Advanced Electrical Basics for the Solo Sailor

By Bill Tucker (January 2014)

Introduction

In 2011 during the Super Mac and Back starting at Port Huron John Olilla gave me a call on the VHF radio just after we had rounded the mark off Chicago and told me that we thought he might need to drop out because his auto pilot was not working. I suggested a few adjustments. He made the adjustments and came back on the VHF only to say that my suggestions had not helped. I then asked what his battery voltage was and he replied that it was 11 volts. I suggested that he turn on his engine and do a battery charge. That did the job! John went on to beat me to the finish line at Port Huron! (My lesson learned: I no longer give autopilot or electrical advice during races.)

During the 2013 race season one boat was experiencing particularly garbled VHF radio transmissions. VHF radios on high power with a mast head antenna usually provide up to a 20 mile range and we knew he couldn't possibly be that far ahead. Finally someone suggested he start his engine. The added voltage from the engine alternator cured the low voltage from the battery and the next transmission was crystal clear.

These short stories illustrate the importance of proper electrical system operation. We are often so busy with other things in preparation, and sailing that we forget to take care of our electrical system. Our electrical system is important particularly to operate our auto pilot if we do not want to continuously hand steer and also for navigation equipment and navigation lights. This article talks about some of the aspects of proper electrical system design and operation. It attempts to provide practical information without getting into too much technical detail. Further reading is encouraged; but save it for the winter when your boat is on dry land covered with snow.

If you are not familiar with basic measures of electricity and their relation it is suggested that you read Appendix A before proceeding. If you feel you understand the basic electrical measurements proceed but refer to Appendix A if you need clarification. In any case I have tried to provide a practical but thorough coverage of the subject so skip through or skim the areas with which you are familiar.

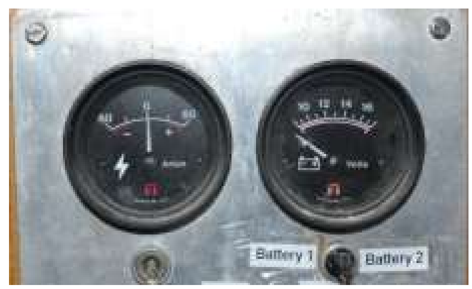
Just so you will understand my frame of reference let me briefly describe my boats electrical system. My boat, GL3, is a 1969 Beneteau First 30. Her electrical system has been extensively modified from the original installation. She has a 13.5 hp Beta Marine Engine with a 60 amp alternator, and a separate 3 stage charging regulator. She has two batteries: a 105 AH battery for house loads, and a 65 AH battery for engine starting. She has two battery switches one for the house loads and one for the engine so either battery can supply the house loads or engine. A 10 amp battery charger charges the battery through diodes when shore power is connected. The alternator also charges the batteries through diodes. These diodes keep the batteries isolated so one can charge both batteries at the same time from the alternator and engine or shore power without any switch manipulation. A Xantrex, Link 20 battery monitor monitors both batteries. A Hamilton Farris water generator, which consist of a generator on the stern connected to a trailing propeller by a tightly wound Dacron line, can be used if the alternator fails or the engine will not start. The water generator is not used when racing as it reduces boat speed by a couple tenths of a knot. Some photos of GL^{3}'s electrical system are shown below.

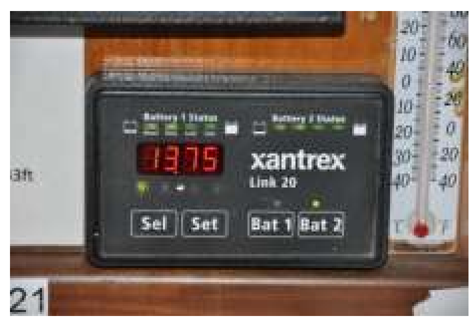
Basic Electrical System

Sailboat electrical systems usually consist of most of the following components:

- *Batteries*- This is the heart of the boat electrical system. Most system include two batteries, one for general house loads and one used just for starting the engine. It is important to keep the starting battery fully charged and isolated from normal house loads. The starting battery can also serve as a spare for house loads in case of a problem with the charging system or the house battery.

- *Alternator* – The alternator is key as it is used to recharge the battery using the engine while sailing. An alternator may have a build in or separate regulator. This is the device that controls the process for charging the battery. More sophisticated regulators have three stages of charging. The first charges the battery at the maximum alternator output rate for the particular alternator until a certain voltage is reached. At that voltage the battery will continue to charge at a constant voltage but decreasing current until a certain current is reached. The alternator will then continue to charge at this lower voltage to keep the battery on float. Charging rates may also be limited by battery size and associated wiring.



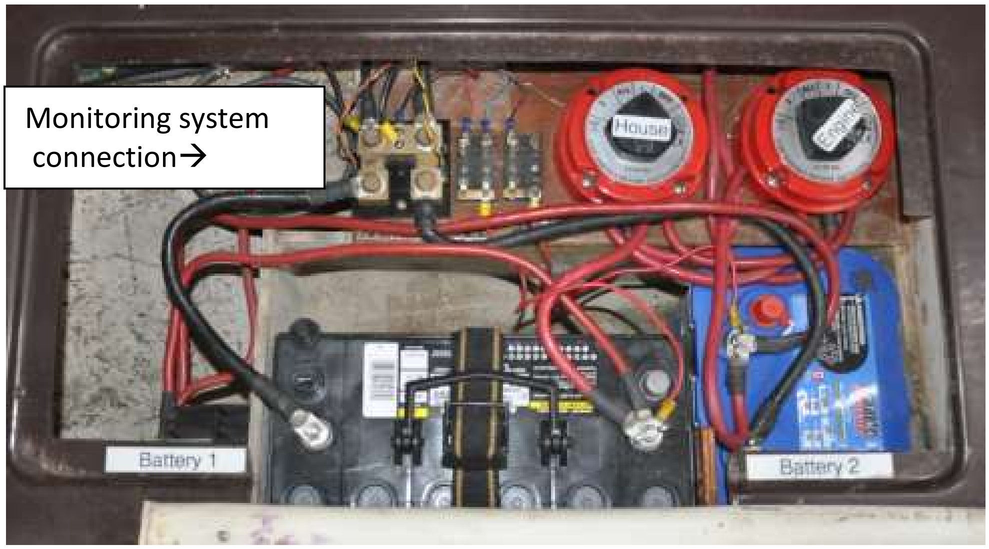


- *Battery Monitor System* – This may include simple volt and amp meters or a more sophisticated battery monitor that provides these functions as well as a number of others. A battery monitor or digital meters will provide more accurate digital voltage and current readings and help you to better analyze and manage your electrical system operation.

- *120 Volt Distribution System* – This is the shore power system. For purposes of this article it primarily serves as a source of power for the battery charger to insure a good battery charge before we go sailing. If a converter, that converts DC to 120 volt AC is installed it may also represent a significant load while sailing if items such as computer, or refrigerator are used.

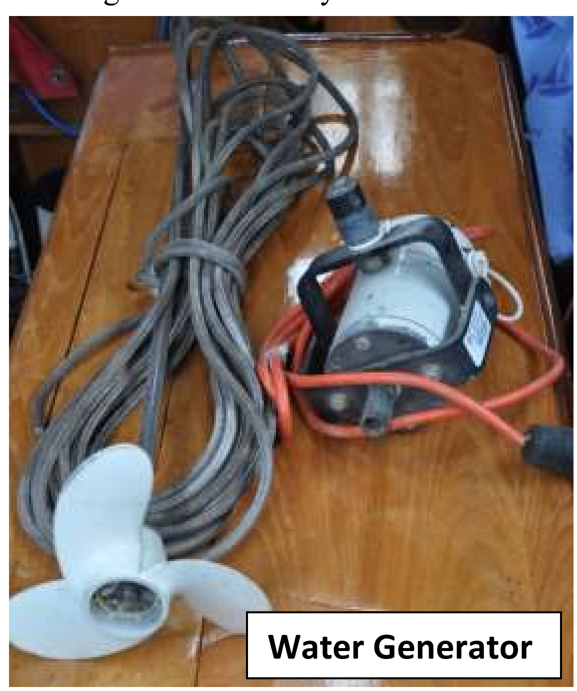
- *Shore Power Battery Charger* – A good shore power charger will help to insure that you start your voyage with a good charge in the battery. At the dock it also provided a source of power in the event you have a leak and your electrical bilge pump goes to work.

- *Battery Switch* – The battery switch or switches determine which battery is connected to the engine and house electrical system. This assumes the house loads and engine are tied together. If two switches are installed one may be used to connect the engine to either battery and the other may be used to connect the house loads to either battery. If two switches are installed typically they will be set to connect one battery to the house loads and the other to the engine. In either case the idea is to keep one battery in reserve for the sole purpose of starting the engine or should the engine not start it will serve as an alternate or emergency source of power.



- *DC Distribution Panel* – The DC distribution panel serves to distribute the power to the various electrical loads. It may also provide switches to turn the various loads on and off. It should also include either fuses or circuit breakers to protect your boats wiring. This is a safety consideration as the small gauge wire if shorted out could draw enough current from the battery to heat the wire and cause a fire. Never attach loads directly to the battery; always connect them through a fuse or circuit breaker.

- *Electrical Loads* – The electrical loads include everything that draws power from the battery. The loads include: navigation equipment such as radar, AIS, GPS, chart plotter, wind instruments, boat speed instruments, also navigation lights, cabin lights, refrigeration and very important for a solo sailor the autopilot.



Water Generator

- *Alternate Charging System* – This general category can cover a number of other possible charging sources such as an independent engine driven generator, a wind generator, solar cells, or a water generator – that is a propeller on a tightly wound Dacron cable that drives a generator attached to the stern of the boat. On larger boats a generator separate from the propulsion engine may serve as the normal source of power for charging the batteries.

- *Converter* – A converter will convert the 12 volt DC electricity from the battery to 120 volt AC and the associated distribution system will distributer this power to items such as microwave, refrigeration, or other more standard household items. This can be very convenient however may of these items can quickly drain your battery.

Now let's take a look at how these components are used together to provide a reliable source of electrical power for the various components on the boat.

Monitoring Your System

Having a good monitoring system is important. It should allow one to monitor electrical use, that is, current flow out of the battery and current flow into the battery during charging. It should also monitor battery voltage. Many boats may have old analog meters that are not particularly accurate. A battery monitor or digital volt and current meters are essential if you really want to know what is going on. You want to be able to measure battery voltage to a tenth of a volt and battery current to a tenth of an amp.

Battery monitors can also monitor battery capacity but this can be tricky. It would be nice if a battery that just stored amp-hours like a bucket holding water. Unfortunately the battery uses a chemical process to store the electrical energy and an amp-hour in does not necessarily mean you can get an amp-hour out. Battery monitors us an equation to figure out how much capacity has gone in and out. If you do several partial charges the percent charged and associated warning lights may not accurately indicate state of charge. Battery voltage is the ultimate indicator of when to charge. More on this below.

A digital volt meter can be purchased fairly economically from a variety of locations such as auto parts store, building supply, or electronics store. These will measure volts and amps to at least .1 volt or amp. If you plan to measure current be sure that it can measure at least 10 amps. This won't let you measure charging current but it will let you monitor current to most other onboard loads.

Batteries

A submarine electrician once told me that a battery is much like a wife (or significant other), if you take care of her she will reward you but if you neglect her watch out you will be in big trouble! Sailors tend to neglect batteries until they really give a problem.

Unfortunately batteries are not as simple as they might look or as we might like them to be. There are many types and sizes of battery. It is strongly recommended that you obtain the manufacturers information, specifications, operating instructions, and maintenance instructions for your specific batteries.

This may be a pain but dig out your batteries and determine their manufacturer, type, and model number. This is important stuff! Then go to the internet and download the specification sheet and any manufacturer application notes or operating instructions. Be sure to note battery type (liquid, gel, AGM), as well as voltage for acceptance, and float charge. Also note the operating temperature requirements. It is important that your battery chargers are set for the specific type of battery you have or you may over or under charge your batteries and damage them.

Battery Types and Specifications –

- Battery Types: There are basically three battery types though many variations on these. The first is the traditional liquid battery. This has liquid acid in each cell and requires considerably more maintenance. The second type is AGM (Absorbed Glass Mat) or maintenance free battery. The third is a gel battery. This article will concentrate on the second type but if you have the first or third type be sure to research the required maintenance thoroughly. If you currently have liquid batteries consider replacing them with AGM batteries but be sure to properly setup your battery chargers, alternator regulators, and battery monitors as the AGM batteries operate at different voltages.

- Battery Specifications: Besides battery type batteries discussed above they are categorized as follows:
    - Deep Cycle or Starting – Deep cycle batteries are intended to support long steady discharge to support loads such as those on a sailboat under sail while a starting battery is primarily intended to facilitate engine starting as in a car. If one has two batteries on a boat both should be deep cycle as the starting battery can also be used to supply ship loads as a backup. The internal construction of these two batteries is different. If a starting battery is deep cycled its life will be greatly shortened.
    - Battery Case Size: Battery case sizes specify the dimensions of the battery and the space it will fit into.
    - Battery Capacity: Battery capacity is specified in amp-hours. This is the number of amp-hours that a battery can supply typically over a 20 hour period before the output voltage drops to 10.5 volts. So for example a 105 amp-hour battery could supply 5.25 amps for 20 hours at the end of which the output would be 10.5 volts. Typically a battery is said to be worn out when capacity drops to 80% , that is the at a discharge rate of 5.25 the battery drops to 10.5 volts after 80% of 20 hours or 16 hours. One may do a battery test to determine this but when you notice that you need to charge more frequently or that a battery does not seem to accept a charge as readily it may be time to get a new battery. Typically a battery will last about 3 years. Appendix C describes discusses battery testing in more detail including how to do a battery

capacity test. If a battery is discharged at a rate greater than the 20 hour rate the capacity will be less and if discharged at a slower rate the capacity will be greater than specified for the 20 hour rate.

Battery Voltage and Charging

Battery voltage is a complicated subject. Battery voltages depend on battery type, temperature, state of the charge, weather the battery is being charged or discharged. Be sure to get the manufacturers specifications and charging instructions as outlined above.

For a typical three stage voltage regulator the process will follow the following three phases. Typically a battery will charge at the capacity of the alternator or battery charger. This phase is called the bulk charging phase. When about 14.7 volts is reached for an AGM battery the voltage will be held at this voltage and the charging current will be observed to decrease. When the current decreases to a few percent of the charger capacity the battery will be considered charged and the voltage will drop to a float voltage of about 13.6 volts for an AGM battery. These voltages assume that no current is being drawn from the system to supply ships loads for example. This also assumes a temperature of 70 F. At lower temperatures a higher voltage must be used and at higher temperatures a lower voltage must be used. Many regulators will compensate for temperature variations.

Battery capacity as specified is more complicated than the specification might imply. If a battery is fully discharged it will significantly shorten the life of the battery. Generally to maintain battery capacity it should not be cycled below about 50%. I will admit to going a bit lower at times. The greater discharge levels result in lower battery voltage. At these lower voltages some onboard devices such as VHF radio, GPS, and auto pilots will not operate properly. One should determine this for each boat. I generally charge my battery when it is at about 12 volts. Below this I experience autopilot problems first. On the other hand it may be inconvenient to charge long enough to recharge a battery to 100%. About 85% is the practical limit. Initially a battery will be charged at the capacity of the alternator on the engine. At a certain voltage set by the alternator regulator the voltage will no longer increase to force amps into the battery and will hold a constant voltage. At this point the battery charging current will slowly decrease and so fewer and fewer amp-hours will be put back into the battery. In short you get a lot more current back into the battery in the hour of charging before current starts decreasing than in the hour after. What this essentially means is that there is a 50% capacity limit on the bottom and an 85% capacity limit on the top giving an available capacity of about 35%. As I mentioned I push the lower limit and that reduces battery life.

Operating Your Electrical System

One needs to develop an operating plan so that the battery is charged consistently to maintain battery life and to be sure all your electrical gadgets work. Briefly the following is my operating plan:

I log battery voltage (my most important parameter), and amp-hours discharged every three hours when other navigation and weather data is logged. This forces me to take a look at how my battery is doing before my autopilot tells me to do so by its erratic behavior. Typically I will start a battery charge when voltage drops below 12 volts where my autopilot starts to malfunction. I have a 105 amp-hour battery so for a sailing load of about 3.5 amps on my battery it is necessary to charge about every 10.5 hours in theory. I actually discharge below the recommended limit of 50% closer to about 30%. I prefer to charge at night so I may change for a short time during the day and then charge for a longer time when it is cooler typically at 1 or 2 AM in the morning. This also helps keep the boat a bit warmer. Full charge on the battery will be achieved when the engine can be run for an extended time when motoring home after a race or when shore power is available to run the battery charger overnight.

Generally one should monitor electrical system voltage and battery capacity if available and set criteria for starting a charge. This may be based on experience with equipment becoming inoperable at a particular voltage. Then add a few tenths of a volt for margin and use that as the charging start point.

I typically charge at an engine steed of 1800 rpm as compared with a full speed of 2800 rpm. At this speed my engine uses about .2 gal of diesel per hour. Above this speed there is no increase in the current flowing to a partially discharged battery. This was determined by increasing engine speed until there was no increase in charging current on a partially discharged battery. When the alternator is charging at close to full load it gets very hot so I also run the engine room blower. I once experienced an alternator failure which was probably caused by overheating.

Make sure your alternator belt is tight. Check for belt tension and wear periodically. If it is slipping one may notice lower charging rates during initial battery charge. I carry a couple of spare belts in case one fails.

Another consideration in determining when to charge is boat heel. Some engines will not operate properly when heeled over. My previous engine had a horizontal cylinder and when heeled over about 25 degrees to port would pick up crank case oil and emptied the crank case fairly quickly. (Jerry Cartwright was disqualified as the result of this problem in the 1980 OSTAR.)

System Design Considerations (or getting battery voltage to boat equipment)

Even though you read 12.5 volts at your battery it may not be getting to your electrical equipment. This is due to the fact that the wires connecting the equipment to the battery have a resistance that reduced the voltage delivered to the equipment. Also your battery terminals may be dirty or loose. If you see green residue on your battery terminals they need cleaning. Battery voltage will decrease in the wiring to the distribution panel and also in the wiring from the distribution panel to the various loads such as VHF radio, auto pilot, etc.

One can determine the voltage decrease with a digital volt meter by measuring the voltage between the battery terminals, between the positive and negative feeds at the distribution panel and between the positive and negative feeds at various pieces of equipment. When the measurements are made be sure that the normal electrical loads are on as the higher the current the greater the voltage drop. One can also calculate the voltage drop using the table in Appendix B. If a piece of equipment is 10 feet from the battery the current must pass through 20 feet of wire going from and coming back to the battery so be sure to use double the distance. Here are some examples using data from the Appendix B tables:

A distribution Panel is Located 15 feet from the battery, normal load is 10 amps:

For AWG #20 wire: 5 amps x 2 x 15 ft. x .01 volt/ft. = 1.5 volts

If the wire is increased to an AWG #8:

For AWG #8 wire: 5 amps x 2 x 15 ft. x .000628 volt/ft. = .094 volts

If the load on the distribution panel is increased to 10 amps the voltage drop in both cases would double.

Another example involves the VHF radio that is 20 feet from the distribution panel and draws .2 amps in standby and 4.6 amps in the high power transmit mode.

If the radio is supplied through 20 feet of AWG #20 wire:

In Standby: For AWG #20 wire: .2 amps x 2 x 20 ft. x .01 volt/ft. = .08 volts

In Transmit: For AWG #20 wire: 4.6 amps x 2 x 20 ft. x .01 volt/ft. = 1.84 volts

Even if the wire to the VHF radio was only 10 feet long the voltage drop would be almost a volt less from the battery in the transmit mode. So the radio might appear to work fine in the standby or receive mode but transmit a garbled message in the transmit mode due to the lost voltage.

If the wire to the VHF radio is increased in size to AWG # 12 here are the results:

In Standby: For AWG #12 wire: .2 amps x 2 x 20 ft. x .001588 volt/ft. = .0127 volts

In Transmit: For AWG #12 wire: 4.6 amps x 2 x 20 ft. x .001588 volt/ft. = .292 volts

With the larger cable there is much less voltage drop, down to just .3 volt loss when transmitting.

Voltage drop to equipment will include both the voltage drop from battery to the distribution panel and from the distribution panel to the equipment. Both larger wire and shorter wiring runs will reduce the voltage loss. Wiring that may be acceptable for an LED light that draws .2 amps or to an instrument that draws .5 amps may not be satisfactory for cabling to items that draw more current such as radar, VHF radio, autopilot, engine blower, or bilge pump. Small wire to these items may force one to charge the battery more frequently starting at higher voltage to compensate for the voltage loss. When checking the VHF voltage drop be sure to switch to a clear working channel and key the radio in high power. Similarly it may be difficult to determine the current draw for an autopilot which is not working as hard as it might be during rough weather. The specifications for the autopilot may provide some guidance on how much current it will draw under load. It is not fun to find this out in 6 foot waves and a 25 knot blow.

Boat instruments may not accurately measure battery voltage. If the installed volt meter is connected to the distribution panel it will not take into account the voltage drop between the battery and the distribution panel. Similarly voltage reading on one of the navigation instruments in an integrated instrument system will show voltage to those instruments but not include the loss in lines to the instrument panel and to the instrument itself.

One more voltage drop issue may be worth mentioning. If one charges two batteries through a pair of diodes this will isolate the batteries but the diodes will also reduce charging voltage by about a half an amp. This will make it difficult to fully charge the battery if the alternator regulator is sensing voltage upstream of the diode. It will be necessary to wire the regulator to sense voltage downstream of one battery preferably the normal house battery.

Load Management

The GLSS king of load management is Blair Arden who sails the Solo Mac in his Columbia 26 on one battery without recharging! He does very little hand steering. If he sounds like he is 30 miles away on his VHF radio he may be closer than you think because he is transmitting on 1 watt and not 20 watts.

I certainly do not like to run the engine when sailing, I just do not like the noise. The table at right shows some of the electrical loads on GL^3. Most of my lights are LEDs which has greatly reduced electrical load. My total load is typically between about 3.0 and 3.5 amps.

Item	Load (amp)
Battery Monitor	0.1
VHF Radio (standby)	0.2
VHF Radio (transmit)	4.6
Mast Head Tricolor (LED)	0.2
Anchor Light (LED)	0.2
Chart Light (LED)	0.1
Overhead Cabin Light (LED)	0.4
Instrument & Chart Plotter	1.3
AIS	0.6
Sirius Satelite	0.3
Autopilot	0.4 to 0.8
Bilge Pump	6.5
Engine Blower	2.2

Here are some suggestions on things that can be done to reduce the electrical load on a boat:

- Make a table of the electrical loads similar to the chart at right. This may help you develop a load reduction strategy. (This can be done with an installed digital amp meter or battery monitor. Analog amp meters are not accurate enough to do this. A digital volt meter, using the current or amps scale can also be used but be sure you do not try to measure currents above the meter range.)
- Turn off stuff you are not using.
- Change out incandescent lights with LEDs. This can reduce the electrical load by about a factor of 10. For example my incandescent tricolor light drew about 2.1 amps and my current LED tri color light uses about .2 amp.
- Turn the light level on your chart plotter down – on my chart plotter this can reduce the load by about .5 amps
- Turn down light level on all instruments and turn it off on instruments you do not need or monitor regularly.

- When you purchase instruments look at the electrical use. For example my VHF draws about .2 amp in standby but others on the market draw 1.0 amps.
- Larger chart plotters draw more current than small ones. The use of LED chart plotter displays has greatly reduced the electrical load demanded by a chart plotter but may place a larger load on your wallet.
- The auto pilot may be a major load. It will use a smaller amount in standby when not pushing the tiller or wheel and considerably more when actively steering. Be sure your boat is well balanced so your autopilot does not have to work so hard. Also proper autopilot tuning can help. Most auto pilots have a course keeping accuracy setting. An autopilot set to keep a very accurate course will use more power than one that is less fussy and allows more variation off course. If you are fanatical about this you can always hand steer.
- Refrigeration can be a big energy use. Be sure your refrigerator is well insulated. Minimize the times you open and close the door. Set the temperature as high as you can. Keep the refrigerator as full as possible to minimize the exchange of warm and cold air when the door is opened.
- Only turn on instruments like Radar, AIS, chart plotter and Sirius Satellite when needed.
- Be sure to turn off running lights, instrument lights, and cabin lights as soon as there is enough light to be seen.

Electrical Emergency Plan

Typically one will run the engine and alternator to charge the boat batteries several times during a solo challenge of several days. But suppose one attempts to start the engine and it refuses as engines are known to do occasionally for a variety of reasons such as dirty fuel, starter failure, or some other mysterious cause only known to professional engine mechanics. Or perhaps the engine starts but the alternator refused to charge the battery. If this should happen you need a plan. With a good plan you will finish the solo challenge and may even win the race.

So here are the initial conditions to consider in developing a plan:

- The house battery has been drained to about 40 or 50% capacity but can still operate your house loads for now.
- The engine starting battery has been depleted to some unknown extent trying to start the engine. It can still turn the engine but not very fast.
- The end of the solo challenge is a couple days away.

The question now is how to proceed. If a small gas generator and battery charger are available or a water generator or solar panels are available these may provide an easy alternate power source. The GL[3] water generator provides about 5 amps when the boat is moving at 5 kts but less at lower speeds. On average that is not enough to meet all the normal electrical loads so it is necessary to shut down some loads such as the chart plotter, AIS and satellite weather. These may be turned on for short periods. There is still adequate power for basic instruments, GPS, chart table light, navigation lights, and most important the autopilot.

The most important services typically provided by the battery are:

- Autopilot power
- GPS
- Night time running lights
- Night time chart table and cabin lighting
- VHF

One can get along without most of the other items such as AIS, Weather Satellite, chart plotter, radar, instruments (depth, speed, wind, etc.), refrigeration, and any other loads that are not absolutely necessary. As a first step in plan implementation immediately shut these off.

The autopilot power is probably the most important of these as its power source can't be replaced. By hand steering and using the remaining energy in both the house and starting battery a number of hours of auto pilot steering may be available. To get the most out of the auto pilots the other loads must be shut down and the required services provided without the use of the house or starting batteries. Here are some suggestions on how this might be accomplished:

- GPS – Use a hand help GPS to get your periodic fixes at intervals of every 3 hours or more often near land or the finish. Turn the GPS off between fixes. If a cell phone is used turn it off between fixes as it may not be possible to recharge the cell phone from the ships batteries and cell phone GPSs tend to use a lot of cell phone power.
- Night time running lights – Use your emergency lights. These are required to be independent of the ships normal electrical system and usually use flashlight batteries for power.
- Night time chart and cabin lighting – Use flashlights instead of the installed lights. If a light is needed to read a compass while hand steering try taping a small flashlight to the steering compass.
- VHF – A hand held or backup VHF is required for a solo challenge. Use the hand held VHF for the periodic check ins. If this does not work use the installed VHF just for check in and keep it off the rest of the time. If possible only use the VHF on low power.

If either battery has the energy to steer the boat this will give an opportunity to rest and get something to eat. If the batteries will no longer support autopilot operation consider heaving to for a period to get some rest and something to eat.

One may be tempted to parallel two batteries that are in a partially discharged state but this is generally a bad idea as the battery with the greater charge will use some of its energy to recharge the other. This is an inefficient use of the energy. It is better to use the available energy in one battery then switch to the other.

If you only have one battery and are using it for house and engine starting be careful not to discharge it too far. If one shuts down most of the loads, particularly large loads like the autopilot, radar, and refrigeration the engine may start. One option is to carry a fairly cheap (less than $100) emergency starting battery that can be obtained from an auto supply store.

Your loads, electrical generating devices and electrical needs may be different but in any case develop an emergency plan for your boat. Should your engine or alternator quit on you, with a good plan it will just be a small bit more of a challenge.

Final Comments

After one has exhausted all your ideas for dealing with an electrical issue give your fellow sailors a call, by phone if ashore or VHF if afloat. We are always glad to help and just occasionally we may be able to help you solve your problem.

This paper is longer then I might have liked but there is far more information available from battery, battery charger, and battery monitor manufacturer on the internet. Taking care of your batteries can prevent a more challenging and frustrating sail.

Thanks to Rick McLaren for his review and coments.

Appendix A – Basic Electrical Theory

This appendix is intended to provide a brief summary of electrical theory. Refer to this material if necessary to understand the discussion above.

Units of Electrical Measure:

- Potential – measured in volts – this is a measure of how hard the electricity is pushing through a wire or other electrical component
- Current – measured in amperes or amps for short – this is a measure of how much electricity is flowing through a wire or electrical component
- Resistance – measured in ohms – this a measure of the a wire or electrical component slows down or blocks the flow of electricity

The above measures are related as follows:

- ➢ *Current = Potential / Resistance* or *amps = volts / ohms*
- ➢ Written another way *Potential = Current x Resistance* or *volts = amps x ohms*

- Power – measured in watts is a measure of the ability to do work or use energy

Power is calculated as follows:

- ➢ *Power = Potential x Current* or *Watts = Volts x Amps*

- Energy – measured in watt hours is a measure of the amount of work that has been done or is available. It is essentially a measure of how long you have been producing or using power at a particular level. Battery capacity is measured in a "short hand" version where voltage is assumed and so capacity or energy usage is measured in amp-hours. Typically capacity is based on the current that can be drawn from a fully charged battery until voltage drops to 10.5 volts over 20 hours. For example a new 100 amp-hour should supply 5 amps over the 20 hours at before the voltage drops to 10.5 volts.

Energy is calculated at follows

- ➢ *Energy = Power x Time* or Watt-Hours = Watts x Hours

Energy used or available in a battery is measured in amp-hours. In this case it is understood that the energy is supplied at a more or less constant voltage, that of the battery or about 12 volts.

Appendix B – Wire Voltage Drop Table

Wire Size AWG gauge	Conductor diameter in.	Conductor diameter mm	Ohms per 1000 ft.	Ohms per km	Voltage Drop per foot per amp	Voltage Drop per 10 foot per amp	Voltage Drop per 10 foot at 5 amp
OOOO	0.460	11.684	0.049	0.161	0.000049	0.000490	0.002450
OOO	0.410	10.404	0.062	0.203	0.000062	0.000618	0.003090
OO	0.365	9.266	0.078	0.256	0.000078	0.000779	0.003895
0	0.325	8.252	0.098	0.322	0.000098	0.000983	0.004915
1	0.289	7.348	0.124	0.406	0.000124	0.001239	0.006195
2	0.258	6.543	0.156	0.513	0.000156	0.001563	0.007815
3	0.229	5.827	0.197	0.646	0.000197	0.001970	0.009850
4	0.204	5.189	0.249	0.815	0.000249	0.002485	0.012425
5	0.182	4.620	0.313	1.028	0.000313	0.003133	0.015665
6	0.162	4.115	0.395	1.296	0.000395	0.003951	0.019755
7	0.144	3.665	0.498	1.634	0.000498	0.004982	0.024910
8	0.129	3.264	0.628	2.060	0.000628	0.006282	0.031410
9	0.114	2.906	0.792	2.598	0.000792	0.007921	0.039605
10	0.102	2.588	0.999	3.276	0.000999	0.009989	0.049945
11	0.091	2.304	1.260	4.133	0.001260	0.012600	0.063000
12	0.081	2.052	1.588	5.209	0.001588	0.015880	0.079400
13	0.072	1.829	2.003	6.570	0.002003	0.020030	0.100150
14	0.064	1.628	2.525	8.282	0.002525	0.025250	0.126250
15	0.057	1.450	3.184	10.444	0.003184	0.031840	0.159200
16	0.051	1.290	4.016	13.172	0.004016	0.040160	0.200800
17	0.045	1.151	5.064	16.610	0.005064	0.050640	0.253200
18	0.040	1.024	6.385	20.943	0.006385	0.063850	0.319250
19	0.036	0.912	8.051	26.407	0.008051	0.080510	0.402550
20	0.032	0.813	10.150	33.292	0.010150	0.101500	0.507500
21	0.029	0.724	12.800	41.984	0.012800	0.128000	0.640000
22	0.025	0.645	16.140	52.939	0.016140	0.161400	0.807000

Voltage drop in a wire is calculated using data for the wire size from the table above as follows:

Voltage Drop = (Voltage drop per ft. per amp.) x feet x amps

Note: Feet should include wire length 2 x distance to load i.e. going and coming from load.

Note: Wire diameter is for uninsulated single strand; actual insulated, stranded wire will be larger diameter depending on strand configuration and insulation type.

Appendix C – Battery Test Procedure

As mentioned above the best indication that you need to replace your battery is when the engine is not turned as energetically at your first starting attempt by the battery. Obviously after multiple starting attempts or cold weather the engine will turn more slowly. Similarly if you find that your battery will not accept the initial charging rate after a partial discharge or you find that under normal use conditions you are charging more frequently it may be time to replace your battery.

The battery tester found in a marina workshop or auto repair shop will tell you if a battery can provide enough current to start an engine. This may also identify the presence of a bad cell. It has the advantage of being simple and quick. Boat yards and auto repair shops will typically have this type of tester. Consider testing your batteries this way in the spring when you launch your boat. For deep cycle batteries used to supply boat loads over an extended period of time one may also want to determine battery capacity, that is, how many amp-hours a battery can supply. Here is the basic procedure:

1. Check the battery manufacturer and model number. Obtain a copy of the manufacturer data from the internet. This should include the battery capacity in amp-hours, the rating period and end voltage. For example it might have a 20 hour rating of 105 amp-hours before dropping to 10.5 volts.

2. Be sure the battery is fully charged and shut off all loads on the battery.

3. A method of measuring battery voltage and current are needed. These may be installed instruments or one may use meters to measure voltage and current. Be sure they are measuring voltage right at the battery. If the volt meter is measuring voltage at a distribution panel use a portable volt meter to periodically measure voltage at the battery terminals.

4. Determine the test current by dividing the capacity by the rated capacity or amp-hours: for example 105 amp-hrs. / 20 hrs. = 5.25 amps

5. Turn on enough equipment to load the battery to the test current. This may be accomplished by turning on navigation equipment, interior lights, navigation lights, etc. This should allow one to get fairly close to the desired test current. Don't turn equipment on and off during the test cycle and do not turn on equipment that will cycle such as air conditioners, autopilots, or refrigeration, cell phone chargers, etc. If normal loads don't provide enough load an alternator and selected loads like light bulbs may be used.

6. From the start record battery voltage and current every hour initially. As the voltage deceases toward 10.5 volts take these reading more often so the exact time voltage passes through 10.5 volts can be determined. If the voltage is not being monitored constantly a graph can be used to determine the end time for the test.

7. Be sure to recharge the battery immediately after the test.

8. Calculate battery capacity by dividing the time to 10.5 volts into 20 or other test period from the battery specifications. For example: If battery voltage dropped to 10.5 volts after 18 ¼ hours Then 18.25 / 20 = 92.5 % capacity remaining in the battery.

Battery tests can be useful in determining end of life which is usually considered to be about 80%, but they are hard on the battery and should only be done infrequently. Be sure to completely recharge the battery after completing the test.