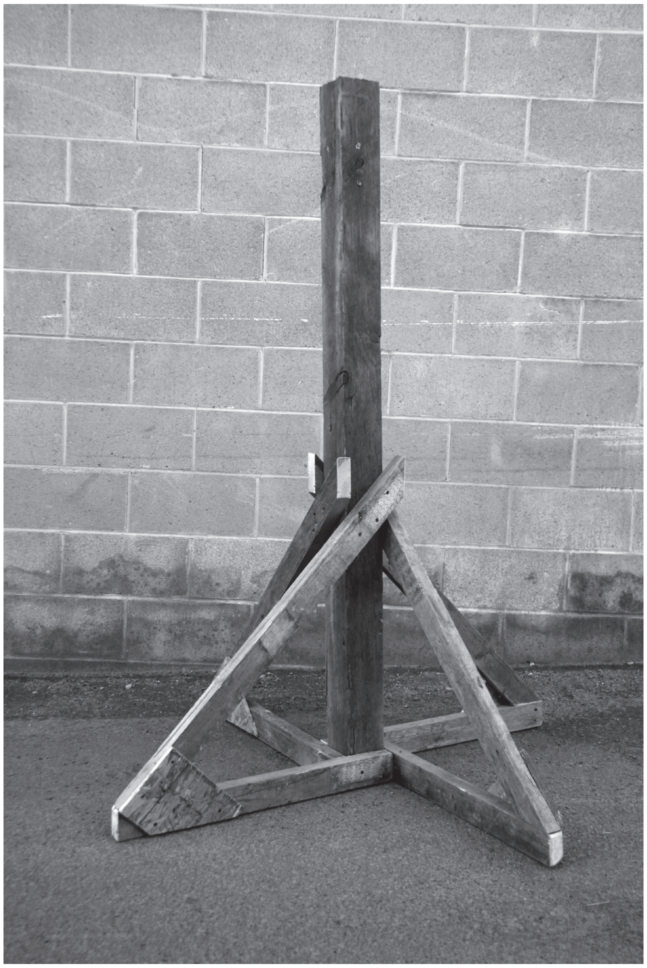
You will need a way to attach your generator to its mount. For a smaller generator motor, hose clamps can work well. For larger generator motors, bolts or lag screws can be used. Most larger motors come with a bracket to mount it to something. Make sure that your motor is secure and that the bolts or clamps will not be loosened by vibrations from the motion of the blades. Using locknuts with a plastic ring inside can keep the bolts from coming loose.

Assembly: Step 1



We started by mounting our hub onto the motor. The picture shows a square piece of metal that fits into a groove in both the shaft of the motor and in the hub. This hub was made by a machine shop, but you can find wheels and pulleys that have keyways. The metal piece that fits in the groove is a key, made from key stock. Ask a hardware store if they have keystock that will fit the hub and motor that you have. Our hub also has a small set screw that is tightened by an allen wrench. It is important to have the hub securely fastened to the shaft to keep it from coming off during high winds.

Step 2



This is the post that we used to test the turbine. It is high enough and stable enough that the blades don't hit the ground, and that the force of the wind doesn't knock the post over. You can test your turbine on any fence post or pole that is securely in the ground. It is important to test your turbine on something that is low enough that you have access to it. Putting the turbine up high for the first time is asking for something to go wrong.

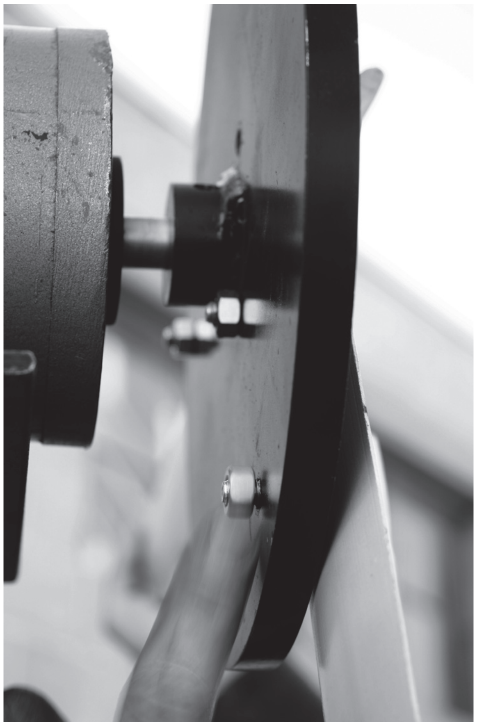
Step 3

We welded a bracket the size of our post onto the bottom of the turbine, and attached it with lag screws. Alternatively, you could mount your bearing on the top of the post and slip the tail assembly over it. How you mount your turbine is dependent on how your yaw bearing and tail assembly are constructed.

Step 4

Next, mount your motor and hub assembly onto the tail assembly. We drilled holes in the mounting plate and used nuts and bolts to secure the motor. Make sure they are tight.

Step 5



Attach the blades to the hub one by one. You will need someone to hold the hub in position while you do this, otherwise the unbalanced blades could swing and hit you. We drilled matching holes in the hub and blades to bolt them in as well. Make sure they are tight.

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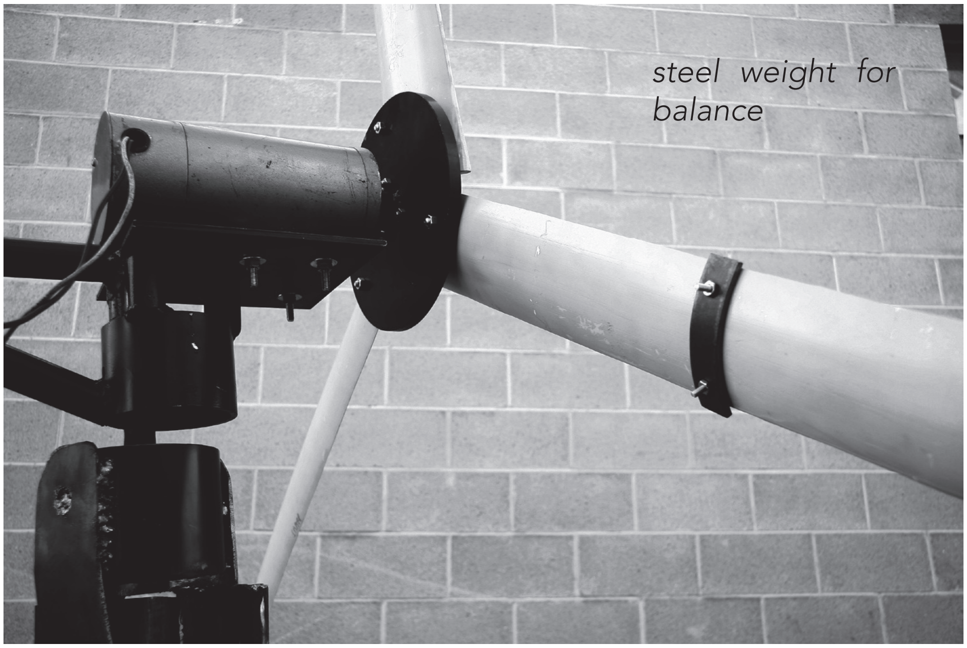
Step 6



The blades will most likely be off balance. If you do not balance them, the vibration of the blades spinning at high speed might cause the whole turbine to tear itself apart. Begin by marking which blade goes to which place on the hub. This will balance the entire assembly: motor, blades, and hub. Spin the blades a few times, and see which blade ends up on the top. This is the light side of the rotor. Move this blade down to the 9 o'clock position, and add a small weight to it, close to the hub (we used a socket from a socket wrench set). Slowly move the weight outward (you can tape it on) until it balances the heavy side. Spin the rotor a few times, if it can stop in different places, your blades are reasonably balanced. Mark where the weight was on the blade, and weigh it. Cut a piece of steel or use lead fishing weights (or whatever you can find) to replicate the weight you need, and bolt it to the blade in the place you marked. Try to have the weight form to the shape of the blade. Also remember to include the weight of the bolts or screws.

Step 7

Your turbine is now ready to test! Take it up on a hill or to a windy spot and connect a multimeter to the wires so you can see what it will yield in the wind. It's a good idea to check the wind forecast so you have an idea of what wind speed is giving you the power you read.

If you've gotten this far, you probably have a good understanding of what could be improved on your turbine. Experimentation is one of the best ways to learn about something.

What do I do now?

To wire the turbine up to a battery system, use the same general setup and steps as we described for the PV panel system. The only differences will be the different charge controller, the diode, and any fuses that the charge controller or inverter need. Again, much of this information comes from the wiring diagrams and manuals that come with the equipment.

See appendix B for our wiring diagrams.

Appendices
A: Safety
B: Electricity and wiring diagrams
C: Blade making and aerodynamics
D: Where to find material
E: Cost
F: Sources

notes

Appendix A
Safety

Working with electricity can be dangerous. Before you begin your first electrical project, you should read a basic overview of electricity and electrical safety. These can be found easily on the internet, or in how-to books at a local library. We do not intend this pamphlet to be a comprehensive guide to electricity, wiring, or alternative energy. However, there are a few things that we would like you to keep in mind.

When using batteries, NEVER touch both a positive terminal and a negative terminal at the same time. This gives electricity a direct path across your body, through your heart. Similarly, never short-circuit a battery. It will spark and melt whatever wires are crossed, and could burn you. Never lay metal tools on top of your battery, and make sure you don't have dangling jewelry or clothing that could catch a wire or a battery terminal. When connecting wires to each other, make sure you know where the wires are coming from and if they are electrified. Touch the insulated part of the wire to handle it rather than the bare copper part. Make sure all your wires are securely attached and fastened out of the way of each other. Tangled wires can cause accidents.

Lead-acid batteries produce hydrogen gas and can explode. We used AGM (absorbed glass matt) batteries that produce much less gas than a regular lead-acid battery, but it is always a good idea to store or mount your batteries in a place where they are protected from sparks and flame. If you have a non-sealed battery, it will need to be watered every so often. Check the battery's instructions to see how often it will need this.

Electricity likes to flow into the ground using the shortest, easiest route possible. That is why the ground wire in your home or on our battery system is thick and short; it provides less resistance than any other path in the system. That being said, it is possible for your body to act as a ground wire as well. This is why it is a bad idea for you to stand

 notes

in a puddle of water or on a metal floor while handling electrified wires. These are conductive surfaces, and will make your body a more attractive path for electricity. Make sure your system is well grounded before you finish hooking it up. Never touch both the ground wire and an electrified wire, or you may become part of the ground wire.

That being said, electricity is something that you deal with almost every day. It is possible to handle it in a safe and informed way, and to make it work for you. Do some reading or talk to an electrician about being safe, and make sure you know what you are touching before you touch it.

Appendix B: Electricity and wiring diagrams

Electricity is measured in three basic ways, volts, amps, and watts.
If electricity in a wire is compared to water in a hose, then:
Volts (v) can be compared to water pressure. Amps (a) can be compared to amount of water flowing through a point on the hose, or the current. Watts (w) can be compared to the combined power of the water pressure and current.

Watts = Volts x Amps (Power = Pressure x Current)

Your wall socket can provide 110 Volts and around 10 Amps. 110 volts x 10 amps = 1100 watts. Our batteries are each 12 volt, 40 amp-hour units. 12V x 40A = 480 watt-hours.

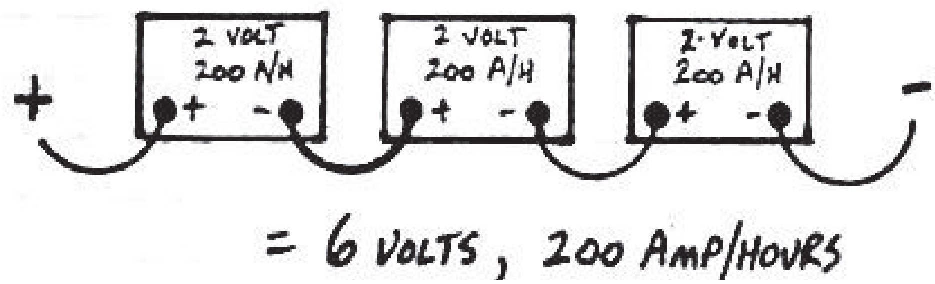
Devices are rated in watts, volts, and amps. If you can find a wattage on the label of a device, you can figure out how long it will be able to run from a particular battery. We do demonstrations with a pair of hair clippers that draw 7 watts. If we are using one battery, with 480 watt-hours in it, we could run the clippers continuously for about 68 hours (480 / 7 = about 68). Batteries can be discharged to about 50 percent on a regular basis and retain a long life, so we could reasonably expect the clippers to run for 34 hours before the batteries should be charged. It is possible to run large loads from small batteries, but they cannot run for very long. If we were to run a 1000-watt microwave on one of our 480 watt-hour batteries, it could run for about 30 minutes, or about 15 minutes to keep the battery life (480 / 1000 = about 0.5 hours).

Wiring

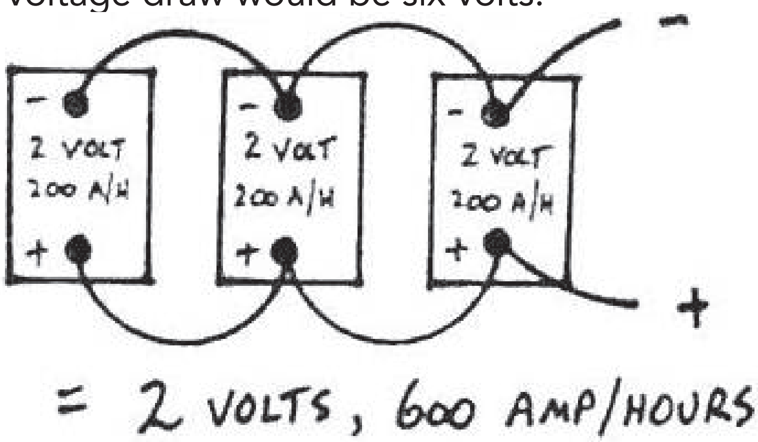
There are two ways to wire electrical components together, each with different effects.

Wiring in parallel will alter amperage.
Wiring in series will alter voltage.

If you are wiring components (like solar panels or batteries) that are sources of current, the output will increase. If you are wiring components that use current, the draw will increase.



In this diagram, three 2 volt batteries are wired in series. Series wiring multiplies voltage by the number of units, so 2 volts times 3 is 6 volts. If these were devices that used electricity, the total voltage draw would be six volts.



In this diagram, three 2 volt batteries are wired in parallel. Parallel wiring multiplies amperage by the number of units, so 200 amp-hours times three is 600 amp-hours.

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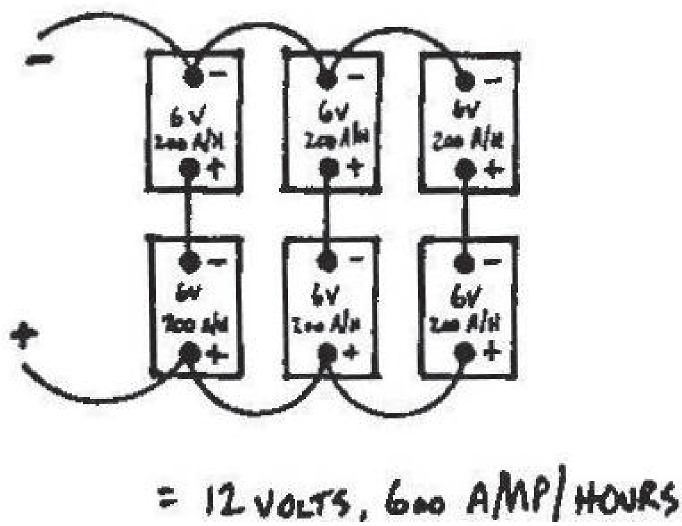
Series and parallel wiring can also be combined to boost both amperage and voltage.

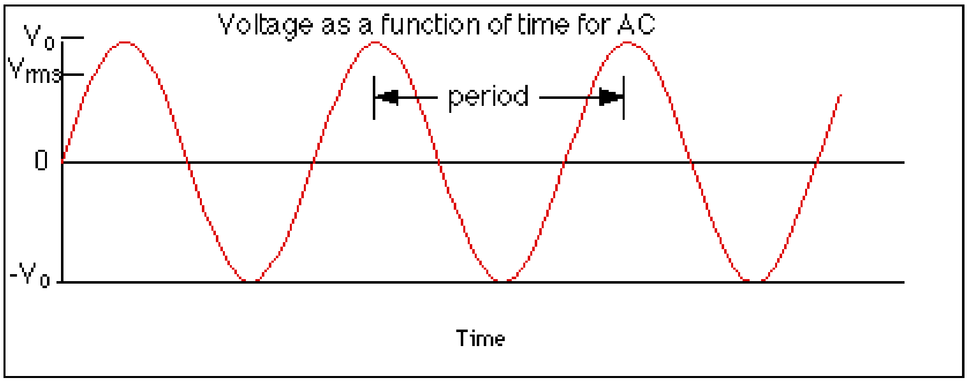


In this diagram, there are three sets of 2 batteries wired in series. These three sets are then wired together in parallel. Each battery is 6 volts, 200 amp-hours. Each set of 2 in series is 12 volts, 200 amp-hours. The entire bank is 12 volts, 600 amp hours.

Alternating and Direct Current

Electricity is transmitted in two ways: Alternating current (AC) and direct current (DC).

AC power switches polarity at 60 Hz, or 60 times per second. The sine wave-shaped graph below represents the voltage of alternating current smoothly switching from negative to positive, or from one direction of flow to the opposite direction of flow. Alternating current is the type of power that generally comes out of a wall socket. It is used in the national grid because it is better suited for transmitting electricity over long distances.



Direct current is the type of power that is given by a battery, a solar panel, or a wind generator. A graph of DC power would look like a horizontal line, because the polarity and voltage remain constant.

To convert DC power to AC power, you need to pass it through an inverter. To convert AC power to DC power, many devices use a rectifier. If you have a device with a DC power supply, the black box attached to the plug is probably a rectifier.

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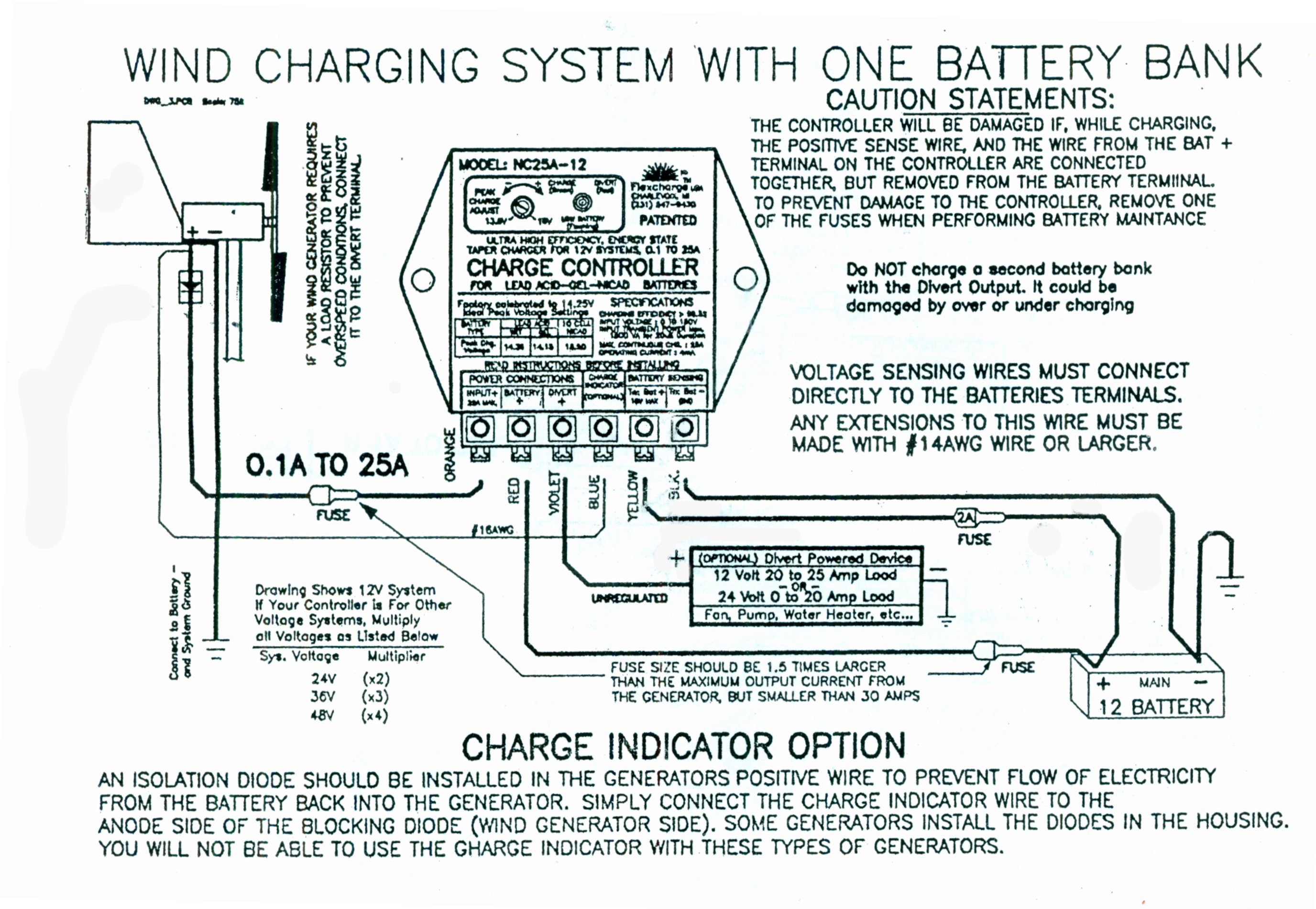
Our Wiring Diagrams

Wind Charge Controller



Inverter

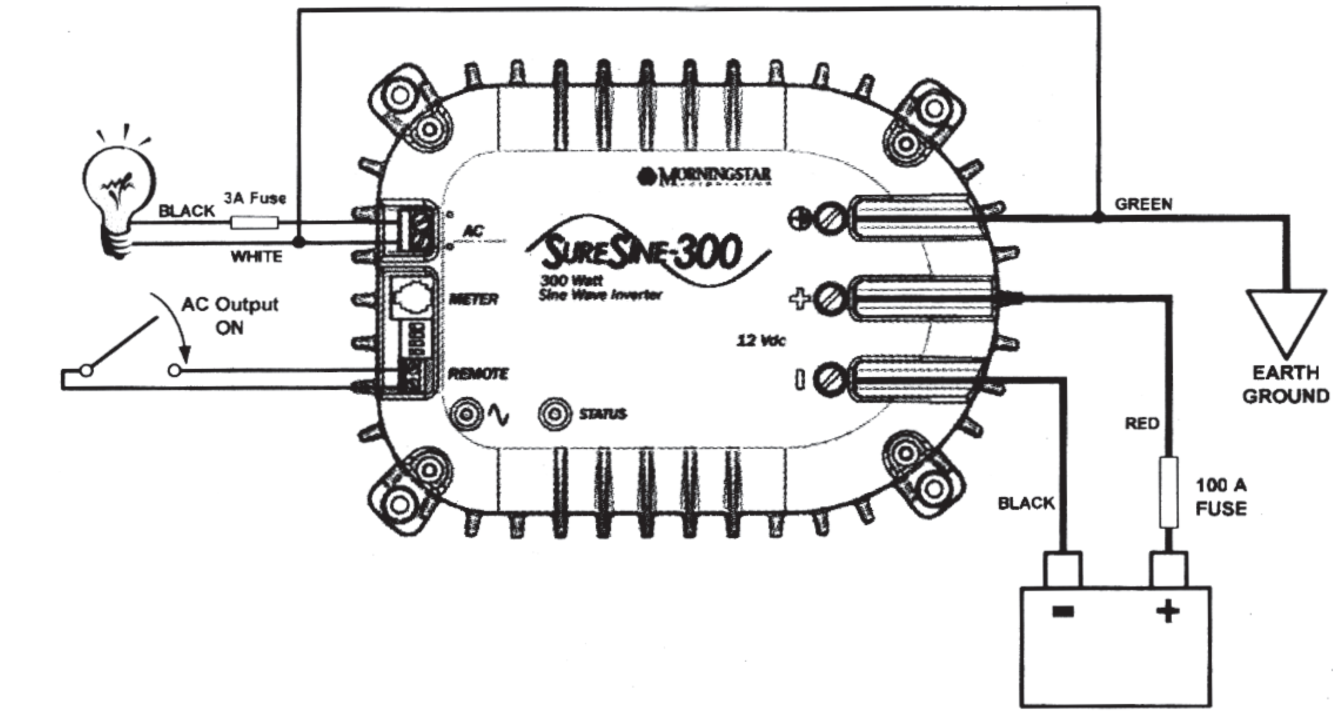


Figure 6 Complete System Wiring Diagram

Our inverter's own fuses are located inside the casing. Some inverters have fuses mounted externally.

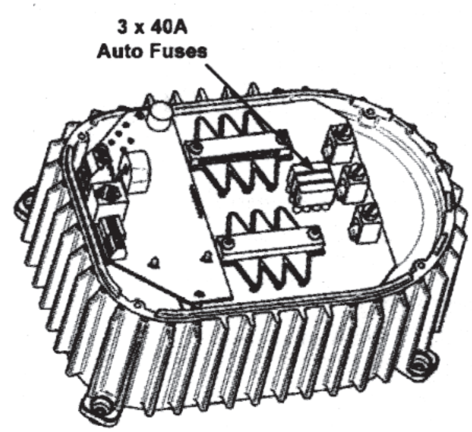


Figure 8 Fuse Location

Wire sizing table

HOOKUP WIRE SIZE CHART

This chart provides the minimum wire size to minimize power loss. Larger wires would are always better for operating efficiency

Max Charging Capacity	WIRE SIZE FOR 1 TO 10FT LENGTHS	WIRE SIZE FOR 10 TO 20FT LENGTHS
OA TO 3A	#14 AWG	#12 AWG
3A TO 6A	#12 AWG	#12 AWG
6A TO 12A	#10 AWG	#10 AWG
12A TO 18A	#10 AWG	#8 AWG
18A TO 25A	#8 AWG	#8 AWG

Diode Selection Table

Ampere Rating	Voltage Rating	Part Number	Type	Manufacturer
1A	40V	1N5819	Schottky	Diodes Incorporated
3A	40V	1N5822	Schottky	International Rectifier
5A	100V	50SQ100	Schottky	International Rectifier
8A	45V	80SQ045	Schottky	International Rectifier
1A	400V	1N4004	Silicon	Diodes Incorporated
3A	400V	1N5404	Silicon	Diodes Incorporated
6A	1000V	6A10	Silicon	Diodes Incorporated

If you cannot find these parts locally, call Flexcharge USA. All the above diodes are in stock.

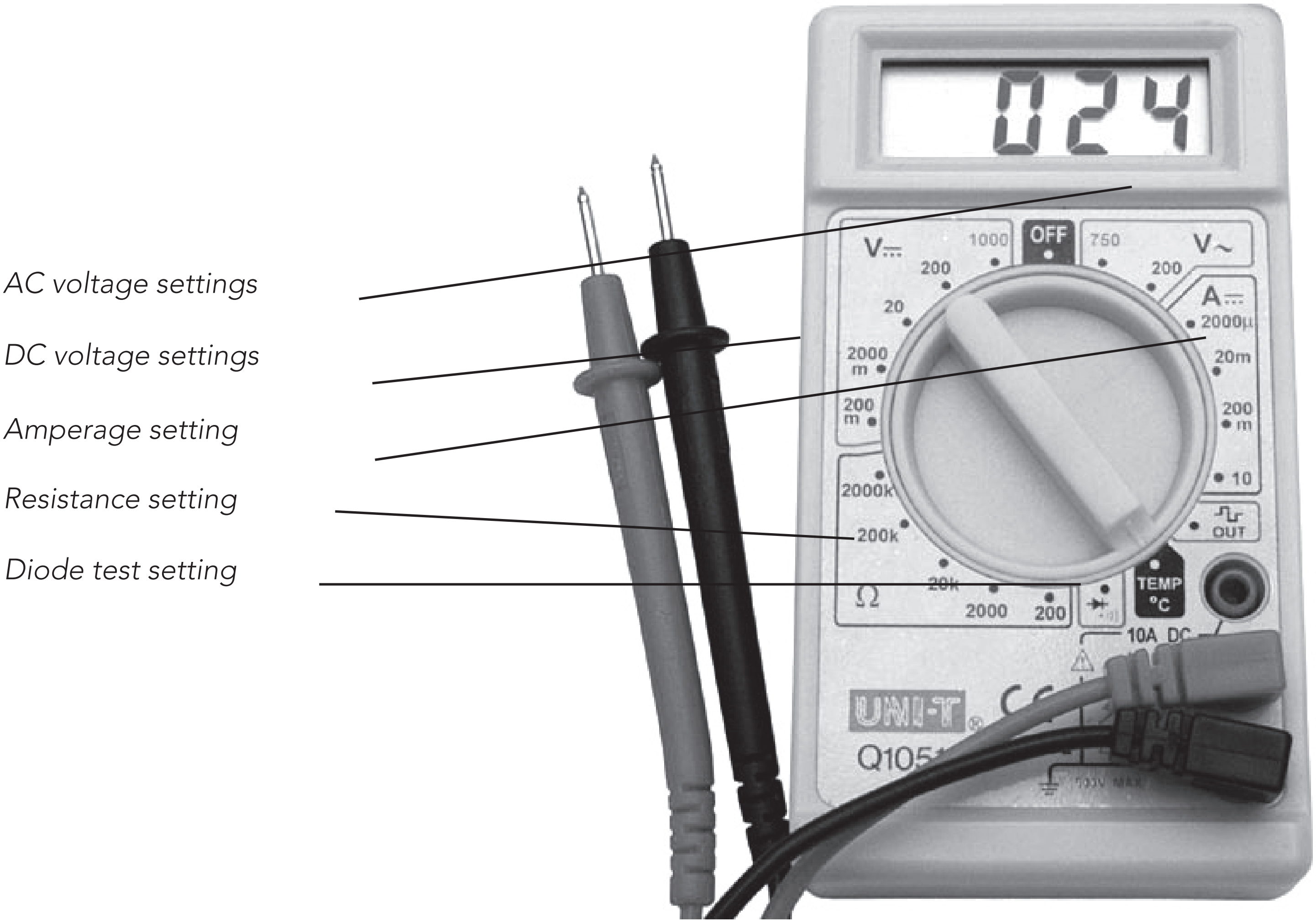
Multimeters

A multimeter is a tool used to measure electricity in a few different ways. It consists of a body, with a dial and a digital display, and two wires that have metal contact tips. The dial on the body can be turned to select what you want to measure. Most multimeters can test AC and DC voltage, current (amperage), resistance, There are different settings for each measurement to scale the reading to be proportional to what you are measuring. The tips are held to different parts of an electrical system to measure the current, voltage, or resistance between those two points. We found the multimeter to be most useful in measuring output of our generator motors and solar panels, as well as making sure that our connections were good. You can do this by using the diode test setting and touching the leads to a conductive point in front and behind the connection. If the meter reacts in the same way that it does when the leads themselves are touching, then the connection is good.

All multimeters are a little different. Play around with yours on a small electronic toy to get familiar with it. If you buy a multimeter, it should come with a manual to explain how to use it.

If you need a more detailed tutorial, visit http://www.ladyada.net/library/metertut/

Multimeters



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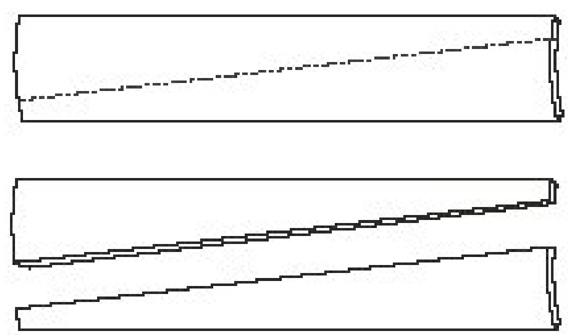
Appendix C
Blades and aerodynamics

One of the simplest ways to make blades uses a wide diameter section of PVC pipe. The curve of the pipe gives each blade a shape that can catch the wind near the hub and mimic an airplane wing shape at the tip. Your PVC pipe section should be no longer than about five or six feet. Longer blades made of PVC are not recommended because they could snap. Five foot blades, however, will give you a ten foot rotor diameter, which is quite good for a home built turbine. Smaller blades from PVC work well also.

Begin by drawing straight lines down the length of the pipe. A piece of angle iron held tightly to the pipe will align itself, allowing you to make straight lines easily. Divide the pipe into 4 equal sections, and cut along the lines. An electric jigsaw will be one of the easiest ways to cut it. You can also use a circular saw. Make sure the pipe is securely clamped to the table.

After you have four sections, divide each section in half diagonally so you have a triangular, curved shape.



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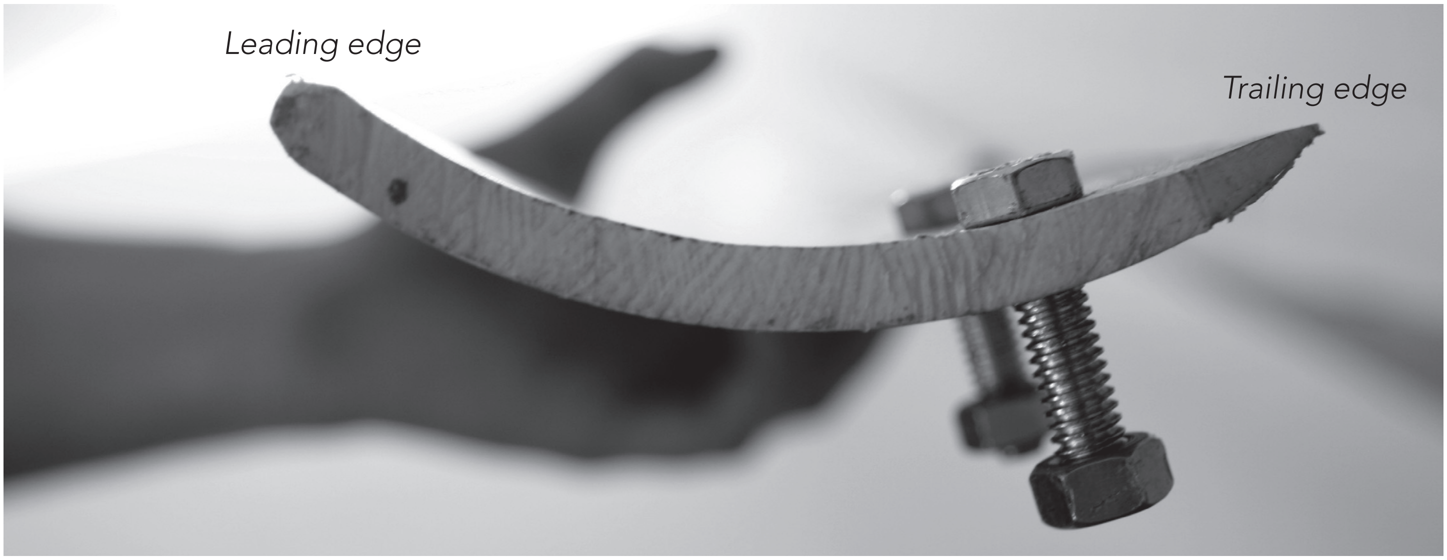
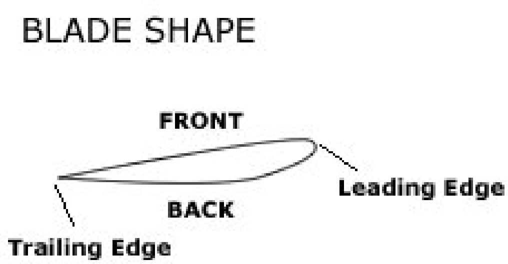
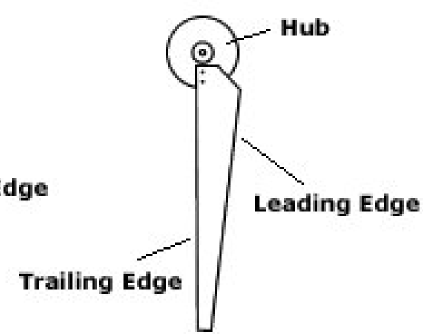


The blades will attach to the hub with two bolts. You will need to make sure that the holes in the blade match up with the holes in the hub. If your hub is metal, it will be easier to drill into the blades after the hub so they match. The holes can be fairly close to each other, but use as much room as you have on the hub.

The leading edge of the blade should be rounded, and the trailing edge should be flattened to a sharp edge. The trailing side will be bolted flat against the hub, and the leading side will curve away from it. You can shape the edges with an electric sander, or you can use a rasp or a surform tool. Shaping them like this loosely mimics the shape of an airplane wing, which can help the blades move through the wind more efficiently.





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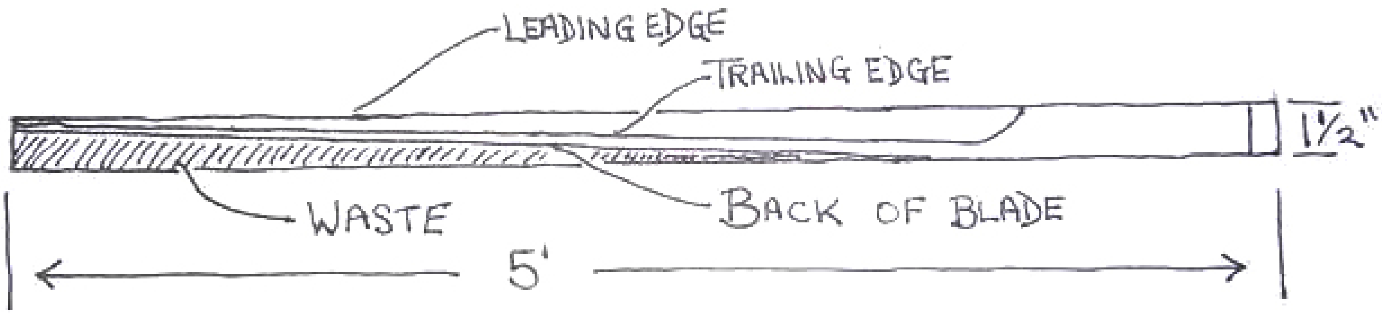
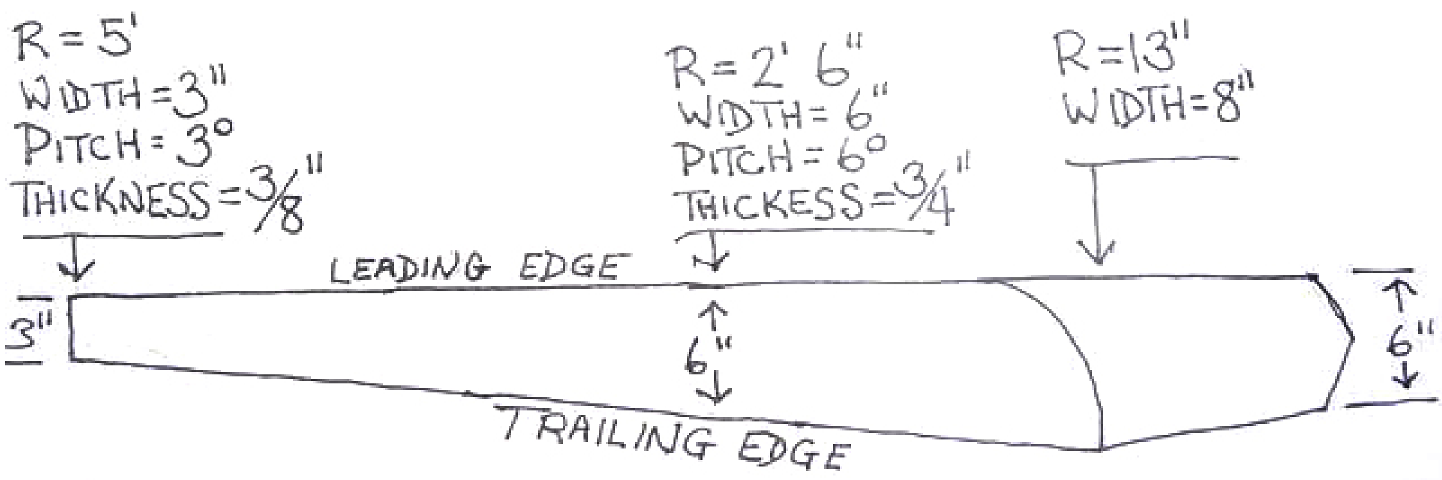
Making wooden blades

Blades made of wood can be shaped into a good airfoil, which will be a more efficient blade than one made quickly from PVC pipe. These diagrams, from otherpower.com, show the cross sections and cut marks of a blade you could carve from a piece of 2”x6” wood. They can also be scaled down proportionally to a smaller piece. Red cedar is a good wood to use, because it is light and relatively rot resistant. Begin by drawing the basic shape of the blade on the widest side of the board and cutting them out on a band saw.





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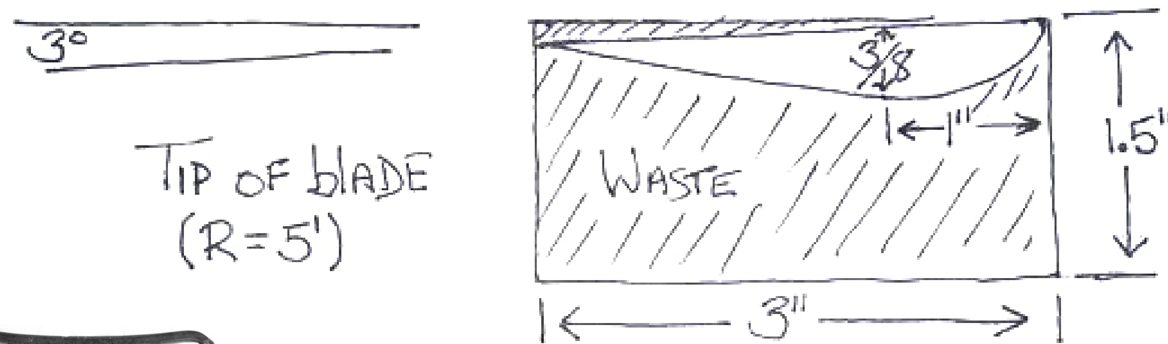
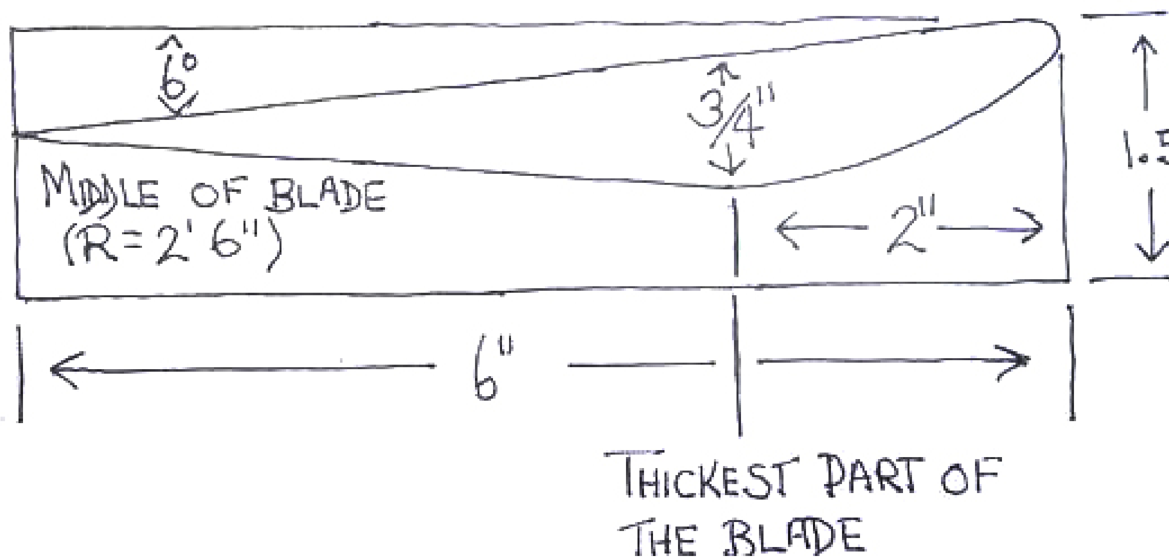
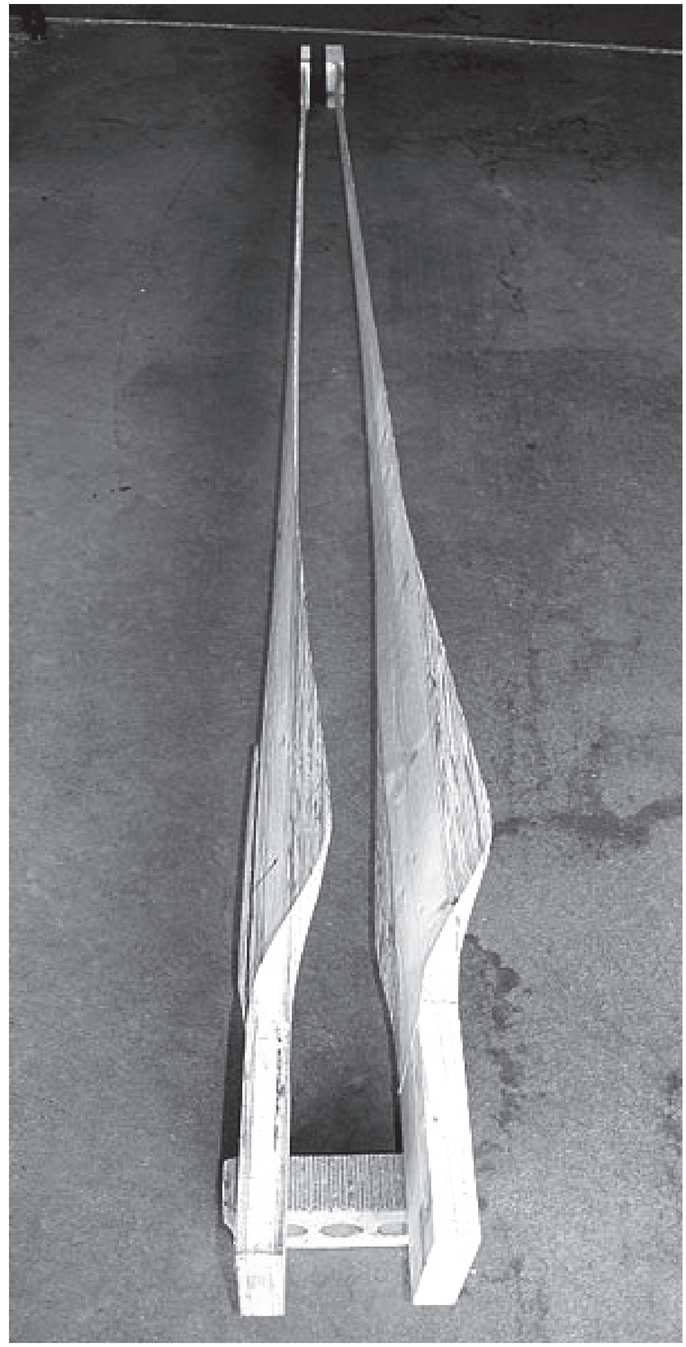
As for the shaping of the airfoil, we found the easiest tool to use was a drawknife. If you have never used a drawknife before, practice on a scrap piece of wood. Note that the angle of the airfoil changes from 3 degrees at the tip to 6 degrees in the middle. Closer to the hub, the pitch should become even steeper (almost to 30 degrees or so). This provides a drag surface for the wind to push, acting as a sort of starting motor for the rotor. Blades can be finished with spar varnish or exterior waterproof paint.

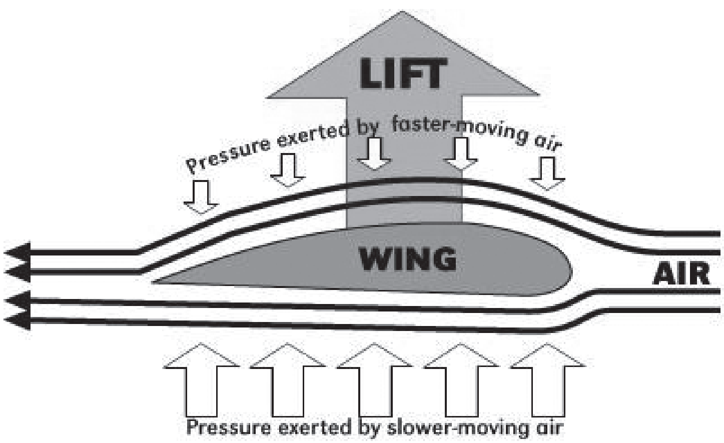


drawknife



In the picture to the right (from cnc-toolkit.com), you can see the tips of the blades are almost flat (perpendicular to the direction the wind will blow). Near the hub, they are thicker and have a much steeper angle compared to the wind direction. This kind of blade engages the wind in two ways: the steep angle at the bottom acts as a drag surface, where the wind is deflected and transfers some of its kinetic energy to the blades. At the tips, which move much faster than the bottoms, the airfoil shape creates lift, which pulls the blades along their paths. This is the same way that an airplane wing works. The added energy extracted from air pressure is the reason that blades that use lift are more effective than blades that use drag.





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Appendix D
Where to find material

Although these systems use many materials that can be bought new for a lot of money, we managed to find almost all of our material, excluding the electronics. Even some of the electronic equipment was donated to us as a sample product by the manufacturer. We called Morningstar (who made our inverter and our charge controller), explained that we were building a photovoltaic system for educational purposes, and asked if they could send us any secondhand equipment samples they had around. This can work for almost any material. Call a company that deals with large quantities of something and ask around to see if they have any slightly damaged, sample, or cutoff material. Oftentimes they won't mind giving you a few pieces of scrap, and it will usually save you some money.

As for electrical parts like wire, fasteners, and the like, if you need things in large quantities, it is usually cheaper to buy online in bulk than to go to the hardware store every time you need a few more connectors. Websites like Jameco.com, Digi-key.com, and Allelectronics.com are good places to look for small PV cells, connectors, adapters, and so on. Alternatively, if you just need a wire or two, junk appliances (on the curb on trash day!) can be disassembled and used for their wiring and switches.

Above all, your local hardware store will be a great resource. Asking someone who is used to building things can yield more information sometimes than a day on the internet.

Other places to look for useful things:

Junk yards
Thrift stores
Dumpsters
Construction sites
Reusable material centers
Abandoned farm equipment
Auto garage scrap pile

Appendix E
Cost

This is a rough estimate of what we would have spent on our wind turbine system had we purchased everything new. We found most of the materials for the actual turbine in scrap piles and old appliances, so our estimate is a ceiling price.

Please note, the method we use is very basic. We are applying it here to the turbine we built, and the battery system that accompanies the solar panel. You can apply it to your system before you build it if you find a price for everything that you will use.

Metal (pipe, angle iron, plate)	*$50*
Motor	*$100*
Bearing	*$10*
PVC pipe	*$15*
Diode	*$3.50*
Charge controller	*$115*
Inverter	*$245*
Batteries	*$260*
Wire, connectors, etc	*$50*
Nuts and bolts	*$10*
Total	**$858.50**

I recently took my electricity bill and divided the total price of the electricity I used by the number of kilowatt hours I was billed for, and came up with a residential electricity price of $0.20 per kilowatt hour. $858.50 divided into 20 cents is roughly 4300, which is the number of kilowatt hours our total price represents at our last residential electricity price. So, our turbine would need to produce about 4300 kWh to pay for itself. 4300 kWh can also be read as 4,300,000 watt-hours.

We tested the turbine and found that in 12 mph winds, it can produce about 12 volts and 7 amps. 12V x 7A = 84 watts. So if our turbine spins for an hour in 12 mph wind, it produces 84 watt-hours.

4,300,000 watt-hours / 84 watt-hours = 51,190 hours
51,190 hours = 2133 days = 5.84 years

This shows that if the turbine were to spin continuously in 12 mph winds for a little less than 6 years, it would have produced enough electricity to pay for itself.

Of course, this figure includes some assumptions. We assume that there is constant wind speed. You can use your average wind speed for your area as a guess, but there will be times when there is no wind, and times when there is a lot of wind. Some of these winds will be too low to spin the turbine, some will be too windy for it to be safe to spin. This indicates that the payback period will probably be a little longer than the figure.

We also assume that electricity prices remain constant. If they were to rise, the payback period would be shorter. If they fall, payback would take longer.

This method is a very basic, but still useful, way of guessing how much you will spend versus what you will get out of it. There are more complex ways of calculating return on an investment that you may be interested in using. Search the web for financial data or the economics of alternative energy, or talk to an accountant or a financial planner to get a better idea of how what you spend now can increase or decrease in value in the future.

Appendix F
Sources

Where did we learn how to do all this stuff?

The internet is an extremely valuable resource. It is likely that you can find someone who has already done what you are trying to do, and whose mistakes you can learn from. That being said, we found that the best way to learn about these things was to try them, screw up, and try again. We also spent a great deal of time talking about wind and solar power to each other, to engineers, specialists, hardware store employees, mechanics, and everyone else who would listen. If you can't figure something out, ask someone else! A lot of creative solutions went into building these systems, so when you are stumped, a fresh brain can often help the problem get solved.

These are the websites that we frequented for information and guidance:

Wind Power Law Blog
http://windpowerlaw.wordpress.com

Northern Arizona Wind and Sun
http://www.windsun.com/index.htm

General information on solar power systems
http://www.solar4power.com/solar-power-basics.html

Solar power retailer
http://www.affordable-solar.com/solar.panels.htm

History of the electric power industry
http://www.eei.org/whoweare/AboutIndustry/Pages/History.aspx

Animated explanation of the power in the wind
http://www.flapturbine.com/betz_limit.html

Simple furling design for a wind turbine
http://www.thebackshed.com/windmill/Docs/Furling.asp

How to make wooden blades
http://otherpower.com/blades.html

Burden Surplus Center (motors, bearings, etc)
https://www.surpluscenter.com/home.asp

Basics of wind power systems
http://www.homepower.com/basics/wind/

Good description of a home-built turbine
http://www.mdpub.com/Wind_Turbine/index.html

Another description of a home-buildable turbine
http://www.velacreations.com/makechispito.html

OtherPower.com, a good resource for alternative energy of all kinds
http://otherpower.com

Economic calculator for wind energy
http://www.windpower.org/en/tour/econ/econ.htm

There are plenty more ways to find information on the internet, at your local library, and through people you know. Be curious, ask around, and don't be afraid of making a mistake.

Good luck.