SSS TransPac 2002 Seminar

ELECTRICAL SYSTEMS FOR OFFSHORE SAILING

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OBJECTIVE

The objective of this seminar is to develop the skills and understanding necessary to put together a robust electrical system appropriate for offshore sailing and long ocean passages. This seminar will cover basic electrical theory, circuit diagrams, energy budgets, batteries, alternators, and alternative energy sources. A full size boat electrical system will be constructed and described. Specific recommendations of electrical systems appropriate for ultralights, stock racer/cruisers, and bigger boats will be made.

DEFINITIONS OF BASIC TERMS

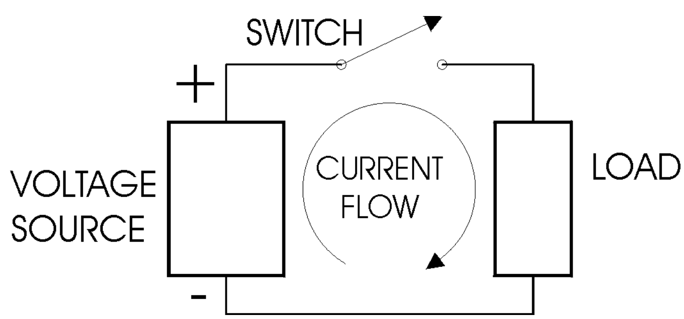
The low voltage DC power systems encountered on boats are very simple in principle. The confusion and feeling of helplessness which many people feel when trying to work on their boat electrical systems stem from a combination of several factors. Some of these factors are a lack of a clear understanding of the basic laws of electricity, the fact that a simple thing, if repeated many times will appear complex, and the generally undocumented and sometimes less than ideal design and construction of the boat electrical system.

Electrical systems obey simple, universal physical laws. Unfortunately, if one does not understand these laws and the terminology used to discuss them, electrical systems can be very confusing. We will begin by defining the terms used in electrical work and setting out the simple relationships between them necessary to understand boat electrical systems.

- **ENERGY:** Energy is the capacity to do **work**. Batteries store energy, which is used to power the electrical appliances on the boat. The scientific units for energy are Joules. The conventional, although inaccurate unit used in boating is the **amp-hour.**
- **POWER:** Power is the **rate** at which energy is being stored, generated or used. In other words, **energy** equals **power** x **time.** The units used for power are **WATTS.**
- **VOLTAGE:** The voltage is the energy per unit charge gained or lost when a circuit is traversed. When you follow a circuit diagram from one point to another, if the voltage is different between the two points, then energy has been gained or lost. The units used to measure voltage are **VOLTS.** A voltage is the driving force for current flow. It is analogous to the pressure in a fluid system.
- **CURRENT:** The current is simply the number of electrons flowing in a circuit (a wire for example) per second. The units used to measure current are **AMPS.**

CIRCUITS

In order to extract energy from a voltage source, a current must flow from the positive terminal of the source to the negative terminal. All electrical systems are composed of circuits, which are conductive paths from one side of the voltage source (battery, alternator, solar panel, etc) to the other. These conductive paths must include the loads which will use the energy and are controlled by switches which break the circuit, preventing current from flowing.



ELECTRICAL FACTS

- The **POWER** being used (or generated) by an object (a light bulb, for instance) is equal to the **VOLTAGE** across the terminals of the object multiplied by the **CURRENT** flowing through the object.
- **POWER = VOLTAGE x CURRENT**

In other words, **WATTS = VOLTS x AMPS**

- The **ENERGY** used by a device is the product of the **POWER** that it uses multiplied by the **TIME** that it has been using it. In other words, **ENERGY = VOLTAGE x CURRENT x TIME.** In boat electrical systems, the voltage is commonly assumed to be 12 volts, so the energy used by the device is calculated by multiplying the **CURRENT** by the **TIME.** This gives the boater unit of energy consumption: the notorious **amp-hour**.

- The flow of electrical charges in a circuit is restricted by the electrical conductivity of the elements comprising the circuit. Specifically, although being driven by an electrical potential (a voltage), in any real circuit the current is limited by the fact that electrical devices oppose the free passage of the electrical charges. This quality of opposing the free passage of charges is known as **RESISTANCE,** and the unit describing it is called an **OHM,** after an early pioneer in electricity. The resistance of an electrical component is analogous to the way that a clogged pipe will restrict the flow of water. Different diameter pipes will conduct more or less current (gallons per minute) at a given pressure.

OHM'S LAW

Resistance, voltage, and current in a circuit are related by a simple formula. If a current is flowing through a circuit element (a wire, a light bulb, a starter motor, or whatever) the voltage measured across the element will be given by the product of the current times the resistance of the element. This is called Ohm's Law:

Voltage (across element) = **Current** (through element) x **Resistance**

This simple formula may be used to understand almost everything about a boat electrical system. If you know two of the quantities (voltage **V**, current **I,** resistance **R**) you may easily calculate the other one. Rearranging terms in the formula allows us to solve for any of the desired quantities:

V = I x R **I = V / R** **R = V / I**

In addition, since power **P** is the product of voltage and current,

P = V x I   P = V x V / R   P = I x I x R

Using these formulas will allow you to troubleshoot your boat electrical system, plan additions, understand energy usage and much more. It requires a bit of practice, but this is the key to all of the stuff going on in your electrical system and anyone can do it.

Note on Resistors:

All conductors have resistance. For some conductors, such as wire, this resistance is intended to be small. For many other circuit elements, the resistance can be large. Resistance is measured in ohms. A milliohm is 0.001 ohm. This might be the resistance of a high current shunt. A kilo-ohm or kohm, is 1000 ohms. A megohm is 1 million ohms.

Any conductive material has a quality known as the resistivity. This is a numerical description of how well the material conducts electricity. For a good conductor such a s copper, this is a small number. For a bad conductor, it can be high. **The resistance of a conductor is proportional to the resistivity of the material**. **The resistance is also proportional to the length of the conductor**. Double the length of a wire, for instance, and the resistance doubles. **The resistance of a conductor is inversely proportional to the area of the conductor**. If the area doubles, the resistance drops in half. Since the area of a round wire is 3.1416 times the radius squared, doubling the radius (or diameter) of a conductor drops the resistance by a factor of 4.

The resistance of resistors in series adds. Three 1 ohm resistors in series is 3 ohms.

The resistance of resistors in parallel is slightly more complicated. For two resistors, R1 and R2 in parallel, the resistance is:

R= (R1 x R2) / (R1+R2)

For more than two resistors R1, R2, R3, R4, etc in parallel, the formula is:

1 / R = (1 / R1) + (1 / R2) + (1 / R3) + (1 / R4) + …

In other words, take 1 divided by the resistance of each resistor and sum them. Then take 1 divided by that number and you have the resistance of the resistors in parallel. Because current divides through resistors in parallel, the resistance of resistors in parallel is always smaller than the smallest individual resistor. For series resistors, the resistance is always larger than the largest resistor.

Examples:

1. You have a light for the boat and the bulb says that it is a 10-watt bulb. How much current will it require? This is easy: We use the relationship that Power = Voltage x Current. If we divide the Power (10 watts) by the voltage in our boat (assume 12 volts), we get the current the light will draw (10/12 = 0.833 amps).

2. Suppose we want to use the light for an anchor light. If we run it for 9 hours, how much energy will we have used? Again, this is an easy one. The energy (in amp hours) is the product of the current times the time. So the energy used is E = I x T. Thus E = 0.833 amps x 9 hours, or E = 7.5 amp-hours.

3. We are at anchor and go to start the engine. OH NO! It won't turn over; it just makes a clicking noise! What is wrong? We grab our trusty digital voltmeter and check the voltage across the battery terminals. Hmmm, reads 12.6 volts. We try to turn the engine over with the starter; it now reads 12.4 volts. We remember hearing somewhere that a starter motor can draw up to 200 amps, and usually such high current will bring the voltage of a small battery bank down to perhaps 8 to 10 volts while the starter motor is running. We attach the voltmeter between the starter motor positive terminal (where the wire from the battery attaches) and the ground. When we try to start the engine, the voltage drops to 4 volts. Getting suspicious, we now attach the voltmeter between the positive battery post and the starter positive terminal. Now when we try to start the engine we read 8.4 volts.

Think about Ohm's law. If there is current flowing through a circuit (the wire between the battery and the starter motor), and we measure a voltage across the circuit, then the circuit resistance is given by the voltage divided by the current. We don't know the current, and have no way to measure it. But we can make a guess! The wire is really heavy, so we would expect a small resistance. If a normal starter draws 200 amps, and we wanted most of the voltage to be applied to the starter, then let us assume that no more than, say, 1 volt should be lost across the cable. This means that the cable resistance **should** be R =V/I , or R = 1/200, or R=0.005 ohm. This is a guess, but it tells us that the resistance from one end of the battery wire to the other should be small. We have no way to measure that small a resistance, but we might assume that a voltage drop of 8.4 volts across the wire is way too much. That means there is too much resistance in the starter wire.

So now we untape the battery terminal lugs and discover that the connections are all corroded by saltwater. After a bit of work with a wire brush and some hose clamps, we have cleaned up the corrosion and made a good connection to the wire. Voila, the engine starts right up! We resolve to replace the starter cable with a good one made of Ancor wire and properly sealed with heat shrink tubing.

ELECTRICAL SYSTEM PARTS

Electrical systems on boats have many parts, some of which look rather odd. We will describe a few, to make it easier to understand your boat wiring.

- **Switches:** Switches make or disconnect circuits. When a switch is closed, it nominally has a resistance of 0 ohms. When it is open it has a resistance of infinity (or a very large number of ohms). Switches are described by their number of poles, which is the number of separate switches in the package, and the number of throws, which is the number of things which may be connected to the common terminal. An SPST (single pole, single throw) switch is a simple on/off switch. A DPST (double pole, single throw) switch is two simple on/off switches in a single package.
- **Fuses:** Fuses are devices which sense current (by heating up due to their small, but well controlled resistance), and destroy themselves by melting if the current exceeds their designed maximum. This opens the circuit and prevents damage to wiring and other things. Don't replace fuses with a wire, or a larger value fuse. They usually blow for a reason. Fuses come in two varieties: fast and slow blow. Fast blow fuses act very quickly, but sometimes blow on momentary surges in current. Slow blow fuses are tolerant of short-term overloads, but blow if the overload persists. They are useful for pumps, motors, and so on where transient conditions during motor startup can blow fast fuses, but are not harmful in themselves.
- **Circuit Breakers:** Circuit breakers are a fuse and switch combined in a single unit. Unlike a conventional fuse, which must be replaced after blowing, a circuit breaker is reusable. After an overload, a circuit breaker will trip, opening the circuit. It may then be reset, by toggling the handle. If it trips again immediately, then something is wrong, so get out the trusty digital voltmeter and start testing for shorts or other damaged parts.
- **Ammeters:** Ammeters are current measuring devices. They may be analog or digital. An analog meter uses a needle and a scale, while a digital meter displays the result as numbers on an LED or liquid crystal display.
- **Voltmeters:** Voltmeters are voltage measuring devices. Although they can be found in both analog and digital forms, since all the action in a boat electrical system takes place in the range of 11 to 15 volts, and variations of 0.1 volt may be significant, only digital meters should be used onboard. Even analog meters with so-called expanded scales are practically useless. It is highly recommended that anyone planning an ocean passage have a digital voltmeter onboard (I prefer those made by Fluke) to troubleshoot the electrical system.
- **Diodes:** Diodes are semiconductor devices that act to pass current only in a single direction. The allowed direction (positive to negative) is in the direction of the arrow, or if only a band is found then that is the negative end. Diodes have a somewhat constant voltage drop of from 0.5 to 0.7 volts when current is flowing through them. Diodes thus dissipate a substantial amount of power when large currents are flowing in them. A diode in a charging system with 100 amps flowing in it will dissipate about 65 watts and needs a big heat sink. Schottky diodes are diodes whose construction allows a lower voltage drop (around 0.5 volts) and are preferred in high current situations because they dissipate less power.

- **LEDs:** LEDs are Light Emitting Diodes. They glow in yellow, orange, green, and blue colors when current is flowing in them. A typical LED has a voltage drop of 2.2 to 3 volts in operation. The appropriate current for most LEDs used as indicators is 0.01 amps (10 milliamps). An LED should never be connected to 12 volts by itself. A series resistor of perhaps 1000 ohms can be connected to allow the correct current to flow. These devices are very useful on power panels to indicate when circuits are energized, especially things like running lights or masthead strobes, which are easy to forget in the daylight.
- **Shunt:** A shunt is a low value precision resistor used to measure the current flowing in a circuit. A shunt rated to have a voltage of 50 millivolts (0.05 volts) at a current of 100 amps has a resistance of 0.0005 ohms). A current of 0.1 amp flowing through this shunt will produce a voltage drop of 0.005 volts (5 millivolts). A sensitive voltmeter can measure the voltage across the shunt and infer the current through it. Due to the low resistance of the shunt, the voltage drop across the shunt is minimal, and has little effect on the electrical system in normal use. Shunts are essential components of electrical system monitors, and are usually placed between the battery negative terminal and the system ground. They are also found in series with the alternator output, to measure the alternator charging current.
- **Barrier strips:** Barrier strips are a collection of metal strips with screws in them mounted on an insulating base. Typically, there are two screws per metal strip. They are used to connect wires terminated with crimp terminals together. This is a simple and effective method of assembling an electrical system that provides reliability, flexibility, and ease of assembly. Use barrier strips and ring crimp terminals liberally. **Power Strips** or **Distribution Posts** and **Bus Bars** are similar in concept. They are usually a heavy metal block with tapped holes or threaded posts used to connect very high power terminals or a large number of smaller terminals to the same circuit. For example, a nice way to set up your ground system is a heavy metal block with posts for the battery, alternator, starter, and SSB grounds, and a large number of tapped holes (#10, for example) for all the grounds of the other circuits (lighting, instruments, VHF radio, etc). Blue Sea Systems makes some very nice barrier strips, and distribution posts.
- **Heat Shrink Tubing:** Heat shrink tubing is a sleeve or tube of a polymer material, ideally coated on the inside with a heat activated glue. This tubing has the remarkable property of shrinking when heated by a hot air gun, and making a waterproof seal around its contents. This is essential for sealing wire splices, the ends of crimp terminals, VHF and SSB coax connectors, and so on. Ancor makes the best.
- **Crimp terminals:** Crimp terminals are electrical connectors attached to a wire by squeezing a crushable sleeve with a special tool. They come in many sizes and types for different applications. Ring terminals are most appropriate for use in a boat, as they will not fall off if the screw attaching them to a barrier strip loosens a bit.

CIRCUIT DIAGRAMS

Circuit diagrams are the charts or roadmaps to the electrical system. People who will unflinchingly navigate the intricate freeways and city streets of Los Angeles are often leery of these diagrams. The trick is to view them as you would a complicated roadmap. Start by looking at the big picture. Try to identify things you know, such as batteries or the alternator or some switches that you recognize.

It is important to realize that all complicated things are built of simpler things. Look for functional blocks and do not be sandbagged by details at first. Try to visualize the flow of information or power in the circuit. Once the overall picture starts to make sense, then one can start to zero in on the part that is of interest. Start tracing wires with a purpose. In other words, ask specific questions, such as "OK, now how does power get from the battery to the cabin light?". Frequently boats do not have a circuit diagram, so you will have to make your own. Nigel Calder's excellent book "Boatowner's Mechanical and Electrical Manual" is a priceless resource and should be aboard at all times. This book contains many examples of typical wiring practice in boats and is a gold mine of useful information and tips. GET IT!

In circuit diagrams, it is essential to be organized and not be confused by things you do not immediately understand. If some part of the diagram is obscure, note it and pass by. Look at the parts around it. Try to understand what its function is in a general sense. Don't be intimidated. Make notes to yourself in the margins. Use colored highlighters to trace specific circuits.

A common problem in boat wiring is that it is often very poorly done in the first place. It seems that most original manufacturers are not entirely competent at wiring and do it in a manner which makes tracing it or figuring out what is going on very difficult. In particular, they often do a terrible job in the wiring of the ground circuit.

GROUNDING

The **ground** in an electrical system is intended to be the common point in the circuit to which all voltages are referred. Since all electrical devices require two terminals or connections to a source of energy such as a battery in order to function, it makes sense to perform all the control functions such as switching, fusing, etc, on a single side of the voltage source. In a boat, this is conventionally done on the positive side of the supply. Then, for simplicity, all the negative supply wires are connected together, and to the negative side of the battery in order to form the so-called "**ground**" system.

The concept of "ground" seems to have originally come from the observation that the earth conducts electricity (sort of….). Since wire is expensive, people tried to use the earth as half of the circuit, and only use wire in the other half. Sadly, this was not a very successful technique, since the earth is a poor conductor, or is at best, an unreliable one. Nonetheless, the term has infiltrated the language and leads to VAST amounts of confusion in the pursuit of a decent boat electrical system.

If you don't have a well thought out, competently built, maintainable, robust grounding system in your boat, you will forever be dealing with electrical problems and mysteries. The engine block should NEVER be used as the so-called "ground". This nefarious practice probably evolved from the fact that the engine needs the most current of all boat systems (when starting). It is therefore connected to the battery by huge wires, and is itself a giant hunk of metal. That it is dirty, oily, hot, inaccessible, and not designed as a grounding system seems to have escaped notice.

A proper ground system should be located in an accessible place. The best practice is to have a large ground distribution block mounted in a dry and convenient place. A single large conductor (really large!) should connect this ground point to the battery negative terminal, usually through a high current shunt, used to monitor the current into and out of the battery. The ground point can be a large block of bronze, brass, or stainless steel, with tapped holes for the various grounds going to the lights, radios, pumps, starter motor, ignition system, and so on. Sometimes, heavy conductors will lead from the primary ground point to secondary ground busses (again substantial pieces of metal) used to fan out the ground leads to the cabin lights or the electronics or whatever. Companies such as Ancor or Blue Sea Systems make ground distribution posts ideally suited for this application.

This leads us to the subject of wiring and electrical circuit construction, so here are some tips.

ELECTRICAL CONSTRUCTION TIPS

- **Neatness counts!** Take your time and do it right. Sometimes it is easier to tear out a bunch of bad or marginal wiring, sort out the mess, rewire the old stuff correctly, and THEN do what you originally set out to do. Try to avoid being so goal oriented that you do something nasty that you will regret later.
- **Think Ahead:** Plan for the future. If you think about your long-term interests you will add extra capacity now, rather than have to redo it all later. Leave some room for added circuits and devices at a later time. Anticipate your electrical requirements at a later date and avoid the “gotta do it in the next 5 minutes” syndrome. It will come back to haunt you...
- **Use the right components:** Only use marine grade wire and components. Ancor makes wonderful wire and terminations. They are more expensive than at the local Home Depot, but they will work forever if properly installed. West Marine and other dealers sell materials and components suitable for the job. DON’T BE CHEAP!
- **Use good tools:** Invest in an Ancor double crimp tool with a ratcheting action. It guarantees that you will make good crimps. Always test crimps with a stout pull. An Ancor wire stripper gun makes it trivial to strip wire without nicking the strands. This is a really good device. The Ancor lug-crimping tool is a wonderful way to make battery cables and other high current connections. A Porta-Sol propane soldering iron has tips for soldering, heat shrinking, a torch, and a hot knife. You MUST have a good hot air gun for heat shrink tubing. Get a good set of wire cutters. Diagonal side cutting pliers for electronics work well. Needlenose pliers can really help in tight spaces.
- **Design:** Design your installation before you build it. Calculate amperage required and use the tables in Calder or the Ancor catalog to size the wires correctly for the load. For SSB radios, do not allow more than a 1% voltage drop from the battery to the radio with 25 amps current. That means 1/2% on the ground and 1/2% on the positive lead maximum. It is very important to make the SSB power wires very heavy. Overkill is good here! Plan the installation. Figure out the routing and the layout of the parts; plan for chafe protection. Design the distribution system, with barrier (or distribution) blocks. Think about dryness, access, and maintainability.

- **Heat Shrink:** Use adhesive-lined heat shrink tubing to seal all electrical connections, which may get damp. If you have a wet boat, that means ALL of them!
- **Crimp:** Use marine grade crimp connections and a good crimp tool. Soldering is tedious and unnecessary with properly crimped connections. Use ring terminals, since they don't fall off if the screw loosens a bit. Test all crimp connections with a good tug. Use the proper size terminals for the wire: red for 18-22 gauge, blue for 14-16 gauge, and yellow for 10-12 gauge. For heavier wire, use solid crimp lugs. If you must solder some leads, use quality 60/40 electronic grade solder with the flux in the solder. NEVER use acid core solder in an electrical circuit.
- **Document it:** Take the time to write down what you did. Draw a decent circuit diagram. Note any oddities you may need to know later. Someday you will be very glad you did this. Make a copy and put it somewhere you can find it later…

A TYPICAL BOAT ELECTRICAL SYSTEM

We will now take a look at a typical boat electrical system, presented in Figures 1 to 5, below. These circuit diagrams follow the evolution of the boat electrical system from a battery and switch to a complicated looking system with multiple switches, loads, current measuring devices, instrumentation, an alternator and alternative energy sources.

It would be easy to be intimidated or confused if one encountered Figure 5 first. As mentioned above, however, most complicated things are derived from simple, more understandable things. That is the case here. The circuit complexity rises in each figure, as we add new functionality. A comparison of each figure with the previous figure will show that the new system added is actually very simple in its own right. Encountered alone it would cause no real problem. It is only in combination with the other circuits that it loses its identity and becomes a seemingly complex mess.

That is the point of this exercise: It is essential that when dealing with a large electrical system that one keep firmly in mind that any given part is simple and understandable. It is important to isolate the circuitry of interest from the other stuff around it and to concentrate attention only on it. In a properly constructed and labeled electrical system this is relatively easy. In the typical poorly wired boat, with multiple grounds, messy wiring, no color coding or labeling, and sloppy lead dress (the arrangement of the wires), it can be very challenging to follow a single circuit and troubleshoot it. None-the-less, the circuit is simple in principle, as the following figures demonstrate. These figures really do represent most of what is necessary for an offshore DC electrical system. The AC system has been left out, as have many other circuit breakers and loads (perhaps 15 to 25 on a typical boat). These left out components would only make the circuit diagram larger- not a bit more difficult to understand.

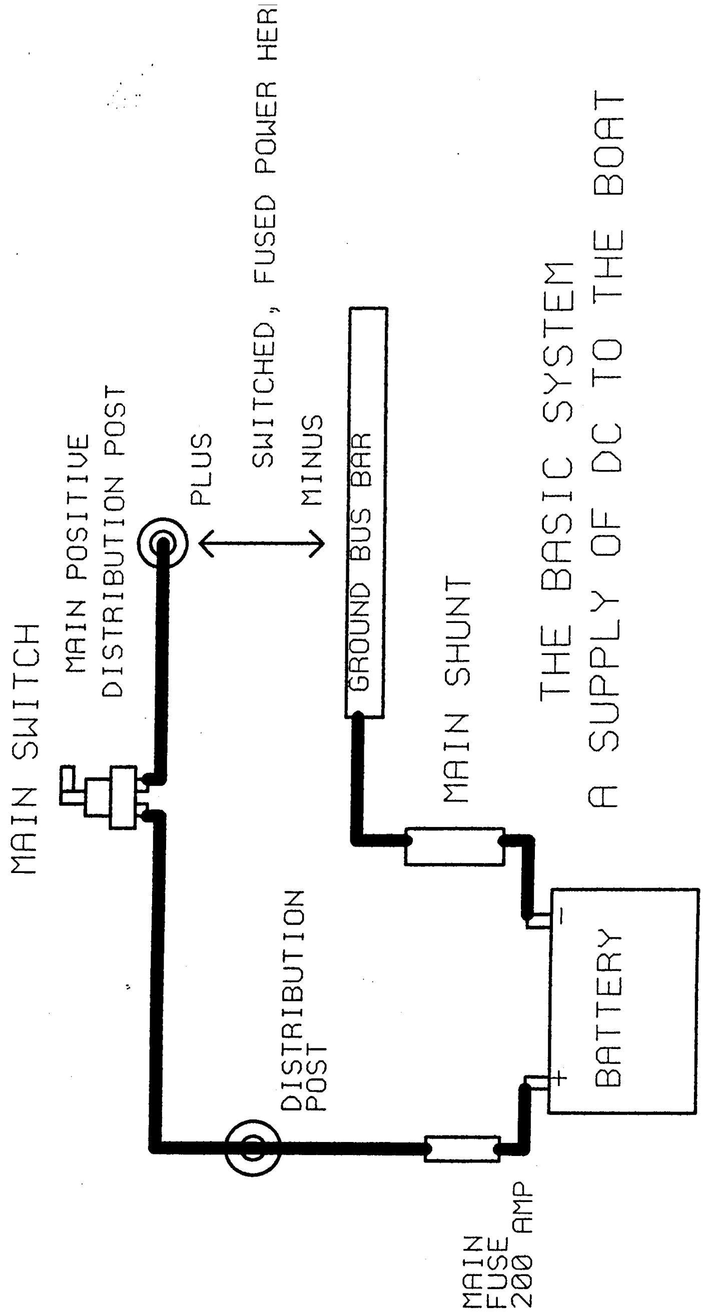


FIGURE 1. The most basic electrical system for a boat. The battery negative terminal is connected to the ground distribution bus bar through a very low resistance (0.001 ohm) shunt for current measurement. The positive terminal is connected to a distribution post for alternator and alternative power attachment. The main positive distribution post is connected to the battery through a very heavy duty switch.

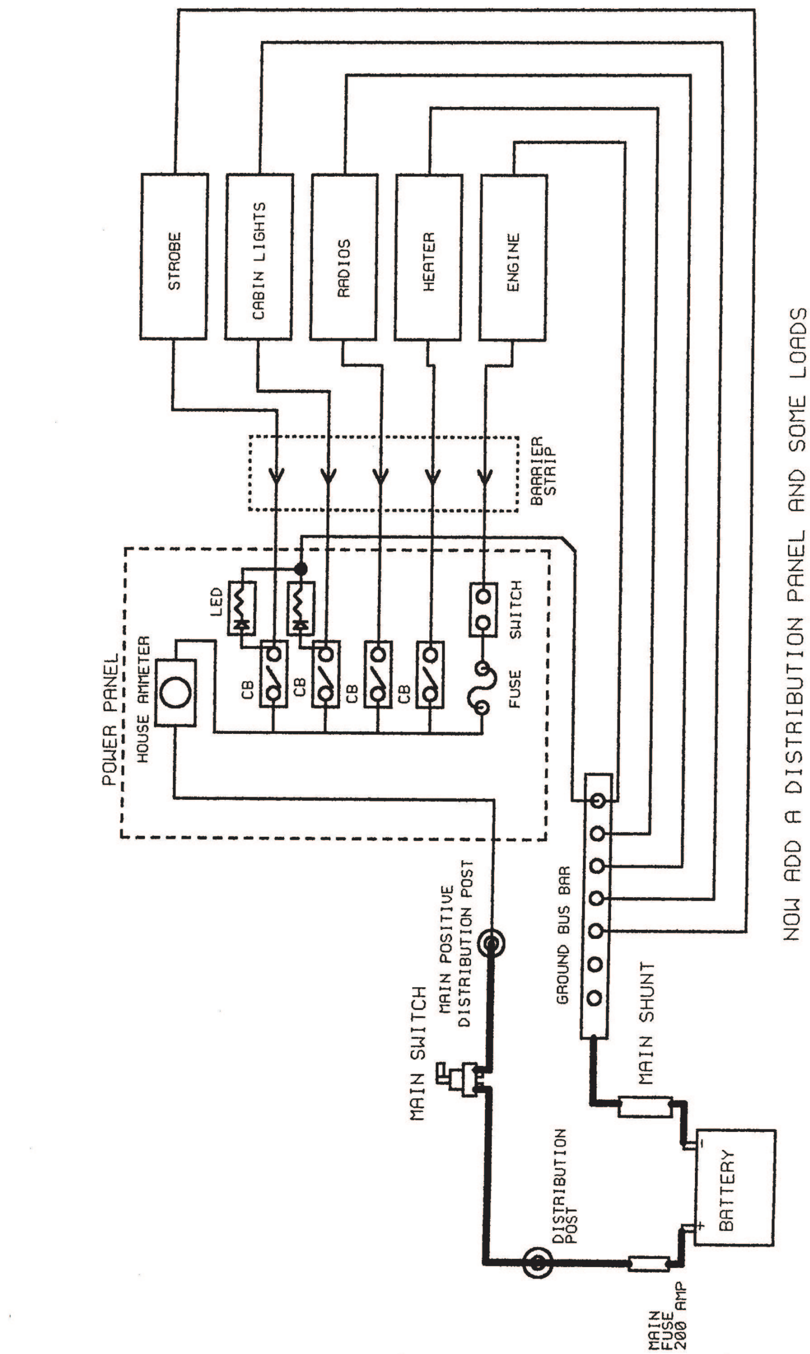


FIGURE 2. The simple electrical system has been made more complex through the addition of a set of circuit breakers (CB) and a fuse and switch. These circuit breakers and switch control the availability of power to the loads, which could be lights, a radio, pumps, etc. An analog ammeter reads the power being supplied to the loads by the battery. Some of the circuit breakers have LED lights in parallel with the loads to indicate that the circuit is powered. Note that the load connections to the switches and breakers are made with a barrier terminal strip. This is a clean and flexible way to make the connections.

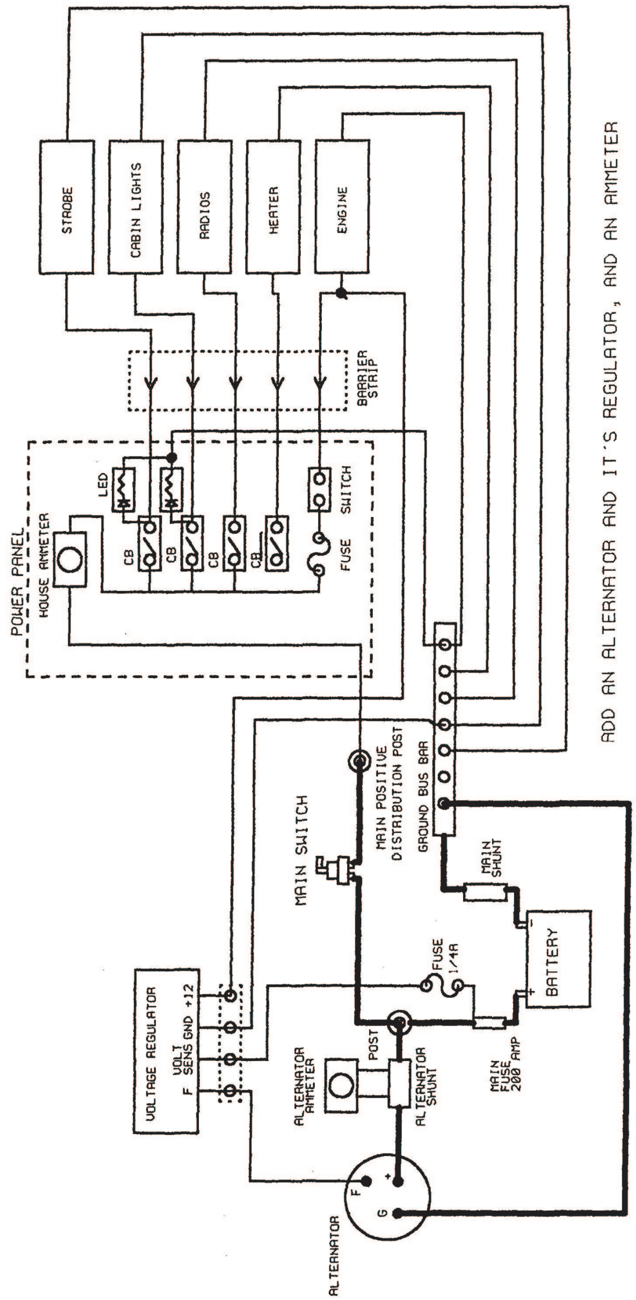


FIGURE 3. An alternator and voltage regulator have been added to the basic electrical system to allow the battery to be recharged by the engine. Note that the voltage regulator gets its power from the engine switch circuit. This is normally the ignition key switch on most boats. The regulator requires +12 volts and ground to provide power to its electronics. It senses the battery voltage through a 1/4 amp fuse, and controls the field current to the alternator to adjust the charging voltage. A separate shunt and ammeter in the positive alternator output wire allows monitoring the charging current.

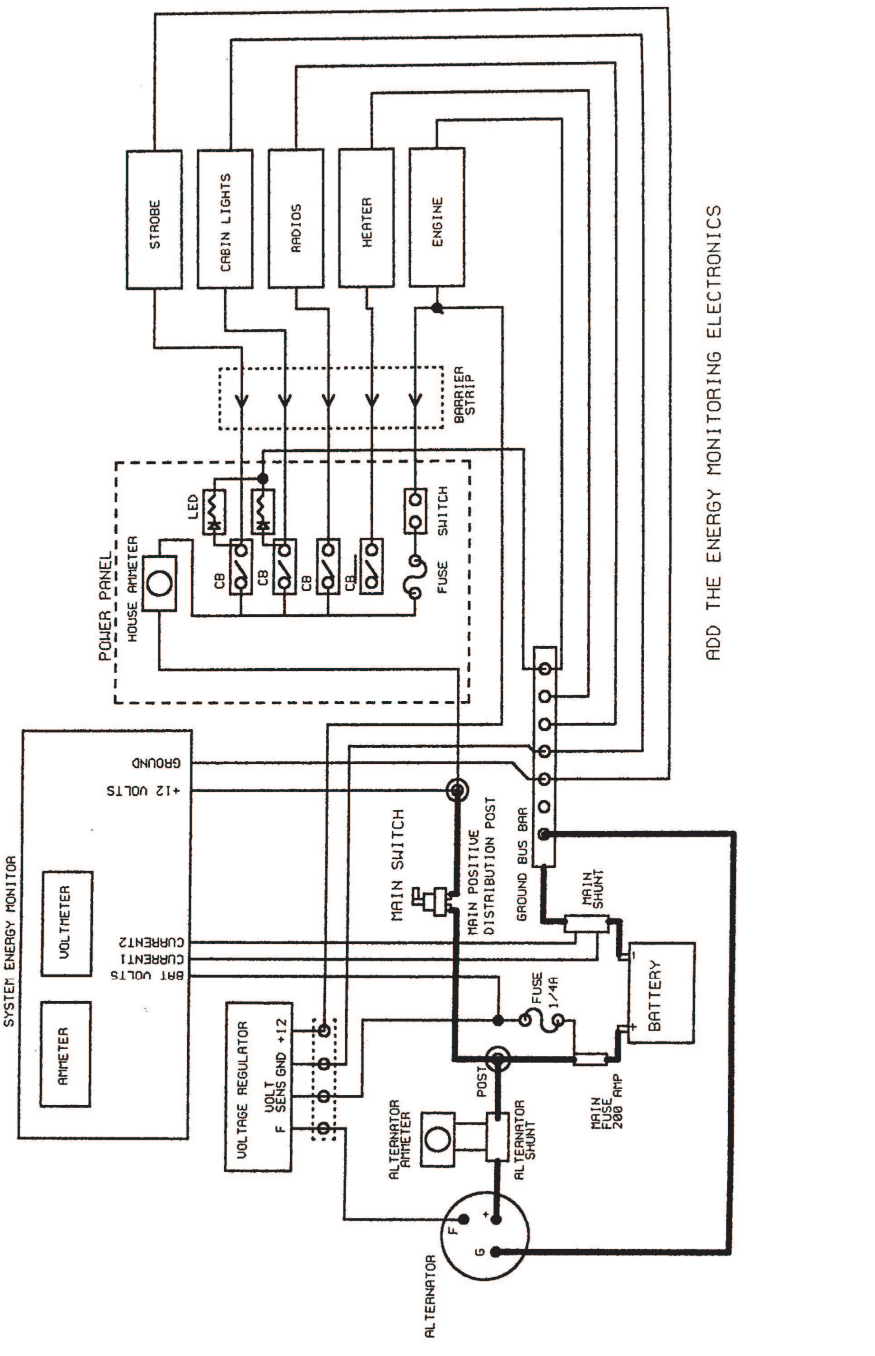


FIGURE 4. A battery monitoring instrumentation system has been added to the boat. This typically is a microprocessor controlled device that measures the voltage of each battery bank, the current flowing into or out of the bank (by means of the shunt in the battery negative lead). The microprocessor will often calculate the number of amp-hours used, those remaining, and other useful quantities. Sometimes the alternator curent is also measured here. This circuit usually needs +12 volts and ground to operate.

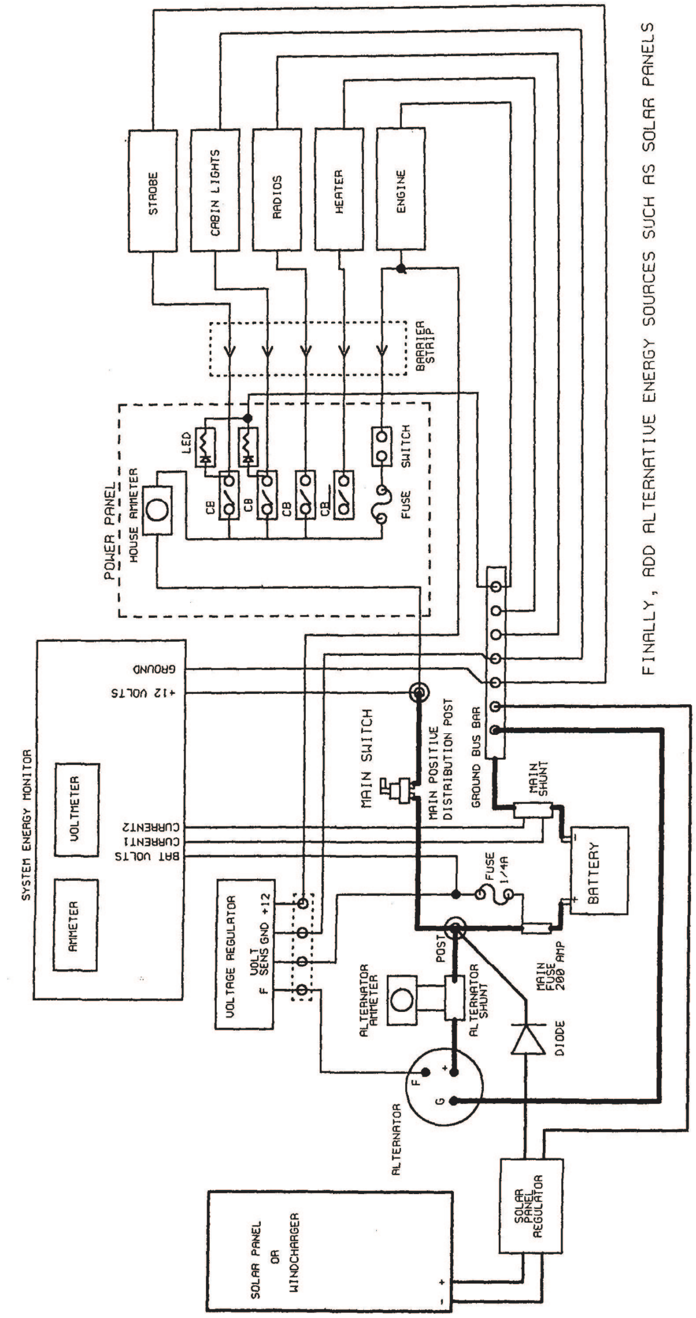


FIGURE 5. An alternative energy supply, such as a solar panel, has been added to assist in charging the battery. With a sizeable alternative energy source, a separate voltage regulator is necessary to avoid overcharging the battery. A series diode is included to ensure that the batteries are not accidentally discharged by the voltage regulator. Multiple energy sources can be tied into the system at this point.

ENERGY REQUIREMENTS FOR THE TRANSPAC

The TransPac is not really like a Farallones race, only longer. The ocean is a big place, and although it may not seem like it, a pretty busy one. It is essential that you have the battery capacity and recharge ability to support the minimum necessary tools for navigation, steering, communications, and survival. Although Joshua Slocum didn't have any electronics, it is also true he died at sea, presumed run down by a steamer. So what do you need for a **minimum safe passage** and how much energy do you need per day? Here is my list:

- **Navigation lights**: I run a masthead strobe (1 amp) and a 25 watt Aqua Signal Nav 40 masthead tricolor (2 amps) simultaneously at night, for perhaps 10 hours. Minimum of 10 amp hours (strobe only), 30 amp hours for both.
- **Compass light:** This draws less than 0.1 amp; total for 10 hours is 1.2 amp hours.
- **VHF:** I run the VHF 24 hours a day scanning many channels. It is amazing how good it is at picking up fishing boats, tugs, ships, etc.; an important safety feature. Mine draws 0.3 amps on receive. Total for 24 hours is 7.2 amp hours.
- **GPS:** I run a GPS 24 hours a day from the ship power; it draws 0.15 amps. Total for 24 hours is 3.6 amp hours.
- **Autopilot:** A Navico TP5500 tillerpilot draws a bit less than 1 amp average current. Assuming 24 hours a day, this totals 24 amp hours. An Autohelm 7000 below-decks Type I autopilot draws 2.5 to 6 amps, depending on conditions. 100 Amp hours is a reasonable estimate for planning.
- **Cabin lights:** Usage of below decks amenities varies with individuals. Assume 3 hours use for cabin lights or other electronics, at 1 amp. Total 3 amp hours.

The grand total is thus 69 to 150 amp hours per day and can exceed 250 amp hours if using radar 24 hours a day.

ENERGY BUDGET

The previous page is the start of an energy budget. It is essential that each skipper prepare such a budget for their own boat. Without the battery and recharging capacity to balance the energy budget, you will be forced to turn something off. My personal belief is that the 69 amp hour budget shown is the minimum for any skipper. To run without lights, especially the high visibility strobe, is irresponsible. There are a lot of ships out there, and you won't see them all even if you look. It is unlikely that they will see you unless you make your presence very obvious. Without the strobe, a GOOD radar reflector (NOT a Mobri!) and a VHF watch, you make it much more likely that you could be run down.

The idea that we are on our own and responsible to no one, although very romantic, is not really valid in the context of an ocean race. If to no one else, you owe it to your fellow competitors to get there alive. Failure to do so will ruin everyone's race, especially your own, and give the race committee ulcers.

So, what is your energy budget? Use the Load Chart or make your own to specify it.

LOAD CHART

DEVICE	Typical Amps	Your Amps	Hours/Day	Amp-hours/Day
Anchor Light	1.0	______	X______	=_________
Autopilot	4.0	______	X______	=_________
Bilge Pump	5.0	______	X______	=_________
Cabin Light (small)	1.0	______	X______	=_________
Cabin Light (big incand)	1.2	______	X______	=_________
Cabin Light (fluorescent)	2.0	______	X______	=_________
Compass Light	0.2	______	X______	=_________
Computer(screen off)	1.5	______	X______	=_________
Computer (screen on)	2.1	______	X______	=_________
Computer Serial adapter	0.5	______	X______	=_________
Fresh water pump	8.0	______	X______	=_________
GPS	0.4	______	X______	=_________
Handheld Spot Light	10.0	______	X______	=_________
Inverter (no load)	1.0	______	X______	=_________
Inverter (computer on)	5.0	______	X______	=_________
Instruments (daytime)	1.0	______	X______	=_________
Instruments (nightime)	2.0	______	X______	=_________
Loran	0.8	______	X______	=_________
Masthead Tricolor Light	2.2	______	X______	=_________
Plotter	5.0	______	X______	=_________
Propane Sensor	0.25	______	X______	=_________
Propane Valve	1.0	______	X______	=_________
Radar Detector	0.1	______	X______	=_________
Radar (standby)	3.0	______	X______	=_________
Radar (transmit)	4.0	______	X______	=_________
Refrigerator	4.0	______	X______	=_________
Spreader Lights	8.0	______	X______	=_________
SSB (receive)	1.5	______	X______	=_________
SSB (transmit)	28.0	______	X______	=_________
SSB Digital controller	0.2	______	X______	=_________
Strobe Light	0.8	______	X______	=_________
Stereo CD/Cassette	2.0	______	X______	=_________
VHF (receive)	0.5	______	X______	=_________
VHF (transmit)	5.0	______	X______	=_________
Weatherfax receiver	1.5	______	X______	=_________
__________________	__._	______	X______	=_________
__________________	__._	______	X______	=_________
__________________	__._	______	X______	=_________
__________________	__._	______	X______	=_________
__________________	__._	______	X______	=_________
__________________	__._	______	X______	=_________

GRAND TOTAL : __________

APPLICATION NOTE: How to Size Battery Banks (from Cruising Equipment)

Overview:

You'll begin by completing the Load Sheet (Next Page). From the Load Sheet, you will supply the information and do some simple math. You'll be able to size your battery bank just like a professional system designer would.

The Calculations:

Daily Amp-hour Load: (from Load Sheet):	______________	
Multiply daily load	X 3	
One Day of Battery Capacity:	______________	
Multiply times days between charging	X__________	(days)
Total Battery Bank Size:	__________________	

Example: 3 days between charging, 100 **Amp-hours daily use:**
100 Amp-hours/ Day X 3 = **300 Amp-hours capacity per day**
300 Amp-hours/day times 3 days = **900 Amp-hours capacity needed.**

Size the Alternator next:

Total Battery Bank Size (from above)	______________
divide by 4	/4
Ideal Alternator Size for System**	______________

Example: The right size for an alternator is between 20 and 25% of the battery capacity in amp-hours. So in our example, a 900 amp-hour bank can use up to 225 amp alternators effectively. But remember that any alternator larger than 100 amps requires double belts and not all installations have room for another set of belts on the front of the engine. If you follow our Mid-Capacity Rule and operate your batteries in their optimum profile (50%-85% full battery) a 150 Amp alternator would put nearly 300 Amp-hours back into the battery in about 2 - 2 1/2 hours. A 100 amp alternator would take more than 3 hours while a small 50 amp alternator would take more than 6 hours to the store the same amount of energy!

Completely recharging the battery takes between 2.5 to 3.5 hours from the 85% full mark to 100% full. Observe the Mid-Capacity Rule and save fuel!

Remember: When the alternator is larger than 100 amps, double belt it!

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BATTERIES

Batteries are electrochemical cells, which store energy in a reversible electrochemical reaction. Batteries for boat power systems are generally divided into two categories: **starting** batteries and **deep discharge** batteries. Starting batteries are designed to produce large currents from a small volume. If deeply discharged, however, they are often permanently damaged. Starting batteries of the sort found in auto stores should be avoided completely in marine applications, which require discharge beyond perhaps 10% of capacity.

Deep discharge batteries, on the other hand, are internally constructed with heavier plates and internal structures, which facilitate deep discharges and complete recharges without damage.

There are three general varieties of deep discharge batteries. All three are variations of the lead-acid battery.

- **Wet cell batteries:** The standard deep discharge marine battery is the familiar wet cell battery similar to the car battery. It is typically designed with heavier plates, and often uses purer lead. Wet cell batteries suitable for deep discharge are sold by West Marine, among many others. The two brands which are considered the best are made by **Rolls** and **Surrette** (see Everfair catalog). Wet cell batteries require attention to insure that the water level (only distilled!) is correct, and they can spill in heavy conditions or a knockdown.
- **Gel Batteries:** Some batteries are made with the electrolyte in a semisolid "gelled" form. These batteries are completely sealed and may be mounted in any orientation. They typically allow faster charging, have lower (or no) outgassing, and do not spill or make a mess. They must be charged at a lower voltage (typically 14.1 volts; see the table which follows). I have found these batteries very satisfactory. They used to be marketed under the brand name "**Prevailer**", but the company is now called "**Gel-Tech**".
- **Absorbed Glass Mat (AGM) Batteries:** AGM batteries are a new type of battery which has the electrolyte absorbed in some sort of glass mat. This acts like a gel battery in that it produces a sealed unit which may be mounted in any orientation, and which needs no water. It is claimed that these batteries offer twice the life of gel batteries, and allow very large recharging currents. They are made by the **Concorde** company. One source is Everfair. West Marine also sells them.

Guidelines for use:

Although batteries are reversible, they are not 100% efficient. This means that you will have to put in more energy than you used in order to get back to the same state of battery charge you had when you started.

This leads to the following rules:

80% Rule: Batteries are 80% efficient, so you will need to return 120% of the amp hours used in order to recharge the battery.

Mid-capacity Rule: For optimum life, battery banks should not be discharged more than 50% of their nominal capacity. Practically speaking, it is rather tedious to recharge a battery above 85% or thereabouts of its capacity, since the charging current tapers off drastically as you get close to full charge. This means that typically, the battery bank is used from a state of 85% of nominal full charge to around 50% of full charge. Thus a battery with a nominal capacity of 100 amp hours will actually be used to supply 35 amp hours of energy before recharging.

Although this strategy will yield the optimum life and a time-efficient charging cycle, it does not mean that if necessary you cannot take the battery bank below 50%. You will just have to charge longer, and if done on a regular basis, it will shorten battery life.

BATTERY CHARGING

Batteries must be recharged. There are limited possibilities for obtaining the energy necessary to do this offshore. Practically, there are really only 4 sources of energy adequate to the task: **engines, solar cells, wind chargers, and water chargers**. We will examine each energy source in turn in some detail, but first a few general comments.

Before discussing charging, it is essential that an **energy budget** be available which reflects the real energy usage, and also a safety factor for unexpected needs. Keeping in mind the **Mid-capacity rule**, if we assume that the battery bank will be recharged once a day, then we will need a battery bank of approximately 3 times the grand total of the daily energy budget.

For example, taking our bare bones energy budget of 69 amp hours calculated earlier, we might expect that a battery capacity of 207 amp hours (3 x 69) would suffice. A “Lifeline” AGM size 4D battery has a nominal capacity of 210 amp hours, so we might select that as the (single) battery bank. Using the **80% rule**, we estimate that we will need to return 82.8 (1.2 x 69) amp hours to the battery in order to keep up with our daily usage. Ok, so where do we get the energy and how long will it take to recharge the battery?

CHARGING SOURCES:

- Engine driven alternators are the fastest and most powerful chargers available at sea. They can produce charging currents in excess of 100 amps with a 5 horsepower engine. They use an **alternator** to generate the power. The voltage produced by the alternator must be carefully regulated to avoid frying the battery. **A rule of thumb is that the charging current (in amps) should not exceed 1/4 of the total battery capacity (in amp-hours).** For our example of the single 4D battery, above, this means a maximum charging current of about 50 amps (1/4 x 210 amp hours). To replenish 82.8 amp hours will take about 2 hours, since the current will be less than 50 amps as the charge cycle goes on.
- **Solar panels** are quiet and dependable (when the sun is shining), but produce fairly small amounts of energy. A large, high efficiency solar panel capable of 3.5 amps peak charging current in direct sunlight will produce only perhaps 12 amp hours per day on the way to Hawaii unless constant efforts are made to keep it pointed directly at the sun, and clear of any shading. A solar panel can save you if your other charging options fail, but unless you have a lot of area in which to place panels, a tiny energy budget, and sunlight (some years there are clouds all the way to Hawaii), then solar should be viewed as a backup to a more robust energy source.
- **Wind chargers** use the force of the wind to turn a generator, which supplies current to recharge the batteries. Wind chargers are capable of supplying as much as 250 amp hours per day if there is enough wind . That is the rub. The energy available to the wind charger depends strongly on wind speed. At wind speeds below about 5 knots they will generate no power at all. How much they generate after that depends on the type of wind generator. There are two kinds, small turbine units (lots of blades) and the larger wind chargers (BIG BLADES). The size of the blade is what makes the difference. The wind on a passage to Hawaii is typically 5 to 15 knots apparent, with 10 being a reasonable guestimate (you are sailing downwind, remember). A small wind charger might put out 1 to 2 amps at 10 knots for a daily total of 36 amp hours. A large unit, like the "Fourwinds II" will produce a solid 5 amps, for a total per day of 120 amp hours.
- **Water generators** come in two types, towed and fixed. The fixed units are small generator units with a propeller and are fixed to the transom with a mount, which keeps the unit submerged. The towed generator is mounted on the stern pulpit with a swivel and is powered by a propeller assembly on the end of a long line, which is towed behind the boat. Either unit can produce 5 to 8 amps at a boat speed of around 6 knots. This would be perhaps 150 amp hours per day. That is a pretty substantial charging source. The drawbacks are that the drag will slow the boat down (especially smaller boats) by perhaps half a knot or so, and the blades may be broken by hitting debris or may be eaten by a shark (it really does happen...). Some units can be quickly switched between wind generators and water generators by changing from wind blade to water propeller and remounting the generator unit.

ALTERNATORS

Alternators are the first choice for recharging batteries at sea. They are electromagnetic devices, which are driven from an engine, either gasoline or diesel powered. Alternators and generators make use of a fundamental physical fact, namely that electrical current can be induced to flow in a circuit composed of a coil of wire and a load if the coil is subjected to a magnetic field which varies with time.

In both alternators and generators, a carefully designed set of coils of wire are subjected to a time varying magnetic field which is created by spinning a magnet (or group of magnets) with an external engine. Before we consider how alternators and generators are built, there are two physical facts which may be of some help in dealing with them at sea. The first fact is that the **voltage** that the coils of wire can produce is proportional to the rate of change of the time-varying magnetic field. In other words, if you spin an alternator or generator more rapidly, it will output more voltage. Once the output voltage is greater than that of the battery which you are trying to recharge, then charging current will begin to flow and will increase as you increase the rotational speed of the engine.

The second useful fact is that the amount of voltage which a generator or alternator coil assembly will produce is proportional to the strength of the magnetic field inside the device. If the speed is constant, increasing the magnetic field strength will increase the output voltage, and hence the charging current. In a generator, the strength of the magnetic field is generally constant, perhaps by use of strong permanent magnets. This results in a device which produces more voltage the faster it is turned, but whose output cannot be regulated externally, except by varying the speed of the driving engine. This is not very convenient, and so alternators were invented to solve this problem. Most wind and water generators use generators, not alternators, as the power-producing device. Generally, these devices are regulated by throwing away energy with a so-called shunt regulator, which diverts the unneeded power into a resistive load such as a heater, or else simply disconnects the charger from the batteries, often many times a second. This can create electrical noise in the radios.

Alternators are more versatile. In an alternator, the magnetic field is created not by permanent magnets, but by an electromagnet, composed of many turns of wire wound on a rather complex iron structure. This structure, called the rotor, spins inside a complicated set of coils called the stator. The power to recharge the battery comes from the stator (so-called presumably because they are stationary) windings. The current to the rotor windings gets into the winding by passing through a pair of sliding electrical contacts on the shaft of the alternator called the brushes. These are usually a pair of spring loaded graphite blocks which rub on a pair of insulated metal rings on the shaft. Their function is to allow the current to get into the rotor coil, and hence the strength of the magnetic field can be adjustable externally.

As we saw earlier, if the magnetic field strength in the rotor winding is varied while the rotor is spinning at constant speed, then the output voltage will vary. This is the underlying principle of voltage regulation in an alternator. It is really very simple: increase the current in the field winding (the rotor coils) and the output voltage goes up. Decrease it and the voltage goes down. If one were to hold the current constant and speed up the rotation, the voltage would also increase. Slow down the rotational speed and the voltage decreases.

The only fly in the ointment, and one that is easily fixed, is that the output of both generators and alternators is alternating current. Alternating current is just what it sounds like. If you measure the output voltage many times per second, you would find that at one instant it would be positive, and later it would be negative. The cycle repeats over and over. This is due to the fact that there are two poles on a magnet, North and South. When the North pole (for instance) goes by a coil, a voltage of one polarity is induced in the coil. When the South pole goes by the coil, the opposite voltage is induced. Since it is physically impossible to have a magnetic field composed only of North or South poles alone (the first person to achieve this will be more famous than Einstein!!!), then it is preordained by the laws of physics that devices using rotating magnetic fields to generate electricity will generate alternating current.

So how come generators and alternators produce DC or direct current at the output terminals? They do so because clever people have designed them to do so. In a generator the trick is obvious: one simply uses a switch mounted on the shaft to switch the windings end for end every time the current wants to reverse. This switch is called a commutator, and is composed of a number of metal pieces which connect to the windings of the rotor and which are contacted by a set of brushes. It’s really a cute trick, mechanically rewiring the generator windings as the rotor spins

In an alternator, the so-called rectification (turning alternating current into direct current) is performed with electronic components called diodes. These devices act as a one way valve for current flow. By cleverly wiring these diodes in a so-called bridge circuit, one can accomplish the same trick as in the generator, but with no moving parts. The stator coils do not move, so it is possible to make alternators capable of extremely large power outputs because the stator coils can be efficiently cooled.

Selecting an alternator

For offshore battery charging, one wants to use an alternator designed for high current charging for long periods of time. This is NOT a car alternator. Just as one would not use a car battery for an energy source offshore, one should pick an alternator, which is designed for the job. In particular, it will be designed to output lots of current when hot (and they get REALLY hot). This means heavier wire and magnetic structures, really beefy diodes, bearings capable of handling the side loads the heavy duty belts put on the cases, and so on. Many vendors make such alternators; consult the vendor literature provided at the lecture. The main tip is that the charging rate in amps that your alternator is capable of should not exceed 25% or 1/4 of the battery bank capacity in amp-hours. To safely use a 100 amp alternator, one should have a battery bank with a capacity of at least 400 amp-hours.

Another important consideration is that the alternator fit the engine. Fortunately, there are form-factor equivalent replacements for almost any stock (i.e., wimpy) alternators your engine may have been originally equipped with. Talk to the vendor.

In addition to a proper physical fit, the drive belt must be the correct size, and the cooling fan on the alternator shaft must be correct for the direction of rotation. An alternator is cooled by drawing air from the back through holes in the case to the front. Make SURE that the fan is correctly specified for the direction of alternator rotation. If in doubt, there are fans that are bi-directional. You may specify this when you order. Another pitfall is that the alternator must spin at a high enough RPM to generate the required current when the field winding is correctly energized. If the alternator is spinning too slowly, it will not generate enough voltage to exceed the battery voltage and no charging will take place. This is corrected by making the ratio of the engine and alternator pulleys big enough.

Measure the diameter of the engine pulley that drives the alternator. If the engine RPM at which one will run the engine to charge batteries (typically 1/2 to 2/3 of full RPM) is known, and the engine pulley diameter is known, the vendor can help you specify the correct diameter pulley for the alternator. As a side note, if your engine is running too slowly, you won't get any charging out of your alternator. So before you panic and sail back to San Francisco, as some worthy souls HAVE ACTUALLY DONE, rev up the engine and see if the alternator starts working. It usually does. Also check that the alternator belt is not slipping. A high capacity alternator requires lots of horsepower to drive it, and the torque is correspondingly high. If the belt is not tight, it will slip. A slipping belt can greatly reduce an alternator's capacity and will soon destroy itself.

REGULATION

You are interested in making sure that your batteries are charged as quickly and as safely as possible. This is done with a 3 step (or more) regulator. Automotive-type voltage regulators are totally useless for energy management, and have no place on a boat.

The correct strategy for charging a fairly discharged battery bank is to charge at whatever current the alternator will output until the voltage on the batteries rises to a set level. This is termed the "bulk" charge. The voltage is then held constant while the battery continues to charge at a high rate.This is the "absorption" charge. Eventually, the battery starts to become charged and the charging current decreases. When the voltage regulator senses that the current has decreased to a sufficiently low level, indicating that charging is essentially complete (greater than 85-90% of capacity), then the voltage is reduced to a "float" value which will do the battery no long term harm. The battery will continue to charge at this level, but at a small rate.

The choice of voltage regulator can be somewhat confusing. The state of the art in this area is rather advanced, and different vendors make a wide variety of claims. The good news is that if you stick to one of the vendors who have sent literature to this seminar, you can be assured that things will probably be ok for a TransPac. If you were world cruising, and needed many hundreds or thousands of charges from your batteries, then some of the subtleties would perhaps make a difference. As long as your regulator is reasonably designed (and most external regulators sold for this application are), you will get good charging, provided you have a decent alternator which has been installed properly, that your batteries and wiring are in good shape, and that you have a decent energy monitoring system.

ALTERNATOR TIPS AND PITFALLS

1. Make sure the alternator fits properly. Consult the vendor and measure everything.
2. Beef up the mounting bracket. High power alternators put considerably more stress on the mountings than a stock alternator does. Consider using threadlocker compound (Loktite) AND lock-washers on the mounting bolts. Also use grade 8 bolts (available in good car parts places- the top has little markings like lines). These high strength bolts will resist shearing due to vibration and stress. Carry a few spare bolts. They really do break occasionally.
3. Align the alternator pulley with the drive pulley by using a piece of metal rod (perhaps 3/8" diameter) which lies in the grooves of both pulleys. It is easy to see any misalignment with this. The two pulleys must be in the same plane and parallel to each other. If this condition is not met, belt lifetime can be vanishingly short.
4. Use ONLY super heavy-duty belts. Gates and Goodyear both make extremely good belts. The part number will have an "X" in it typically, such as 3VX280. The belt should be cogged, i.e., it has teeth on the inside. The teeth don't grip anything; I think it is for cooling. Make sure it fits properly and buy a bunch of spares. At least 3 or 4. If it is a good belt you probably won't need them, but if you do, there is no substitute. This is really IMPORTANT!
5. Make sure the wiring is the correct size. If upgrading a stock alternator, you WILL have to make the positive AND ground wiring of suitable size. Check the Ancor wire tables. Use the 3% voltage drop table. Make sure the crimps are good and heat shrink them. Use aircraft nuts AND lockwashers and tighten well (don't break them though). An alternator wire getting loose can be a very dangerous!
6. Be sure to install an ammeter in the alternator charging (positive) wire somewhere. Even if it is a regular analog meter (with a shunt), you need to see the charging current somehow. You must have an energy monitoring system with a shunt (ammeter) in the battery negative lead. These monitoring systems usually have alternator current as an option.
7. Be sure the grounding from the alternator to the battery is clean. DON'T use the engine block. Run separate well-sized cable and use proper distribution posts.
8. Consider filters for the field, power, and tachometer wires. This can reduce electrical noise for the radios. They must be sized properly for the expected currents. Don't cheat!
9. Make sure that the alternator belt is tight enough. A 100 amp alternator will require 4 to 5 horsepower to drive it. I run a 3/8" belt, but this is marginal. (Good belts!!!!!). Don't overtighten; it eats the bearings and wears out the belts. You need a lever to adjust tension. I use a small crowbar and carry it onboard.

Charging system spares and tools

- At least 3 spare extreme duty spare belts.
- A bar to tighten the alternator.
- Spare high strength (grade 8) bolts for all attachments.
- Appropriate wrenches to remove and replace the alternator.
- Consider a spare regulator and also an alternator rebuild kit. I neglected this and spent two weeks in a dark boat without power. It was educational, but not an experience I would recommend.

- Hydrometer and **distilled water** if you have wet cell batteries.
- A Fluke digital voltmeter and long alligator clip leads.
- Really good fuel filters (Racor 500) with plenty of spare elements and a means to easily drain the filter bowl (The bowl should be BIG and CLEAR).
- Spare battery post attachments for the battery. They are cheap and a showstopper when they fail.
- Fuses for all the charging system parts, including the super big battery fuse.
- Safety glasses for working around the beast with the engine on. BE CAREFUL!
- Some spare wire and crimp terminals (including butt connectors) for all wire sizes. It is embarrassing when a crimp fails and you can't fix it.

ENERGY MONITORS

Energy monitors are essential tools for an offshore energy system. You may get by without them, but they are very helpful in keeping within your energy budget and finding trouble before it becomes serious. If your energy system starts to crash and you have no diagnostic tools, you are screwed. I hope you LIKE hand-steering for 18 hours a day!

There are many energy monitors on the market. Check the supplied vendor literature. The minimum functionality is battery amps, battery volts, and amp hours used. Most monitors will do a lot more than that. My Ample Power monitor is great, but no longer manufactured. If I were to replace it, the Link 10 looks like an appealing, inexpensive unit. I think the Link 2000R looks good in a slightly more sophisticated model. Ample Power, Cruising Equipment, SALT, Cruising Equipment, and many others make excellent stuff. It boils down to what you like and how you deal with information. Some people like to avoid lots of numbers, so things like "7/8 FULL" are great for them. Others, like me really want to see detailed information. It's a personal choice. But: you MUST have **digital** volts and amps. Almost all the action of interest in a boat electrical system takes place in the span of 11 to 14 volts. Changes of 0.1 volt can be significant, so digital meters with a minimum resolution of 0.1 volt (0.01 volt is better) and 0.1 amp are essential. The analog meters commonly sold (even the ones with so-called expanded scales) are basically worthless and should be replaced before going offshore. Carry a portable digital voltmeter (I like Fluke) for troubleshooting, and as a spare monitor.

SOLAR PANELS

Solar panels convert the energy in sunlight into a voltage, which can be used to charge the battery. Solar cells are made of silicon. Each cell individually outputs about 0.6 to 0.7 volts if there is no load on it and it is illuminated. The current it can deliver into a load varies with the intensity of the light. In order to construct a useful solar panel, many solar cells are wired in series in order to provide a large enough output voltage to overcome the batteries' own voltage and allow charging current to flow.

The output of a solar cell is a function of the temperature of the cell. As the cell heats up, its output voltage decreases. Since the function of the solar cell is to absorb light, they become very warm in the tropics. As a result, manufacturers make solar panels with different numbers of cells, ranging from about 30 to perhaps 36. The more cells, the more open circuit voltage, and the higher temperature the panel can withstand before the voltage drops below that required to charge the battery.

The charging capacity of a solar panel depends on two factors: the material of the cell and the usable area of the panel. Solar cells can be made of thin films of silicon, polycrystalline silicon (sort of partially crystallized), and pure crystalline silicon. Thin film panels offer the convenience of flexibility, but their output is about half that of crystalline cells. They are generally a poor choice for a TransPac unless you have a LOT of area to use. It seems that the only company making thin film solar panels is United Solar. In any case, you need twice the area of a good crystalline panel. Polycrystalline panels are less efficient than crystalline panels, but not hugely so. The company one thinks of for polycrystalline panels is Solarex. For serious charging work, single crystal panels are best. The top names in this area are Siemens and Kyocera.

How many amp hours can you expect from a solar panel? My rule of thumb, confirmed by a passage from Hawaii using ONLY a single 55 watt Siemans panel for power (not recommended...) is that one should take the peak current output of the panel, multiply by 10 hours of daylight, and divide by three to get the equivalent number of amp hours returned to the battery if there is decent sunshine, a reasonable fixed mounting, and no particular attention paid to orienting the panel. My panel puts out about 3.5 amps in direct sunlight at normal incidence (the sun directly overhead). The rule of thumb says that I could expect 3.5 x 10/3, or about 12 amp hours per day out of a panel about 51 inches long by 13 inches wide. It is important to evaluate the need for a regulator. Most solar panels large enough to be of interest for the situations discussed here will require a regulator. Talk to the vendor and see what they recommend.

What this is telling you is that although solar is great, you need a lot of area to really get many amp hours. I would not want to sail offshore without my solar panel, and it DID get me back from Hawaii, but I was living in a dark fiberglass cave. It is not adequate as a primary charger, given the minimum (69 amp hour) energy budget for the TransPac.

A final point is that regardless of promotional literature claims to the contrary, if you walk on solar panels, you will damage them eventually. It is really not a good thing to do, and they are slippery.

WIND / WATER GENERATORS

We have already discussed how a generator can produce power. The issue is: what is turning the generator? Two viable sources are wind generators and water generators. As already mentioned, the wind generator uses a large diameter spinning propeller, and the water generator uses either a rigid prop or a towed propeller on the end of a long torque line to turn the generator.

Sailboats use the wind for power, so if you are sailing, you have wind, by definition. You are also moving through the water, so you can use a water generator. Wind and water generators sound like a great idea. There are a few rubs, however.

Problem #1 is that the density of air is small. That means that the amount of energy that can be extracted from a square inch of flowing air is rather small as well. You need a large propeller to get much energy from the wind. Problem #2 is that the energy available from the wind goes up very fast, as the cube of the wind speed. You can get great gobs of power from winds above 20 knots. At 5 knots, you can get very little. This phenomena is familiar to racing sailors...

So one question is your expected average wind speed. The answer is: a lot less than you expect. Although we remember the times it is howling, it is calm a lot more often. For the TransPac, you are sailing downwind most of the time. If the true wind is 12 to 20 knots, and you make 5 to7 knots boatspeed, your apparent wind will be from about 7 to 13 knots, and you may see quite a bit less in a light year. Coming back, you can expect apparent winds of 12 to 25 knots for a few days, followed by several weeks of 10 to 16 knots or less.

There are cute little wind chargers with lots of blades. In the range around 10 knots apparent wind speed, they put out ballpark of 2 amps. That is still 48 amp hours per day. A more robust wind generator like the Fourwinds II will put out 5 amps in 10 knots of wind. It is a big noisy sucker, however. A good compromise might be the Fourwinds III. It is smaller, quiet (they say…), and outperforms all the other compact units. Another possibility is the AirMarine, sold by West Marine. There is a nice (and I think honest) comparison chart of all the different models in the Everfair catalog, reproduced on a following page.

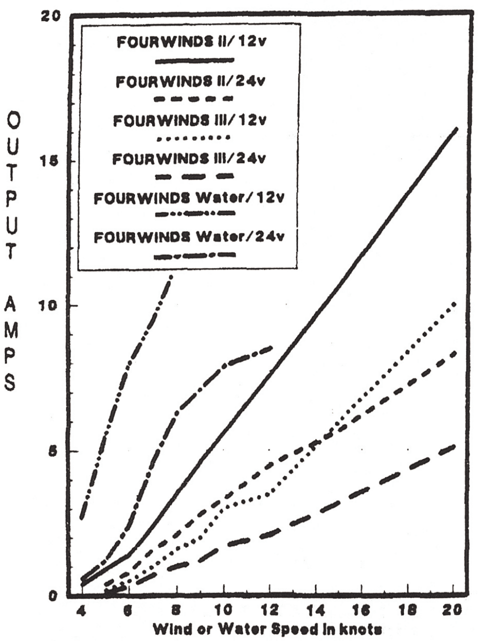
Whatever your choice, it must be mounted well above reach, and have a provision to control or stop rotation in high winds. Different manufacturers handle the problem in different ways. Read the literature carefully. Almost all windchargers will require a regulator. Consider the one recommended by the manufacturer.

Water generators are similar to the wind generators. They can consistently put out 5 to 8 amps at normal sailing speeds. The drawback is that they slow you down due to the drag. There is no free lunch! A unit that converts between a water generator and a wind generator might be a good choice. Use the wind when racing, convert to the water when cruising and crank up the tunes! The graphs below are from Southwest Windpower for their Air Marine wind charger (as sold by West Marine and others) and a comparison of various wind chargers put out by Everfair Enterprises, manufacturer of the Fourwinds II.

MARINE INDUSTRY COMPARISON: GENERATORS

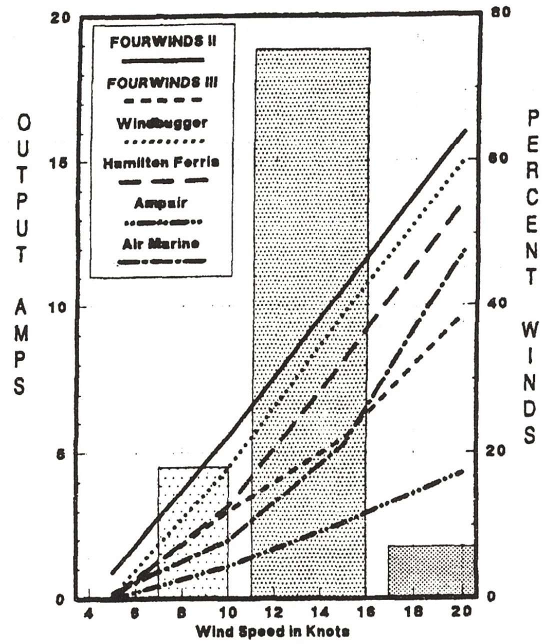
Comparison from Everfair Enterprises Catalog.

FOURWINDS GENERATOR OUTPUT

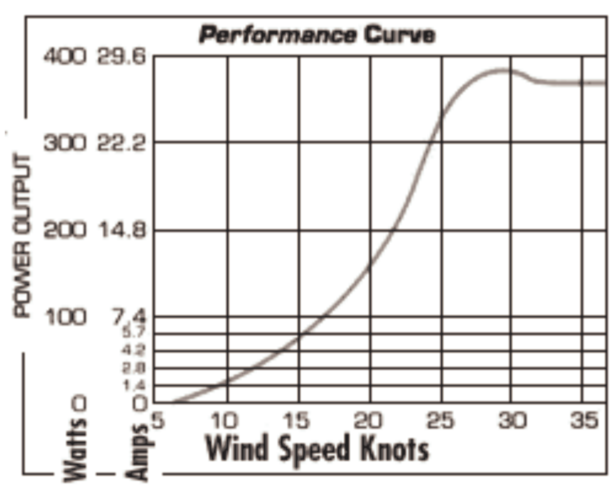


Water generator output above 10 knots should approximate a straight line extension of the lines shown. *The 24-volt output is estimated.* Water generator output above 6 knots is estimated.

WIND GENERATOR COMPARISON



The shaded areas are Beaufort Scale wind groups: (left to right) 7-10 knots, 11-16 knots, 17-21 knots. Use the axis at the right for percent in each group.



Southwest Windpower
Air Marine windcharger

(from website)

RECOMENDATIONS

The following recommendations are merely suggestions to stimulate the imagination. There are many possibilities, and many good manufacturers. These scenarios are not to be swallowed whole, but to serve as a basis for discussion and analysis.

Ultralight:
You need a minimum of say 75 amp hours per day. This implies a battery capacity of 225 amp hours. Battery possibilities are 3 Group 24 batteries in parallel (210-240 amp hours, about 150 pounds weight). Recharge with something like the gas powered 50 amp alternator charger E-Power 12-50 from Hamilton Ferris. For backup use a Kyocera KC120 120 watt solar panel (56" x 25") mounted on a rotating mount across the span of the rear pulpit. Carry enough gas in an external can to charge 2.5 hours daily for 21 days, and have a reserve of 5 days. Use a Link 10 energy monitor.

Stock racer/cruiser:
You have an inboard engine. You need, say, 100 amp hours per day. This implies a battery capacity of 300 amp hours. Keep your starting battery separate from the house bank (see Cruising Equipment recommended method) and add three Group 31 batteries in parallel (290 amp hours, 210 pounds). Add a 75 amp alternator and a good regulator. Upgrade the wiring from the alternator to the battery. Add a Link 10 monitor. Have a Kyocera LA51 51 watt or Siemans SM55 55 watt solar panel, and also a Fourwinds III windcharger. This is a pretty cushy, robust system, with enough reserve in the alternative charging solutions to give you a few electrons to spare if the engine dies. Take lots of fuel filters and clean out the fuel tank before you go.

Fat cruising boat:
You need in excess of 150 amp hours a day. You run radar, refrigeration, lots of radios, a computer, and play loud obnoxious music. You need at least 450 amp hours in battery capacity. You have a starting battery, isolated as described above. Add 3 Group 4D batteries for 540 amp hours capacity. You upgrade to a 100 amp alternator (108 amps hot rated), and add a Link 2000R energy monitor/ alternator regulator. You also get an alternator rebuild kit at the same time. You add two Kyocera KC80 80-watt solar panels and a regulator, and a Fourwinds II wind-charging system with WT-2 water generator conversion kit from Everfair, with a regulator. You carefully overhaul and clean the fuel system, install Racor 500FGSS2 fuel filters, and plenty of filter elements. You fill up on clean automotive #2 diesel and add Biobor to kill the algae.

Again, these are only scenarios to stimulate the imagination and provide some structure for your catalog perusal. A well-done boat electrical charging and distribution system takes a lot of careful work and thought. It is not technically difficult if you make a commitment to doing it correctly, invest in the right tools, buy quality components, and have some patience. The work, although awkward at times, is generally clean and fun. The results will astound you and you will have endless delight in showing your shiny system to all your friends, and any other poor souls foolish enough to come within reach!

Final Thoughts

- **DO NOT connect things to your batteries without fusing them near the batteries. This includes** solar panels, windgenerators, or SSB radios. This can lead to a fire that will burn your boat down.
- **If your alternator system is not charging:**

1. Check the belt tension, if the belt is slipping it won't charge.
2. Check if the engine RPM is high enough. Too low an RPM will not generate enough voltage to overcome the battery voltage, so no charge results.
3. Check that the regulator has power. Usually it gets it from the ignition switch. Check the fuses and the voltage at the regulator.
4. Check that the regulator is connected to the field coil of the alternator, and that the regulator is grounded.
5. Check that the connection from the Alternator to the battery is good- no corrosion, bolts tight. Also check the alternator ground. This should NOT be through the frame and adjustment arm to the engine block, but should be a high current wire directly from the alternator to the DC negative return, and thus to the batteries.

- If the alternator field winding requires current from the battery to produce field current, you can "hotwire" the field winding by disconnecting it from the regulator and hooking it directly to +12 volts. BE CAREFUL, and keep the RPM's down. This will, if successful, make the alternator produce full current. You can use this to charge the batteries, but watch the voltage on the batteries like a hawk!! Use the engine speed to adjust the charging voltage (and thus current). Once you hit the absorbtion voltage (14.1 volts for gel batteries, 14.4 volts for flooded cell) turn off the engine and disconnect the field wire. If you are stuck offshore with a blown regulator, you can wire the field winding to the battery with a fuse and a switch. Turn on the engine, warm it up a few minutes, turn the RPMs down to a minimum, connect the field winding with the switch, turn the RPMs up to get charging going and WATCH THE VOLTAGE!! This is an emergency procedure, but it will work.

Electricity is easy, but neatness counts. The laws of physics are being enforced here, so pay attention to wire sizes, cleanliness, and so on. If you think it through, it will work. Have a digital voltmeter (and a few spare batteries for it), along with the tools and spares (crimp connectors, wire, etc), and you can jury rig amazing things.

MARINE ELECTRICAL AND ALTERNATIVE ENERGY SUPPLIERS

Northern Arizona Wind and Sun
800 383-0195
2725 E Lakin Dr, #2, Flagstaff AZ 86004
http://www.windsun.com/
Note: This is THE best place for solar panels, Air Marine wind chargers, charge controllers, and bits and pieces for making alternative energy systems. Very informative and best prices in the USA.

Ample Technology
206-789-0827 . . . Fax: 206-789-9003
2442 NW Market St., #43, Seattle, WA 98107
e-mail: info@amplepower.com
website: www.amplepower.com
I prefer Ample Power equipment. I have used it for years, and admire the design. Reliability has been excellent.

Blue Sea Systems
360-738-8230 . . . 800-222-2617 . . . Fax: 360-734-4195
3924-D Irongate Rd., Bellingham, WA 98226
e-mail: conduct@bluesea.com
website: www.bluesea.com/electric/
These people make many of the switches, fuses, bus bars, and so on you need to build your electrical system.

Everfair Enterprises, Inc.
941-575-4404 . . . Fax: 941-575-4080
1205 Elizabeth St., A2, Punta Gorda, FL 33950
website: www.charternet.com/fourwinds

Hamilton Ferris Co. Inc.
508-881-4602 . . . Fax: 508-881-3846
P.O. Box 126, 200 Homer Ave., #L-117, Ashland, MA 01721
e-mail: hfcopower@aol.com
website: www.hamiltonferris.com
These people make some nifty gas powered auxiliary chargers with real high capacity alternators, and have many other interesting alternative power accessories.

Siemens Solar
805-482-6800 . . . 800-947-6527 . . . Fax: 805-388-6395
4650 Adohr Ln., Camarillo, CA 93012
e-mail: info@solar.siemens.com
website: www.solar.siemens.com

Balmar
360-629-6100 . . . Fax: 360-629-3210
27010 12th Ave. NW, Stanwood, WA 98292
e-mail: balmar@balmarvst.com
website: www.balmarvst.com

Rolls Battery Engineering
800-681-9914
8 Proctor St., Salem, MA 01920
e-mail: batsales@sarrette.com
website: www.sarrette.com

Surrette America
603-286-8974 . . . Fax: 603-286-7770
P.O. Box 249, Tilton, NH 03276

East Penn Mfg. Co., Inc.
610-682-6361 . . . Fax: 610-682-4781
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e-mail: eastpenn@eastpenn-deka.com
website: www.eastpenn-deka.com

Statpower Technologies Corp.
604-420-1585 . . . Fax: 604-420-1591
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website: www.statpower.com

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e-mail: sales@ancorproducts.com
website: www.ancorproducts.com