The Electrical System

Most equipment related to the safe, comfortable use of your vessel has at least some vital ingredients that are electrical in nature. Combine this factor with the harsh environment found on the water, and you'll understand why 75 percent of all yachting-related frustration has to do with wiring. On the other hand, if good equipment is properly installed, and if wiring is well done and protected as much as possible from the marine environment, then electricity can be a good shipmate.

A good electrical system needs a strong foundation. This is provided by the wiring harness. The type of wire utilized varies widely, as do types of end fittings, insulation, and protection. Quality is a function of time — all electrical systems get cranky with age. But better systems will operate far longer before they start to give problems.

WIRE

The best grade of wire is drawn through a solder bath, leaving it in a "tinned" condition. Tinned wire is more resistant to corrosion than plain copper and is easier to solder initially. Once untinned copper has been in salt air for a year or two, the entire length of copper inside its insulation will take on a greenish tinge. Not only does this weaken the wire and increase resistance to electricity, but over time it makes it almost impossible to solder should connections be required.

CONDUCTOR GAGE	MINIMUM ACCEPTABLE CM AREA	MINIMUM NUMBER OF STRANDS TYPE 1*	TYPE 2*	TYPE 3*
18	1537	7	16	–
16	2336	7	19	26
14	3702	7	19	41
12	5833	7	19	65
10	9343	7	19	105
8	14810	7	19	168
6	25910	–	37	266
4	37360	–	49	420
2	62450	–	127	665
1	77790	–	127	836
0	98980	–	127	1064
00	125100	–	127	1323
000	158600	–	259	1666
0000	205500	–	418	2107

Here's a chart showing wire size (left column); cross-sectional area, which is helpful for calculating resistance; wire type; and the number of strands typically found in that construction.

Wire construction varies much like rigging wire. The more strands in the wire, the better the flexibility and the greater its resistance to vibration. Household wire is usually made of a single strand, while aircraft wire has dozens of extremely fine strands. Good-quality marine wire falls somewhere between that made for the automotive market and what is supplied to the aircraft industry. The number of strands varies with wire size.

Wire is covered with a temperature-related PVC plastic sheath. The higher this rating, the lower the fire danger. Marine wire should be resistant to at least 105 degrees centigrade. (Household wire insulating is typically rated at 70 degrees centigrade.)

Coaxial Cable

Coaxial cable is used to transmit radio frequency (RF) energy from radio to antenna and to send incoming signals back to radios and navigational receivers. Since the wire is usually long, careful consideration should be given to coax size in order to prevent signal loss.

Using small coax to a VHF antenna at the masthead can result in a signal loss of 40 percent or more. However, the large-diameter coax adds quite a bit of weight aloft. On balance, over the years we've opted for the lightweight cables.

Many quality levels of coax are on the market. All work well for the first few weeks, but most coax cable starts to deteriorate rapidly thereafter. Use the best material you can get your hands on.

Wire Protection

Wire must be protected from chafe and kept out of low spots in the bilges where it might soak up water. There are three approaches to this. The first is to bundle the wires together using plastic wire ties, then wrap the entire bundle in a protective semi-rigid PVC plastic. Always have on hand a large inventory of wire ties in a variety of sizes for rewiring and maintenance. These are inexpensive and easy to use. The "loom" is then fastened down every few feet.

With simpler systems it's possible to use double-insulated twin flex wire. Here, two individually insulated wires are held together inside a plastic cover. The outer cover provides chafe protection. However, the extra weight, bulk, and cost of twin flex makes it impractical for a more complex system.

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The third way to go is to put wiring into conduit, with removable covers. Many sizes, weights, and junctions are made for industrial applications and are ideal for use aboard. Conduit is quick to lay out and has the advantage of providing a channel for additional wiring that may be laid in the future. Drill weep holes every foot or so in case the conduit gets wet from condensation or some other problem.

Any time wiring is run in hidden areas, such as behind a headliner, it should be placed inside of conduit. This way you're sure it's protected. If wiring needs to be replaced someday, the old wire can be removed and new wire introduced in the same conduit.

Layout

A fastidious wire layout reflects on the electrician who did the work. Neat-looking layouts typically indicate a better-quality job. The opposite is also true.

If you plan to do some wiring of your own, take the time before starting to figure out how and where to run your cables, and how they will be brought to the panel for final connection. If you are doing a big job, odds are you will use lots of wire ties. Using them temporarily to assist with routing makes it easier to do a neat job.

Providing for the Future

Whenever a new boat is wired or replacement work is done on an older boat, it's important to consider future needs. Pull through a few extra wires, because something always pops up later. On our boats we allow an extra six pairs of wire to the forward section, three pairs to each mast, ten pairs to the engine room, and two or three pairs to each interior section. This might add $100 in wiring costs and 50 pounds in weight, but it saves thousands of dollars later in life.

Amp-Carrying Capacity

The amp-carrying capacity of a given wire is a function of wire size, insulation, and the ambient heat it is likely to encounter. Ambient heat is an important variable, both in terms of cruising vicinity and where the wire is located. When wires are bundled together, it is possible for the resistance-generated heat from one wire to affect the capacity of another, so bundled wires are typically de-rated as well. Fortunately, in the real world this is seldom a problem, as wires are almost always sized for voltage drop. This forces you to go to a much larger wire with higher amp-carrying capacity so that de-rating due to temperature or bundling does not become a concern.

Segregation

Whenever possible, DC and AC wiring should be separated — even though this is not always practical. Likewise, noise-sensitive antennae cables for equipment like loran, SSB, and VHF should be separated from the rest of the wiring harness, in order to avoid electrical interference.

Temperature Rating of Conductor Insulation

CONDUCTOR SIZE	60° C (140° F)		75° C (167° F)		80° C (176° F)		90° C (194° F)		105° C (221° F)		125° C (257° F)		200° C (392° F)
ENGLISH (METRIC) SEE TABLE IV	OUTSIDE ENGINE SPACES	INSIDE ENGINE SPACES	OUTSIDE ENGINE SPACES	INSIDE ENGINE SPACES	OUTSIDE ENGINE SPACES	INSIDE ENGINE SPACES	OUTSIDE ENGINE SPACES	INSIDE ENGINE SPACES	OUTSIDE ENGINE SPACES	INSIDE ENGINE SPACES	OUTSIDE ENGINE SPACES	INSIDE ENGINE SPACES	OUTSIDE OR INSIDE ENGINE SPACES
18 (0.8)	10	5.8	10	7.5	15	11.7	20	16.4	20	17.0	25	22.3	25
16 (1)	15	8.7	15	11.3	20	15.6	25	20.5	25	21.3	30	26.7	35
14 (2)	20	11.6	20	15.0	25	19.5	30	24.6	35	29.8	40	35.6	45
12 (3)	25	14.5	25	18.8	35	27.3	40	32.8	45	38.3	50	44.5	55
10 (5)	40	23.2	40	30.0	50	39.0	55	45.1	60	51.0	70	62.3	70
8 (8)	55	31.9	65	48.8	70	54.6	70	57.4	80	68.0	90	80.1	100
6 (13)	80	46.4	95	71.3	100	78.0	100	82.0	120	102.0	125	111.3	135
4 (19)	105	60.9	125	93.8	130	101.4	135	110.7	160	136.0	170	151.3	180
2 (32)	140	81.2	170	127.5	175	136.5	180	147.6	210	178.5	225	200.3	240
1 (40)	165	95.7	195	146.3	210	163.8	210	172.2	245	208.3	265	235.9	280
0 (50)	195	113.1	230	172.5	245	191.1	245	200.9	285	242.3	305	271.5	325
00 (62)	225	130.5	265	198.8	285	222.3	285	233.7	330	280.5	355	316.0	370
000 (81)	260	150.8	310	232.5	330	257.4	330	270.6	385	327.3	410	364.9	430
0000 (103)	300	174.0	360	270.0	385	300.3	385	315.7	445	378.3	475	422.8	510

There is a maximum amperage rating for each type of wire insulation.This varies with ambient temperature. In the chart above, if you look at #16 wire with 105-C insulation, you will find that in the interior it is rated for a maximum of 25 amps. In the engine room this is de-rated (due to higher ambient heat) to 21.3 amps.

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Voltage Drop

The diameter of the wire is related to the electrical load it has to carry, and how much loss due to friction you’re willing to tolerate. Friction creates heat — as the wire gets warmer, there’s even more friction, creating more heat.

The net result of the friction is voltage drop. Voltage drop in a lightbulb just means a somewhat dimmer light. But with electronics, particularly radios, voltage drop has a substantial impact on performance range. Voltage drop in motors can be a real problem with maintenance. It causes heat and greater arcing in brushes. The more heavily loaded the motor is, the worse the problem.

Ideally, all wires aboard would be sized for minimum voltage drop. However, that is not always practical, nor is it always necessary. Since it is not unusual for a total wiring loom to account for one or two percent of a boat’s displacement, and much of this weight is up high, keep wire weight to the minimum necessary to accomplish the job at hand.

Wiring from alternators to batteries, between batteries, and from batteries to control panel should be sized for minimum drop. Otherwise you lose charging efficiency and battery power, and that doesn’t make sense. Starter cables, anchor windlass, electric winches, autopilot, and invertor should also have maximum-sized cables. In the final analysis the output power of the electric motors involved is a function of their operating voltage. No sense giving away line pull because a wire size is too small. The same holds true for radio gear.

But from here on out, some weight compromise is in order. You can size lighting circuits based on the *average* number of lights in use, rather than assuming all lights will be turned on at the same time. Gear that runs on an intermittent basis, such as the water pump, can tolerate smaller wire than continuously running gear like a fridge compressor.

How do you know what size to use? Look at the sample tables presented here, or use those found in electrical handbooks for more detailed analysis.

In general, work toward a 3-percent voltage drop where you’re concerned, and 10 percent where it’s not as critical.

Length of Conductor from Source of Current to Device and Back to Source — Feet

12 Volts — 10% Drop Wire Sizes (gage) — Based on Minimum CM Area

TOTAL CURRENT ON CIRCUIT IN AMPS.	10	15	20	25	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170
5	18	18	18	18	18	16	16	14	14	14	12	12	12	12	12	10	10	10	10
10	18	18	16	16	14	14	12	12	10	10	10	10	8	8	8	8	8	8	6
15	18	16	14	14	12	12	10	10	8	8	8	8	8	6	6	6	6	6	6
20	16	14	14	12	12	10	10	8	8	8	6	6	6	6	6	6	4	4	4
25	16	14	12	12	10	10	8	8	6	6	6	6	6	4	4	4	4	4	2
30	14	12	12	10	10	8	8	6	6	6	6	4	4	4	4	2	2	2	2
40	14	12	10	10	8	8	6	6	6	4	4	4	2	2	2	2	2	2	2
50	12	10	10	8	8	6	6	4	4	4	2	2	2	2	2	1	1	1	1
60	12	10	8	8	6	6	4	4	2	2	2	2	2	1	1	1	0	0	0
70	10	8	8	6	6	6	4	2	2	2	2	1	1	1	0	0	0	2/0	2/0
80	10	8	8	6	6	4	4	2	2	2	1	1	0	0	0	2/0	2/0	2/0	2/0
90	10	8	6	6	6	4	2	2	2	1	1	0	0	0	2/0	2/0	2/0	3/0	3/0
100	10	8	6	6	4	4	2	2	1	1	0	0	0	2/0	2/0	2/0	3/0	3/0	3/0

24 Volts — 10% Drop Wire Sizes (gage) — Based on Minimum CM Area

TOTAL CURRENT ON CIRCUIT IN AMPS.	10	15	20	25	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170
5	18	18	18	18	18	18	18	18	16	16	16	16	14	14	14	14	14	14	12
10	18	18	18	18	18	16	16	14	14	14	12	12	12	12	12	10	10	10	10
15	18	18	18	16	16	14	14	12	12	12	10	10	10	10	10	8	8	8	8
20	18	18	16	16	14	14	12	12	10	10	10	10	8	8	8	8	8	8	6
25	18	16	16	14	14	12	12	10	10	10	8	8	8	8	8	6	6	6	6
30	18	16	14	14	12	12	10	10	8	8	8	8	8	6	6	6	6	6	6
40	16	14	14	12	12	10	10	8	8	8	6	6	6	6	6	6	4	4	4
50	16	14	12	12	10	10	8	8	6	6	6	6	6	4	4	4	4	4	2
60	14	12	12	10	10	8	8	6	6	6	6	4	4	4	4	2	2	2	2
70	14	12	10	10	8	8	6	6	6	6	4	4	4	2	2	2	2	2	2
80	14	12	10	10	8	8	6	6	6	4	4	4	2	2	2	2	2	2	2
90	12	10	10	8	8	6	6	6	4	4	4	2	2	2	2	2	2	1	1
100	12	10	10	8	8	6	6	4	4	4	2	2	2	2	2	1	1	1	1

Here’s a chart showing correct wire size for 10-percent voltage drop. Pick the total current in amps from the left column, then measure the distance out to the device being wired and back to the power source —e.g., something 10 feet (3m) away has 20 feet (6m) of wire. Next, find the appropriate wire size in the matrix below.The chart on the next page is for a 3-percent voltage drop.

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Length of Conductor from Source of Current to Device and Back to Source — Feet

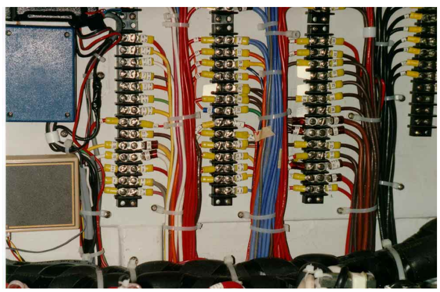
12 Volts — 3% Drop Wire Sizes (gage) — Based on Minimum CM Area

TOTAL CURRENT ON CIRCUIT IN AMPS.	10	15	20	25	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170
5	18	16	14	12	12	10	10	10	8	8	8	6	6	6	6	6	6	6	6
10	14	12	10	10	10	8	6	6	6	6	4	4	4	4	2	2	2	2	2
15	12	10	10	8	8	6	6	6	4	4	2	2	2	2	2	1	1	1	1
20	10	10	8	6	6	6	4	4	2	2	2	2	1	1	1	0	0	0	2/0
25	10	8	6	6	6	4	4	2	2	2	1	1	0	0	0	2/0	2/0	2/0	3/0
30	10	8	6	6	4	4	2	2	1	1	0	0	0	2/0	2/0	3/0	3/0	3/0	3/0
40	8	6	6	4	4	2	2	1	0	0	2/0	2/0	3/0	3/0	3/0	4/0	4/0	4/0	4/0
50	6	6	4	4	2	2	1	0	2/0	2/0	3/0	3/0	4/0	4/0	4/0				
60	6	4	4	2	2	1	0	2/0	3/0	3/0	4/0	4/0	4/0						
70	6	4	2	2	1	0	2/0	3/0	3/0	4/0	4/0								
80	6	4	2	2	1	0	3/0	3/0	4/0	4/0									
90	4	2	2	1	0	2/0	3/0	4/0	4/0										
100	4	2	2	1	0	2/0	3/0	4/0											

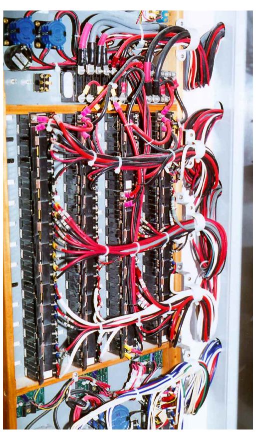
24 Volts — 3% Drop Wire Sizes (gage) — Based on Minimum CM Area

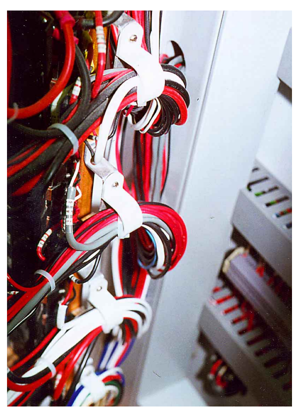
TOTAL CURRENT ON CIRCUIT IN AMPS.	10	15	20	25	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170
5	18	18	18	16	16	14	12	12	12	10	10	10	10	10	8	8	8	8	8
10	18	16	14	12	12	10	10	10	8	8	8	6	6	6	6	6	6	6	6
15	16	14	12	12	10	10	8	8	6	6	6	6	6	4	4	4	4	4	2
20	14	12	10	10	10	8	6	6	6	6	4	4	4	4	2	2	2	2	2
25	12	12	10	10	8	6	6	6	4	4	4	4	2	2	2	2	2	2	1
30	12	10	10	8	8	6	6	4	4	4	2	2	2	2	2	1	1	1	1
40	10	10	8	6	6	6	4	4	2	2	2	2	1	1	1	0	0	0	2/0
50	10	8	6	6	6	4	4	2	2	2	1	1	0	0	0	2/0	2/0	2/0	3/0
60	10	8	6	6	4	4	2	2	1	1	0	0	0	2/0	2/0	3/0	3/0	3/0	3/0
70	8	6	6	4	4	2	2	1	1	0	0	2/0	2/0	3/0	3/0	3/0	3/0	4/0	4/0
80	8	6	6	4	4	2	2	1	0	0	2/0	2/0	3/0	3/0	3/0	4/0	4/0	4/0	4/0
90	8	6	4	4	2	2	1	0	0	2/0	2/0	3/0	3/0	4/0	4/0	4/0	4/0	4/0	
100	6	6	4	4	2	2	1	0	2/0	2/0	3/0	3/0	4/0	4/0	4/0				

Many boats are wired with terminal blocks between the panel and the wiring loom. This allows for a neater installation but adds two connections (a potential problem source) to each circuit. Nevertheless, properly crimped fittings are not usually a problem. The panel shown was done by TPI on a Sundeer 64.



A detailed look at the terminal blocks from the photo to the left. When you lay out an area like this, leave space for ancillary equipment such as the alarm system to the left. As a general rule, allow at least twice the space wiring itself will take.





The two bottom photos (left and right) show *Beowulf*'s wiring. Note how the cables are loosely bundled, run through a large strap at the edge of the panel, then dropped into a U-shape. This provides slack for opening and closing the panel door without binding the wires.

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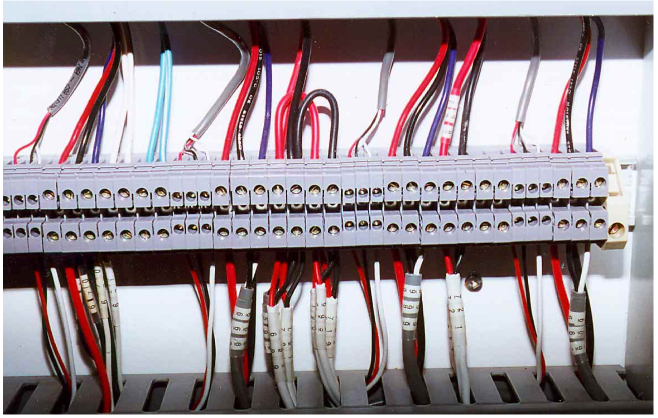
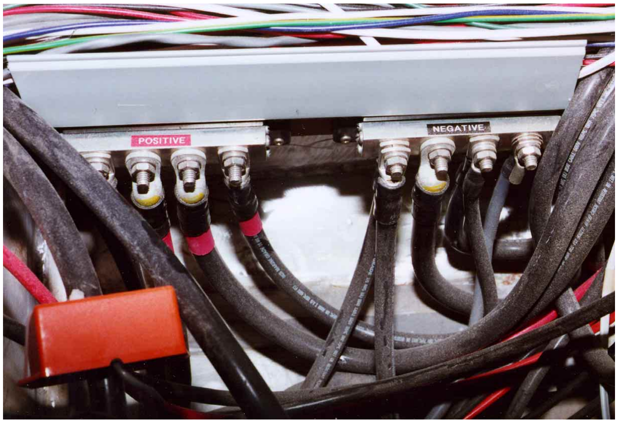
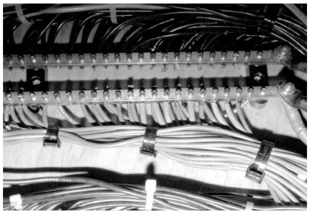


There are all sorts of terminal strips. This one is quite clever, in that you can remove individual clips to make them easier to work on. They can also be ganged together for power distribution.

The wires that have been twisted carry AC power from a large alternator to a rectifier assembly. They tend to be noisy on some radio frequencies. Twisting the wires helps to cancel out the RF interference.

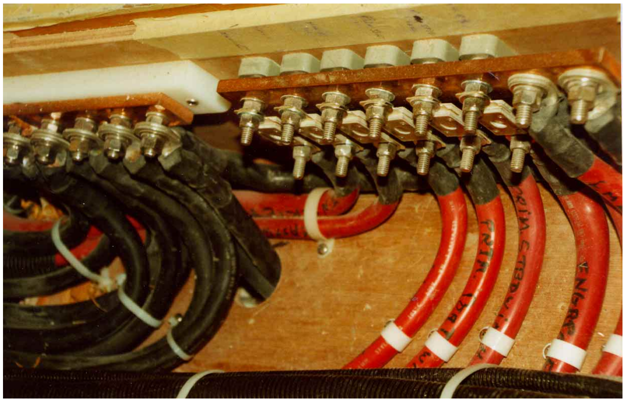




High-power-carrying cables are difficult to deal with. They tend to be very stiff and take up lots of space. The wires shown in these two photos (above and below) range from 2/0 to 4/0.

The bottom photo shows a copper terminal strip to distribute power. On the right-hand side, just below the terminal strip, notice the row of fuses.

On most boats (but not metal vessels) the ground system (negative wires) are common. In this case a drilled and tapped brass or copper bar serves as the terminal strip.



The crimp tool at the top of this photo is a double acting unit which will not release until a complete cycle has been made. This ensures that proper pressure has been applied to the crimp. Wire strippers, shown at the bottom, are a real help with a major wiring project.

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END TERMINALS

There's a debate on what type of end terminal is best. Soldering guarantees maximum electrical conductivity, and when done properly prevents the wire from pulling out of the terminal.

However soldering, also creates a hard spot right where the wire exits the terminal. Add in a bit of vibration and a crack is sure to appear.

Good-quality crimp connections, applied with the proper tool, also generate good electrical and structural connections, without the hard spot at the end of the terminal. They are also a lot quicker to do.

I've used both types and after many years of looking at the results have come to the conclusion that I prefer crimped terminals for end connections. But, where two pieces of wire are joined together I usually specify a soldered joint. (Try to avoid joints in wire between the control panel and the end as these are almost always a trouble spot in later years.)

When terminals, fuses, or relays are located where they can get wet (from an outside leak or perhaps a hose coming loose) making the connections in a watertight box pays dividends. If the box has a clear cover, so you can see what is going on, so much the better. A unit like this can be purchased for under $30 and is well worth the investment.

Moisture Proofing

Once a terminal has been affixed or a joint made, some form of protection from the elements will have to be provided. There are three ways to handle this.

The quickest is to use heat-shrink tubing over the joint. A section of heat shrink is slipped over the wire before the connection is made. Then, once the joint is finished the shrink wrap is slipped over, heated with a match, soldering iron or heat gun, and a neat, tight, semi-water-resistant cover results.

Second, a dollop of silicone can be put over the ends of the terminal. This is somewhat messy, but it will do the job.

Finally, there's self-amalgamating tape. This is a 3M product which bonds to itself. It's been used for years in the telephone industry to make waterproof connections. You peel off a bit from a roll, remove the protective cover, then stretch it (up to five times its length) as it is wrapped around the wire. In the self-bonding process a very watertight joint is made. This tape is also ideal for chafe protection on deck.

Wire Identification

Nothing causes more of a headache (nor runs up the electrician's bill faster) than trying to figure out which wire goes to what.

When a boat is being built it's so easy to number each wire at the control panel and saves time downstream that I've never understood why some builders resist the practice. We always do the panel end, and the accessory end in the engine room. Then, all you have to do is dig out the master list and/or refer to the schematic diagram to know what's happening.

Even if your boat doesn't have numbered wiring, start the practice as you add new circuits. Any industrial electrical supply will be able to sell you stick-on numbers.

Different colors are used to differentiate functions. The actual system varies from country to country. Whatever is in use on your boat should be continued. A common approach is to use black for negative, and red for positive in the DC circuits. AC circuits use green for ground, white for live, and blue for neutral.

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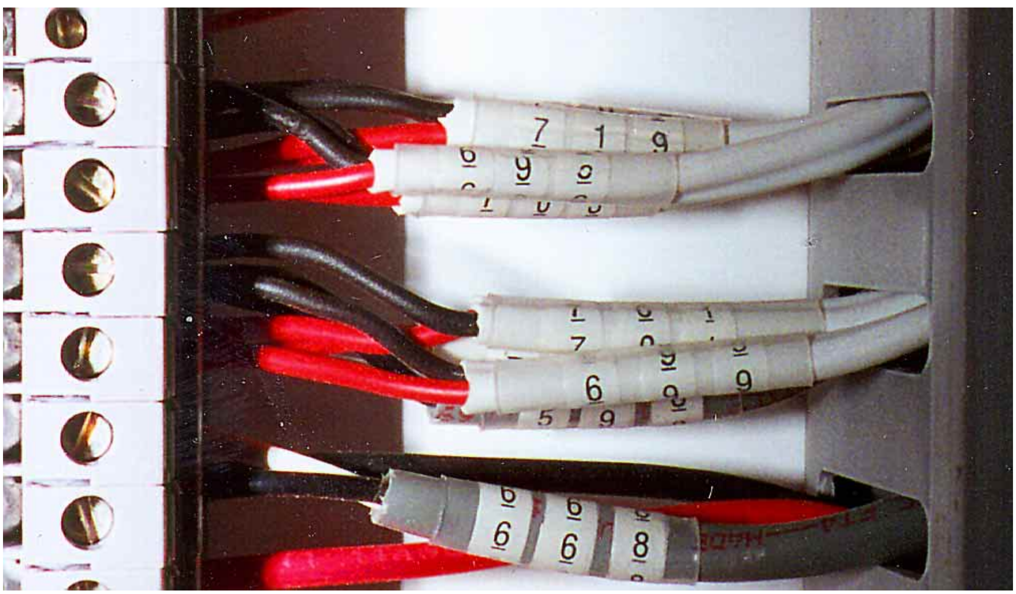
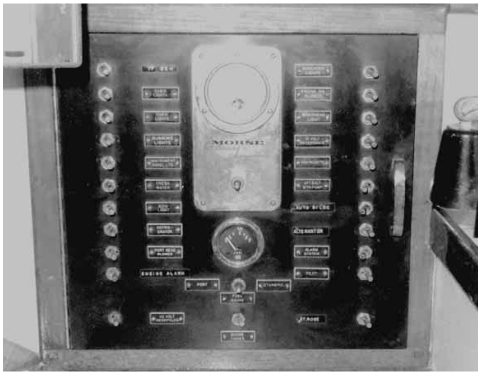


The best way we've seen to I.D. wires was suggested to us by Skip Schroeder. By placing *clear* heat shrink over the numbers you are assured that they will always stay in place. It is such a simple idea you have to wonder why its never been done before (especially when you consider the very common problem of wire I.D. numbers falling off over time)

CONTROL PANEL

The control panel is the nerve center of the electrical system. Its layout and location have a significant impact on its functionality. Obviously it should be installed so that it is easy to see and use, with good access to the back for maintenance work. Ideally it will be on a protected dry bulkhead with full access to the back. If the panel is against the hull side, it should be hinged, with enough slack in the wires to allow it to swing open.

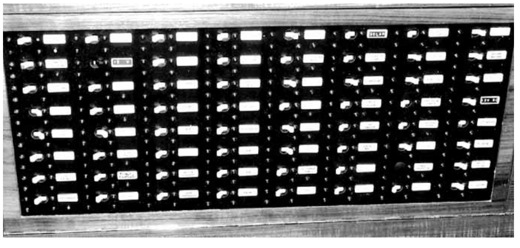
It's generally better to have several separate functions on the panel, rather than numerous items on a single circuit. Isolating each accessory simplifies fault tracing later on. In addition, when one accessory goes bad and trips the breaker or blows a fuse, it won't shut down everything else. From a wiring standpoint, most electricians say it doesn't cost any more to take this approach. The extra cost of additional breakers is offset by quicker wiring time.

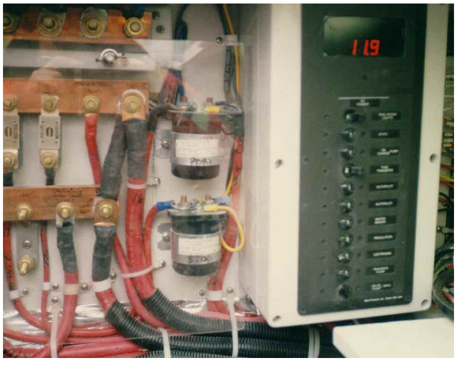


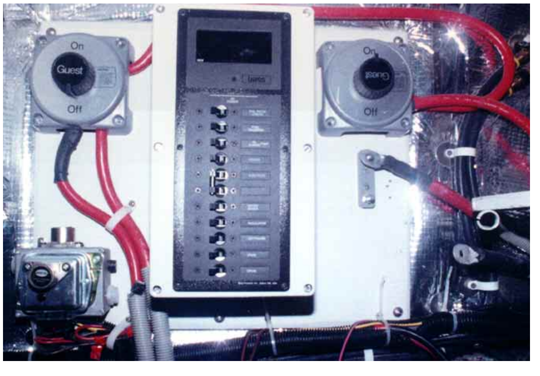
The high-tech panel on the upper right was on *Intermezzo*. It was one of the few panels with circuit breakers we saw when we first started cruising. Compare that to what's considered the norm today.

The photo below shows *Sundeer's* panel. These are all double pole breakers — with any metal boat, always break negative and positive to facilitate ground-fault tracing.

The middle right panel is a typical Bass panel used with many production boats today.







We've found that having a separate panel for the engine room makes wiring simpler, aids the owner in maintenance, and makes it easier to add or change equipment as time goes on. These two setups are on Sundeer 56 and 64s. Note the digital voltmeter, handy for setting alternator output. The shield shown on the left protects the equipment from spray.

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Controls should be grouped by function. Keep all engine-related items in one area, possibly with an engine master breaker. Nighttime gear should have its own group — i.e., running lights, tricolor, windex, compass, chart lights. I like to keep breakers used for passaging — sailing instruments, pilot, navigation gear — in another area. Also, there will be a grouping of pumps. All AC breakers should be in one area, separated from the DC gear.

The labeling system should be flexible and easy to change. Pop-in or slide-in nameplates are ideal. Regardless of how careful you are with layout the first time around, time will bring changes. An engraved panel might look nice at first, but when you add paper labels, it starts getting shabby.

Certain switches, such as the pilot, must remain on at all times. With these switches, any accidental disconnect could create problems. It makes sense to fit a guard over these to prevent problems.

Visual Indicators

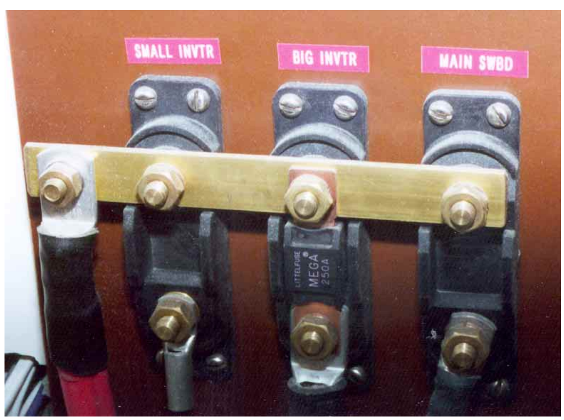
Light-emitting diodes (LEDs) signal certain control functions and help keep you aware of what's happening. They look sexy, too. But, *LEDs should be limited to where they really do a job.* Used indiscriminately, they just confuse the operator, ruin night vision, and waste power.

I like to see different colors in use, such as red in areas requiring immediate attention — bilge pump–running indicators, propane solenoid, or damage-control-pump engagement, for example. Amber is a not-too-serious reminder that something has been left on, such as engine-room lights or the hot-water circulating pump. Finally, for certain items that are supposed to be left on for long periods, we use green to indicate that they are indeed on. The freshwater pump, diesel heater, and fridge compressors are examples.

Overcurrent Protection

Every circuit in the boat should have some form of overcurrent protection. Otherwise, a short may some day cause a fire. A circuit breaker, acting as an on/off switch at the same time, is a functional and cost-effective approach. Fuses, sometimes found on older boats,

The top panel is typical of a modern custom-boat panel, in this case for *Beowulf*. Fridge control circuits and digital thermostats are at the very top. In the upper right-hand corner is one of Bob Williams's SALT monitors for digitally tracking of amperage, voltage, and power consumed in the boat. Below this are the dimmers for controlling lights in the saloon, office, and galley areas. Then you get to the DC breakers. The two linked breakers on the left are the masters for the 24-volt section of the panel. In the middle is a selector switch for 12-volt sources. In this case, we can select from a 24 to 12-volt converter (normally used for all 12-volt electronics), a tap of the 24-volt house bank, or the engine starting battery (12 volts). Below this are the double-pole breakers for each circuit. At the very bottom of the panel are meters for the AC system; the selector switch (shore power, large inverter, small inverter); and the dual-pole breakers.



The brass bar at the top of this photo transfers power to the fuse blocks below. These are fast-acting class-T fuses.

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% rated amperage	seconds
140	200
160	14
180	6
200	3.5
220	2.6
240	1.8
260	1.5
280	1

% rated amperage	seconds
180	300
200	30
220	10
240	7
260	4
280	3
300	2.7

% rated amperage	seconds
150	1000
200	100
250	20
300	10
400	.2
450	.06
500	.03

There are two key factors in sizing fuses. One is the interrupt rating — the amperage at which the fuse will no longer isolate the short circuit. The second is the time it takes the fuse to react.

Both of these factors vary widely between fuse types.

The three charts above, from Blue Sea Systems, show different fuse designs.

The top is a "Mega" fuse, with an interrupt rating of 2,000 amps. This is not that high for heavy-gauge wire. However, it is the fastest acting of the three fuse types.

The middle chart is for "ANL" style fuses. These have a 5,000-amp interrupt rating, but are considerably slower in reaction time.

The bottom chart is for a class-T fuse, with an interrupt rating of 20,000 amps. This is what you would use for the primary feeds of your battery bank and perhaps a large inverter. Since they are slow acting, they must be sized close to the working limit of the circuits in question.

make sense if you're conscientiously trying to restrict overcurrent flows to a given piece of gear. Fuses are available in lots of low ratings, as fast, normal and slow-blow configurations.

It's a good idea to have a panel master breaker for each voltage — i.e., 12 volts, 24 volts, and 110 volts.

Fuse Logic

High-capacity fuses should be fitted to all heavy-load circuits on the boat, in addition to fuses on the battery-output cables, and alternator-output cables.

Fusing is done for two purposes. First, to guard the circuit from fire in the event of a short. Second, to protect the electrical device in the line from overheating with excess load.

Fire risks are relatively easy to quantify. A wire of a certain diameter has the ability to carry up to so much power before it overheats. As long as the fuse blows before this point, you are safe.

Motor protection is a more difficult job, since both time and amperage are involved.

For a device like a pump or fridge compressor, running at a relatively constant amperage draw, the fusing is easy to work out. The situation with winches is more complex, as the load varies substantially and the winches (at least the sheet and halyard winches that are electrified) are used for relatively short periods of time. However, you may find that in some situations, such as kedging off a reef, you'll need far more power from the winch for short bursts of time. With a fused system you can put in a higher-capacity fuse for this emergency, bearing in mind that you will only run the winch at high loads for a few seconds at a time.

Carry an inventory of fuses for each amperage on board, with some variety in capacity to allow fine-tuning later on.

When you start to look at fuse ratings, you will find that each comes with a curve representing amperage and time. A fuse rated at 100 amps may require 2 minutes before it will blow at a 150-amp load. On the other hand, at a 1,000-amp load (representing a dead short) the time to blow might be down to microseconds. This curve needs to be checked against the amp capacity of your wire and the motor requirements. Different types of fuses have varying speeds of activation. Class-T fuses are an example of the fast-acting type.

It's also good to check on the interrupt capability. This is the highest capacity a fuse can handle before it will cease to function (if this rating is exceeded it will continue to carry current). We frequently use Blue Sea fuse blocks in the T-type configuration. These have an interrupt capability of 20,000 amps.

DC Ground

The proper way to tie a DC ground together is with some form of bus bar. This ensures a good connection back to ground for every circuit. If this connection is not properly made — for example, if terminals are corroded, loose, or too small — voltage will drop substantially, leading to power loss or increased electrical consumption. Certain vessels, especially older yachts, use the engine block as a common grounding point. This is not good practice, because the cast iron or aluminum block is not an efficient conductor.

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External Electrical Controls

The best way to deal with external electrical controls is not to have them. There is almost always a way to mount outside switches in the protection of the companionway or under a pilothouse or dodger. Anything left in the direct elements, no matter how well protected, will eventually fail — sometimes when you need it most. On our own boats we never have electrical switches outside of shelter. When gear is located under a dodger or near the companionway, we try to protect it from moisture and spray. Still, if you have externally mounted gear, there are a few caveats.

First, keep it high off the cockpit sole. Look at it in the context of the cockpit being full of water, then slowly draining. Will your gear stay dry in this situation? If not, you need to have a fast-acting way to disarm the damp circuits and to control critical items from a switch in the interior. Few cockpit installations will pass this test.

The next step is a “waterproof” enclosure. Most are spray- and rain-resistant, rather than truly waterproof. Still, they are better than nothing.

If you are using switches with rubber membranes, look carefully at how they are installed and how fair the mounting surface is on which they lie. If this surface is anything other than perfectly flat, fair it out or use a bit of silicone. Boots tend to deteriorate with age and should be replaced at least every two years.

Meters

To monitor the performance of the electrical system you’ll want several different meters. A decision will have to be made as to meter scale and size. Pick a scale (range) that corresponds to what is normally shown on the meter. The larger the meter, the easier it will be to read, and usually the more accurate its movement will be. Mirrored meters are even easier to read.

At the minimum there should be a meter for battery voltage, hopefully with an expanded scale showing from 10.5 to 15 volts for a 12-volt circuit, or 21 to 30 volts for a 24-volt circuit. If a selector switch is used, this can be wired to each of the battery banks. The switch can be a rotary for three or more banks, or a simple single-pole, double-throw, center-off switch for dual banks.

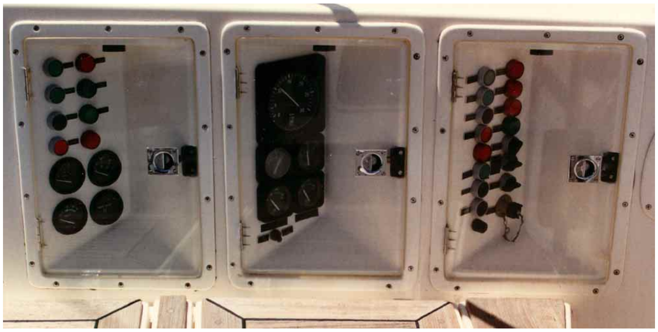
An amperage meter wired in to show consumption is very helpful, as well as, of course, a charging amperage meter.

Amp meters use “shunts” to measure voltage. Small meters, typically reading below 30 amps, have the shunts built in. It is better to set up a meter for an external shunt. This way the shunt can be installed in a convenient spot, usually right near the batteries. Sensing wires (which are light) run from the shunt to the meter.

An AC system will call for voltage, amperage, and cycles-per-second meters.

The price of digital meters has come down to the point that they’re certainly worth considering. Not only do they look cool, but they’re usually more accurate. For DC voltage and panel amperage, they make a lot of sense.

Integrated digital meters are also on the market and will tell you both amperage and voltage in a single unit. Some models also display total consumption (in and out) in an amp-hour format. However, take amp-hour readings with a grain of salt as an indicator of battery state of charge. It’s much better to use a hydrometer.



For years, Swans have been fitted with veritable electrical panels in their cockpits. The enclosures shown protect gear from spray and rain, but are far from waterproof. The photo at the left is a “sealed” switch. These are usually good for a year or two of outdoor service, assuming they don’t get too much spray.

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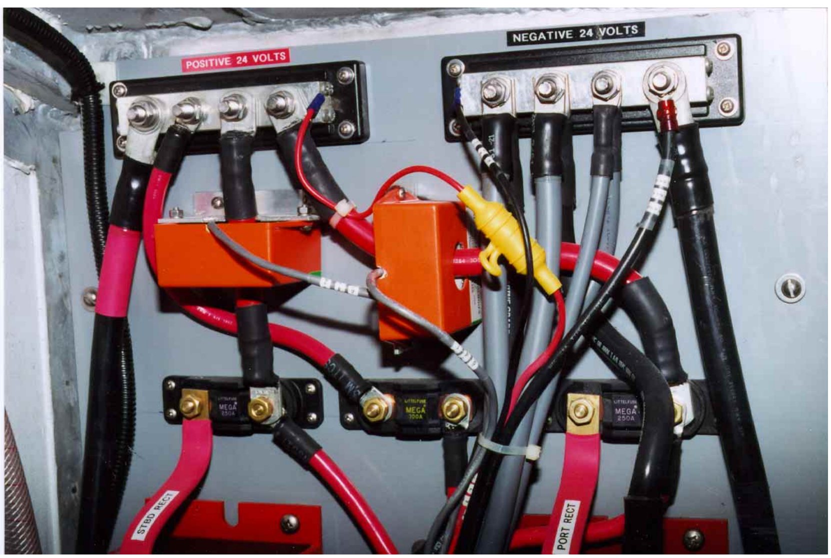
Sometimes the best way to check voltage and amperage is with a portable digital meter. These are simple to use and usually less expensive than built-in meters. For measuring over 10 amps, you will need a special shunt. The one at the left clamps over the wire. Available for most digital meters, they're very handy for checking alternator output.

The photo above shows amperage and amp-hour meters.



Bob Williams at Sea Air Land Technologies has developed a microprocessor-based digital meter system that does all sorts of nifty things. What I like best about it are the "Hall Effect" current sensors. These are placed over the wire, instead of having to break the wire like a common shunt. Bob's SALT Monitor can track four circuits for daily current consumption. *Beowulf* has these on both alternator circuits to check output, as well as on the total electrical system, and one extra for checking fridge, pilot, etc.

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THE DC SYSTEM

Of all the systems to be considered, nothing will have a bigger impact on your lifestyle than the way the DC electrical system works. The key to cutting through the mumbo-jumbo that often accompanies this entire subject is to understand exactly what is happening between batteries, chargers, and the various accessories dependent thereon.

The difficulty is that DC systems engineering is more of an art than a science. Talk with four experts, and you'll get four different versions of what's happening and what needs to be done. Even the subject of batteries — how they work and how they should be treated — is a major topic of debate.

Safety First

Before we get into the details of the DC system, a comment on safety. While we're dealing with low voltages here, it's important to understand that batteries and alternators have the capacity to do tremendous damage when in a dead-short condition. A moderate-sized battery bank can easily chew a hole through a metal hull or tank if a hot wire to the alternator or starter is grounded. Likewise, the heat of a substantial short, unprotected by fuse or breaker, can start a fire quickly in insulation or surrounding structure. Finally, a shorted or overcharged battery has on rare occasions exploded, spewing sulfuric acid and doing considerable damage in the process. If you're working with large metal tools around the batteries, be careful not to drop them between the battery terminals.

Minimize your risks by taking care with fuses and circuit breakers, watching for chafe on moving gear and at bulkheads, and shutting down the master battery switch when working on alternators or starters.

You probably know that most batteries give off hydrogen gas as they charge. This gas is lighter than air, so it tends to float away. It's also very explosive. (That was the problem with the Hindenburg dirigible.) Be sure batteries and/or the interior are well vented when charging.

BATTERY SWITCHES

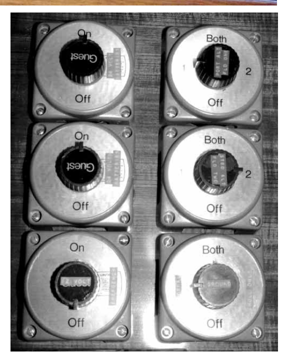
A battery selector switch allows you to use the battery banks separately or together. These switches must always be "make before break," meaning that the new bank is switched on before the old is turned off. This is important for electronics, and to prevent the alternator from running on an open circuit for an instant. Should this occurs, the voltage spike will probably burn out the alternator diodes, along with anything else currently turned on.

Some battery switches have a terminal for the alternator regulator feed, so that in case the switch is turned to the "off" position, the alternator field coil is disabled, preventing the aforementioned voltage spike.

Battery switches are typically rated in terms of momentary capacity for engine starting and continuous capacity for everyday use. Higher capacity costs a few bucks more but pays off in longevity.

Bilge-Pump Wiring

It's often a good idea to have bilge pumps on their own circuit, connected direct to the batteries (with a fuse or breaker in line, of course). This allows you to shut down the main breaker upon leaving the boat, with the bilge pumps able to run in case a leak should occur. It's also a good idea to have the radio on this circuit. In an emergency — perhaps fire or flooding — everything else can be shut down, keeping power available for a distress call.



Battery switches are not the place to economize. Low-quality units tend to burn their internal contacts with age, creating a voltage drop. In severe cases, they become impossible to disengage under high-amperage conditions (as in a dead short).

With several types of battery switches, the actuating handle can be removed (top). These offer an obvious security function.

The other photo shows *Sundeer*'s switches. There are positive and negative switches for both house banks, a crossover switch to allow the 24-volt house bank to be tapped for 12-volt engine starting, and a ground switch that ties the DC negative to the hull whenever a lightning storm is in the vicinity.

BATTERIES: HOW THEY WORK

The principle of batteries has been around since the nineteenth century, and guess what? Construction hasn't changed much in the last 80 years except for the introduction of gel cells.

The most common batteries both then and now are made from a combination of lead-alloy plates with sulfuric acid and water as an electrolyte. The exact shape of the plates, along with the metals added to the lead, have a big impact on the life, capacity, and usefulness of a battery in different situations.

When the battery is fully charged, all of the sulfuric acid is in solution — that is, in a liquid form, evenly dispersed throughout the battery. As the battery's capacity is used up, the sulfuric acid begins to combine with the plates, creating a lead sulfate and leaving behind a much-diluted battery acid (water is a byproduct of the reaction). This explains why you can tell the state of charge with a hydrometer. The hydrometer simply measures the specific gravity or density of the electrolyte. Since sulfuric acid is heavier than water, the higher the state of charge of the battery, the higher the specific gravity, and vice versa (more about this later).

Charging the battery reverses the process. The lead sulfate is converted back into liquid sulfuric acid, raising the specific gravity of the electrolyte as the lead-sulfate crystals break back down, leaving a clean lead plate for the next cycle.

The tricky part is that you may not get all the sulfate back into solution. A small amount may cling to the plates. That not only reduces capacity the next time around, and since part of the active area of the plate is covered, unless you can get the plate cleaned by forcing the sulfate back into solution, the battery life has just been shortened. If the battery is deeply discharged and allowed to stay in that condition for a long period of time (typically four weeks in the tropics and six to eight weeks in temperate climates), it becomes impossible to get the sulfate off. Hence it's critical to recharge a flat battery as soon as possible. To further complicate matters, some of the surface of the plates themselves will slough off, forming a paste at the bottom of the battery. Not only does this affect capacity, but if that paste builds up far enough off the bottom of the battery case, it can create a short between some of the plates, eventually discharging the entire cell, battery, and battery bank. To offset this buildup, the plates stop a distance up from the bottom of the battery case. This allows space for the paste to accumulate without shorting the plates. Better-quality batteries have more space at the bottom.

How you and the battery manufacturer deal with the above difficulties is the key to the batteries' capacity and longevity.

Starting Batteries

The battery in your car is designed to give high surges of power for short periods of time when starting the engine. This will generally use one or two percent of the battery's capacity. The rest of the time, the engine's alternator keeps the battery at a constant, happy voltage. To make this task easy, the battery manufacturer puts in plenty of very thin plates. This gives the acid more surface area to work against, hence more short-burst power. But these plates are unhappy if they get deeply discharged, and after a few deep cycles they will give up the ghost.

Deep-Cycle Batteries

Enter the deep-cycle battery. On a boat, the battery has to supply voltage for all sorts of gear, sometimes for days on end, so it ends up going through a substantial discharge cycle before being recharged with a generator, engine-driven alternator, or battery charger when connected to shore power. Since a long, slow discharge is easier to deal with than a short, quick one, less plate surface area is necessary. However, in the deep cycle the lead sulfate forms right through the plate instead of just on the surface. This makes a denser, thicker plate necessary. The plates also expand during this process, so more space is required between them. As a result of the extra thickness and density, they stand up to a deep cycle extremely well.

It seems obvious then that for most marine applications you want a deep-cycle battery. But which one? You can go into your local discount store to buy a "deep-cycle" battery that won't give a year of decent service. And today there are literally dozens of brands touting deep-cycle and/or marine capabilities. The answer is to go down to the local golf course to see what they're using. The electric golf cart is a perfect example of a deep-cycle application.

The Trojan Battery Company probably makes the best deep-cycle battery for the money. With their T-145 style battery you can expect a three-year life and 600 or more deep cycles.

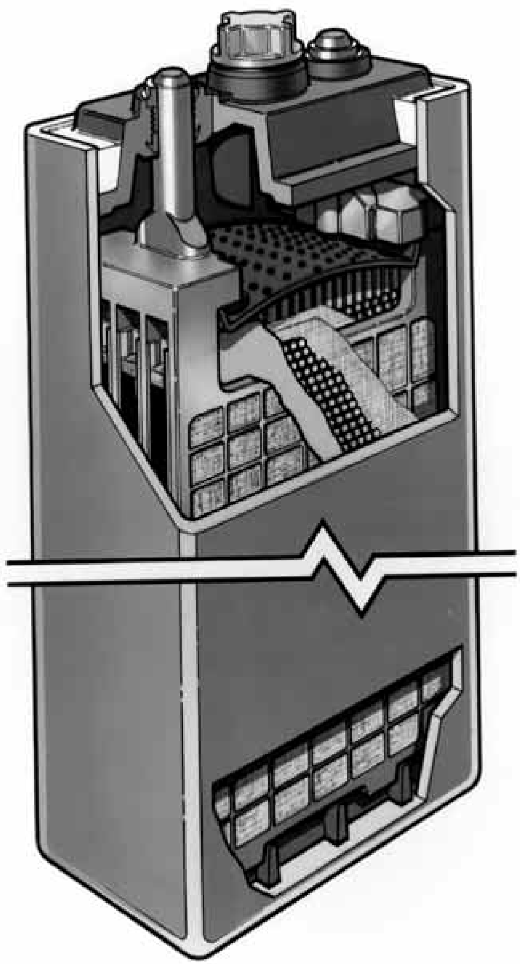
If you have more budget and are looking at a longer-term answer, then consider the Surrette Group 400 batteries, or comparable ones made by John Surrette's new company, Rolls Batteries. These have been the standard in deep-cycle batteries for years. They claim the ability to go 1,400 full deep cycles and 2,400 if only cycled 50 percent. Life-spans of 10 to 12 years are not that uncommon.

Traction Batteries

The ultimate battery, as far as we are concerned, is the "traction" battery. These are extremely heavy-duty industrial batteries used in forklifts, diesel electric locomotives, and telephone switches for standby power. Extremely rugged, with very thick plates, they can be discharged more deeply than any other form of battery.

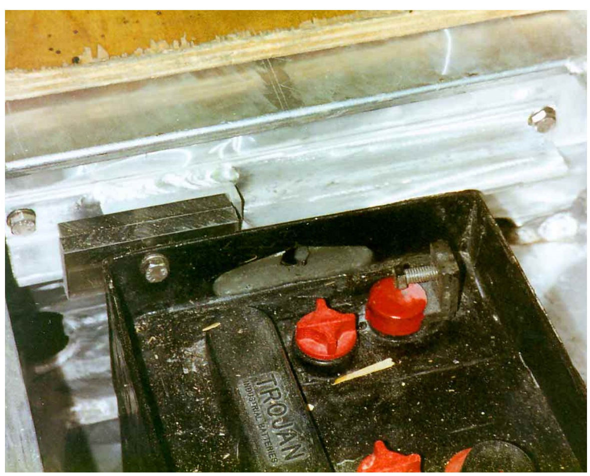
We've been using traction batteries manufactured by the Trojan Battery Company for years and have found them to be almost indestructible. In normal marine service, with proper periodic equalizing, they will last 15 to 20 years! They also have a very high charge-acceptance rate (i.e., speed at which they can be recharged).

Traction batteries can be purchased as individual cells, or in banks of three, six, or 12 cells, with literally dozens of heights and cross-sections available to fit different requirements. We find that ordering the batteries pre-installed in epoxy-coated steel trays makes the best installation sense.



A cutaway drawing of a Trojan traction battery. These cells are typically taller than other types of batteries. They can be installed as individual cells or in banks.

When you specify traction batteries, ask that the steel trays be extended vertically about 1 inch (25 mm) (lower photo). This helps to contain potential spills.



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Two views of Trojan traction batteries. Above shows what they look like before being dropped into the boat. To the right you can see how they fit into the keel sump on one of our designs (where they form part of the ballast package). Note the metal restrainers (to hold the batteries in place during a rollover) and Hydrocaps.

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NiCad Batteries

Nickel cadmium batteries are another avenue. These batteries are designed for many deep cycles and extremely long life. They're frequently used in backup systems for hospitals, telephone switching systems, and railroad signals. Lifespans of 20 years are possible, with deep cycles in the thousands. But there are several major drawbacks. First, they are inordinately expensive, even if you amortize the cost over the greater lifespan. Even if cost is no object, the fact that they take about 40 percent more space and weight per given capacity is a real negative. They also require a higher charging voltage, about 16 volts with a 12-volt system. This means electronic gear may have to be shut down or run on a separate bank when charging. At one point I was very excited about the possibilities of NiCads, but after a lot of research we came back to good old lead acids.

Gel Cells

Some years ago a new type of battery made by the Sonnenschein Company was introduced to the cruising market. These patented batteries use more or less normal plates, but they have a double-acid system in a paste rather than liquid form. They're totally sealed, which means no hydrogen gas (normally) to worry about, and no watering problems. The double-acid system prevents the plates from forming lead sulfate. Hence they can in theory be cycled many, many times, to a fully discharged level. They can also be recharged more quickly than conventional batteries.

These batteries came on the scene with much publicity. Some have worked very well — we retrofitted a set on *Wakaroa* ten years ago that still works today. On the other hand, we've heard stories of shorter life-spans.

Many companies now make gel cells. If you need to install a battery in other than a top-up mode (they can be installed on their side because there is no acid to spill), or if you are concerned about production of hydrogen gas, they make sense. Many builders use them today because they do not require the same ventilation as conventional lead/sulfuric acid batteries.

One caveat — be very careful with overcharging. These batteries will be quickly ruined by charging at more than the specified rate (usually 14.3 volts in a 12-volt system).

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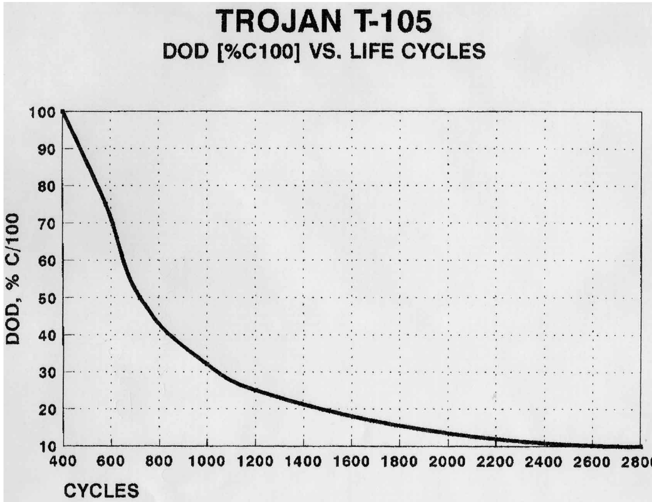
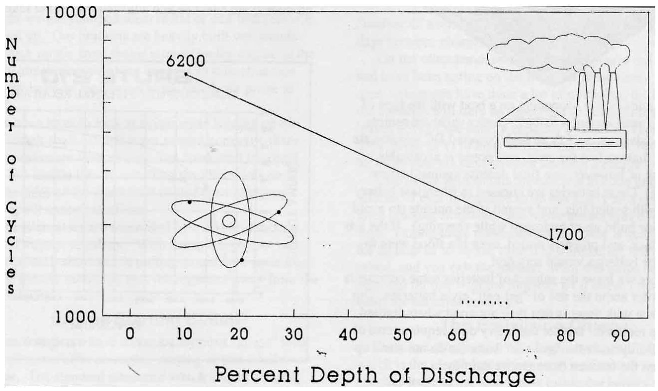
Battery Life

Every battery has a finite life, whether or not it's cycled. Even sitting at the dock with a perfect float charge, the battery will die in a certain amount of time — usually one week after the guarantee expires! This is because each day a small amount of plate is sloughed off, regardless of use. In fact, most batteries will actually last longer with occasional use than just sitting around waiting for a load. Pulling the bank down 5 to 10 percent once a month will help longevity when you're tied to the dock. The second life-limiting factor is the quantity and depth of the cycle. Where you might get 300 cycles from a battery by drawing it down to 10.5 volts (from a 12-volt battery), if you only draw it down to 12.2 volts it will last for 700 or 800 cycles. So you can see that when the time comes to calculate battery requirements you have to trade off battery longevity for daily capacity. More capacity means shallower cycles, which means longer life.



A comparison between a good-quality golf-cart battery (above) and an industrial traction battery below. For the golf-cart battery at 50 percent depth of discharge, you get a little over 600 total cycles. The traction battery, on the other hand, will go to almost 3,000 cycles at the same depth of discharge! (Charts courtesy Trojan Battery Company)



When deciding on a battery, look carefully at depth of discharge versus life factors. A battery that can be more fully discharged without excessively shortening its life will offer more capacity with which to work. Sometimes the differences are startling. For example, Trojan traction batteries offer roughly 1,700 cycles at the 80-percent discharge rate. This means you can use basically the total capacity of the battery. Compare this to a more normal deep cycle battery that typically wouldn't use more than 50 percent of capacity, and you see that for a given amount of usable amp-hours, the rated capacity of the traction batteries can be 40 percent less. For example, to get 200 usable amp-hours at the 50-percent rate, you need a 400-amp-hour bank. At the 80-percent rate, the same usable capacity could be obtained with a 250-amp-hour bank.

Other Battery-Choice Factors

For most cruisers the battery selection debate comes down to golf-cart batteries, high-quality deep-cycle batteries (like Rolls or Surrettes) or the Sonnenschein/Prevailer type of gel cells.

While the gel cells do not last nearly as long as the higher quality deep-cycle batteries, they do offer some mitigating characteristics that will endear them to you. First, because they do not require equalizing, they are not as sensitive to mishandling. Lead-sulfate batteries that are not properly equalized on a periodic basis gradually lose capacity and suffer through a higher and higher internal discharge rate.

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Gel cells have almost zero self-discharge when sitting around unused. Many lead-acid batteries discharge anywhere from one to three percent of their capacity just sitting idle.

For me, the decision-making process comes down to this: Assuming you do not have space for traction batteries (the ultimate cruising battery in my opinion), if you plan to live aboard and to keep an eye on the batteries, I would go with the highest-quality lead-acid types. If you are not as maintenance-oriented and don't want to be bothered with equalizing and checking electrolyte level, then go with the gel cells.

Cell Size

The batteries used in your boat are actually an amalgamation of smaller batteries or cells tied together. A 6-volt battery has three 2.2-volt (at full charge) cells, while a 12-volt battery has six cells. You can have a series of small cells wired together to form a small battery, or a series of larger cells wired together for a bigger battery.

An alternate approach is to break the battery bank into two cell groupings, ending up with two separate 12- or 24-volt batteries. This is a common technique on many boats. The theory is that you always have one bank in reserve.

Now let's go back to the depth-of-discharge concept for a moment. If you are working against half of your total battery bank for a given amount of capacity, you will be discharging twice as deeply, shortening the battery's life in the process. This is not terribly efficient.

The same thing happens when charging. It's much more efficient to charge one larger bank than two smaller banks. Finally, capacity is related to the percentage of total amps drawn at any one time. A 10-amp load on a 200-amp bank will last longer than a 10-amp load drawn from first one and then a second, 100-amp bank. For this reason, we favor a single, large battery bank on our boats.

If you are concerned with engine starting should the main bank become discharged, keep a second, small starting battery in reserve.

How Much Capacity?

You would think that battery capacity would be relatively easy to define. Guess again. There are all sorts of amp-hour ratings, reserve-minute ratings, etc. To make matters more confusing, capacity varies with temperature. Most ratings are run at 77 degrees Fahrenheit. But at higher temperatures you get a bit more, and at lower temperatures you get less (at 0 degrees capacity is a little less than half of normal). Capacity also varies with age. Most lead-acid batteries only give 65 percent of their rating at the end of their life. It's not uncommon for one battery company executive to accuse his opponent of hyping the electrolyte to get better short-term performance in testing.

To further complicate things, you have to consider how deeply the batteries are to be cycled in each period. The charging cycle — i.e., how quickly you can put back what you have taken out — is also affected by capacity. Bigger banks accept a faster charge and hence less running time on the engine or genset if you have a big enough alternator. It's also important to think about engine or genset failure and how much reserve capacity is necessary in this situation.

Against all of this you need a way to accurately project your own requirements. There are two situations — on the hook, and passaging. Passaging usually takes several more times the power of lying at anchor. On the other hand, you may be using a trolling generator to supply or supplement passaging power requirements.

The actual calculation process is pretty straightforward. Make a list of everything aboard that uses power. Then figure how many minutes or hours a day you expect to run the item in question. Total the figures, and that, more or less, is your daily requirement.

The biggest factor is refrigeration. If it's electrically driven with an efficient system, in the tropics expect to use 40 amp-hours a day for a 7-cubic-foot fridge/freezer system. You can easily consume another 20 to 40 amp-hours for reading lights, anchor light, fans, inverter, etc.

Count on using a maximum of 30 percent of the 20-amp-hour rating in capacity calculations. Let's say that we figure 60 amp-hours per day consumption, and we want to have a two-day capacity. If we're using just 30 percent of capacity, we need a battery bank of 400 amp-hours. But if

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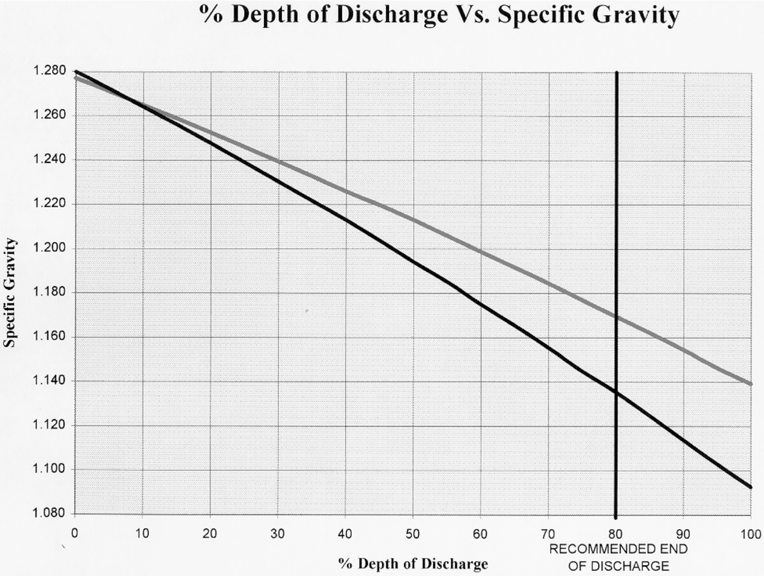


Battery capacity is best measured by checking the specific gravity with a hydrometer. The actual state of charge is a function of battery cell construction, the specific gravity of the original electrolyte, and the temperature of the electrolyte.

This chart is for two different types of Trojan batteries. The upper line is their T-105 and L-16 designs, while the lower is the 85T-11.

The top two batteries are designed for golf-cart and floor-sweeper applications. They are deep-cycle-type batteries, but optimized for a fast discharge over a matter of a few hours. The bottom unit is a traction design (for forklifts), the type we've used over the years on our own boats. This battery is designed for discharge over a full work day. The difference in the specific gravity readings is a function of the active material on the plates and the amount of sulfuric acid in solution (the electyrolyte).

The key fact we want to point out is that every battery has a different specific gravity/discharge relationship. Be sure you have the correct data for the batteries on your own boat.

there is space, and if the batteries are stored low in the boat where they help stability, a bigger bank would be even nicer.

For an engine-drive fridge system, you will want to balance DC capacity (both batteries and alternator) against daily compressor running cycle. Having a huge battery bank and alternator doesn't make sense if you plan to run the engine every day for an hour or so just to charge the batteries.

Another approach (discussed a little later) is to supplement the bank with solar or wind-generated power. Once again, this reduces capacity requirements.

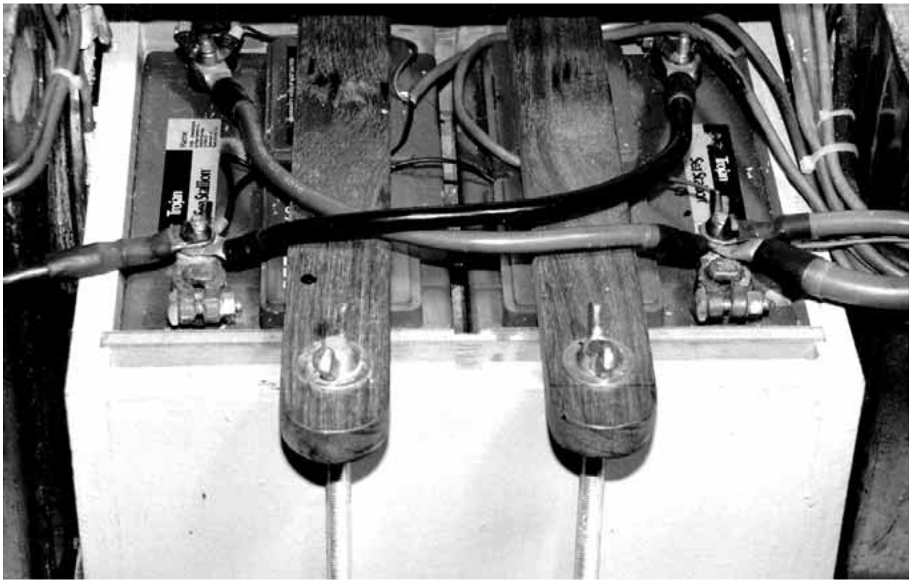
% CAPACITY	APPROX. SPECIFIC GRAVITY	OC VOLTAGE
0	1.285	2.13
10	1.270	2.11
20	1.253	2.10
30	1.236	2.08
40	1.219	2.06
50	1.201	2.05
60	1.183	2.03
70	1.163	2.01
80	1.143	1.99
90	1.123	1.97
100	1.101	1.95

If your battery starts out with a specific gravity of 1.285 (fairly typical), this chart provides an idea of the capacity denoted by the specific gravity and the corresponding cell voltage.

State of Charge

The best way to check battery condition is with a hydrometer. This measures the specific gravity (density) of the electrolyte.

Now we come back to that lead sulfate on the surface of the battery plates. The more lead sulfate left on the plates in a permanent state, the more resistance the battery will show to a charge. This has the effect of increasing battery voltage. The charge controller senses this higher voltage and begins to cut back the charge rate. The problem is that the battery is not really getting a proper charge, since the lead sulfate is not going back into solution, yet the regulator thinks that everything is fine. This is why equalizing to get that leftover lead sulfate back into solution is so important.



Regardless of the type of battery you install, it must be held in place in case of a severe knockdown or rollover. This can take the form of straps, a bar like the one shown, or metal angles.
Be sure to check your hold-downs on a periodic basis, since they can be corroded and weakened by the hydrogen sulfide gas given off by the batteries.

Installation

Batteries make relatively efficient ballast, so keep them as low in the boat as possible, preferably under the floorboards. Make sure they're well secured. In the unlikely event of a rollover or even a severe knockdown, it would be unpleasant to find them flying through the interior. Access must be good, so you can keep the tops clean and check the water level occasionally. Have a way to contain battery acid should a battery case crack. The best way to do this is to fiberglass in a plywood case to take all the batteries in the bank. The fiberglass will resist battery acid. If this cannot be done, each battery should have its own plastic battery box.

While it's advantageous from a stability standpoint to store the batteries low, consider what happens in the case the bilges flood. A charged battery, sulfuric acid, and salt water end up in a mess of chlorine gas — a most unpleasant breathing environment. If you're concerned with this possibility, think about sealing the battery box to make it watertight, but be sure to allow for a hydrogen gas vent to the outside. Even if you take this precaution, always have a battery somewhere high enough to allow a radio to be operated right to the last minute, in the event of a sinking.

With sealed batteries this won't be a problem. But there will be fairly substantial shorting across the terminals when they're submerged. Sealing the terminals in anhydrous lanolin or various lacquer sprays has been suggested as a way to prevent or reduce shorting in a submersion. Certainly this approach can't hurt.

Another thing to consider is one-way battery caps. These have a miniature check valve in the cap itself, allowing hydrogen gas to escape but preventing anything from flooding back into the cell in case of submersion.

If your batteries are flooded and water penetrates the battery caps into the cells, it will float on top of the battery acid, since it is lighter. It can then be removed with your hydrometer. However, if this occurs, be sure to remove the seawater before charging. Otherwise, charging will mix the salt water with the electrolyte, and the electrolyte will have to be changed.

To avoid the mess around terminals from hydrogen sulfide (the green yuckies), place anti-corrosion pads at each terminal.

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Hydrocaps

These are a wonderful invention that replace the normal battery cap. Inside the Hydrocap is a catalytic converter that turns the hydrogen gas back into water. This reduces battery maintenance, almost eliminates hydrogen gas from the interior, and stops the formation of the hydrogen sulfide on battery terminals. The only negative is that they add 2 inches to battery height.

Note that when you are doing an equalizing charge, if the charge rate is very high (commonly over a couple of amps per cell), the Hydrocaps should be removed.

Battery Temperature

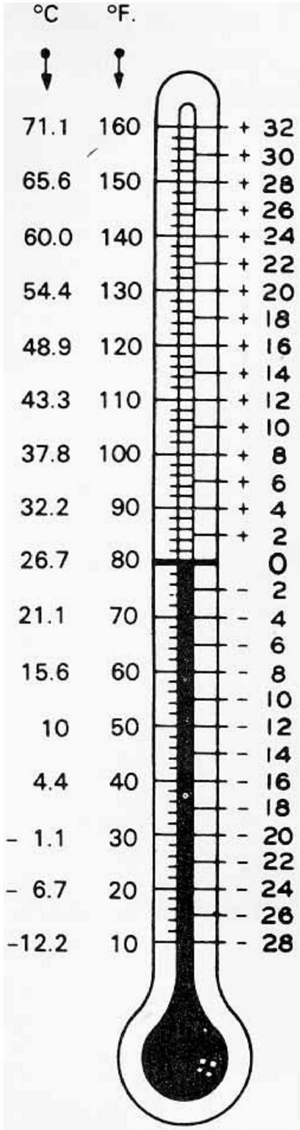
Batteries are happiest when warm, to a point. If the ambient temperature is much above 90 degrees Fahrenheit, or if their internal temperature rises above 125 degrees Fahrenheit, the battery life will be shortened from sulfation or by the plates themselves warping. If you expect to be cruising primarily in the tropics, and if the batteries are located in a warm spot, you may want to reduce the specific gravity of the electrolyte (your battery acid) to around 1,250 from a norm of 1,265.

On the other hand, if you are cruising in very cold climates, you may want to increase the specific gravity of your batteries. This helps to improve cold-weather capacity and reduces any chance of freezing the electrolyte.

Specific Gravity of Electrolyte

Before leaving this, subject we should discuss the type of electrolyte used in your battery. Its specific gravity is a function of the temperature at which the battery manufacturer expects the battery to be used. In colder climates, higher levels of specific gravity are used to protect against freezing, and to provide more amperage capacity at the lower temperatures. However, these more dense concentrations of electolyte are more corrosive and attack the grids and separators of the battery more quickly.

Batteries intended for tropical usage typically have a lower specific gravity, usually around 1.23 (as compared to 1.265 to 1.285 for cold-climate batteries). Their advantage is a longer lifespan.



To be accurate you should correct your specific-gravity reading for the temperature of the electrolyte (taken with a glass thermometer).

The correction factors for various F and C temperatures are shown in the right hand column.

For example, assume a hydrometer reading of 1.200. If the acid temperature is 100 degrees F (37.8 degrees C) you would add 0.008 to the hydrometer reading. This would give you a corrected specific gravity of 1.208.

Going the other way, if the hydrometer reading were the same (1.200) but acid temperature was 50 degrees F (10 degrees C) you would subtract 0.012 from the reading giving you a corrected specific gravity of 1.188.

Because batteries tend to heat up during their charging cycle these corrections are best made a couple of hours after you've completed the charge process.

STATE OF CHARGE	SPECIFIC GRAVITY AS USED IN COLD AND TEMPERATE CLIMATES	SPECIFIC GRAVITY AS USED IN TROPICAL CLIMATES
Fully Charged	1.265	1.225
75% Charged	1.225	1.185
50% Charged	1.190	1.150
25% Charged	1.155	1.115
Discharged	1.120	1.080

Here is charge/discharge data for two different levels of specific gravity.The specific gravity shown on the left is frequently found on batteries sold for use in temperate climates.That shown on the right is for the tropics. Note that you can have the electrolyte in your batteries changed if required by significant changes in usage.

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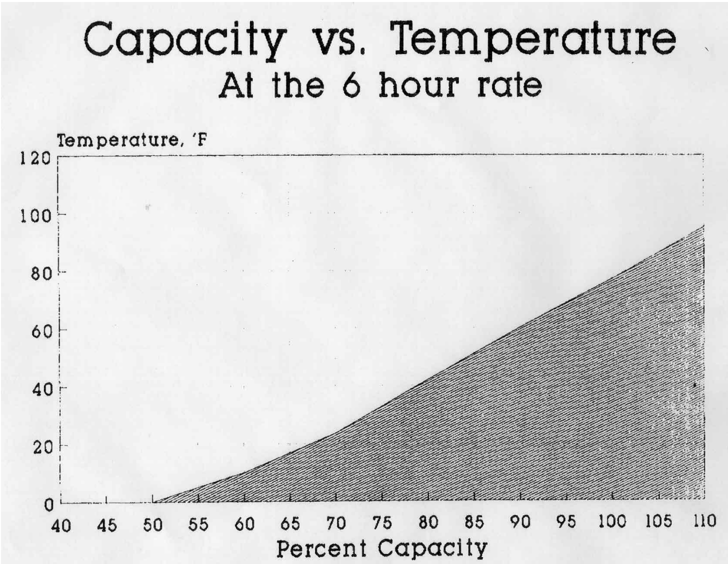
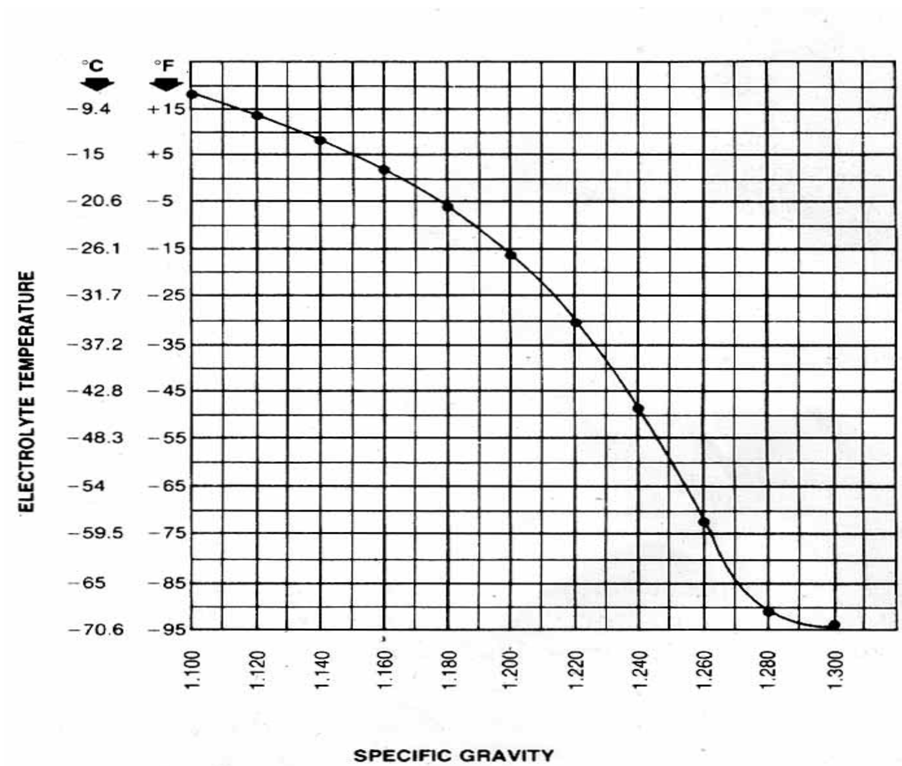


Temperature has a major impact on battery capacity, as you can see from this chart. The higher the ambient temperature, the higher the battery capacity in a given situation. Most batteries are rated at 77 degrees Fahrenheit. In a cold climate, with standard batteries and an ambient temperature of 60 degrees Fahrenheit, battery capacity would drop to just under 90 percent of normal.



As this graph shows, the higher the state of charge, the better the battery resists freezing.

If you intend to lay up for the winter, it is important to keep batteries fully charged so that they do not get into a freeze/thaw cycle.

The specific gravity can be adjusted upward a bit to compensate for cold-weather cruising, but there are limits beyond you'll have a problem with sulfation and a resulting premature death.

The Charging Cycle

The more efficient your charging system is, the less you'll have to listen to the engine or genset run, and the longer you can go between cycles. This makes for a happier diesel engine and enhances quality of life aboard. But defining what is required to develop an efficient charging system is a real challenge. There's even more diversity of opinion about this topic than about batteries.

Let's start by defining the parameters. What we're after is an approach to battery charging that allows us to recycle the batteries as quickly as possible without damaging the batteries, in keeping with the other requirements for diesel power. Thus, with an engine-driven fridge compressor, as we've already mentioned, the battery charge cycle should tie to the daily compressor running time, at least.

Charge Acceptance Rate

We then get into the issue of how hard to charge the batteries. This is usually expressed as a percentage of the bank's capacity per hour. If you have a 500-amp-hour bank and charge at a 20-percent rate, that would be a 100-amp charge on the ammeter. Here's where the experts disagree: Some say 10 percent should be the maximum. Others say it really doesn't matter — the battery is a self-regulating mechanism, and as the charge builds up in the battery, the internal voltage rises, causing the alternator or battery charger to cut back. The latter school of thought also says you can charge up to half the battery's capacity on an hourly basis.

My own experience tends to validate the "hit' em hard" theorists. We've used high charge rates for years without difficulty. At the start of the charging cycle the alternators may be going full bore, but within 15 or 20 minutes (depending on battery state) the alternators cut back on output as internal battery voltage rises.

Which brings us to the charge-acceptance curve. When the charging cycle starts, the batteries will take everything the alternators give them. But as they approach the 75-percent-capacity mark, internal voltage begins to rise and charge rate tapers off. This means you can really pump the amps back in for the first part of the cycle, but getting that last 20 to 25 percent takes a long time.

If you look at this in terms of amp hours consumed, between the 80-percent discharge level and 20-percent discharge level, almost 100 percent of what you put into the battery goes toward charging the battery with an industrial battery. This number is closer to 90 or 93 percent with a more normal golf-cart battery. When you get to that last 20 percent, which is required for a full charge, the acceptance rate of the battery sharply decreases. At this point, as much as half of the charge goes into hydrolyzing the battery acid (i.e., turning it into hydrogen gas, etc.). At the same time, as part of the charging process, the positive plates are being corroded by the current that isn't going into the direct charge or the hydrolyzation. Eventually this corrosion will eat through the positive plates — one of the limiting factors on the battery life.

With this in mind, it starts to make sense when cycling on the hook to forget about the last 20 percent of capacity. Bring the batteries up to where the alternator really starts to cut back, then shut down. On the other end, by limiting the depth of the discharge to the 40- to 50-percent range, you extend the life of the plates. (If you have traction or other super-heavy-duty batteries, you can drain them further.) Hence the 30 percent of capacity figure mentioned earlier is a good starting point when considering how big a battery bank to get, if you're using conventional deep-cycle batteries. This approach, leaving the bottom for reserve and longevity, and the top because it takes too long to recharge, will yield the fastest recycling of the 30 percent of capacity used between charges.

Topping Off

Every now and then, however, the batteries should be topped off. Otherwise, sulfation becomes permanent and battery life and capacity is diminished. Topping off tends to occur naturally, since most cruisers move every week or ten days. If you power for three or four hours during the move, you'll be right back up to top battery capacity.

When you try to figure out just how long it will take to put amps back into the batteries, assume 90 percent of the amps you see on the charging meter will stick to the battery.

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Charging Voltage

The situation starts to get complicated when you look at "proper" charge voltage. It varies. If the boat is tied to the dock, a maintenance charge of 13.2 volts is about right. This is high enough to keep the plates at their best, but not enough to heat the batteries and consume water. When the shore-power cord is cut and diesel power is doing the charging job, things change drastically. On the hook, 14.4 to 14.8 volts works well for a fast daily cycle. But this voltage is too high for long periods of powering, as it will overheat the batteries and gradually consume water. For powering, lower the voltage to about 13.8 volts.

Gel-cell batteries will not tolerate high charge rates. Check with your specific manufacturer, but these typically charge at between 14.2 and 14.4 volts.

Note that charging voltage should be checked directly at the battery bank. At the alternator or panel there can easily be a reading difference of 1/2 volt or higher, due to the voltage drop between the alternator and batteries.

Equalizing Charge

Remember those lead-sulfate crystals messing up the plates for lead-acid batteries? Well, the way to get rid of most of them is with an equalizing charge. In this case, after a full deep cycle, bring the batteries up on a normal charge basis. Then, having topped out at that voltage, crank the volts up to the 15-to-16-volt range for three to six hours. Do this every six to eight weeks in temperate climates, and somewhat more often in the tropics. (Be sure to check that the electronics won't suffer at these higher voltages.) The equalizing charge gets various individual battery cells as close to each other as possible.

The first couple of times you do this, you'll have to check each cell with a hydrometer. One cell will probably be lower than all the rest, even at the end of the process. Once that cell has been identified, you can go back and check it toward the end of each equalizing charge. This one will let you know when you're up to snuff on the entire bank.

ALTERNATORS

A few basics are in order. An alternator produces power when a wire breaks a magnetic field. Since the design of the alternator inherently causes the current flow to reverse itself with each alternator revolution, the power is in AC form. This doesn't do much good for the batteries, so a series of rectifier diodes are installed in line to smooth out the power pulse, producing heat and direct current in the process. (In effect, half of the power goes up in heat.) The amount of power produced, or the amperage, is a function of the strength of the magnetic field and alternator rpm.

A regulator senses battery voltage and regulates voltage flow to the field coil (and hence the magnetic force of the field), in turn controlling output of the alternator to the battery bank. It does this by cycling the power on and off in quick pulses, typically at 500 to 1,000 cycles per minute.

Most marine diesels are automotive adaptations, as are their alternators. Automotive alternators aren't designed for charging, but rather for maintaining the battery when lights, radio, etc. are in use. Therefore, they don't do much of a job at charging your batteries. The job will eventually get done, but in the process you might end up listening to the engine for hours a day.

Output Curve

The output curve of the alternator is crucial in our application. You want an alternator capable of putting out lots of power at low speed, so that you get a decent charge when the engine is being used as a genset at idling speed or just above. A typical automotive alternator doesn't start to maximize output until reaching cruise rpm.

By varying the amount of wire and the ratio of the wires in the various parts of the alternators, engineers can increase the amount of power at the low end. However, this is a zero-sum game. Increase low-end output, and top output is reduced. The total power output of the alternator can be increased by making the magnetic field stronger and cramming in more pounds of copper wire into a given size of case.

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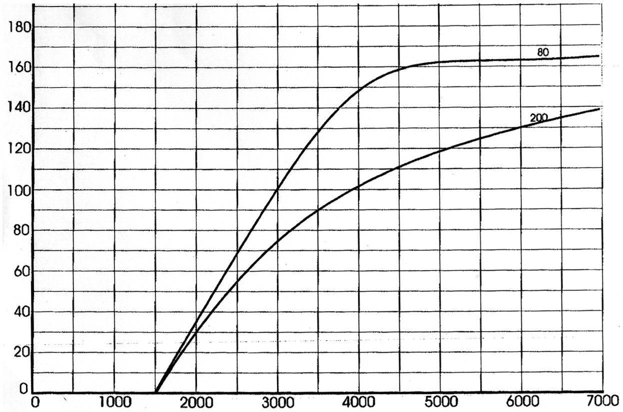
Heat Impact

Alternators are adversely affected by heat, both internally generated (which is tremendous) and engine-room ambient temperatures. If a given unit puts out 75 amps at 80 degrees Fahrenheit, at 200 degrees Fahrenheit this might drop to 50 amps.

The answer is to employ an alternator that puts out plenty of amps in the heat and rpm ranges in which you expect to operate. An output curve on prospective alternators will help to make an apples-and-apples comparison, as long as the curves are based on the same ambient temperature.



This shows the difference in hot and cold output of a Balmar 91-150 alternator. The upper curve is based on 80 degrees Fahrenheit temperature. The bottom curve is a more realistic 200 degrees Fahrenheit. (Courtesy Balmar)

Rpm Ratings

While output curve is being investigated, there are several other things to look at. One is the permissible rpm range of the alternator. The higher this is, the more the alternator can be overdriven — i.e., geared up with a large-drive pulley. Suppose the alternator has a capacity of 10,000 rpm at the top end. If you normally cruise the engine at 2,500 rpm (tops), a 4-to-1 pulley ratio could be used. This would keep the alternator within the maximum allowed speed, yet give a good gearing-up at lower engine speed. In this example, if the engine were idling at 1,000 rpm, the alternator would be turning at 4,000 rpm. Since most output curves begin to flatten out between 3,500 and 5,000 rpm, you would probably get close to full output at fast engine idle.

If you expect to use the engine at idle as a charging source, you will want the largest diameter drive pulley and smallest alternator pulley practical. This is a more complex issue than at first meets the eye (and is fully covered in the section on V-belts). Usually, 2 3/4-inch (70mm) is the smallest alternator pulleys go. If you overdrive this with a 10-inch (254mm) power take-off pulley, you will have some serious output at low engine rpm.

Case Size

The bigger the alternator case, the more wire you can cram in and the higher the output you can achieve. At the same time, bigger cases with moderate amounts of wire have more space for air flow, run cooler, and last longer. Alternators typically come in three standard case sizes: 6-inch (150mm), 7 1/2-inch (190mm), and 8-inch (200mm).

Engine-Mounting Issues

Alternators consume significant amounts of horsepower. Without friction, it takes 1 horsepower for every 750 watts of output. With frictional losses the figure is more like 550 watts per horsepower. So, a 120-amp 14.5-volt alternator output means you are pulling 3 horsepower off the front end of the engine.

Then there is the diesel power pulse. Diesel engines do not rotate smoothly. Rather, they jump as each piston fires. You don't notice this because of the rapidity of the firing sequence, the dampening effect of internal balancing, and the flywheel — but the alternator feels these pulses. The combination of high horsepower requirements and this power pulse makes life tough on alternator brackets. Most automotive engineers design brackets that work well on cars but that fail after a few hundred hours on a marine diesel. There are no hard-and-fast rules, except to make brackets three times as strong as seems reasonable and to inspect them frequently.

Another issue has to do with the front bearing and oil seal on your engine. After 1,000 or more hours of asymmetric loading, if the crankshaft and front bearing are not up to the load, the front oil seal will begin to break down (or premature bearing wear). This can be mitigated by keeping

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the power take-off pulley as close the crankshaft bearing as possible. If several devices are being driven at once from the PTO pulley, make sure the highest load goes on the inside. Even better, try to balance the load between two devices pulling in opposite directions.

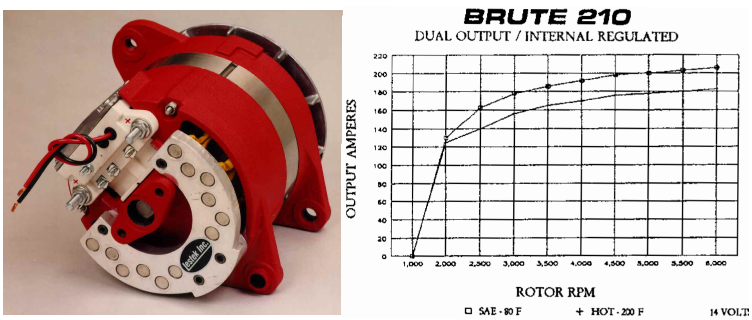
All engines have a PTO pulley rating that will indicate maximum load — usually based on the PTO bolt pattern, or crank-shaft keying — as well as sideways pull on the crank shaft. There is often a curve that relates power available to engine rpm. More rpm gives more available power. Consult this data when designing or inspecting your installation.

Dual Alternators

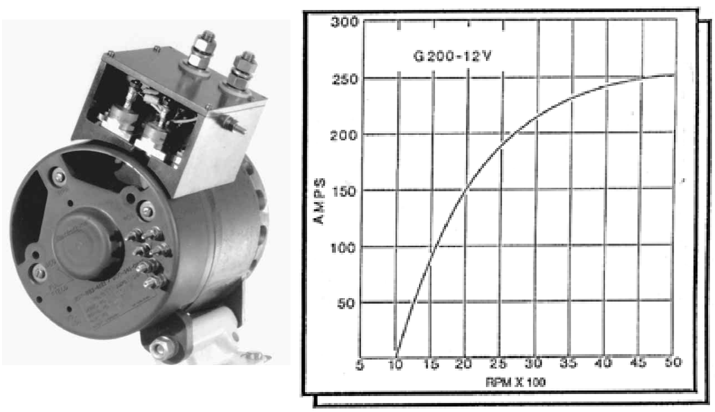
It is quite common to find two identical alternators in use at one time. If you have this type of system, they should be arranged as close to opposite each other as possible. This way the sideways torque of one cancels the other's out. You still have to be concerned with total load, in terms of the PTO capability, but at least side loading is no longer a problem.

If both alternators are charging the same battery bank, both must be run from the same regulator. Otherwise, once the charge cycle begins to taper off, one regulator (and its attendant alternator) will carry all the load. There is simply no way to set two regulators at the same voltage. Don't let anyone tell you different. Fortunately, dual-output regulators are readily available.

If your alternators are not matched — for example, if you have added a second larger unit to supplement the stock alternator that the engine arrived with — have the two alternators charge separate banks. This way you can use two regulators.



The Sundeer production vessels use Lestec alternators marketed by Balmar. Their Brute series, with external diodes and remote-mounted voltage regulator, works fine for 12-volt applications. However, we have found them to be unreliable for high-powered 24-volt applications. After burning up five of these on *Beowulf* we went back to Electrodyne!



Electrodyne makes the best high-output alternators. I would call this one (above) a medium-output unit. The diodes are externally mounted and are substantial in size (compare them to the Lestec). The output curve shows almost 250 amps at 5,000 rpm, and the alternator will do it!

In a 24-volt application we use a similar unit, but with diodes remotely mounted so the heat does not go into alternator windings. These 24-volt units put out about 50 percent more power.

Mega Alternators

On certain occasions you may want to use an alternator much larger than your engine can handle from a bearing side-load perspective. If this is the case, you can add a pillow block bearing to the front of the engine. This pillow block bearing, typically supported by a weldement attached to the front motormounts, takes the side load of the alternator.

Full-Field Operation

You must also ascertain if the alternator is able to operate at full field for long periods of time. This occurs when batteries are low and the regulator, sensing this, tries to boost output.

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When maximum is reached, it keeps the juice flowing full-bore to the field coils instead of cycling on and off as previously referred to. The alternator starts to really get hot then, since neither the field coil nor the stator windings (where the current is built up) have that “off” period in which to cool. This extra heat causes increased resistance, which reduces output, causing the alternator to try to put out more, which makes it hotter. You get the point. The heat can burn insulation, melt solder, ruin diodes, and make regulators very unhappy.

To build an alternator that will withstand heat, manufacturers increase wire thickness, use high-temperature solder, employ extra thicknesses of insulation, and, for really high-output units, remote-mount the rectifier diodes and regulators.

Very few alternator manufactures understand about the stress of full-field charging with marine deep-cycle batteries. Many times we’ve asked if a given alternator will operate at full field. “Sure,” the engineers always answer. We’ll run them for thousands of hours this way — then, a few days offshore en route to the South Pacific, the alternators start to burn up!

The way around this is to oversize the alternator relative to the battery bank, so it spends most of its life loafing.

Since the alternator is such a key piece of gear, you probably have a spare stored under a bunk somewhere. Why not take this out and mount it right on the engine? This doubles the capacity, reduces the load on both alternators, and probably lengthens their combined life.

24-Volt Alternators

Alternators designed to operate at higher voltages are subject to much higher operating temperatures than lower-voltage units. This is because they typically put out more total power or watts. A standard-sized 12-volt unit might be rated at 100 amps at 14 volts for 1,400 watts. That same casing might yield a 65-amp, 28-volt alternator for 1,820 watts. Since heat is a function of power, the higher voltage alternators tend to run hotter. As a result they are more subject to heat failure when they go to a full field.

This can occur inadvertently when engine speed is dropped as you’re maneuvering in harbor. If the batteries are low when the engine rpm drops, the output potential of the alternator also decreases. Although it might only carry the load of a low battery bank at a higher rpm, at the slower speed it drops into full field. If you begin to smell burning insulation a short time later, you’ll know why.

REGULATORS

The next factor is the regulator. Most automotive regulators today are inside the alternator. They may be impossible to adjust and are substantially more prone to heat failure sitting on the inside of the alternator. A better bet is an externally or remotely mounted regulator. This way it’s easy to replace and not subject to heat damage.

There are a number of ways to improve regulator operation, in the process making it more responsive to the varying needs found aboard a cruising yacht.

The simplest and least expensive strategy is to go inside the alternator to make a break in the field-coil control wire from the standard regulator. With a switch, you then select either the normal regulator or a rheostat that manually controls the output. This works well as long as you don’t forget the rheostat and overcharge the batteries, and as long as the alternator can withstand full-field operation! Also, although this works on older alternators with lower output, don’t try it with modern high-output units.

If the regulator is externally mounted, or if the internal regulator has an adjustment (a trim pot), the unit can be regulated from time to time. Unfortunately, this is difficult. You have to keep running back and forth between engine and voltage meter to see how things are going (unless a voltage meter is mounted near the alternator).

We’ve been successful at putting a switch on our regulators to allow us to select from three trim pots. One is set at a powering voltage, the second at the at-anchor rate, while the third is set for equalization.

When you adjust the regulator control voltage, do it with the batteries in a fully charged state, with a light load — say, 5 to 10 amps on the alternator. This is better than when the alternator is working hard.

A series of regulators that supplant normal units on the alternators are now on the market. These can do all the above, as well as vary the charge rate logic within a given cycle.

Bob Williams of SALT has developed a Pulse Width Modulator–style of regulator that works in conjunction with the digital processor on his SALT Monitor. This unit takes into account state of charge, battery type, charge acceptance rate, and temperature to optimize the best and fastest charge rate. Because it scans so much different data, it is not as easily fooled by the battery's counter EMF.

Alternator Sense Voltage

If you are using large alternators and have a good-sized battery bank, the charging rate will be quite high. This creates a voltage drop in the wiring between batteries and alternator, unless they are close together or you use large wire.

By setting regulator voltage when the batteries are pretty much topped off (the suggested method), alternator output is low and voltage drop minimal. So the regulator senses the correct battery voltage. But at the beginning of the cycle, when the amps are really pumping, resistance and therefore voltage drop may be significantly higher. If the voltage regulator senses voltage at the alternator (the norm), it will regulate the early part of the charge cycle based on a voltage that is higher at the alternator than at the batteries, due to the voltage drop in between. This causes the regulator to prematurely cut back on the charging rate. To avoid this problem, take both negative and positive sense wires from the regulator directly to the battery bank, with a fuse for protection at the battery end. This gives the regulator an accurate reading of battery condition during the early part of the cycle.

Installing a Second Regulator

If you carry a spare regulator, why not install it with a double-pole double-throw switch to select between it or the normal regulator? This way they can be set at different voltages.

BATTERY CHARGERS

It used to be that there was only one question when thinking about a battery charger — how big does it need to be? Nowadays, all sorts of electronics are involved (if you want them to be), in addition to the issue of stand-alone, voltage, cycles, or built-into-inverter models.

Capacity

Capacity needs depend on how you use the boat. Tied to the dock and living aboard with a DC fridge system, even a 10- or 15-amp unit will get the job done. Remember, it is working 24 hours per day. Larger battery chargers come in handy when you have a large bank and want it to do the odd equalizing charge.

AC-Power Decisions

If you plan to stay close to home, you need concern yourself only with a single-input-voltage battery charger. In the U.S., Canada, and parts of the Caribbean, this is 120 volts. Most other parts of the world require 240 volts. Then there's the question of cycles. Most battery chargers are cycle-sensitive. This means 60 cycles for 120-volt systems, and 50 cycles where 240 volts is the norm. Certain battery chargers work with both types of AC power but cost quite a bit more money. Sometimes it is simpler to invest in a two-to-one step-up or -down transformer, as long as your battery charger will operate on the different cycles. Typically, a charger designed for 50 cycles will be okay on 60-cycle current. The opposite is not always the case, although many 60-cycle chargers will work on 50 cycles if you reduce their output 20 percent or so. Check with your supplier.

Marine Construction

There's a big difference between marine chargers and those sold at the local autoparts store. They differ in the way they handle the grounding of the shore-power system. A land-style charger

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in a poorly wired marina can cause all sorts of problems for underwater metals. The marine charger isolates the ground from the ship's negative, reducing the risk of electrolysis. The isolated transformer makes all transfer and modification of power via the coils of the transformer. There is no direct contact between ship's system and shore power.

Resist the temptation to use an automotive unit on your boat. They are too dangerous.

Ferro Resonant

The simplest chargers, and the ones that have been around the longest, are based on a carefully wound transformer. The windings are set up so that without any fancy controls the batteries end up at a specified float voltage, typically around 13.8 volts.

These chargers cannot be used for equalizing. Also, some people feel that for the long term, a floating at 13.8 volts is a bit high.

Microprocessor Control

You can also opt for one of the new microprocessor-controlled sets. These have windings that allow for a higher voltage, along with some form of circuitry (frequently an electronic "chopper" circuit) that reduces voltage to required levels. These units are more expensive but will pay for themselves in battery longevity — as long as you take advantage of the equalizing capabilities.

Microprocessor-controlled chargers start out with a bulk charge, usually at 100 percent of the rated capacity. As voltage builds up in the battery, they cut back to what is called a "bulk" charging rate. After a set amount of time at the bulk rate (typically 3 to 6 hours), they reduce again, this time to the final "float" charge at which the batteries are held indefinitely.

For best battery life, the charger will shut down periodically, allow the battery voltage to drop, then come back on with the three-step charge cycle.

Inverter Chargers

If you are installing an inverter, most of the better sets come with a built-in battery charger. Some are quite sophisticated, allowing control of the three typical stages of charging, together with occasional equalization.

You will frequently be financially ahead to buy an inverter with this capability, rather than a simpler inverter and separate battery charger.

DC GENSETS

You may feel that an AC genset is overkill, but that you would really like some backup for the engine on the DC side. Or, perhaps you don't want to run your engine as a genset. If this is the situation, you have a variety of small DC gensets from which to choose. Some are air-cooled, very compact, and lightweight. Others are quite a bit fancier, with fridge compressors, alternators, and even watermakers mounted.

When putting together *Intermezzo II*'s engine room, we took a 5-horsepower Yanmar diesel and married it to a large DC alternator, a damage-control pump, and a fridge compressor. At the time I figured AC was a luxury, but that without DC and the ability to cool the fridge, we would someday be in trouble.

This little diesel was a hand-start model, saving a few hundred dollars and a small amount of weight. What a mistake — we rarely used the unit because it was such a pain to start!

The alternator and fridge compressor were mates to what was on the main engine, so they were interchangeable. If you plan to use the DC genset as anything other than occasional backup for the main engine, make sure it is water-cooled. Air-cooled diesels are too noisy.

Backup or Everyday Use?

This is a tough question. On the one hand, you put lots of low-load hours on the main engine by relying on it for charging, which is not healthy. It also forces you to carry more spare parts to keep the engine running. In addition, over time your maintenance schedule will be more severe. You could say that a good chunk of that extensive spare-parts list and maintenance schedule would go a long way toward paying for the genset.

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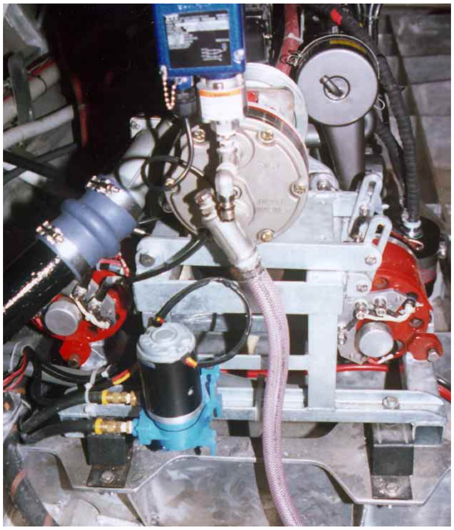
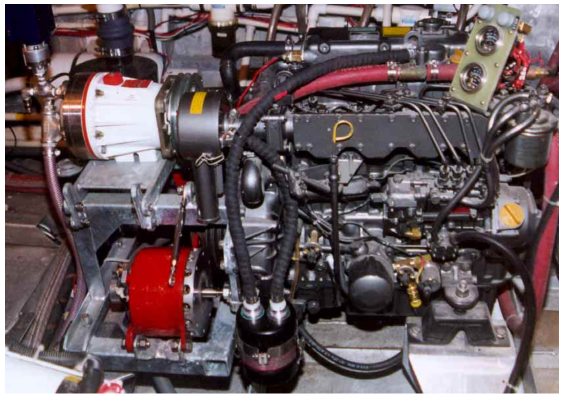


Two views of a recent DC genset we built for *Beowulf*. This unit is based on a 4-cylinder 50-horsepower Yanmar. (The same block is used up to 100-horsepower with a turbo.) There are two 166-amp (hot), 29-volt Electrodyne alternators and a 50-gallon-per-hour (190-liter) watermaker. This gear is optimized for full output at 1,750 engine rpm. The watermaker has a 10-percent rpm operating range, so within a given pressure setting the throttle can be varied a bit to optimize charging speed, and the watermaker will remain happy.

In normal cruising mode, on the hook, the two alternators kicking out their 332 amps only need to be run every third day or so, for about an hour and 15 minutes.

In reality, water usage is what determines the number of times the genset is run. Excluding clothes washing, water consumption matches our charging cycle. However, the genset is usually run when the washing machine is on (for power and water). This seems to cover electrical needs for the rest of the systems between washes.



Then you have the actual costs of mounting alternators on the main engine. If stock mounts are available, it's easy. But with custom mounts, the cost starts to catch up with a small genset.

Engine drive fridge and watermaker? These are more easily mounted on the genset and can be engineered to run at a more-or-less optimum rpm, as opposed to the varying requirements of the propulsion engine as you speed up and slow down.

On the other hand, adding a DC genset takes space, weight, and cash, all of which might be better spent elsewhere.

How do you decide? Having gone both routes, here's what we tend toward: First, if the electrical requirements are modest and you can accomplish half your goal with solar panels, I would invest in a good-sized battery bank and solar panels, and use the engine as a genset — hopefully only when moving the boat under power.

If the solar installation is a problem, if there's plenty of room for the genset, and if you want a big watermaker, the DC genset begins to look more attractive.

Doing It Yourself

Over the years we've built up a number of DC gensets for our boats. We prefer this to buying a stock unit when we can't find what we are after in charging capacity, and because we know in the end exactly what we've got! It typically costs about the same in the end.

It's better to spend a few extra pounds on the genset diesel, and get a unit that can be run more slowly. More cylinders run more smoothly than fewer cylinders. The difference in noise and vibration between a 1- and 2-cylinder diesel is amazing. And that continues up the line.

One-lungers are typically so obnoxious when running (to you and your anchorage neighbors), they the engine is often used instead.

Look at all the diesels available — Yanmar and Kubota are two of the better-known. If the choice is anywhere close, we go with Yanmar, as these are true marine diesels and tend to run more quietly than other brands.

The same rules about brackets, PTO loads, and pulleys apply to gensets. Look carefully at the load capability of the ends of the engine. Frequently you will be pulling power off the flywheel instead of the PTO (the flywheel can usually handle more torque). Sometimes both ends are used.

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ALTERNATIVE ENERGY

The most exciting thing about the charging systems available today is the aspect of incorporating wind, solar, and water energy sources. How these sources are used varies with the overall systems philosophy of the boat. There are several basic approaches. The most ambitious is total replacement of diesel or shore power without altering life-style. Sometimes it's more practical, however, to look toward a partial approach, supplementing perhaps 50 percent of the daily requirement. This assumes that by doubling the batteries' time between charges, you may naturally be running the engine every fourth or fifth day to move the boat. In this scenario, if the engine fails, your life-style can be modified to meet the capacity of the alternate sources. Last, you may just want to keep batteries topped off without depending on the costs and potential electrolysis problems of shore power.

One key element in your analysis will be the fridge system. If alternative energy is to be seriously considered, you'll want to be able to run the fridge/freezer compressor with DC power, or with AC via an inverter (but this is much less efficient than DC).

TOWING GENERATORS

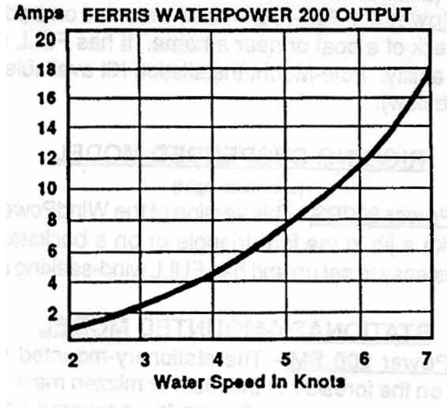
In the mid-1970s my dad sent me a prototype towing water generator developed by Hamilton Ferris. A few previous units had been used in the OSTAR. What a difference it made aboard *Intermezzo*. This little unit would put out between 4 and 7 amps as we sailed along at our usual 5 1/2 to 8 knots, yielding an average of about 125 to 150 amp-hours per day. This was enough power to cover the autopilot, radar (at night), and most other electrical gear. Now, of course, towing generators are a common sight, and a number are available with substantially increased output.

Enlarging propeller size and flattening pitch increases output at low speed. But if the prop is too large or the pitch too flat, the generator will overheat, and the trailing prop will dance around like crazy at higher speeds. It may take some experimentation to get the best compromise. Lengthen the tow rope. Use a smaller prop, or one with more pitch. Add weight to the end of the tow rope. We used to slide a piece of heavy pipe over the towing shaft to weigh it down.

Be aware that the trailing prop will torque itself to one side, usually to port. It should be mounted so that it torques away from the centerline. This allows you to use a taffrail log and fishing line at the same time. If you ever get one of these tangled with the taffrail generator, you'll understand Alexander's solution to the Gordian knot!

A considerable amount of load is on the tow rope at speed, so the bracket holding the generator should be through-bolted. Keep the gimbals well lubricated in order to let the generator easily track the prop as it moves on the wave faces. Choose an installation spot as far from the cockpit as possible, so noise level will be reduced. Allow plenty of room for the generator to rotate. It will swing an easy 30 degrees from side to side. Wiring ought to be large enough so that voltage drop is not a major problem and is sealed from moisture. You may want to use a blocking diode to prevent backfeeding in light airs. (Current flow will reverse and the battery will begin to turn the generator at slow speeds.) However, a diode costs 7/10 volt — that's about 5 percent off the top. It's more efficient to turn off a switch when going slow, so that the batteries don't backfeed.

The Ham Ferris rig shown here has provided power on many passages. Just remember to mount it on the port side, so prop torque walks the prop and line out away from the boat. If it is mounted to starboard it will eat any fishing lines or taffrail logs streamed from the port side. (Sea Air Land Technologies photo)



If you multiply the amps in the left column by 24 hours, you can see that it doesn't take much boat speed to generate some real power!
At left is a close-up of a typical towing generator.

Of course there will be fuses or a circuit breaker not too far from the generator. If you're going offshore, carry a spare tow line and prop unit.

Periodically check the condition of the tow rope at the prop as well as at the generator end. This is easier said than done, as with any speed on, the prop is spinning. So, to check you need to heave-too.

Dave Wyman has come up with a clever solution to this problem. Split one side of a large funnel, then slip it down the tow line. The funnel will shroud the prop, making it impossible for the waterflow to rotate the prop and easy for you to pull it in with the boat still moving forward.

Now, this wonderful device does not come without its problems. We've already alluded to noise, which can be very annoying. Then there's drag. I figure that in moderate airs — say 12-knot broad-reaching conditions — on *Intermezzo* our trolling generator probably cost 2 to 4 miles per day. But then you have to weigh against this the ability to steer the boat more aggressively with the pilot, which means you can carry more sail. So, in the end, I doubt it really cost us anything significant.

PROP SHAFT POWER TAKE-OFF

If you have a fixed propeller or a variable-pitch Saab or Hundestadt-style prop, it's possible to use it for generating power. By combining a large drive pulley on the shaft with a small pulley on the alternator, and a low-speed alternator such as is used in delivery vehicles (they spend a lot of time with engines idling), considerable power can be generated.

There are several problems, however, with this approach. First, there's a tremendous amount of drag from the large fixed prop. Second, the prop has to overcome the drag of the transmission and miscellaneous bearings before it will generate any power. Third, the constant spinning of the prop is annoying as hell. You hear and feel this rumbling sound day and night. At least with a variable pitch prop, the blades can be feathered most of the time.

Once the prop shaft gets up to speed, tremendous power is available to drive the alternator. However, shaft rpm's will be low, so you need a very substantial step up in pulley ratio. Go with the largest shaft pulley you can mount, hopefully 10 or 12 inches (250 to 300 mm) in diameter, with the smallest alternator pulley, something in the 1 1/2-inch (40mm) range.

A hybrid solution is available with a Max-Prop feathering prop. If the engine is turned on, and the prop put into reverse, and then the engine shut down, the prop will stay locked in reverse. This is substantially more efficient than forward for absorbing power from the water. Then, when charging is finished, simply start the engine, drop the prop into forward, and allow it to feather.

Using a shaft alternator on a fixed prop is not a good trade-off, in our opinion. But using one with a feathering or variable-pitch propeller can be a bonus.

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SEPARATE CHARGING SHAFT

For lots of power efficiently generated, go with a totally separate prop shaft dedicated to generating DC power. We started playing with these years ago on *Wakaroa* and *Intermezzo II* and have subsequently fitted them to a number of other yachts.

It will take some experimentation to get this system right, but here's the basic approach: Install a second shaft, preferably facing forward and located so that the prop stays in the water when the boat is heeled on both tacks. Hopefully this will be aft, away from anyone's bunk, as there will be a persistent noise attached to the operation.

The prop shaft enters the hull via a shaft log and stuffing box, just like the engine prop. Use the low-friction LASDROP-style stuffing box. At the end of the shaft is a small P bracket for support. If the shaft runs aft, the bracket is ahead of the prop. If the shaft runs forward, the shaft is still ahead, protecting the prop from debris.

A large pulley is put on the inboard end of the prop shaft, usually about 8 inches (200 mm) in diameter. A bearing, preferably sealed, will be needed just before the pulley to take side thrust. A soft-mounted low-speed alternator is then belted to the shaft, using a 2-inch pulley.

With a delivery van–style alternator such as the Electrodyne 80LC, you'll generate an easy 15 amps at 7 knots and 25 to 30 amps at 8 knots, using a 12-inch (300mm) diameter prop with about an 8-inch (200mm) pitch. Increasing diameter to 13 inches (325 mm) will have a substantial impact. The charging propeller is placed on the shaft in reverse — i.e., opposite its normal direction. Don't forget, the bigger the prop, the more drag. It's better to experiment to get a realistic usable output at normal cruising speed, remembering that engineering requirements vary from boat to boat. Generating heaps of unusable power only makes for a slower day's run.

With *Intermezzo II* we found that the charging prop worked great in the trades. It provided power to run fridge, inverter, and everything else. However, for all other sailing we would remove the prop to reduce drag and noise. It seemed the engine was on almost every day anyhow.

Today we go with bigger battery banks and bigger alternators, using the engine when powering to bring the batteries back.

This is the installation on *Intermezzo II*. It worked like a dream, taking care of 100-percent-plus of all power needs. A bonus was that we could tell how fast we were going by the noise it made. At 16 knots, surfing off a wave, it would start to cavitate, signalling us to take a look at the speed to see some exciting numbers.

We put forward-facing shafts on several of our motorsailers (this one is on the Deerfoot 74 *Interlude*). Facing forward positions the prop more in line with the water flow and is probably 15 percent more efficient than facing aft.

The only negative is in hitting things, since the prop is not protected by the P-bracket. However, this has not seemed to be a problem.

A side benefit is that the alternator is relocated aft to the back of the lazaret. This moves a large noise source farther from living quarters.

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WIND GENERATORS

I have mixed feelings about windmills. On one hand, when they are cranking out that free energy, they're wonderful. On the other hand, they are very noisy, and that noise goes up and down with the wind velocity.

What concerns me most, however, are the safety issues. A windmill can easily remove your hand or slice open your head. There are several examples of people losing their lives to these units.

If you plan to use a windmill, do so with the utmost care and caution. Treat it like a loaded gun. Both the gun and the windmill can quickly kill.

Installation Safety

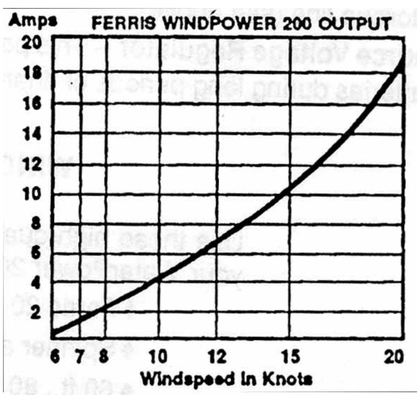
This means locating the windmill so that it does not swing over anyone's head, and so that a blade flying off will not come forward and harm a crewmember sitting in the cockpit.

This leaves the foredeck.

Most permanent installations are on the stern. We feel this is too risky, even if the odds of failure are low.

The ideal location is right on the bow, perhaps on a pole fitting in a socket that has been welded to the bow roller. Rotational angle would be limited by the headstay, but on the hook this should not be a problem. The bow forward installation has the further advantage of keeping the noise as far away from the living area as possible.

A Ham Ferris towing generator with a 60-inch (1.52m) blade (right and below). This unit starts charging at a very low speed, according to the accompanying graph, and has a centrifugal over-speed brake. (SALT photo)



We first saw this variable-pitch windmill (right) in New Caledonia in the late 1970s. With a centrifugal pitch control, it started producing power at a very low windspeed — around 6 knots or so — yet could also be flown in strong winds. The blades would simply feather themselves the faster they tried to spin.

Jim Schmidt ordered one for *Win'son*, which is still aboard *Wakaroa* 18 years later.

What stopped us with *Intermezzo* was our fridge system. With engine-drive refrigeration we still would have had to run the engine every day.

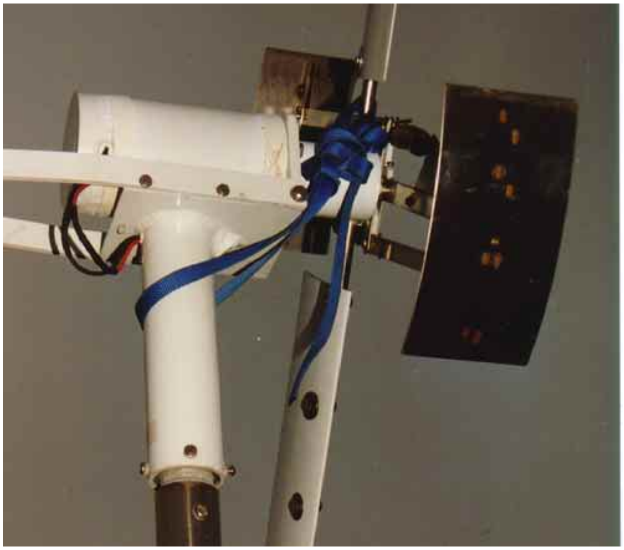
Use as a Towing Generator

Many of the windmills can also be used as a towing generator (where they are far more effective at generating power under way).

This will involve a taffrail level installation of the generating unit, a long length of stiff line, and an outboard prop on a metal shaft (usually about three feet — (0.9 m long).

It is usually best to mount the towing generator on the port side of the boat as prop torque will take the line and propeller out to port (and away from fishing or log lines).

These two photos show the over-speed brake on a Four Winds windmill. This unit, like most U.S.-made windmills, is based on a DC motor.



Output

Output varies with wind speed, and as most areas of the world have pretty light wind, the better the low-end output, the more useful the windmill will be. Getting better low-end is achieved with larger props — bigger is definitely better. You'll want the best-quality blade, both in finish and balance, as this has a big impact on longevity and vibration noise.

Overspeed Issues

Look carefully at overspeed provisions. If a squall blows through, does the unit have a reliable overspeed clutch, or do you have to go forward, grab the tail, and feather the prop to slow it down? Many manufacturers offer centrifugally operated brakes.

A very clever approach to this was developed 10 years ago by Wardy Ward, an old California sailing buddy turned New Zealand farm boy. Wardy's windmills used a simple centrifugally operated counterweight to control prop pitch. As the prop accelerated, the weights forced more pitch into the blades and slowed them down.

From time to time we've seen smaller windmills, 2 to 3 feet in diameter, that can be permanently mounted. The output of these units is so low because of their small blade size that I don't think they make a lot of sense.

Regulating Output

Sitting on the hook in a good breeze, many windmills on the market will generate 200 or more amps per day. Unless you have huge electrical loads this will quickly charge the batteries. You then have to look at some form of charge controller.

Because you are charging with a generator there is no field current to reduce to limit charge levels. So you have to look to other means. The first and simplest thing to do is to simply turn the windmill away from the wind. However, this requires your attendance. Too often the batteries are fully charged and the breeze comes up on a dark, rainy night, just as you're drifting off to sleep.

The alternative is to divert the output to a resistance shunt. The shunt simply turns the power into heat. With an AC-powered water heater and an inverter, this can easily be accomplished, for a while anyway, by turning on the water-heating coil.

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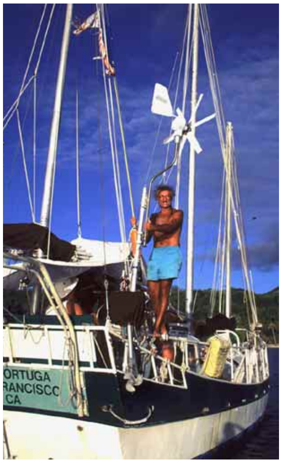
Several manufacturers now make automatic charge regulators that work in a three-step process, just like the sophisticated battery chargers that work on shore power. At the end of the charge cycle, excess power is diverted to a resistance shunt and worked off as heat.

You may be wondering, why not just open the switch to the battery? This does stop power from going to the batteries. However, deprived of the battery load, the windmill has no restraint and so can rapidly accelerate. This increases noise levels and can be dangerous as centrifugal forces quickly build up.



We've seen many Aerogen windmills (above and right). For small requirements, or to keep the batteries topped off on the hook, they make sense. But for heavy usage, their output is too low and starting wind requirements too high (10 knots or so). However, they reportedly do well in high winds and are relatively quiet — a function of many small-diameter blades.

Unlike U.S. models, which are usually generated-based, these models use an alternator to produce AC current that is rectified with diodes in the same manner as the engine alternator.

Two different approaches to mounting. Far left: Pole-based, attached to the mizzen mast. Note the tail line for feathering the windmill in squalls. At first these seem like a good way to go. However, if you have a cockpit ahead of the mizzen, the blades are directly overhead. Also, any noise made by the windmill is transmitted down the mizzen mast and magnified.

The adjacent photo shows a foredeck installation, where the windmill is hung from the jib halyard and bridled between headstay and mast.

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SOLAR PANELS

Of all the alternative forms of energy available, the one I get the most excited about is solar. With no noise, no maintenance, and very little hassle, you get lovely, clean watts from the sun. When a solar array is cranking out power, there's a wonderful feeling of getting something for nothing. Of course, there are a few trade-offs. The panels are expensive and have to be mounted somewhere, but in the end they're usually worth it.

How Much Capacity?

The first question is how much power is really needed. For boats with simple systems doing without refrigeration, a few panels will easily take care of your needs. But as things get more complicated, there will rarely be enough space aboard for panels to take care of all the requirements.

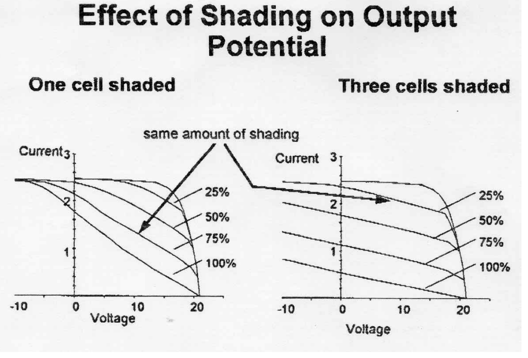
I think it's more practical to use solar as a backup in case of loss of engine power and as a supplement the daily charge cycle. A battery bank capable of going two days without a charge (using the 30-percent capacity discussed previously), together with a solar array providing half of what is needed on a daily basis, will let the batteries last four or five days between engine charging.

Another way to define requirements is with the fridge compressor. If there's enough solar power to keep the fridge even, you can leave the boat unattended for long periods of time and not worry about finding the freezer thawed when you come back. This also eliminates the hassle of someone having to come on board to run the engine every day or two for fridge maintenance — a real blessing if you want to get off the boat for a week to do some sight-seeing inland.

Solar Output

How much power can you get per panel? That varies with weather, declination of the sun (angle of the panel to the sun), and the amount of shading. Siemens Solar has a program that allows you to input various solar arrays and check output in different locales around the world. When we were researching our system, we found that the data they gave us agreed with what our friends, the Naranjos, had found with their four-panel system. And when we finally got the system going aboard *Sundeer,* the results were as expected. With eight Siemens Solar M55 panels (their largest), we generated an average of 1,200 watts per day. The Naranjos, with half as many panels, averaged approximately half the output. These figures are about 15 to 20 percent under the optimum without shading, true to the predictions of the Siemens Solar engineers.

To determine how power output varies with angle, first calculate the angle of the sun to the panel. This is done by finding the difference between your latitude and the sun's declination. Say you're in Baja California during the winter, at 20ºN latitude, and the sun is down in the southern hemisphere at 20ºS latitude. Your difference in angle is 40 degrees. Using a calculator equipped with trig functions, key in the angle (40 degrees), hit the "sin" function key, and read the answer — in this case, 0.642. Multiply 0.642 by the flat panel output to determine available power. Alternatively, this predicts how much more power is available if the panels are tilted at 40 degrees to face the sun's declination.



Shading is not generally a major issue as long as you are careful with installation. The chart above shows what happens with shading. On the left side you have voltage drop from the entire panel if one cell, or a portion thereof, is shaded. It really hurts.

On the right is the same data, but spread over three cells. One cell shaded at 75 percent is affected a lot more than three cells at 25 percent each.

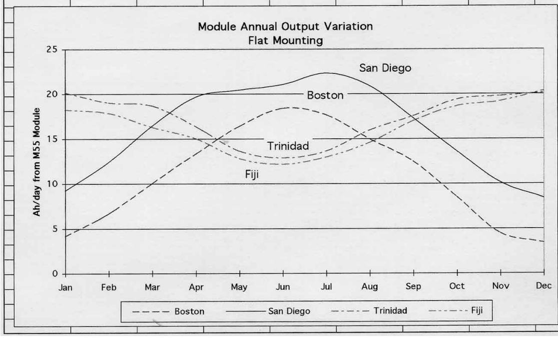
On *Sundeer,* with eight panels arrayed outboard of and behind the mizzen mast, we were frequently shaded by rigging. However, over the long term, net reduction in output from the theoretical optimum was in the range of 10 to 15 percent.

Solar arrays shaded by the boom or by a radar antenna fare worse because of the thickness of the shadows, compared to a relatively thin rigging shadow.

Wiring

The wiring of a solar array takes some thought. You can't just wire it into the batteries and forget it. For one thing, there's a slight reverse current flow at night, so an on/off switch or blocking diode needs to be installed in the line. I prefer the simplicity of the switch. Also, the blocking diode eats up a fair amount of power, about 7/10 volt.

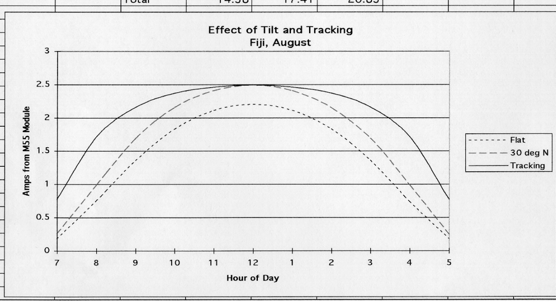
	Ah/day Flat Mounting			
	Boston	San Diego	Trinidad	Fiji
Jan	4.17	9.22	20.14	18.22
Feb	6.66	12.4	19.04	17.84
Mar	10.05	16.41	18.68	16.31
Apr	13.33	19.66	16.37	15.03
May	16.38	20.41	13.64	12.8
Jun	18.38	21.03	12.85	12.17
Jul	17.65	22.29	13.62	12.97
Aug	14.95	20.89	15.96	14.59
Sep	12.5	17.31	17.52	16.98
Oct	8.5	13.6	19.39	18.64
Nov	4.49	10.14	19.76	19.2
Dec	3.44	8.39	20.13	20.35



This graph shows projected amp-hours per day from a single Siemens M-55 panel in four different locations. Power production drops as the sun heads away in the winter. The drop is biggest in the high latitudes where the sun's declination is lowest in the sky in winter.

This data takes into account the Siemens computer-model analysis of typical weather conditions in each location. (Courtesy Siemens Solar)

Effect of tracking on output			
August, Fiji, module flat , tilted to 30 degrees, and then tracking at 30 degrees.			
Hour	Flat	30 deg N	Tracking
7	0.18	0.26	0.77
8	0.75	0.99	1.71
9	1.36	1.69	2.16
10	1.83	2.16	2.37
11	2.11	2.41	2.46
12	2.2	2.49	2.49
1	2.11	2.41	2.46
2	1.83	2.15	2.37
3	1.36	1.69	2.16
4	0.74	0.99	1.71
5	0.18	0.25	0.77
Total	14.58	17.41	20.83



Here is an interesting comparison between a flat panel; one that has an angle but remains pointing north; and a third that tracks the sun at the proper declination. This sample panel is set up in Suva, Fiji, in August (southern hemisphere spring).

What is immediately apparent is that the gain of tracking over proper tilt hardly seems worthwhile. For the same cost as setting up an autopilot-based tracking system (and with less complexity), you could add a panel or two and be way ahead. The same is almost true of angles compared to flat.

However, if you have a simple means of angling, this might make sense. (Data courtesy of Siemens Solar)

Batteries approaching full charge must be monitored for overcharge. This usually isn't a problem when living aboard, since the panels will rarely equal consumption. But if the boat is left alone for a period overcharging can become a problem.

There are solid-state solar regulators available to sense battery voltage and burn up excess power as heat. Unfortunately, they're not very reliable, and they waste power. Once again, the simplest route is the best. Rather than using a sophisticated charge controller, I prefer to disconnect several cells and leave just enough to trickle-charge the batteries. One way to control the cell output is with simple toggle switches on each unit. Simply turn on the amount of cells that you know will be required to keep things up while you're away.

You'll want to use extremely heavy wire to connect the cells to the batteries. The distance may be 30 to 40 feet to the batteries and back, and, for maximum efficiency, voltage drop should be minimized, due to the length of the run. I like to figure what's required for a 3-percent drop, then double the wire size.

Mounting

Solar panels have some very particular requirements in mounting. For one thing, they hate shadows. Even a thin shadow line from a piece of rigging will substantially cut the output of an entire panel. So locations all the way aft, where shadows are a minimal are ideal. Next, if practical, output can be increased 30 percent or more by being able to tilt the panels towards the sun. Ideally they'll be at right angles to the sun's declination. However, on most boats it's not practical to try to work in the gimbaling mechanism necessary for this. If space is available it will usually be less expensive to buy another panel to boost capacity.

Finally, it should be easy to fold them out of the way for docking and/or heavy weather.

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The last time we came through French Polynesia we saw quite a few French boats with solar panels mounted port and starboard, on poles off the aft deck. Each pole had a gimbaling feature to allow the panels angular adjustment. These were typically on 35- to 40-footers. It looked like the approach would be practical with two panels per pole if necessary.

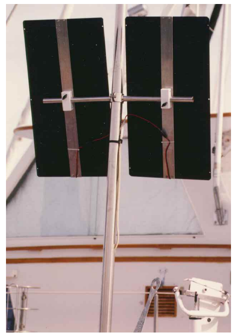
Another approach is to mount the panels on top of the dodger frame. While this does subject them to a bit more shading it's easy to execute and keeps the panels inboard, where they're protected.

On quite a few boats, fitting the panels to the pushpit makes the most sense. We took this approach on *Sundeer*, with panels inside and outside of the top rail. Both could be folded down when they were in the way.

Finally, for those considering a solar installation aboard a powerboat, the ideal platform exists on top of the deckhouse or flying bridge awning — lots and lots of space, with a minimum of shadows. The average 40-foot motoryacht could easily generate enough power to run fridges, supply lighting, and handle miscellaneous needs with 12 to 16 cells, and 16 cells will fit in an area 8 by 8 feet. The cost of such an installation would be less than a 4-kW genset!

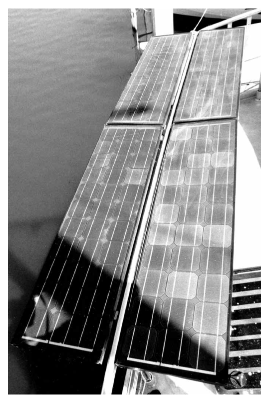


Three adjustable installations (above). If space is limited and you can't find room for a third panel, it makes a difference to be able to tilt and manually track.


Here are two simple installations (above) that can be made to manually track the sun as well as have the correct angle of declination. Both are simply supported on a single aluminum pole. Note the simple attachment hardware in the right photo.

With this type of system you always have the option of leaving the panels flat if you feel lazy or are off the boat for some time.


Three views of the eight panels on *Sundeer*. (above and left) Over several years of cruising we found that these provided about 15 amp hours per panel per day (at 12 volts). Four of the panels would stay even with the fridge/freezer if we left the boat. But opening and closing the fridge/freezer doors this would jump us up to six panels.

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Above: When panels are mounted on a radar arch, the antenna should be mounted below the arch so that it does not shade the array (as it does here).

Davits (left) are an excellent spot to mount an array. Take a look at the simple adjustment mechanism here — a couple of telescoping aluminum poles.

These two photos (above) both show a brace that can be tilted over the stern. The panel can then be rotated in a single axis on this brace. Being able to move the panel outboard or inboard (in crowded harbors) is a help. However, the single axis angle will not be very useful, as the stern would have to point north to make it efficient.

Dealing with Heat Build-Up

Regardless of the installation procedure, you do have to make sure of good airflow around the panels. They tend to get very hot in the sun, and the heat reduces output. The cooler the panels run, the more power you'll get.

Self-Regulation

Solar engineers have a rule of thumb for self-regulating systems using the higher voltage arrays: If you take the amperage output of each array and multiply it by 50, the result shouldn't be more than the deep-cycle amp hour rating of your batteries. Thus, by connecting a 3-amp array to a 150-amp-hour battery, you needn't worry about overcharging.

Type of Panels

As this is being written, there's really very little choice for seagoing solar panels. The problem is in the space limitation aboard. We need the most efficient panel-per-square-foot we can get. That leaves us with the crystal-based panels like those made by Siemens Solar, AEG, Telefunken, or Solarex. These are manufactured from crystals and convert about 13 percent of the sun's energy to electricity. There are amorphous film-based solar panels that are much less expensive per watt of power, but these take too much space to be practical, since their efficiency factor is about 5 percent. But stay tuned. Millions of dollars are being spent on research and development, and someday there may be a breakthrough.

One of the keys to a good solar system is choosing the right voltage for the panels. The manufacturers vary this by adding or subtracting cells from an array. Nominally, you need a solar array that produces 14.5 volts. However, in the tropics, as the cells heat up, they lose voltage. At 85 degrees Fahrenheit one volt is lost. At 95 degrees the loss is one and a half volts. If any sort of a blocking diode is employed, take off another chunk. Pretty soon the batteries can't get much boost.

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By adding cells to an array, however, the voltage is increased. For work in the tropics, arrays up to 17.5 volts are available. That leaves plenty leftover for heat and diodes. Of course, in cooler weather, with fully charged batteries, you'll have to watch for overcharging.

In the Real World

Sundeer was our first significant experience with solar panels. We had two goals. First, we wanted enough solar energy to handle the fridge system if we were off the boat so that we wouldn't have to worry about someone running the engine during our absence. The second goal was to supply a high-enough percentage of our power so that the engine would only need to charge the batteries only when we were moving the boat.

We used eight Siemens Solar M-55 panels, wired in a series/parallel setup to give us a nominal 24-volt circuit. We didn't use a regulator as we felt our battery bank was large enough (over 1,000 amp-hours) that this would not be a problem. As you can see in the photos, these panels were arrayed off the stern pushpit and so were shaded to some degree by the mizzen mast and shrouds.

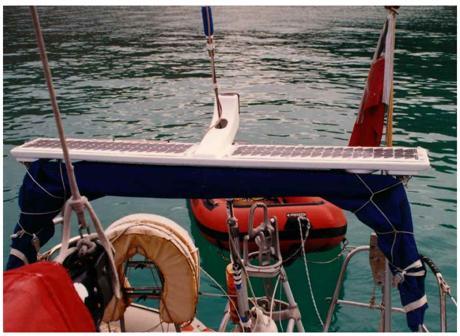
Over several years of cruising we found that we averaged about 1,200 watts per day of power generation. This was enough to cover about 65 percent of our total power needs. The batteries easily supplied the rest of the requirements.

When we left the boat, power needs dropped. The fridge/freezer stayed closed and other electrical devices were not run. In this situation, if we left with the batteries already charged, we'd fold down half of the panels. The four panels left would cover the fridge/freezer with something leftover for the burglar-alarm circuit.

There was a two-week period when we left the boat in Seattle, with its typically overcast weather. In this case we left all eight panels in place. When we returned to the boat, the batteries were fully charged.

Having lived with this system and watched the mizzen shadows play across the solar panels, I now feel that an array off the stern, clear of the boom, would easily be 25 percent more efficient. I feel that our target of providing two-thirds of total power needs with solar still makes sense, so I would take this increase in efficiency back in the form of a smaller solar array.

Sharp corners on panels (above and below) can be a danger to crew and sails. These need to be filed down, or better yet, covered with a timber cap.

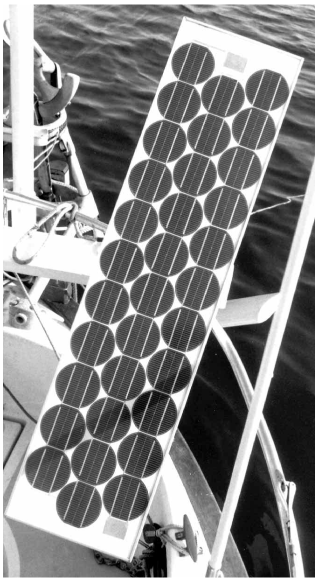


Above and left are installations that have trouble with shading. The radar and miscellaneous antennae will cut output significantly.

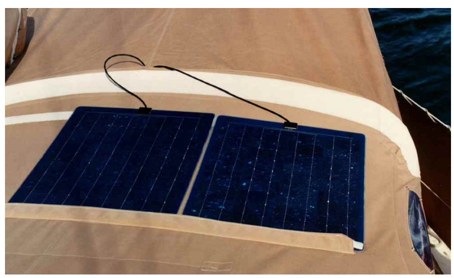
These units (above) are available at electronics stores for charging NiCad batteries. The solar cell can be used flat on deck, or can be angled to the sun.

The top three are all interesting installations.

Left: Four angled panels, which should create enough output to handle a small fridge system as well as lights and a tape deck.



Ideally, you would like to be able to angle panels in any direction, depending on where the sun is and how you are laying to the wind. Here are three simple approaches toward this aim.



Above and right: The correct installation over the dodger will require the boom to be swung out of the way at anchor. Even so, this is one of the best all-around places for a solar array. Note the handrail that has been built into the stainless rack.

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12 OR 24 VOLTS?

As vessel size increases, it starts to make sense to consider higher operating voltages. While 12 volts is the norm in small- to medium-sized vessels, 24 becomes alluring from 50 feet and up.

Why? For one thing, 24-volt gear tends to be a little more efficient, especially with electric motors and large inverters. Second, wiring size, weight, and bulk is cut in half. That may not sound like much, but a typical 60-foot (18.4m) yacht today carries over 1,000 pounds of electrical cabling! Reducing that by 50 percent is nothing to sneeze at.

Of course, there has to be a negative — in this case, availability. It is easier to get 12-volt gear than 24. So if you go the 24-volt route, you'll carry more spares in the electrical department. Also, some gear is just not yet available in 24 volts. Included are ham radios, many SSBs, VHF radios, cassette players, and certain forms of high-intensity low-voltage bulbs. This forces a dual-voltage system onto the boat — an added complication. The necessary 12 volts are really a pretty small draw and can be had in several ways. One is to use a solid-state "chopper," which takes 24 volts and cuts them down to 12. Choppers are pretty efficient, losing only about 20 percent of power transferred in the process. Or, you can tap the 24-volt bank to pull out 12 volts. For minimal use this is okay, but it can eventually lead to battery-life problems.

If you do tap a 24-volt bank, be sure that both 24- and 12-volt systems use the same negative terminal on the batteries.

Another way to go is to have a separate 12-volt system with its own charging source. There are alternators on the market that put out 12 and 24 volts for just this purpose. Or a 12-volt engine can be employed, with the engine's starting batteries also serving as the 12-volt source. Then the standard alternator on the engine (or genset for that matter) can do the charging chores.

AC POWER

There's nothing like a touch of household-type electricity to make cruising life more bearable. With modest amounts of power one can use a microwave, toaster, blender, or Cuisinart, not to mention various power tools like drill motors, saber saws, soldering irons, and grinders. Then there are the host of battery-powered devices that depend upon an AC source for charging. How could you consider going to sea without a Dustbuster in this day and age?

If AC is aboard in reasonable quantities, other options for fridge/freezer systems open up, a watermaker may find its way aboard more easily, and propane may be dispensed with as a primary cooking fuel.

SAFETY

The major problem with an AC system is that it runs at 110 or 220 volts and, if your body happens to become a path for the current, the experience will shocking for sure, and possibly life-ending. So it behooves anyone using AC power near the water to be extremely careful.

Rule one is always shut off all sources of AC power before doing any work on electrical gear in general, and AC gear in particular.

Second, never use AC equipment in bare feet or damp shoes. Dry boat shoes that insulate you from the potential ground of the hull or its equipment are essential.

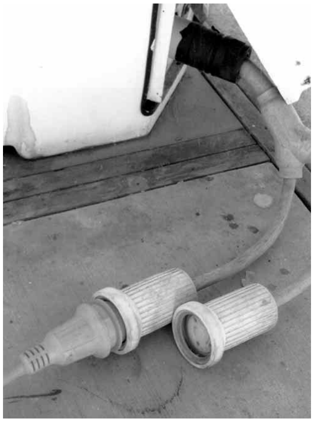
Third, be sure that all tools and appliances in use aboard are double-insulated.

Last, when hooking up to shore power, connect the boat end of the wiring first, leaving the final plug into the dock for very last.

AC BASICS

Let's start at the shore-power generator. There are two primary wires, the hot lead, and what is referred to as a neutral wire. The path of the power is similar to a DC system. The current starts out down the hot wire and returns via the neutral leg. At the power station, the neutral leg is also attached to a large plate buried in the ground. As you progress down the power lines and distribute power here and there, in each case the neutral wire is grounded, typically by attaching it to a metal stake driven into the ground. All of this works fine as long as your body doesn't become part of the circuit.

But say there is a problem in the wiring. Something comes loose inside, and a hot wire touches the case of some device. Because no circuit has yet been completed, no current is used, and so a



This is a "splitter" connection. It takes two-phase 220V and splits it into two legs of 110V, each of which is single phase.

The shore-power cord should come off the boat in a manner where it will not fall into the water, and where chafe is minimized or eliminated as shown below.

normal circuit breaker will not trip. However, if you touch the case while you happen to be grounded (by water, standing on the earth, etc.), the circuit will try to complete itself via your body to ground. To avoid the problems that would obviously occur with this scenario, the cases of all electrical devices are typically connected by a grounding wire back to the ground stake. With this wire intact, if a problem occurs where the hot wire hits the grounded case, an immediate short circuit occurs and a circuit breaker or fuse blows. If you were to happen to get involved with this circuit, very little if any current would flow through your body, as it would prefer the easier path down the ground wire

On-Board Wiring

Your AC circuits throughout the boat should be wired in what is called a "polarized" fashion. This means that each of the three plug points on all receptacles are wired the same at each receptacle. The neutral wire (white), hot wire (black) and ground (green wire) are always tied to the same point on the plug.

If you or anyone else does any wiring on the AC circuits, be sure to be consistent with this approach. Your life could depend on it!

Bonding System

All of the AC appliances and the electric plug receptacles are bonded together electrically via the green ground wire. This is in turn connected to the shore-power ground, unless you have an isolation transformer aboard.

This AC ground wire is also connected to the negative DC side of the vessels circuit and via the through-hull bonding system to the water. This bonding system is important for a number of safety reasons. First, proper lightning-protection measures require that all electrical gear be connected via a single bonding system so there is no potential between circuits during a lightning hit. Next, if there is an AC leak from a faulty appliance into the DC system, without a proper ground path through the water back to shore, anyone getting physically involved with the electrical leak is liable to provide a ground path.

The problem comes with electrolysis in the underwater fittings. If there is a difference in voltage (or potential) between your underwater fittings and those on a nearby vessel or dock, the "least noble" fittings will corrode away. Zincs will partially, but not totally, reduce this problem. The only 100-percent clean way to avoiding this is to not hook up to shore power!

Galvanic Isolators

What you can do, however, is insert a galvanic isolator in the grounding circuit. This uses a series of diodes to stop low-voltage DC current from passing through the ground wire, while providing a path for the AC current via a capacitor. It sounds pretty complex, but in reality it is very simple. However, be sure that the unit you employ has a capacity equal to your shore-power system and that it is properly installed.

If you have AC leakage aboard which is above the threshold of the diodes, the ground path will be made on the DC side and you will be back again with the electrolysis problem.

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Isolation Transformers

Isolation transformers offer both shock and corrosion protection. They do this in a very simple manner. Shore power feeds into one side of the transformer winding. A secondary winding magnetically induces power from the primary winding (which is connected to shore power), providing the power source for your circuits aboard. The shore-power circuit is grounded to the primary winding shield (case). The ship side of the circuit, however, may float (be ungrounded), or may be grounded to the secondary winding shield. In either case, any shorts or leakage to ground go no further than the secondary winding. This isolates you from neighbors and shore power in general.

If your system does not float, then you will want to tie the DC bonding system to the ground on the secondary side of the isolation transformer

The transformer will have to be rated to handle your largest loads. A 3-kW (25-amp/120-volt) transformer will weigh about 75 pounds (32 kg).

If 220 volts is the common shore power in your cruising vicinity, consider having an isolation transformer with two sets of windings. Use one set for low voltage (a 1-to-1 winding) and the second set for reducing the higher voltage (a 2-to-1 winding) back down to your normal current. If you have a 240-volt system and are cruising where 120 is the norm, the step-down transformer can be used to step up the voltage to your norm.

GFI Plugs

Each AC plug should have a feature called “ground fault interruption,” or GFI. The purpose of this is to act as a circuit breaker in the event of a short. This is significant safety feature, one you want to make sure is always operational. Your life could depend on it!

These GFI plugs are sensitive to moisture, and a buildup of moisture or salt in the plug or the appliance to which it is connected may trigger the disconnect. There’s a “test” button and a “reset” button on each GFI receptacle. Periodically trigger the test button. If the plug is working correctly, the red reset button will pop out. To reset the plug, simply push the red button back in until it clicks and is held in the detente position.

From time to time you may find a dead plug (i.e., one in which there does not seem to be any power). Assuming that you have power elsewhere on board, and the circuit breaker is on, odds are the GFI will have tripped.

CONNECTING TO SHOREPOWER

This issue is so important that you should acquire a basic understanding of AC power in general, and your relationship to shore power when you are about to connect to it.

There will be occasions when problems with the shore-power system can cause severe electrolysis of underwater metal parts. And the possibility of severe shock to crewmembers and swimmers nearby is always a possibility.

We strongly urge you to have a qualified electrician run through the basics with you, and be sure that you have them down pat. If you don’t fully understand the AC system, stay away from it.

Conventional Wiring

The green wire at the shore plug is supposed to represent ground. Whether it does, or whether it is shorted out, is something that needs to be checked before connecting to shore power.

Because shore-power plugs vary, make sure that the green or ground on the boat side of the circuit is connected to ground on shore power. The black or hot wire on the boat should go to the hot side of shore power, and the white or neutral wire of the boat should go to the neutral side of the shore power.

If you understand AC power and have a multimeter, you can check to be sure the proper wiring relationship exists. If you don’t understand how to check and/or do not have a multimeter, we urge you to find a technician who can do this for you.

Assume that the shore power is wired improperly until proven otherwise, and you won’t go wrong.

For maximum safety when connecting to shore power, one person should connect the plug, while another keeps an eye on the polarity indicator at the main panel. Because your on-board AC system is polarized, if you get a polarity warning signal when you connect to shore power you will know that the problem is at the plug or in the shoreside system. If you get this signal, disconnect from shore power immediately.

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Polarity Testing

We've discussed how your electrical system needs to be polarized on the boat. This also applies to shore power.

At some point in the AC power grid, the neutral (white wire) and ground (green wire) are connected. If there's a wiring screw up between this point and your boat, where the neutral and hot wires get crossed, then you've got a potentially lethal situation on board the boat (not to mention huge problems with electrolysis). Most shore-power panels come with a polarity tester built right in. If yours doesn't have such a feature, one is very simple to create. The easiest way to do this is to take a light bulb and connect one terminal to the ground wire and the other terminal to neutral. If everything's okay, no circuit will be made and the light will stay off. If, however, there is a polarity problem, you will have a completed circuit between neutral and ground, and on goes the light.

Foreign Power

Most of the world runs on 220 volts and 50-cycle power as compared to 110 volts and 60 cycles in the U.S. The voltage can be adjusted with a step-down transformer, but you are locked into the cycles.

As previously discussed, it is possible to buy isolation transformers with taps that allow stepping or down voltage, so you can kill two birds with one stone.

Cycles are only a problem with some 60-cycle transformers and electric motors. The 50-cycle system causes 60-cycle motors to run more slowly and heat up if under much load. However, as a practical matter we have not found this to be a serious problem with most on-board appliances. Many motors can be purchased today that run on either 50 or 60 cycles.

Foreign 220-volt dock power is usually configured similar to what we find at the 110-volt plug in the U.S. There is a live and a neutral which together give you the 220 volts, plus of course the ground wire.

AC SYSTEMS LOGIC

The simplest approach to using AC is to kick it in only when shore power is available. In this case, what you allow for in on-board wiring will be a function of the power available on the dock. In most cases service will be about 25 amps on a single line, or two lines at about 15 amps each. This provides plenty of power for a water heater, washing machine, and various tools and appliances. The wiring and circuitry needn't be particularly heavy for this sort of draw, although dividing a circuit-breaker panel into several sections makes sense from a maintenance standpoint. If you do bring two separate shore-power circuits aboard, make sure they are wired the same. If they have been "split" from a three-wire, 240-volt circuit, you will find the polarity different from one side to the other.

When you start to consider using AC away from the dock, the best approach is to be modest in the amount of power that will be needed. If you're prepared to stagger usage, run only one large appliance at a time. This lets you employ smaller inverters or generators, saving space and capital cost. Managing AC power use is really not that big a deal.

Of course, you may want to have lots of AC power available and to use household-style appliances throughout. What is lost on the generating side in cost, weight, and space, is gained back by the convenience of walking into the local department store to buy your appliances.

Capacity

If you investigate the capacity question in detail, you'll find there are two aspects. The first is running load, as we've just been discussing. The second is a little less straightforward. This is starting load. When an AC motor starts, a substantial surge of power is used — typically two to three times the normal running load. If you have a watermaker that takes 15 amps when running, odds are there will be a 45- to 50-amp surge for a second when it starts. The AC power sources will have to be able to handle this surge load.

Selector Switches

If you have more than one potential source of AC power, a selector switch is necessary. This switch enables you to select from a genset, cruise generator, inverter, shore power, or whatever configuration of AC you have aboard. The switches take up substantial space and are very expensive. But if they aren't used, and by mistake two sources of power feed the same circuit at the same time, sparks will fly!

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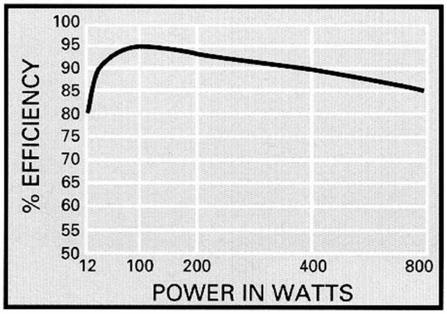
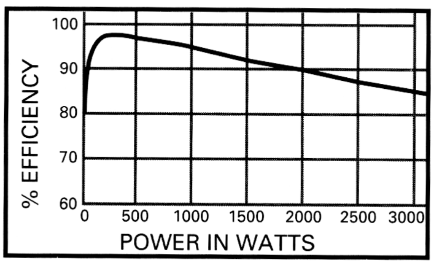


Picking an inverter that is the right size for your loads has a big impact on efficiency. The curve above is for a Trace Model 800, with a continuous rating of 575 watts. Notice how much more efficient it is than the model 2500 below, which is rated at 2,500 watts continuous output. For smaller loads, the smaller inverter uses much less battery power. On the other hand, as loads climb past 400 watts, the larger unit comes into its own. (Trace graphs)



INVERTERS

When we first left on *Intermezzo* in the mid-1970s, inverters were somewhat of a novelty. After two days of searching I tracked down a 300-watt unit in an electronic-hobby shop. It might come in handy with my power tools, I reasoned. While the concept was correct the hardware didn't live up to expectation. It would barely start a small drill, although it did run the electric mixer in the galley.

Two years later, lying at anchor in Rabaul in the Solomon Islands, one of our neighbors mentioned he had a 700-watt unit still in its original box. That sounded like a real waste, so I traded him our smaller inverter and some other gear. The larger unit now allowed us to run our miniature washing machine and, most important, a vacuum cleaner.

Of course these were inefficient pieces of equipment. We were lucky if we got away with a 50-percent loss in power conversion. So we always ran the engine to maintain the batteries when the inverter was in use.

MOSFET Efficiency

But technology marches on. And today, thanks to something called a field-effect transistor, or MOSFET, larger inverters are available with efficiency rates between 90 and 97 percent. It becomes practical to consider a whole range of AC equipment options with these inverters.

For starters, if a powerful DC alternator is belted on the main engine to maintain the batteries, the inverter can be used in much the same manner as a cruise generator except that it isn't rpm-sensitive. That's a big plus. This allows fridge compressors and watermakers to be run from the inverter in case the genset fails, with the engine keeping the batteries topped off at the same time. This provides an easy source of AC power whenever the engine is running.

If the battery banks are big enough, large loads can be carried for short periods of time without running the engine.

Several inverter manufacturers have units available that can be run in tandem, doubling capacity and providing a backup (at lower loads) in case of failure.

Defining Capacity?

In shopping for an inverter, the first question will be load. Load capacity is time-sensitive. An inverter may handle 1,500 watts for five minutes, but only 1,000 watts on a full-time basis. Next, check surge capacity. Most inverters are rated at two to three times normal capacity for starting the motor. Check efficiency and note where the curve starts to really work for you. Some models hit peak performance once they reach an operating load of 20 percent or so of rating. Look at the idling current, or what is referred to as overhead. The newest inverters consume just a few watts of power while waiting. This makes it reasonable to use them for charging battery-powered appliances.

Square Wave or Sine Wave?

Finally, a decision will have to be made on what type of alternating current output is needed. The early inverters produced what is known as a square-wave oscillation. This worked well with heating-type loads, but certain motors wouldn't take to it, and most microwaves ovens would barely work. Then along came modified square-wave inverters, which is what you normally find in this day and age. These work with just about everything. However, some microwave ovens prefer one brand of inverter to another. Check with the inverter manufacturers for what works well with their equipment.

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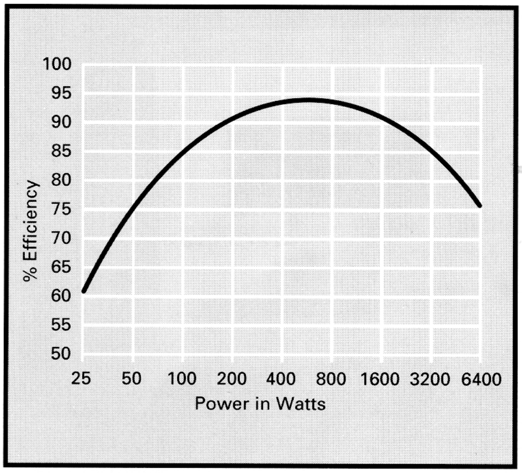

This efficiency curve is typical of a true sine-wave inverter. Compared to the modified-sine-wave inverters shown on the preceding page, it is pretty inefficient. Pick your operating range quite carefully, or you'll be wasting a lot of battery power.

Models are available with frequency stabilization, to maintain almost exactly the required 60 cycles. This is important for certain record players, cassette decks, and test equipment. However, we've always used unstabilized machines without difficulty.

Some manufacturers are starting to market true sine-wave inverters. This equipment offers interesting advantages, such as the potential of running in parallel with a genset or shore power to augment capacity for starting loads. True sine wave will also run electronic equipment quite nicely, as well as bread makers, which for some reason don't do well with the modified sine waves produced by most other inverters.

However, the sine-wave equipment so far is still less efficient and substantially more expensive than modified square-wave units.

Built-In Battery Charger

As we've already discussed, many inverters come with built-in battery chargers, some of which are quite sophisticated. This makes sense as the same transformer that is used for stepping up the battery current also goes from shore power back down to DC power.

Installation Issues

When the time comes to install the inverter there are several things to keep in mind. First, the efficiency and capacity of this equipment is related to its temperature, so a good flow of air will be needed. Ideally, the inverter will be mounted somewhat in the open. If this isn't possible, you can duct air to the cooling fan, or provide large inlet and escape grills for hot air. Under smaller loads, or when used for short periods of time, inverters may be installed in pretty tight areas.

The second question is distance from power source. Lots of amps are traveling from the batteries through the feed cables to the inverter. The resistance heat loss is a function of cable size and distance. Keeping the inverter close to the power source reduces the need for extremely large cables. If this isn't possible, be sure to size cables for maximum load and 3-percent (maximum) voltage drop.

With the ideal location defined as one with good air flow and close to the batteries, there is one last consideration — operating noise. Some inverters have an annoying hum when inverting or charging. Fans, which are also noisy, tend to be intermittent, triggered by temperature rises. So for an ideal installation location, remember to think about noise. This varies between models and manufacturers, so if at all possible, try to hear a unit in operation.

Crossover Switches

Many inverters come with built-in crossover switches. These switches sense shore power, and when it is present, automatically switch the boat AC circuits to the shore-power source. Simultaneously they go into a battery-charging mode. Crossover switches eliminate the need for a selector switch on the main panel — an admirable feature.

Some crossover switches work faster than others. The best is to switch on the inverter fast enough so that if shore power is interrupted (by someone tripping over your power cord, for example), they instantly go into the inverter mode. This keeps the juice flowing. If you happen to be at the end of a long piece of work on the computer, and it hasn't been saved for a while, this feature could save a few four-letter words.

What Doesn't Work?

You will probably hear many stories about what does and does not work. Over the years we've tried just about everything on modified-sine-wave inverters. We've run laser printers, a variety of computers, TVs, VCRs, and even a sophisticated video-editing deck without difficulty.

Only two items have not been happy. The most important, as already mentioned, is the bread maker. We've seen three boats with different models of breadmakers that could not get them to work. Certain NiCad battery chargers, such as those used with video-camera batteries or portable power tools, also seem to have problems. On our last cruise we burned out a Makita portable-drill battery charger but found that the video battery chargers were fine.

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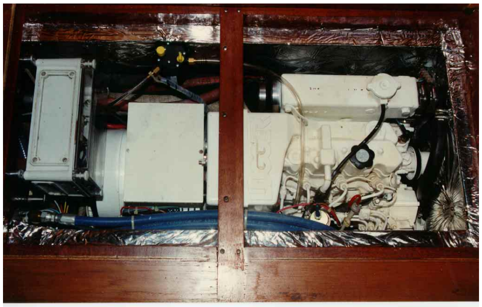

AC gensets are best located away from the living area. This one, under the saloon sole, is going to let you know it's running, regardless of how much insulation surrounds it.

AC GENERATORS

In the olden days it wasn't practical to consider a generator on a yacht less than 50 feet (15.4 m) in length. But now with compact, lightweight gensets proliferating, one can be fitted on a vessel of almost any size.

Do you need a genset? That's a tough question, because there are lots of other ways to generate AC power. If you want air-conditioning away from the dock, an auxiliary genset is definitely in your future. If you're hooked on the concept of using household-style appliances for cooking and refrigeration, the answer will be the same. And, if you want another diesel aboard to back up the main engine for maintaining lifestyle, an AC genset with enough power to serve several large battery chargers may be the best bet.

Location

Having answered the question just posed in the affirmative, you then have to decide where it goes. Location will dictate the size of the genset, and that will control a host of other considerations.

Gensets are noisy, regardless of the size, rpm, or sound enclosure. The farther away from the living area they are, the more tolerable the noise level will be. It's not unusual for a genset in a well-insulated engine room to be noisier than the much larger main engine. Mounting well forward, perhaps in the bow area, is a good location — as long as you can keep the unit dry and get reasonable access. Stern lockers are another approach, but then you're right on top of the noise when sitting in the cockpit, and cockpit lockers tend to leak. Of course, a proper engine room is ideal, assuming the installation of the genset doesn't ruin access to the main engine and other equipment. Remember that you will need access to the various bits and pieces on the diesel, as well as to the alternator itself for service.

Capacity

Some folks advocate adding up all the loads you're ever likely to run at once, adding a safety factor, then buying the biggest unit you can fit. However, as we've already observed, diesel engines like to run under load. The norm with most AC systems is that 90 percent of the time, only a few appliances will be running.

Of course, when considering capacity, you must look at starting requirements of the electrical motors being used. I feel it's far better to look at your average daily cycle, then pick a genset capacity for the average, rather than for peaks. That way you can keep a reasonable load on the genset most of the time.

Peak generating loads come at mealtimes. Even when cooking with gas rather than AC, the chef will be using AC accessories during meal preparation. If the genset is going for this, you might as well take care of the fridge, watermaker, and battery charging at the same time. We have used 8kW gensets on many of the larger yachts we've built, and as long as basic cooking was done with gas, they have worked out well — even to the point of providing air-conditioning, albeit on a managed basis.

One of the problems with the logic that employs AC as the workhorse is that it forces you to have a backup system with plenty of punch for generating power. This means another smaller genset, a cruise generator on the main engine, or stacking inverters and a large DC alternator on the main engine.

Impact of Air-Conditioning

Air-conditioning can force you up to the 20kW range, unless you say, "Okay, we'll budget the watts when we're using the air-conditioning system." If you're prepared to do this, then the 8kW will easily buy 60,000 Btu of air when other accessories are not running.

Of course, you can also go smaller on capacity, especially if the AC is used primarily as a backup to the engine and for occasional AC draw. Then you could drop down to a 3kW genset with ease.

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Diesel Considerations

Having decided on capacity you next must consider the genset itself. The first question is rpm. Gensets come in 1,200-, 1,800-, and 3,600-rpm versions. The slower the engine, the quieter it will be, the longer it will last, the heavier it will be, and the more space it will take. Slower-turning gensets handle greater starting loads and are capable of delivering 220- as well as 110-volt service. If the genset is primarily a backup for occasional use, 3,600 rpm doesn't hurt. But if you're going to be using it a couple of hours a day, every day, then 1,800 rpm is a max.

Next, give the basic diesel engine the once-over. Generally speaking, the more cylinders, the smoother the engine. Note where injectors and fuel bleed points are located, how easy the fuel and oil filters will be to service, and what's involved in getting at the electrical circuitry. One company may use a detuned engine with more potential capacity than another. This diesel will probably last longer than one which is pushing hard to make its ratings.

All of the same issues that apply to the main engine for exhaust, air intake, and access are germane to the genset. You also need to look at how the generator end is coupled, controlled, and maintained. Be especially careful about ease of diode replacement, and learn how to do it first thing. Any time someone forgets and starts or stops the generator with an electrical load on, it blows the diodes. It happens a lot, so be prepared.

Another thing to look at is the power take-off situation. With an AC generator it's nice to belt on a DC alternator and sometimes a damage-control pump (when the genset is mounted high, where it's the last thing to be flooded, the damage-control pump really becomes beneficial).

If the genset comes with a DC tap on the AC generator end, be sure it is regulated. Some gensets have unregulated DC taps, which means they put out the same amperage all the time. It's a good way to cook your batteries.

Automatic shut-down in an overheat or low-oil situation is a good idea, too, and adding some form of oil-treatment system will reduce engine wear.

The last consideration is a sound enclosure. These can have a tremendous impact on the sound level throughout the boat. The heavier it is the better from a noise standpoint. But, you need good access. If it takes half-an-hour to break open the sound box to check the oil and belts, guess how often this is going to happen?

Remember that the genset prefers to run under load. Starting it up for five minutes to make a piece of toast in the morning, then shutting it back down right away will shorten the life of the diesel drastically. Try and plan your usage so there are lots of things turned on when it's running, and keep it going at least long enough to get up to normal operating temperature.

Spare parts inventory will vary with your perception of how important it is to get back in service after a failure. The same spares as you carry for the main engine are ideal, plus lots of diodes.

Cruise Generators

Another way to generate AC power is by belting a large generator directly onto the main engine. This is relatively simple to do and has just two problems. First, since voltage and cycles are rpm-sensitive, there will be a finite range of engine rpm at which you can use the generator (and if rpm drops when there's an AC load, be prepared to replace some diodes). Second, the generators tend to be large and heavy, so good-sized mounting brackets are going to be called for.

You will have to decide first what rpm generator to use. The high-speed 3,600-rpm machines are smaller, lighter, and less money. And for occasional use and backup they'll do a good job. But if you intend to really work the cruise generator hard, then an 1,800-rpm design will be better.

A decision must be made on what engine-operating range will give you usable power. I find it best to use pulley ratios that start to give us power at the lower end of normal cruising rpm. The generator and electrical appliances will tolerate over-voltage, which results from higher engine speed a lot better than the reverse. On *Intermezzo II* we set the generator so we could begin to use it at 1,300 engine rpm, or about 7.5 knots of boat speed. If we increased speed to 1,500 or 1,600 rpm we might have seen 150 volts, but the electrical gear running seemed happy enough.

Over the years a variety of companies have developed cruising packages, including controllers to cut out power if rpm or voltage are too high or too low. The problem with most of these has been reliability and price. For a few hundred dollars you can walk into Sears and pick up a generator that will cost you several thousand if it has a marine label on it. Of course, you're still stuck with making the bracket, but the difference in price will go a long way toward solving that problem.

There are several hydraulic-drive cruising packages available. Typically these are constant speed systems, so that when engine rpm varies, the generator maintains its normal operating speed. If you don't mind the hydraulic system and have the space and the budget, this approach frequently makes sense.

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Generator Wiring

There is a final decision that has to be made with your AC generating system. This is how the field output is wired into the boat's AC system. If you are using just 110 volts for your AC gear, and have a 3,600-rpm genset you will have the option of either taking a single tap off the generator and running everything on that one tap set or splitting the loads into two legs. With an 1,800-rpm set there is a single tap on the windings. If the loads are split (with the 3,600-rpm set), then you should try to balance them when the generator is in use — i.e., have comparable amperage draw on both sides of the wiring.

110 Volts or 220 Volts?

The question will undoubtedly arise about operating voltages for heavy accessories such as watermakers, fridge compressors, and air-conditioning. Higher voltages have a slight advantage in efficiency, and the motors are much lighter and can be more powerful (110-volt motors are usually limited to 1.5 horsepower).

But using a split-voltage system means more complex wiring, extra meters on the control panel, and additional costs. It also limits flexibility with inverters and cruise generators.

My own preference is to stay with a single-voltage system (110 volts) until the size of the electric motors forces me to adopt a 220-volt alternative.

Portable Generators

Quite a few cruising yachts carry a compact, gasoline-powered, portable generator as a backup. They are reasonably priced and in some situations may make sense. However, remember that if you lose the main engine the prime need will probably be for battery charging power. In order for the gas generator to be of much assistance you need a very substantial battery charger.

If the DC charging side of the gas generator is of interest, check its capacity. Most units will only put out about 10 amps. If that is being used to charge the batteries, be prepared to listen to a lot of generator noise. The standard alternator on the engine (or genset for that matter) can do the charging chores.

ELECTRICAL NOISE

Electrical noise or radio frequency (RF) interference can be a major headache, or not a problem at all. If it is a problem it usually shows up at lower frequencies on the SSB, ham, or weatherfax.

RF noise can come from almost any piece of electrical gear aboard. However, there are several items that tend to be the usual culprits: fluorescent lights, large alternators, inverters, and motors with brushes (especially worn brushes).

Sometimes the noise is so constant, and at such a low level, that you don't at first realize it is there.

When we were first cruising with *Beowulf* we had a major noise source that interfered with our reception on the SSB and weatherfax. It was so steady that we thought band conditions were poor.

One afternoon while we were anchored at Nieue Island we were visiting some friends on a nearby boat. Their weatherfax charts were much clearer than what we were getting. It turned out that a small computer was putting out all sorts of low-level RF energy.

Metal versus Fiberglass Boats

Metal boats tend to have less of a problem with RF noise. Their hulls seem to absorb quite a bit of what is radiated. Glass boats, on the other hand, especially those without good ground systems, tend to be much noisier.

FInding the Source

Finding the source of RF energy is a pretty straightforward task. Just start shutting down various bits of gear. Eventually turning off one switch will correspond to a noise reduction, and you'll know where your problem is.

RF Suppression

Large alternators, especially those with external diodes, tend to be noisy. The problem starts out with the AC current the alternators initially produce. This is three phase, from three sets of windings. If all of the wiring is within the alternator case, the case typically acts as a shield. However, if you have a remote-mounted rectifier assembly, the wiring between it and the alternator may radiate. Twisting these wires around each other and keeping them separated from other cables will held reduce RF output.

In fact, where possible, it is a good idea to keep all AC wiring separated from DC to avoid RF problems.

Other noise problems can sometimes be cleared up with a simple grounding of the case of the device in question. By tying the case to the ship's electrical grounding system, the noise tends to be suppressed.

If this doesn't work, the next step is to install an electrical choke between the noise source and ground.

There are situations in which it is impossible to deal with the noise source in a satisfactory manner. If this happens you have two choices: turn the gear in question off when it affects operation of other gear, or replace it.

To avoid potential problems it makes sense to ask your local electronics experts what gear they've had problems with and what works. This will give you a start in the right direction.

METAL BOAT ELECTRICAL SYSTEMS

Aluminum and steel hulls present special wiring challenges. Because of the risk of electrolysis from stray currents and of shock from high-voltage AC sources, you need to take special precautions with the electrical system that are not required with fiberglass or timber construction.

Everyone agrees that stray DC currents, if they are positive and get to the hull, will quickly wreak havoc with metal (this applies to the underwater fittings on all boats). The negative side of the equation is open to debate.

The U.S. Coast Guard, for example, requires that the negative side of commercial vessels be bonded to the hull. Most yacht builders and the U.S. Navy isolate their negative side from the hull.

I don't know what the correct answer is, so we isolate, just to be sure.

Electrolytic Corrosion

So far we've touched briefly on electrolytic corrosion as it applies to aluminum, and steel construction, and stainless steel. Even if you own a fiberglass vessel this process needs to be understood as it affects all of your underwater parts (through-hull fittings, props, shafts, even the main engine).

Different metals have specific electrical properties (called potential). When the metals are immersed in a liquid, like salt water for example, and connected electrically (through a bonding wire or perhaps the metal of a hull), they will try and equalize the difference in the potential voltage.

The flow of electrons is from the metal with the higher potential to that with the lower. Take for example aluminum and copper, a deadly combination for hulls. Aluminum has a potential voltage of 0.75 to 0.99 volts (depending on alloy) whole copper is down in the -3 to 0.6-volt region (both voltages are based on a silver chloride reference cell).

Because the copper has a much lower voltage potential, the aluminum will try to equalize itself to the copper taking metal in the process. The result is an eating away of the aluminum surface, or corrosion.

Metals are sometimes rated in terms of their nobility. Those with the lowest voltage potential are the most noble. Electrolysis always flows from the less noble to the more noble.

Another way this is expressed is that the least noble is the anode while the more noble is the cathode.

You use zinc anodes on your prop shaft because they are less noble (the zinc, that is) that the stainless prop shaft and bronze prop. This means that they will protect the other metals to which they are electrically connected by degrading over time.

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To recap, for electrolytic corrosion to take place you need metals in an electrical contact with one another, an electrolyte (salt water), and a difference in nobility or voltage potential. The rate of corrosion is a function of the difference in electrical potential, the efficiency of the electrolyte, the amount of surface area exposed.

Alloys

You can also have corrosion occur in an alloy, where the different materials which make up the metal alloy (for example, in brass, which is made up from copper and zinc) start to react with each other.

This happens in the presence of an electrolyte and can be accelerated by stray DC currents (we'll discuss more about this later).

If you've ever used a brass screw around the water, you will know what we mean. In the salt air or water, the zinc will quickly be drawn out of the fastener and the screw will simply crumble.

Aluminum and stainless work a little differently (as we've discussed above). They both form a protective coating when exposed to oxygen in the air. But if they are sealed away, such as under a paint film or in a bedded fitting, and become wet with salt water, they will start to corrode.

The very best way to check for stray current and the correct galvanic protection is to use a silver-chloride reference cell and accurate voltmeter. By testing the voltage between your hull or underwater fittings and this cell, you can tell if it is properly protected or corroding.

We've used the meter above, made by Engleheart Minerals, for the last 20 years.

Avoiding Corrosion

There are several things you can do to avoid corrosion problems. First, be sure you are using the correct alloys for the marine enviroment. Second, never mix alloys underwater unless it is unavoidable (and if this is the case, make sure you have proper anode protection, typically zincs).

Keep different materials (like stainless and aluminum) physically isolated from one another (on spars, always use some form of plastic isolator between winches or stainless hardware and the mast. On fasteners, use a non-copper-containing isolating paste like Never Seize).

When you look at a hull or are building one, make sure that there aren't tight areas that can accumulate salt or moisture. If salt builds up, it will attract moisture, at the same time it prevents the area in which it has contact from getting a good supply of air.

In metal boats it makes sense to periodically rinse bilge areas with fresh water to keep them salt-free.

Paint Protection

Properly applied, paint films protect the surface to which they are bonded from the electrolytic process as long as they are impermeable (i.e., moisture proof). However, if the surface becomes porous and allows moisture enter between it and the metal underneath, you have a much worse situation. There is an electrolyitc potential while the paint film keeps the heeling oxygen-rich atmosphere at bay.

Paint companies frequently use zinc or other less noble metals in their undercoats so that if there is a failure of the paint film, the zinc is what is eaten away rather than the structural metal underneath. With steel this works quite well. With aluminum it is more of a chancy affair.

Bonding System

In order to have good protection from lightning and AC power shocks, all of the metal on board is typically bonded together. It is also common to include the underwater fittings in this bonding circuit.

"This doesn't make sense," you may be saying to yourself. "The bonding wire on the submerged fittings provides the connection for corrosion to start."

This logic is correct. What we do to protect the underwater items is to wire in a zinc into the circuit. This zinc is the least noble of the fittings, so it is the one that gives us metal, protecting the items to which it is wired in the process.

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Berylium
Aluminum Alloys
Cadmium
Mild Steel, Cast Iron
Low Alloy Steel
Austenitic Cast Iron
Aluminum Bronze
Naval Brass, Yellow Brass, Red Brass
Tin
Copper
Pb-Sn Solder (50/50)
Admiralty Brass, Aluminum Brass
Manganese Bronze
Silicon Bronze
Tin Bronze (G&M)
Stainless Steel - Types 410,416*
Nickel Silver
90-10 Copper-Nickel
80-20 Copper-Nickel
Stainless Steel - Type 430*
Lead
70-30 Copper-Nickel
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Nickel-Chromium Alloy 600*
Silver Braze Alloys
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Silver
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Nickel-Copper Alloys 400, K-500
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Alloy "20" Stainless Steels
Nickel-Iron-Chromium Alloy 825
Ni-Cr-Mo-Cu-Si Alloy B
Titanium
Ni-Cr-Mo Alloy C
Platinum
Graphite

This periodic chart of common marine materials is a good indicator of how much of a corrosion problem will exist between materials. The further apart on the chart, the more the potential for trouble. If a material is higher on the chart than another, it is the one that will give up material in a cathodic situation.

Stray Currents

If you measure the amount of voltage or amperage between a pair of anodes and cathodes, you will find that corrosion can occur at hundredths of a volt. Consider then what the consequences are of a leak from your on-board DC system, or something coming aboard via a faulty ground wire from shore power. With full amperes of power available, it is easy to see where a lot of damage can be done in a hurry, as the stray currents try to find their way back to ground via the hull and underwater fittings instead of through the correct circuit.

Where typical galvanic corrosion takes place over long periods of time, stray currents can reduce a fitting to junk in a matter of hours.

Since the issue we are dealing with is mainly DC negative currents trying to find there way back to the negative terminal on the batteries, the first defense is making sure you have properly sized ground wires, with good-quality, sealed terminals. It is also important to be sure these fittings have a good electrical connection to the electrical device to which they are attached.

In the marine environment, where salt-air corrosion (not to mention the odd dunking) is an ever-present problem, vigilence is required.

Isolation

All electrical gear must have an isolated ground. Sometimes this can be a problem with motors. Alternators and starter motors in particular can be a source of difficulty. Inquire with any gear you're buying to make sure it is isolated, and then check between motor terminals and the case to make sure (with a voltmeter).

Because isolation frequently breaks down with age or the build-up of salt inside a case, it is best to physically isolate electrical gear where possible.

With light-duty motors, electronics, lights, inverters, etc., using rubber mounts or bolting the gear in question to a piece of fiberglass or plastic, and then mounting that to the hull is a simple procedure which will yield long term benefits.

With terminal blocks, fuse holders, battery switches, and related items you will want to be sure that there is plenty of physical separation between them and the hull. What you have to be concerned with is the isolation breaking down as dirt accumulates and then allows stray currents to wander into the hull.

Powered winches, because of their loads, are more difficult to physically isolate. You can use the same procedure as with smaller gear, only in a more robust fashion. However, the engineering has to be carefully done so that loads are adequately transferred between the isolation panel and hull structure.

What we tend to do is to set each winch up in such a fashion so that if isolation fails, it can be quickly identified and the wiring in question disconnected until the problem is corrected.

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Engines and Gensets

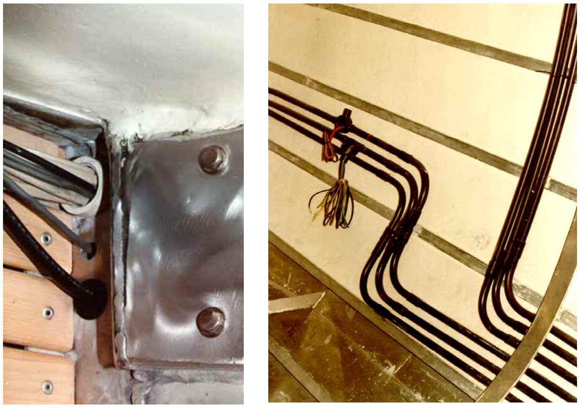
Very few diesels come with isolated senders or starter motors. Most have this gear grounded to the engine block. With a propulsion diesel it is virtually impossible to isolate it from the hull. With gensets you can do a bit more, but they are difficult as well.

There are two answers. First, replace gauges and senders with models that are isolated and then have alternators and starters re-wired to isolate their grounds. Or second, do nothing but isolate the negative side of the diesel circuits when they are turned off, leaving them connected to the hull when they are in use.

We've done it both ways and find that the latter method seems to work okay.

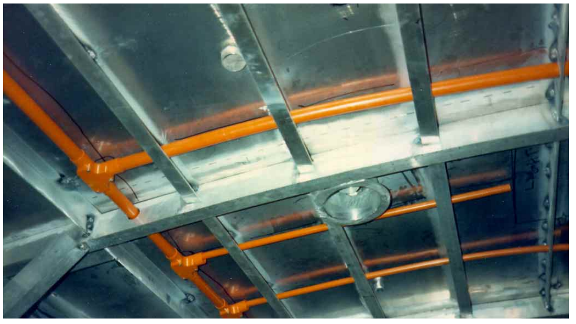
There are several approaches to wiring the negative side of the engine. The simplest is to take it through a heavy-duty battery switch, the same as with the positive side of the circuit. When you shut down, simply turn off the negative switch and you're done. If you use a switch that has an alternator-field wire-disconnect terminal, this part of the switch can be wired to an alarm to remind you to turn the switch off.

Or, you can use a heavy-duty solenoid, tied to the ignition key. When the key is on, the solenoid closes, making negative available to the various starter, alternator, and instruments.



Two different approaches to conduit. On the right, conduit installed after foaming. This is a quicker approach since you do not have to penetrate the webs of the frames. However, it is not quite as neat.

The top left photo shows the minimum. A PVC pipe section to act as a chafe guard.



Where we have wiring buried behind head or hull liners, we usually put PVC conduit in before insulating foam is sprayed. This keeps wiring isolated from any possible contact with the hull.

Whatever you do, make sure it is good-quality gear. Should the ground disconnect fail while the engine is starting or while the alternators are under load, the engine will try and complete the path back to the battery through the hull. This means it will be looking for any circuits which are even lightly grounded. Serious damage can result to anything not isolated, due to the high loads involved.

Windlasses

There is no possible way to isolate a windlass, given the chain contact as well as the loads on the windlass itself. So, we take a similar approach as with the engine. When the windlass is in use, if the motor isolation fails it will find ground through the case to the hull. When it is off, both sides of the motor are disconnected. Rather than use a single pole solenoid to trigger the motor, we use a double pole and connect and disconnect both sides of the circuit at once.

Bilge Pumps

Because of the need to keep things isolated, especially in the bilge, you should never use submersible pumps. There is too much risk of stray currents getting into the bilge water and thus to the hull.

The same applies to float switches. Use only the very best quality, and stay away from anything which works with exposed contacts. We like to use sealed reed switches, or bellows systems connected to microswitches well out of the bilge.

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RF Grounds

All of your electronics are going to require some form of RF ground between the case and/or a ground terminal. If you make this connection directly, you have broken the isolation. However, you can insert a capacitor into the RF ground wire between the electronic device and the hull. This capacitor allows RF energy to pass but blocks DC transmission, so the hull is still electrically isolated.

Circuit Breakers

The more your electrical systems are separated, the easier it is to find the source of any problem and turn it off until it is fixed. So, having a breaker for each pump, piece of electronics, motor, etc., makes sense. The only areas in which we gang devices is with lighting.

Breakers should be double-pole; that is, they should have two sets of terminals and disconnect both positive and negative when switched off. These cost about 50 percent more than single-pole breakers (around $25 each) but are a necessity.

Electrical Fault Alarms

You will want to have some form of alarm on both negative and positive sides of your circuit so that you are made aware when you have either positive or negative connected to the hull.

Our major concern is with positive, since even a few hours of positive connection to the hull can do substantial damage.

We handle this with a very simple alarm circuit. It is set up as follows: There is an light-emitting diode connected via a selector switch (the switch selects positive, negative, and off) for each side of the system. The positive alarm LED has its positive lead connected to the hull and negative lead connected to the batteries' negative side (with an annoying alarm buzzer in parallel).

If positive current is detected in the hull, it finishes the circuit, through the LED to the negative side of the batteries. Because the LED is a diode, no current can flow backwards from the batteries into the hull (we put an additional diode in the circuit just to be sure).

The negative alarm is just the opposite. In this case, the negative wire from the LED is connected to the hull and the positive goes to plus on the batteries.

We typically leave the positive alarm on all the time and only check the negative from time to time.

Shore Power

If you are connected to shore power, make sure it is done via an isolation transformer. Never connect to shore power with a metal boat if you don't have this isolation in your system.

AC Ground

Now we get to the tough question, do you tie the ship's side of the AC ground to the hull, or allow it to float? I don't know the answer. There's an argument for tying the two together from a safety standpoint. On the other hand, with no connection to the shore-power grid, there's an argument that says that you do not need to ground the ship's side of the AC circuit, as long as it floats free of shore power with an isolation transformer. If you further protect all outlets with ground-fault receptacles, it seems reasonable that you can leave the ship's AC ground isolated from the hull. But the subject is so controversial that we suggest you check with your own experts.

Wiring Protection

You will want to be sure that there are no possible points of contact between the wiring loom and the hull. Where wire passes through structure, rubber grommets need to be employed on the metal to prevent chafe. Elsewhere, wire should be wrapped in chafe guard, placed in conduit, or some combination of the two.

Leads to vibrating motors need special attention to make sure that they cannot touch any metal, where, over time, abrasion of the wiring insulation would take place.

SYSTEMS INTEGRATION

If you've made it through all the detail in the preceding chapters, you're probably having nightmares thinking about all the possible combinations of equipment. You're not alone. With all the boats we've done in the past, and with all the experience Linda and I have had using this gear, we still spend hours and hours agonizing over which way to go with the integration of our systems.

Technology marches on, and new gear becomes available. Its characteristics offer new advantages, but there are always some negatives in the equation. Our own objectives change, so past experience doesn't necessarily fit the new concept. I guess that's why the perfect yacht is always the next one!

There really are no hard-and-fast rules about how to go about integrating your needs into an efficient, comfortable, easy-to-maintain set of systems. Every set of circumstances is going to be different.

Decision-making Process

If you're new to cruising or haven't had experience with some of the more complex systems, avoid rushing into the decision-making process. Do everything possible to build your experience base before making up your mind. Equipment that seems essential now may be less important after a summer's worth of cruising, while gear you wouldn't have dreamed of having aboard suddenly looks pretty good.

If you're purchasing an existing boat, use it first before making changes. There may be a valid reason for some of the things the previous owner has done. Or it may be more economical to leave things as they are, even though you planned to make changes. Perhaps the change budget can be spent elsewhere with better efficiency.

A couple of the comments made at the start of this section bear repeating. First, don't try to do too much in too little space. This is the cause of more frustration than anything else afloat. And it applies just as much to a 75-foot (23m) yacht as to a 35-foot (10.8m) cruiser.

Second, try to be realistic about your needs and plans. If your boat is used primarily on weekends, with the occasional trip for a couple of weeks in the summer, a much simpler approach will be better, even to the point of adopting a camping lifestyle.

Remember, one of the things that ruins marine gear faster than anything else is inactivity.

Third, as the need for a more sophisticated ambience increases, look to the simplest approaches to gain your objective.

Fourth, balance your backup needs. Many folks who are serious about their cruising plans go overboard in this regard. While I would be the last to recommend going unprepared, there are usually simple ways of repairing a broken system, or adapting yourself to its loss, and in many cases this approach is more sensible than trying to provide a complete backup for every piece of gear.

Fifth, remember that with the exception of some of the safety gear covered so far, there's nothing that's absolutely necessary to the cruising lifestyle. The human animal is extremely adaptable, and a lot of things you feel you just can't do without become a lot less important once you're away from the dock. If you're contemplating going now with a simple boat, or working another few years so you can afford more goodies, go now. If there's a budgetary compromise between a simple set of systems and more waterline length, or lots of gear and a smaller boat, go with the bigger boat.

Finally, keep in mind that systems are best employed on a stepping-stone basis. Put in the foundation now, use it for a while, then go onto the next step, building on what's already been done. This gets you sailing more quickly and helps build an experience base.

Simple Approach

Odds are you'll be starting out with a basic diesel engine, alternator, and a battery or two. Adding hot-water capability for showers will usually be first on the list (even if this is via a Sun-Shower).

In most cruising, if you add two large solar panels (like Siemens M-55s), you will have enough ower to cover your lights, VHF, and music while on the hook.

The next step involves upgrading the electrical system. If the boat has shore power available for charging, then changing to deep-cycle batteries and/or adding to the battery bank capacity provides a good foundation.

Following this would be an alternator capacity upgrade.

Finally, for occasional AC power for tools or galley accessories I would add a small inverter, something in the 300-to-500-watt range.

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Adding Refrigeration

The major question with refrigeration will be your daily cycle. For occasional use, a simple Danfoss compressor-based system with its own integral evaporator (cooling unit) will be ideal. For more serious cruising, adding a small heat exchanger makes sense. (Bringing down pre-chilled and/or frozen foods for the weekend and dropping them into a box that has already been pulled down to temperature with shore power helps a lot.)

As your desire for more fridge capacity and/or cooler temperatures (and perhaps a medium-sized freezer) come into play, the obvious choice becomes a mechanical compressor belted to the engine. You then have lots of capacity and an engine running time of 30 minutes to an hour per day.

It's true that using the engine as a genset on a daily basis isn't the best thing for it, but with short oil-change intervals, or by using some of the oil treatment systems already discussed, the average engine will give you 5,000 to 7,500 hours of service.

Electrical Refrigeration

Using a larger, more efficient electrical-based fridge system now makes more sense with the advent of large alternators and availability of high-quality deep-cycle and traction batteries. Properly set up, engine running time can be kept to the same range as if you had an engine-driven compressor. You now have the added advantage of being able to use solar/wind/water power to run the fridge and do away with the engine.

However, this approach is more costly on an initial basis.

A major factor in the fridge equation will be your insulation. If you use the new high-efficiency vacuum panels, you can then get by with much smaller battery and alternator capacity. Depending on fridge size, two to four solar panels could do the trick without adding to electrical capacity.

Going with Air

The minute you start to get serious about air-conditioning, a generator becomes necessary. Since the generator is going to be aboard anyway, why not use it for other things as well?

When Linda and I developed the specifications for the Deerfoot 2-62s we knew that each of the owners wanted air. An 8kW, four-cylinder Nanni diesel (1,800-rpm) was specified. Staying with 110 volts for simplicity, the 25-gph Sea Recovery watermaker, 16,000-Btu fridge/freezer compressor, and two 80-amp battery chargers were all run from the genset. The battery bank was made up from six deep-cycle Surrette EIG 262 batteries, giving us a little over 750 amp-hours of capacity in the bank. Since all the major systems were run on 110 volts, and the generator was going to run a minimum of one hour a day, the battery bank was really sized for the higher DC passaging loads.

For backup to all the AC, the same generator end as used on the genset was belted to the main engine. The problem here was sensitivity to engine rpm. If I were doing this again now, I'd go with a large DC alternator and inverter. While there would be less capacity with the engine running, it would not be rpm-sensitive.

Today there are some very interesting, compact, 3- to 4-kilowatt diesel gensets on the market, which open further possibilities for the use of AC power on even smaller boats, even without air-conditioning.

If you like the concept of air-conditioning but are scared off by its seeming complexity, let me outline for you what we did on *Intermezzo II*.

Most engineers would have said she needed a minimum of 50,000 Btu to keep her cool in the Florida summer. But there was no way we were going to invest that much space (or money!) in air.

We said we would take advantage of our insulation, keep the awnings up when it was really hot to reduce heat load, and accept an 80 degree ambient temperature when it was in the mid-90s outside.

So we put in a single 16,000-Btu compressor that could be run by either shore power or our cruise generator which was belted to the main engine.

We used two evaporators, a 12,000-Btu unit mounted on the forward bulkhead of the main saloon, where it could cool the main saloon or our sleeping cabin (which was forward), and a second 6000-BTU unit mounted at the aft end of the saloon, where it cooled the galley and/or the aft starboard stateroom.

During the day all air was devoted to the saloon. Yes, the sleeping cabins were pretty toasty, but we didn't sleep during the day, and the saloon stayed nice and cool.

In the evening, when the heat load was a lot less, the air-conditioning could handle the sleeping cabins, too.

We never intended to use the air other than at the dock. But when we were sailing for Panama our sailing generator went out and we'd developed such bad DC consumption habits that we were forced to run the engine three to four hours a day for battery charging. It was getting pretty warm below and Linda asked if we could use the air. Well, nobody was looking, so why not! I have to tell you, one enthusiast of the simple cruising lifestyle was instantly corrupted.

On smaller boats, say 50 feet and down, the same approach we used with *Intermezzo II* will work well even without awnings, and in many cases you can get away with a combination compressor/evaporator unit, perhaps with a bit of ducting.

Adding Hydraulics

If there's going to be substantial hydraulic capacity aboard for a thruster, then there's another approach that can be looked at. If a second hydraulic motor is added to the circuit, this can be used to drive a lay shaft onto which are mounted your various accessories. With a pump mounted on the engine, a second diesel to drive the accessories is just a matter of a couple of T fittings and two valves. This gives you total backup.

Adding a layshaft, with its bearings, pulleys, and belts, may seem more complicated than a series of small hydraulic motors. However, as we mentioned earlier, balancing out a series of hydraulic motors with varying loads when they're run off a single source can be difficult.

The major negatives with hydraulics are weight, noise, and leaks. We've fitted sophisticated systems on a number of large motorsailers, using the best engineering and components, and I have never seen a system that didn't require a fair amount of maintenance and that didn't have at any one time at least a small leak going somewhere.

Our Next Boat!

We haven't even finished the present boat, and I am already thinking about the next one! This sailing stuff really is a disease.

Our systems approach has always been driven by technology. In the last year a couple of things have changed, and the next time around this will affect what we do. The first is the availability of highly efficient, compact vacuum-panel insulation for the fridge. Using the Owens-Corning Aurora panels means we'll be cutting fridge amp hour needs by 50 percent.

Couple this with a modest improvement in solar-panel output and we are in a position where we can cover 100 percent of our daily living requirements on the hook without ever running a diesel engine.

A six-to-eight-panel array of Siemens M55 panels should easily do the job. The minute this happens we can back off on battery capacity, and if we back off on battery capacity we can reduce the need for huge alternators. With the solar array and efficient fridge system we'd probably cut our battery capacity down to two full days worth, with an alternator reduction to match.

The only problem this leaves is power when we're sailing. The lifestyle electrical needs are way down, but we still have the pilot, electronics, running lights, etc., to contend with.

If we had a boat with moderate performance we'd handle this with a trolling generator, as in the old days. However, for the speeds we now sail at this is not really an option. This means we run the engine a couple of hours a day at sea (smaller battery bank, and alternator make this a requirement) or add a small DC genset, perhaps a light, water-cooled, single cylinder unit (and put up with the noise).

How will it work? I guess we'll have to wait and see.