MARINE ELECTRICAL SYSTEMS

The complete guide to expanding, upgrading, surveying and troubleshooting your boat's AC and DC electrical system.

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Design a Trouble-Free ELECTRICAL SYSTEM

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Are you contemplating a major overhaul of your boat's electrical system? Here's how to design an efficient trouble-free DC system and the proper techniques for installing electrical cables and circuits.

By Kevin Jeffrey

A circuit is a path that, if followed completely, leads back to the starting place. Here we are concerned with marine electrical circuits that provide a reliable path for direct current (DC). While there are definite rules to follow when wiring a new boat or rewiring an existing one, the DC portion of the electrical system can be set up in a variety of ways. With some creative thinking, proper circuit components, and good wiring techniques, you can take the best advantage of battery-supplied electricity on board.

In DC circuits an electrical potential, or voltage, drives the electrical current. Charging sources create the necessary voltage to drive current into the batteries and, in turn, the batteries serve as a voltage source for operating all DC loads on board, including inverters that, in turn, provide AC power. A boat has both charging circuits and load circuits, yet all DC circuits must include the batteries. Individual batteries can be connected in a variety of ways to give you the system voltage and total battery capacity you require for house loads and engine starting (see **Figures 1** and **2** for sample schematics and refer to pages 68, 72 and page 73 for setting up batteries).

A DC system has a positive and negative side to each circuit. The positive side originates at the positive terminal of the voltage source and goes to the positive distribution point (if provided), then on to individual loads. The negative side of the circuit provides a return path back to the voltage source. The flow of electricity is determined by the electrical resistance of the loads. For example, engine starters, freezers and large inverters have relatively little electrical resistance compared to lights and navigation instruments and, therefore, allow much more current to flow.

Sample Circuits

DC marine electrical circuits fall into two categories — main circuits and branch or subsidiary circuits. Main circuits originate from the batteries and provide current directly to large appliance loads or to distribution points housing multiple branch circuits. While the methods of routing and controlling these circuits may vary, the wiring techniques for the best safety and efficiency remain the same.

Shown in **Figures 1 and 2** are three sample schematics depicting main and branch DC circuits commonly found on boats. Keep in mind that components in a DC system can be arranged in a variety of ways.

Codes for Conductors

Wire conductors carry the current from the voltage source to the loads. Other circuit components to consider include connectors to join conductors to electrical equipment or two or more wires together, distribution posts or busbars to conveniently join groups of positive or negative wires, manual or automatic switches to control current flow, diodes to prevent reverse current flow, and meters and monitors to help make electricity visible.

Wire conductors provide the supply and return path from the voltage source to the various electrical loads. DC wiring is selected for the type of job it must do, and is sized according to how much current it's expected to safely carry and the allowable voltage drop over its length of run. Conductors from 8 AWG (American Wire Gauge) to 4/0 AWG, usually referred to as cable, is used for positive and negative conductors where high current is expected, such as battery banks, large high-output alternators, starter motors, and large inverters and chargers. Marine cable should meet the same standards as other conductors on board.

Wire and cable conductors are insulated for safety and should be installed to make certain electricity stays in its intended path. If the electrical load is bypassed due to an

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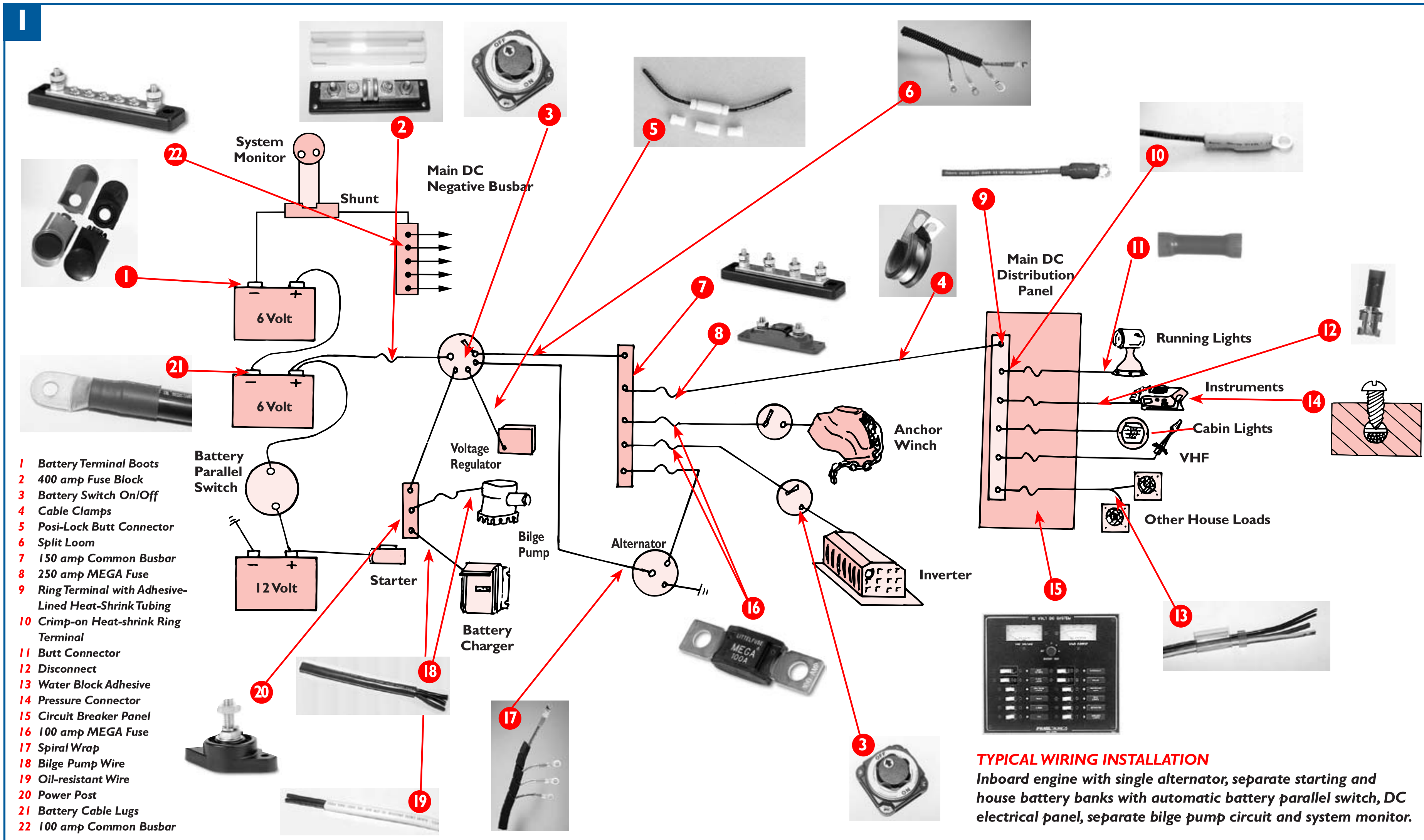

1 Battery Terminal Boots
2 400 amp Fuse Block
3 Battery Switch On/Off
4 Cable Clamps
5 Posi-Lock Butt Connector
6 Split Loom
7 150 amp Common Busbar
8 250 amp MEGA Fuse
9 Ring Terminal with Adhesive-Lined Heat-Shrink Tubing
10 Crimp-on Heat-shrink Ring Terminal
11 Butt Connector
12 Disconnect
13 Water Block Adhesive
14 Pressure Connector
15 Circuit Breaker Panel
16 100 amp MEGA Fuse
17 Spiral Wrap
18 Bilge Pump Wire
19 Oil-resistant Wire
20 Power Post
21 Battery Cable Lugs
22 100 amp Common Busbar

TYPICAL WIRING INSTALLATION
Inboard engine with single alternator, separate starting and house battery banks with automatic battery parallel switch, DC electrical panel, separate bilge pump circuit and system monitor.

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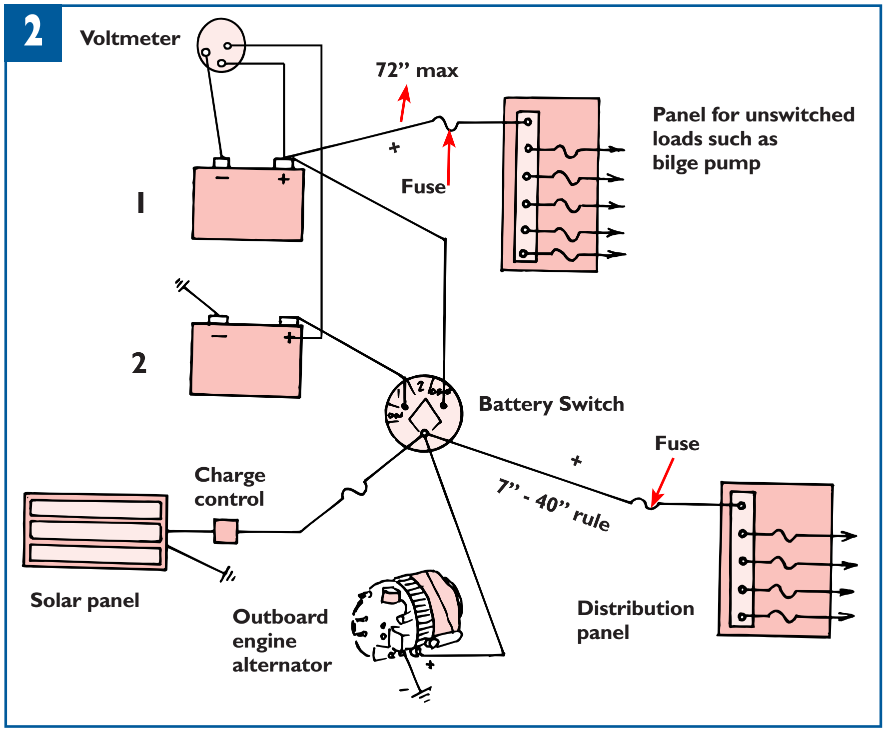

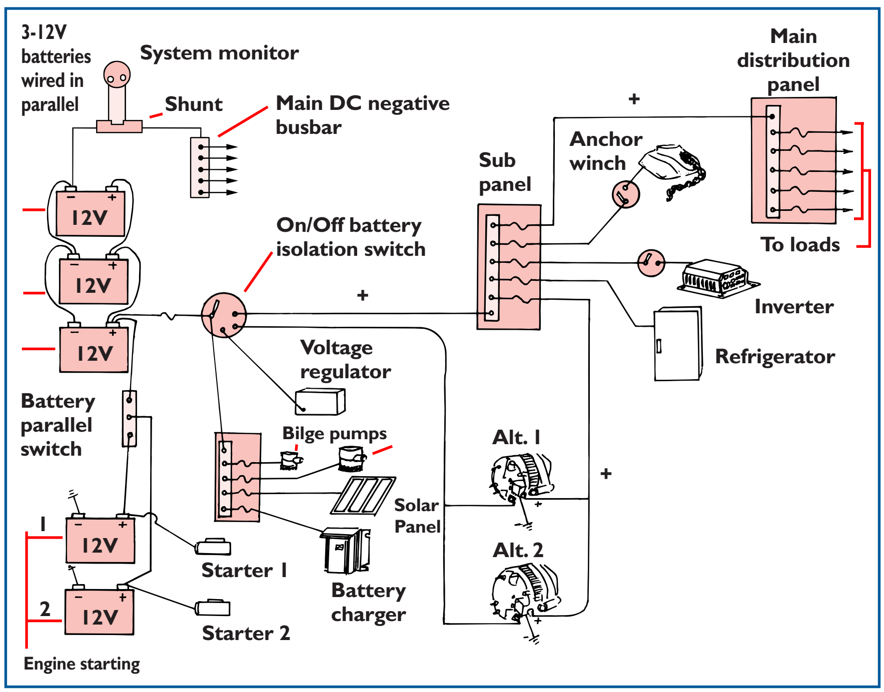

ANNE-MARIE HENDRY

***SAMPLE BOAT SCHEMATICS** (Top) Single engine with alternator, two batteries with manual battery switch, simple DC electrical panel, separate bilge pump circuit, voltmeter (battery condition meter) and solar panel.*

(Bottom): Dual inboard engines with alternators, two starting and one house battery bank with automatic parallel switch, multiple renewable charging sources, DC electrical panel, separate dual bilge pump circuits, system monitor, inverter, anchor winch and refrigeration.

accidental "short" circuit, resulting high current can cause serious damage and possibly a fire unless proper current protection devices — fuses (Figure 1, #8) and circuit breakers — for each circuit are in place.

The integrity of a DC circuit is only as good as the individual components and connections. Selecting the proper conductor type and size is a good place to start. Even though high-quality conductors made to AWG standards are more expensive for a given size, they can actually save you money over the long term. AWG wires are up to 12% larger than the same

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size SAE wire used for "surface vehicles," so in many applications a smaller gauge AWG wire can stay within the voltage drop limits recommended by American Boat & Yacht Council (ABYC) and other marine standards (Tables B and C on page 8).

Wire conductors in a marine installation face harsh conditions, and must adhere to the following criteria:

1. ABYC standards state that "Conductors shall be at least 16 AWG (except 18 AWG may be used as internal wiring in panelboards), and shall have a minimum rating of 50 volts."

2. Wire with multiple strands (**Table D** on page 8 has a better ability to cope with repeated flexing without breaking, and it makes for a much more reliable crimp connection since the strands mold more completely to the terminal barrel. Solid wire or wire with only Type 1 stranding is not recommended for marine use. ABYC standards state that "Conductors with at least Type 2 stranding shall be used for general purpose boat wiring. Conductors with Type 3 stranding (many more strands per wire size) shall be used for any wiring where frequent flexing is involved in normal use." Also look for wire with tinned copper strands, since it offers the maximum protection against corrosion and electrolysis.

3. The wire insulation should be able to withstand the maximum ambient conditions: temperature; moisture; contact with saltwater, oil, boat fuel, battery acid or other chemicals; exposure to sunlight.

What to look for: A commonly available conductor such as UL 1426 boat cable meets most ambient conditions found on board **(Figure 1, #19)**.

4. The ampacity (ability to carry current) of the conductor and its insulation should be sufficient to avoid overheating. The ampacity rating is independent of conductor length of run and voltage drop.

What to look for: Refer to **Table D** ampacity ratings for marine conductors under 50 volts. These values are the safe amperages which the conductor can carry on a continuous basis. They do not apply to intermittent starting loads such as motor start currents. Wiring in and passing through engine spaces must be able to operate at higher ambient temperatures.

5. The wire should be of sufficient size so that the voltage drop over the length of run not impair the load's ability to function.

What to look for: Voltage drop is a function of expected amperage (current) and length of run; increased amperage and longer runs require larger wire size. Conductors used for electronic equipment, navigation lights or other circuits where voltage drop should be kept to a minimum shall be sized for a voltage drop not to exceed 3% (**Table B** on page 7). Conductors used for general lighting and other circuits where voltage drop is not critical may be sized for a voltage drop of 10% (**Table C** on page 8).

6. There should be a means to easily identify a conductor's function in an electrical system.

What to look for: **Table E** on page 10 shows the recommended color code for DC conductors used for general, engine and accessory wiring purposes on boats. ABYC standards state "Color coding may be accomplished by colored sleeving (i.e. colored heat shrink tubing) or color application (such as colored plastic tape) to wiring at termination points."

Getting Connected

Wire connectors come in a variety of designs as shown in **Figure 1** on page 5. Solderless crimp-on ring (**#10**) and captive spade terminals are the most commonly used terminals, but they must be installed properly (See “Wiring Runs and Connections” on page 56). It's important to realize that crimping is a system, in which the wire, connector, crimping tool and installation technique must be matched to create a good electrical connection.

Other accepted terminals include friction connectors (**#5, #12**) — male and female components that pull apart — and pressure connectors (**#14**) — wires are joined and held together with pressure from a bolt or set screw — provided these types of connectors meet certain standards outlined below.

Crimp-on butt connectors (**#11**) are available if needed to splice two conductors in the middle of a wire run. Some controls and monitoring devices are supplied with wire pigtails; for this gear you'll need to use crimp-on butt connectors, or friction connectors that allow for easy disconnect and removal.

Wire connectors are available as: 1) non-insulated, 2) with an insulated barrel, 3) with an insulated barrel with additional insulation grip (on connectors made to be double-crimped — one crimp on the barrel for electrical contact and one on the insulation for added strain relief), and 4) as fully insulated disconnects (when connected, no bare metal is visible).

Terminals for connecting battery cable from 8 AWG to 4/0 AWG are available as

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TABLE B: AWG CONDUCTOR SIZES FOR 3% VOLTAGE DROP AT 12 VOLTS

CURRENT (amps)**

LENGTH*	5	10	15	20	25	30	40	50	60	70	80	90	100
10'	18	14	12	12	10	10	8	8	6	6	6	4	4
15'	16	12	10	10	8	8	6	6	4	4	4	2	2
20'	14	12	10	8	8	6	6	4	4	4	2	2	2
25'	14	10	8	8	6	6	4	4	2	2	2	1	1
30'	12	10	8	6	6	4	4	2	2	2	1	1/0	1/0
40'	12	8	6	6	4	4	2	2	1	1/0	1/0	2/0	2/0
50'	10	8	6	4	4	2	2	1	1/0	1/0	2/0	3/0	3/0
60'	10	6	6	4	2	2	1	1/0	2/0	2/0	3/0	3/0	4/0
70'	10	6	4	2	2	2	1/0	2/0	2/0	3/0	3/0	4/0	4/0
80'	8	6	4	2	2	1	1/0	2/0	3/0	3/0	4/0		
90'	8	4	4	2	1	1/0	2/0	3/0	3/0	4/0			
100'	8	4	2	2	1	1/0	2/0	3/0	4/0	4/0			

Use this table for any critical applications: bilge pumps, navigation lights, electronic, etc. The next larger conductor should be used when length falls between two conductor sizes. For determining conductor size in 24-volt and 32-volt systems see "Formula For Sizing Conductors" on page 65.
**Length of wire from the positive power source (battery, panelboard or switchboard) to electrical device and back to the negative power source in feet.*
***Total current on circuit in amps. Where there is a variance between the voltage drop and the ampacity (Table D on page 9), use the larger wire size.*

SOURCE: ANCOR MARINE

TABLE C: AWG CONDUCTOR SIZES FOR 10% VOLTAGE DROP AT 12 VOLTS

CURRENT (amps)**

LENGTH*	5	10	15	20	25	30	40	50	60	70	80	90	100
10'	18	18	18	16	16	14	14	12	10	8	8	6	6
15'	18	18	16	16	14	14	12	12	10	8	8	6	6
20'	18	16	16	14	12	12	10	10	8	8	8	6	6
25'	18	16	14	12	12	10	10	8	8	8	6	6	6
30'	18	16	14	12	10	10	8	8	8	6	6	6	4
40'	16	14	12	10	10	8	8	6	6	6	4	4	4
50'	16	12	10	10	8	8	6	6	4	4	4	4	2
60'	16	12	10	8	8	8	6	4	4	4	2	2	2
70'	14	12	10	8	8	6	6	4	4	2	2	2	2
80'	14	10	8	8	6	6	4	4	2	2	2	2	1
90'	14	10	8	8	6	6	4	4	2	2	2	1	1
100'	12	10	8	6	6	4	4	2	2	2	1	1	1/0

Use this table for any non-critical applications: cabin lights, stereo, etc. The next larger conductor should be used when length falls between two conductor sizes. For determining conductor size in 24-volt and 32-volt systems see "Formula For Sizing Conductors" on page 65.
*Length of wire from the battery to electrical equipment and back in feet.
**Total current on circuit in amps. Where there is a variance between the voltage drop and the ampacity (Table D on page 8), use the larger wire size.

SOURCE: ANCOR MARINE

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heavy-duty lugs (**#21**), similar to ring terminals used for smaller wire, and heavy-duty butt connectors. For heavy-duty applications, lugs are available with a thicker wall for higher strength and less heat, a wider pad for better contact and a longer barrel for more crimp area.

Protective sleeves that insulate the metal shank of terminal connections are recommended. The best way to comply is to use short sections of adhesive-lined heat-shrink tubing. When heated they form a tight, moisture-resistant seal over the terminal shank. Not only do adhesive-lined sleeves seal out moisture, they also provide additional strain relief between connector and wire. Terminals from 22 AWG to 10 AWG with preformed adhesive-lined heat-shrink are also available, making installation convenient for the DIYer. In areas where moisture is a concern, seal multiple wires with Water Block Adhesive (**#13**) from Ancor Marine, a combination of heat-shrink adhesive with preformed wire channels and a clear outer section of heat-shrink tubing.

Power Distribution Points

It's best to make all wiring connections at equipment termination points, instead of joining conductors in the middle of a run — additional connections increase the potential for problems down the road. Convenient termination points are found at batteries, distribution posts and blocks, electric panels **(Figure 1, #15)**, loads, switches, controls and other devices in the circuit.

Battery switches isolate the batteries from the charging sources or electrical loads, but they can also serve as a convenient power distribution point. For example, on systems with a separate engine starting bank and a simple ON/OFF disconnect switch **(Figure 1, #3)** for a single house bank the switch terminal closest to the positive post of the batteries can be used for connecting the positive leads of bilge pumps and renewable chargers that you don't want to accidentally disconnect with the other loads. For systems with dual battery banks for either house loads or engine starting **(Figure 2, top)**, the common positive terminal on a 1-2-BOTH-OFF switch can be used to connect the positive feeds to the starter circuit and the load distribution panel, as well as the positive leads from renewable chargers.

Multiple conductors can be joined in a

TABLE D: CONDUCTOR RATINGS

AWG	AWG CM	Minimum Number of Strands		Ampacity in Engine Space[3]	
		TYPE 2[1]	TYPE 3[2]	OUTSIDE	INSIDE
18	1,600	16	—	20	17
16	2,600	19	26	25	21
14	4,100	19	41	35	31
12	6,500	19	65	45	38
10	10,500	19	105	60	51
8	16,800	19	168	80	68
6	26,600	37	266	120	102
4	42,000	49	420	160	136
2	66,500	127	665	210	178
1	83,690	127	836	245	208
0	105,600	127	1064	285	242
2/0	133,100	127	1323	330	280
3/0	167,800	259	1666	385	327
4/0	211,600	418	2107	445	378

[1] Conductors with Type 2 stranding used for general purpose boat wiring.
[2] Conductors with Type 3 stranding used where frequent flexing occurs.
[3] Ampacity values for cables in circuits under 50 volts based on an ambient temperature of 50°C (122°F) and are independent of conductor length of run. See Tables B and C for specifics. Where there is a variance, use the larger wire size.

SOURCE: 1998 ABYC

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TABLE E: SAMPLE WIRE COLOR CODE

COLOR	ITEM	WIRE USE
Black or yellow	Ground	Negative mains
Blue, dark	Cabin & instrument lights	Fuse or switch to lights
Blue, light	Oil pressure	Oil pressure sender to gauge
Brown w/yellow stripe or yellow*	Bilge blowers	Fuse or switch to blowers
Gray, dark	Navigation lights Tachometer	Fuse or switch to lights Tachometer sender to gauge
Green or green w/yellow stripe	Bonding systems	Grounding conductors
Brown	Generator armature Alternator charge light or alternator Pumps	Generator armature to regulator Generator terminal Auxiliary terminal to regulator Fuse or switch to pumps
Orange	Accessory feed	Ammeter to alternator or generator output and accessory fuses or switches
Pink	Fuel gauge	Fuel gauge sender to gauge
Purple	Ignition Instrument feed	Ignition switch to coil and electrical instruments Distribution panel to electric instruments
Red	Main power feeds	Positive Conductors
Tan	Water temperature	Water temperature sender to gauge
Yellow w/ red stripe	Starting circuit	Starting switch to solenoid

*If yellow is used for negative, blower must be brown with yellow stripe.

SOURCE 1998 ABYC

circuit by using a power distribution post, busbar or splicer block. Distribution posts are used for large battery cable to branch out from a central positive connection, or to consolidate a number of negative return cables, allowing you to take one large cable to the engine block. These posts are available with 1/4", 5/16" or 3/8" diameter studs **Figure 1, #20)**. Busbars **(Figure 1, #7)** and splicer blocks perform the same function as distribution posts, only they offer multiple connection points. Branch circuits for large loads, such as windlass, large inverter, or refrigeration are often distributed through a separate heavy-duty busbar as shown in **Figure 2**, bottom.

Make sure that all branch circuits on board are protected with appropriately sized fuses **(Figure 1, #16)** or circuit breakers.

Most branch load circuits on a boat are connected inside a DC distribution panel. Marine panels typically have a positive busbar and disconnects, and fuses or circuit breakers for each branch, and may also include additional circuit switching or monitoring functions.

Setting Up The Circuits

First, create a rough system schematic of how the electrical components and circuits will be arranged on your boat. Using the schematic as a guide, determine where the components will be placed on board; make sure major components are readily accessible. Next, select and purchase the appropriate electrical gear and mount it securely in the desired locations.

Once the major components are in place, choose wire paths that are practical and aesthetically pleasing, and that keep wires away from excessive heat, moisture or sharp objects. Wires and connections that must pass through bilge areas must be watertight. Route conductors as far away from exhaust pipes and other heat sources as possible. ABYC recommends a minimum 2" (5cm) clearance from wet exhaust components and minimum 9" (22.8cm) clearance from dry exhaust components. Wire runs should avoid obvious chafe points such as steering cable or linkages and engine shafts or throttle connections. Try to allow for future access to all wiring connections.

Select the wire size, type and length of run for each application. Remember that in addition to using markers, adhering to standard wire color codes helps identify a conductor's function in an electrical system (**Table E**). Using wires with multiple conductors encased in an outer sheath where possible is a handy way to keep wiring runs tidy. Specialty cables are available for bilge pumps (**Figure 1**, **#18** with two or three color-coded conductors 18-14 AWG, water-resistant jacket), masts (five color-coded conductors 14 AWG, round sheath) and other applications.

Now choose the types of terminals and connectors that work best for your system, and the necessary wiring tools for the job.

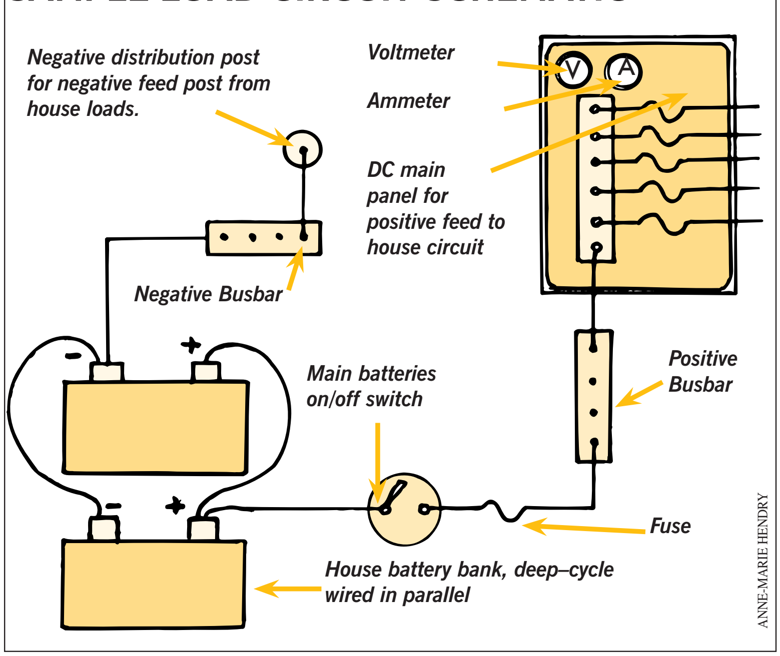
CHARTING A BALANCED POWER SYSTEM

Here's how to design a proper electrical schematic so you can view your boat's entire system at a glance, pinpoint problem areas and avoid costly mistakes.

By Kevin Jeffrey

Figure 1

SAMPLE LOAD CIRCUIT SCHEMATIC



If you're in the process of upgrading your boat's existing electrical power system or installing one on a new boat, usually you'll go through the same step-by-step procedures. First, you'll likely research all the various electrical components on the market. Next, you'll narrow the equipment choices to gear that seems right for your installation and budget, typically with the help of an electrical system consultant or supplier. Once the major components are selected, it's not unusual for you to reach an impasse as you try to make sense of how all this electrical gear goes together.

You now have two choices: one is to give the job to a marine electrician; the other is to follow your do-it-yourself instincts and take the time to understand the system and its individual circuits. For the DIY approach, I suggest you create a visual representation of the power system before you purchase the equipment. A proper electrical schematic can highlight and force you to quantify all those subtle system components and considerations. It can also pinpoint problem areas and help you avoid costly mistakes.

Drafting the Power System

Your boat's power system is a compilation of electrical circuits and sub circuits. In an electrical schematic diagram the goal is to represent all major components, including wire paths and connection points. The more detailed you make the diagram, and as neat and clear as possible, the better your chance of installing the system properly.

In a DC electrical load circuit **(Figure 1)** electricity follows a wire path from a voltage source (ie. batteries) to an appliance load and back to the voltage source. A variety of electrical components such as meters, distribution and connection points, switches and circuit protection devices can also be in that circuit.

In an electrical charging circuit **(Figure 2)** electricity flows from a source of higher voltage such as renewable (solar, wind or water), engine-driven or shore-based chargers to the batteries, which are at a lower voltage, and back to the higher voltage source. If loads are drawn from the batteries while they are being charged, some of the charging current goes directly to the load.

To create an overall system schematic, you simply draw the various sub circuits and connect them. Start by making a list of your power system components. Begin with the house and start batteries. Next list the DC charging sources and their controls, including battery charger or an inverter-charger. This naturally leads to a list of all AC power sources,

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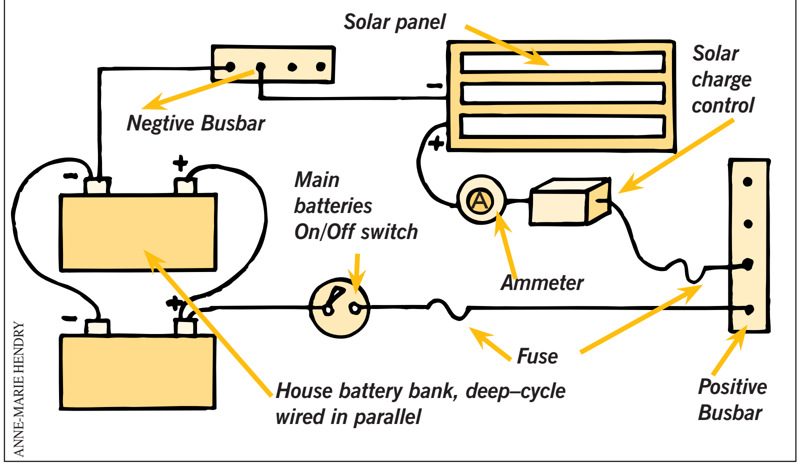
which might include a shorepower connection or a gen-set. Put on the list some way to monitor system performance. Follow this with a list of DC and AC electrical loads to see how they are connected in the system and to help you determine what type of electrical panels to choose. Make your component list as complete as possible, but don't worry — as you create the schematic other necessary parts of the system will become apparent. You can now start to rough out the system on a blank sheet of paper.

Figure 2

SAMPLE CHARGING CIRCUIT SCHEMATIC



Completing the DC/AC Schematic

Let's list the components and number requirements for a hypothetical electrical power system, then create the schematic diagram **(Figure 3)** for it.

1 House bank of batteries
1 Starting battery
1 Main battery disconnect (On-off switch)
1 Parallel charging device (to keep starting battery charged)
1 Auxiliary engine with starter
1 Alternator with charge control
1 Solar charger
Circuit disconnects (On-Off switches as needed)
Circuit protection devices (fuses and breakers) as needed
Meters, as needed
Distribution busbars and posts (positive and negative connection points) as needed
System monitors, as needed
Bilge pumps, as needed
Heavy loads, as needed (i.e. windlass, DC holding plate refrigeration)
1 DC load panel
1 Inverter-charger
1 AC load panel
1 30A/120VAC shorepower inlet
1 Isolation transformer

Begin by drawing the house battery bank. If the house bank is comprised of multiple batteries, draw each one and show how they are interconnected (series, parallel, or series-parallel). Now add the start battery and auxiliary engine.

Coming off the positive post of the house battery bank should be two connections: a heavy cable feeding the main battery disconnect and a small wire feeding the parallel charging device. On the battery side of the main disconnect tie in a feed to the bilge pump(s). This prevents the bilge pump from being accidentally turned off. [Ed: See DIY's MRT "Plumbing 101" CD-Rom.]

Now locate positive and negative busbars for connecting all the remaining DC wires. The positive

TIPS

POWER CAD

For the computer literate, there are available technical drawing programs, such as KeyCAD, for diagraming power systems.

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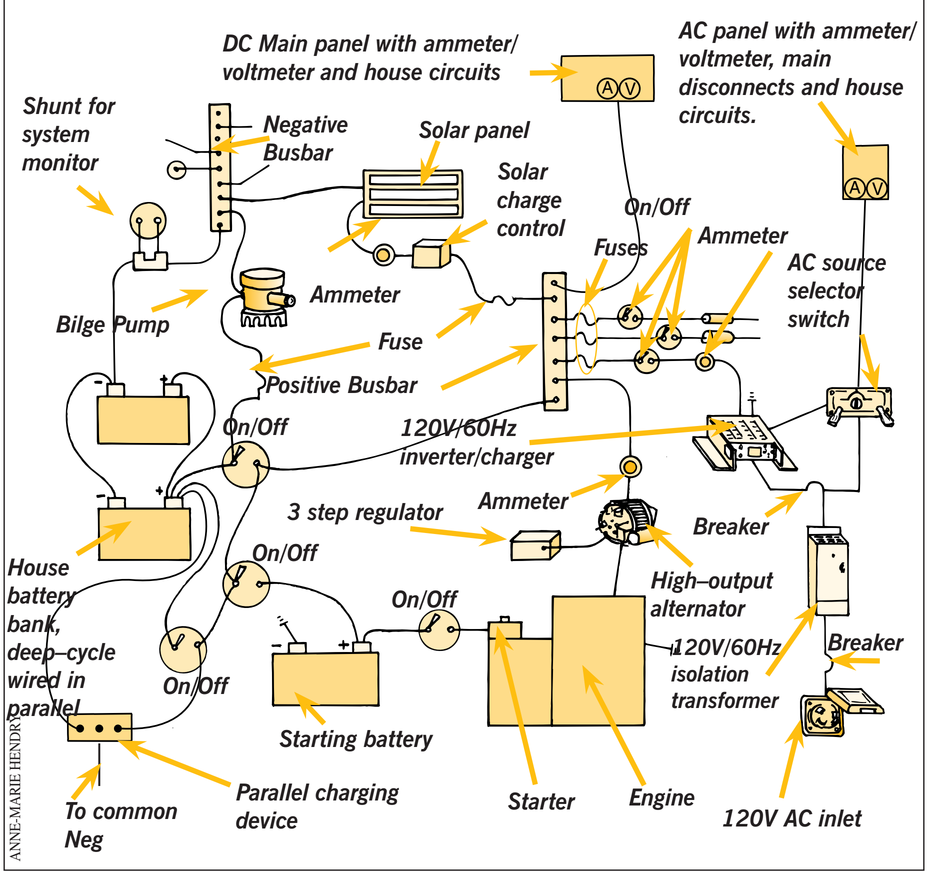
Figure 3

COMPLETE SYSTEM SCHEMATIC



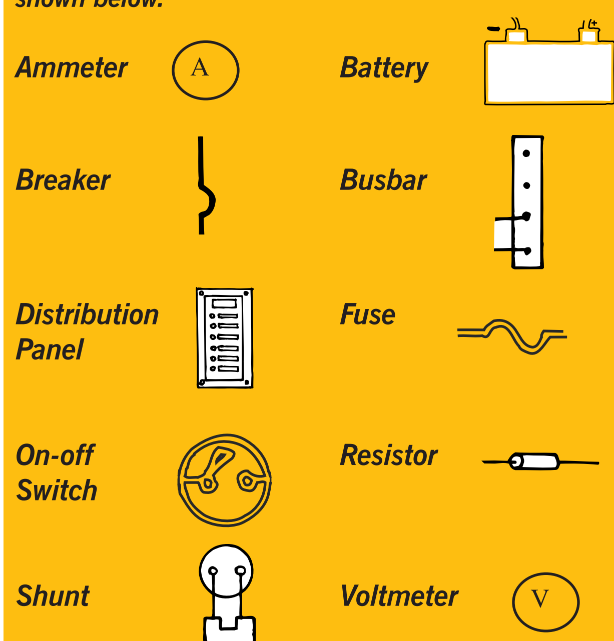
busbar feeds the DC load panel and the heavy DC loads, and provides a convenient connection point for the alternator, solar panel and inverter-charger feed. The negative busbar does the same for the negative wires. You can elaborate the schematic by drawing all individual circuits in the DC main panel.

Place fuses and on-off switches as needed to provide safety protection and flexibility. Heavy-duty DC circuit breakers can replace fuse and switch combinations if desired. Analog ammeters and a voltmeter are good for basic at-a-glance system monitoring. The addition of a shunt in the negative feed from the house bank allows for the installation of a system monitor that can accurately track total system performance. I usually recommend both for redundancy.

Now place the AC circuit in the schematic. Start with a shorepower inlet, feed this through an isolation transformer

COMMON ELECTRICAL SYMBOLS

Creating an electrical schematic diagram should primarily be for your needs, not some professor in an electrical engineering course. General conventions should still be followed, however, to make it easy for others to understand and work on your system if needed. Some conventional schematic symbols are shown below.



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(optional), and feed both the inverter-charger and the AC main panel. Most inverters have an automatic transfer switch that sends AC current to the main panel, but the addition of a source selector switch allows you to bypass the inverter if desired (a good option for inverter maintenance or repair). The single wire shown in this schematic actually represents a three-wire cable for hot, neutral and ground. Make sure you properly size and specify all circuit protection devices, wire and wiring connectors. [Ed: Refer to page 55 for complete wiring specifics.]

When creating the electrical schematic for your boat add as much detail as possible. Sketching all components, even the small ones, and circuits helps a supplier provide an accurate quote. It also helps you install the system properly and troubleshoot problems later on.

Power Consumption Worksheet

To estimate your daily power consumption, make a chart with four columns.

Column 1: List all DC appliances (lights, radios, fans, clocks, etc.) and all AC appliances (microwave, computer, etc.)

Column 2: List the power usage in amps for each appliance.

Column 3: Write down the number of hours each appliance is used every day.

Column 4: Multiply the number of amps for each appliance times the number of hours and write the value in this column. This represents the power consumed for each appliance (amp-hrs/day). Total this column.

To determine the size of solar panel(s) needed, divide the total power consumption obtained from Column 4 by the power output from the solar panel(s).

Note: Manufacturers' power output specs are usually based on "ideal" light conditions and vary greatly with mounting location, time of year and geographic area.

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DC Upgrades

A complete guide to upgrading, expanding or modifying your boat's DC electrical system. (Also refer to page 2 to 12 for system design and proper installation techniques.)

Many production boats come with sorely inadequate electrical wiring systems. Designed merely for the equipment installed at time of purchase, they come from the manufacturer with only the bare necessities: one battery, a single six-circuit fuse panel, and no means of monitoring the status of the electrical system. Moreover, a large number of boats are wired incorrectly or with non-marine-grade components that are highly susceptible to moisture, corrosion and certain failure; some older boats may even have solid core wiring commonly used in household AC circuits. Other elements in a marine environment — saltwater, oil, gasoline, diesel fuel, heat, cold and never-ending vibration — quickly consume a poorly installed wiring system.

Surveying and Planning

The type of refit discussed in this article is suitable for any pleasure boat up to 200' (60m). Your system may be as simple as a single battery and instrument panel or as complex as multiple batteries and circuits. Larger power boats will have more circuits but the principles remain the same. Before upgrading or modifying your electrical system, you need to survey the existing components to determine what is salvageable and needs upgrading. Do a random check of wire conductors for discoloration and corrosion by stripping back the insulation at a few terminals. As long as wire and insulation are intact and pliable, and along with the terminals show no signs of corrosion, there is no need to replace.

With the survey completed, you need to compile a list of all your electrical needs. Include all electronic equipment you have on board plus any items you plan to add in the future; it's important to plan for expansion. If your boat's existing distribution panel is full, adding another six-circuit panel allows a separate circuit for each electronic device. More importantly, if there was ever a short on one circuit, it would not put any other devices out of use. To monitor the system, you'll need a voltmeter and ammeter. A voltmeter checks condition of the batteries and monitors the charge from the alternator or battery charger. The ammeter measures current loads in circuits and monitors alternator output. To be functional for marine use, the voltmeter should have an expanded scale (8 to 16 volts); the ammeter is sized to fit the boat's amperage range.

BLUE SEA SYSTEMS

Figure 1: A four-position master switch lets you isolate the batteries, select which battery requires charging or completely cut off all power.

BLUE SEA SYSTEMS

Figure 2: Bus bars centralize multiple wires, shortening multiple cable runs to common positive or negative power points.

To meet additional power loads, consider adding a second battery and a three-way master switch (**Figure 1**). Mounted on a bulkhead close to the battery, this switch lets you isolate the batteries, reserving one (a starting battery) for the engine and the other (a deep cycle) for all other loads. You can also select which battery requires charging or completely disconnect all power. Multiple battery systems should also have a battery isolator coupled to a "smart" regulator. Both devices recharge batteries simultaneously without danger of one discharging into the other. In a dedicated battery system, where one battery is used solely for engine starts, you may elect to eliminate the master switch. In this case, the starting battery is connected

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TABLE 1: DISTRIBUTION PANEL (FUSE)

	Circuit	Amps
Cabin lights**	1	0.6 x 4
Cabin fan		1.2
AM/FM cassette	2	1.0
Navigation lights	3	Port 0.8
		Stbd 0.8
		Steaming 0.8
		Masthead Trilight 2.0
		Deck light*1.6
Bilge pump	4	4.0
Compass light	5	0.1
Instrument lights		0.1
Cockpit light		1.7
Chart light		0.4
Spotlight	6	10
Autopilot	7	4.0
Depthsounder	8	0.1
VHF radio	9	4.5 max
Speedo/Log	10	1.5
Spare	11	
Spare	12	

*Halogen light
**Flourescent lights
(Note: To estimate amperage draw of any electrical device, divide its rated watts by the ship's voltage, either 12, 24 or 32 volts.)

to a 200-amp, single-pole key switch that lets you disconnect all power if there is an electrical short or emergency. This prevents accidental battery drain of the boat's main power source. The auxiliary battery connects to a similar switch. A master switch would be required only if the boat was equipped with two deep-cycle batteries, usually linked in parallel, so that the "Both" position on the switch charges them simultaneously.

Now draw up a wiring plan. The easiest way to do this is to sketch the interior of the boat to scale, showing all electrical equipment and proposed routing of all wires. Where possible, follow existing wiring paths for there are only a limited number of ways to get from the bow to stern and side to side. Measure the approximate length of each wire from the battery, switchboard, or distribution panel to the electrical device and back. Allow an extra 3' (.9m) for slack at the ends.

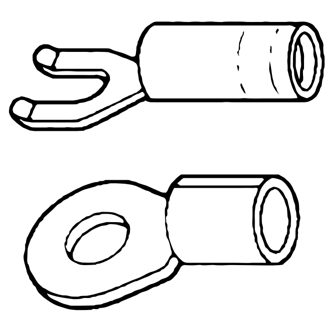

Figure 3: Ring or captive-spade type terminals are preferred since they will stay in place even if the attachment screw or nut works loose.

Calculating Wire Size

Total load in amps on a circuit and wire size should be determined at this point. Both 12- and 24-volt systems are extremely sensitive to voltage drop. Even short lengths of wire can produce a voltage drop at high current draw. This is often evident when the lights dim as a fan, bilge pump or pressure pump starts.

Start by calculating the amperage of each device. If only wattage is known, divide it by the system's voltage, either 12, 24 or 32 volts. A fluorescent 6-watt light bulb, for example, draws 0.5 amps at 12 volts. Now determine which devices you can safely group on a circuit without overloading; 10 amps per circuit gives plenty of room for future expansion. Group items that are used together, such as cabin lights or instrument lights on one circuit, but attach no more than four terminals to any terminal stud. Items that are critical to a boat's safety (bilge pump, navigation lights, instruments) should be connected to separate circuits (see **Table 1**). Wire heavy current draw items, such as an electric anchor windlass, directly to the main distribution point or the battery, with a separate in-line circuit breaker. If necessary, split a circuit and run extra wires to keep the individual currents down. Overloaded wires will heat up, a potential source of fire.

To minimize the number of circuits for low current loads, consider mounting sub

TIP:

Never mix voltages inside the same panel. If 12 and 24 volt and shorepower panels are located in close proximity, design them so each is easily serviced without opening the other. Having to disconnect all power sources means you cannot use alternate lighting to see what you are working on.

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panels. Instead of having a circuit breaker for each navigation instrument, have one 20 amp breaker marked navigation and use a sub panel of four or six switches without fuses right at the chart table to control separate items like night light, main light, log and navigation receiver. Many of these devices come with their own fast-blow, in-line fuse on the power wire lead. You should retain these fast-blow fuses to protect the instrument. The galley area is another instance where a single large amperage breaker with multiple switches placed close at hand makes good sense.

Before determining wire sizes, you need to estimate voltage drop. This value is proportional to wire size and length of the circuit between the power source (a battery, distribution panel or instrument panel) to the electrical device and back to the negative source. Lengthy distances require larger wire to prevent excessive drop. For electrical devices where voltage must be keep to a minimum to ensure the safety of the boat or passengers, such as navigation lights, navigation receivers (GPS, loran or radar) or bilge blower, wire is sized for a maximum voltage drop of 3% (see **page 8**). Wire sizing for other non-voltage-drop sensitive equipment, such as interior or instrument lights, is based on a voltage drop of 10% or less (see **page 8**).

Knowing the amperage requirements and voltage drop on any given circuit, you can now compute wire size and length. Remember: the number of wires installed on any one circuit is limited to the size and total length of the wire and the amperage of the fuse or circuit breaker (refer to **page 25**). For example: a circuit carrying 20 amps a distance of 15' (4.5m) requires a #10 wire to keep the voltage drop to 3%; a #16 wire for a 10% drop. Positive and negative wires must be sized the same, since each carries an equal load. Generally, #12 or #14 AWG will be adequate for most applications; it is always better to err on the side of caution and use the larger size. Tally all lengths and add the sum to your shopping list.

Materials

When purchasing electrical components, it's imperative you use only marine-classified products manufactured to UL/CSA, SAE as well as coast guard and American Boat & Yacht Council (ABYC) standards. Automotive terminals, wire and switches do not belong on any boat. Some automotive parts stores sell products that meet marine standards,

TIP:

DC wires installed within .9m (3') of a compass or sensitive electronics, should have the positive and negative wires twisted in a continuous spiral in pairs to reduce magnetism induced by a flowing current. Ancor Marine offers a twisted pair cable with a braided shield for sensitive installations.

so it's important that you know what you're buying.

Wire must be fine-stranded, which means it has plenty of strands; a minimum of 19 is standard. Fine multiple strands are more flexible and are necessary for vibration-prone areas. Look for tinned copper wire (**Figure 4**) that has up to three times more corrosion resistance than copper, which often corrodes under the plastic covering; tinning prevents this corrosion. Wire is sold in different diameters and colors; the larger the American Wire Gauge (AWG) number, the smaller the wire. Never substitute AWG wire with SAE, an inferior wire designed for surface vehicles such as cars, motorcycles, etc., that is up to 12% smaller than AWG. It's a good practice to follow the recommended color code for general purpose and accessory wiring on boats (see **page 62**). You may use other colors provided they are clearly marked on the wiring diagram. The only exceptions: red leads on positive circuits and black or yellow on negative. Try not to mix colors from one end of a circuit to another. It makes tracing and troubleshooting later on extremely difficult. Color-coded wires inside a common

Figure 4: Never use SAE wire (left), an automotive copper wire that has few strands and is 12% smaller that marine grade. Multiple-stranded, tin-plated copper AWG wire (center) is more flexible and offers three times more corrosion resistance than SAE. To reduce magnetism when routing wires near compass or sensitive electronics, use a twisted pair cable (right) with a braided shield (Ancor Marine).

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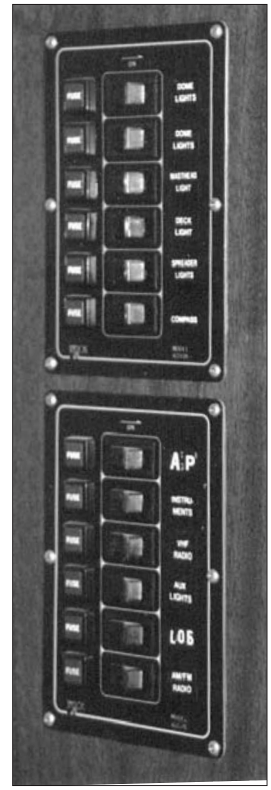
Figure 5: A negative consolidation terminal such as the PowerPost+, provides an attachment point for multiple negative cables, allowing a single cable to connect to the engine ground.

jacket simplify wiring and are readily available from most marine or electronic supply stores.

All wires are terminated with crimp or swage-type **terminals** made of tinned copper or brass and seamless. Ring or captive-spade types (**Figure 3**) are preferred since they will stay in place even if the screw works loose, which causes the circuit to first become intermittent without the wire dropping off and may cause a short elsewhere. Ter-minals must be sized correctly to the wire being used: yellow for 10 to 12 gauge; blue for 14 to 16 gauge; and red for 18 to 22 gauge. While common practice for many years has been to solder the wire ends, properly applied crimp terminals are accepted by the coast guard, ABYC and others. As most solder joints are "cold joints," galvanic corrosion may cause premature failure. Soldering also creates hard spots and prevents multi-strand wire from flexing. Eventually, vibration causes wires to break at the solder joint. If you insist on soldering, you must also use a crimp-on terminal. Never use household-type, twist-on connectors (also called wire nuts or Marette plugs) that cannot withstand the vibration and pounding.

Distribution panels or panelboards (**Figure 7**) have either fuses or circuit breakers. Fused panels are less expensive than panels with circuit breakers but you'll need to carry spare corrosion-resistant fuses. Circuit breakers do offer several advantages over fuses. Sealed magnetic breakers are temperature independent and provide the same degree of protection regardless of ambient temperature. Breakers have a delay curve built in to compensate for momentary start-up surges above the nominal rating. Unlike fuses, the protection mechanism is corrosion proof. A corroded fuse holder can build up resistance causing overheating and a blown fuse; breakers are resettable, allowing power to be restored quickly once the fault has been cleared.

Figure 7: A separate circuit for each electrical grouping (cabin lights, for example) or electronic device is easily identified on the panel.



The Right Tools

Your DIY electrical kit should include (**Figure 6**): wire cutter, wire stripper and crimp tool, assortment of screwdrivers, needle nose pliers, assorted ring terminals and butt connectors, heat-shrink tubing, #14 AWG and #12 AWG wire, wire markers, nylon


J. MUNDY

Figure 6: A typical DC electrical tool kit for DIY installations: crimp tool, lug crimper, multimeter, wire stripper, coaxial cable stripper, AWG wire, cable ties and clamps, fuses, assorted crimp and heat-strink terminals, butane lighter or heat gun, heat-shrink tubing, spiral wrap, wire/cable cutter and wire markers (missing).

TIP:

Use yellow wire for negative grounds rather than black which may be confused with the AC hot wire which is also black.

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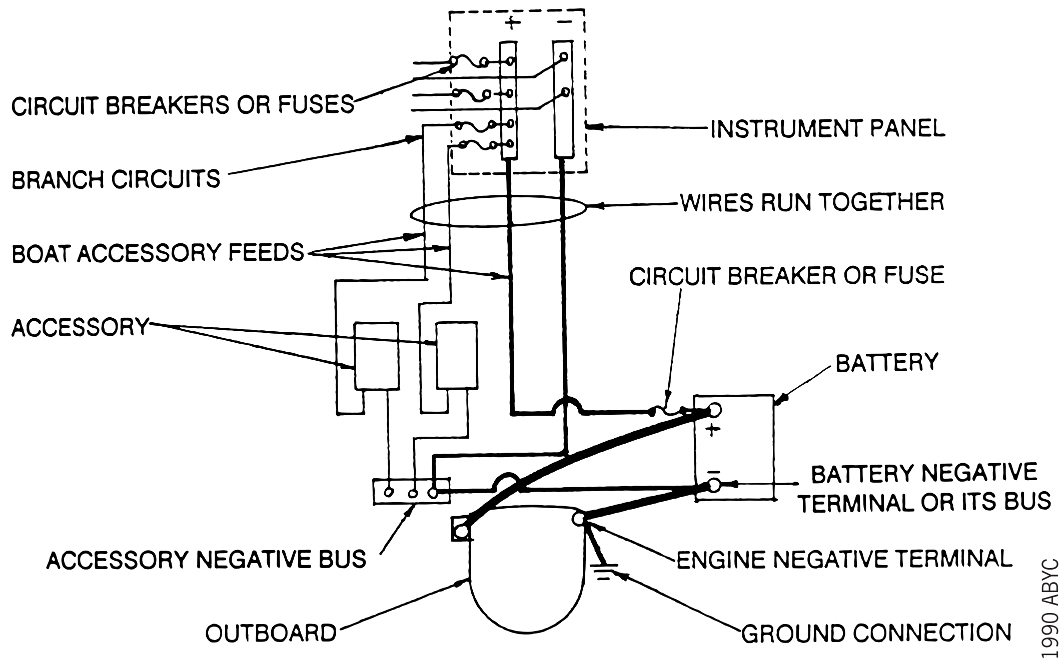
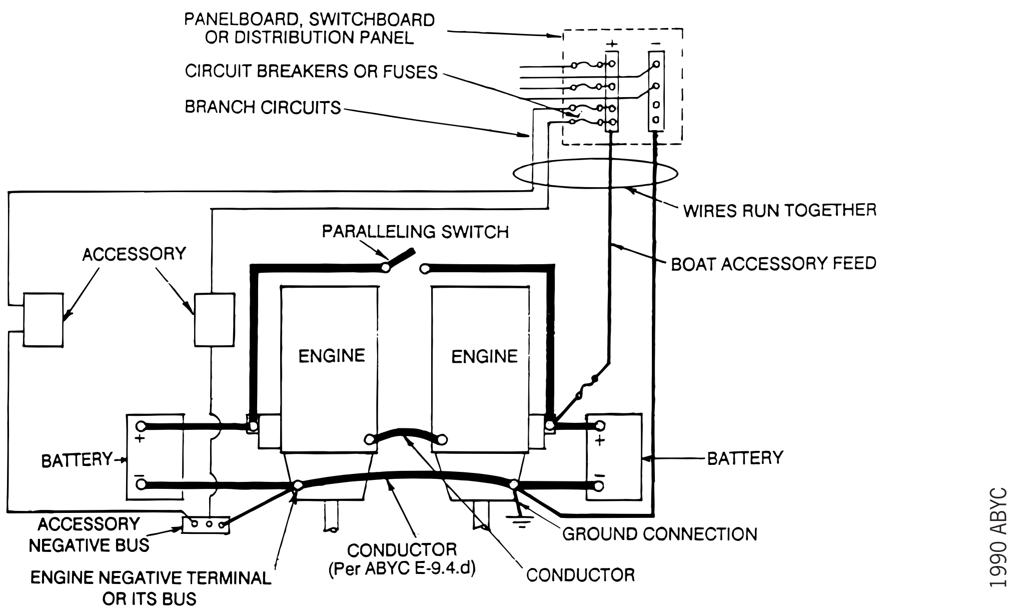
Typical Outboard DC System



Typical Twin Engine Inboard DC System



cable ties and clamps, spiral wrap, spare fuses, multimeter and test lamp (optional).

A general all-purpose crimping tool sold by automotive suppliers is usually inadequate for marine use. A good quality crimping tool locates the terminal so that the seam is in the right position and all crimps will be secure. The better ones are designed so the jaws are properly matched for the particular terminal and won't release until the crimp is properly formed. Look for one that has dies for both insulated and non-insulated connectors in three sizes: #8 to #10; #12 to #14; and #16 to #18. You may pay as much as US$40 for a heavy duty crimp tool: the payback is peace of mind and a safe, trouble-free installation.

Putting it all Together

The heart of a boat's DC electrical system is its power source: the battery. From here, a

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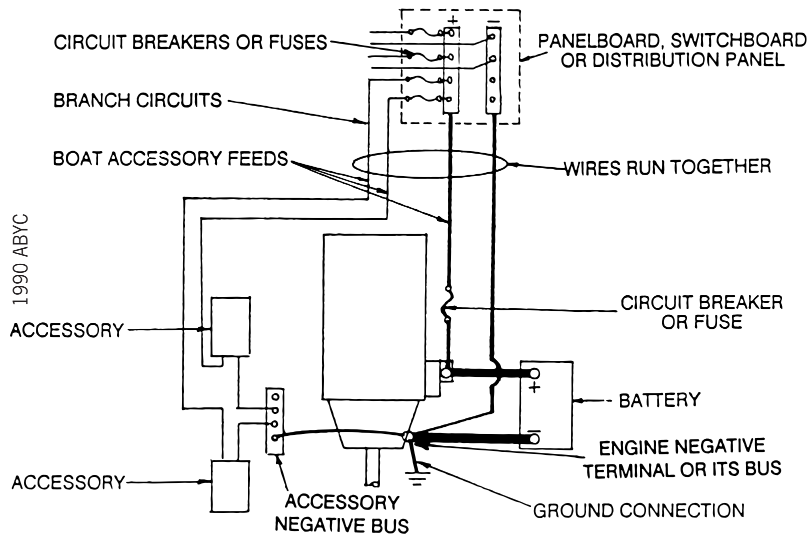
Typical Single Engine Inboard DC System



positive cable (preferably #8 AWG or larger) leads to a master switch, distribution panel or switchboard (instrument panel). The negative battery cable goes to a ground, most often to the engine negative terminal. Any electrical device or appliance in contact with bilge water or seawater (windlass, bilge pump, washdown or shower pump), must also have the non-current-carrying cable (cold) connected to a ground to minimize stray current corrosion. Rather than attach multiple negative cables directly to the engine, a better method is to attach wires to a DC grounding terminal post, such as the PowerPost+ made by Blue Sea Systems. A single cable then connects directly to the engine ground.

Securely mount the second battery, then install the master battery switch in a dry location that's easily accessed — you may need to quickly shut off power in case of an electrical fire. Using a cardboard template of the distribution panel, select a location that is easily accessible, well-ventilated and protected from rain and spray. Allow a minimum of 4" (10cm) behind the back of the panel; the exact amount is determined by meter size and type of fuse holder or circuit breaker installed. You would be surprised at how much space bunched wires take up.

Check your wiring plan and bundle wires passing along the same route. To facilitate passing wires from one location to another, group all wires together first, then pull the whole bundle as one harness. Run wires neatly in straight lines, following the perimeter of bulkheads, deckheads and cabin interiors; do not run across on a diagonal. When you pass a wire or cable bundle through a bulkhead, protect insulation from chafe by inserting a rubber bushing or smooth-edged plastic grommet. For greater protection, bundle wires with plastic spiral wrap, which is sold in diameters from 1/8" (3mm) to 1" (2.54cm). Routing wires through an area that's difficult to access, such as under the floor or deckhead, generally requires hand feeding, pushing the wire through one way or the other. If you can follow an existing wiring harness, use one wire as a "messenger." Disconnect an independent wire or cable from the panelboard or instrument panel, tape the new wire and a return line (#4 polyester cord works best) to the wire, then pull it through until it exits. Remove the new wire and using the messenger, pull the old wire back to the starting point. It's important to label or tag each individual circuit (wire) before pulling them through or you will have a tough job tracing each circuit afterwards.

Never run bundles of wires through the bilge where they might get submerged in water. All connections and splices should be made high above normal water levels. Don't bury in-line splices away in some hidden corner. Wire splices must be protected against water or moist salt air, especially in bilge areas or on deck. If you have to make a splice, use a crimp-on butt connector and heat-shrink tubing (see page 58) to insulate and seal. Keep detailed notes of what wires you ran where and which circuit feeds what equipment.

Strip wire with the properly sized stripping edge on the crimping tool or use an automatic wire stripper, a handy tool that

WIRING SENSITIVE NAVIGATION EQUIPMENT

By Arild Jensen

Navigation instruments are sensitive to electrical noise created by motors, relays and other appliances. Momentary voltage drops created during heavy current surges can play havoc with computerized GPS or loran receivers. Motors and alternators can produce electrical noise in the power lines that disrupt reception thus rendering your navigation and communication receivers useless.

Sailboat auxiliaries are especially prone to this problem. When under sail everything works fine. Start the engine, however, and the voltage dips, momentarily causing the navigation receiver to go haywire. Loran sets often have to be shut down and reset with a new initialization point. GPS receivers may recover on their own but only after several minutes wait.

Navigation equipment should be provided with a separate circuit fed from the battery with large size wires to isolate heavy current draw circuits from noise-sensitive circuits. The cable joining the distribution point to the battery should be very large, #4 AWG or larger if your maximum total draw is more than 20 to 30 amps.

Several products on the market help overcome these difficulties. Newmar makes two versions of a backup power supply filter. The basic device is a gel cell battery with a diode and isolating relay. The coil wires are run out to the starter's solenoid connection. When you turn the key to start the engine, the relay disconnects the receiver from the ship's battery. The internal battery provides enough power to keep the receiver going during the voltage dip. The diode provides a charging path so the gel cell recharges from the engine alternator when the engine is running. A more sophisticated version has additional filtering circuits that are more suited to a powerboat containing multiple sources of noise such as automatic water pumps, fans, refrigerator motors and air conditioning. Provision is made for two start circuits in dual engine boats. In either unit, the gel cell has enough power to keep the navigation receiver running long after the main battery runs out. In an emergency, this may be enough to obtain an exact fix when radioing for help.

cuts and strips wire to the exact length in one squeeze of the trigger (available from Ancor Marine). Never use a knife that can easily nick the conductor and cause the wire to fail under vibration, loosening the entire joint. One of the most common electrical problems and potential sources of fire is a terminal that is loose on the terminal stud or wire. This creates a high-resistance path and overheats. Always use the correct size terminal and proper crimp tool. Follow wire preparation and crimping procedures on pages 57 and 58. Problems with crimped connections are usually caused by using wrong tools, technique or materials. Many crimp terminals fail when the wire breaks off just past the crimp where the wire flexes the most. Blinking lights are an early warning to inspect and tighten all loose screws on panels and terminal blocks.

Use marine-grade heat-shrink tubing (such as those made by Ancor Marine) to waterproof connections and protect against accidental shorting.(Do not use silicone sealant to waterproof connections for it releases acetic acid as it cures and may cause premature failure.) The tubing slides over the wire, or the terminal if already crimped. Heat is then applied to the tubing with a butane lighter or heat gun (the kind used for paint stripping) to make an airtight seal. Some shrink tubing has an adhesive lining that when heated, seals the tubing to the wire insulation. For areas where connections are exposed to immersion (bilge pumps) or

TIP:

SOURCES OF WIRING FAILURES

Loose crimp on wire terminals.
Loose screws on panels, switchboards or terminal bus.
Unsecured wires or terminals.
Bad ground.
Corroded wires or connectors.
Worn insulation on wire causes a short circuit.

subject to rain, spray or splash, Ancor Marine produces a three-in-one terminal with a connector, terminal and heat-shrink tubing in one unit that is CSA and UL approved for prolonged submersion.

When wire runs have to be joined, split, or have a removable connection point use a terminal bus (**Figure 2, page 17**). This device is also used to shorten multiple cable runs to common positive or negative power points. Mount bus blocks in a dry location as high as possible. Never mount a terminal strip directly on any metal surface that is electrically connected to a metal hull. Trapped moisture will provide a leakage path for electrical current, resulting in stray current corrosion and extensive damage. Metal boats must provide an insulated surface (wood or other) as screws could short out to the conductive surface underneath. If you must mount a bus on a metallic surface, either get the type with a blind hole covered by insulation or use insulated liners available from the manufacturer. Shield all positive connectors and any terminal bus with an insulating cover to prevent shorting. Terminal strips and all positive connectors should have a protective box or insulating cover to prevent accidental shorting.

Label the wire at both ends near each terminal. Electrical suppliers stock a variety of wire ties, numbered tags and stick-on labels. Alternatively, you can write on white or light colored heat-shrink tubing with a ball point pen. This provides a permanent wire marking. Connect terminals to the terminal block or panelboard leaving some slack in the wires to prevent them from pulling loose under vibration and give room for repairs. Protect wires from abrasion in lockers with a conduit made of PVC pipe, available at hardware stores. Drill small holes in the pipe at low spots for water drainage. Wires and cables not run in a conduit must be carefully supported throughout at 46cm (18") intervals or less with snug-fitting screw-eye cable clamps or ties screwed to a secure surface. Wires should also be fastened near each terminal and at either side of a butt splice. If you do not want to drill screw holes, use adhesive-backed mounting pads. Never use these in engine rooms or other high-temperature areas as heat softens the glue and pads falls off. Use cable ties to fasten additional wires to existing wiring that is already routed and firmly secured. Finally, spray the entire surface with a heavy duty corrosion inhibitor.

Improper wiring is the most common source of fire in boats. Anyone contemplating a major overhaul of their boat's wiring system should first consult ABYC's Standards and Recommended Practices for Small Craft, sections E-8 and E-9; also in Canada, the Canadian Standard Association standards covering DC wiring for boats; and in the US, National Fire Protection Association's National Electric Code. If in doubt, consult a marine electronics technician.

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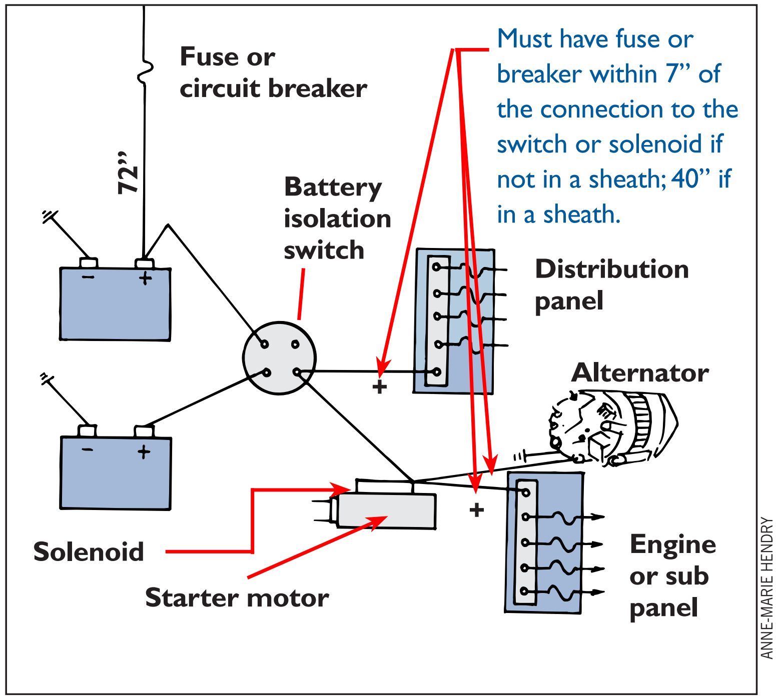
Circuit Protection Devices

All marine DC circuits, with the exception of starter motor cranking circuits, should be protected by circuit protection devices (CPD), such as circuit breakers or fuses. As shown below, main battery circuits must adhere to the 7", 40" and 72" rules. Main feeds connected directly to a battery must have a CPD within 72" of the battery. Main feeds connected to a battery switch or starter motor solenoid switch must have a CPD within 7" of the connection if unsheathed or within 40" of the connection if in a sheath.

All branch circuits should also be protected by CPDs. **Figure 2** (shown on page 6) shows the levels of circuit protection recommended for a boat with a single house bank system and multiple sub-main circuits. While your electrical system may not be this complex, the basic principles of circuit protection can be applied to any boat.

CPDs should be sized according to the expected load in the circuit: have a DC voltage rating of not less than the nominal system voltage; and have an appropriate ampere interrupting capacity based on battery capacity. Contact your electrical equipment supplier for help sizing and selecting CPDs.



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THE WEAK LINK

Fuses and circuit breakers prevent too much amperage from traveling through a wire, building heat through resistance that may damage electrical and electronic equipment, and more important, cause an electrical fire. You can avoid potentially dangerous problems by reviewing ABYC standards to make sure adequately sized circuit protection devices are installed properly.

[By Kevin Jeffrey]

"Electrical circuit" refers to a complete path for electrical current flowing through wires. A boat's power system is comprised of various electrical circuits formed by connecting a voltage source such as a battery bank or AC power source to one or more electrical loads (equipment that uses electricity) by means of a conductor (wire or cable). In a DC (direct current) circuit, battery voltage pushes electrical current through various electrical loads when they are switched on, using some of the energy stored in the battery to perform useful work. In an AC (alternating current) circuit the voltage source (shorepower, inverter or gen-set) pushes electrical current in a similar manner, again using energy in the process.

There are primary or main circuits, which typically include the main power sources, either DC or AC **(Figure 1)**. There are also secondary or branch circuits that are complete electrical paths within the primary circuits. All electrical loads on the boat, for example, are individual secondary circuits. Finally, there are internal circuits within each electrical or electronic device.

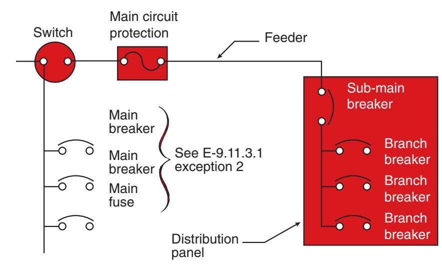

FIGURE 1
Main and Branch Circuit Protection

All electrical circuits must be protected from too much current flow, which can cause wire conductors to overheat and wire insulation to burn, and can damage internal circuits in individual appliances. Protection of an electrical circuit is in the form of an intentional weak link, typically a fuse or circuit breaker, which the industry refers to as a overcurrent circuit protection device (CPD). Circuit protection on board a boat must be taken seriously. A potentially devastating electrical fire can result when too much amperage travels through a wire and enough heat is generated to melt and burn the wire insulation and surrounding materials, causing a fire.

CPDs are meant to protect against unexpected problems, and shouldn't preclude proper wire sizing and adherence to proper electrical system design and installation practices. Sizing wire is relatively easy. You simply match the maximum sustained amperage in a given circuit and the total length of the circuit wiring with a proper wire size that will be safe and also prevent an excessive voltage drop for the type of appliance used **(Figure 2)**. [Ed: For specifics on wire sizes, factoring in voltage drop, length of run and whether or not the wire passes through a heated space (i.e. engine compartment), refer to pages 64-66 or sections E-8 and E-9 of ABYC Standards.]

Sizing wire correctly can't protect against accidental grounding through wire chafe, equipment failure or grounding a circuit while performing system maintenance that temporarily allows a dangerous amount of current to flow. CPDs handle unsafe levels of current by opening the circuit, either through thermal devices or devices that sense a magnetic field created by excess amperage.

Allowable amperage of conductors under 50 Volts with 105° C insulation

AWG Wire Size	Metric (Sq mm)	AWG CM area	SAE CM area	Ohms /1000 ft	Ampacity Engine Space Outside	Ampacity Engine Space Inside
18	.8	1,600	1,537	6.385	20	17
16	1	2,600	2,336	4.016	25	21.3
14	2	4,100	3,702	2.525	35	29.8
12	3	6,500	5,833	1.588	45	38.3
10	5	10,500	9,343	.9989	60	51
8	8	16,800	14,810	.6282	80	68
6	13	26,600	24,538	.3951	120	102
4	19	42,000	37,360	.2485	160	136
2	32	66,500	62,450	.1563	210	178.5
1	40	83,690	77,790	.1239	245	208
0	50	105,600	98,980	.09827	285	242.3
2/0	62	133,100	125,100	.07793	330	280.5
3/0	81	167,800	158,600	.06180	385	327.3
4/0	103	211,600	205,500	.04901	445	378.3

FIGURE 2
ABYC Amperage Recommendations

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Types of CPDs

Fuses are strictly thermal devices that melt at a predetermined amperage. They are reliable and relatively inexpensive, although total cost includes the purchase of a fuse mounting block and a protective cover of some type, spares, since fuses must be replaced after each overcurrent condition, and some form of circuit disconnect. Circuit breakers can be thermal or magnetic devices, or a combination of the two. Circuit breakers are typically more expensive than fuses, especially for high load circuits, but they also serve as circuit disconnects and since they are resettable the need to carry spares is not as critical. (**Figure 3** illustrates a quick-reference comparison of CPDs.)

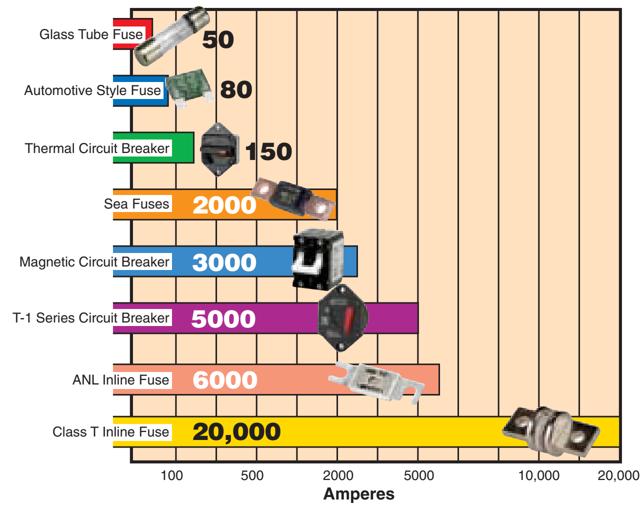

FIGURE 3
Quick-Reference Comparison of CPDs

Class T Fuse: Recommended by most inverter manufacturers, it has an extremely fast short-circuit response, a 20,000 ampere DC interrupt capacity, and is rated for up to 160 volts DC (VDC).

ANL Fuse: With a 6,000 ampere DC interrupt capacity, it meets ABYC requirements for main DC circuit protection on large battery banks with a voltage up to 32DC.

Total Connected Battery CCA*	Main Circuit Breaker	Branch Circuit Breaker
12 Volts and 24 Volts	**Amperes**	**Amperes**
650 or less	1500	750
651 - 1100	3000	1500
over 1100	5000	2500
32 Volts		
1250 or less	3000	1500
over 1250	5000	2500
AC Shore Power Source	**Main Circuit Breaker**	**Branch Cuicuit Breaker**
120V - 30A	3000	3000
120V - 50A	3000	3000
120/240V - 50A	5000	3000
240V - 50A	5000	3000
120/208V - 3 phase/WYE - 30A	5000	3000
120/240V - 100A	5000	3000
120/208V - 3 phase/WYE - 100A	5000	3000

*Cold Cranking Amperes

FIGURE 4 *How to Determine Interrupt Rating*
Use the table above to determine the required minimum interrupt rating per ABYC, or how much current the fuse or breaker can safely handle in a short circuit condition.

Sea Fuse: An economical choice for circuit protection between 100 and 300 amperes. It has a 2,000 amperes DC interrupt capacity and is rated for up to 32VDC.

Automotive Style Fuse: Inexpensive and widely available through automotive stores, it's the most economical choice for between 30- and 80-ampere circuit protection. It has 1,000-ampere DC interrupt capacity and a 32DC voltage rating.

Glass Fuses: Available in current ratings from less than 1 up to 50 amperes, these inexpensive fuses are used for branch circuits in a variety of applications. AGC models are fast-acting fuses, while MDL models are time-delay fuses for high inrush motor type loads.

Thermal Circuit Breakers: The T-1 series CPD from Blue Sea is thermally responsive bi-metal breakers combining switching and breaker function in one unit. They are available with ampere ratings from 25 to 150 amperes, a voltage rating of 48VDC, and 5,000 amperes at 24VDC interrupt rating. Blue Sea's standard thermal circuit breakers are similar to the T-1 Series but have a 3,000-ampere DC interrupt rating, a 30VDC voltage rating.

Magnetic Circuit Breakers: Available in a wide range of styles and ratings, there are standard DC and AC single pole circuit breakers used for protecting branch circuits in electrical distribution panels. Some low ampere models, rated as "quick trip" are designed specifically for electronics. Double pole AC breakers are available to switch both hot and neutral legs of a 120VAC circuit or two hot legs of a 240VAC circuit. Standard

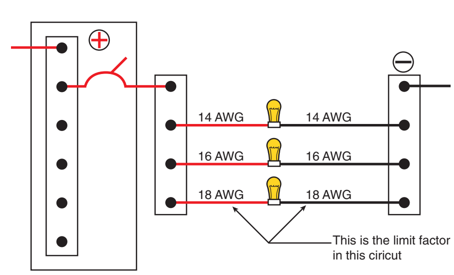

FIGURE 5
Factoring Wire Size
The smallest wire in a circuit determines the amperage of the fuse or circuit breaker.

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magnetic circuit breakers typically have a 2,000- to 3,000-ampere interrupt rating, although some models are available with a 5,000-ampere interrupt rating.

It used to be that only fuses could handle heavy DC loads, but high load circuits can now be protected with single, double or triple pole breakers, such as those from Blue Sea Systems and Paneltronics. In these devices breakers rated up to 100 amperes each are ganged to provide various levels of protection. Sizes range from 50-ampere single pole to 300-ampere triple pole models.

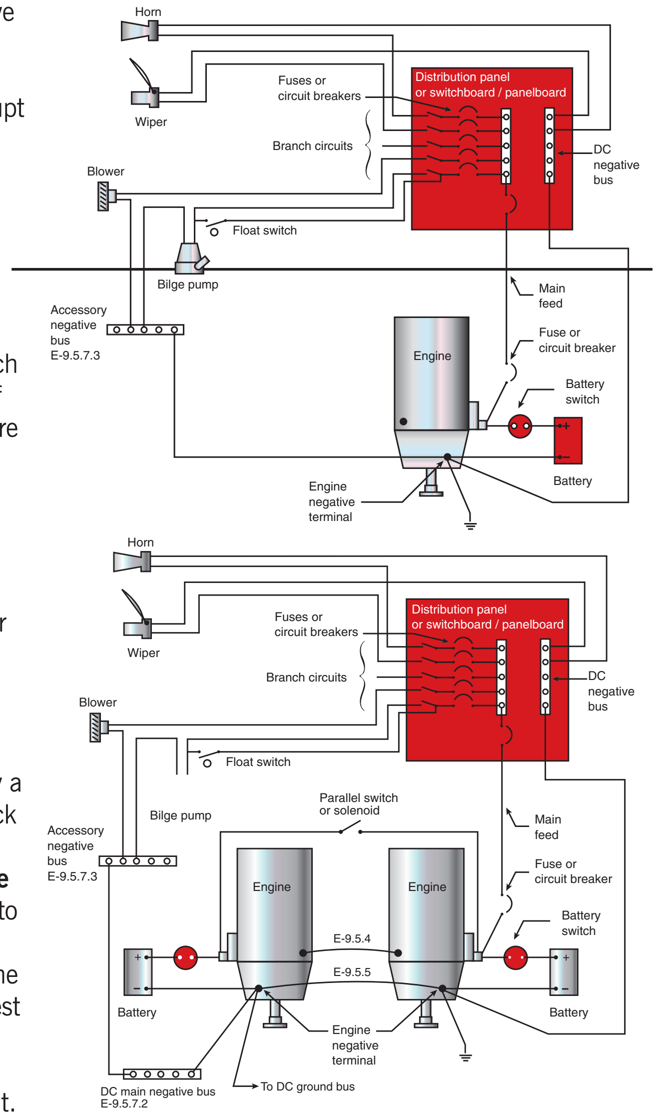


FIGURE 6 *Sample DC Circuits to ABYC Standards*
(top) Single engine and (bottom) twin inboard engine DC electrical systems without AC power systems.

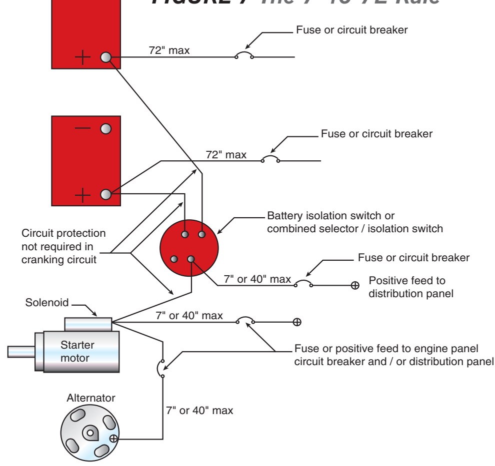
Sizing and Selecting

When choosing CPDs, take it one circuit at a time. First, choose whether you want a fuse or circuit breaker for each circuit. Circuits in an explosive vapor area, such as gasoline engine rooms, battery compartments and propane lockers, must be protected by a vapor-proof circuit breaker. Then, check to see what ampere interrupt rating is required for the application (see **Figure 4**). Next, make sure the CPD is rated to open at an amperage greater than the maximum circuit load and less than the rated amperage capacity of the smallest wire in the circuit. It's also useful to know the maximum momentary or surge current experienced in the circuit. Choosing CPDs that can withstand this surge and still offer the required protection means you'll avoid nuisance tripping. As a final check, make sure the CPD's voltage rating meets or exceeds the circuit voltage.

Where to Install?

Before locating CPDs in your electrical system, it's important to understand the concept that CPDs are installed to protect individual wires in a circuit, and that they should be sized specifically for those wires. Secondary and small branch circuits use smaller (in number only, larger in size) gauge wires, so smaller CPDs should be used **(Figure 5)**.

FIGURE 7 *The 7-40-72 Rule*



Ultimately every wire on board would be protected, but that is impractical. In the DC side of an electrical power system, ABYC standards take a reasonable approach to circuit protection by exempting mandatory CPDs from wires between batteries, battery switch and engine starter motor **(Figure 6)**. CPDs are required within 7" (18cm) of the battery switch and starter motor on wires leading to various loads, and within 72" (183cm) on wires leading to

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loads directly from a battery. The 7" (18cm) dimension can be extended to 40" (101cm) if wires are enclosed in a sheath or other enclosure in addition to the wire insulation **(Figure 7)**.

In the AC side, there should be a main circuit breaker at each AC power source, i.e., at the shorepower inlet(s), generator output and inverter output **(Figure 8)**. In addition, there should be branch circuit breakers on every branch circuit. On boats with multiple sources of AC power, the main circuit breakers can be conveniently located in an AC source selector panel **(Figure 9)**. This type of panel allows only one AC power source to be capable of supplying power at any given time. In this case the main circuit breakers also are serving as manual circuit disconnect switches.

Resources
"Standards and Technical Information Reports for Small Craft," American Boat & Yacht Council; Tel: 410/956-1050, Website: www.abycinc.org

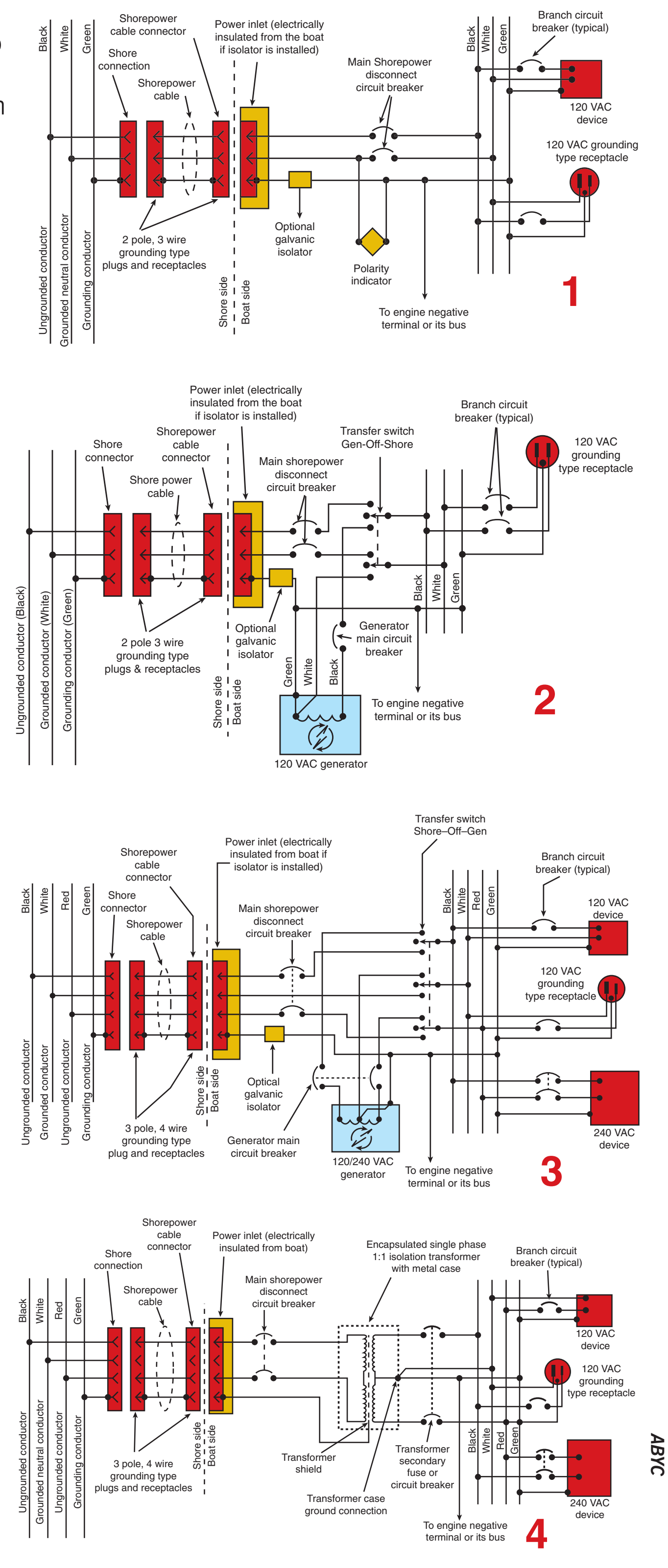

FIGURE 8
Sample AC Circuits to ABYC Standards
(1) Single-phase 120V shorepower with shore-grounded (white) neutral conductor and grounding (green) conductor. (2) A 120VAC generator included as an additional AC power source. In both diagrams the ungrounded conductor and the grounded neutral are protected with a single overcurrent protection device that simultaneously opens both current-carrying conductors. ABYC does not recommend fuses to serve this function. 120VAC branch circuits are permitted to be single pole in the ungrounded current carrying conductors. (3) Single-phase 120/240VAC system with shore-grounded (white) neutral conductor and grounding (green) conductor. Each ungrounded shore conductor connects through the shorepower inlet to the boat's AC electrical system through a single overcurrent protection device that simultaneously opens both ungrounded conductors. The shore-grounded neutral connects to the boat's AC electrical system without overcurrent protection. It may be used provided the overcurrent protection device opens all current carrying conductors in the circuits (in this case a 3-pole switch is needed). (4) An isolation transformer system with single phase, 240VAC shorepower input and 120/240VAC output from the transformer. Circuit protection is provided by a main shorepower disconnect on the shore side of the transformer and secondary overcurrent protection on the boat system side of the transformer. Each ungrounded shore current carrying conductor connects from the shorepower inlet to the primary winding of the isolation transformer through an overcurrent protection device that simultaneously opens both ungrounded conductors. 120VAC branch circuit breakers are permitted to be single pole in the ungrounded current carrying conductors. 240VAC branch circuit breakers must be two-pole and simultaneously open all current carrying conductors.

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Fine Tuning DC Systems

Heavy-duty wire connection and switching devices add a dimension of flexibility in DC (direct current) system planning and installation, as well as improved safety. Here's how to choose the best equipment for your next upgrade.

By Kevin Jeffrey

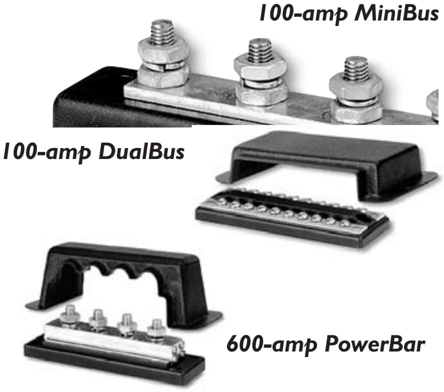
Beyond the glamour of high-output alternators, solar and wind-driven battery chargers, battery banks and system monitors are the hidden essentials of any respectable marine electrical system; namely, heavy-duty DC circuit components that provide safe, efficient wire termination points and switching ability. These devices, often not considered by boat owners, boatbuilders and electrical system suppliers, are fast becoming standard equipment in first-rate marine installations with high-energy demands.

I use the term "heavy duty" to describe this class of electrical devices, not to imply that they all have the same degree of robustness, but to focus on devices that are designed and built to perform well at their rated capacity in rugged marine environments.

Wire Connections

The first heavy-duty DC circuit components to plan for are wire termination devices, which include common electrical busbars, distribution posts and terminal blocks. Battery posts, battery switch terminals and other adhoc connection points have been used for attaching positive and negative wires in an electrical system. Now specially-made wire termination devices provide safe and convenient ways to connect wires and cables.

Electrical busbars are solid blocks of conductive material, such as tin-plated brass, with multiple wire connection points. These connection points can combine individual studs and/or screw terminals for attaching wires in a DC circuit. Since all termination points on a busbar are electrically connected, the busbar itself acts as a jumper from one connection point to another. These features make busbars the preferred method for connecting common groups of positive or negative wires. The conductive material on a busbar is fastened to a base block of non-conductive material such as plastic used for mounting the busbar to a bulkhead or other convenient surface. Ground wires can be connected on a grounding busbar, which is similar to a standard busbar, but lacks the thick metal heat sink and the non-conductive mounting surface.



Busbars are available in a range of styles and electrical ratings. Some models have only stud termination points (typically four). Others have two studs, one at each end, with smaller screw terminals in between. Some have only screw terminals. Dual common buses with screw terminals are also available for terminating both positive and negative wires on a single mounting block. Dual common buses have one common bus for terminating positive wires and a second common bus, electrically isolated from the first, for terminating negative wires.

Busbars are rated for their continuous current capacity and maximum DC voltage. Since busbars can also be used for AC systems, a rating for AC maximum voltage is also given. Be sure you select busbars with sufficient current and voltage ratings for your needs.

Busbars have advantages over single stud distribution posts. They can handle more wire terminations on a single device. ABYC (American Boat and Yacht Council) standards state, "No more than four conductors shall be secured to any one terminal." Busbars also allow wires of varying sizes to be connected on the same device, and wires can be arranged in an orderly pattern.

The connections on a busbar should always be protected with a non-conductive cover. Some busbars on the market have specially-made plastic covers for this purpose.

Distribution posts provide safe, secure connection points for up to four high-amperage cables on a single post. Distribution posts are

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Blue Seas PowerPost

Dedicated terminal block for negative wires.

not typically rated for amperage since current flows between the various conductors and their terminals, not through the post itself. They are, however, rated for maximum DC voltage. Distribution posts for the marine market are typically rated up to 48 volts DC.

Some distribution posts also provide low-amperage screw terminals for connecting conductors from controls, displays, monitor shunts and appliances with small electrical loads. In certain applications, this device can eliminate the need for an additional post or busbar.

As with busbars, distribution posts typically are made with mounting bases of non-conductive material, with recessed mounting screw holes to avoid contact with the conductors on the post. Some models come with a rubber or plastic insulating boot, color-coded for positive (red) or negative (black) wires. The boot is good for one or two wires only, so terminal protection for the other wires on the post is often left to the customer.

Terminal blocks provide a convenient common connection point for wires in multiple DC circuits. Individual circuits in a wire harness can be terminated on a terminal block, and rerouted to an appliance, a power source, or a monitoring or control device.

A typical terminal block has individual pairs of screws serving as circuit connection points for incoming and outgoing conductors. These screw pairs are isolated by the mounting base itself and by raised plastic separators between circuits, and they can be easily joined by a properly rated metal jumper to give the required number of connection points for each circuit.

Terminal blocks typically have a closed back design that completely insulates the electrical power at the screw terminals from the mounting surface.

Switch Controls

The ubiquitous 1-2-Both-Off battery switch used to be the only heavy duty switch on a boat. Boaters can now choose from several varieties of switches that perform a wide range of tasks.

1-2-Both-Off battery switches, supplied with most production boats, are primarily intended for electrical systems that have two battery banks. The switch directs which battery bank accepts the charging current, which battery bank supplies the load current, and it can disconnect the batteries completely from the rest of the electrical system.

Many four-position battery switches on the market are equipped with an alternator field disconnect (AFD) switch that protects the diodes in an engine-driven alternator if the position of the main switch is changed while the engine is running. An AFD is a secondary switch inside the main switch, connected to the field wire of the voltage regulator. When the position of the main switch is changed, the AFD opens, stopping the alternator output before the main switch contacts open, and the AFD closes again before the main switch contacts close.

Battery switches can be directly mounted to a bulkhead or other flat surface, or they can be flush mounted in standard or custom electrical panels. The electrical contacts are on the back of the switch, protected from accidental human contact.

Many boaters set up their electrical systems with one large house bank and designated starting batteries for auxiliaries and generators. For these systems, a simple On-Off battery switch to isolate or disconnect the house bank and the individual starter batteries makes sense. Main battery switches for the house battery bank and engine starting battery(s) should be rated to handle the maximum current expected in the system. A house bank battery switch with a continuous rating of 300 amps and intermittent amperage rating of 400 amps is a good choice for most marine systems.

Lighter duty On-Off switches, known as mini battery switches, can be used to disconnect small starting batteries, but

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Four-position switch.

they have other uses in an electrical power system. They can serve as convenient circuit disconnects for larger branch DC circuits onboard, including circuits for high-amperage appliances and charging sources. Mini battery switches from Blue Sea Systems are rated at 250 amps continuous and 375 amps intermittent. Some models have a removable key to avoid accidental switching of critical loads or charging sources.

On-Off switch

Another option for heavy duty switching in a DC circuit is to use a properly rated, high-amperage DC circuit breaker that combines switching and circuit protection in a single device. Heavy-duty magnetic DC circuit breakers are available in the 50- to 300-amp range for use with inverters, bow thrusters and windlasses. These devices are not designed to open a circuit when the load is drawing current under normal conditions. Interrupting the circuit at high current flow can cause pitting of the contacts that can lead to undesirable resistance. Use a relay to handle the high current arcing that occurs when large DC motors are turned on and off.

Mini battery switch with removable key.

Fine Tuning

There are many reliable wire connection and switching devices to fine-tune simple and sophisticated electrical power systems. These devices improve flexibility in system planning and installation as well as improved safety, security and aesthetic appeal. If you're uncertain about the components or installation in a wiring upgrade you're planning, sketch it on paper, and consult a qualified marine electrician before you proceed. [Ed: For instructions on producing a proper electrical schematic, see page 12.]

About the author: Kevin Jeffrey is an independent electrical power consultant, and is the author of the "Independent Energy Guide" and the publisher of "Sailor's Multihull Guide."

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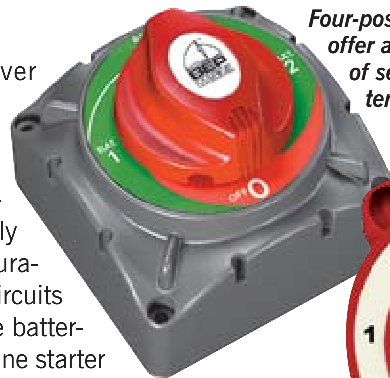
Switch Power

The master of a boat's 12-volt DC electrical system is the battery selector switch. It routes power to and from the engine, start and house batteries. Proper switch selection, installation and usage ensure a trouble-free system.

By John Payne



Four-position battery selector switches offer a simple, economical method of separating two batteries or battery banks (start and house).

Sometimes called a changeover switch, the battery master switch has become standard on boats largely due to the combined starting/charging system configuration that is used with virtually all engines. In this basic configuration, the charging and starting circuits share the same cabling from the batteries to the engine so that the engine starter motor takes electrical current in one direction from the batteries through the master switch. Once started, the alternator sends current back in the opposite direction to the batteries via the master. The negative return is also a single cable, bi-directional conductor that is installed from the engine block to the battery bank negative terminal. This same negative conductor also has an additional role as a polarizing conductor that uses the mass of the engine to do so.

The stock red multi-position master switch found on many boats usually consists of three positions and an off position. Effectively, it is two switches using a common output point. The center position, marked "Both," connects two batteries or battery banks in parallel, effectively combining all into one larger battery bank. The battery switch has three large terminals at the rear to terminate the positive supply cable from each of the batteries. Many battery switches also have an advance field disconnect switch that was originally available for connecting an alternator field circuit. When turning the master switch to the off position, this field disconnect isolated and de-energized the alternator field circuit before actual main circuit switching so as to avoid accidental damage to diodes. This feature is somewhat redundant and I have rarely seen it used as all modern alternators have integral voltage regulators. This was a practical measure when voltage regulators were separate and mounted external to the engine. In operation, when transferring from position "1" to the center position "Both" and then to "2," the main sliding contacts are "make-before-break." This means that there is no (or should be no) momentary break in the circuit that would otherwise create a diode-damaging surge.

Some boats have a simple on-off master switch. Often, two are used; one for the engine and one for the house battery supply. In these cases, a third bridging switch is used to emergency parallel the battery banks. This configuration usually has the input side of both switches bridged together. This does create problems in the charging of the batteries. Battery distribution clusters from BEP Marine include a voltage sensitive relay module (a.k.a. battery combiner) to allow charging of different battery banks from each engine.

Power Ratings

A battery master switch, like all electrical equipment, is selected based on the current demands to be applied to it. It is also rated to at least the rating of the cables that are connected to the switch. Switches

(across) Basic on-off selector switch; (bottom) BEP battery distribution cluster simplifies installation of outboard engines without auxiliary output and a built-in battery isolator (VSR) allows charging of start and house batteries.

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generally have standardized current ratings and, nominally, most switches are continuously rated at 250 amps to 300 amps with short-term intermittent ratings of 600 amps. Heavy-duty rated switches have ratings around 600 amps and 1,000 amps respectively, and some also quote a higher current cranking rating for a shorter period. The short-term rating generally applies to the heavier current that is applied during engine starting. The continuous rating generally applies to the battery alternator charging current. In reality, master switches rarely have the nominal continuous rating applied, which is generally less than 100 amps even on comparatively large engines.

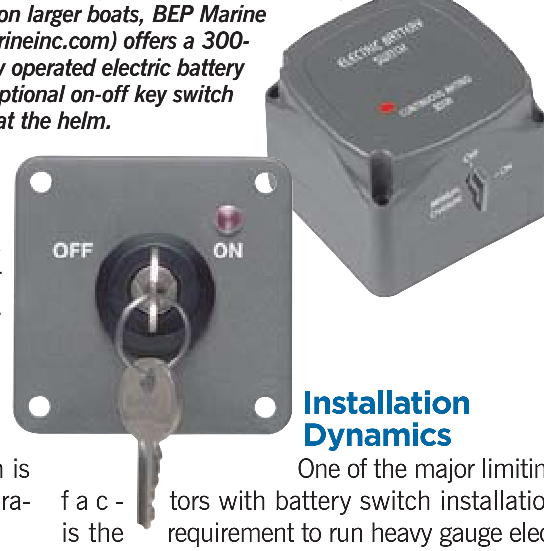
Switch current ratings are specified as a function of time and at a nominal temperature. The standard for rating battery switches is Underwriters Laboratories (UL) standard 1107. The voltage rating for most battery switches is 32 volts to 48 volts, though some may be lower at 24 volts and it's rare to see a 12 volts rating.

Proper Multi Position Use

The simple boat power configuration is one start battery and one house battery (bank), the latter often consisting of two batteries (a bank). For this example, let's assume that the start battery connects to position "1" on a three-position switch and house battery connects to "2". To start the engine, always turn the selector to "1". It's always good practice to allow the start battery to recharge for 15 minutes if possible. Any electronics will also be supplied from this source in this case and the alternator is supplying the load. Next, switch to "Both" for dual battery charging. When you reach your destination or are stopping, you should switch to the house battery, position "2". This way, power for house loads comes off the house battery and the start battery is not drained.

This setup has a start or cranking type battery and a deep-cycle battery for house loads. Deep-cycle batteries are not designed for starting engines so starting the engine on "Both" unnecessarily stresses the house battery as well as impresses a large surge on the electronics power supplies. Also be aware that the paralleling of a heavily discharged battery and a fully charged one during charging can sometimes cause some power instability. The fully charged start battery begins to equalize to the house battery and discharges it. After a period using the house battery, it's good practice to start the engine on "1" (start battery) then switch to "2" (house battery) so that it rapidly recharges by the alternator.

To eliminate long battery cable runs and resulting voltage drop on larger boats, BEP Marine (www.bepmarineinc.com) offers a 300-amp remotely operated electric battery switch with optional on-off key switch mounted on at the helm.



Installation Dynamics

One of the major limiting factors with battery switch installation is the requirement to run heavy gauge electrical cables to the switch. For boats with long cable runs, this introduces voltage drops into the circuits. In many smaller boats, the master switch is generally located close to the batteries, but the problem often becomes finding a protected location away from water and spray. A high quality switch, rated for such conditions, is essential to its endurance in the wet environment. There is always a compromise involved between cable lengths and protection.

The termination of cables to the switch terminals is also one that requires careful thought. The cable lugs should fit neatly onto the switch terminals, I have seen plenty that don't, resulting in poor contact . Many switches don't have the recommended washers or spring washers. The routing of cables through the relatively small cutout is often very difficult as heavy cable is not easy to bend. It is important not to stress the terminations. Applying stress to terminals often causes distortion and I have seen cases where this stress has caused terminals to move creating poor internal contacts on some of the cheaper units.

Wiring configurations are generally related to the various charging and starting arrangements and some of these are displayed on the facing page. In all of these configurations, the battery switch serves as isolation switch for the batteries, a battery source switch for supplying power to start the engine or supply house power to the boat systems and, finally, to select the direction for charging current to go to the selected batteries.

Remote Control

Remotely operated master switches are becoming quite common. These are essentially solenoids with a remote control switch to energize the coil and switch on the power supply. The major advantage is a significant reduction in the cable lengths required to run to the switch and back. This device also allows the isolation to be close to the battery where it belongs and also has less of the common problems of mounting and operating the switch. This configuration does require some re-engineering and requires the complete separation of both the battery charging and engine starting circuits, which does away with the bidirectional arrangement or circuit sharing and provides two unidirectional circuits.

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Payne's Five Switch Perils

Operating the Switch Under Load. You have to use caution when operating a changeover switch under charging load conditions. If the contacts don't make correctly or you accidentally switch to the off position, the surge created, several hundred volts for just several milliseconds, is enough to probably destroy the alternator bridge diodes.

Damaging Surges. Many people parallel both batteries in the "Both" position to start an engine. Often a boat is set up with one battery (house) supplying power to electronics and other house loads. Applying a large current load to that battery during engine starting can damage the sensitive electronics by the surge or "brown out" that is created when voltage first drops and then suddenly increases.

High Circuit Resistance. In most cases, cables are routed from batteries to the switch location and back to the starter motor. This has the effect of introducing unwanted voltage drops into the circuit. Cheap switches have long had a notorious reputation as being unreliable.

Switch Left in "Both" position. A very common mistake is to inadvertently leave the battery switch in the "Both" position. This has the undesirable effect of draining both house and start batteries simultaneously.

Poor Quality Switches. I have frequently come across battery switches that are hot after engine starting or during or after a charging cycle. This is due to an internal high resistance across the sliding contacts which has the effect of reducing starting current and making the engine hard to start or reducing the charging voltage due to the voltage drop so batteries do not charge properly. You should always opt for a quality battery master switch from reputable suppliers such as BEP, BlueSea, Guest and Perko.

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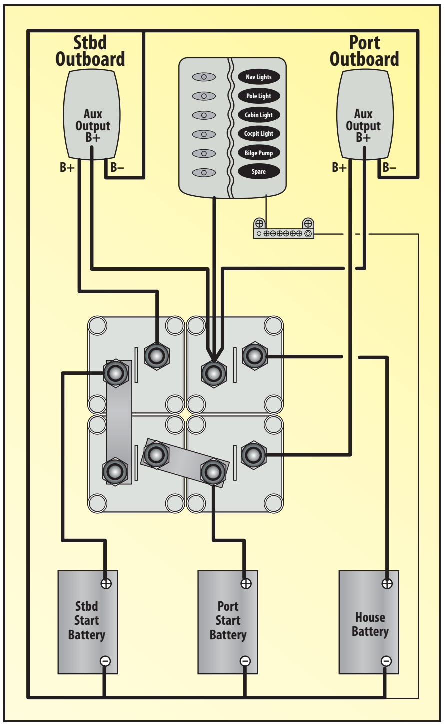
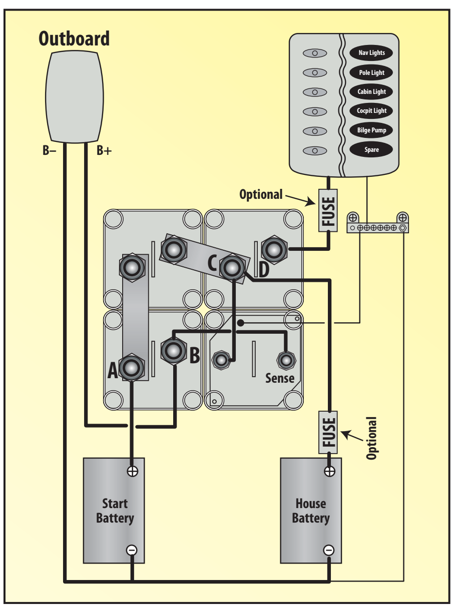
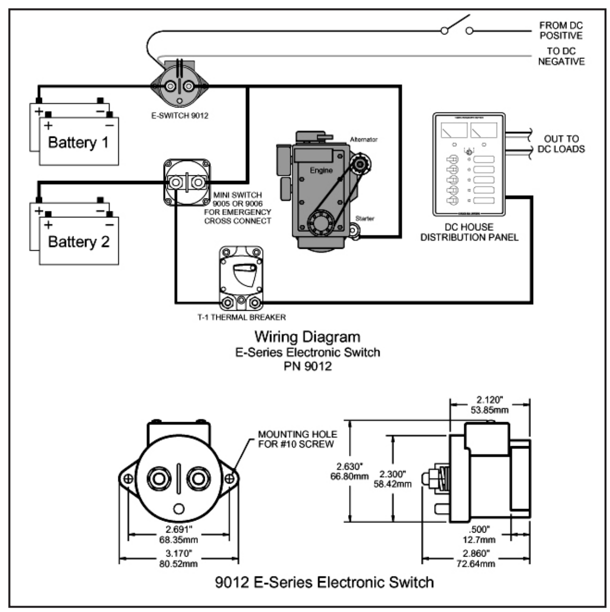
Sample Installations with Single and Multiple Switches

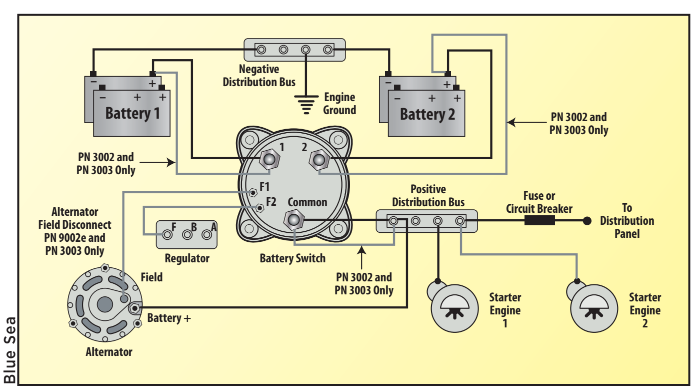
(across) Twin inboard engines: when it is not practical to have both alternators in parallel because of the types of regulators used, DC power is managed by BEP Marine 718 battery distribution cluster, which consists of four on/off battery switches and a 100 amp voltage sensitive relay (VSR). The VSR allows for two batteries to be charged at the same time. When the engine is started and the start battery reaches 13.7 volts, the relay closes, combining the port start and house battery banks and allowing them to be charged simultaneously. When the engine is stopped and voltage drops to 12.8 volts, the relay opens separating the batteries. This system eliminates the possibility of draining the wrong battery and protects sensitive electrical equipment, powered from the house battery, from harmful engine start up spikes. (bottom left) Dual battery charging is easy on boats with a single outboard or inboard engine. A BEP 716 battery distribution cluster consists of an on/off battery switch for each battery or battery bank and a 100 amp voltage sensitive relay (VSR). Operation is the same as the 718 above. (left) High amperage, electronic solenoid switches allow shorter cable runs and eliminate manual switching. Shortened cables save material costs, reduce weight and exposure to short circuits and most importantly, permit high circuit voltages. (bottom) Four-position battery switch with alternator field disconnect. This field disconnect isolates and de-energizes the alternator field circuit to avoid





BEP Marine





Blue Sea

accidental damage to diodes on engines with externally mounted voltage regulators. When moving the switch from "1" to "2 always move the selector through “Both” (not through “Off”) to insure a constant supply of power.

Note: The above illustrate generic systems and are not intended to be detailed wiring instructions.

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All About Electrical Panels

Modern electrical panels blend form with function so you can tailor your boat's electrical power distribution to your present and future requirements. Spend the time to choose the right panel and understand its configuration.

By Kevin Jeffrey

Marine electrical panels are at the heart of a boat's electrical power distribution. They offer safety, convenience, control and monitoring in one convenient package. Electrical panels are principally used to distribute electricity from a primary power source — house battery banks for DC power; and shorepower, gen-set or inverter for AC power — to the various loads on board. Planning for and selecting the appropriate panels for your boat helps you organize and understand the distribution side of your electrical system. Even if your existing panels meet your present needs, studying their configuration can tell you a lot about your electrical power system.

Electrical panels serve a variety of functions. They provide convenient connection points for all wires leading to various electrical loads on board. This makes it easy to troubleshoot and service these circuits. They also provide switching and circuit protection for all branch load circuits, and often for main power supply circuits as well. Panels also serve to indicate circuit status, either through simple LEDs or more sophisticated analog or digital electrical meters.

Conventional panel with glass tube fuses comes with 60 interchangeable, self-adhesive nameplates.

Panel Types

Standard panels available from marine chandleries are flexible enough to satisfy simple installations. When you needed added features or design flexibility, or a set color-coordinated to your boat's interior, there are manufacturers who offer custom panels built to your specifications. Paneltronics, for example, offers 150 different panels designs in black, gray or white, or three faux wood finishes.

The two basic categories of electrical panels are main distribution panels and sub panels. Main panels contain the standard house load circuits. Many boats only require a main panel. Sub panels are used for special circuits, such as large DC loads, emergency paralleling of battery banks, AC loads supplied only by shorepower or a gen-set, or for special functions such as metering or primary switching (i.e. switching between battery banks or between shorepower and gen-set AC power). On larger craft sub panels are common.

There are subtle differences between a simple main panel and sub panel. They both likely have branch circuits. Since a main panel, in most installations, receives the main feed direct from the power source (AC or DC), it normally provides an overall disconnect of some type and circuit protection to

Figure 1

A single electrical panel on a Cabo Rico sailing yacht combines DC and AC circuits, circuit breakers, analog DC and AC voltage and amperage monitors, three-position switching to monitor multiple battery banks, and LEDs. Note the AC source selection panel (bottom left) with circuit breakers for switching between the gen-set and inverter.

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protect the electrical power feed. Main panels may offer general monitoring of system voltage, load amperage, and for AC panels, reverse polarity of the AC feed. A sub panel receives power from the main panel and distributes it to special branch circuits, such as sub panels for heavy-duty DC loads. Or it controls the power feed before it reaches the main panel, as is the case with AC source selector panels that provide switching between shorepower and another AC power source, such as gen-set or inverter.

Backlight switches for easy nighttime viewing.

Electrical panels designed for AC circuits are very similar to those designed for DC circuits. General layout and overall appearance are the same; the differences are in the panel components and the wiring. DC and AC circuits can be integrated into one large main electrical panel **(Figure 1)**. If space is available for a larger panel, and you know what your DC and AC present and future needs will be, a single panel may be the best choice. For integrated DC and AC panels, marine electrical standards require that a physical, non-conductive barrier, be provided by the manufacturer between the DC wiring and the AC wiring to prevent accidental crossover of the two power sources, or contact with high voltage supply or connections. DC and AC circuits can also be handled by matching, yet separate, main electrical panels **(Figure 2)**.

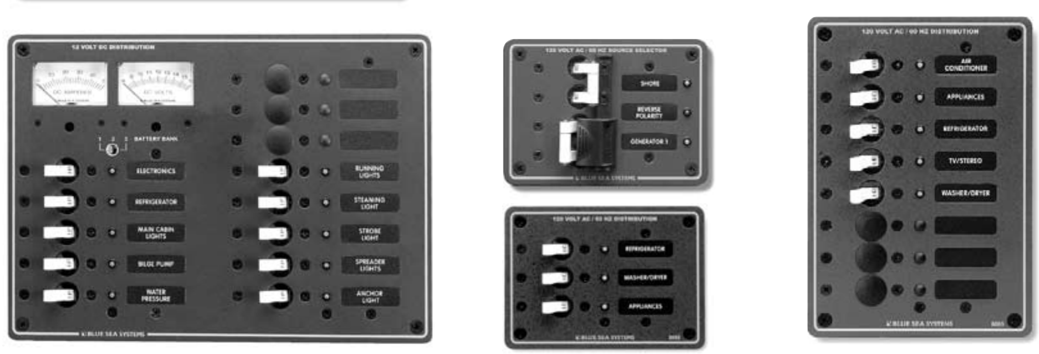
Components

Getting familiar with the individual components of an electrical panel will help you during installation and servicing.Faceplate: A faceplate made of aluminum or plastic provides a structural housing and allows the panel to be flush-mounted against a bulkhead. Faceplates have cutouts for various switches, circuit protection devices, indicator lights and monitors.

Busbars: On the backside of an electrical panel are a series of busbars, rigid copper (good) or tin-plated copper (better)) conductors. Busbars are simply common distribution points configured to easily allow for a number of individual electrical contacts. On a DC panel, there are typically three busbars, one for DC positive, one for DC negative, and one connected to the DC grounding system **(Figure 3)**. The positive busbar is usually bolted directly to contacts on the backside of the circuit protection devices that are conveniently arranged in a straight line. Multiple positive busbars, used when there is more than one line of circuits on a panel, are joined by a heavy-duty jumper bar or cable. Negative and ground busbars fasten to the backside of the faceplate, held off the plate with non-conducting material. Screws inserted

Figure 2

Separate DC panel is practical where you have limited space.



Premium panels with standardize height and widths allow either vertical or horizontal arrangements to create one large panel assembly.Three-position switch allows volt and amp readings of multiple battery banks.

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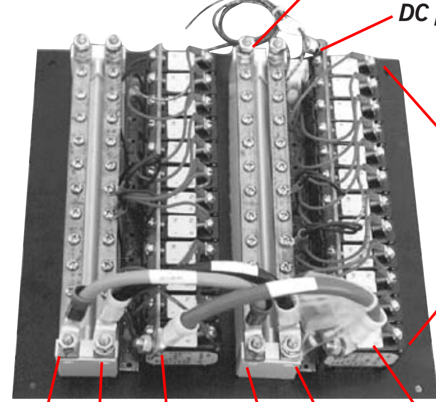
into tapped holes in the busbars provide a series of contact points for the individual load negative wires and load ground wires.

On an AC panel the layout is similar, except there is an AC hot busbar connected to the circuit protection devices, an AC neutral busbar, and an AC grounding busbar **(Figure 4)**. Some AC circuit breakers are double pole, double toggle switches that break both the hot and neutral legs of the circuit simultaneously. This type of breaker offers a greater level of safety, and is recommended if no isolation transformer is installed in the system.

Figure 3

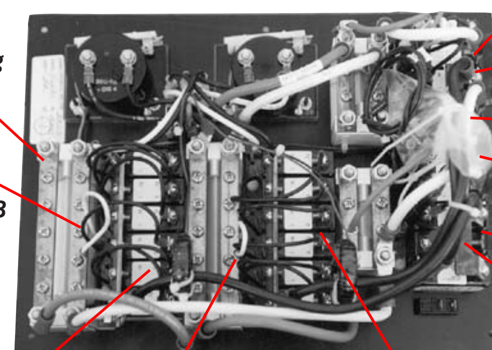
Typical DC Wiring Schematic



Circuit Protection: Modern electrical panels now use circuit breakers as the preferred circuit protection device. They are convenient to use, and provide switching and circuit protection in one single device. You'll still find electrical panels with the old glass tube fuses, and Vetus makes an 8-circuit DC panel that incorporates same function as a circuit breaker, but operate in an electronic instead of an electro-magnetic manner. They also have a "slow blow" characteristic, which means that loads with high surge power (and therefore current) will operate without any problem. In the case of continuous overload or an extreme peak current (short circuit), the fuse automatically disconnects the switch. Remove the cause of the overload and, after a time lapse of about 20 seconds, the switch is set in the "on" position again, making the circuit operational again.

Figure 4

Typical AC Wiring Schematic



Switching: Circuit breakers have largely replaced standard fuses, though when fuses are used as the circuit protection device, separate disconnect switches are needed, typically simple on-off toggle switches rated for the maximum amount of current in the circuit. Circuit breakers satisfy the switching requirements for both main and branch circuit disconnects, and can even be used to control AC power source selection. But some auxiliary switching may also be included on the panel even when circuit breakers are present. On some panels a heavy-duty battery disconnect switch (On-Off or 1-2-Both-Off) is incorporated, although it's common for this to be mounted separately, usually as close to the battery bank as possible. Another common type of auxiliary switch found on DC electrical panels is a two, three or four position selector switch; this allows voltage monitoring of multiple banks of batteries with a single meter.

Status Indication: LEDs indicate when power is supplied to an individual circuit. When lit

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Combination AC/DC panel. More is better when purchasing new panels — spare circuits allow for future expansion as needed. (inset) Digital voltmeter provides an accurate precise reading with intense red LED numbers easily viewed from a distance.

the user knows that power is available to the load. Some loads, such as running and anchor lights, have no other switching and are thus on and consuming power when turning on the breaker switch. AC main panels, or sub panels that include main circuit disconnects, typically have a reverse polarity indicator to indicate a problem with incoming shorepower. Circuit Labeling: When purchasing a new panel, it is best to choose one that has replaceable circuit labels. Your electrical power system can change, so give yourself built in flexibility as to what type of circuits you have and where they are located. New panels are sold with an assortment of labels in either stick-on or screw-on format, and many chandleries sell replacement labels.

5 Steps to Panel Selection

Here's a step-by-step selection procedure to determine your electrical panel needs that works.

1 Decide how many individual circuits you require. Each distinct type of load, such as an anchor light, cabin lights, running lights, instruments, etc., should be on a separate circuit. The number of circuits relates to how you want to group loads and control them. For instance, on smaller boats all cabin lights are on a single circuit, whereas on larger boats they might be divided into multiple circuits, perhaps one each for fore and aft, or port and starboard lights. Be careful not to exceed the load carrying ability of the panel. When wiring, use conductors sized for a voltage drop not to exceed 3%. [Ed: Tables for determining conductor sizes based on length of run and voltage drop appear on page 66.]

2 Determine what your DC and AC requirements are. If you have both power systems on board, consider what works best for you, either integrate DC and AC circuits into one panel or keeping them on separate panels. Space and panel availability are probably the determining factors. According to the American Boat and Yacht Council (ABYC), panels must be installed in a readily accessible location, shall be weatherproof or protected from the weather and splash. Select a DC panel that suits your sense of aesthetics and offers enough circuit flexibility for present and future needs. Then choose your AC panel, preferably one that matches or is integrated into your DC panel. If your AC power requirements are modest, a main circuit and a few branch circuits could be sufficient.

3 Select sub panels that compliment your main panel(s). On the AC side, you'll need a separate main breaker sub panel if the main AC panel is more than 10' (3m) away from the shorepower inlet. An AC source selector sub panel is necessary if you have multiple sources of power (i.e. shorepower, gen-set and/or inverter) feeding the same AC distribution panel. Loads that you only want supplied by a designated AC power source such as shorepower can be put on an AC load sub panel; several AC loads that you definitely wouldn't want to be supplied by an inverter are a battery charger and water heater.

Figure 5

Vetus 8 circuit DC panel incorporates new "smart" electronic fuses and LED indicators. Compact design, postcard size and horizontal layout fits into dashboards and other confined areas.

4 Decide if you want monitoring of DC or AC voltage and amperage on the panel(s). Most panel meters are analog (moving needle), which are fine for many applications, but they lack a high degree of accuracy. With analog meters, you need a separate meter for each function (voltage, load current, charging current, etc.) I prefer a single digital system monitor that displays volts, amps, amp-hours and percent of charge all in a single, accurate device. [Ed: For how to select and install a system monitor, refer to page 115.] If you do choose to include metering on your electrical panel, decide if you want to include this function on your main panel or make it a separate sub panel.

5 Choose panel options such as backlighting systems for easy viewing at night, or color coding collars that, at a glance, allow you to distinguish groupings of circuits, such as DC from AC.

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UPGRADING A 70s CRUISER

The need to replace an older fuse panel leads to an upgrade of this cruiser's entire electrical system.

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By Dwight Powell

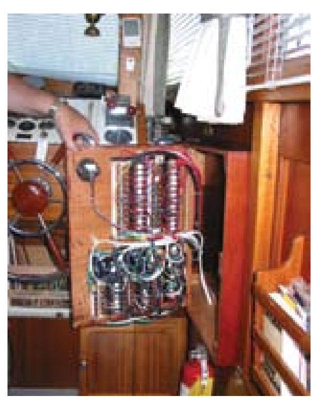
Last year about this time, I wrote about a plan to rejuvenate the electrical wiring onboard "Wiking," an 37' (11.2m) Egg Harbor Double Cabin with twin 427 Crusaders. The entire system was housed under the wheel at the main helm console and consisted of household-type components, such as a common breaker panel and solid core copper wire for the AC circuits. On the DC side were Klixon breakers that don't allow shutoff except in the event of a circuit overload. These components have worked well for 34 years, but the installation didn't meet the American Boat & Yacht Council (ABYC) standards and prevented our ability to expand the system.

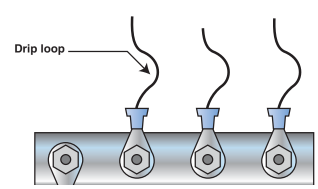
This major refit involved installing high amperage alternators, new electrical panels, battery switch and charger, and inverter to replace the 7.2 kW gen-set. For the most part, I stayed with the original plan, though there were a few changes made, which are mentioned below.

Raising the Power Grid

This refit began with the purchase of two new 100-amp "smart" alternators from Battery Shack in Florida. These units have built-in regulators that apparently work like the three-stage battery chargers. Charging begins with high amperage to bulk charge the batteries, and then amperage is lowered while keeping the voltage high until batteries reach full charge, after which volts drop to a float voltage of about 13.25 volts. So far, these alternators have worked flawlessly, and the great thing about them is the single wire hook-up as the case is grounded to the engine. Purchasing and installing a Xantrex TRUEcharge 40+, a 40-amp multistage battery charger, gave the flexibility to charge the batteries on shorepower. These chargers are relatively small, light in weight, make no noise whatsoever and do an excellent job of charging and maintaining batteries.

The boat's current battery set up includes two Group 30 deep cycle batteries for the house system and one group 30 deep cycle used exclusively to crank both engines. As the house and starting (or cranking) batteries are completely isolated, they can be paralleled for an emergency-starting situation using a special 100-amp battery switch panel from Blue Sea (#8080). This DC parallel circuit switch features a 100-amp breaker for the house side, an On-Off switch for the cranking side and an emergency cross connect circuit for starting the engine from the house bank. Each of our two alternators is separated as well, one for the cranking battery and the other for house duties.





GUY DRINKWALTER

Building, staining and varnishing the box for the panels took about 6 hours. Box top hinges and opens for easy access to wiring. (right):Though it wasn't done in this installation, you should always provide a drip loop, just after all connections.

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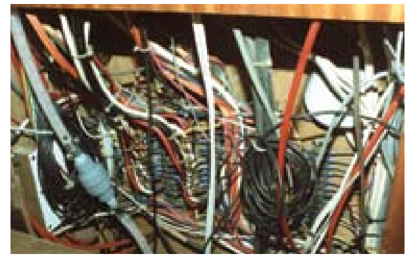
Panel Picks

Panels were ordered and few weeks later arrived from Paneltronics (Tel: 800/36-PANEL, Web: www.paneltronics.com). This south Florida-based manufacturer designs and builds panels of all sizes to the buyer's specifications. Panels are top quality and shipped completely wired and labeled, where possible.

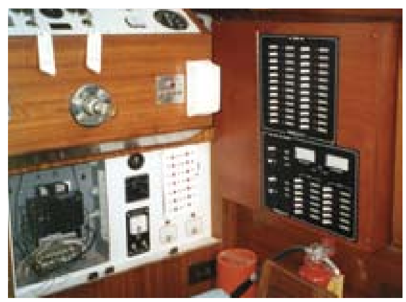
My set up required an AC panel (#3307) measuring 13.75" x 10" (35cm x 25cm) with 12 AC breakers oriented in two buses, two 30A shore cords, one 30A inverter and volt and amp meters. For the DC panel (#5202), 24 breakers divided into 5, 10, 15 and 20 amps, and a cutout for a Link 10, resulted in a panel that measured 11" (28cm) square.

Installation of the AC and DC panels was routine, especially after I decided to move their location from under the wheel to the starboard cabin side near the lower helm. My original plan involved removing the original cabinet, then trying to reconstruct the wiring, a task that left me somewhat uneasy. The change placed the new panels where we could monitor them at a glance and easily operate the switches. Wires and leads were moved one at a time and in the process, we cleaned up a few poorly done prior hook-ups and gained a better understanding of our overall electrical system.



Before ***"This was intimidating because I'd look at it and say, "How are we ever going to figure this out."***

After ***"AC and DC are rather simple, straightforward, not hard as hard to do as I thought."***



Terminal blocks were robbed from the original AC panel and securely mounted for ganging all common (white) and hot (black) wires. As it's not necessary to run each circuit back to the AC panel, just the one common heavy-gauge wire to each of the A and B common buses on the panel, this greatly simplified AC wiring. Each individual circuit was "hot spliced" into new stranded cable. Green tape was used to identify circuits.

Adhesive-lined, heat-shrink tubing is "hot spliced" to the connector after crimping, then "melted" with a butane torch. Once the glue hardens, it will never come apart. Tip: Keep the torch moving to avoid damaging the wire insulation.

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As mentioned above, present on the AC side is solid copper wire leading to each fixture. Rather than tear the entire boat apart and route all new cables, I decided to crimp to these new stranded wire leads to the new panel. I was told that a crimp-type butt connector would work so first I did a test crimp and it held perfectly. Adding adhesive-lined shrink tubing at each joint produced a solid, waterproof connection. I'm sure this method doesn't meet ABYC standards, but it appears to be a strong compromise as routing new cables from the original busbar was totally unworkable.

Fortunately, the terminal strip that carried all the DC house loads was easily located and wiring simply involved removing the old wires and connecting new ones and routing each to the panel. Amperage loads were carefully matched from each AC and DC fixture to the appropriate sized breaker. It was a relatively simple matter to fish wires to the new panels for both the AC and DC connections. All wires were then well secured with nylon wire ties.

Much to my surprise, each panel and all circuits worked perfectly when turned on and put into service. The breaker switch indicators are amber for DC and green for AC with red lighting the labels from behind. The night lighting system is impressive, even somewhat sexy. The system has now run for a few months with no overheating or blown breakers. Paneltronics includes meters to monitor voltage and amperage in its AC panel. To monitor our DC side, I installed a Xantrex Link 10. As amperage is the flow of electrical current through a power system, it's important to know at any given time how much current your system is using. Excessively high amperage can cause heat build-up that, at extremes, lead to a fire. When rebuilding a system, give strong consideration to the addition of monitoring devices. I don't think you'll be sorry.

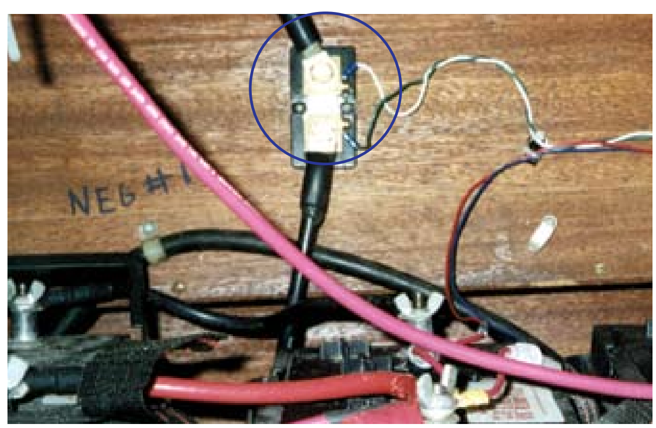
Improvements

We initially intended to sell the gen-set and purchase an inverter

Terminal blocks from right to left: DC house circuits; starboard engine circuits; port engine circuits; tach circuits and remainder to be identified; and house busbar.

Identifying the old circuits and cleaning up the old wiring (left) and tie wrapping into bundles (below) was a time-consuming job, taking about 8 hours. Not surprising, Egg Harbor had a wiring "plan," though this wasn't in writing, many wires were color coded, which simplified circuit identification.

Two three-way battery switches are removed (top) and replaced by a DC Parallel Circuit Battery Switch (bottom). TRUEcharge 40+ multi-stage battery charger at 40-amp output is one of the biggest available.



Shunt for Link 10 is included with unit.

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instead. But after using the gen-set last summer and earlier this year, we decided to keep it to charge batteries or run the air conditioner, and then add a slightly smaller inverter for the fridge, microwave and the few AC lights we need from time to time. With a 1,500- to 2,000-watt inverter and a gen-set we can have the best of both worlds. Adding a DC fridge may follow, but the new inverter easily powers our current household-type AC unit, albeit for only 12 hours or so on our current battery capacity, which inevitably also needs expanding. Still to install is a West Marine/ Yandina battery combiner (www.yandina.com). This small black box automatically connects the batteries together when there is a charge of 13.8 volts or more for the purpose of charging. When voltage drops below this value, it separates the batteries so one cannot drain the other. Everything is now grounded to the engine, but will be transferred to a large brass, tin-plated plate mounted to the hull when the boat is hauled for winter storage. The planning and installation of "Wiking's" new electrical system took about 40 hours to complete. This project has proven to be less painful than I originally thought and works very well. There's still much work to tidy things up and of course an inverter to add when the budget permits, but we're quite content with the way things turned out.

DIY REFIT BILL

2, 100-amp alternators	$270 each $540
1 DC Parallel Circuit Battery Switch	$150
1 5202 Premier DC panel	$334
1 3307 Premier AC panel	$527
TrueCharge 40+	$500
Link 10	$250
Ancor Marine Grade Wire and cable	$500
Miscellaneous connectors, heat-shrink tubing, busbars, etc.	$250
TOTAL	$3,051

Note: All costs are approximate and in U.S. dollars. Make sure to consider the ignition protection requirements for this gasoline engine powered boat. ABYC E-8 and E-9 are the guidance standards.

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AC POWER ON BOARD

Underway or at the dock, enjoy all the comforts of home with an AC power system.

The desire to have a few household conveniences on a boat is natural and often enhances rather than diminishes the pleasure of getting away from it all. Household appliances run off of AC (alternating current) electricity, so if you want to bring them on board you must have some provision for maintaining a reliable AC power supply.

You can use an inverter to supply usable AC power indirectly through the stored DC (direct current) power in your battery bank. Or you can provide your own direct source of AC power from a shorepower connection for use at a dock, an engine-driven AC generator (commonly referred to as gen-sets), or a modified AC alternator driven off the main auxiliary engine. Inverters are convenient and easy to install and use, but you must have a reliable means of replacing the power they draw from the batteries. Direct AC sources don't rob the battery bank of stored energy, but you must be dockside using a shorepower connection or you must use engine-driven equipment to generate the power. A good review of the options available will help you decide which AC power sources are best for your needs.

Option 1: DC-to-AC Inverters

There are several other ways to provide remote AC power, but none match the freedom and convenience offered by DC-to-AC inverters (hereafter referred to simply as inverters). If your AC loads are moderate and your battery capacity and charging system sufficient, inverters can eliminate the need for any other AC source.

Inverters allow you to have AC power almost anywhere. They don't actually create electricity, they only change it from one type to another. Modern solid-state inverters draw upon the energy stored in a bank of batteries. They simultaneously raise the voltage, create a simulated AC waveform and the final product is 110V/60Hz AC power (or 220V/50Hz for overseas use). If your charging sources have sufficient output, they can keep an inverter from depleting your batteries.

The electricity inverters draw from the batteries can be supplied by renewable chargers such as solar panels and wind- or water-powered generators. Many factors determine whether or not renewable charging sources can supply your total AC load, but at least you have the opportunity to do so with an inverter.

Modern inverters use very little idle current - standby power when the unit is on but no load is being drawn - compared to engine-driven AC power sources. For many boaters this can be a large portion of the time. Previously, it was necessary to turn an inverter on for a specific task, then off again to prevent high standby losses. Now an efficient inverter may consume only half a watt on standby. Compare this to an engine-driven AC power source that is cranking away, consuming fuel whether you are using the AC power or not. Other inverter advantages include their relatively small size and weight, lower initial cost and reliability. Installation is uncomplicated and there's no additional engine to maintain.

Inverters come in a variety of sizes and output ratings, from small 50- to 250-watt pocket inverters, ideal for powering computers, radios, tape decks, TVs and VCRs, to large units of 2,500 watts or more. Most of the larger inverters also have a powerful performance charging function that automatically kicks in when AC power from dockside or a gen-set is available. This feature eliminates the need for a separate battery charger.

Inverters for marine use are most practical for supplying AC loads up to about 2,500 watts, particularly if the larger loads in your system are only on for short periods of time. Even though the current draw of large intermittent loads may be high when the appliance is on, the total energy consumed by microwave ovens, toasters and coffee makers is usually moderate. Loads that are usually not supplied by inverters

TIP
Hot, Neutral or Ground?

You must use a polarity tester to make sure correct polarity is maintained in the black and white wires. Marinco offers an inexpensive polarity tester that plugs into any AC outlet and warns of such common AC wiring problems as reversed hot and ground, reversed hot and neutral, open safety ground, and open hot conductor.

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include AC-to-DC battery chargers (in essence, you would be trying to use battery power to charge your batteries!), air conditioners (unless supplemented by an engine-driven, high-output charging source), and appliances with large heating elements, such as hot-water heaters, space heaters and electric ranges.

AC electricity from the utility company is in the form of a pure sine wave. Inverters, which attempt to duplicate utility power electronically, are often classified by their type of output.

Modified Sine-Wave Inverters. Most of the inverters presently on the market have a modified sine wave output that closely approximates utility power. Heavy-duty models are suitable for running electric motors with high start-up loads, since their surge capability is typically three to four times their rated power. Some electronic equipment, including certain computers, laser printers and some fax and answering machines, won't run properly on modified sine wave output. Most other appliances, including TVs, VCRs, ink-jet printers and laptop computers, have no trouble at all.

Cost. Inverter cost is proportional to the rated output. Pocket inverters of 250 watts cost around US$150; 1500-watt inverters cost around US$625 without a charger and US$900 with; and 2500-watt models with a charging option or pure sine-wave output cost around US$1,250 to US$1,500 and higher. Additional battery charging sources needed to replenish inverter loads should also be taken into account.

Shorepower components include a cord-set, one-piece adapters, pigtail adapters and non-metallic or stainless-stell inlets.

Option 2: Shorepower Connection

If you spend a lot of time dockside, have very large AC loads or limited battery capacity, you might find it necessary to have your boat's AC appliances run off a direct AC power source. If you can get by with having direct AC power only when you're at a dock, then a shorepower connection is all you need. It's relatively inexpensive to install and operates quietly. A complete shorepower system consists of electrical components that bring power to the boat and distribute it to the individual AC circuits on board.

Figure A

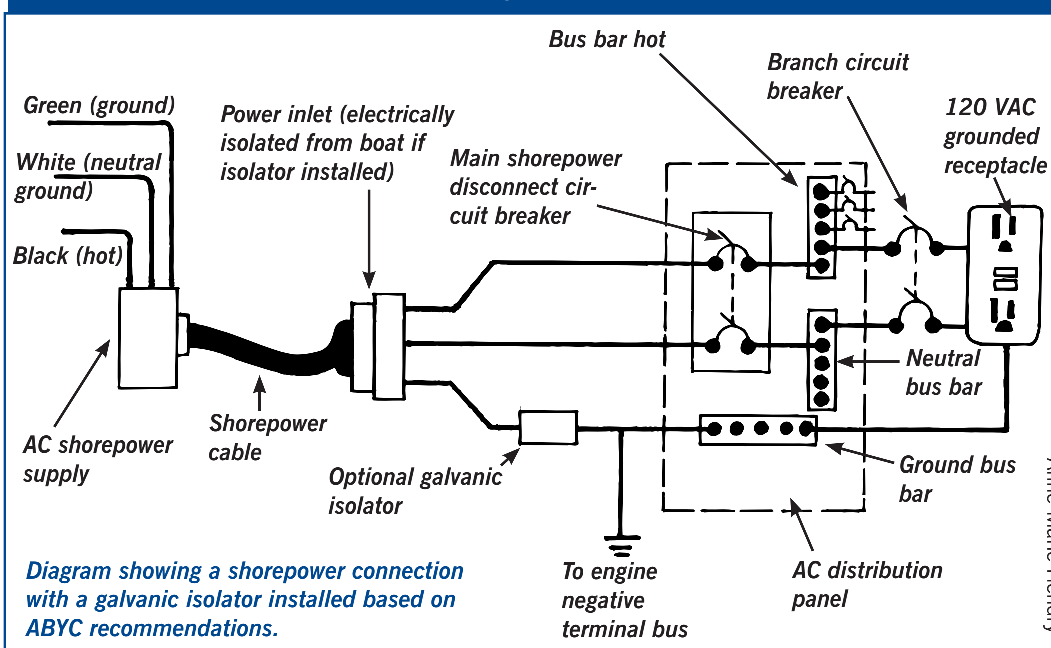

Diagram showing a shorepower connection with a galvanic isolator installed based on ABYC recommendations.

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Shorepower Cord. Similar to heavy-duty outdoor extension cords, these have a male plug on one end and a female receptacle on the other. Unlike straight blade ends found on standard cords, they incorporate twist-lock devices at each end so the cords can't be accidentally unplugged in areas of foot traffic. Shorepower cords also have an outer coating highly resistant to ultraviolet rays, salt and moisture. Cord sets complete with end plug and receptacle are available in 12-, 25- and 50-foot lengths, with either a 15-, 30- or 50-ampere rating. Amperage ratings are applicable for both 125-volt and 250-volt services. The end plugs on 250-volt cords have a slightly different configuration to keep the two services separate. End connectors and insulated wire can be purchased separately for custom owner-assembled cords.

Shorepower inlet. This is where the shorepower enters your boat. It consists of a male plug that is flush-mounted in a waterproof box with a tightly sealing cover, similar to outdoor electrical outlets for homes. The box is placed at some convenient location close to the boat's AC electrical panel.

Galvanic Isolators: American Boat and Yacht

SAFETY WITH AC POWER ON BOARD

• Before working on AC circuits on board, disconnect the AC power from its source. Take your time and observe correct polarity. Have a referse polarity indicator on board, either integrated into your AC panel or in a hand-held model. Check for correct polarity every time you plug into shorepower. Dockside AC with reverse polarity (the hot and neutral wires are crossed) can damage onboard AC equipment and be a definite safety hazard if the neutral and ground wires on board ever become shorted, carrying hot AC current through the ground wiring.

• Use GFCI receptacles on each circuit. A GFCI at the head of a branch circuit can protect outlets downline in the same circuit.

• Installan indicator light that clearly shows that live AC power is present on board.

• Make sure your boat is wired by a competent marine electrician and adheres to ABYC recommendations.

Shorepower inlet mounted in the bow of a Nonsuch 30 requires a watertight unit. Inlets are usually mounted in areas that are not normally subject to submersion, such as the cabin side or cockpit coaming.

Figure B

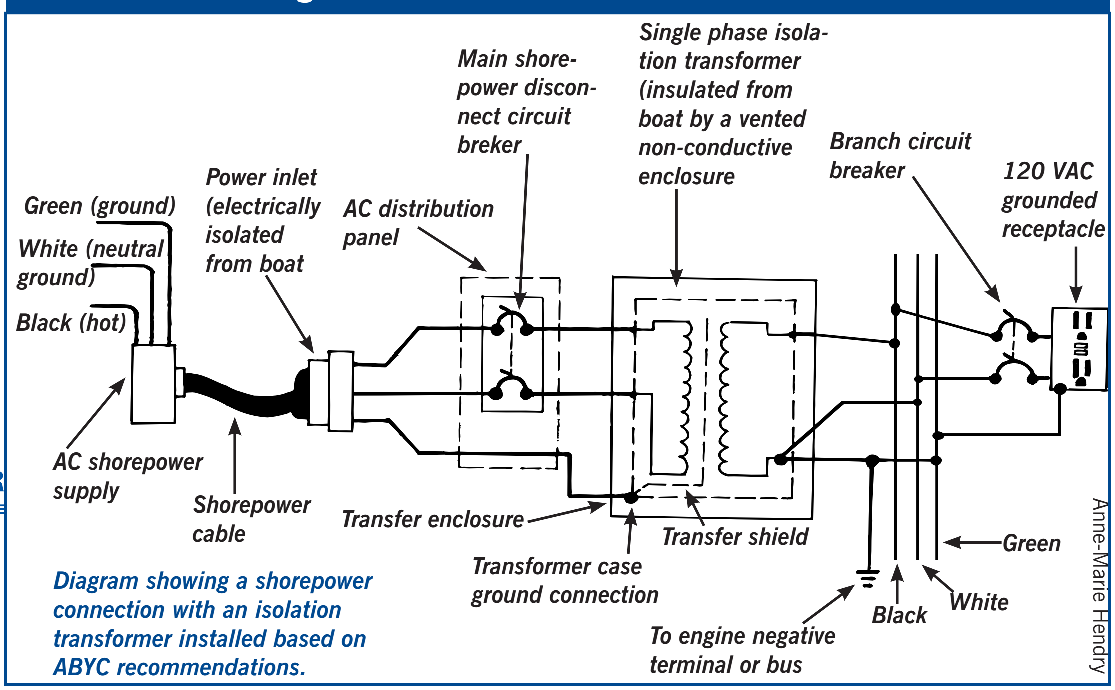

Diagram showing a shorepower connection with an isolation transformer installed based on ABYC recommendations.

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Council (ABYC) recommends that the incoming AC green ground wire be bonded to the DC ground on board. This common ground provides protection from electrocution in the event that AC current escapes from the AC wiring on board (i.e. through a short in an AC battery charger). This common ground, however, can set the stage for major galvanic corrosion problems, since stray current in a marina can enter a boat through the AC ground wire and pass into the boat's DC system. An galvanic isolator (see **Figure A**), which typically installs in the green ground wire from the shorepower supply, can protect against corrosion and still allow your AC circuit to adhere to ABYC recommendations.

Quicksilver's galvanic isolator protects the hull, zinc anodes and aluminum drives (powerboats) from galvanic corrosion when your boat is plugged into shorepower.

Galvanic isolators are relatively inexpensive (around $225 for a good-quality model), lightweight and easy to install, since they are wired directly into the green AC grounding wire. A good quality UL-listed model is available from Quicksilver, a subsidiary of Mercury Marine. Other models are available from Newmar and Professional Mariner.

It would be nice to have some type of indication or alarm on the unit that alerts a boatowner to the fact that stray current is being handled by the galvanic isolator. Future

TROUBLESHOOTING AC SYSTEMS

Problem	Solution
Tripped Breaker	Loose wires at the breakers are a common problem. Occasinally bundled wires are bundled so tightly that the hot and neutral have chafed to the point of shorting.
Breaker Tripping Repeatedly	Check for loose connections, corrosion or, if the breaker capacity is smaler than the load it is serving, faulty breakers.
Battery Failure When AC Charer is Present	The most common cause of battery failure when an AC battery charger is present on board is due to the charger not being fully automatic with 100% shutoff capability. Ferro-resonant chargers made for long-term dockside use may continue to trickle charge even when when the batteries are full, causing excessive voltage and inevitable battery damage. Check to make sure your charger'ss current stops completely when the batteries are full.
Excessive Galvanic Corrosion On Board	If a shorepower connection is used, check to make sure that stray current from the dockside AC power supply can't find its way to the DC circuit on board. If the incoming green AC ground wire is bonded wi the boat's DC ground, as recommended by ABYC, install a galvanic isolator or isolation transformer to prevent stray current from following that path.
Voltage Reading Between The White And Green	Indicates that these wires are bonded somewhere in the circuit, something that must be avoided. If your AC circuit is properly wired, you should get a voltage reading between the black and white wires, the black and green wires, but NOT the white and green.

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models may incorporate this feature.

Isolation Transformers: Additional protection is found in an isolation transformer, a device that transmits dockside power magnetically to onboard circuits without direct wire connections. With this device, the incoming AC power is kept completely separate from the DC power on board, so there is no chance for stray galvanic current from dockside to reach the boat, and no chance for dockside AC problems to pose a safety hazard for the boat's crew. As shown in **Figure B**, when using an isolation transformer, the boat's AC ground wire is still connected to the DC ground to provide protection against faulty AC circuits on the boat. The down side to isolation transformers are their weight (70+ pounds) and their installed cost (over $500). They are typically found only on larger boats.

DC REFIT WITH YELLOW

Black is the standard for the AC hot wire and for many older boats, the standard for DC negative wire. Confusing these two when cutting wires can produce deadly results. When rewiring your DC system, use a yellow negative wire instead of black, as recommended by ABYC.

Option 3: Gen-sets

If you need to have direct AC electricity when no utility power is available, then some type of engine-driven AC power source is your only alternative. Gen-sets are rated according to their continuous AC output capability, ranging from 2.5kW to 6.0kW for the smaller units to over 15kW. Self-contained gen-sets closely match a gasoline- or diesel-fueled engine with an AC electrical generator. Gen-sets can power heavy AC equipment that is on for long periods of time, such as air conditioning units, as well as large yet intermittent AC loads, such as electric cooking appliances, high-capacity water-makers, holding-plate refrigeration systems, washing machines and battery chargers.

Any generator that is coupled with an internal combustion engine could reasonably be called a gen-set, but industry practice is to reverse the term for permanently mounted units. Gen-sets are similar to small boat main engines in construction and appearance. The engine shaft is combined with a specially designed AC generator. Fuel is supplied through a separate tank or through the fuel tank for the main engine.

Most gen-sets create a considerable amount of noise when operating, from both engine and exhaust, although water-cooled units tend to be less noisy than air-cooled units. Gen-sets are usually installed in mechanical compartments that are acoustically and thermally isolated from the living spaces, but additional steps can be taken to decrease noise. Most manufacturers offer some type of sound shield or sound-deadening panels that completely surround the unit, greatly reducing noise transmitted through the air. Additional noise reduction comes from rubber mounting feet and the use of flexible water, fuel, exhaust and electrical connections.

The engine and electrical generator shafts are directly coupled so that the engine rpm is also that of the generator. Engine rpm is governed so that the frequency of the AC output is held fairly constant. Large gen-sets have AC generators that are designed to operate at lower engine speeds of 1,800 rpms for 60Hz output and around 1,500 rpms for 50Hz output. On these larger gen-sets, lower engine speed reduces vibration and increases fuel consumption by about 25% over large portable generators.

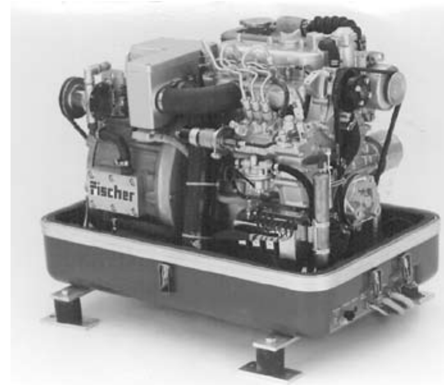
A concept known as variable speed technology (VST) is a control logic that allows a generator to adjust engine speed to the AC load being drawn, while keeping the AC output current voltage and frequency more or less constant (similar to the technology used on modified AC alternator systems). This results in additional savings in fuel and wear on the gen-set since, if the AC load is small or nonexistent, the engine speed will be reduced accordingly.

Marine gen-sets are typically water-cooled in one of three ways: directly by seawater pumped through the cooling system and into the exhaust system; indirectly through the use of a heat exchanger, where heat is exchanged between captive oil or water in the gen-set and seawater; or indirectly by way of keel- or skin-cooling where pipes in the keel or a section of the hull act as the heat exchanger.

Efficiency. When a gen-set is running, AC power is available but not necessarily being used. This is quite different from DC charging systems, where every time they operate useful energy is being stored or consumed. Gen-set fuel consumption, to a certain extent, is proportional to load, so there is some fuel savings at loads less than rated output. If the unit has VST, the fuel savings can be significant when smaller loads are present.

With this in mind, if a 4.5kW gen-set is running and close to 4,500 watts of AC electricity is being consumed, then the overall efficiency is around 20%. If the load drops to 1,000 watts, the overall efficiency can drop to around 10%, unless the unit is equipped with VST, in which case efficiency will be closer to 15%.

System efficiency can be increased by closely matching a gen-set's output to your electrical needs; operating your AC loads together when possible to make full use of a gen-set's capacity; turning the unit off when it is not needed; using an inverter when possible; and by running an AC-to-DC battery charger to recharge your batter bank at any time the gen-set is on.



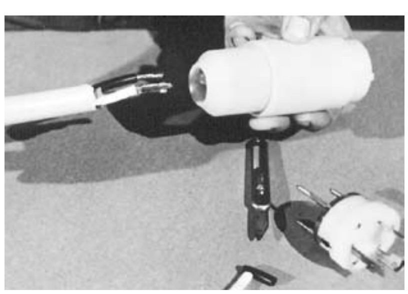
Fischer Panda water-cooled generators with three-piece insulated fiberglass sound shields are extremely quiet: the 7.8kW Panda 8 (shown) has a noise level rating of just 53 dBa.

Cost. Compact gas- or diesel-fueled gen-sets in the 3.0kW to 4.5kW range are readily available, with costs ranging from US$3,500 to US$10,000. These units can fit into spare lockers and other small spaces on board. If you need more power, consider a unit in the 6kW range; they are still of modest size and weight, run in the US$5,000 to US$12,500 range, and typically have enough power to run the charging side of a large inverter-charger rated at around 120 amperes.

Option 4: Modified AC Alternators

Modified AC alternators and control systems are powered by a boat's main engine, eliminating the need for a secondary engine. Power Technology's SeaPower 5kW and 10kW models employ a custom, high-voltage alternator intended to replace or supplement the existing alternator on board. They produce precise 115-volt/60Hz utility-type power (230-volt/50Hz power on the export versions). Most boaters leave their existing alternator in place for battery charging. If a modified AC alternator system must replace your existing alternator due to space limitations, you can use the AC power to run a battery charger or the charging side of an inverter-charger. As with a standard alternator, you'll be charging whenever the main engine is running.

If you are considering upgrading your present alternator and also want high-capacity AC power without a gen-set, this is a good system to investigate. Powerboaters won't need to run a gen-set while underway and sailors get a convenient, lightweight direct AC power source without buying and maintaining another engine. Keep in mind that a modified AC alternator only operates when the main engine is running; you may want to consider using an inverter for the small, continuous AC loads on board, or during times when you'd prefer not to listen to the engine.



When a bad shorepower connection develops, splice a new plug or connector onto the cordset.

Output. The alternators supplied with the SeaPower systems are custom, high-voltage units. A separate AC power unit takes the alternator output and converts it to pure sine wave 115-volt/60Hz or 230-volt/50Hz output capable of running sophisticated electronic equipment, digital controls and inverters with integral chargers. Output voltage is regulated to within plus or minus 5 volts and frequency is held to within .01%. A remote control/display panel completes the system.

Alternator speed. Alternator speed can vary from 1,600 rpm to 8,000 rpm continuous or 10,000 rpm intermittent, while the AC power unit ensures that the AC output remains clean and constant at any

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alternator speed.

Input load. The engine power required to produce AC power is about 1.7 hp for every kilowatt of power produced. That's about 8.5 hp for the 5kW SeaPower and 17 hp for the 10kW model. It's clear that an engine with a minimum of around 25hp is needed to operate these units.

SeaPower's AC alternator bolts directly to the engine, eliminating the need for a secondary engine.

Protection. These units have built-in circuits that protect the system in the event of high voltage, high temperature of the alternator or AC power unit, short circuit, low battery voltage and excessive load.

Efficiency. Running the main engine to produce electricity is typically not as efficient as operating a gen-set or portable generator. The overall system efficiency is around 10% to 15% for the AC output under maximum load. This occurs when all of the energy being produced is put to use. If the unit is producing 4,000 watts of power, but only 1,000 watts are being used, then the overall efficency drops to around 5% to 8%. Charging batteries anytime AC power is produced can increase efficency.

Other AC System Components

Other components to complete an AC system installation include:

AC Master Control Panel: The master control panel distributes the power to your individual circuits, including 110-volt refrigeration, lights, water heater and groups of AC outlets. The master control panel is equipped with a master breaker that disconnects the entire AC system on board and individual breakers for each circuit. Panels from BEP, Blue Sea, Marinetics, Paneltronics and others have reverse polarity indication, an added safety feature that indicates faulty utility-power wiring.

AC panels come in a variety of configurations, depending on your requirements: (right) panel with five-branch circuit capacity for basic installations; (left) Paneltronics' full-function distribution center with controls for shorepower, generator and inverter, current and voltage meters and 10-breaker capacity. Both panels are equipped with reverse polarity lights.

AC Outlet: Outlets for marine use are almost identical to those used on land. Outlets with ground fault circuit interrupt (GFCI) protection should be used near the head and galley, and can be used throughout the boat for added protection. One GFCI outlet can protect downline outlets on the same circuit. Marine outlets are available with teak or stainless-steel cover plates.

AC outlet receptacle with GFCI, reset and test buttons to protect the user from line-to-ground electrical shock hazards.

Ship-To-Shore Selector Switch: This double-pole, double-throw switch allows you to select either shorepower or output from your onboard AC power source. You may elect to install one of these switches for future use if you don't presently have an onboard AC power source in the system. The switch cuts off power from one source before engaging the other, preventing the two systems from

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mixing. The power switch is a device that automatically transfers the load from your inverter to "grid power" when you start your generator or plug into shorepower. The power switch is available in 30-amp and 50-amp models for 120-volt AC circuits.

DIY INSTALL BILL

Cost of a typical shorepower connection for power or sailboat.

PARTS

	15m/50' shorepower cord	$63
1	30A shorepower inlet with stainless-steel case	$91
1	galvanic isolator (best quality)	$225
1	basic AC panel (with double-pole main breaker, 4 branch circuits, and reverse polarity indicator)	$230
3	AC outlet, GFCI type (Ground Fault Circuit Interrupter)	$84
	30m/100' spool of primary AC boat cable, 10/3 AWG	$154
	Miscellaneous parts	$75
	TOTAL	$922

Labour Rate for Professional Installer

8 hrs @ $50 per hour $400

Note: Prices are in Canadian funds. U.S. parts prices will be about 30%

MARINE ELECTRICAL SYSTEMS

AC WIRING TIPS

Many production boats built between the 1960s and mid-80s are incorrectly wired. We've compiled a few wiring AC tips (to ABYC standard), but you should be aware that this is by no means a complete treatment of the topic and you should consult a marine electrican before undertaking any AC wiring.

• All conductors and flexible cords should meet the requirements of the applicable standards of Underwriters Laboratories, Inc. The minimum surface marking on individual conductors and their jacket should include: A. type/style, B. Voltage, C. Wire size, D. Temperature rating dry.

• All conductors should be at least 16 AWG (18 AWG is permissible as internal wiring in panelboards).

• Conductors should be identified to indicate circuit polarity as follows:
BLACK - Ungrounded conductor
WHITE - Grounded neutral conductor
GREEN, GREEN WITH YELLOW STRIPE - Grounding conductor
RED, ORANGE, BLUE - Additional ungrounded conductors
BLACK WITH RED STRIPE, BLACK WITH BLUE STRIPE, BLACK WITH ORANGE STRIPE - Additional colors for ungrounded conductors (black)

• Conductors and flexible cords must be stranded copper.

• All connections normally carrying current should be made in approved enclosures. Junction boxes, cabinets and other enclosures should be made weatherproof or installed in a protected location to minimize moisture accumulation. Unused openings in electrical enclosures should be closed.

• All conductors should be supported and/or clamped to relieve strain on connections.

• When AC and DC conductors are run together, the AC conductors should be sheathed, bundled or otherwise kept separate from the DC conductors.

• Current-carrying conductors should be routed as high as practical above the bilge water level and other areas where water may accumulate and as far away as practical from exhaust pipes and other heat sources.

• Terminal connectors should be the ring or captive spade types and they should be the same nominal size as the stud. Connections may be made using a set-screw pressure-type conductor connector providing a means is used to prevent the set-screw from bearing directly on the conductor strands. Twist-on connectors (wire nuts) should not be used.

•Solder must not be the sole means of mechanical connection in any circuit.

• No more than four conductors should be secured to any one terminal stud. If additional connections are necessary, two or more terminal studs shall be connected together by means of jumpers or copper straps.

• The shanks of terminals must be protected against accidental shorting by using insulation barriers or sleeves, except those used in grounding systems.

• Install a weatherproof shorepower inlet in an area free of spray or splash; otherwise, you must install a watertight inlet.

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WIRING: The Right Tools

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There are specialty tools available that can simplify wiring installations and help boaters comply with industry standards. Although sophisticated gear is available for professionals and DIYers tackling large projects, most boaters can get the job done with relatively inexpensive wiring tools and accessories. If it doesn't seem worth even the modest expense to purchase specialty tools to make a few cable connections, cables made to order with the appropriate connectors can often be purchased from marine power suppliers. On the other hand, once you own a complete set of wiring tools and are proficient at using them, you may be able to earn money by helping other boaters with their wiring needs.


Cut/Strip/Crimp Tool (top); Wire and Cable Cutter (bottom).


Heavy Duty Lug Crimper


5 Marine Prep Pen


Mini butane torch.


Wire Marker Dispenser (top); Write-On Indentification Tubing (bottom).

Cable Tie Gun

Cut, Strip, & Crimp Tools

The first thing to look for is a good-quality combination wire cutter, stripper and crimper that can handle wire down to 10 AWG. Ancor supplies a model (#701008) that includes needle-nose pliers for pulling and looping wire, cushioned grips, cutting blades, wire stripping and single crimping stations for 22 AWG to 10 AWG, and the ability to cut up to 10-24 machine screws commonly found in electrical systems (**Figure 3, top**). Professional quality single- or double-crimping tools are available for those who need or can afford them. Some professional models have a ratchet mechanism that won't release until a proper crimp is made.

Battery cable needs to be cut with a heavy-duty tool such as the Wire and Cable Cutter (**Figure 3, bottom**), from Ancor Marine rated for 22 AWG to 2/0 AWG non-ferrous wire and cable. With some elbow grease and patience you can even cut 4/0 cable with this device. Crimping large cable lugs can be an easy task for the DIYer with the reasonably priced Heavy Duty Lug Crimper, which crimps 6-4/0 AWG lugs and 6-3/0 terminals (**Figure 4**). Lug crimpers with compound lever action are available for a price justified only by professionals.

Wire & Terminal Cleaning Tools

It helps to have a convenient way to clean wire terminals and connection points prior to crimping or soldering. A small wire brush will work fine, but the Marine Prep Pen from Ancor makes this job much easier (**Figure 5**). Held like a pen, this device has 20,000 retractable glass fibers that can scrub away marine corrosion and rust in hard-to-reach places.

Solder and Heat-Shrink Tools

Most DIYers use crimp-on type mechanical wire connections, but occasionally the need arises for solder connections. While any good quality soldering iron works well for small gauge wire, a compact butane torch offers more flexibility. A mini butane torch has a focused flame that can be used for soldering large or small wire and, if used with a little care, installing heat-shrink tubing (**Figure 6**). It can also be used for plumbing and other jobs on board requiring a small yet intense heat source.

Special heat guns are available that use hot air (much hotter than the average blow-dryer) to shrink the tubing rather than an open flame, avoiding discolored tubing and

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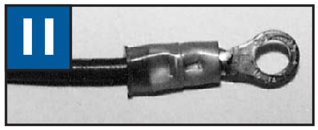
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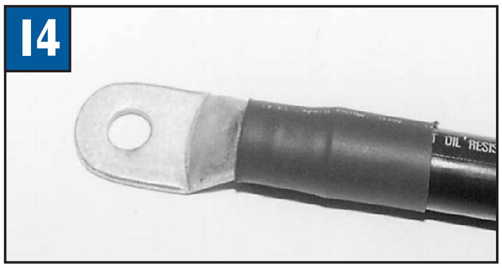
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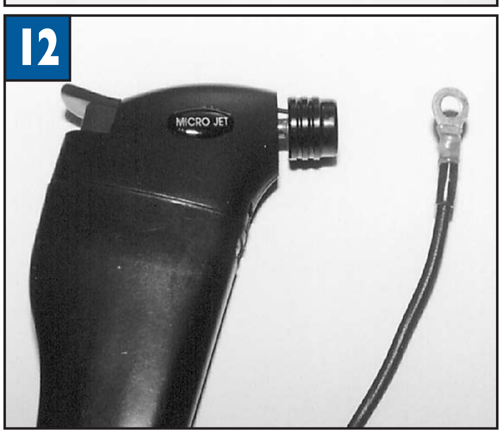

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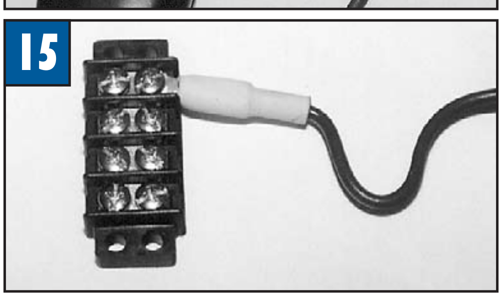
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accidental scorching. Entry-level models start around US$80.

Wire Markers, Cable Ties and Mounts
Maintaining neat, well-secured and marked wiring runs lends a measure of safety and professionalism to your installation. Plastic cable ties hold multiple conductors securely. Cable ties are available in assorted colors in standard and releasable (for changing or adding wires) models. You can purchase cable tie mounts that attach ties to a wall or bulkhead with a single screw, or you can purchase special cable ties that have a mounting eye at one end. Cable clamps (**Figure 1, #4**), available in either nylon or cushioned steel, wrap around one or more wires and provide a single-screw attachment point. Wire ties can be pulled tight with a pair of pliers, although you might be inclined to purchase an inexpensive cable tie gun that rapidly tightens cable ties to the proper tension (**Figure 7**).

In most instances wires and what they are used for can be identified by color, but in complex wiring installations it's best to mark each wire to avoid confusion. One convenient way to do this is with the Wire Marker Dispenser. This device (**Figure 8, top**) holds 10 rolls of adhesive-backed stickers, individually marked 0 through 9, that peel off in 1-1/4" strips. Select a wire, assign it a number, and attach strips with that number at easy access points; with markers you'll always be able to trace wire runs.

Although some boaters mark wires with a pen and strips of tape, a better method is to use small sections of heat-shrinkable Write-On Identification Tubing from Ancor (**Figure 8, bottom**). Available in 1/4" (6mm) and 1/2" (12mm), this product consists of 3" (10 7.6cm) sections of white heat-shrink tubing held by polyester strips and cost less than US$20. It can be marked with a pen, or fed through most typewriters or printers for the professional touch. Once heated the tubing shrinks to fit securely around the wire and the marking becomes permanent.

Wiring Runs and Connections

Once you have wire, connectors and tools on hand, you're ready to set up the wiring runs. Using color-coded wire and markers, install the conductors between pieces of electrical equipment.

Wiring is easy when you follow the strip, terminal crimp and heat-shrink sleeve installation technique for wire to 10 AWG as provided by Ancor Marine.

1. Select the correct terminal. Make sure the wire range of the terminal is compatible with the actual wire size.

2. To insure a good connection, make certain the terminals and wire strands are free from oxidation and corrosion.

3. Using the correct wire strip die on your cut, strip and crimp tool, strip the correct amount of insulation off the wire, exposing the conductor (**Figure 9**).

4. Place the terminal (shown is an adhesive-lined, heat-shrink ring terminal) in the proper cavity of the crimp tool and insert the stripped wire. Make sure the strands do not extend into the contact area.

5. Center the crimp to ensure even pressure and squeeze the handles of the tool (**Figure 10**). An adequate amount of pressure must be applied so oxides on the inside of the terminal are broken down, but not so much pressure that the overall terminal shape is distorted.

6. Crimp the insulation grip sleeve if using a double crimp terminal (**Figure 11**).

7. Check the finished crimp to see that the wire is held firmly in place.

8. Heat connector until insulation shrinks and seals the wire and adhesive flows freely (**Figure 12**).

The technique is the same for larger cable. After cutting it with a cable cutter, stripping the insulation can be done with a sharp utility knife set at the depth of wire insulation and used with care to avoid cutting fingers or individual wire strands. Special battery cable strippers that attach to the cable and cut with a quick circular motion can make the job safer and easier, but a utility knife works fine for making up a few cables. Place the cable lug into the proper cavity of the Power Crimper and insert the cable (**Figure 13**). Strike with a hammer or squeeze with a vice. Since cable lugs are uninsulated, they must be sealed with heat-shrink tubing or an equivalent type of protection (**Figure 14**). Adhesive-lined heat-shrink tubing also seals and supports the lug.

Sometimes it's more convenient to install end connectors before running the wires, but first make sure the connector will fit through wire chases and thru-holes in bulkheads. Use added wire protecting at all potential chafe points. Allow some excess wiring at all termination points to provide tension relief, to form drip loops for condensation (**Figure 15**) and for future wiring repairs. Follow ABYC standards by making sure all wires are supported with cable tie mounts or anchors at least every 18" (45.7cm). Exceptions: Battery cables within 36" (92.4cm) of a battery terminal and cables attached to an outboard motor.

Fasten multiple wires together with cable ties frequently to keep runs neat. In areas where additional abrasion resistance is desired, wires can be encased in plastic spiral wrap (**Figure 1,#17**) or split loom casing (**Figure 1,#6**). With these products, individual wires can enter or exit the wiring harness as needed. Make notes of all wire locations to prevent future fastener penetrations.

Install the appropriate connectors and install wires at preselected termination points. Make sure the terminal surface is free of dirt, oil or corrosion. Tighten all connection fasteners; when the system is completed, double-check all connection points for tightness.

A thin coating of moisture-displacing spray can keep connection points corrosion-free. Battery terminals should be coated with CRC Terminal Protector or similar product to form a corrosion-resistant barrier.

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Crimping Techniques

1 Select the terminal that is correctly sized to the wire.

2 Using the proper stripping die on the crimping tool or an automatic wire stripper (Ancor Marine), strip about 1/4" (6.3mm) to 5/16" (7.9mm) of insulation off the wire (**Picture 1**).

3 To ensure a positive connection, make certain all terminals and wire strands are free from oxidation and corrosion.

4 Place the connector in the crimp tool and insert the stripped wire. The wire insulation should be flush against the barrel of the connector. Make sure the strands do not extend into the contact area.

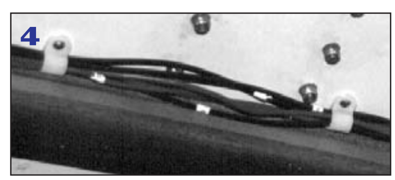
5 Center the crimp in the die and firmly squeeze the handles. If using double crimp terminals, crimp the insulation sleeve (**Picture 2**). For butt connectors, crimp each end. A single crimp is all that's needed. If cracks appear in the connector barrel or insulation you're using the wrong die.

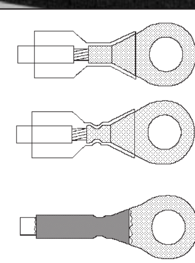
6 Lightly pull the finished crimp to see that the wire is held firmly in place.

7 Waterproof the connection with heat-shrink tubing (**Picture 3**).

8 Support wire at (8") intervals and at both terminal ends with screw-type cable clamps or ties. Identify wire with numbered, stick-on labels (**Picture 4**).

J. MUNDY





INSTALLING ADHESIVE-LINED, HEAT-SHRINK TERMINALS: *(1) Strip wire and insert into crimp barrel; (2) Apply crimp with proper die on crimp tool; (3) Heat connector until insulation fully recovers and adhesive flows freely.*

MARINE ELECTRICAL SYSTEMS

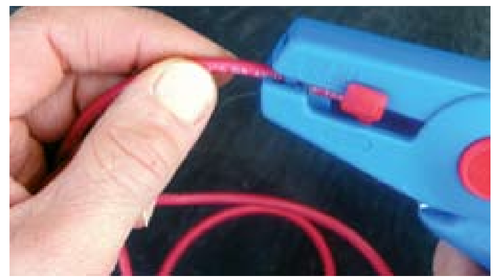
WIRING BASICS

There comes a time during your tenure as a boat owner when you will have to install or reinstall electronic or electrical equipment. With the proper tools and instructions, wiring can be an easy job for the do-it-yourselfer.

[By Jan Mundy]

Electrical wiring in boats has advanced from the sole realm of professionals to mainstream practice. Nowadays, you can purchase all the required tools and ABYC recommended wire, connections and other components from any well-stocked marine retailer. An investment of less than US$100 can buy you the basic tools you need to get started, including a quality wire stripper, crimper and butane torch. You'll need various sizes of wire, different styles and sizes of terminals both standard and heat-shrink type, several diameters of heat-shrink tubing and a few adhesive-lined heat-shrink terminals for use on wires that pass through the bilge. Wiring is easy when you follow the strip-crimp-shrink technique.

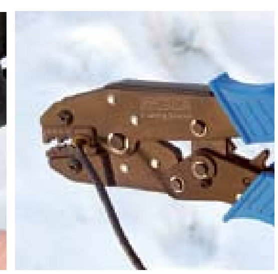
1. Set the indicator on the wire stripper to the size of the wire you are stripping. This tool automatically removes the correct amount of insulation from the wire. To ensure a positive connection, make certain all terminals and wire strands are free from corrosion.



2. Select a terminal that is correctly sized to the wire. Make sure the wire range of the terminal is compatible with the actual wire size. Terminals come in three colors to match wire sizes: red for 22 to 18 gauge; blue for 16 to 14 gauge; and yellow for 12 to 10 gauge.

3. Place the terminal in the proper color-coded jaw of the crimp tool. Slide a length of heat-shrink tubing over the wire end and insert it into the terminal. The wire insulation should be flush against the barrel of the connector. Make sure the strands do not extend into the contact area.

4. Center the crimp in the jaw and squeeze the handles with enough pressure to make the crimp. An adequate amount of pressure is required. Two crimps are required. If using a ratchet-style double crimper, firmly squeeze the handles until the jaws release — a single squeeze is all that's needed to make both crimps. Lightly pull the finished crimp to see that the wire is held firmly in place.



5. Waterproof the connection with heat-shrink tubing. To do this, slide the tubing over the end so it butts against the terminal base. Use a butane mini-torch to heat the tubing until the insulation shrinks and seals the wire. Identify each wire with stick-on labels when installing.

BOAT WIRE LIST

When rewiring or troubleshooting, a wire list is very handy.

By John Mason

Our boat, like most, came with a lot of complex wiring not done to American Boat and Yacht Council (ABYC) standards, no wiring diagram and no labels. Some of the wiring was original, some added by the previous owners or their contractors. Most was adequately done but some of the wiring was (and is) downright dangerous. Wires disappear into nooks and crannies and tracing is quite difficult.

I was faced with making a record of the existing wiring before I could re-engineer the system and make the changes I needed. Drawing an entire schematic while tracing every single wire is simply too massive a task. I started with a patchwork of limited wiring diagrams done in pencil (they changed a lot). But I wanted a more maintainable record of the wiring and the changes I was making. I started a wire list on our laptop computer.

Wire lists are standard features in electronic manufacturing and they are easily implemented with a computer. I use a Microsoft Word table, but other word processing, spreadsheet or data base programs will work. The key requirements are the ability to sort the rows on the column entries and a good "find" function for the text.

My list consists of four columns and two rows of information per wire. The columns are "Wire Number," "From," "To," and "Circuit." The second row is a reverse entry. In this case, a "wire" is a continuous conducting physical segment with a named source terminal and a named destination terminal. A "circuit" is a functional, electrically contiguous path and may consist of multiple "wires" in series.

Column 1 (Wire Number): The wire number I use is a unique reference designator (number) for the wire. I use a five digit numbering system with leading zeros. For example: "00060" and add an "R" for the reverse path or "00060R." This gives me the sorting characteristics I desire. I simply started with "00001" and increase by 1 for each new wire, making no attempt to correlate a range of numbers with function. When I sort on this column, I can tell what new numbers are available for use and can check the forward and reverse listings for consistency.

Columns 2 (From) and 3 (To): These are named points of origin and destination with a sequence of wires on the terminal. For example: from "Alternator B+ Terminal (1 of 2)" to "F 0001 Alternator Fuse Input (1 of 1)". The sequence is reversed for the reverse path entry. I make some effort to have the primary line match the positive (+) to negative (-) current flow. By sorting on column 2 (or 3) I can see all the wires on a given terminal grouped together. I use a consistent name for each terminal so the points will sort out together. This often flushes out "mystery" wires which may represent a problem such as an unexpected load.

Column 4 (Circuit): This column entry box has four lines. The first line is a circuit name, such as "Alternator Charge Circuit," which is used for all wires in the same circuit. Sorting on this column allows me to see all the conductors in that path grouped together, so I can trace the circuit through fuses, connectors, etc. The second line describes the physical characteristics of the wire (e.g. "1 AWG red"), the third is for comments, and the fourth is the proper ABYC color code for the wire (most of our boat's wiring was not to code). [Ed: Refer to "DC Wiring Handbook" DIY 1998-#4 issue for complete wiring techniques, color codes, etc.]

This may seem a rather clumsy procedure for producing a less than fascinating document, but when troubleshooting or redesigning, a wire list is very handy. My list is up to 14 printed pages and contains perhaps 10% of the boat's wires. Primary use is directly from the computer screen, though I print it infrequently to have a hard copy for troubleshooting when underway.

Wiring Standards

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A condensed version of ABYC standards regarding wire connectors is as follows:

▲ All connections shall be protected from the weather or in weatherproof enclosures. Connections exposed to immersion shall be watertight.

▲ Wiring connections shall be made without damage to the conductors.

▲ Metals used for terminal studs, nuts and washers shall be corrosion resistant and galvanically compatible with conductor and terminal lug.

▲ Terminal connectors shall be the ring or captive spade types with one exception: Friction-type connectors may be used if the voltage drop from terminal to terminal does not exceed 50 millivolts for a 20-amp current flow, and the connection does not separate if subjected to a six-pound tensile force along the axial direction of the connector for one minute.

▲ Ring and captive spade-type terminal connectors shall be the same nominal size as the stud to which they are mounted.

▲ In pressure-type connectors, a means must be provided to prevent the pressure screw from bearing directly on the conductor strands (see recommended type in Figure 1, #14 on page 4).

▲ Twist-on connectors (wire nuts) and terminals where solder provides the only mechanical connection are not recommended in marine applications, although solder can be the sole connection in battery lugs provided that the solder contact length is not less than 1.5 times the diameter of the conductor.

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SAMPLE WIRE COLOR CODE

COLOR	ITEM	WIRE USE
Black or yellow	Ground	Negative mains
Blue, dark	Cabin & instrument lights	Fuse or switch to lights
Blue, light	Oil pressure	Oil pressure sender to gauge
Brown w/yellow stripe or yellow*	Bilge blowers	Fuse or switch to blowers
Gray, dark	Navigation lights Tachometer	Fuse or switch to lights Tachometer sender to gauge
Green or green w/yellow stripe	Bonding systems	Grounding conductors
Brown	Generator armature Alternator charge light or alternator Pumps	Generator armature to regulator Generator terminal Auxiliary terminal to regulator Fuse or switch to pumps
Orange	Accessory feed	Ammeter to alternator or generator output and accessory fuses or switches
Pink	Fuel gauge	Fuel gauge sender to gauge
Purple	Ignition Instrument feed	Ignition switch to coil and electrical instruments Distribution panel to electric instruments
Red	Main power feeds	Positive Conductors
Tan	Water temperature	Water temperature sender to gauge
Yellow w/ red stripe	Starting circuit	Starting switch to solenoid

*If yellow is used for negative, blower must be brown with yellow stripe.

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ENGINE WIRING COLOR CODES

Some engine manufacturers use standardized color codes, such as that from ABYC, while others have their own standards. When troubleshooting, refer to the color codes marked on the engine schematic in your service manual. For practical purposes these markings are rather small. It's a good idea to laminate a copy in plastic to ensure a working copy is ready to use when troubleshooting. Even better is to have a copy with the charging system marked out in colored pens or highlighters, the same for the charging system and the instrumentation. The following table gives equivalent color codes between various makers, although check your own drawings for your engine.

Purpose	ABYC	Yanmar	Volvo	Perkins	Mercruiser
Ignition Start	yellow/red	white	red/yellow	white/red	yellow/red
Ignition Stop	black/yellow	red/black	purple	black/blue	
Preheat		blue	orange	brown/red	
Negatives	black or yellow	black	black	black	black
Alternator	Light orange	red/black	brown	brown/yellow	
Tachometer	gray	orange	green	black/brown	gray
Oil Press Gauge	light blue	yellow/black	light blue	green/yellow	light blue
Oil Warning Lt		yellow/white	blue/white	black/yellow	
Wtr Temp Gauge	tan	white/black	light brown	green/blue	tan
Wtr Temp Lt		white/blue	brown/white	black/light green	

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Every UL-listed wire, including UL 1426 Boat Cable, is required to be identified with the manufacturer's trade name as well as an "E" number — a PIN for the particular company or plant that made the wire. The term "Marine Grade" on an electrical product is a trademark of a particular manufacturer. The term "Boat Cable" or "BC" means the wire has passed a rigorous test by an independent testing laboratory to ensure it meets the UL 1426 standard for heat, cold, flexing and resistance to acid and water. It does not imply corrosion or oil resistance. Corrosion resistance is a function of tinned conductors and only those conductors specifically marked "oil resistant" are in fact so rated.

Other markings on the insulation of wire or cable describe the conductor or cable type and how it's rated. Unmarked conductors are not recommended by ABYC and may be disallowed by marine surveyors for insurance purposes. Listed below are some sample markings and what they describe:

Marine Grade	**Manufacturer's trade name**
2 con	Two separate conductors within an outer sheath
12 AWG	Conductor size is 12 American Wire Gauge
(UL) boat cable	Conductor conforms to UL 1426 standards for wire specially designed for boats
50V	Conductor's maximum voltage rating 105C dry, 75C wet Insulation's maximum temperature rating
Oil resistant	Insulation is resistant to damage from oils
BC5W2	Qualifies this wire as boat cable with 105°C dry and 75°C wet temperature rating
E67078	Number assigned to manufacturer by UL
LL22035	Wire lot number
CSA	Conductor conforms to Canadian Standards Association (CSA)
AWM	Meets CSA standards for "Appliance Wiring Material"
II	CSA two-conductor wire with external jacket

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Formula for Sizing Conductors

Use this formula for calculating conductor sizes not included in tables on page 65:

$$CM = \frac{K \times I \times L}{E}$$

▲ CM = Circular mil area of conductors as found in Table D on page 24

▲ K = 10.75 (constant representing the mil-foot resistance of copper)

▲ I = Current in amps

▲ L = Total length in feet from power panel to negative panel

▲ E = Voltage drop at load in volts (either 3% or 10% drop, and 12V, 24V or 32V)

For example:

CM =

$$\frac{10.75 \times 10\text{amps} \times 27' = 4{,}031}{.72\ (3\%\text{ of }24\text{ volts})}$$

The table on page 67 shows that 14 AWG is the correct conductor size to use.

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Conductor Size and Voltage

AWG CONDUCTOR SIZES FOR 3% VOLTAGE DROP AT 12 VOLTS

CURRENT (amps)**

LENGTH*	5	10	15	20	25	30	40	50	60	70	80	90	100
10'	18	14	12	12	10	10	8	8	6	6	6	4	4
15'	16	12	10	10	8	8	6	6	4	4	4	2	2
20'	14	12	10	8	8	6	6	4	4	4	2	2	2
25'	14	10	8	8	6	6	4	4	2	2	2	1	1
30'	12	10	8	6	6	4	4	2	2	2	1	1/0	1/0
40'	12	8	6	6	4	4	2	2	1	1/0	1/0	2/0	2/0
50'	10	8	6	4	4	2	2	1	1/0	1/0	2/0	3/0	3/0
60'	10	6	6	4	2	2	1	1/0	2/0	2/0	3/0	3/0	4/0
70'	10	6	4	2	2	2	1/0	2/0	2/0	3/0	3/0	4/0	4/0
80'	8	6	4	2	2	1	1/0	2/0	3/0	3/0	4/0		
90'	8	4	4	2	1	1/0	2/0	3/0	3/0	4/0			
100'	8	4	2	2	1	1/0	2/0	3/0	4/0	4/0			

Use this table for any critical applications: bilge pumps, navigation lights, electronic, etc. The next larger conductor should be used when length falls between two conductor sizes. For determining conductor size in 24-volt and 32-volt systems see "Formula For Sizing Conductors" on page **50***.*
**Length of wire from the positive power source (battery, panelboard or switchboard) to electrical device and back to the negative power source in feet.*
*** Total current on circuit in amps. Where there is a variance between the voltage drop and the ampacity (Table D on page* **9***), use the larger wire size.*

SOURCE: ANCOR MARINE

AWG CONDUCTOR SIZES FOR 10% VOLTAGE DROP AT 12 VOLTS

CURRENT (amps)**

LENGTH*	5	10	15	20	25	30	40	50	60	70	80	90	100
10'	18	18	18	16	16	14	14	12	10	8	8	6	6
15'	18	18	16	16	14	14	12	12	10	8	8	6	6
20'	18	16	16	14	12	12	10	10	8	8	8	6	6
25'	18	16	14	12	12	10	10	8	8	8	6	6	6
30'	18	16	14	12	10	10	8	8	8	6	6	6	4
40'	16	14	12	10	10	8	8	6	6	6	4	4	4
50'	16	12	10	10	8	8	6	6	4	4	4	4	2
60'	16	12	10	8	8	8	6	4	4	4	2	2	2
70'	14	12	10	8	8	6	6	4	4	2	2	2	2
80'	14	10	8	8	6	6	4	4	2	2	2	2	1
90'	14	10	8	8	6	6	4	4	2	2	2	1	1
100'	12	10	8	6	6	4	4	2	2	2	1	1	1/0

SOURCE: ANCOR MARINE

Use this table for any non-critical applications: cabin lights, stereo, etc. The next larger conductor should be used when length falls between two conductor sizes. For determining conductor size in 24-volt and 32-volt systems see "Formula For Sizing Conductors" on page **50***.*
**Length of wire from the battery to electrical equipment and back in feet.*
*** Total current on circuit in amps. Where there is a variance between the voltage drop and the ampacity (Table D on page* **9***), use the larger wire size.*

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CONDUCTOR RATINGS

AWG	AWG CM	Minimum Number of Strands		Ampacity in Engine Space[3]	
		TYPE 2[1]	TYPE 3[2]	OUTSIDE	INSIDE
18	1,600	16	—	20	17
16	2,600	19	26	25	21
14	4,100	19	41	35	31
12	6,500	19	65	45	38
10	10,500	19	105	60	51
8	16,800	19	168	80	68
6	26,600	37	266	120	102
4	42,000	49	420	160	136
2	66,500	127	665	210	178
1	83,690	127	836	245	208
0	105,600	127	1064	285	242
2/0	133,100	127	1323	330	280
3/0	167,800	259	1666	385	327
4/0	211,600	418	2107	445	378

1 Conductors with Type 2 stranding used for general purpose boat wiring.
2 Conductors with Type 3 stranding used where frequent flexing occurs.
3 Ampacity values for cables in circuits under 50 volts based on an ambient temperature of 50°C (122°F) and are independent of conductor length of run. See Tables B and C for specifics. Where there is a variance, use the larger wire size.

SOURCE: 1998 ABYC

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Ratings, Performance, Efficiency

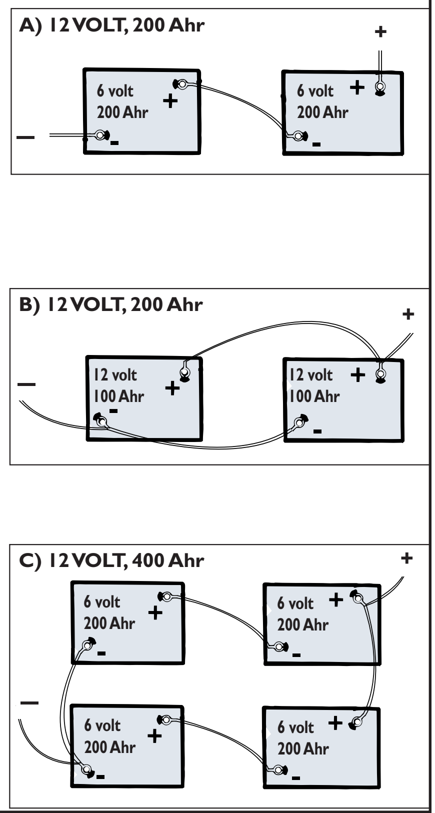
Storing electrical power for later use means getting the greatest possible output while engine-driven charging sources are in use, then tapping your stored electricity until it's time to generate again. This first of a two-part series looks at battery selection, ratings, reliability, performance and efficiency.

By Kevin Jeffrey

Batteries have traditionally been high on the list of nautical gear that boaters love to hate — they are bulky and heavy, can be a safety hazard, and seem to let you down when you need them most.

The cause of dead or malfunctioning batteries is either in the batteries themselves or in the way the batteries are charged and discharged. Cheap batteries don't give the service or dependability of high-quality models and poor charging techniques and negligent monitoring can quickly turn a great set of batteries into nothing more than expensive ballast. Understanding their operation and the differences between models, as well as proper charging techniques, may give you a whole new appreciation of your batteries.

FIGURE 1



A) Two 6-volt, 200 ampere-hour (Ahr) batteries connected in series to make a 12-volt, 200-Ahr bank. When batteries are connected in series (positive post of one battery connected to the negative post of another battery) the voltage doubles while the ampere-hour capacity remains the same.

B) Two 12-volt, 100-Ahr batteries connected in parallel to make one 12-volt, 200-Ahr bank. When batteries are connect in parallel (positive to positive, negative to negative), the ampere-hour capacity doubles while the voltage remains the same.

C) Four 6-volt, 200-Ahr batteries connected in series-parallel to make one 12-volt, 400-Ahr bank. Electrical components are first connected in series to double the voltage, then connected in parallel to double the capacity.

There are three types of lead-acid batteries appropriate for onboard use, each designed and constructed for a specific task and categorized by their ability to deliver current and hold up to repeated discharge. The difference between them is the thickness and number of the positive and negative plates, the strength of the lead alloy in the plates and the type of electrolyte used, either liquid or gel.

Starting-Lighting-Ignition (SLI) starting batteries have a great number of thin positive and negative plates that create a large total surface area capable of producing high-cranking power for the few seconds it takes to start an engine. These batteries can't maintain high discharge for very long and have a relatively high self-discharge rate. SLI batteries should always be isolated from the house bank through a battery isolator, a battery link or combiner, or a manual battery switch. Deep discharging will greatly shorten SLI battery life, since the plates aren't thick enough to handle it.

Deep-cycle batteries have the ability to withstand repeated deep discharge without harm, have lower self-discharge rates and are used to supply typical house loads. The plates in a true deep-cycle battery are thick and heavy, trading surface area for strength and starting power for reserve capacity. They often come in 6-volt configurations for easy transport and longer life, and can be connected in series or series-parallel to achieve the desired system voltage. Deep-cycle batteries can also be used for engine starting, if you have enough total capacity (several hundred ampere-hours or more).

It may be tempting to buy inexpensive 6-volt deep-cycle batteries, which have only a three-year life expectancy (less in the tropics), but you'll be better off in the long run with high-quality models such as the new Surrette Red line of batteries (marketed as Rolls in the U.S.). These batteries cost more initially but

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FIGURE 2

The following chart shows typical battery sizes and ampere-hour (Ahr) capacities.

Battery Type Ampere-hour	Typical Size	Typical (Ahr) Capacity
Group 24, 12V	11” x 7” x 9”	85-90
Group 27, 12V	12” x 7” x 10”	100-105
4D, 12V	21” x 8.5” x 10”	160-180
8D, 12V	21” x 11” x 10”	220-250

easily last eight to 15 years in normal service. Surrette batteries have heavy-duty plates that are individually wrapped with a protective envelope to eliminate short-circuiting and cell damage due to sediment buildup or faulty or misaligned plate separators. Other unique features of Surrette’s new batteries are the large electrolyte reservoir over the plates and the virtually indestructible structural foam-and-polyethylene outer case.

Between the SLI and true deep-cycle batteries is the hybrid deep-cycle with plates of medium thickness and either gel or absorbed electrolyte (see below). Commonly used as house batteries, they also have cranking power for engine starting, can be moderately discharged repeatedly without harm, have a relatively low self-discharge rate and come in 6- and 12-volt configurations. Because of the moderate plate thickness these batteries typically don’t have the service life of good-quality deep-cycle models. Immobilized-electrolyte batteries are also more sensitive to voltage, which means that your charge controls must be properly set and provide temperature compensation to make sure the voltage stays within acceptable limits.

The electrolyte in a lead-acid battery is the material surrounding the internal lead plates that allow them to chemically store or release electrical energy. The electrolyte in most lead-acid batteries is a sulfuric-acid solution in liquid form. Distilled water must be added to liquid-electrolyte batteries periodically to replace losses that normally occur during performance charging. They must also be periodically equalized — charged at a higher voltage under controlled conditions — to prevent sulfation deposits from decreasing battery capacity.

Batteries that are permanently sealed with the electrolyte immobilized are increasingly popular with boat owners. There are two basic types of sealed batteries: absorbed electrolyte and gelled electrolyte. (Note: these high-quality hybrid deep-cycle batteries should not be confused with inexpensive “no-maintenance” SLI batteries.)

In an absorbed-electrolyte battery, the electrolyte is contained in thick, felt-like glass-fiber mats that are compressed between the plates. During construction, some of the electrolyte is also absorbed by the battery plates. The mats serve as receptacles for the electrolyte as well as plate separators. Compressing the plates and mats together lowers the internal resistance of the battery and allows for higher charge and discharge rates. These batteries are best suited for power systems with light electrical loads.

In gel batteries, the electrolyte is contained in gel form. Gel batteries are hybrid deep-cycle batteries with high performance characteristics, allowing them to be used in power systems with heavier electrical loads. They typically don’t have the service life of true deep-cycle batteries.

Battery Ratings

Batteries are rated according to their construction and how they perform, allowing boaters to make an intelligent selection according to their needs. The various ratings are: voltage, marine cranking amps, reserve capacity, and size and ampere hours.

Voltage Batteries are composed of a series of 2-volt cells. Individual batteries for marine use are typically available in 6- or 12-volt models. They can be connected together in series, in parallel or in series-parallel **(Figure 1)** to create the desired system voltage and capacity.

Marine Cranking Amps (MCA) This rating tells the current that a battery at 0°C (32°F) can deliver for 30 seconds while maintaining a minimum cell voltage of 1.2 volts. Gasoline engines require about 1 MCA per cubic inch of displacement, diesel engines about 2 MCA per cubic inch.

Reserve Capacity This refers to the number of minutes that a fully charged battery at 26.6°C (80°F) can be discharged at 25 amperes while maintaining a minimum cell voltage of 1.75 volts. Reserve capacity can also be expressed for other rates of discharge such as 5, 10 or 15 amperes. The higher the rate of discharge, the lower the total reserve capacity rating.

Size and Ampere-hour Rating Marine

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batteries are most often marketed according to their case size and corresponding ampere-hour capacity **(Figure 2)**. Ampere-hour (Ahr) capacity is an energy rating similar to reserve capacity. It refers to the amperes a battery can supply at 80°F (26.6°C) in a specific period of time, while maintaining a minimum cell voltage of 1.75 volts. Many battery manufacturers use a 20-hour rate. In this case, a 100 Ahr battery could supply 5 amperes for 20 hours. When comparing batteries, it's essential to make sure they use the same hour rate.

Capacity, Discharge & More

Here are a few rules about battery performance.

Ampere-hours and Energy The rating of ampere-hours is really an indicator of the amount of usable electrical energy the battery can provide. Remember that volts x amperes = power and power x time = energy. This means that ampere-hours x battery voltage = watt-hours, a true measurement of electrical energy. A 6-volt battery rated at 100 ampere-hours has half the total available energy than a 12-volt battery with the same rating.

Usable Battery Capacity The rated ampere-hour or reserve capacity of a battery is quite different from the amount of energy you can actually store and retrieve on a daily basis. Deep-cycle battery life can be greatly extended if you discharge to only about half of its rated capacity, or 50% charged. Frequent deeper discharges will shorten battery life dramatically. And because of the low rate of current a battery will accept during the final charging stages, it's likely that with an engine-driven charging source you'll most often charge the battery to only about 90% of its rated capacity. In effect you have about 40% of the total battery-rated capacity at your disposal as usable electrical energy. (The relatively constant output from solar panels and wind- and water-powered generators easily completes the final stages of charging, making that extra 10% of battery capacity available.) For long battery life, it's important to periodically bring the battery to a full state of charge.

Recharge Energy Losses Some of the electrical energy used to charge a battery becomes lost as heat or wasted on hydrolysis, the breakdown of water into hydrogen and oxygen gas. Hydrolysis in a battery is referred to as battery gassing. It begins when the charge rate exceeds what the battery can naturally absorb. Gassing can be limited by using good performance charging techniques, but you still lose about 15% of the charging energy. In other words, it typically takes 115 Ahr to completely charge a 100-ampere-hour battery.

Charge and Discharge Rate The rate of charge and discharge greatly affects the amount of usable electricity (capacity) you can get from a battery. As a rule the higher the charge rate, the less efficient the battery is at absorbing all of the available energy. Conversely, the higher the discharge rate, the lower the total amount of usable energy. This has definite implications when choosing high-draw appliances for your power system.

Capacity and Temperature Battery temperature will also affect capacity, as it does corresponding specific gravity and voltage readings. While chemical reactions are accelerated at higher temperatures to improve battery performance, hot ambient temperatures most definitely shorten battery life. This is why it's best to keep batteries in a cool, dry location.

Age & Use Batteries eventually lose their capacity to store energy, although higher quality batteries have a greatly extended life expectancy. Proper charging methods and routine care will also extend battery service life.

Number of Cells & Life Expectancy Using high-capacity 6-volt batteries can reduce the total number of cells in your battery bank. Since you'll have fewer cells to maintain, you'll effectively increase the life expectancy of your battery bank. For example: To create a 12-volt, 400-Ahr battery bank, you use two 6-volt, 400-Ahr batteries connected in series and there would be only six cells (2 volts per cell) in this battery bank to maintain. If, instead, you use four 12-volt, 100-Ahr batteries connected in parallel, there would be 24 cells to maintain.

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Selection & Sizing for House Loads

In part 1, we reviewed the various types of batteries and how they are rated. In this second part, we'll focus on selecting and sizing batteries for your house loads on board.

By Kevin Jeffrey

The first thing to do is determine your total house battery capacity, which relates to two things: your total electrical load drawn from the house batteries, excluding those supplied by direct AC power sources; and the reserve battery capacity you'd like to have — the amount of time you can live solely off battery power before needing to recharge. The reserve capacity you choose determines the time between regular engine-charging cycles. If your contribution from renewable chargers (solar, wind or water-powered generators) is small or nonexistent, you'll have to adhere to this regular engine charging schedule. If renewables are making a significant contribution, you can extend the length of time between regular engine charging or eliminate the need for it altogether.

Sizing Battery Capacity

When sizing batteries, there are certain rules to follow. First, your usable battery capacity is the amount of energy available when the batteries are between 50% and 90% of full charge. This means that your usable capacity is about 40% of the total capacity. Battery life is extended if you don't discharge below the 50% level on a regular basis, and topping up the last 10 percent of charge usually takes too long with an engine-driven charging source since charging current drops significantly during the latter stages of charging. Not all of the charging power that reaches the batteries actually gets stored as electrical energy; some is lost in the process. It's a good idea to make provisions for battery losses of about 15%.

In addition to these rules, I usually recommend sizing total battery capacity as if no renewable chargers were present. That way the more power renewables produce, the less you'll need to be concerned with a regular engine-charging routine. For example, assuming an electrical load of 110 amp-hours per day and a one-day reserve capacity, requires roughly 320 amp-hours of battery capacity **(Figure 1)**.

Increasing your electrical load or the length of your reserve capacity increases the total battery capacity required. For instance, if you wanted two days between regular engine-charging cycles, you would need to roughly double your total battery capacity.

Before proceeding, check to see if the total battery capacity you've calculated is suitable for your charging sources.

To make the most efficient use of your alternator, total battery capacity should be at least four times the amperage delivered during bulk charging (when your alternator is producing the most current). With 320 amp-hours of total capacity, you could have a 100-amp high-output alternator producing about 80 amps or so when it's warmed up; larger amperage alternators should have more battery capacity to keep their amperage levels from dropping prematurely, although the only harm done if you don't have more capacity is a loss in alternator efficiency.

Now check to see if you have enough storage capability for your renewable

BATTERY CAPACITY

Figure 1

Assuming an electrical load of 110 amp-hours per day and a one-day reserve capacity, sizing total battery capacity would be as follows:

110 amp-hours per day load x 1 day of reserve capacity
= 110 amp-hours of usable battery capacity needed

110 amp-hours of usable capacity
= 40% of total battery capacity

110 amp-hours divided by 0.4
= 275 amp-hours of total battery capacity before losses

275 amp-hours of total capacity x 1.15 (accounts for 15% battery losses)
= roughly 320 amp-hours of battery capacity required.

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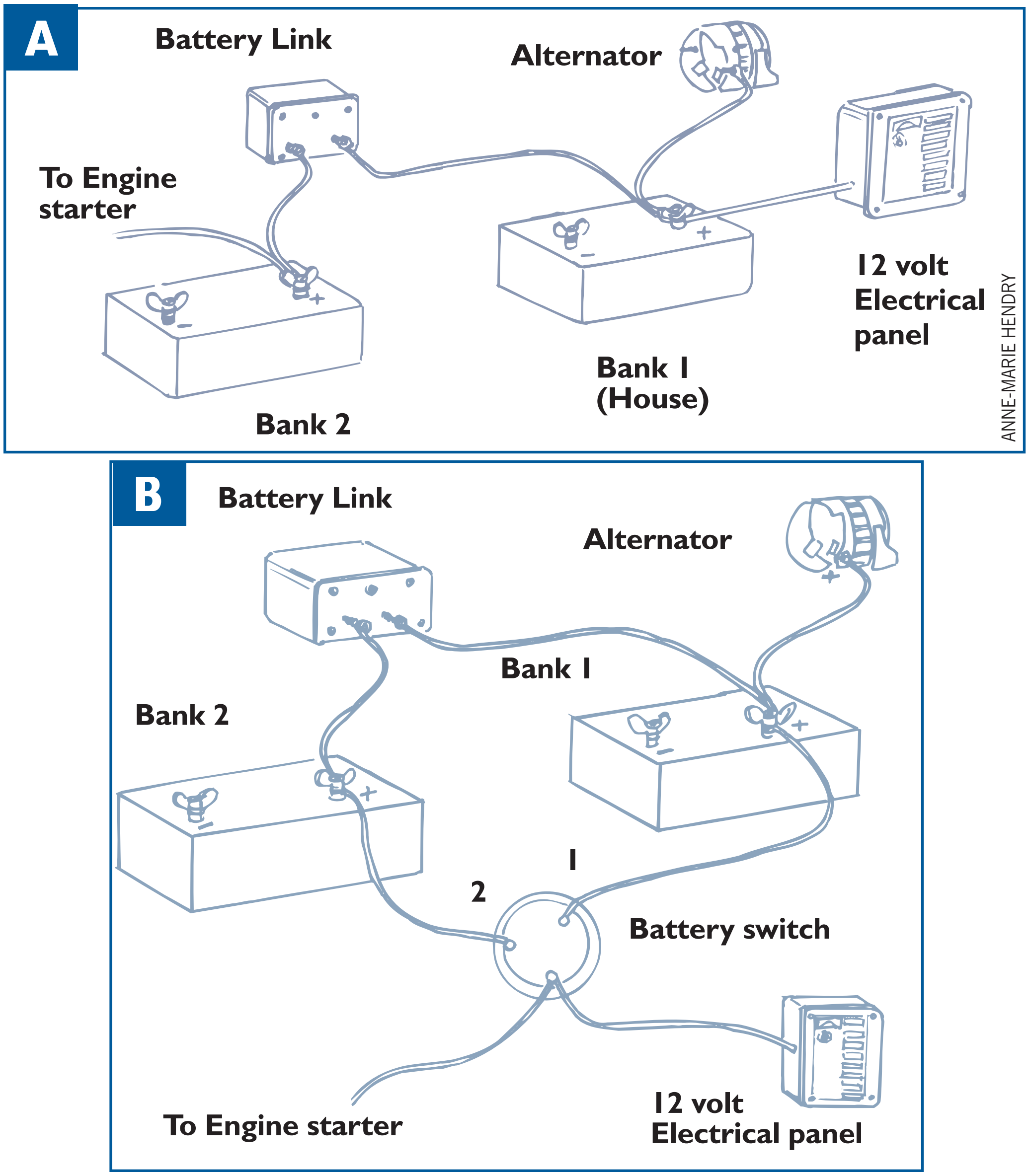


Figure 2

A battery link joins battery banks together during charging then disconnects them when the charging source is off so that all battery banks automatically receive the charge they need. When the alternator is on, separate banks are "linked" together temporarily.

A) Loads supplied separately from each bank.
B) Loads supplied through battery switch.

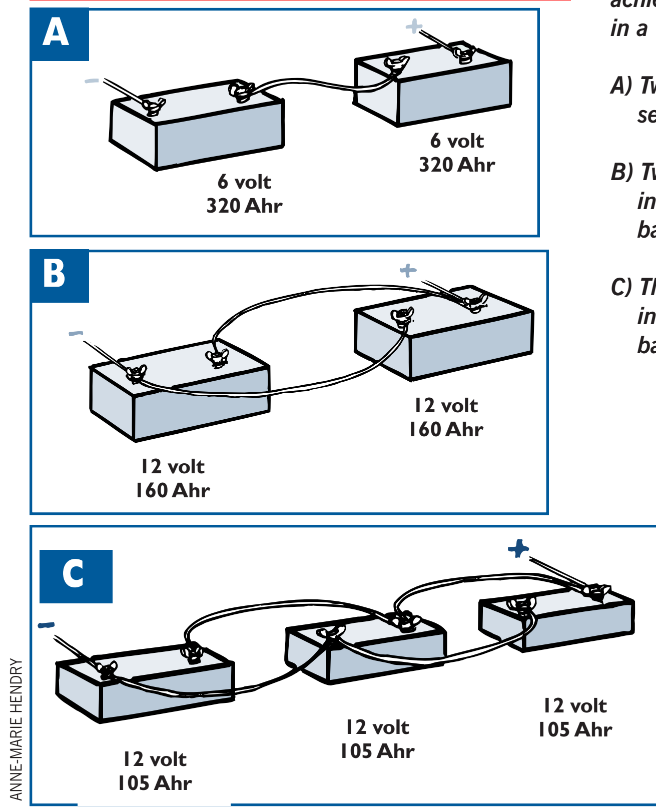
chargers. You should be able to store all the charging current produced during a full day of maximum output. This is usually not a problem with solar panels, but a wind or water generator could produce upwards of 200 amp-hours per day. With a 320 amp-hour battery bank you could only store 200 amp-hours if the bank was discharged to 50% at the beginning of the day (with 160 amp-hours to reach full charge) and you used the remaining 40 amp-hours to supply loads. If the batteries were more fully charged to begin with, or you used less power during that time, or you had optimal charging conditions for several days, some of that hard-won electrical power would go to waste. In this case, it might be a good idea to add a bit more battery capacity if you can.

Number of Banks

For most marine applications a single house bank of batteries with a designated engine-charging battery makes the most sense and is the easiest to control and monitor. With this arrangement, you can track charging performance, load draw and battery condition with a low-cost system monitor, and there's no need for switching banks to supply your loads. With the addition of a battery link or combiner, even the charge distribution to the house and engine-starting banks will be automatic **(Figure 2)**.

Sometimes it's useful to keep certain

Figure 3



Three different battery configurations to achieve 320 ampere-hours (Ahr) total capacity in a 12-volt system:

A) Two 6-volt, 320 Ahr batteries connected in series to make a 12-volt, 320 Ahr bank.

B) Two 12-volt, 160 Ahr batteries connected in parallel to make one 12-volt, 320 Ahr bank.

C) Three 12-volt, 105 Ahr batteries connected in parallel to make one 12-volt, 315 Ahr bank.

house loads, such as an anchor windlass, separate from the main bank to simplify wire runs. Two-bank systems are also popular on wide catamarans with an engine in each hull.

Battery Type Versus Performance

As we discussed in part 1 (page 67), you'll need to choose between deep-cycle, hybrid deep-cycle or starting batteries, between gel or liquid electrolyte, and between batteries that are inexpensive but with modest life expectancy or more expensive models with increased life and performance. Batteries strictly for house loads should be true deep-cycle or hybrid deep-cycle, and batteries strictly for engine starting should be starting or hybrid deep-cycle. It's important that you don't mix batteries of different size, type, or age in one bank — this can lower the life expectancy of the bank.

Total battery capacity can be achieved in various ways. In a 12-volt system, the 320 amp-hours of total capacity calculated in Figure 1 can be supplied by two 6-volt batteries of 320 amp-hours wired in series, by two 12-volt batteries of 160 amp-hours (4D) wired in parallel, or by three 12-volt batteries of 105-110 amp-hours (Group 27) wired in parallel (**Figure 3**). With two 6-volt batteries, there are only 6 battery cells; with two 12-volt batteries, there are 12 cells; and with three 12-volt batteries, there are 18 cells. The more cells in a bank, the more potential for problems. On the other hand, Group 27 batteries are much easier to handle and accommodate than larger batteries.

Once you've sized and selected your house and engine-starting batteries, make provisions in the way you install them for simple charging and discharging sequences and proper monitoring so you can visually track battery performance. A discussion of the proper charging techniques and the various charging controls appears in an upcoming issue.

Battery Terminology: House vs Starting

House batteries are used to supply normal daily operating loads — everything except engine starting. They are either deep-cycle or hybrid deep-cycle batteries that can be discharged to 50% of capacity repeatedly without harm.

Starting batteries are used for starting engines, both main auxiliaries and gensets. They have a high Marine Cranking Amps rating due to large plate surface area inside the battery. These batteries get their surface area by having lots of thin plates, as opposed to deep-cycle batteries, which have fewer, thicker plates.

ENERGIZE YOUR DC SYSTEM WITH POWER TO SPARE

The average life of a car battery is 48 months. The average life of a marine cranking battery in recreational marine use is only 22 months. Marine batteries can last much longer if you make a few wise decisions about their selection, installation and maintenance.

Is choosing the right battery a test of your brainpower?

Story and Photos by Larry Blais

Replacing a battery in a car is a simple matter. The car's manufacturer has determined the appropriate type, shape and capacity, and published these specifications. So all you have to do is decide what quality of battery you are willing to pay for. Recreational boats, on the other hand, are rarely equipped with batteries adequate to the power hungry "gotta have" extra equipment that most of us think we need to enjoy boating. So, we approach the task of having to buy new batteries with some disdain, sometimes because the old ones either didn't last as long as we thought they should or as long as we were told they would.

Capacity And Usage

If you need a battery for a small runabout with an outboard motor, deciding on a battery will be a relatively simple task but if you have a yacht with multiple engines, several radios, radar, refrigerator, inverter, etc., then the decision becomes more complicated. Let's start with the simplest application and work our way up to the more complex.

Any small boat that just needs a battery to start the engine and run some navigation lights from time to time can probably get by with just one Group 24 or 27 battery. Check with the engine manufacturer for its recommended minimum cold cranking ampere (CCA) rating required to start your engine and buy a quality marine battery with enough CCA capacity.

ABYC standard E-10 defines cranking performance (also referred to as marine cranking amps at 32°F/0°C or MCA at 32°F/0°C) as "the discharge load, in amperes, that a new, fully charged battery at 32°F (O°C), can continuously deliver for 30 seconds and maintain a terminal voltage equal to or higher than 1.20 volts per cell." The standard further states that, "Cranking batteries shall have at least the cold cranking performance rating (CCA at O°F/-17°C) or marine cranking performance rating (MCA at 32°F/0°C) amperage required by the engine manufacturer." For added peace of mind, consider adding a second battery of the same type and size. In any case, one battery or two, install a marine battery selector or On/Off switch. Although ABYC (E-9 and E-11) does not require these switches unless the battery output rating is at least 800 CCA, it's still a good safety practice.

Adding an electric trolling motor? You'll probably need a separate deep-cycle battery dedicated to its service. After a day of trolling, this battery can usually be at least partially recharged by your engine's alternator if a battery isolation diode or selector switch is installed. If your boat has more than one engine, each engine should have it's own cranking battery with a CCA rating appropriate for the engine's need. Here again, adding a second battery or an emergency cross-over switch or a selector switch that would connect a cranking battery from the other engine would be prudent.

If you operate lights, radios or other DC equipment without the main engine running (such as when at anchor or while under sail) or depend on a DC-powered bilge pump, then you may need a separate "house" electrical system energy source. This system is independent from the engine electrical system and has its own battery(s). House batteries should be true deep-cycle batteries that can tolerate deep discharge cycles between charging cycles. These batteries are rated in ampere hours (Ah). Because of the internal construction of these batteries, they rarely have the high ampere capacity to crank an engine and they can be damaged trying to do so. Likewise, cranking batteries, because of their internal construction, will not tolerate sustained discharging like deep-cycle batteries can.

DC-to-AC inverters put very heavy demands on their host boat's batteries. For a 12-volt inverter to supply 10 amps at 120 volts, it must draw over 100 amps from the batteries. To supply 20 amps, it would draw over 200 amps and so on. Having a dedicated inverter battery bank might be very wise.

A good quality 235 Ah golf cart battery can produce a continuous 75 amps for about 2 hours, 40 amps for about 4 hours, 20 amps for about 10 hours and 10 amps for about 25 hours. Since these batteries are only 6 volt each, two batteries must be connected in series to produce 12 volts and another set of these batteries connected in series may have to be connected in parallel to the first set to safely produce enough amps for sustained use of the inverter.

Battery manufacturers are constantly looking for ways to satisfy the consumer's needs. It would seem that a combination cranking/deep-cycle battery would be great idea. With the exception of a few very high-end batteries, most dual or combination starting/deep-cycle batteries are simply a poor compromise between a cranking battery and a deep-cycle battery and have not proven to be very good at either task. Be aware that some battery manufacturers have simply added handles and stud-type terminals to their standard cranking batteries and have sold them as marine deep-cycle batteries. Needless to say, they don't last long.

Pick One, Just One

Today, there are three distinct types of batteries available. They are flooded acid (a.k.a., wet cell), gelled acid (a.k.a., gel cell) and absorbed glass mat (AGM). Each type can be designed and constructed for either engine cranking or deep-cycle applications.

Flooded acid batteries are by far the most popular and generally seen as the most cost effective. Commercial vessels use them almost exclusively. Flooded low-maintenance batteries have filler caps and a lead-antimony/calcium dual alloy or hybrid plate formulation that helps reduce gassing. Flooded maintenance-free batteries are sealed and have a lead-calcium/calcium plate formulation that helps the hydrogen and oxygen gasses recombine back into water rather than needing to be vented.

The gelled acid batteries lost popularity very quickly partly because they require special low, slow recharging rates. Many gel cell batteries have been destroyed by being charged at the normal rate for a flooded battery. Sealed valve regulated lead-acid (VRLA) gel cell batteries are usually spiral wound and use a thickening agent like fumed silica gel to immobilize the electrolyte. The pressurized cells help hydrogen and oxygen gasses recombine back into water. They can withstand a deep discharge but not temperatures over 100°F (37.8° C) due to "thermal runaway." They work best at an ambient temperature of 72° F (22.2° C). They generally produce less cold cranking amps than other batteries. Gel cells require longer recharging times at lower charging voltages. Of all the sealed batteries, the gelled acid battery is the least tolerant of the heat found inside most engine rooms.

The top plate is from a heavy-duty deep-cycle battery used by railroads. The middle plate is from a popular deep-cycle battery used to power electric golf carts. The bottom plate is from a high-quality marine cranking battery. The plates in a typical car battery are more than 30% thinner than the plates in a high-quality marine cranking battery. The thinner more porous plates are more easily damaged. [Ed: One of the many reasons marine batteries are more expensive than automotive.]

The AGM battery has not faired much better, often due to improper installation. Sealed VRLA AGM batteries have a very fine fiber boron-silicate glass mat between their plates that absorbs and holds the liquid sulfuric acid. The pressurized electrolyte starved cells help hydrogen and oxygen gasses recombine back into water rather than needing to be vented.

Ventilate And Contain

Batteries must be protected against saltwater as this, mixed with electrolyte, produces deadly chlorine gas. Batteries also need to be protected against extreme temperatures. When underway, the temperature in boat engine compartments can exceed 120°F (48.8°C). A flooded battery loses half of its service life for every increase of 15°F (9.4° C) over 80° F (26.7° C). A hot engine compartment is not a good place for any battery.

All batteries need ventilation, even sealed ones, as they have pressure relief valves that will open if the battery is worked hard enough. Batteries, especially batteries connected to an inverter, can produce explosive hydrogen gas that should be vented to the outside of the vessel. Some modern yachts are built with power ventilation ducted right into the battery boxes, blowing the fumes overboard.

A battery On/Off or selector switch should be installed in the positive battery cable. It should be placed where it can be turned off without opening the engine compartment, just in case the compartment is aflame and opening the compartment would fuel a fire with an influx of oxygen. Select a switch with enough capacity to carry the current required without overheating the contacts. Overheated battery switch contacts often result in high resistance that keeps the battery from receiving a full charge and high resistance connections that overheat are a source of fire.

Tips For Longer Battery Life

Normally all batteries "age" as the active positive plate material sheds due to the normal expansion and contraction that occurs during the discharge and recharge cycles. Eventually, this sediment builds up in the bottom of the case and can even short out the plates of a cell. The "aging" process is accelerated when the battery endures heat, vibration, overcharging, positive grid growth, positive grid metal corrosion, negative grid shrinkage, freezing, buckling of plates, loss of water or sulfation. Sulfation occurs when a battery drops below a full charge for long periods and hard lead sulfate crystals fill the pores in the plates.

Always wear protective glasses to protect your eyes in the unlikely event of an explosion when working with lead-acid batteries. Battery plates need to be covered at all times to prevent an internal battery explosion or sulfation. Avoid overfilling, especially in hot weather, because the heat causes the electrolyte to expand and overflow. In an emergency, use rainwater rather than reverse osmosis or tap water because rainwater doesn't contain calcium or magnesium. Using tap water to refill batteries can produce calcium sulfate crystals that fill the pores and coat the plates. Don't add battery acid except to replace electrolyte spills.

Use an hydrometer to measure the specific gravity (SG) of the electrolyte in flooded acid batteries. This reading tells you the battery's degree of charge. SG readings should not differ more that .030 between the lowest and highest reading. Use the following table to determine the battery's degree of charge.

100%	1.265
75%	1.225
50%	1.190
25%	1.155
Discharged	1.120

Always charge with a "smart" or "float" charger. An inexpensive, unregulated trickle charger can destroy a battery by overcharging it. Battery isolation diodes (also known as split charging diodes) allow the alternators to charge multiple batteries. These diodes have an inherent voltage drop of .6 volt to 1 volt that prevents them from fully charging the batteries unless the alternator output voltage is increased to compensate. If your alternator regulator doesn't have an external adjustment, you may still

Screw-down covers that hold these batteries securely in place, even in rough seas. They also cover the terminals so nothing metallic can short-circuit them.

Smart chargers and battery isolation diodes allow the alternators to charge multiple batteries.

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be able to increase its output by installing a diode with the same voltage drop in the regulator sensing wire between the alternator and the regulator. This way the alternator "sees" the reduced voltage and increases the alternator output accordingly.

Clean and tighten any loose hold-down clamps, battery terminals and connectors. High resistance in a cable connector can keep the battery from receiving a full charge. Remove any corrosion with a brass wire battery brush by brushing the corrosion away from you. Take care to avoid poking yourself with the brush as a wound from the brush could lead to a serious infection. Neutralize heavy corrosion with a mixture of 1lb (.45kg) of baking soda (bicarbonate of soda) to 1gal (3.78L) of warm water. Be sure to keep this mixture from entering the battery cell where it can neutralize the acid. Treat the terminals with corrosion-inhibiting formula. Clean the battery top to eliminate conductive paths created by dried or wet electrolyte and to prevent corrosion.

Check alternator belt pulleys for corrosion and the belt for proper tension. A slipping belt prevents the alternator from properly charging the battery. Without being fully charged the battery will sulfate and lose capacity.

Most of the defective batteries returned to the manufacturers during the free replacement warranty period are still serviceable. This strongly suggests that an undiscovered problem with the electrical system was what prompt-ed the replacement of the original battery in the first place. Had this problem been discovered and corrected, the battery may not have even needed replacement.

This boat needs to be protected against acid spilling from the battery. A drip tray might help but a battery box is better. Note how these boxes attach to the boat by external screws. Never drill holes through the bottom of the boxes to fasten them down as this gives any leaking acid a path to leak from the container.

(left) Note the black powder on the front of this engine. It formerly was part of the alternator belt. The belt pulley sheaves have rust pitted so badly that they are eating up the belt to the point that the belt is so loose that it's slipping. Sometimes sandpaper can smooth the pulleys. Sometimes the pulleys have to be replaced. If not attended to soon, the belt will fail. (right) This belt pulley is in better shape but is too loose and needs to be tightened until it deflects only about 5/16" to 3/8" (7mm to 9mm) when pushed with one finger.

If the electrolyte levels in non-sealed wet batteries (with filler caps) are above the plates but low, allow the battery to cool to room temperature and add only distilled, deionized or demin-eralized water to the level indicated by the battery manufacturer or to within 1/4" to 3/8" (6mm to 9mm) below the tops of the filler tubes, vent wells or splash barrels.

To use a hydrometer, simply hold the hydrometer vertically and squeeze the rubber bulb to force the air out. Now put the rubber tip into the electrolyte through the battery filler hole and release the bulb. The electrolyte is sucked up into the hydrometer allowing the float to ride freely. Read the SG at the point the surface of the electrolyte crosses the float markings. The SG reading should be between 1.100 and 1.300. Squirt the electrolyte back into the cell from which it was taken and record the reading. Repeat the process for each individual cell. Rinse the hydrometer with water when you've finished.

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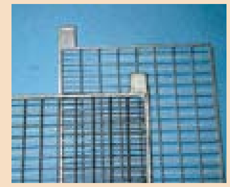
The Pickled Amp

Lead-acid batteries have seen few major changes since they were first developed over 100 years ago. The most common became known as a “wet cell” or “flooded acid” battery. Most U.S. manufacturers use flat plate technology in their positive and negative plate designs for this battery.



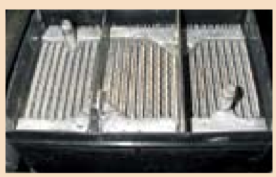
Lead grids serve as the supporting framework for the active, porous material pasted to them. Lead oxide (PbO), sulfuric acid (H2SO4) and water are blended in a mixture to the approximate consistency of stiff mortar cement. Once the grids are covered with this blend, they are cured in an oven.

Plates are then stacked; alternating positive and negative plates, separated with thin sheets of electrically insulating, porous spacers.

Enough plates for one cell are jigged together so all the positive plates can be soldered together (in parallel) with a torch.

Then the negative plates are soldered together (in parallel).

After the soldered plates have cooled they are checked for connection penetration and cleaned of any loose lead that might short out the plates. Plates are now slipped into the case.



Each cell will produce approximately 2.11 volts. The only way to increase the voltage is to connect cells together in series (negative to positive). Three cells in series will produce about 6.3 volts.

Six cells in series will produce about 12.6 volts. Once the lid is on and sealed, the battery is filled with diluted sulfuric acid and ready for charging. During the initial charging, the lead oxide in the positive plate is converted to lead dioxide (PbO2) and the lead oxide in the negative plate is converted to sponge lead (Pb). When fully converted, the battery is called “formed.” After the spent electrolyte is replaced with fresh diluted sulfuric acid, the battery is given a finishing charge.

Calculating Battery Requirements

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To determine the total daily load on a battery, take the power usage including surge loads in watts of all appliances, multiplied by the hours of use between battery charges. If an appliance is rated in amps, multiply volts by amps to obtain watts. For example, a 120-volt appliance rated at 10 amps requires 1,200 watts of power. Convert the total watts to amp/hours by dividing by the DC system voltage (12, 24 or 32) then add the values. Multiply amp/hour value by 1.1 to 1.2 (depending on the inverter) to determine the total battery drain. Since the number of amp/hours consumed by AC loads before recharging the battery should be no more than 50% of the battery's rated capacity, you'll need about 288 amp/hours (or three 100-amp batteries) to provide the AC power in this example.

Appliance	Total W Rating	Hours of Use Per Day	Total Watts	Amp/hours Use(÷12)
13" TV	80	2	160	13
Stereo	50	2	100	8
VCR	50	2	100	8
Blender	300	1/6	50	4
3/8" drill	500	1/12	42	3
Hand sander	500	1/12	42	3
Ice maker	200	1/6	33	3
Coffee maker	1000	1/6	167	14
Hair dryer	1500	1/6	250	21
Portable vacuum cleaner	1100	1/12	92	8
Compact microwave	750	1/4	187	15

Total amp/hours consumed = 100 (Sum of right column).

Multiply by 1.2 for inverter inefficiency = 120

Recharging requires 120 x 1.2 = 144 amp/hours

(Note: numbers rounded to nearest whole number.)

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Reducing Electrical Demands

Conserve battery power without sacrificing comfort or safety. Here's how.

By Kevin Jeffery

One of the best ways to make sure there's always enough battery power onboard is to reduce your electrical demand. This doesn't mean giving up conveniences or safety gear you've come to enjoy and rely on. Most boaters can reduce their electrical load significantly simply by choosing efficient appliances and operating them wisely.

The first step is to have a good estimate of your current electrical load, since your load and your ability to replace this load (either with 12-volt charging gear or other power sources) must be evenly matched. This approach allows you to view your total energy budget and target problem areas effectively. The results may surprise you. (For a quick review of how to estimate your electrical load see **Figure 1** on page 47.) Now, go through your appliance list and choose loads that can be reduced. Start with the most universal and easiest to alter, lighting.

Cabin & Deck Lighting

Kerosene lanterns are hard to beat for atmosphere and low battery draw, but electric lighting is one of the simple luxuries of our times. Cabin lighting typically accounts for a large portion of a boater's electric load, but you can reduce consumption by up to 75% with energy-efficient fluorescent lights or up to 20% with halogen lamps. Lighting efficiency is measured in lumens per watt, or the light output in relation to the energy consumed. Incandescent bulbs are notorious energy wasters, operating in similar fashion to heating elements — only about 10% of the electricity consumed is turned into light, while 90% dissipates as heat. A typical 8-watt fluorescent lamp delivering 60 lumens-per-watt gives the same light output (lumen level) as a 40-watt incandescent bulb yielding 12 lumens-per-watt.

On one boat I owned there were 11 8-watt fluorescent cabin fixtures, and if all were on at once the total draw was still less than a single 100-watt incandescent bulb. On a typical evening we would operate the equivalent of four cabin lights for about four hours, so our average cabin lighting load was 0.67 amps per light x four lights x four hours per night

or just over 10 amp-hours per night, about the same as using one 30- to 35-watt incandescent bulb.

Most anchor lights, including those incorporated into a sailboat's masthead tricolor light, have a large electrical load. They consume between 10 amp-hours (if a 12-watt bulb is used) and 20 amp-hours (with a 25-watt bulb) in one night. A good alternative is to get a low-drain anchor light. Battery-powered versions that hang in the rigging, some with photoelectric switches that shut the unit off at dawn, are readily available or can be easily made. I made one out of a fractured glass preserve jar, two 100-milliampere high-intensity DC lamps from Radio Shack, an automatic light-sensitive "eye," and some exterior-grade wire that doubled as the hanging lanyard. It produced as much or more light than a kerosene lantern, consumed only 2 amp-hours per night, and cost around $10.

Sailors can greatly reduce the total electrical draw of their boat's running lights

Energy-efficient transistorized lights with fluorescent bulbs (these are from Hella) consume only one-fifth of the power of incandescent bulbs.

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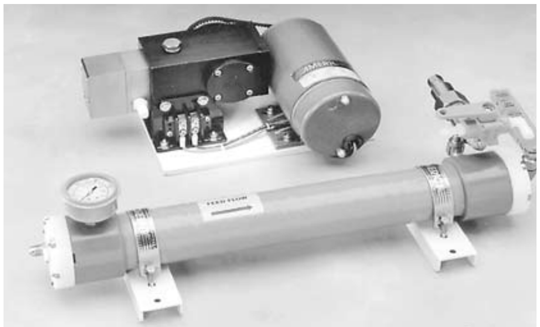

An efficient 12-volt watermaker such as the Village Marine Little Wonder (CDN$3,900/ US$2,899) produces 22.7L (6 gal) of water in an hour using only 15 amp-hours of electricity.

by switching to a masthead tricolor fixture. It uses only one 25-watt incandescent bulb instead of three separate deck-mounted lights for port, starboard and stern, which together can consume 60 amp-hours of electricity if on for 10 hours. Using a tricolor reduces the load to 20 amp-hours. (Keep your deck-mounted running lights for use when under power or in areas of heavy traffic.) Make sure that your energy system is sized so that you always have enough energy for running lights.

Refrigeration & Water Making

On-board refrigeration places you in a fairly high energy category, especially when cruising in warm climates. Powerboaters can reduce their electrical load by choosing modest-sized, efficient marine or RV refrigerators (check the energy-use rating on the label). Or they can cut their electrical load significantly by converting to a built-in system with a super-insulated, top-loading box with multiple lid seals (similar to those used on sailboats as described below), as opposed to an upright box with modest insulation where the cold is released every time you open the door.

Sailors have several types of refrigeration systems from which to choose. Engine-driven refrigeration using holding plates (plates that "store" cold and keep box temperatures low for 24 hours or more) is perhaps the most complete method to reducing electrical consumption, since it eliminates it altogether. In fact, the boat's main engine, or one of the many small diesel chargers on the market, can be powering a refrigeration compressor as well as a water-maker pump and a high-output alternator for charging batteries. The downside of this type of system is that you must run an engine every day and you'll get no contribution to your refrigeration or water-making loads from renewable energy sources, such as solar or wind power. An alternative is to have an efficient 12-volt holding plate refrigeration system, such as those offered by Glacier Bay, Grunert, Nova Kool, Sea Frost, Technautics and others. With a 12-volt holding plate system, if renewable charging sources can't keep up with the load, you simply run an engine-driven high-output alternator to supply electricity for refrigeration, water-making and storing surplus electricity.

Other Equipment

STOVES Eliminate appliances with heating elements where possible by cooking with propane. If you like to use a coffee-maker, despite its 100-amp draw when brewing, drip the coffee into a thermal carafe and turn off the machine. If your model has a built-in clock or timer, disconnect it when it's not being used to eliminate the "phantom" load (see below). Microwave ovens are fairly efficient, especially when used for warming food quickly, but they can drain batteries rapidly if used indiscriminately.

RECHARGEABLES Rechargeable communication devices and cordless appliances use an AC plug-in transformer or "power cube" — a small device that transforms standard AC power into low-voltage AC or DC power. These appliances draw modest amounts of power when charging or running, but they never completely shut off. If the power is supplied by a large inverter, this phantom load — drawing power even when appliances are turned off — means the inverter may never go into its standby mode, therefore wasting a lot of power. Since most gear can be recharged quickly, it's best to recharge the battery pack, then disconnect the power cube from the circuit. You can do this by placing all your rechargeable gear on one power strip that can be manually turned on for an hour or two when needed. (Caution: Never use an electric timer for the charging cycles — it also has a constant power draw.)

INVERTERS Today's inverters are very efficient at converting battery power to household AC power, but they still consume about 10% of the available electricity in the process. Use 12-volt appliances where possible and disconnect all rechargeable AC gear when not in use so that the inverter can revert to its standby mode (see above).

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FIGURE 1: Calculating Electrical Loads

To estimate your electrical load, set up an appliance load chart similar to the one to the right. List all electrical appliances you would like to have on board. If you plan to upgrade your boat soon, this is a good time to think about future electrical demand. List your DC loads first, followed by your AC loads as this allows you to assess your DC charging sources as well as various methods of providing AC power.

Next to each appliance, note the average current draw. Average current draw takes into account the fact that, for some appliances such as autopilots, the current draw varies with how hard the appliance is working when operating. Average draw also accounts for appliances with multiple speed or other operation settings.

In the next column, bring time into the equation by noting how many hours on average each appliance is used. Take into account that some appliances are used every day while others are used occasionally, and that some appliances are operated mostly in port and some are used exclusively at sea. To find the average daily hours of use for occasional loads, calculate average hours of use per week and divide by seven days.

Now multiply the average current draw in column two by the average daily hours of use in column three to get your average daily electrical energy consumption in amp-hours. You'll find that some appliances with high power draws consume a modest amount of energy if operated only for short periods of time, whereas a relatively low-draw appliance like an anchor light consumes a surprising amount of electricity when operated nightly for 10 or more hours. Add the values in column 4 to determine your total average daily load.

Sample Appliance Load Chart

APPLIANCE	AVERAGE CURRENT DRAW (amps)	AVERAGE USE (hours/ day)	AVERAGE CONSUMPTION (amp-hours /day)
DC LOADS			
Cabin lights	3	4	12
Running lights	2	2	4
Standard anchor light	1	10	10
VHF receive	0.5	4	2
transmit	5	0.4	2
GPS	0.5	3	1.5
Instruments	0.5	3	1.5
Stereo/tape deck	2	2	4.0
Bilge pump	4	0.1	0.4
Marine refrigeration	5	12	60
Autopilot	2	2	4
AC LOADS			
TV/VCR	6	0.5	3
Laptop computer	1	2	2
Microwave oven	80	0.17	13.6
Coffee mill	8	0.01	0.08
Coffee-maker (brewing)	100	0.13	13

Total Average Daily Load = 133 amp-hours per day

COMPUTERS Laptop computers use only a fraction of the power of desktop models, especially once the laptop's internal battery is charged. Use a direct DC charger if possible. If an AC power cube is used, disconnect it from the power source whenever you can.

ENTERTAINMENT TVs, VCRs, stereos and other entertainment appliances vary widely in the amount of power they draw. In general, DC equipment for the automotive and marine markets is much more energy-efficient. Electricity use is proportional to a stereo's upgrade your charging ability. Only you can decide when conservation measures become draconian and rob you of simple pleasures on board.

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EASY-TO-MAKE BATTERY CABLES

A custom installation of a battery charger usually requires that you make your own cables rather than purchasing pre-made cables in standard lengths. Installing lugs onto thick marine cable is not difficult if you have the proper tools.

By Kevin McGoldrick

You'll need the following tools and materials to make one cable. Prices are approximate and in U.S. dollars.

- Cable cutter, to produce a smooth straight cut — $36
- Lug crimping tool — $29
- Butane torch or heat gun to shrink tubing — $22 to $70
- Hammer
- Sharp utility knife
- Cable
- Lugs sized for the cable and connecting stud
- Adhesive-lined, heat-shrink tubing

Determine the length of the cable by actually routing it and supporting it every 18" (45.7cm). Allow extra length at each connection point to create a drip loop so that water cannot travel the cable to the connection point. Make sure the ends of the cable are cut cleanly and evenly with the cable cutter. Remove the cable and cut approximately 16cm (5/8") of the vinyl cover off each end. Be careful not to nick the wire strands with the knife when removing the cover. It's best to cut the cover around the circumference of the cable, then make one cut from there to the cable end. This will allow you to peel the cover off rather than attempting to slide it off as is done with smaller wire. The exposed wire should bottom out in the lug with little bare wire visible.

Using the crimping tool select the correct size slot for your wire and align the lug so that it crimps at its midpoint. Strike the crimping tool with a hammer, using multiple blows if necessary, until the tool is fully compressed. Be sure to hold the tool and lug in place so that subsequent blows strike the lug in the same spot each time.

Next, cut a length of shrink tubing long enough to extend from the barrel of the lug to about an inch over the vinyl cover. Be sure to purchase adhesive-lined shrink tubing. During shrinking the adhesive melts to form a strong and watertight seal. Shrink the tubing using a heat gun, butane torch or similar device until a bead of adhesive is formed around the ends of the tubing. Be careful not to burn the wire cover. Use caution when using an open flame on a boat especially in compartments that may contain explosive gases. Ventilate the work area well before starting the flame and always have a fire extinguisher at hand for instant use. Allow the lug to cool completely before disturbing the wire. This gives the adhesive time to set and produce a strong bond. Reinstall the cable and stand back and admire your work. A cable created in this manner will likely last the life of the boat.

Position the crimp tool in the middle of the lug barrel.

Little or no wire should be visible outside the lug.

A heat gun produces the best results when shrinking tubing. Note how the adhesive is squeezed out forming a watertight seal.

Example of what a good crimp looks like after the hammer blows. Note how the strands of the wire and the walls of the lug appear as solid copper.

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Marine Electrical Systems

Batteries and Charging FAQ

John Payne, DIY's electrical advisor provides solutions to questions submitted to DIY's Technical Helpline concerning batteries, battery switches and charging systems.

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Is 24/7 Charging Okay?

Q: Should I charge the batteries on my boat all the time with the onboard charger while the boat isn't in use?
Doug Alderman, "Southern Breeze," Paris Landing, Tennessee

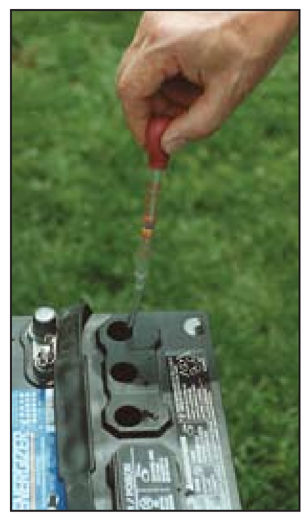
A: Most batteries can be directly connected to a charger all the time providing the charger is a smart unit with multi-stage charging that automatically shuts off when batteries are fully charged. It's important that the charge rate be a float charge level only, not a full charge rate, such as 14-volts, or your batteries will gas up and boil dry.
Three stages of smart battery charging.

Two Leads Versus Three

Q: I plan to replace the battery charger on my Catalina 36. The boat has one stand alone start battery and two deep-cycle batteries wired in parallel. Is there any advantage to a three-wire charger and connecting one charger wire to each battery? How will the charging be affected in the parallel bank?
Edward Nappi, "Polaris," Douglaston, New York

A: A two lead charger is essentially replacing what you have now. Using a dual output, three-lead charger allows each battery bank to charge simultaneously. This normally requires switching between batteries with a negative lead that is common to both batteries and two output charging leads. Each charging circuit operates independently, so you should have no problems but I suggest you read the charger specification sheet to confirm this. Fishermen with trailerable boats often have this type of battery charger, particularly if they have trolling motor batteries.

Fix for Drowned Batteries



Q: Recently my start and house batteries were completely submerged in freshwater for about two days. How might this submersion impact my batteries?
Jerry Perry, Ahousaht, British Columbia

A: Generally the first thing you should do is to check the battery electrolyte density with a hydrometer. This will determine whether water entered and diluted the acid to a degree where the battery cannot work. If it has and it's a top quality battery, take the battery to a service shop and have it refilled with acid. This option works as long as the actual battery plates are okay.

Redistributing Power

Q: I have recently purchased a 1989 3288 Bayliner. The factory wiring separates the single start and house battery banks. The port alternator charges the house batteries through a wire run to a four-pole solenoid mounted on the engine starter and the starboard alternator charges the start battery. This solenoid has cables running to both the start and house batteries. Both alternators are wired through an on-off battery switch but there's no switch to join the battery banks in case of a start battery failure. Batteries need replacing as they don't hold much charge and so does the charger, an old transformer type that makes a buzzing sound when on. In

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addition, the boat is very stern heavy due to optional equipment that has added weight to the boat, making it difficult to get on plane even with 100% trim tabs. I can't easily access the engine compartment because the house batteries fill up the access area under the hatches. To resolve all this, I'm considering buying 400 amp hours of AGM batteries and installing them in the bow along with a new charger. This will give me a 600lb (272kg) weight shift. I would prefer to utilize the power from both alternators more effectively to charge the house bank but I don't know the best way to do this.
George Cartwright, "Pacific," Vancouver, British Columbia

A: My recommendation is to have a set of jumper leads ready. It's normal to have all negative terminals between start and house batteries connected so you only need emergency jumper cables with clips. Maintenance free AGM batteries generally require a more precise output charger than the one you have and transformer-based chargers that buzz or hum isn't a reason to change as they run forever and a hum is quite common. Moving the batteries forward is an uncommon arrangement and does have drawbacks. Because of the distance back to the alternators, you'll need to use heavier gauge battery cables, which adds weight. Battery capacity seems excessive and I suggest you analyze exactly how much capacity is needed. The best solution is to find a midship location for the batteries. This, coupled with fewer batteries will assist with trim problems. Be sure to connect to the alternator with heavy capacity positive and negative cables to eliminate voltage drop. Why a battery switch is used is hard to determine without seeing a circuit diagram and it does not appear to be serving any purpose. I'm unsure why a solenoid unit is there if it doesn't distribute charge between both batteries. A single alternator with a suitable smart regulator will maximize charging and the AGM batteries have a much higher charge acceptance rate than ordinary lead-acid units. It's common to have two alternator arrangements with one feeding the start battery exclusive of the other. I suggest you leave the starboard alternator feeding the start battery as this gives you some charging redundancy. Install a suitable fast charge regulator on the port engine so the alternator can maximize charging of the house bank. [Ed: A boat that is not properly trimmed adversely affects the boat's safety, stability and performance. See "Is your Boat in Trim," on DIY's "Powerboat Rigging" MRT CD-ROM for more on this topic.]

AGM and Outboard Chargers

Q: I'm having a boat built and have ordered twin Yamaha F150 four-stroke outboards. I have been unable to determine whether the outboard alternators reduce their current output as the batteries charge. I'm considering going with AGM batteries for starting and house bank and understand that overcharging could kill them. I called Yamaha and they could not provide an answer. Sadly, they have a policy not to provide technical assistance like this to the consumer. Yamaha says to get answers from my local dealer, which has given me poor information several times in the past.
John Holcomb, "Tough Enough," Anchorage, Alaska

A: All modern outboards have fully regulated charging systems but are designed to charge one battery at a time. In order to protect AGM batteries from overcharging damage, I would advise you to install a battery isolator. This directs the current only to a battery that is discharged and will not overcharge any that are already fully charged. (Ed: For details on wiring a battery isolator refer to page 112.)

Wiring the Negatives

Q: I'm wiring a Xantrex 20-amp battery charger to my two battery banks; namely, one start battery and a house bank that consists of two Group 31 lead-acid batteries wired in parallel. All batteries connect with one ground (two positive leads, one to each bank) to the engine. The Xantrex unit has only one ground that the instructions specify wiring to the battery negative bus bar, which I do not have. Is it okay to wire the negative into one of the two battery banks?
Mark Hoesman, "Mystic Pleasure," Cheboygan, Michigan

A: You have the correct arrangement with negatives wired to each other and the Xantrex negative output can connect to either battery negative point. A negative bus is not that common and often a generic term to mean the negative polarity part of a circuit. In actuality, you usually have a

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negative bus at the main switch panel for house loads with a single cable going up from the house battery negative terminal. The negative to the engine point goes from the engine battery negative terminal, often called the ground, and this polarizes the power supply.

Blending Charging Voltages

Q: I have a two-bank battery system in my 36' (11m) S-2 sailboat. Bank one consists of two 6-volt batteries in series. Bank two is a single 12-volt battery. When charging these banks, should I set my battery charger to 6 volt or 12 volt for bank one? Where should I connect the battery charger connectors? I also have a "1-2-Both" battery switch. Does it matter what position the switch is set during charging and is there a way to charge all three batteries at once?
David Saunders, "Ursa Major," Cranston, Rhode Island

A: As the two 6-volt batteries are in series to make 12 volts, this should be seen as one 12-volt bank. Set the battery charger at 12 volts for bank one and connect the charger leads across the positive and negative of the combined 6-volt batteries. As the battery switch combines both battery banks, the best option and one I use is to connect the charger across any of the two battery banks and then set the switch to both. This then charges both banks simultaneously.

Voltage Swap

Q: I'm paranoid about discharging my start battery while at anchor. Currently, all loads come off the same feed via fuses and connect to a "1-2-Both" switch with the single start battery at "1" position and two 6-volt golf cart batteries as the house bank at "2." If I forget to switch to "2" position while at anchor, I stand a chance of draining my start battery. I'm inclined to rewire the boat so that the start battery only supplies the engine and the house bank supplies everything else and charge both batteries while running via a battery isolator. What are the current trends in how battery banks are connected? *Geoff Brown, "Nexus," Turkey Point, Ontario*

A: Remembering to switch from one battery bank to another is a common problem yet your configuration is the one that I personally prefer in a boat. Complete separation of house and start battery banks as you describe is best and a very reliable arrangement. The main trend changes have occurred with charging isolators that have gone more hi-tech with smart battery isolators. Otherwise separation via a "1-2-Both" switch remains the most popular.

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Generating Power with Fuel Cells

Imagine having a clean and quiet source of 12-volt power available 24/7 anywhere you choose to cruise. No noisy engine or gen-set, no relying on solar power, no whirling wind generator. Imagine no longer — fuel cell technology has arrived!

By John Payne

MaxPower MFC 100 AHD, one of the first fuel cells packaged for boats, produces electrical energy efficiently, quietly and without combustion.

Charging technology continues to evolve and the latest development for boats, in common with the powering of automobiles, is the fuel cell. Though NASA has been using fuel cells to power its space craft for more than 40 years, the biggest barrier to more readily available cells has been both the cost and the fuel type and storage. The new fuels cells are commonly called direct methanol fuel cells or DMFCs. The replacement of hydrogen with an alternative fuel such as methanol has allowed an economically viable fuel cell to be manufactured and one that can be used on boats. Such technology was originally invented at General Electric, who in the early 1960s developed a small fuel cell for a program of the U.S. Navy Bureau of Ships (electronics division). Later, fuel cells were developed for use by the British Royal Navy submarine fleet.

The basic fuel cell is an electrochemical energy conversion device also known as reverse electrolysis. The cell converts the chemical energy of a fuel, such as hydrogen, natural gas or hydrogen rich fuel such as methanol, and an oxidant such as air or oxygen into water to produce electricity as a direct electrical output similar to a battery. In principle, a fuel cell operates somewhat like the lead-acid battery, another electrochemical device.

The fundamental difference between them is that where a battery needs recharging, the fuel cell does not discharge or have to be recharged from a charging source. Electrical and heat output, similar to having fuel in the diesel- powered generator or wind for the wind generator or sun for solar panels, will always continue as long as the fuel and an oxidizer are available in adequate quantities. One similarity between batteries and fuel cells is that they both have a positively charged anode and a negatively charged cathode. They also both have an ion-conducting material that is also called an electrolyte. There are a variety of fuel cells and each type utilizes different chemistry. The classification of fuel cells is generally based on the electrolyte material that the fuel cells use. The proton exchange membrane (PEM) fuel cell device has the most common application in powering automobile and boat charging systems.

How's it Work?

Basic construction of a fuel cell comprises a fuel electrode (the anode) and an oxidant electrode (the cathode). The anode and cathode are separated by an ion-conducting membrane. Oxygen continuously passes over one electrode and hydrogen continuously passes over the other electrode. This generates electricity, water and heat. What occurs in fuel cells is that they chemically combine the molecules of the fuel, such as methanol, and the oxidizer without any combustion or burning. As such, they are pollution-free — no toxic or high temperature exhaust emission. The byproduct of a fuel cell is a very small quantity of carbon dioxide, some pure water and a little heat. The carbon dioxide is around the same as a person's breath, so some basic ventilation is required.

The anode is the negative part of the fuel cell. The function of the anode is to conduct electrons that are released from the hydrogen molecules and these electrons can then be

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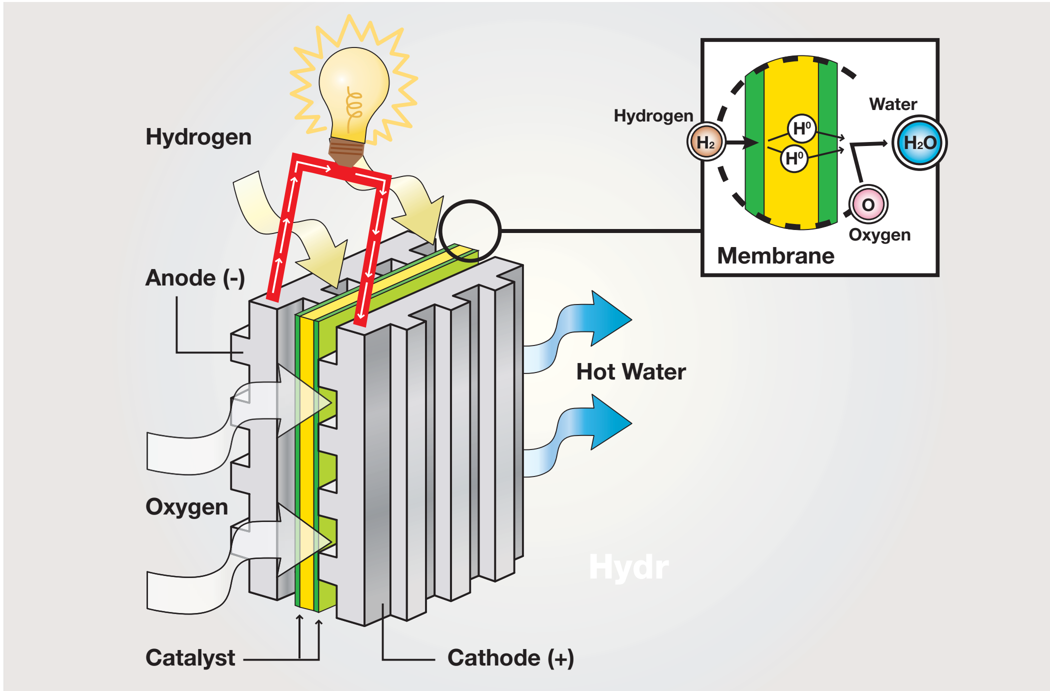

Fuel cells are a power "generating" device as they draw fuel from an external source, such as a hydrogen cylinder, and mixes with oxygen to produce water and generate electricity for as long as the fuel is supplied.

used in an external electrical circuit. That is the battery part or motor or other electrical equipment. The anode is constructed with a series of channels that is used to aid in the even dispersal of the hydrogen gas across the catalyst surface so maximizing efficient reactions.

The cathode is the positive part of the fuel cell. It also has a series of channels etched into it to ensure reaction efficiency and to aid in the even distribution of oxygen across the surface of the catalyst. The cathode also conducts the electrons in the external circuit from the catalyst, which then recombine with the hydrogen ions and oxygen to release water.

The electrolyte is the PEM. It consists of a specially treated solid polymer electrolyte material that resembles kitchen plastic wrap. This membrane conducts the positively charged ions through it and blocks the passage of electrons. It works at very low temperatures, about 175F (79.4C).

The catalyst is manufactured from a special material that triggers and speeds up the reaction of the oxygen and hydrogen. Typically, it comprises a thin coating of platinum powder that is layered onto a substrate of carbon paper or cloth. The catalyst is also rough and very porous. This ensures that a maximum surface area of the platinum material is exposed to the hydrogen or oxygen to ensure maximum reaction takes place. The catalyst is always orientated towards the PEM. For this type of fuel cell to work, the PEM electrolyte must allow passage of the hydrogen protons but prevent the passage of electrons and other heavier gases.

Fuel Conversion

While hydrogen was a major component of earlier basic fuel cells, it's not readily available to buy and is inherently dangerous. To overcome this, a device called a reformer is used. This converts hydrocarbon or alcohol fuels (i.e., methanol) into hydrogen and then supplies it to the fuel cell. Reformers also generate some heat and produce other gases in addition to hydrogen and this tends to lower the overall efficiency of the fuel cell. Methanol is a liquid fuel that has many similar properties to gasoline. Better yet, it's a farmed fuel, a renewable source, processed from sugar cane. It also is less flammable than hydrogen so is ideal for carrying safely on a boat.

Efficiency

If the ideal fuel cell is powered using pure hydrogen, it can be up to 80% efficient, a very high number. Using a reformer to convert methanol to hydrogen drops this efficiency to around 30% to 40%. Converting electrical energy into mechanical work using an electric motor or an inverter, this number falls to around 24% to 32%, still a lot more efficient than solar, wind or generators. The reaction in a single fuel cell produces a fairly low

0.7 volts. However, like a 12-volt battery that consists of six cells, basic fuel cells are built to form a fuel cell stack. To increase power source availability, fuel cells can be connected in parallel, the same as getting more amp-hour (Ah) capacity with a battery. For example, two 100 Ah fuel cells wired in parallel equals 200 Ah.

Here and Now

MaxPower (www.max-power.com) MFC 100 AHD fuel cell units now available require a 10 lb (4.4 kg) fuel cartridge that lasts three days or 72 hours on full power. It produces 340 Ah of 12-volt DC power over a longer period if charging intermittently. The MaxPower unit is made by the Navimo group and utilizes the Navimo distribution network (Scandvik in the U.S.) to distribute fuel cartridges. Fuel cells are not service or maintenance free; however, given there are no moving parts, this is significantly reduced. A fuel cell stack gradually degrades with a slow decrease in performance during its operational life. Stack life typically is a minimum of 1,500 hours up to or exceeding 5,000 hours. Stack replacement is relatively simple and fast. Given that a basic fuel cell unit weighs in at just 16 lbs (7 kg), it's easy to ship replacements to the nearest service center.

MaxPower units are distributed in the U.S. by Scandvik (800/535-6009; www.scandvik.com), which is also handling fuel cartridge recharging and fuel cell replacement. Current retail price for the MFC 100 AHD is US$5,999. Laboratory grade methanol to refill one fuel cartridge is expensive, $40 for 1.3gal (5L), though sales manager Sabastian Blackman expects prices to drop substantially. Replacement fuel cells are available to purchase from Scandvik for US$700.

Selection Criteria

A fuel cell is designed to run constantly over a 24 hour period. It can be operated in either a standby or in float charge mode for charging batteries; whereas, solar and wind charging systems depend on the elements being available for limited periods. Fuel cell costs equate to a very small 2kW diesel gen-set but without any of the installation and engineering costs or issues, such as seawater plumbing and exhaust systems.

The big savings are realized because, when a fuel cell operates in continuous float mode, the batteries are always topped up, constantly held at between 70% to 85% of their full charge. Battery life is greatly increased when the batteries do not have to go through the discharging and repeated deep cycling that taxes their performance. This also allows you to install a much reduced battery bank size. The battery bank ultimately ends up doing float service and supplying system power surges or higher demands, while the fuel cell supplies the main power. Power transfer is completely automatic. The MFC 100 AHD, for example, automatically monitors the battery voltage, switching on and off as needed. When the engine alternator kicks in, this device switches off.

As technology continues to improve, the fuel cell will become an integral part of an onboard renewable power source to charge batteries.

REAL-TIME USAGE

DIY asked bluewater cruisers and professional videographers Paul and Sheryl Shard for their opinion on the use of fuel cells. Here's what they had to say.

On our 37' (11.2m) we use 60 to 80 amp-hours (Ah) of electricity per day at anchor (fridge, computer, lights, etc). This is replaced into the battery by our solar panels which generate roughly 30 Ah per day in the Mediteranean. So we have a shortfall of 30 Ah to 50 Ah per day.

The MaxPower unit produces 340 Ah of power on one fuel cell. Therefore, I can get from seven to 11 days of use from one cell before changing it, assuming the solar supplies the rest. So before leaving for a three-week cruise we might need to purchase two to three extra cells from a local fuel cell supplier. As these cells weigh 10lb (4.5kg), that's an extra 30lb (13.6kg) onboard. Finally, after between 1,500 and 5,000 hours of operation we would need to replace the stack. We would need to return the unit to have this replaced.

— Paul and Sheryl Shard have logged more than 40,000 nautical miles aboard "Two-Step" a Classic 37. They have crossed the Atlantic Ocean three times and have sailed to more than 35 countries including the Caribbean, South America, Europe and the Middle East. They are currently in the Mediterranean filming a new season of their sailing adventure TV series, "Distant Shores" (www.distantshores.ca).

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USING BATTERIES TO PRODUCE AC POWER

If your total AC load is moderate and your battery capacity and charging system sufficient, an inverter can eliminate the need for any other AC power source.

By Kevin Jeffrey

Today's boaters want the comfort and convenience of using standard household appliances on board, such as coffee makers, microwave, toasters, TV, VCR, stereo, drills, sanders and other power tools. Away from the dock an alternative source of AC power must be provided. Boaters with larger AC appliance loads have traditionally chosen an engine-driven power source such as a gen-set (Ed: Refer to page 108 for gen-set selection, installation and options) or a modified AC alternator running off the main engine (for information on high-output alternators see page 118), yet these devices don't match the freedom, convenience and quiet operation offered by DC-to-AC inverters. Inverters are relatively small and lightweight, low cost and reliable. Installation is uncomplicated, and there is no additional engine to maintain as with engine-driven AC power sources.

How They Work

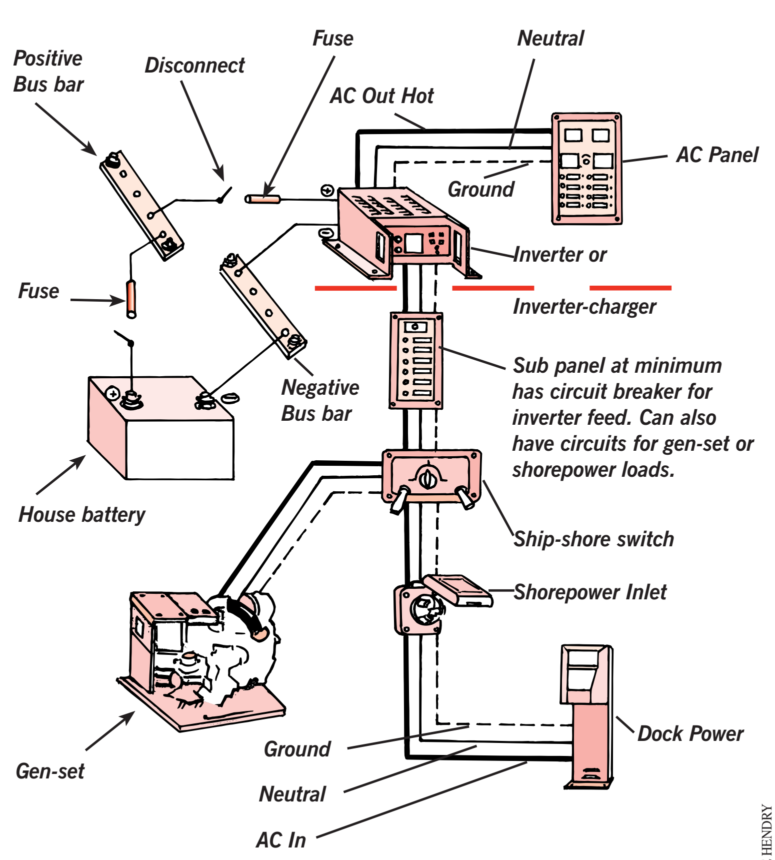
Inverters don't actually create electricity; they only change it from one type to another. Inverters take DC power stored in a battery bank and convert it to household AC power. They simultaneously raise the voltage and invert DC to AC power and supply this electricity either directly to a built-in AC outlet on small inverters or to the AC circuits installed on the boat **(Figure 1)**. Inverters need to draw power from a battery bank, although if charging sources are operating and the current produced is adequate, the inverter won't deplete your batteries.

Power Options

The big difference when using an inverter for AC power is that engine(s) do not need to be running when you are using AC appliances. Of course, the batteries must eventually be recharged with an engine-driven power source, but it's usually possible to schedule engine-driven charging for more convenient times.

Inverters are most practical for combined AC loads up to 2,500 watts, particularly where the larger loads are intermittent, or only on for short periods of time. Even though the current draw of large intermittent

Figure 1



Typical inverter powerboat or sailboat hookup to AC outlet on inverter; inverter-charger installation connects to onboard AC circuits, gen-set and shorepower as shown below dotted red line.

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loads may be high, the total energy consumed is usually moderate **(Figure 2)**.

Loads that are usually not supplied by inverters include: AC-to-DC battery chargers — you would be using battery power to charge your batteries; air conditioning, unless supplemented by an engine-driven, high-output charging source; and appliances with large heating elements such as water heaters, space heaters and electric ranges. If the size of your total AC load places you on the borderline between an inverter and an engine — driven AC power source, try staggering the use of AC loads to make it work — don't run the power tools at the same time dinner is cooking in the microwave.

Inverter-chargers: (top left, clockwise) Heart Freedom Marine Series, 1,000 to 3,000 watts; Xantrex Prosine 2,500 and 3,000 watts; Trace Mariner Series, 2,000, 2,500 and 3,000 watts.

If your total AC requirements exceed the practical limits of an inverter and you need to invest in an engine-driven AC power source, an inverter is still useful for quiet-time loads and for some smaller continuous loads. Under these circumstances, you might be able to get away with a relatively inexpensive inverter.

Many inverters also double as smart-charging, high-output AC-to-DC battery chargers (known as inverter-chargers), eliminating the purchase of an additional piece of equipment. Use the inverter in the battery charger mode when the engine-driven unit is running, then with the engine shut off, use it in the AC supply mode as needed. The same applies for AC power connections while at a dock. Use the utility-supplied AC power with the inverter in the DC battery-charging mode; use the inverter in the AC supply mode when utility power is not available.

Understanding Ratings

As you might suspect, an inverter's size and weight is proportional to its rated output, and also whether or not it's designed to operate as a battery charger. Inverters are rated for both continuous operation and for the ability to surge initially for starting motors. High quality models have surge ratings up to three times their continuous output rating. Inverters come in a wide variety of continuous rated outputs, from small 50- to 250-watt pocket inverters — ideal for powering computers, radios, tape decks, TVs and VCRs — to large units of 3,000 watts or more. Input voltage lets the buyer know the range of battery supply voltages over which other specifications will be valid. Typical inverters operate on either 12- or 24-volt DC input voltage ranges. Most of the better sine wave inverters allow battery input voltages to vary over the battery bank's entire normal operating range (around 10 to 15 volts DC) without disrupting output voltage. Some inverters are equipped with low battery cut-out protection that prevents the inverter from working if the battery voltage drops below a preset or adjustable voltage setpoint.

An inverter is also rated according to the AC power output voltage. Current models are available with roughly 110-volt/60-Hz output (North American models) or 220-volt/50-Hz output (European models). Actual ratings list the exact output voltage and the allowable variation (± 2% is good, 4% to 5% is common).

Fine Tuning

Main buying features on inverters are waveform, idle current, efficiency and charging mode. As inverters attempt to duplicate AC electricity from utility companies, which is in the form of a pure sine wave, they are classified by their waveform. Modern solid-state inverters produce either square-wave, modified sine wave, or pure sine wave output. While the new pure sine wave inverters can run any AC appliance without harm or annoying "buzz," at this time they are more expensive and often less efficient than modified sine wave versions. Most boaters choose modified sine wave inverters, but there are many good pure sine wave models available for those

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Figure 2

Calculation of Electrical Energy Consumed for 12-Volt System

Amp draw of loads x time they operate = Energy out of batteries

Example: Anchor light 1 amp x 10 hours =
10 amp-hrs removed from the batteries

Example: Toaster 80 amps x .03 hours (2 minutes) =
3-4 amp-hrs removed from batteries

that need them.

A modern inverter uses very little idle current — standby power when the unit is on but no load is being drawn — compared to engine-driven AC power sources. An efficient inverter may only consume half a watt on standby, whereas an engine-driven AC power source will be cranking away, consuming fuel whether you're using the AC power or not.

Inverter efficiency varies with output power. Most modern sine wave inverters operate above 90% efficiency under moderate appliance loads, usually somewhat less for smaller loads. This means that the inverter consumes less than 10% of its output power whenever a moderate load is drawn. A graph depicting power versus efficiency for a typical inverter is given in (Figure 4). A unit's rated efficiency is usually listed as its average efficiency over a given range of output power. For example, one inverter is rated at 90% efficiency at half-rated power, while another is rated at 85% to 96% efficiency from 50 watts to rated power.

Some inverters have a high-performance, three-step battery-charging mode as a standard feature. These units are labeled inverter-chargers. A 1,500-watt inverter-charger operating at 12 volts can charge up to 70 amps when AC power is available; 2,500-watt inverter-chargers can produce approximately 120 amps at 12 volts.

Many inverters come with voltage and current meters and basic controls, either integral to the unit or offered in a remote panel.

Cost and Selection

First decide how much continuous power you need. Small 50-watt pocket units (US$75) can handle a laptop computer, while a 150- to 250-watt unit (US$150) can also handle a computer, TV-VCR combination, blender and small power tools operating one at a time. If you feel you need a 1,000 to 2,000-watt inverter, see if a 1,500-watt unit (US$900 with charger, US$600 without) will meet your needs, even if you have to stagger appliance use. This size is particularly practical, since the cost is reasonable and it can run almost anything that operates on standard household outlets, which are typically on circuits rated at 15 amps at 110 volts. For larger applications, 2,000- to 4,000-watt units (US$1,200 to US$3,000) are available.

Now decide if you want a unit with battery-charging mode. Even if you presently have a battery charger, chances are you'll improve performance dramatically by using an inverter-charger.

Select the input and output voltage you need. Most marine applications require 12-volt input; output depends on where you expect to use the inverter. Boaters who mainly use their boats in North America should purchase a unit with 110-volt AC output. For occasional travels to Europe and other locations with 220 volt/50 Hz power, simply carry a 220 volt/50 Hz battery charger.

Finally, choose the waveform best suited to your needs. Laser printers and some other electronic devices need pure sine wave output, but almost all other appliances will work well on modified sine wave output. If necessary, you can always get a modified sine wave unit (up to US$3,500 for a 4,000 watt inverter-charger) to handle most of your needs, and a small pure sine wave unit (US$400 for a 400 watt) for a particular appliance.

Battery Capacity

Imprudent use of even a small inverter can drain a typical battery bank. The battery bank the inverter is connected to must be capable of supplying full instantaneous current to the inverter. For example, an AC power draw of 1,500 watts results in a DC current from the batteries of almost 140 amps at a 90% inverter efficiency. Since I recommend that a battery bank's capacity be four times the maximum current draw, a bank of approximately 560 amp-hours would be

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advisable. The battery bank must also have enough reserve capacity to supply all AC and DC loads drawn from that bank between normal charging cycles.

Figure 3

Appliance	Typical Wattage	Appliance Run Times / Amp Hours *							
		5 Min.	15 Min.	30 Min.	1 Hr.	2 Hr.	3 Hr.	8 Hr.	24 Hr.
13" Color TV	50	.33	1	2	4	8	12	32	96
19" Color TV	100	.66	2	4	8	16	24	64	192
VCR	50	.33	1	2	4	8	12	32	96
Lamp	100	.66	2	4	8	16	24	64	192
Blender	300	2	6	12					
Curling Iron	50	.33	1	2					
3/8 Power Drill	500	3.3	10	20					
Icemaker*	200			2.6	5.2	10.4	15.6	41.6	83.2
Coffee Maker	1000	6.6	20	40	80	160			
3 cu' Refrigerator*	150			2	4	8	12	32	96
20 cu' Refrigerator*	750			21	42	84	126	336	672
Compact Microwave	750	5	15	30	60	120	180		
Full Size Microwave	1500	10	30	60	120	240	360		
Vacuum	1100	7.3	22	44	88	176	264		

HEART INTERFACE

The number in each box represents the total amp hours used in a 12-volt DC system. Divide amp hours by two for 24-volt systems.
****Refrigeration is typically calculated using a 1/3-duty cycle.***

Installation Tips

Wiring between the inverter and the batteries must be properly sized. Cable size depends on inverter output and length of run between inverter and batteries. Cable sets with varying gauges of wire and wire lengths are available from any independent power system supplier. For larger inverters, 2/0 or 4/0 welding cable in 5' or 10' (1.5m to 3m) lengths with cable lugs are available.

Most inverters on the market have an internal fuse or circuit breaker and an on-off switch that serves as a safety disconnect for the unit, but there is still a need for a main fuse and safety disconnect between the batteries and the inverter.

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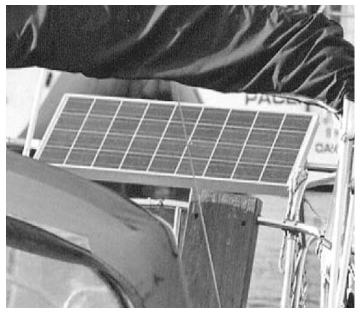
Solar, Wind & Water Power

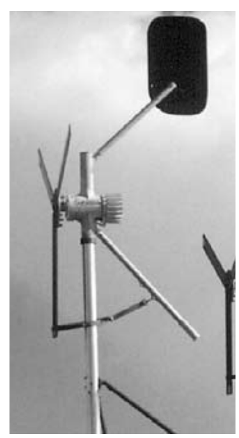
Charging sources that rely on solar, wind and water power to generate electricity are surprisingly efficient and effective at keeping your batteries full.

By Kevin Jeffrey

Imagine being out on the water, enjoying the sunshine, the wind on your face, and the steady movement of your boat through the water. To me these sensations represent the essence of boating, but they also represent the three main methods of charging batteries using renewable sources of power. In this column we'll review what gear is currently on the market, and why renewables are a good choice for today's boater.



Renewable chargers are clean, reliable and, unlike most marine gear, will eventually pay for themselves in fuel savings. Renewable sources of power are also free for the taking anywhere in the world, although the amounts available vary considerably from region to region. Some boaters use renewable chargers as their main or even sole source of electricity while away from the dock, while others use them as a convenient backup to engine-driven power sources. Either way, they should be given serious consideration when upgrading an existing electrical power system or installing a new one.



(Clockwise, top) Siemens rigid PV panel; Ferris Waterpower 200; Unisolar flexible PV panels; Kiss; Windbugger; Ampair 100; Southwest Air Marine.

Basking in the Sun

Photovoltaic (PV) solar panels are now an accepted part of a cruising boat's electrical power inventory, and rightly so — they produce consistent power year after year with no noise, smell or moving parts. Unlike solar panels used for heating, PV panels convert light energy directly into electricity through the use of thin, specially treated silicon cells.

When exposed to sunlight, each cell in a panel produces about 0.5 volts, regardless of cell size. Roughly 36 cells are connected in series to create sufficient voltage (17 to 20 volts) to charge a 12-volt battery even when light levels are low. When a sun-drenched PV panel is connected to a battery, current flows. How much current relates to cell size as well as how much light is reaching the cells.

PV panels are rated according to their "peak" output in watts (ie. their best performance in favorable conditions). Shade, clouds and facing away from the sun all contribute to power loss. Multiple PV panels can be wired in parallel according to desired current output, available mounting space and budget.

"Standard" PV panels, such as those from Siemens, Kyocera, and Astro Power, have sturdy tempered glass covers, aluminum perimeter frames for rigidity, and long warranties against power loss (up to 20 years). "Marine" PV panels, such as those from Solarex and Unisolar, have polymer covers and no perimeter frames. Both are completely weatherproof and able to withstand tough conditions at sea. Marine panels are lightweight, can be walked on, and can be mounted in a variety of ways. Some Unisolar models are even fully flexible for convenient mounting to biminis and dodgers. The use of blocking diodes between cells (on all Unisolar models) prevent total power loss when part of the panel is shaded, a great asset on a boat. Standard panels are the most cost-efficient in terms of dollars per watt, but they cannot be walked on, are quite a bit heavier, and don't have as many mounting options.

Panels average US$6.50 per watt for the standard ones up to US$12 per watt for the fully flexible models. They are expensive in terms of dollars per watt produced, but their advantages are too numerous to list. If you have the space, solar panels can be your sole source of electricity. For example, four large 80-watt panels produce around 100 amp-hrs per day in average conditions. My family lived on two different catamarans and all our power was produced by a single 40-watt solar panel. Although we had no refrigeration or other heavy loads, we did have lights, music and communications, and I wrote two books on board with a laptop.

The best way to mount solar panels on a boat is horizontally. This gives the best average solar coverage during the day. If you want to tweak the output, you can reposition them several times a day into the sun.

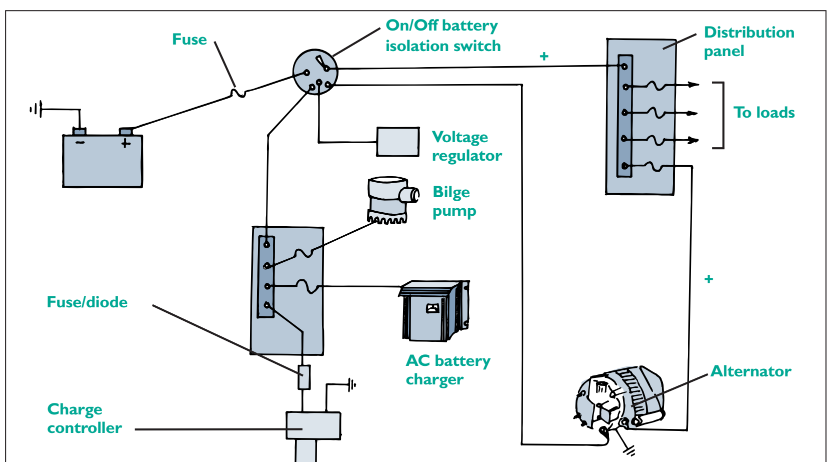
PV solar panels work well on their own, or in combination with wind and water generators or engine-driven power sources.

Harnessing the Wind

Wind-powered generators for marine use were introduced in the mid-70s, and they have been constantly improving since then. Wind units currently on the market can produce a formidable amount of electrical power for both sail and powerboats, but only you can decide if wind power is right for your needs and, if so, which particular model is best.

All wind generators consist of a rotor with aerodynamic blades, an electrical generator, a tail vane to keep the unit facing into the wind, and some type of protection against overspeeding in high winds. A few wind units can also be converted to a trailing-log water generator for downwind passages, when the apparent windspeed is low.

There are two basic wind unit types, small-rotor and large-rotor. In general, small-rotor units, such as the Ampair and Rutland models from the UK, have multiple blades, a rotor diameter of around 91cm (36") and modest average output. The advantages of this type of unit are reduced size and weight and



The important components when wiring a solar panel, wind or water generator are a charge controller, diode and fuse. Wiring then leads directly to a large single house bank or to a common terminal on a master battery switch. Never connect to an alternator isolator as it's an unnecessary voltage drop.

inherent overspeed protection in high winds. Small-rotor units are good for light electrical loads or as a complement to other charging sources.

Large-rotor units produced in the U.S., such as the Ferris Windpower 200 and Fourwinds, have two blades, a rotor diameter of around 1.5m (60") and high potential output. The main advantage of this type of unit is the high output, although you still need reliable winds for good average performance (you may be cruising in the trades, but if you like to anchor in the coziest part of the harbor you probably won't have exposure to reliable wind). Most large-rotor models are also relatively quiet and have either standard or optional overspeed protection. Large-rotor units are most popular with cruising sailors who have refrigeration and other large electrical loads.

I view Southwest Windpower’s Air Marine 303 and new 403 models as something of a cross between a small- and large-rotor type. Its sleek, three-blade design, small size, high rated output and unique feathering plastic blades have created a great deal of excitement in the industry. This design is good but not perfect — when the blades distort in high winds to provide overspeed protection, noise levels can be unacceptable to some boaters.

Wind units can be mounted temporarily in the fore or main triangle of a sailboat (used mostly for combination wind-water units), or permanently on a pole or radar arch at the stern or on a sailboat's mizzenmast. They should always be mounted solidly to avoid vibration and well above head and hand height. Vibration is accounted for with rubber isolation pads, but the installer must also make certain the mounting pole and struts are well-secured and stiff.

Wind units work well for powerboats that spend long periods of time away from a dock. Integrating a wind unit into your independent power system is easy, since the output is compatible with other renewable and engine-driven charging sources and all monitoring systems. Battery protection is important and demands a shunt regulator or charge controller, an all-in-one unit that regulates battery voltage, monitors current and indicates battery states. Wind generators cost between US$550 to US$1,500.

Water Power

Of the three renewable charging sources for marine use, water-powered generators are the most overlooked and least understood. The fact is that they can be an important part of a sailboat's independent power system, quietly and reliably producing large amounts of electrical power whenever a boat is under sail. Prices for water generators range from US$725 to US$1,100. These units are not recommended for powerboat applications.

Water-powered generators take advantage of the relative motion between a sailboat and the surrounding water, and so actually use the wind for mechanical power, unlike land-based water-powered generators that rely on falling water under the influence of gravity. With a charging rate of 8 to 10 amperes in cruising speeds of 5 to 6 knots, water generators can produce over 200 ampere-hours of electrical power per day. There are several types of water-powered generators available. On Trailing-Log units, such as the Ferris Waterpower 200 and Fourwinds, the electrical generator is typically suspended on a gimbal mount at the stern, while an 8" to 10" (20cm to 25cm) diameter rotor mounted on a short stainless-steel shaft trails behind the boat at the end of a 60' to 75' (18m to 22.5m) tightly wound braided line. The line spins rapidly, turning the shaft of the generator directly to create electricity for charging batteries. In use for many years, this type of unit is simple, moderately priced, and often converts to a wind-powered generator for use in port. These water units, however, are only intended for blue-water passage-making, and sailors must ensure that the trailing rotor remains submerged or is physically removed from the water at higher boat speeds or in certain sea conditions. Otherwise the rotor may skip clear of the water and cause the rotor line to kink and knot up unmercifully.

Outboard leg water generators, such as the Aquair UW, have the electrical generator submersed on a pivoting bracket at the stern, similar to an outboard motor. These units are heavier, more expensive, and require more mounting space, but they remain operational at any boat speed or in any sea condition or cruising area. Electrical generators can be coupled to a free-wheeling inboard engine prop shaft with good results — high water-driven power output with no additional gear mounted on the stern. They can also be coupled to a small auxiliary rotor shaft placed through the hull for the sole purpose of battery charging — probably the cleanest, most efficient installation for those undaunted by yet another hole below waterline. Parts for these types of systems can be purchased from several marine power gear suppliers.

Solar Solutions

Once you establish how much solar power is right for your onboard power needs, a little creativity can help you find practical mounting solutions for a functional yet visually pleasing installation.

By Kevin Jeffrey

Photovoltaic (PV) solar panels are a great way to charge batteries on any power or sailboat. These technological marvels are able to convert light into electricity with no noise or moving parts, and they do it with greater efficiency (over 16%) than standard incandescent light bulbs can change electricity into light (10% efficient). Their advantages are becoming well known, but boat owners still face the sometimes-daunting task of finding suitable places to mount solar modules.

Boat types and the owner's preferences impose limits to how much solar power to include onboard. There are several ways to determine the right number of solar panels for your situation. One approach is to simply include one or two medium size solar panels (50 to 100 watts of total power) in your battery charging mix. This gives you a good introduction to solar panel operation, as well as an opportunity to see how solar panels affect your battery charging needs and the appearance of your boat. You can always add more panels later. This is particularly easy if your charge control is sized to handle additional current (see "Key Components" on page 83). Another approach to determining how much solar power to have onboard is to put as many solar panels on your boat as you have space and money for. You could also estimate your total electrical load, and select a panel to match your consumption **(Figure 1**). Though more scientific, this method doesn't guarantee a perfect match as there are so many variables, such as mounting location, geographic area, time of year. Whichever approach you take, the first step is to review the various types of solar panels on the market and their mounting options.

Selective Options

There are three basic types of panels: standard models with glass cover and aluminum perimeter frame (Kyocera, Siemens, BP Solar, Solarex); semi-flexible marine panels with a polymer cover and rigid backing plate (Solarex MSX-L panels); and fully flexible models (Unisolar). When planning for solar panels, keep in mind that, for best performance, the panels should have good average exposure to direct sunlight throughout the day. Unlike home solar installations, there is usually no "south" side to a boat, so your best option for permanent mounting is to install the panels horizontally, facing up. You can increase performance substantially if your panel mounting allows you to pivot the panels into the sun, but be aware that getting those extra amps can become tedious, and you can actually decrease solar performance if you forget and leave the panels pivoted in one direction. Another consideration when mounting panels is that thick, dark shadows can diminish solar output dramatically, although fully flexible panels have blocking diodes between strings of cells that minimize this effect.

With this in mind, let's look at the various mounting options.

Deck Mount

The classic solar panel mounting location is on an unobstructed area of the boat's cabintop or deck. Semi-flexible marine panels, such as the Solarex MSX L-series, are best for deck mounting in areas where the crew may walk. These panels can be stepped on without harm, although I recommend you avoid mounting them in areas of high foot traffic. Since these panels are thin and can assume a slight curve, they are fastened directly to the deck, passing the fasteners through rubber grommets in the corners of the panels (**Figure 2**). The grommets protect the deck and keep the panels just above the deck surface, allowing for some necessary airflow. Fully flexible panels are also mounted on the deck, although they are put to better use on soft surfaces such as biminis and dodgers. You cannot step on rigid solar panels. If you do deck mount them, it's best to do so on hardtops or other places well away from normal foot traffic. When mounted on sailboat hardtops, leave ample space on mainsail and to prevent the panels being shaded by the boom and sail cover.

The best way to deck mount a rigid solar panel is to provide two parallel rails (**Figure 3**). Fashion the rails from teak and secure

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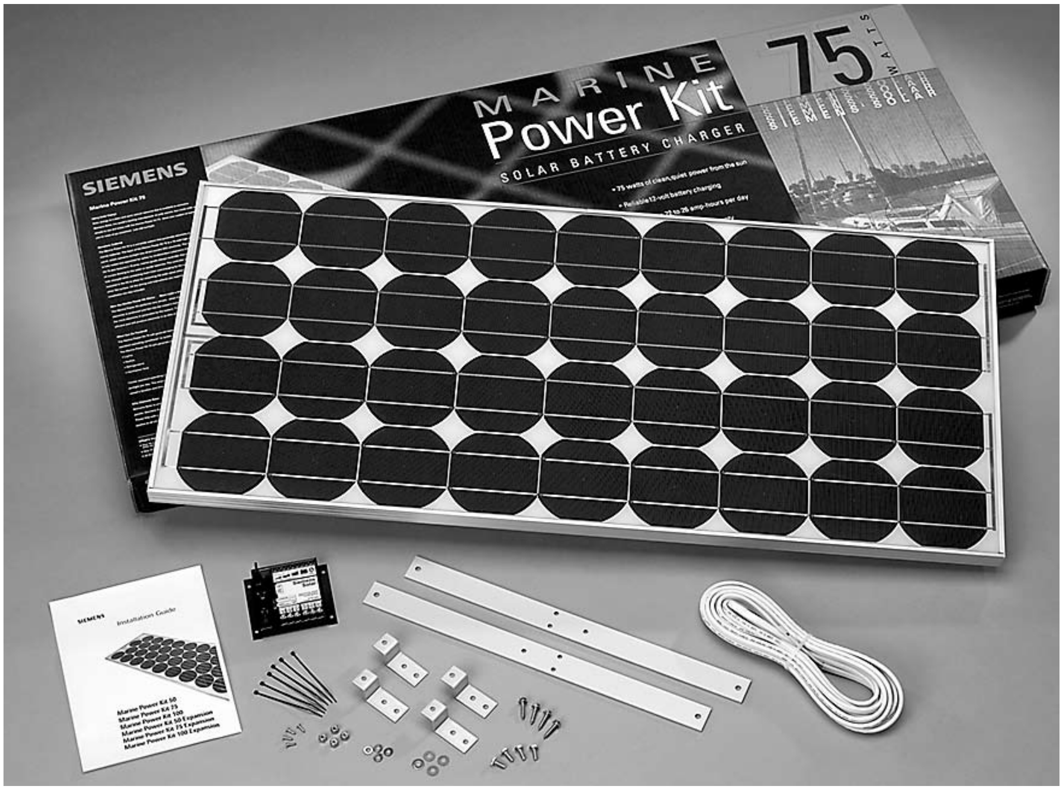

Siemens rigid solar panel kits available in 10, 50, 75 and 100 watts, include charge controller, mounting hardware and 25' (7.6m) of wiring.

to the deck with screws. You can build up fiberglass rails, and fair them into the glass deck surface. Either way, construct the rails so the panel is recessed yet still has airflow underneath. Fasten the panel to the rails with screws or pivoting clips that allows easy removal of the panel when in port so you can keep it faced into the sun. [Ed: DIY's "Better Boats" MRT CD-Rom includes a project on how to make a combination teak handrail and support rail for solar panels.]

Hatch covers seem like a conveeither side of the boom for access to the nient place to mount solar panels, but there are several drawbacks. Hatches are usually located along the centerline and any above-deck obstructions (i.e. a sailboat boom) shade the panel. It's often difficult to find panels of exactly the right shape, and if the hatch is transparent or translucent, the panel tends to block the light and view, and may restrict hatch operation.

Rail Mount

Stern rails provide a convenient mounting location for standard or semi-flexible marine solar panels. Solar panel manufacturers supply rail mount kits that consist of plastic rail clamps, either 7/8" or 1" (19mm or 25mm) in diameter, attached to aluminum mounting struts sized for the width of the solar panel. The panel attaches to the struts (Figure 4). Panels mounted in this manner can be rotated about the rail to increase performance or tilted out of a passageway. Rail mounts also allow solar panels to be easily removed. There are four variations on the rail mount theme.

To mount to a stanchion, some solar suppliers offer an angled piece of stainless-steel tubing that attaches to a stanchion with a double set of rail clamps **(Figure 5)**. Solar panels are mounted to the outer part of the tubing using a regular rail mount clamp set. In this arrangement, the panel can be rotated about the tubing, and the tubing can be rotated about the stanchion, allowing the panel to face directly into the sun regardless of boat position or time of day. This rig is especially useful when in port.

Another clever rail solar panel mounting system is stanchion-to-stanchion mount. Sold as a kit, it creates a rigid section of rail tubing at the top lifeline between two stanchions **(Figure 6)**. The lifeline passes through the tubing that attaches to each stanchion with special adapters. This arrangement allows you to mount even large solar panels where they can be rotated to seek the sun or tilted outboard in a passageway.Davits are a convenient place to mount standard solar panels. A davit mount kit features a piece of stainless-steel tubing installed between the davits (**Figure 7**). This tubing not only allows a solar panel to be mounted with a standard solar rail mount kit, but also gives the davits better resistance to lateral movement.

Mounting solar panels on a stern arch can be a variation of a deck mount or a rail mount, depending on your method of attachment. The simplest approach is to weld or bolt horizontal struts, the width of a solar panel, onto the top rail of the arch (**Figure 8**). The solar panel bolts directly to the strut in a fixed position. Another approach is to weld a smaller diameter rail 7/8" or 1" (19mm or 25mm) over the top bar of the arch. The upper rail provides a convenient place to attach standard rail mount hardware, which allows the panel to pivot into the sun, yet easily removed if necessary.

Bimini/Dodger Mount

Biminis and dodgers are great places to attach fully flexible solar panels. Fully flexible panels are less efficient, which means they take up more space for a given power output, but that extra space is often available on large areas of canvas overhead. Fully flexible panels are attached using their corner grommets or by actually sewing them onto the bimini or dodger fabric. When choosing a mounting location, make sure that the panels will not be directly shaded by the boom or other overhead obstruction.

For those trying to maximize solar charging potential, rigid panels can be mounted on a separate metal tube frame installed over a conventional bimini. Alternatively, you can skip the soft bimini and simply create a “solar bimini” consisting of two arrays of standard solar panels, one on each side of the boom. For additional weatherproofing, astrong yet lightweight rigid hardtop can complement, or even replace, the metal tube frame. This arrangement is especially practical on catamarans or beamy monohulls.

A healthy dose of ingenuity can help you find practical mounting solutions that don’t detract from your boat’s appearance while allowing the panels to have good average exposure to the sun.

KEY COMPONENTS

To make your solar installation complete, you’ll need the following components.

Wire. Properly sized two-conductor wire rated for marine use. Even though the current is relatively low, the length of a run can be substantial. Size the output wire for no more than a 3% to 5% voltage drop.

Deck plug. A high quality deck plug to lead the solar output belowdecks to the charge control. Make sure the plug is rated for the maximum amperage expected.

Charge Control. A charge control sized for the maximum amount of solar current for present and future needs. New solar controls on the market have pulse-width-modulated (PWM) circuitry for efficient charging, and either analog or digital monitoring of solar current. Some type of current monitoring — a simple analog meter with a full scale close to the full rated output of the panel(s), a digital ammeter, or a complete system monitor such as the Link 10 from Xantrex, the BTM1 from Mastervolt, or the TM500 from SALT — is essential for accurate tracking of solar performance.

Diodes. Only a few panels on the market have built in blocking diodes that allow unshaded portions of the panel to keep working near full capacity, or a main diode to prevent reverse leakage at night. Most charge controllers supply reverse leakage protection, but you may need additional diodes, especially if you have panels mounted port and starboard wired in parallel. Diodes allow an unshaded panel(s) to produce full power if the other panel(s) becomes shaded.

Fuse and disconnect or circuit breaker. A properly-sized fuse or circuit breaker should be placed as near the battery being charged as possible; some convenient method of electrically disconnecting the panels — a fuse or circuit breaker rated slightly above the rated output of the solar panel(s) — makes for a good installation.

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MOUNTING OPTIONS

Figure 1 Semi-flexible panels mounted directly to a catamaran deck with corner fasteners.

Figure 2 Rigid panel mounted on top of companionway hatch roof on raised aluminum brackets allow airflow underneath.

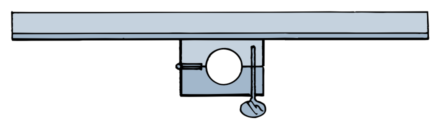
Figure 3 Rigid panel mounted to tube arch on stern.

PAUL SHARD

PAUL SHARD

Panels securely mounted to tube supports that fasten to bracket on stern tower.

Figure 4 A rigid solar panel fastens to the boat's stern with rail mount clamps.



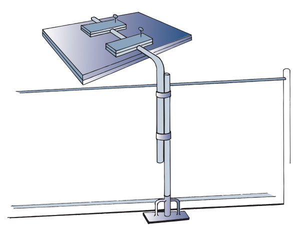


Figure 5 Stanchion mount kit consists of a curved pole that pivots outboard or inboard and fastens to a stanchion with rail mount clamps so the solar panel tilts up or down.

Figure 6 A pivoting stanchion-to-stanchion mount secures the solar panel on a rigid piece of metal tubing secured between stanchions with rail mount clamps.

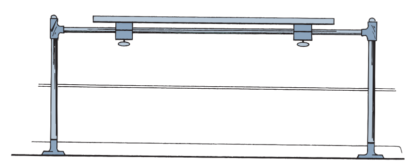
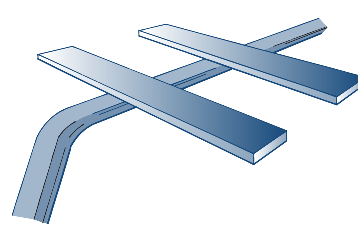


Figure 7 Panels mounted on metal frame suspended between davit arms.

Figure 8 Two metal struts bolted to a stern or radar arch make a convenient place to fasten a solar panel.



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MARINE ELECTRICAL SYSTEMS

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Charging Issues

Five common charging problems and their solutions.

By John Payne

Battery Charging with Isolators

Q: I am considering installing one isolator for each of the two main engines. Each engine has its own starting battery. The charging output for each engine will go to its respective isolator, which will then be split so that one side of the isolator goes back to its dedicated starting battery. The other side of the isolator will be wired to a house battery. This will be the same for the second motor; one side wired to its own starting battery and the other side wired to the same single house battery. Under this system, the house battery would have two charging leads coming in from two different isolators. This system would theoretically charge the house bank if either motor were running. Would this cause problems when both engines are running? What other options are available that accomplish the same task of charging the house battery with either engine? This same system will also have a parallel switch between the two starting batteries.
Nathan Onken, "The Roamer," Excelsior, Minnesota

A: This is a common scenario on dual engine installations. In practice, having two alternators charge the same battery would not cause problems. One tends to act as master and one slave, as there will be one with marginally higher output voltage than the other. Also, one regulator tends to read the output voltage of the other alternator and so you don't get any improvement in charging and charging always benefits from a smart regulator. The upside is that you have some redundancy in charging. I prefer, where it's possible, to have a relatively large house bank split into two banks, one for high current loads, the other for more sensitive electronics' loads. Each charge output then feeds a self-contained system. The house banks can have an emergency crossover switch.

Voltage Formula

Q: Is there a table that I use to predict voltage in my house batteries over a period of time? Three deep-cycle batteries, totaling 420 amps are monitored and I normally use 0.9 to 1 amp hours to power alarms and propane fridge when I'm not onboard. Battery voltage drops to 12.25 volts after using 33 amps, 11.75 volts after 100 amps. Is this in the normal range?
Andre Massicotte, Bayside, Nova Scotia

A: There is a standard table for battery state of charge on flooded-cell batteries. Your readings indicate that after 33 amps the battery is nominally at 50% charge at 12.25 volts and around 25% charge level for 11.75 volts. However, this is not a correct state of charge and state of charge tables are generally given as open circuit values. These are always higher and more accurate than ones taken as on-load readings, which are inaccurate. When you take readings, it should be without any loads switched on. This gives a lower voltage reading than a stable off-load one. This explains why after using 100 amps, the battery reads around 25%, instead of what should be 12.45 volts and 75% for batteries in good condition. Nominal 100% reading of a battery in good condition at 80F (26.6C) is 12.65 volts, 75% equals 12.45 volts, 12.24 volts equals 50% and 12.06 volts is 25%. Of course, the voltage readings are also directly correlated with the battery density readings. Also, note that these readings vary a little between batteries, battery chemistry and temperature. To get accurate readings switch off loads and measure an hour later when battery voltage recovers and stabilizes.

Solar Charging

Q: I run two 180-amp batteries, one engine and one house, and an isolator. How should I wire my batteries to keep them charged all the time? I plan to wire them directly to the bank but I'm concerned that, since the house battery is always the lowest, the charge will likely go to the circuit with least resistance and charge one battery. I was thinking to run from the solar controller (positive to battery one and then battery two) and then use a common ground for both. I leave my boat unattended for 30 days at a time and I must keep the batteries charged for bilge pumps etc.

A: I'm not sure about whether you are referring to a diode isolator or a switch isolator. Charging is not dependent on resistance. It's based on voltage. You can do as you suggest and connect the output of the switch isolator to each battery in turn. A simpler method is to simply connect or parallel all the batteries as one bank and charge them all together. A quality solar controller or regulator should maintain a float charge of around 13.2 to 13.8 volts. In fact, unlike deep-cycle batteries, start batteries don't self-discharge within 30 days, so just maintaining the charger on the house battery bank alone is sufficient. You can freshen up the start battery when you are on the boat.

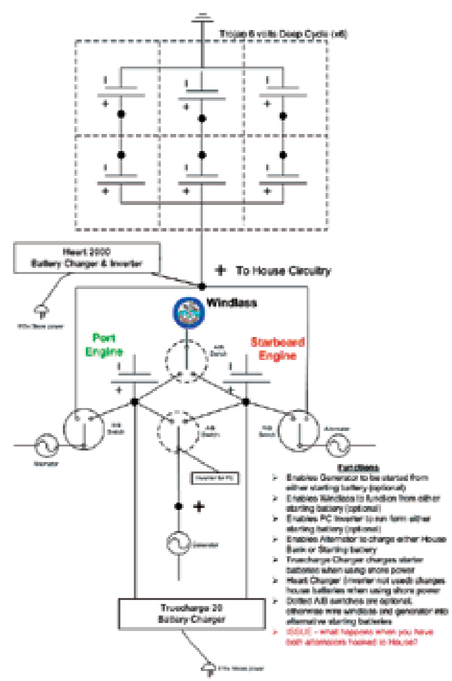
Overcharging Problems

Q: When underway, the starboard engine voltmeter acts strangely. Sometimes charging shows 14.4 volts, rises to 15.4 and then returns to 14.2 volts where it stays for a while and then goes back to 15 or 16 volts. I have checked my batteries and the two voltmeters are okay. Any idea what else to check?
Walter Czycz, "Fairbanks," Horseshoe Bay, British Columbia

A: The symptoms you describe can be caused by a couple of things. First, eliminate a voltmeter problem by swapping the voltmeters. If all checks out, do the same with alternators and verify the fault follows the change. This type of fault occurs with fast charging regulators whenever the sensor wire is disconnected or is loose. Again, if all checks out, the problem might be an internal type alternator regulator malfunctioning. Check the alternator brush gear. Sometimes a brush sticks and affects the regulator field control. In many cases, such faults also manifest themselves with interference on radios and other electronics.

Charging off Alternators

Q: I need a good 100-amp charge when underway to top up the battery banks on my 38' (11.5m) 1984 Chris-Craft Catalina with Mercruiser 454 inboards and alternators rated at 55 amps each. At the dock, I switch to a Heart 100-amp charger. Can I hook up my two engine alternators to charge a large battery bank according to the diagram below? My boating buddy, who has the same boat, was advised that this configuration is problem-free provided the engines aren't run for too long.
Peter Preager, Aurora, Ontario



A: The short answer is yes. Having two alternators feeding the same bank doesn't cause any concern for overcharging as they are, in fact, both nominally 14-volt output. No matter how many alternators connect to one battery, the charge voltage remains the same. Charge input capability relates to the charge acceptance rate of the battery bank. Having two 55-amp alternators doesn't equate to a good 100-amp charge. Also, one regulator tends to read the output voltage of the other alternator so adding a smart regulator improves charging. You'll have some redundancy in charging. Where possible, it's better to have a relatively large house bank split into two banks, one for high current loads, and the other for more sensitive electronics loads. Each charge output then feeds a self-contained system. A good option is an emergency crossover switch on the house banks.

MARINE ELECTRICAL SYSTEMS

Inverter: Selection & Installation

An inverter lets you add creature comforts on board with very few drawbacks.

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When you leave shore, there's no need to leave the comforts and conveniences of landlubbers behind. With an inverter and a beefed-up direct current (DC) system you can operate a hair dryer, power tools, computer, use a toaster, coffee maker, compact microwave, watch TV, recharge your hand-held radio battery or vacuum the cabin sole. On boats without alternating current (AC) system or shore power, an inverter offers an economical way of operating appliances off the battery. On larger cruisers already equipped with a generator, inverters supply immediate AC power for operating light loads without the need to start up the generator.

The key components of any on-board energy system are an inverter, battery charger and bank of batteries. An inverter converts battery-stored DC power to 115- or 120-volt AC energy. The battery charger recharges the batteries from AC power supplied by the engine alternator, generator, solar panel or shore power. Installing an inverter is quite simple and easily accomplished in a few hours. Selecting the proper inverter and upgrading your DC system to handle the additional power load is somewhat more complicated.

Inverter Selection

Inverters are rated in watts according to the continuous power they can produce. Most units have higher start-up (surge) capabilities that deliver large amounts of power for short periods of time. Inverters for on-board use range from 100 to 2,500 watts (larger units are

Figure 1 **Calculating Battery Requirements**

To determine the total daily load on a battery, take the power usage including surge loads in watts of all appliances, multiplied by the hours of use between battery charges. If an appliance is rated in amps, multiply volts by amps to obtain watts. For example, a 120-volt appliance rated at 10 amps requires 1,200 watts of power. Convert the total watts to amp/hours by dividing by the DC system voltage (12, 24 or 32) then add the values. Multiply amp/hour value by 1.1 to 1.2 (depending on the inverter) to determine the total battery drain. Since the number of amp/hours consumed by AC loads before recharging the battery should be no more than 50% of the battery's rated capacity, you'll need about 288 amp/hours (or three 100-amp batteries) to provide the AC power in this example.

Appliance	Total W Rating	Hours of Use Per Day	Total Watts	Amp/hours Use(Ð12)
13" TV	80	2	160	13
Stereo	50	2	100	8
VCR	50	2	100	8
Blender	300	1/6	50	4
3/8" drill	500	1/12	42	3
Hand sander	500	1/12	42	3
Ice maker	200	1/6	33	3
Coffee maker	1000	1/6	167	14
Hair dryer	1500	1/6	250	21
Portable vacuum cleaner	1100	1/12	92	8
Compact microwave	750	1/4	187	15

Total amp/hours consumed = 100 (Sum of right column).
Multiply by 1.2 for inverter inefficiency = 120
Recharging requires 120 x 1.2 = 144 amp/hours
(Note: numbers rounded to nearest whole number.)

available but not practical for pleasure boats). For runabouts or small weekend cruisers, an inexpensive, portable 150-watt inverter that plugs into a 12-volt receptacle is ideal for powering lights, TV, fans, mixer or other small appliances. To operate a microwave or power tools, an inverter needs to provide more than 600 watts.

Models are available with 12-, 24- or 32-volt DC input and a variety of accessories and options. Most inverters have a display on the front panel showing the voltage status of the DC system. Many manufacturers offer optional remote panels that provide information on battery volts, amps and AC input. "Smart" inverters have a built-in, automatic three-stage battery charger that senses when there is no power consumption and goes into idle mode, drawing minimal current from the batteries. Turn on an AC appliance and the inverter switches into charge mode. Such units extend the life of your batteries and eliminate the cost of buying a separate battery charger. Units not equipped with charging systems monitor battery voltage and shut down if the voltage goes too low or too high. Alarms and LED indicators give advance warning of overheating or overloading. Larger inverters often automatically transfer AC power from the batteries to a generator or shore power when available.

The inverter you choose must be able to handle all the appliances you plan to use. List the appliances that would be running at the same time and determine their continuous power rating and surge requirements in watts (see **Figure 1**). If you are planning to use large powerful motors with high surge load requirements, you may need a larger inverter than if you were running just lights or small appliances. Total wattage determines the maximum power output of the inverter. Always select a unit slightly larger than your maximum load requirement — once you become accustomed to using electrical appliances on board, it's likely you'll want to add more.

Buy the best unit you can afford and one that meets your power requirements and space limitations. Cost for a basic unit averages $1 per watt. Options such as battery charger, remote control, transfer relay or 24-volt input substantially increase the selling price.

ESTIMATING BATTERY POWER

After determining the power requirements of the AC appliances operated on board, you need to calculate the available capacity of your boat's battery bank (see **Figure 1**).
For an inverter to operate efficiently, your boat must be equipped with a good battery system and adequate recharging capabilities. Space, weight and budget limitations determine the size, type and number of batteries. The batteries you use affect the performance you can expect from your inverter. The larger the battery capacity, the longer the time between battery recharges. Only use deep-cycle batteries (never starting batteries) which can withstand repeated cycles of heavy discharge and recharge without damage. Deep-cycle batteries are rated in amp-hours. This rating is usually relative to a 20-hour discharge cycle. A 100 amp-hour battery, for example, will provide 5 amps for 20 hours (5 x 20 = 100). If the rate of discharge is higher, the battery will not deliver its full rating. A DC system rated at 200 to 400 amp-hours provides adequate power for a weekend of average use of a

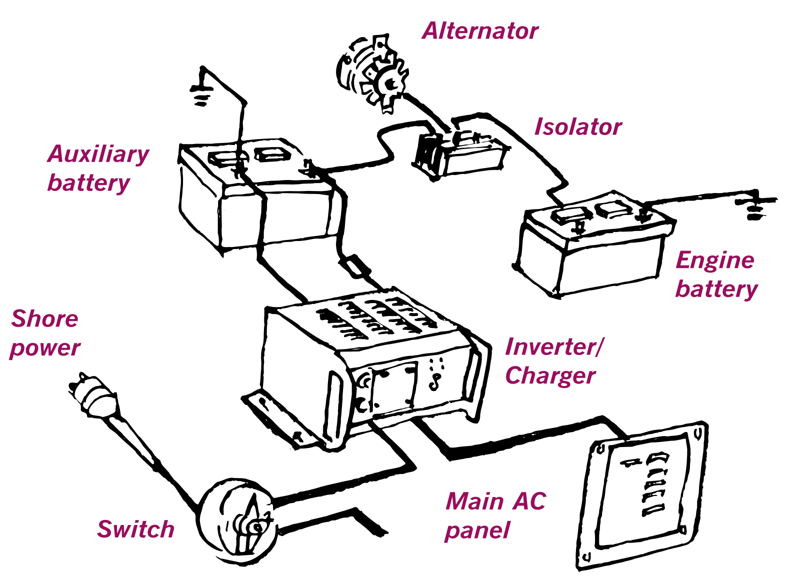

Figure 2

Typical installation with shorepower, generator and self-charging inverter powering a single AC panel.

microwave, lights, coffee pot, hair dryer, TV and VCR. (See **Figure 1** for determining battery amp-hours.)

Depending on the unit, some manufacturers recommend installing a separate bank of wet or gel cell deep-cycle batteries. To create a battery bank, batteries are linked using either parallel or series connections. When batteries are connected in parallel, the voltage of the battery bank is the same as that of each individual battery. When connected in series, the total available voltage is equal to the sum of the voltages of each battery.

To meet increased AC power demands, existing DC systems on most boats are most likely insufficient. When calculating the amp/hour drain on your batteries you probably discovered that your boat's present battery is too small. Operating AC appliances is limited by the amount of DC power you can generate and the boat's recharging capabilities. Increasing the size and number of batteries will help. If the total battery drain between recharges is 144 amp/hours, you will need a minimum battery capacity of 288 amp/hours just to power the inverter, without considering other everyday DC loads (cabin lights, VHF radio, etc.). Sailboats that use the alternator as the main source of charge to the batteries should also consider adding a high-output alternator along with a smart regulator to increase charging rates. Consult with the engine manufacturer when upgrading these components.

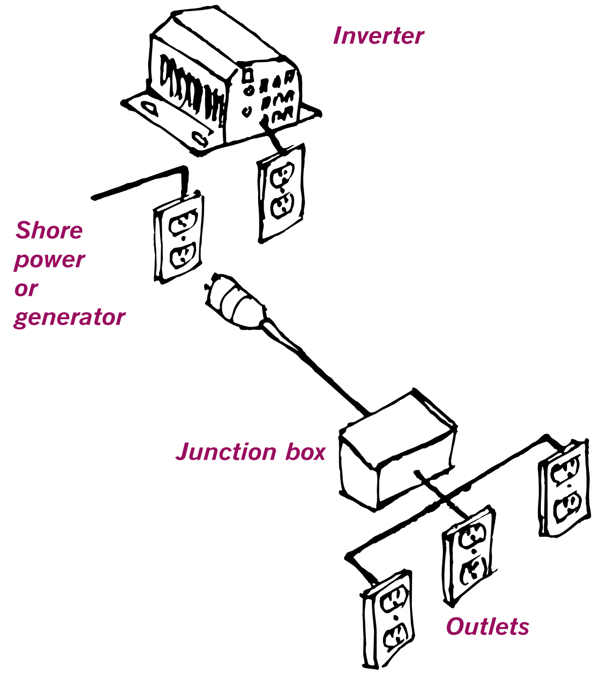

Figure 3

A switching device can be as simple as an AC plug that plugs into the desired AC power source.

Installation

Inverters mount either vertically (bulkhead mount) or horizontally (shelf mount) in a dry location away from water, condensation and excessive heat **(Figure 2)**. Do not install near hatches or exhaust manifolds or in compartments containing batteries or flammable materials. Inverters run hot and need plenty of "breathing" space to prevent overheating. A good rule of thumb is to allow enough room to be able to reach around the unit on all sides. If housed in an enclosed compartment, provide ventilation to allow easy air flow. (Many units are thermally protected, however, and will shut down in excessively high temperatures.)

Place the inverter within easy access to 115- or 120-volt AC system wiring and input wiring from shore power (if equipped). Proper wire and wiring are important to the efficient operation of your inverter. Use only heavy insulated, stranded copper wire (no aluminum) with crimped and soldered lugs. Keep the total DC cable run to under 3m (10') to minimize line voltage loss. It's better to run longer AC wires that are less expensive than DC cables.

Most units come with DC cables that connect to the batteries or a battery switch. Before connecting the cables, make sure the power switch on the unit is in the "off" position. If you are using a battery selector switch set it to the "off" position. Cables must be as short as possible and large enough to handle the required current. The inverter's size and distance from the unit to the batteries determines the correct wire gauge. Run cables from the battery posts to the positive and negative input terminals on the inverter. Most inverters are not protected against reverse polarity and permanent damage may occur if improperly connected. Tighten all cables to reduce excessive voltage drop and prevent overheated wires and melted insulation.

It's recommended to install an in-line fuse in the positive battery cable to protect against DC wiring short circuits. Install the fuse holder as close to the battery as possible. Use a slow-blow fuse with an amp rating that's sized to allow operation of all your DC-powered equipment. If the battery posts are the terminus for the starter motor, alternator and battery selector switch, you will need to add a negative and positive distribution panel with a single heavy cable leading to each battery post. Separate battery bank from the boat's starting battery with an isolator. This device allows equipment to be operated from an auxiliary battery without danger of discharging the boat's starting battery. When the engine is running, the battery isolator automatically directs the charge from the alternator to the battery requiring the charge.

With smaller inverters, appliances plug directly into standard AC receptacles on the unit. These units are ideal for small boats with confined spaces and minimal AC demands such as powering a small TV or computer. Larger inverters with chargers are wired directly to the boat's existing AC wiring or an AC control panel. Before working on AC wiring always disconnect DC power from the inverter. Also, disconnect any other AC power source such as a generator or shore power. Electrical shocks from AC power can be fatal.

Modern AC wiring systems have three conductors: hot (black wire), neutral (white wire) and ground (green or bare wire). Screws on terminals are typically color-coded brass for hot, silver for neutral and green for ground. Use multi-strand, marine-grade, tinned wire; household type, solid-core wire has no place on a boat. It's important to maintain correct wiring polarity, otherwise you risk permanent damage to the inverter. Do not install the inverter to another AC power source (generator, shore power) at the same time, even when your inverter is equipped with an AC sensing and transfer function.

On boats equipped with other AC power sources, you must install a manual **(Figure 3)** or automatic **(Figure 4)** switching device so that only one power source connects to the AC distribution panel at any time. Available from many marine stores, they are commonly used to transfer between the generator and shore power. Do not attempt your own AC wiring unless you have the knowledge and experience to do a safe job. Follow the manufacturer's instructions carefully. It's a good idea to have an authorized electronics dealer check the installation when completed.

Lastly, ground the inverter to the boat's grounding system. With the installation completed, turn the battery selector switch (if using) to select one of the batteries and switch on the inverter. Check the meters and indicators on the unit or optional remote panel. Voltage should read 12 to 13 volts, depending on the battery voltage. Test the system by plugging in a low power load, such as a 100-watt lamp.

Operating tips

When operating an inverter, always use appliances that are within the unit's wattage handling capacity. If the in-line fuse or circuit breaker blows when you turn the appliance on, the high start-up surge requirement exceeds the inverter's rating. Never replace a blown fuse with one of higher value. When operating several appliances, turn each on separately to reduce the start-up load on the inverter. The output power of an inverter is not exactly the same as household power. Slight differences may cause oddities: some appliances with complex electronic controls may buzz or not work at all under inverter power. Microwaves take longer to cook and dimmer switches won't dim. Inverters

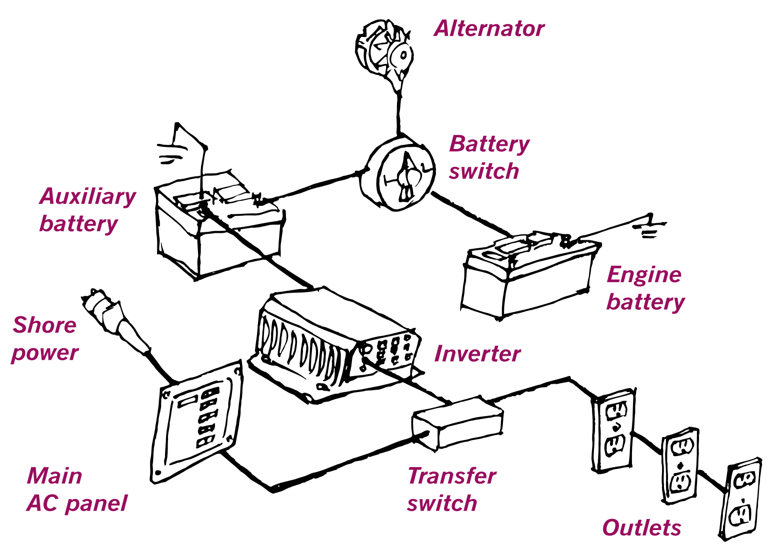

Figure 4

Installation with inverter and an automatic transfer switch.

sometimes interfere with radio and TV reception and may cause a hum on audio systems.

An inverter easily handles light AC loads for extended periods or intermittent heavier loads such as cooking veggies in the microwave. If you find you need to run your engine all day just to recharge the batteries, then use your generator. Power-hungry appliances like air conditioners and refrigerators are best left to the gen sets. On installations that combine an inverter and generator, save the latter for heavy duty continuous loads that also provide power for a battery charger or a self-charging inverter. At all other times or when the main engine is running, use the inverter to supply AC power without the noise, vibration, fumes or maintenance costs (gas, oil or spark plugs) of a generator.

Determining Recharging Times

To calculate the amount of time you can use only one appliance before it becomes necessary to recharge the batteries, first determine the wattage of the appliance. For example, a 100-watt TV attached to an inverter powered by a 200 amp-hour, 12-volt battery bank will draw about 10 amps whenever it is on (divide the running wattage by 10). Since batteries should only be discharged about 50%, the TV can run for 10 hours before recharging is necessary (assuming the batteries were fully charged). The formula is: 1/2 the battery capacity of 200 amp-hours divided by 10 amps (current draw of the TV) equals 10 hours. Use the same method to calculate time before recharging on 24-volt systems except divide the wattage of the appliance by 20. For 32-volt systems, divide by 27.

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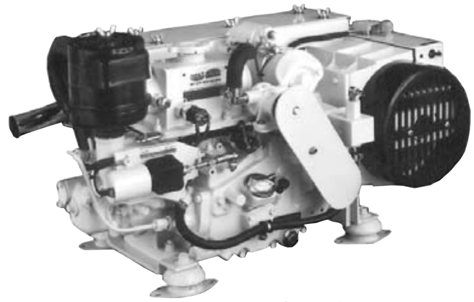
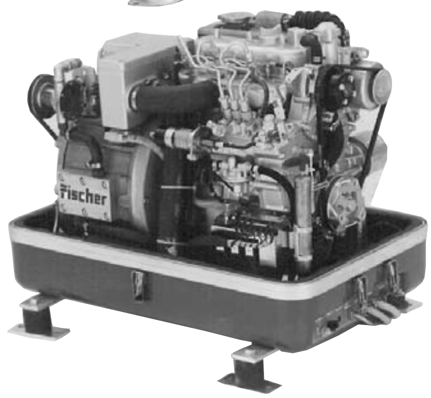
GEN-SETS: SELECTION, INSTALLATION AND OPTIONS

Once you've accepted that a gen-set is right for your power needs, do your homework before you shop around.





Top, clockwise: Next Generation 3.5kW, Yanmar, Kohler, Fischer Panda 7.8kW.

By Kevin Jeffrey

If you have a large AC electrical load and spend time away from dockside shorepower, you'll probably need to look beyond the capabilities of DC-to-AC inverters and start investigating gen-sets. Even if a properly sized inverter is capable of handling your load, the charging system needed to replace battery drain may be impractical.

A good example of an AC load too large for most inverter installations is air conditioning. The instantaneous AC current draw from air conditioning ranges from fairly modest to high, depending on the BTU rating of the unit. But it's not the current draw that creates the problem for inverters, which can comfortably handle large loads such as microwave ovens, toasters and coffee makers. The problem lies in the length of time and the time of day air conditioning is normally operating. Air conditioning runs for long periods of time and is used primarily at night, when charging sources have a tough time replenishing the battery drain. Large AC loads that run for extended periods of time generally require an engine-driven AC power source, the most common option being a diesel- or gasoline-fueled gen-set.

Gen-sets use two primary pieces of equipment, a rotary AC generator and a matched diesel- or gas-fueled engine. For the sake of efficiency, a gen-set's engine is properly sized to do the job required, usually with little or no wasted capacity, but you can increase the overall system efficiency dramatically by using an inverter along with the gen-set: use the gen-set to power large or constant AC loads, then use an inverter to power smaller or intermittent AC loads.

Selection

Equipment weight and size are important considerations for boaters, especially those with light displacement craft, and cost is a universal concern. Gen-sets can be big, heavy and expensive to purchase and to install, but don't let that deter you from considering one. There are compact units on the market that are reasonably priced and relatively lightweight, ideal for those with modest size boats.

An ideal gen-set would be lightweight, smooth, quiet, fuel-efficient, powerful, low cost, reliable, and would fit in a spare locker. Since it's difficult satisfying all of these requirements

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in a single unit, you'll need to establish an order of importance for your situation. If high power and low cost are your priorities, you may end up looking at models that are heavy, bulky and only moderately quiet. If silent operation, lightweight and compact size are the top requirements on your list, you'll undoubtedly have to pay a premium price in terms of dollars per kilowatt (kW). It's best to determine what characteristics are most important for your situation before you shop around.

The first thing to determine is fuel type. It's logical to choose the fuel that powers your auxiliary engine. Diesel is the marine engine of choice as it tends to last longer and be more fuel efficient, yet it's typically more costly to purchase and repair. If you are considering a gas-fueled model make certain it's approved to operate in a gasoline atmosphere — proper venting and exhaust are crucial for a gasoline engine used below deck as well as a carbon monoxide detector, as required by ABYC.

Gen-set engines vary in how many cylinders they have. Many of the small, high-speed models use Farymann or Yanmar single-cylinder engines, which are surprisingly balanced and relatively quiet. Kubota, Mitsubishi and Yanmar two- and three-cylinder engines are also popular for modest sized gen-sets. In general, three- and six-cylinder engines tend to be the most quiet and have the least vibration.

Electrical generators on gen-sets have magnetic poles that create AC power when they are rotated by the engine shaft: 1,200 rpm for 60Hz, 1,000 rpm for 50Hz gen-sets usually have six-pole generators; 1,800/1,500 rpm gen-sets usually have four-pole generators; and 3,600/3,000 rpm gen-sets usually have two-pole generators.

Industry standard gen-sets such as those from Kilo-Pak, Kohler, Northern Lights and Onan are made to run at 1,800 rpm for 60Hz output, 1,500 rpm for 50Hz output. Large gen-sets (over 20kW) using six pole sets in the generator run at 1,200/1,000 rpm, while the compact gen-sets from Entec West, Fischer Panda, HFL and Mase are designed for high-speed operation at 3,600/3,000 rpm. Relative newcomers to the field are the compact models from Next Generation Power, which operate at a mid-range speed of 2,800 rpm. The 1,800 rpm proponents claim lower noise and longer engine life, while the manufacturers of high-speed models claim they've designed their units accordingly and can produce more electrical power for a given weight and volume by using high-speed diesels.

Gen-set prices vary widely, mainly because the high-speed, low noise units are so much more expensive. Prices range from US$8,000 to US$13,000 for 4kW to 5kW units installed with soundshield, US$11,000 to US$16,000 for 8kW units installed with soundshield.

Soundproofing

All gen-sets make noise, but some manufacturers have gone to great pains to make their units run as quietly as possible. Next Generation claims its mid-speed models are as quiet as the 1,800-rpm units, without the need for sound enclosures as with the high-speed units. Compare decibel ratings of the various units on the market **(Table 1).** If noise is a big concern, choose a model with a good soundshield, or have a soundshield made (hard case or soft-sided) to help insulate gen-set noise from the rest of the boat.

While it's true that gen-set noise varies widely, I feel all engines on board need to be soundproofed if you're going to enjoy your time on the water. Most of the high-speed

TABLE 1 DECIBEL EQUIVALENTS

Diesel engine room	120	Aircraft take-off @ 200’
	110	Rock band, Table saw
Diesel generator @ 3’	100	Car horn @ 16’
	90	Heavy traffic
Most diesel generatrs with soundshield @ 6.5’	80	Electric shaver
	70	Average radio
Fisher Panda generator @ 6.5’	60	Normal conversation

models use water cooling in both the engine and the electrical generator itself, allowing the gen-set to be completely enclosed in a well-insulated, soundproof box.

Power Rating & Efficiency

Power ratings for gen-sets begin in the 2.5 to 3kW range, and continue up to 20kW or more. The most common gen-sets for pleasure craft are in the 4 to 12kW range. Gen-sets achieve their rated power at a given engine speed necessary to produce the required AC frequency; engine speed remains fairly constant, regardless of electrical load. Even though the actual load on the engine is related to how much electricity is being used, running a gen-set to satisfy a small AC load is inherently inefficient. Some gen-set manufacturers (notably Balmar) have embraced what is known as VST (variable speed technology). Gen-sets with VST adjust their speed according to electrical demand, while maintaining the correct AC frequency and waveform. These models cost more, so you'll have to decide if you can afford the extra efficiency.

Cooling & Exhaust Method

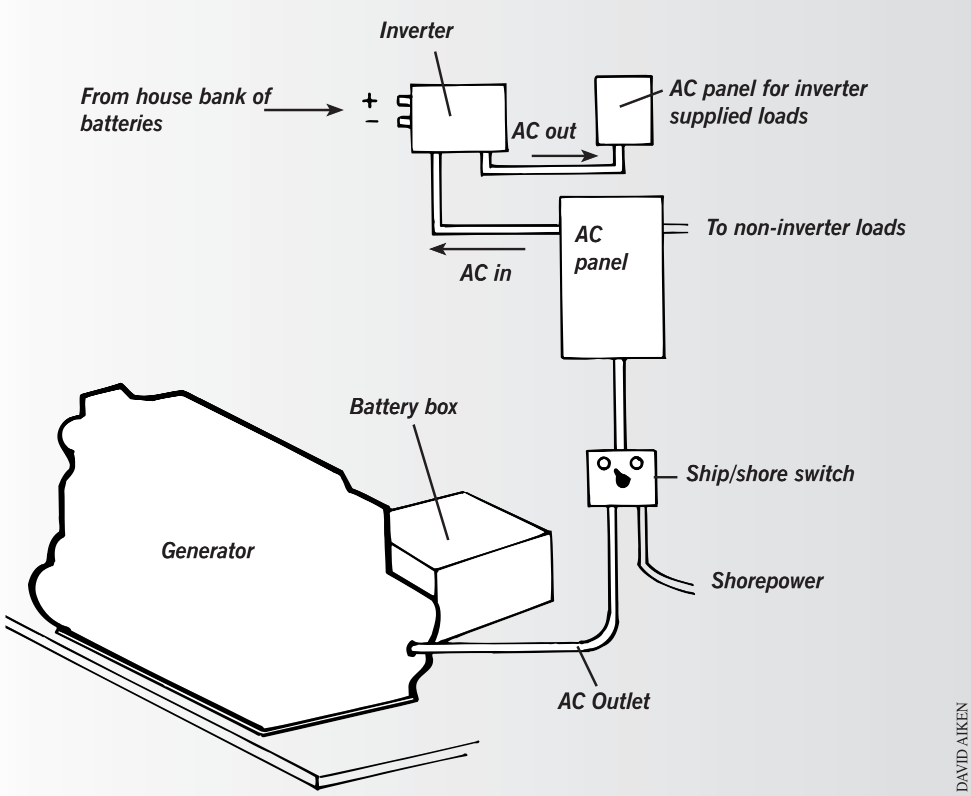
Most marine gen-sets are water cooled with two separate cooling circuits. One circuit pumps seawater from outside the boat, up through a heat exchanger, and back overboard. The second circuit pumps freshwater from the heat exchanger, through the engine block and exhaust manifold, and back to the heat exchanger. Many of the high-speed gen-sets incorporate an additional cooling loop in the generator itself, which increases efficiency and allows the unit to be completely enclosed in a soundshield without worry of overheating.

Some gen-sets installed in monohull sailboats are "keel cooled." In this type of system a cooling pump moves freshwater through a cooling grid on the bottom of the boat. You'll still need a seawater circuit (intake, pump, siphon break etc.) if you want to have a wet exhaust.

Engines on pleasure vessels usually have a wet exhaust to dampen the exhaust noise. Dry exhaust systems are more appropriate for workboats, although there are devices that

TABLE 2 TYPICAL INSTALLATION WITH AN INVERTER

Output from generator goes to a ship-to-shore switch up to the AC panel which then leads to an inverter and to a subpanel for non-inverter loads. This isolates heavy loads from the inverter. A sub-panel connects to the inverter for devices with low power demands.



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separate the water and exhaust air before they exit the boat, eliminating that tedious splashing sound of wet exhaust outlets just above waterline [Ed — refer to DIY's MRT "DIY Mechanic" CD-ROM for information on wet exhaust systems.]

Installation

Any marine engine should be mounted on a well-reinforced platform using rubber isolation mounts. Some gen-set suppliers offer "hydrolastic" mounts that provide the ultimate in vibration resistance. Check with your dealer for his/her recommendations on platform material selection, thickness and reinforcing.

For wet exhaust systems, plumb raw seawater through a strainer and into the engine's heat exchanger, then into the exhaust piping; exactly where depends on how the gen-set sits in the boat. If the point where the cooling water is injected into the exhaust is less than a foot above the waterline, you'll need a vented loop (siphon break) to prevent seawater from siphoning back through the raw water pump after the engine is shut down. Never use a scoop-type water intake on the outside of your hull, since this can inadvertently force water past the raw-water pump, into the muffler, then on into the exhaust manifold and into the engine cylinders. You'll need to have a good diesel fuel filter/water separator installed in your fuel line, and a separate battery for starting your gen-set. See Table 2 for a typical electrical set-up; for complete installation procedures, refer to the instruction manual supplied with your gen-set.

Make sure to plumb a loop between the muffler and exhaust outlet. This loop should be at least 12" (30cm) above the loaded waterline. An alternative to this type of arrangement is to use Soundown's Waterdrop Silencer or a Gen-Sep from Northern Lights, which separates exhaust and water before they exit the boat, eliminating splashing or pulsating water flow at the exhaust outlet. [Ed — see "Silent Exhaust" in "DIY Mechanic" MRT CD-ROM.]

Options & Accessories

Gen-sets are designed to maintain starting battery charge. Additional safety and monitoring equipment includes start/stop panels, engine hourmeters, AC and DC electrical meters, ship/shore switches and carbon monoxide detector. Automatic controls can be installed to shut down the engine on high exhaust temperature, engine overspeed, low water level and low oil level.

Some gen-set manufacturers mate their engines with a high-output DC generator to provide high-capacity battery charging instead of AC output. This option works well if all of your AC needs can be supplied by an inverter, but don't consider this system for air conditioning — that load is simply too large and on too long to make this set-up practical.

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No Hassle Charging

These devices connect two or three battery banks to a single charging source and isolates the battery banks during discharge. When properly sized and installed, they are trouble-free.

By John Payne

Ever since the engine starting battery was supplemented with a second battery to run house service loads, charging them both satisfactorily has been a problem. The common practice of connecting batteries in parallel to enable charging from a common charging source often leads to problems. The most basic battery combiner is the familiar large red master switch with “off/1/2/both” positions. Many boaters have accidentally left the switch in the “both” position causing the paralleled bank to discharge. Another familiar scenario is the accidental switching to the “off” position of the switch, which promptly blows the alternator diodes. There are also other problems of reliability that come with poor switch contacts and high resistance. These factors inspired the search for a method to overcome these drawbacks and led to the emergence of isolators and combiners.

The earliest “automated” combiners involved a high current relay or heavy-duty solenoid that was activated from the ignition switch. These solenoids or relays had high quality low resistance contacts. Of course, the terms battery combiner and battery isolator are functionally similar but they employ different concepts. The diode isolator is, in effect, also a battery combiner for use when charging two batteries from a single source. The diode isolator had a few drawbacks, one being the inherent voltage drop across the diode, which required compensation with the alternator voltage regulator, and the heat that it generated under high loads. The two main advantages were that it was passive and reliable and had few components that could fail.

When voltage drops below the pre-set charging voltage, the BlueSea BatteryLink ACR opens to prevent accidental discharge of a battery bank.

The Battery Mate electronic isolator is the ideal accessory to a non-adjustable alternator to maintain the output voltage at a constant level.

New Generation Combiners

The smart relay or battery combiner interconnects both batteries during charging. When the ignition switch is turned off, the relay coil de-energizes and separates the batteries. This isolates the start and house battery banks to prevent discharge between the batteries.

Smart relays or battery combiners have evolved into the smart voltage sensed relay. Voltage sensing means that the combiner does not activate and close until a preset voltage is attained. The control circuit senses this voltage and voltage builds up across the main alternator charged battery as it starts to charge. Typically this can be in the range 13.5 to 14 volts when the control circuit outputs a voltage to the solenoid or relay to energize the coil and close the main contacts, which is considerably more sophisticated from these basic relays. The solid-state relay found on some units is, in effect, a large power transistor mounted on a heat sink along with appropriate control circuits. This allows the reduction in size, however, ratings selection and mounting in properly ventilated areas to dissipate heat is essential for reliability. The battery combiner is also versatile in its applications. Use it to charge off outboard engines, which is an area where diode isolators were never very good. Or use it with shore-powered battery chargers when the boat is in the marina or ashore.

The term “smart combiner” is generally applied, as these

Newmar Battery Integrator allows the single charging output of an inverter-charger to maintain both the start and house battery banks. Batteries are isolated during inverter operation so current draws from the house bank only.

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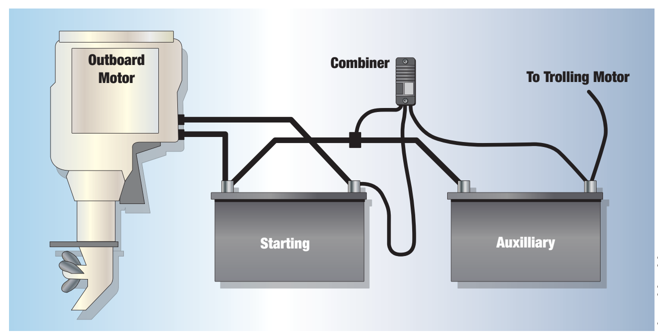
PathMaker 250 has user-selectable connect and disconnect voltages and a toggle switch to manually parallel battery banks for emergency starting power.

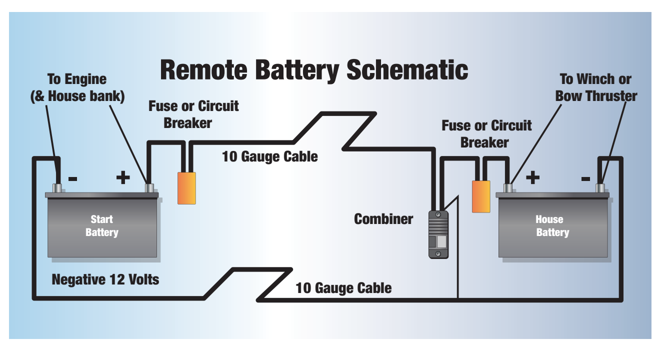
devices are microprocessor controlled. Essentially, this means the device includes a more sophisticated voltage detection and control circuit. When a charge voltage is detected that exceeds the preset voltage; for example, 13.5 volts the unit activates. When the charging either reaches a certain preset maximum or charging ceases and the voltage falls to typically around 12.7 volts, the combiner opens, isolating the batteries to prevent discharge between each battery bank. These more sophisticated units have temperature monitoring and indication outputs or lights to show when the unit is combined. Some units also have a manual activation switch to allow parallel connection of batteries where they are needed to start an engine.

The battery combiner is also known as a charge distributor, equalizer and integrator, such as the Newmar Battery Integrator, a diode isolator that acts as a "smart" switch to connect battery banks only when a charging source is present. Smart combiners on the market include the Xantrex PathMaker 250, which allows charging of two or three batteries from one alternator or battery inverter-charger. There is also the Isolator Eliminator from Ample Power, which is a multi-step regulator that controls charge to the second battery bank, commonly used for engine starting. This is temperature compensated like an alternator control system and effectively functions as a secondary charger. The Battery Mate from Mastervolt is a charge splitter that can supply three batteries, without voltage drop. Another system is the AutoSwitch from Ample Power, which is a smart solenoid system. An electronic sensing circuit will enable the setting of the different operating modes. The Hell Roarer is another system, as is the DualPro ProXtra II. Both are found on bass fishing boats. These reduce the chances of overcharging secondary batteries such as the start or trolling motor battery. Some smart battery combiner units incorporate operating status indication and user adjustable cut in and cut out settings.



Sample installation of combiner and a two battery bank system charging from an outboard engine.

It is important to understand selection criteria, which primarily revolves around the correct amperage ratings. Some units are heavy current devices that can be used to parallel batteries for discharge applications like engine starting; however, this is a different application from the main charge distribution function. You must be careful not to mix the applications. If you do, make sure the device is rated for the heaviest duty it will be expected to perform.



A trolling battery connects through a Hellroaring BIC-75150 com- biner to the starter to charge while charging the starting battery.

Rating Systems

Correct selection for the anticipated charge load is very important. Combiner ratings should at least match the maximum rated output of the alternator although, in practice, this maximum will never be reached. In many cases, the combiner is rated considerably less than the alternator output. Caution dictates the configuration of the unit in your charging arrangement. Even the heavy-duty solenoid or relay can be a point of failure if incorrectly rated for the job. If they are under-rated for the current they will carry at full loads, excessive voltage drop and the resultant high resistance and overheating will occur.

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Installation Guidelines

As the house battery bank is normally the one that receives the greatest current flow, this should be the bank connected directly to the alternator supply. The start battery bank generally doesn't need a great current flow and so the rating requirement is smaller as it is fed from the house bank through the combiner. It's a big mistake to install the system with the start battery bank as the primary connection to the alternator. With the higher capacity house bank then connected, under-rated combiners can fail due to the overload.

It's also critical that cables and connection terminals that interconnect the batteries through the combiner are rated for the maximum current they will carry. Undersizing the cables is also a common error in a new installation.

Troubleshooting

When your battery combiner will not operate the most common cause is that the voltage doesn't rise to a high enough value to activate the combiner switch-on circuit. On an alternator with integral regulator, the most common causes are as follows:

• The engine speed is too low and the alternator doesn't reach cut-in speed. In other words, it won't work at idle speeds. A slipping drive belt produces similar symptoms.

• The battery banks are discharged so low that it takes time for a charge voltage to build up across the batteries and reach the switch on voltage. This is common on boats with large deep-cycle battery banks.

• The alternator is faulty. Usually this is because some or all of the output bridge rectifier diodes have failed.

• If the battery combiner is a smart type with an overvoltage shutdown protection, the alternator regulator may have failed, outputting a high voltage that causes the combiner to open up. Some combiner indicators will alert to this condition.

A battery combiner simplifies the connection of additional batteries to a single charging source. When correctly selected and installed, it delivers trouble-free service. Combiners have many applications, including connection of wind generators, solar panels, AC-powered chargers and inverter-chargers to batteries for no hassle, worry-free charging.

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System Monitors

Proper controls for 12-volt charging sources will protect and extend the life of your boat's battery banks. Here's what you need to know to keep your batteries in peak condition.

By Kevin Jeffrey

Each charging source you install on your boat must have some sort of charging control to limit or shut off the current once the batteries are full. Alternators and other charging sources are designed strictly to provide power, a given amount for the conditions they operate under. They provide the electrical "brawn;" if no electrical "brain" in the form of an automatic charge control is in the system, and the operator doesn't manually intervene, charging sources will happily supply power indefinitely (as operating conditions allow), destroying batteries in the process. Controllers vary in price, costing roughly US$175 for three-stage alternator controls and US$50 to US$250 for solar or wind controllers depending on maximum charging amps and features desired.

Before purchasing and installing a charging source, it's wise to investigate which types of controllers are available for that source and select the one best suited for the job.

Automatic Versus Manual

Charge control can be achieved automatically, manually or some combination of the two. Since automatic controls are generally reliable and modestly priced, boaters usually choose them over manual controls. Alternator controls are almost always automatic, although I can think of two devices for alternators where both automatic and manual control are available.

The first is an adjustable two- or three-stage control for a high-output alternator. An example is the two-stage external, adjustable controller for the Ferris Powermax alternator. The control functions automatically, but the user can tweak the voltage setpoint to allow for different motoring patterns — a higher setpoint for occasional motoring and a lower setpoint for more frequent motoring. The second device, marketed under the name Auto-Mac, allows the user to dial up the charging current even after the standard voltage regulator determines that it's time to limit the current. Originally intended to over-ride the voltage regulator on a standard alternator, the Auto-Mac is less popular now that high-output alternators and fully automatic three-stage controls have come down in price.

Some liveaboard boaters choose to manually control the output from a renewable charger (see "Solar, Wind & Water Power" on page 77), at least initially, in an effort to save money or maintain simplicity in the system. Manually stopping the rotor of a wind or water generator or switching off the output of a solar panel is relatively easy and can be effective, but failure to do so when the batteries are full can be an expensive mistake. And without an automatic controller you won't be able to keep your batteries charged if you have to leave your boat for an extended period of time.

Charge Controls for Alternators

Charge controls for alternators are commonly known as voltage regulators, although I feel that name is a bit dated, especially for multi-stage controls designed to achieve high performance. An alternator control does indeed regulate output using some voltage setpoint — or multiple setpoints if a multi-stage control is used — as a reference, but it's the amount of current that is being regulated to prevent battery overcharge.

(top left) Powerline Aqualine three-stage regulator has LED status, electronic reset field current protection, turn-on delay, battery over-temperature protection and amplified tach circuit; (top right) Heart in-charge 12-volt regulator features LED status, adjustable voltage setpoints, short and open circuit protection; (bottom left) Powersource flush-mounted solar control digital meter displays charging voltage and current, has low-voltage warning and is temperature compensated.

(right) Trace 12/24-volt charge or load controls are available in 12- or 40-amp capacity, have adjustable voltage setpoints, equalize function, optional temperature sensor and digital display; (top)) Ample Power Next Step alternator regulator for 12/24-volt systems, controls one or two alternators on same engine, has adjustable voltage setpoints, temperature compensated and overload detector.

For a given rpm, the output of an alternator is regulated simply by reducing or increasing the level of what is known as the "field current," or the small amount of DC current needed to create electro-magnetism inside the alternator. The smaller the amount of current passing through the field current windings, the weaker the magnetic field and the less electricity produced by the alternator. Instead of handling the full output current, as do controls for wind and water generators, an alternator control handles only the field current, which varies from 0 to 6 amps for a standard alternator and 0 to 10 amps for a high-output alternator. This is why charge controls for alternators are typically not suitable to handle the output of renewable chargers, and why you need a separate charge control for each unit in a dual alternator installation.

There are three main battery charging cycles to consider when you have a relatively high-output charging source: bulk, absorption and float (for a review of these charging cycles refer to "High-Output Alternators" starting on page 92). Standard two-stage voltage regulators (included with all marine alternators) allow for the bulk cycle and essentially an indefinite absorption cycle (they don't drop to a lower float level).

Battery protection is achieved through a reduced voltage setpoint, which to some degree compromises the performance of the charging source. Two-stage controls work fine for most powerboat applications using a lower voltage setpoint, and for sailors who motor infrequently and use a higher voltage setpoint. However, three-stage controls from Ample Power, Balmar, Heart Interface and Powerline offer a higher level of performance and battery protection to sailors and even powerboaters who spend time at anchor and want to minimize engine-running time just for charging batteries.

Two-stage controls are typically installed inside the alternator, and thus the voltage setpoint is not adjustable. This type is the most common and least desirable. Externally mounted, adjustable two- and three-stage controls are preferable since the voltage setpoint can be adjusted to meet individual needs. Three-stage controls are best since they automatically provide a good balance between performance charging and battery protection.

Controls for Battery Chargers and Inverter-Chargers

Battery chargers, and inverter-chargers in the charging mode, usually have an internal charge control circuit; on some models the voltage setpoints are adjustable (i.e. Trace inverter-charger). High-performance models take the batteries through a three-stage charging cycle and automatically shut off when the batteries are full. Less sophisticated "trickle-charge" models reduce charging current to a low but constant trickle charge that can spell disaster for batteries when the charger is plugged into dockside power and left unattended. If there is no electrical load to moderate battery voltage, the voltage can rise to unacceptable limits and destroy the batteries.

If you are in the market for a battery charger, make sure you purchase one with three-stage operation and a model that automatically shuts off 100% when the batteries are full. An inverter-charger may make the most sense if you presently, or in the near future, wish to operate household appliances on board.

Controls for Renewables

The output from solar, wind- and water-powered generators is typically fed to individual charge controls for each source, although there are some multi-source controllers, such as Ample Power Solar/Wind Controller, that can handle charging current from any renewable power source up to the control's maximum current limit. If the idea of a single controller intrigues you, your aim should be to find one that has the capacity to handle your present as well as your

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future needs; units include ASC Controllers (4, 8, 12 and 16 amp models) and Trace C-12 and C-40. For instance, a multi-source control rated at 30 amps may be able to handle a 20-amp wind generator and two 60-watt solar panels, but if you decide to add more solar panels at a later date a second controller will be needed.

Three-stage charging is less of a concern for renewable chargers. Unlike high-output charging sources, their current output is usually low compared to the size of the battery bank. This means that almost all of the charging power is converted to stored power in the batteries, reducing the need for the absorption cycle. When the voltage setpoint of the bulk charging cycle is reached, the batteries will be nearly full. When the voltage setpoint is reached most renewable charger controls simply disconnect the circuit until the voltage falls to some preset level, then reconnect again. This on-off action continues until the batteries are completely filled.

Battery Type Selection

Most alternator and battery charger controls allow the operator to select which type of batteries they are using, either gel or wet. Changing the battery type selector switch on the control changes the bulk voltage setpoint, which is usually 14.1 or 14.2 for gel batteries, and 14.4 for wet batteries. Solar, wind and water controls typically use the lower of these two values and are therefore suitable for use with either type of battery. The slight difference in voltage (and therefore charging performance) isn't a problem with renewable chargers, since by the time the voltage setpoint is reached the batteries are very nearly full, and there is no concern about how long an engine is running.

Temperature Compensation

An important optional feature found on many controls for a high-output charging source is temperature compensation. All charging controls base their operation on battery voltage and its relationship to state of charge. The relationship between battery voltage and state of charge, however, changes with battery temperature. In fact the difference can be rather dramatic when the batteries are very warm or very cold. A temperature compensation circuit in an alternator or battery charger control ensures that the various charging cycles begin and end when they are supposed to, and that the batteries aren't routinely under- or over-charged.

Controls with temperature compensation come with a temperature sensor that adheres to one battery in the bank. A low-voltage wire links the sensor to the charge control. Locating the sensor on a battery in the middle of the bank will give best accuracy.

As with multi-stage charging, temperature compensation is less of an issue with renewable charge controls since the current levels are usually low relative to battery capacity. Even so, if this option is available for a solar, wind or water controller (i.e. Pulse PM Series controllers or Powersource PSR-16 and PSR-24), I recommend you opt for it.

Equalization Cycle Feature

Some alternator and battery charger controls allow you to equalize wet batteries (equalization cycle). They do this by temporarily, under controlled conditions with low charging current, allowing battery voltage to rise until the batteries are gassing vigorously to remove sulfate deposits on the battery plates. The operator should always monitor conditions during an equalization cycle, and keep in mind that gassing means the release of hydrogen gas. Proper ventilation and the elimination of any possibility of sparks or open flames are essential. Under no circumstances should you attempt to equalize gel batteries — they don't need it and a potentially dangerous condition will result from applying high voltage to a gel battery.

Monitoring Functions

Many charge controls incorporate monitoring functions so you can see what is happening as the batteries are charged. Some have basic LED lights that indicate if there is power to the control, if conditions are right for charging (on solar, wind and water controls), which charging cycle is in process (bulk, absorption, float), and basic battery state-of-charge information.

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THE MOST CHARGING AMPS FOR THE LEAST

High-output alternators deliver maximum output for minimum engine running time. It's a worthwhile upgrade if you spend large amounts of time away from a dock, are planning some serious cruising or have a sizable electrical load.

By Kevin Jeffrey

Typical Power Consumption									
Appliance	Typical Wattage	Appliance Run Times / Amp Hours *							
		5 Min.	15 Min.	30 Min.	1 Hr.	2 Hr.	3 Hr.	8 Hr.	24 Hr.
13' Color TV	50	.33	1	2	4	8	12	32	96
19' Color TV	100	.66	2	4	8	16	24	64	192
VCR	50	.33	1	2	4	8	12	32	96
Lamp	100	.66	2	4	8	16	24	64	192
Blender	300	2	6	12					
Curling Iron	50	.33	1	2					
3/8 Power Drill	500	3.3	10	20					
Icemaker*	200			2.6	5.2	10.4	15.6	41.6	83.2
Coffee Maker	1000	6.6	20	40	80	160			
3 cu' Refrigerator*	150			2	4	8	12	32	96
20 cu' Refrigerator*	750			21	42	84	126	336	672
Compact Microwave	750	5	15	30	60	120	180		
Full Size Microwave	1500	10	30	60	120	240	360		
Vacuum	1100	7.3	22	44	88	176	264		

If you have an inboard auxiliary engine and want the most charging amps for the least expense and maintenance, you should consider replacing your standard alternator with a high-output model. Boaters who do so typically receive up to four or five times the power of their existing alternator for a relatively modest investment.

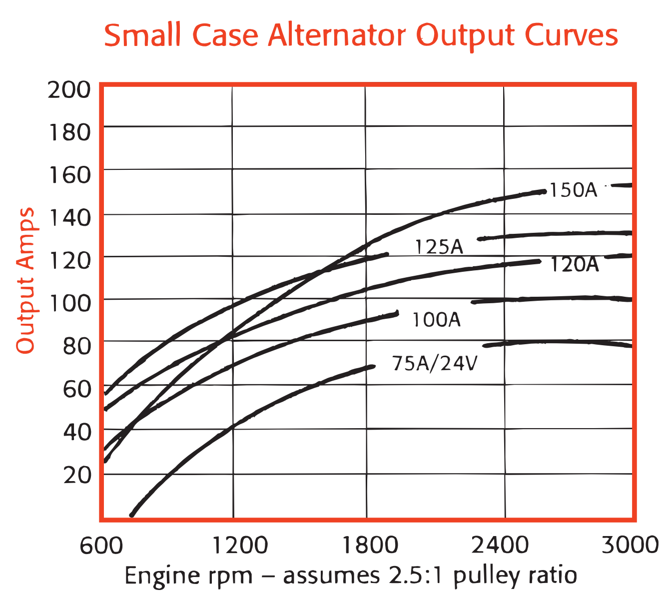
Standard alternators are fine if you use your boat like a car — that is, you go aboard, motor to your destination, then either leave the boat or plug in to dockside power. But most sailors and a large percentage of powerboaters need more from their engine-driven charging source — they need to produce the most electricity they can during the times when the engine is on.

High-output alternators aren't just alternators with more amperage. They have heavier wire windings, better cooling characteristics and higher output at lower engine rpms. Unlike standard alternators, they are made to run at their rated capacity indefinitely in a hot environment.

There are a number of models currently on the market to choose from. Many independent power system suppliers have their own brand of high-output alternators, although in most cases they are privately labeled versions from one of the few high-output alternator manufacturers such as Lestek and Powerline. Before adding it to your list of new gear to buy, determine if you really need to upgrade to a high-output alternator, and if so, what you should look for.

Figure 1

Alternator Output Curve



Selection

My guidelines to follow are: you probably don't need to upgrade if you spend most of your time at the dock, if your electrical load is light or if you don't want to run your engine for battery charging and have sufficient alternate power sources to do the job.

You probably would benefit from upgrading to a high-output alternator if you spend large amounts of time away from a dock, if you are planning some serious cruising, if you have a sizable electrical load (i.e. refrigeration), or if you simply want a high-power, engine-driven back-up to your renewable chargers (solar, wind, and water power).

It would be a great help in the decision-making process if you knew just how much (actually, how little) power your standard alternator produces. An accurate ammeter on the output line of the alternator is needed, yet few boats are equipped with this simple device. Typically, a 35-amp alternator driven off an engine running at idle speed for battery charging, produces about 1/3 to 1/2 its rated capacity for a few minutes as starting current is replaced. As voltage rises, alternator output quickly diminishes. After 15 minutes or so, output is usually down to a small percentage of rated capacity, mostly due to the type of voltage regulation inherent in standard alternators. I estimate that a 35-amp standard alternator driven off a 25-hp engine at idle speed for battery charging has only about a 2% energy-conversion efficiency from liquid fuel to stored amps in the battery. High-output alternators with performance charging controls can increase this efficiency up to 10%. (Solar panels have 16% energy-conversion efficiency from sunlight to amps produced.)

If you decide a high-output alternator should be part of your charging mix, you need to select the right type for your needs. High-output alternators come in small-case and large-case models. Small-case versions, which include all models up to about 150 amp rated capacity, are direct replacements (often bolt-for-bolt) for your standard alternator. They can usually be driven from a single pulley and belt set-up, although some suppliers recommend only high-grade belts such as the Gates Green Stripe brand for this application. Large-case versions, usually all models above 150 amps of rated capacity, have a slightly larger body diameter and may not fit the space you have available. It's best to check the measurements before purchasing a large-case design.

Alternators are typically "cold rated," which means their actual output decreases by about 10% to 15% after they warm up. They are also rated at a relatively high engine rpm, which means at engine idle speeds they produce much less than their rated output. To make matters a bit more confusing, each model of alternator has its own output curve that determines how much current it produces at various speeds. Some alternators build power slowly, then increase rapidly at higher rpms. Others power up quickly, then level off in the higher rpm ranges. By studying the output curves of the models you are considering **(Figure 1)**, you may find that a 125-amp alternator that builds power quickly actually produces more power at low engine rpms (when you'll be doing most of your battery charging) than a 150-amp model that builds power more slowly. Your alternator supplier should be able to provide you with output curves for the models it sells.

An engine of sufficient size is required to drive a high-output alternator. For example, an alternator that produces 100 amps after it's warmed up can rob the engine of about 4 hp. Keep in mind that the horsepower an alternator takes from the engine is proportional to the alternator's output — when the regulator cuts off the alternator's field current (or if you do it with a simple on/off switch), it can't produce any power and, consequently, places no load on the engine.

Many cruising sailors ask me if they could simply use a manual alternator control (remember the Auto-MAC) for their existing standard unit instead of buying a new alternator. The original idea behind those controls was to temporarily over-ride the voltage regulator of a standard alternator so it would produce maximum output. These devices are still available, but why spend about $200 for a control where you have to manually boost the output of a 35- to 55-amp standard alternator that isn't even made to run at full capacity for extended periods? You can buy a 125-amp high-output model that will give you 4 to 5 times the output for around CDN$400/US$350.

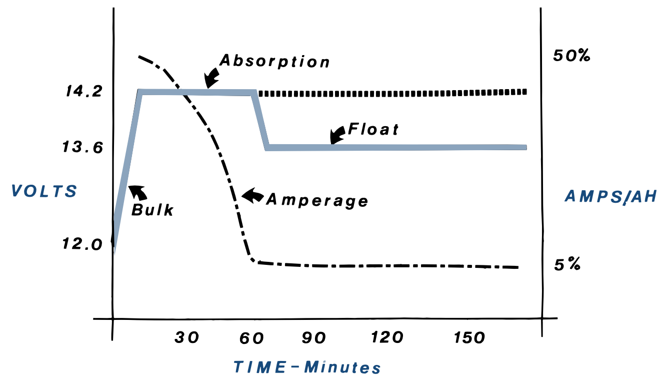
Monitoring Output

Some high-output alternator suppliers include an adjustable, two-step control with their alternators. These low-cost controls have the first two steps of a "smart" three-step control (available from Ample Power, Balmar, Cruising Equipment and Heart Interface) and are not nearly as convenient to use.

Step one is bulk charging up to an adjustable cut-off voltage **(Figure 2)**, typically set at 14.1 volts for gel and 14.4 volts for wet batteries if you want performance charging. During this cycle the alternator is producing maximum current for a given engine rpm and battery voltage is rising as the battery becomes charged. Step two is absorption charging, where the voltage is held constant at the cut-off setpoint for a specified length of time, while alternator current is correspondingly reduced (it has to be reduced or the voltage would continue to rise). Missing in a two-step control is step three, where the voltage automatically drops to a safe float voltage after the absorption cycle, typically to around 13.2 volts. Lowering the voltage in this manner eliminates any possibility of overcharging the batteries during long periods of motoring.

Figure 2

Diagram of Control Sequence



Two-step controls maintain the cut-off voltage indefinitely as long as the engine is running. This can be a problem if the cut-off voltage you select is too high for the type of motoring you are doing. This is set by adjusting the cut-off voltage setpoint (usually with a small screwdriver and a digital voltmeter). The higher the setpoint, the higher the performance, up to the battery manufacturer's recommended maximum setpoint. However, that higher voltage setting can lead to battery damage during long stretches of motoring. But if you are motoring for long periods of time, chances are you don't need performance charging and can reduce your liability for battery damage by lowering the voltage setpoint temporarily. I'd recommend reducing the cut-off voltage of a two-step control to around 13.8 when you know you'd be motoring a lot. If your electrical load is large and much of that load is used when you're motoring, you may be able to bump that voltage cut-off up a bit without harm. The main advantage of a "smart" control (US$150 to US$300) is automatic battery protection from the effects of excessive voltage. If you are in doubt about which approach is right for you, go with the automatic three-step control and eliminate the worry.

Hook-up

There are a few other considerations when switching to a high-output alternator. You'll probably need to increase the size of the alternator output wire. You should also have some method of monitoring alternator output, either with a system monitor or a single ammeter placed in-line in the output wire.

Correct pulley size and width are important, since the ratio of engine pulley diameter to alternator pulley diameter determines the alternator shaft speed. Too large a pulley on the alternator will cause it to turn too slowly with less current output. Too small a pulley causes the alternator to turn too fast with the potential for damage at high engine rpms. Large-case alternators require dual pulleys and belts, so you might have to change the pulley set-up on your engine shaft. A professional electrical power expert can ensure that the alternator you are purchasing is properly matched to your existing engine and its pulley set-up.

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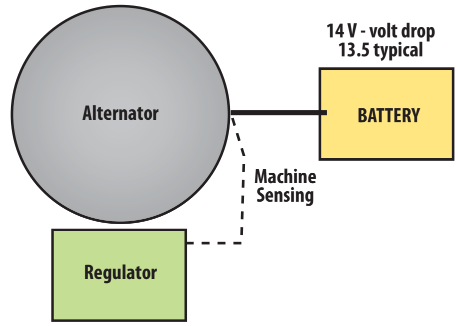
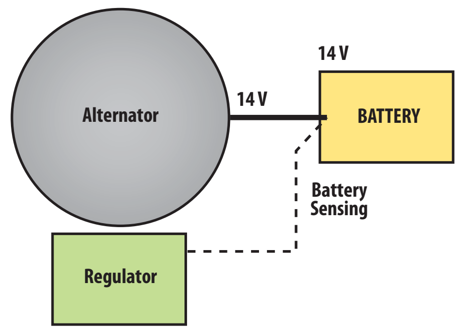
Power Generation

Upgrading an alternator or regulator isn't simply an off-the-shelf purchase. You need to consider all components of the boat's charging system.

By John Payne





An alternator is the electrical powerhouse for most boats. There is a wide range of alternators available, from air cooled to water cooled, and all are derived from various vehicle applications. In most cases, you get what comes with the boat's marine engine with its purpose of simply topping up the start battery. On many boats, the alternator is then required to change function to that of charging large capacity and deeply discharged battery banks. Vehicle alternators are designed around the basic criteria that includes the maximum current required not just to charge but to also supply electrical power to the vehicle systems and the rotational speed range, that is the operating speed of the engine, including the low idle speeds of many engines including slow traffic conditions. Of course, this varies considerably to the service we want to subject the alternator to on our boat; namely, charging large capacity deeply discharged battery banks in short time periods with relatively low engine speeds, where the engine changes from a propulsion source to just a power generation source.

Alternator 101

The alternator consists of a fixed three-phase winding called the stator, and stator windings are formed onto a laminated core. The rotor is the rotating part of the alternator and the rotor shaft typically comprises 12 magnet poles, along with the excitation winding that terminates at each of the two slip rings. There is also a cooling fan at either one or both ends of the shaft and the bearings that support and enable the rotor to turn. As the rotor turns, the magnetic flux flows through the pole body and across the air gap to the stator winding and back across the air gap and opposite pole to complete the magnetic circuit. During this rotation, this field of force cuts through the three stator phase windings and every 360° rotation induces six sinusoidal waves within each phase. An excitation current is used to generate a magnetic field within the rotor so that required alternator voltage can be induced into the stator windings. The excitation current flows through the exciter diodes, then through the brushes to the slip rings and to the excitation winding. The brushes are normally made of copper graphite and are spring-loaded to maintain correct slip-ring contact pressure. This goes to the field terminal of the voltage regulator and then to negative terminal of the voltage regulator. The circuit is completed as it goes back to the stator winding through the power diodes where it's then rectified to produce a DC output for battery charging though the full wave bridge rectifier. There are variations in alternators and they tend to follow automotive developments with a trend towards higher outputs for smaller package sizes and lower weights. There have been significant diode rectifier improvements that also improve the cooling and therefore efficiency and power outputs. Improved heat transfer from the stators also improves efficiency so that many modern vehicle alternators are far superior to standardized units often coupled to marine engines and worth consideration when planning to upgrade. Marine alternators are ruggedized units that are over engineered, corrosion resistant and ignition protected.

One must also consider the engine speed because, if you are trying to charge at low or idle speeds, the factor of pulley ratios is important. The alternator will only start to produce electrical power at a specific cut-in speed and this is the ideal maximum alternator output at the lowest possible engine speed. The alternator has three speed levels that need to be considered as there is a direct relationship between the alternator output current, efficiency, torque, horsepower (kW) and the alternator speed. Makers produce graphs and the ideal speed can be selected from these characteristics, so get hold of those for your alternator. The alternator speed ratings are called the cut-in speed when a

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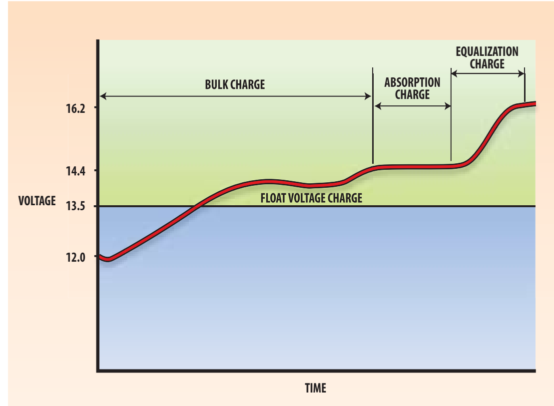
voltage is generated; the full output operating speed when full rated output is available and the maximum output speed for the alternator, after which destruction will occur. The trade-off is that if the pulley size is too small the alternator may over-speed and if too large the proper cut-in speeds may be wrong.



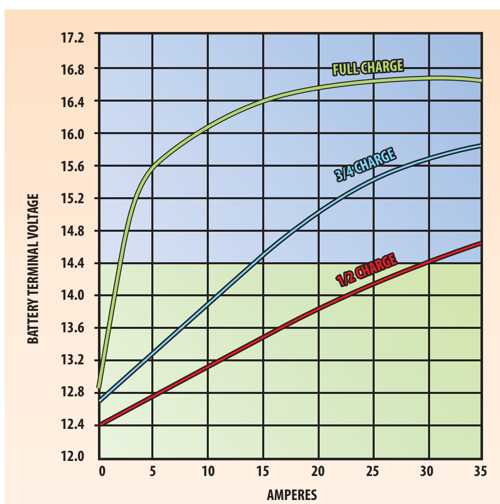
There are four recognized stages of a charging cycle and understanding these stages is crucial to understanding charging problems.

Making DC from AC

The rectifier part of any alternator comprises a bridge or network of six diodes and these are interconnected between the positive and negative plates. Two power diodes are connected in each phase, which means that one diode is connected to the positive side and one to the negative side. These diode plates also serve as heat sinks to help dissipate the heat generated from the power conversion process within the diode. The positive sinusoidal half waves pass through the positive side diodes and the negative half waves pass through the negative diodes. This rectifies the three generated AC phase voltages into the DC output for charging. Two diodes are used on each winding to provide full wave rectification. The rectifier diodes also prevent the battery discharging through the three phase winding as the diodes are polarized in the reverse direction.

Role of Exciter Diodes

The exciter or pre-excitation diodes are a network of three low power diodes that rectify each AC phase and then give a single DC output for the warning light function. The exciter diodes are necessary as the residual magnetism of the stator core is generally too low when engine is operating at relatively low revolutions during starting and idle to initiate the self-excitation that is required to build up the magnetic field. This condition only occurs when the alternator voltage exceeds the voltage drop across the two diodes. Current then flows through the alternator warning light, through the excitation winding then back through the voltage regulator to ground. This current then pre-excites the alternator. The warning lamp also functions as a resistor and provides pre-excitation current, which generates a field in the rotor. The power rating of the lamp is quite important and 2 to 5 watts is typical. As many have discovered, the alternator will often not operate when the lamp fails and this is due to the dissipation of the residual voltage or magnetism. When the lamps are undersized you will see that characteristic need to "rev" the engine to get the alternator to "kick" in.



When battery voltage rises to 50% charge, the regulator starts limiting the voltage level. As battery voltage level rises, the charge current levels off and this is called the regulation zone.

About Voltage Regulators

The voltage regulator is essential to the safe and efficient charging process of any battery and also to prevent the alternator voltage from going above a nominal set value that is typically 14 volts. Higher voltages could damage the battery, the alternator and other boat electrical and electronic equipment. The voltage regulator used to be a large and separate electromagnetic contact type device. Modern electronics design has seen the development of regulators that are solid state with no moving parts, very reliable and temperature tolerant with high control accuracy. Earlier solid-state regulators had discrete components and they are now what are called monolithic with everything in all one microchip or hybrid regulators that incorporate both integrated circuits and transistors. The regulators are usually integrated with the brush gear or mounted internally adjacent to it. Voltage regulator sensing is normally connected to the main output circuit. The voltage regulator is a closed-loop controller that var-

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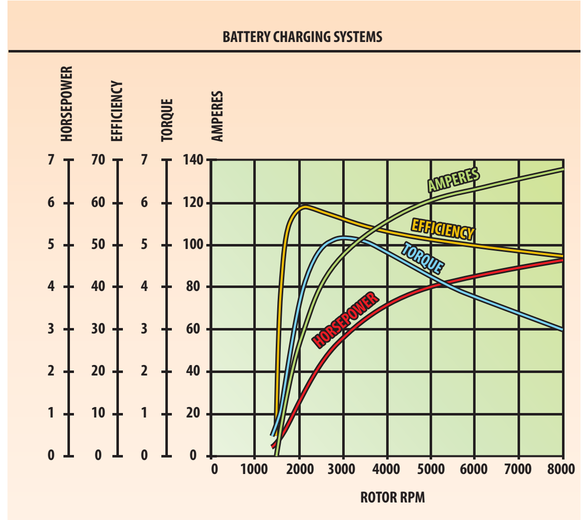
ies the field voltage when the voltage drops below the set value or exceeds the upper set point value. The majority of alternators are configured as machine sensed. This means that the regulator senses the output terminal voltage and then controls and maintains the alternator output voltage to the nominal set value. The machine sensed voltage regulator does not compensate for charging circuit voltage drops. Voltage drops include under-rated terminals, cables and the negative path back through the engine block. Many regulators now have battery-sensing capability that will sense the voltage at the battery terminals and adjust the alternator output voltage to the nominal voltage. The battery sensed regulator compensates for voltage drops across diodes and charge circuit cables. As a note, regulators and field windings have two possible field polarities and this has nothing to do with the positive output of the alternator. The positive polarity regulator controls a positive excitation voltage. Inside the alternator, one end of the field is connected to the negative polarity. The negative polarity regulator controls a negative excitation voltage. Inside the alternator, one end of the field is connected to the positive polarity. You have to make sure you get the right regulator.



This graph shows the relationship between output current, efficiency, torque and horsepower against rotor revolutions. Optimum speed can be selected from these characteristics.

Increasing Charging Performance

The simplest way to improve charging performance is ensuring that all cables and terminations are rated for the maximum current, so that voltage drop is reduced or minimized. Additionally, you can reduce losses by installing a negative cable the same size as the positive from the alternator case or negative back to the battery. Also ensuring good ventilation helps to reduce overheating when using a special regulator so reducing losses. You can opt for installing a much higher output alternator; however, if the output is within the 70- to 90-amp output range, the best solution is often to use of one of the many regulators designed to maximise the output and optimise charging. Larger output alternators often require multiple drive belts and pulleys and this costs more in engineering and economic terms.

Smart Regulators

The traditional voltage regulator is designed to recharge a partially discharged battery in a relatively short period and also to supply the onboard electrical power in the vehicle. To achieve the efficiencies we require on a boat, we have to look at improving the power availability of the alternator. The best way to do this is by using one the many "fast charge" voltage regulators on the market. These often "intelligent" regulators tend to be multi stage, step charge or programmed cycle devices that have either automatic or user settable charge settings. Alternators and regulators are inextricably linked to the battery sizes along with battery types, and matching of charging characteristics is important. The use of any fast charge regulator must consider the whole system and not simply be used in isolation as a cure for charging problems. Most multi-step regulators have similar operating principles. The first charging step is the bulk charge phase and this is where voltage rises steadily up to approximately 14.2 to 14.4 volts and maximum current output occurs up until approximately 80% charge level. Many fast charge regulators allow this to be set to suit the battery type and are different for AGM, gel or flooded cell lead-acid batteries. The second charging step is the absorption or acceptance phase and this is where the charging voltage is maintained at a constant level and the charge current slowly reduces. The third and final step is the float charge phase where voltage reduces to approximately 13.8 volts and maintains a float charge to the battery and this stage suits most boats where there are long motoring periods. Some cycle regulators repeat this so that the battery is brought up to full charge and follows the optimum charge curve to a battery, which can only accept charge current at a finite rate. Of the Balmar regulator range, one has a microprocessor-controlled regulator and also has several user selectable multi-voltage variable-charge time programs that suit six battery types. The basic principle is the use of an automatic absorption time program. Some regulators also incorporate battery temperature compensation sensors and alternator temperature sensors for improved accuracy. Some of these units have an equalization function that is a user adjustable feature. The function enables the application of an equalization current until battery voltage reaches 16.2 volts. Other regulators generally follow similar principles that are variations on step charging techniques.

The smart fast charge voltage regulator is only effective in upgrading the charging performance of an alternator when all parts of the charging system are considered. If the battery bank is too large for the alternator capacity, the smart regulator may simply stress and overheat the alternator, causing early failure. The charging source must be capable of meeting the expected maximum charge current demands. The factor of speed range also needs to be considered and getting the right pulley ratio is an important issue. In many cases, under rated cables and terminations also become a problem as the circuits are designed on some systems to carry less than the rated maximum output of the alternator.

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Using a Multimeter

A multimeter is the quintessential tool to detect DC and AC electrical faults and to measure voltage, current and resistance.

By Larry Douglas

There are few worse environments for electricity than a boat. Combine broad temperature ranges, vibration, moisture and salt spray and electrical problems are a common enigma for most boaters. When it happens, you need to be prepared with the knowledge and proper tools to solve the problem. Perhaps the most common and most important tool for electrical troubleshooting is the portable multimeter, also referred to as a voltmeter or VOM for an analog unit, or DMM for a digital one.

Multimeters come in many sizes, prices and types. All measure voltage, current and resistance; some models also measure inductance, frequency and/or capacitance. Though more costly, my preference is a digital unit. Those who have used analog multimeters (VOM) will find that the increased accuracy, repeatability and ruggedness of the modern DMM, although more expensive, makes them a better choice for marine use. A suitable DMM for boat use should measure common AC and DC voltages, DC current up to 10 amps and resistance from less than one ohm to over 10,000 ohms. It should display at least three full digits plus a leading "1" and be accurate to 1% or better. Some DMM units are auto ranging, which means once you select a function, the meter adjusts the decimal point based upon the measured value. This makes them slightly easier to use but adds to the price. You can spend less than US$20 or more than US$170 on a portable DMM

Always ensure selector switch is in the correct position and the red (hot or "+") and black ("COM" or "–") lead ends are in the proper input jacks before taking a measurement.

Check meter operation before every use: move the selector dial to the X1 ohms scale and touch the probe ends together. If you get a reading other than "0," the battery or fuse needs replacing or the leads or meter are defective.

Selector switch on "DC voltage" scale checks battery voltage (no loads).

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DMM checks loads or voltage drop on an existing circuit before adding accessories.

and, as with most other tools, you get what you pay for. Pick a name-brand meter that gives you the features you like. If you choose a meter from the low end of the price scale, you might want to buy two. The second unit will come in handy when you drop the first one. Also purchase a spare set of leads with probes. They will probably wear out long before the meter needs replacement and a broken lead results in an erroneous reading or worse, fools you into thinking the power is off when it's not.

Measuring Basics

Everytime you turn on your multimeter, form the habit of moving the dial to the "X1 ohms" scale and touching the two probes together. The display should move from indicating an open circuit to nearly 0 ohms. This confirms that the meter and probes work and is an important safety check. Now select the appropriate measurement type (AC voltage, DC voltage, resistance) and the range, except auto ranging meters. The following information is not intended to replace the manual that accompanies your meter. Now place the red and black probes across (in parallel with) the circuit to make the voltage or resistance measurement.

Current (amps) measurements are not made in exactly the same way, as are voltage or resistance measurements. They require electrically inserting the DMM in series with one of the load wires. This usually requires relocating one or both probes into sockets on the DMM that are used only for current measurements. Form the habit of always returning the probes to the proper locations for voltage and resistance measurements immediately upon completing the current measurement. If you forget, you'll cause a short circuit the next time you use the DMM for a voltage measurement. Most digital meters have internal fusing and often a spare fuse for such an occurrence.

***Top:* Use the low-resistance scale to test a fuse. *Left:* To test equipment for resistance, disconnect the circuit (otherwise, you will measure the entire circuit), set selector switch to the proper resistance scale and connect test leads, red to the positive side. Defective equipment will have no resistance reading.**

TIP:

MEASURING THE LINE

When troubleshooting electronic equipment, don't overlook the obvious. Connections on a boat eventually work loose. Fuse holders corrode. Batteries need constant attention. Any wire that moves will eventually fail and will do so at the worst time. Starting at one end of the circuit, use your meter to measure all components in the line. Often it's a minor problem that's easily fixed.

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CORROSION CONTROL

A bonding system is only as good as its conductors, connections and sacrificial anodes. Using a digital multimeter or analog corrosion test meter, you can measure current at an underwater metal fitting and prevent costly damage from self-generated corrosion.

Story and photos by Sue Canfield

The potential for galvanic and stray current corrosion is a fact of life for many boats, especially those that operate in seawater. Galvanic corrosion can occur whenever a boat's dissimilar underwater metals are electrically connected, whether by direct contact, a wire conductor or even an opportunistic conductor like bilge water. Differences in the inherent electrical potential of dissimilar metals in seawater, typically measured in millivolts (mV), generates low-level currents (Figure 1). These currents over a period of months or years gradually erode the least noble metal (anode) while protecting the more noble metal (cathode). Stray current corrosion is induced by the leakage of higher levels of current from an external electrical source, through a boat's underwater metal fittings. Stray current (DC) is like galvanic corrosion on steroids; it can destroy underwater metals in a few weeks, days or even hours.

A proper bonding system, one that electrically ties together all of your boat's metals in contact with the water prevents corrosion damage due to self-generated (coming from your own boat) galvanic and stray current. It does not prevent damage due to galvanic or stray current coming from sources outside your boat. That requires measures that are beyond the scope of this article.

In a bonding circuit installed solely for corrosion control, the interconnected metals are protected by one or more sacrificial anodes typically made of zinc, although magnesium and even aluminum anodes are sometimes used. On most boats, this corrosion protection circuit is part of a larger bonding system connected to the engine negative terminal or its bus. This system typically includes other major metal objects onboard: rigging and chainplates, engines, metal tanks, metal cases on electrical equipment and so on. By providing a low-resistance electrical path to ground, a proper bonding system prevents the build up of voltage differences between otherwise isolated metal objects. It also minimizes stray current corrosion.

A bonding system is only as good as its conductors, connections and

Galvanic Series	Corrosion Potential Range in Millivolts	
Magnesium and Magnesium Alloys	-1600	-1630
Zinc	-980	-1030
Aluminum Alloys	-760	-1000
Cadmium	-700	-730
Mild Steel	-600	-710
Wrought Iron	-600	-710
Cast Iron	-600	-710
13% Chromium Stainless Steel, Type 410 (active in still water)	-460	-580
18-8 Stainless Steel, Type 304 (active in still water)	-460	-580
Ni-Resist	-460	-580
18-8, 3% Mo Stainless Steel, Type 316 (active in still water)	-430	-540
Inconel (78% Ni, 13.5% Cr, 6% Fe) (active in still water)	-350	-460
Aluminum Bronze (92% Cu, 8% Al)	-310	-420
Nibral (81.2% Cu, 4% Fe, 4.5% Ni, 9% Al, 1.3% Mg)	-310	-420
Naval Brass (60% Cu, 39% Zn)	-300	-400
Yellow Brass (65% Cu, 35% Zn)	-300	-400
Red Brass (85% Cu, 15% Zn)	-300	-400
Muntz Metal (60% Cu, 40% Zn)	-300	-400
Tin	-310	-330
Copper	-300	-570
50/50 Lead/Tin Solder	-280	-370
Admiralty Brass (71% Cu, 28% Zn, 1% Sn)	-280	-360
Aluminum Brass (716% Cu, 22% Zn, 2% Al)	-280	-360
Manganese Bronze (58.8% Cu, 39% Zn, 1% Sn, l% Fe, 0.3% Mn)	-270	-340
Silicon Bronze (96% Cu Max., 0.80% Fe, 1.50% Zn, 2.00% Si, 0.75% Mn, 1.60 % Sn)	-260	-290
Bronze-Composition G (88% Cu, 2% Zn, 10% Sn)	-240	-310
Bronze ASTM B62 (thru-hull) (85% Cu, 5% Pb, 5% Sn, 5% Zn)	-240	-310
Bronze Composition M (88% Cu, 3% Zn, 6.5% Sn, 1.5% Pb)	-240	-310
13% Chromium Stainless Steel, Type 410 (passive)	-260	-350
Copper Nickel (90% Cu, 10% Ni)	-210	-280
Copper Nickel (15% Cu, 20% Ni, 5% Zn)	-190	-250
Lead	-190	-250
Copper Nickel (10% Cu, 30% Ni)	-180	-230
Inconel (78% Ni, 13.5%, Cr, 6% Fe) (passive)	-140	-170
Nickel 200	-100	-200
18-8 Stainless Steel, Type 304 (passive)	-50	-100
Monel 400, K-500 (10% Ni, 30% Cu)	-40	-140
Stainless Steel Propeller Shaft (ASTM 630: # 17 & ASTM 564: # 19)	-30	+130
18-8 Stainless Steel, Type 316 (passive) 3 % Mo	0	-100
Titanium	-50	+60
Hastelloy C	-30	+80
Stainless Steel Shafting (Bar) (UNS 20910)	-250	+60
Platinum	+190	+250
Graphite	+200	+300

FIGURE 1
The galvanic series of metals in seawater (relative to a Na/NaCl reference electrode) flowing at 8' to 13' (2.4 to 4m) per second and at a temperature range of 50°F to 80°F (10°C to 26.6°C). In general, the greater the difference in electrical potential between two connected underwater metals, the greater the likelihood for galvanic corrosion. Actual corrosion rates are the product of many factors, including the exposed surface area of the metals, the conductivity and flow rate of the electrolyte.

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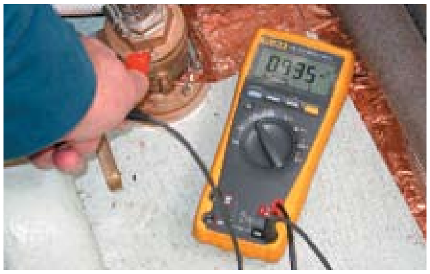

The reading taken at this bronze seacock (935 mV) indicates it's actually overprotected, although not dangerously so. Note the copper bonding strip.

sacrificial anodes. If a low-resistance electrical path is not maintained, galvanic and stray current corrosion can occur. If the anodes supply too little voltage, bonding will actually promote corrosion by providing the electrical connection needed for galvanic current to flow.

System Continuity Scan

To insure a low resistance current path, bonding circuit conductors should be at least 8 AWG insulated, stranded copper or, if copper tubing or strips are used, have a minimum thickness of 1/32" (.8mm) and a minimum width of 1/2" (12mm). Per ABYC, insulated conductors should be green or green with a yellow stripe. Check for bonding system continuity while your boat is blocked ashore or sitting on its trailer. After setting your multimeter to measure ohms, just touch the probes of a digital multimeter to any two metal fittings tied into the bonding circuit, such as the propeller and sacrificial anode on the propeller shaft, the rudderstock and an adjacent thru-hull fitting. All readings should be electrically perfect, such as 1 ohm or less. If not, check for damaged conductors and loose or corroded connections at the affected fittings. Make repairs as needed and retest. Once your boat is back in the water, the electrical current produced by dissimilar underwater metals will make continuity readings impossible.

Performance Check-Over

After you've launched your boat, you can avoid potentially costly and time-consuming repairs by checking bonding system performance at regular intervals. Hire a marine surveyor or marine electrician to do a corrosion control survey for you, or save money by doing it yourself. In the latter case, you'll need an analog corrosion test meter or a good quality digital multimeter, and a silver/silver chloride (Na/NaCl) reference electrode. Reference electrodes, stable mixtures of a metal and metallic salt, are often called half-cells. They function as one electrode in an electrochemical cell when measuring the electrical potential of other metals. (Refer to Figure 2 for equipment sources and prices.) A multimeter with high input impedance allows you to test your boat in either fresh- or saltwater with repeatable results.

You'll also need paper and a pen to record your test data. Start by listing all the underwater metal fittings (those that are accessible from inside the hull) that are or should be included in your boat's bonding circuit. Fittings include thru-hulls, transducers, engines, strainers, propulsion and rudder shafts and logs, sacrificial anodes, etc. Don't worry if you forget some, you can add them later as you move through the boat.

Next, unplug your boat's shorepower cord (if any) and disconnect your batteries. If you'll be using a multimeter, set the function switch to DC volts. Connect the reference electrode to the volts input jack. Lower the electrode over the side until it's a foot or more below the water's surface. You'll get more reliable readings if the electrode is near rather than not immediately next to the fittings being tested.

If necessary, tape the lead to the toerail or tie it to a nearby stanchion so you won't pull the electrode out of the water as you move through your boat. Connect the test probe you'll be using to contact each underwater metal fitting to the multimeter's common jack.

Starting at one end of the boat and working toward the other, take a voltage reading at each metal fitting. If the lead on the reference electrode is too short to allow you to reach all of your boat's underwater fittings, buy or fabricate an appropriate extension. Analog corrosion meters typically display all millivolt readings as positive values and indicate the degree of protection for bronze, steel and aluminum. When using a digital multimeter to test your boat's bonding system, keep a copy of the table in Figure 3 handy

You can check the performance of your boat's bonding system using an analog corrosion test meter (left) or a good quality digital multimeter (right) and a silver/silver chloride (Na/NaCl) reference electrode. The corrosion meter above is the Capac unit sold by US Filter; Guest and Professional Mariner make less expensive models.

for quick reference.

Voltage at all bonded underwater hardware should be the same. If not, check for damaged bonding conductors and loose or corroded connections at the affected fittings. Make repairs as needed and retest.

How much sacrificial anode alloy does your boat need? Enough to maintain a minimum negative shift of 200 mV relative to the potential of the least noble metal being protected as listed in Figure 1. If the voltage shift is less than 200 mV, add more anode. Allow for normal wastage during the boating season. Remember that overprotection can create problems, especially for wood or aluminum boats. Be sure to write down the voltage reading for each fitting. You'll want to keep a copy of the data you collect with your boat's maintenance records for future reference.

FIGURE 2 Corrosion Test Equipment

If you own a good quality digital multimeter, you can buy everything else you'll need (blue type) to monitor your boat's bonding system for US$100 to US$130.

Guest www.guestco.com	Analog meter, Na/NaCl reference electrode on Na/NaCl half cell on 10' lead (#2435)	$ 70
Professional Mariner www.pmariner.com	Analog meter, Na/NaCl reference electrode on 20' lead, 10' test lead with clamp (#20086)	
	Na/NaCl reference electrode on 20' lead (#20008)	$169
	20' red lead extension (#20009)	$ 33
	10' black test lead with clamp (#20007)	$ 33
	Corrosion Workbook (#20001)	$ 50
US Filter www.usfilter.com	Capac analog meter, Na/NaCl reference electrode on 75' lead (33419)	$760
	Na/NaCl reference electrode on 75' lead (#33428)	$225

Listed prices are in U.S. funds. Prices for Guest products were taken from West Marine 2003 catalog. All other prices are for direct purchase from the manufacturer. Prices may be lower than those listed.

Stray Current Audit

Next, reconnect your batteries and turn on each DC circuit, one at a time. Check the voltage at any bonded fitting as each circuit is activated. Make sure that the equipment controlled by the circuit is turned on as well. If the voltage reading changes, stray current is leaking into the bonding system, either from DC circuit wiring or the equipment it serves. Turn off the circuit until you can track down and eliminate the problem. Hire a qualified marine electrician to help you, if needed.

Finally, plug in your boat's shorepower cord. If doing so produces a sustained change (not just a pulse) in the voltage reading at any bonded fitting, current is leaving or coming onboard via the cord's green grounding wire. To correct this problem, you'll need to install a galvanic isolator or isolation transformer. [Ed: Refer to page 112 for more on isolator installation.] Now check the voltage at any bonded fitting as each AC circuit is activated. Again, make sure any associated equipment is turned on as well. If there's a sustained change in the voltage reading, stray current is leaking into the bonding system from the AC circuit that has just been turned on. Since alternating currents are equal and opposite, stray AC current theoretically causes little corrosion. That's the good news. The bad news is that it poses a potentially lethal electrical shock hazard. Keep the shorepower cord unplugged until you can track down and eliminate the problem. As needed, hire a qualified marine electrician to help you.

How often should a bonding system be checked? At least annually, after moving to a new (permanent) slip, or whenever there is accelerated wastage of the sacrificial anodes on your own or neighboring boats.

About the author: Susan Canfield is a NAMS-certified, SAMS-accredited marine surveyor in Annapolis, Maryland. A frequent DIY contributor, she also teaches marine surveying at WoodenBoat School in Brooklin, Maine.

FIGURE 3

If you use a digital multimeter to test your boat's bonding system, keep a copy of this table handy for quick reference.

Metal	Degree of Protection/Millivolts			
	Freely Eroding	Protected	Overprotected	Damaged*
Bronze	<500	500-700	>700	>1250
Steel	<750	750-950	>950	>1200
Aluminum	<800	800-1050	>1050	>1200

*To metals and/or paint coatings

Diagnostic Troubleshooting

When things go wrong, you are best equipped to make the repairs if you follow straightforward procedures. A systematic approach to diagnosis can often get you underway again or be the logical precursor to having cost-efficient service.

By John Payne

As a boat owner, it's important to develop some diagnostic skills and strategies. Diagnostic skill is what separates the rookies from the masters. It follows a logical process of evaluating equipment or a system and determining why it's not functioning or is deviating from normal performance. This process involves the collection and identification of evidence, such as signs of burning or heating, any unusual sounds or any acrid or other unusual burning smells, a rise in temperature or variations above normal. This physical round of investigation is then supported by the proper use of instruments and data analysis. This forms the basis for testing theories and assumptions, so that the precise fault can be identified and subsequently rectified.

Key D-Factors

Consider the factors in any electrical or electronics diagnostic exercise. First is "systems knowledge." Understand the basic operations of the equipment. It's common to find that faults are in fact only improper operation of the equipment. If there is a basic understanding of the system it's considerably easier to divide the system into functional blocks, which makes the process much easier. A circuit diagram, for example, shows all system components, which makes it a primary functional block.

Next is "systems configuration." Understand where all the system components are installed, where connections and cables are and where supply voltages originate.

The third factor is "systems operation parameters." Understand (and memorize) what is "normal" operation and the parameters or operating range of the system. All too often, expectations are very different from reality. Last, is "test equipment." Understand how to use a basic multimeter. Be able to perform the simple tests of voltage and continuity of conductors. [Ed: Refer to page 125 for instructions on how to use a multimeter.]

Five-Part Harmony

The following approach should be used in troubleshooting electrical and electronics systems. This is the groundwork for possible service person intervention and follows procedures commonly done in the trade.

System Inputs. Check that the system has the correct power input. Don't assume anything. For example, there may be a voltage input but it may be too low. Check it with a multimeter.

System Outputs. Does the system have an output? Is the required voltage or signal being put out? If there is input and no output, then you have already isolated the main area of the problem.

Fault Isolation. In any diagnostic exercise split the system in two. This method is ideal when troubleshooting lighting circuits. It instantly isolates the problem into a specific and smaller area.

Fault Complexity. Most problems usually turn out to be rather simple. Start with the basics. Don't try to apply complex theoretical ideas you don't fully understand, as the result is a lot of wasted time. Stop and ponder the situation first.

Failure Causes. When a fault has been isolated and repaired, ascertain why the failure occurred, if possible.

Verify the Evidence

For many, calling a service person is an inevitable part of boating with modern electronics. In some cases, the fault is obvious and the call could have been avoided. Before you seek

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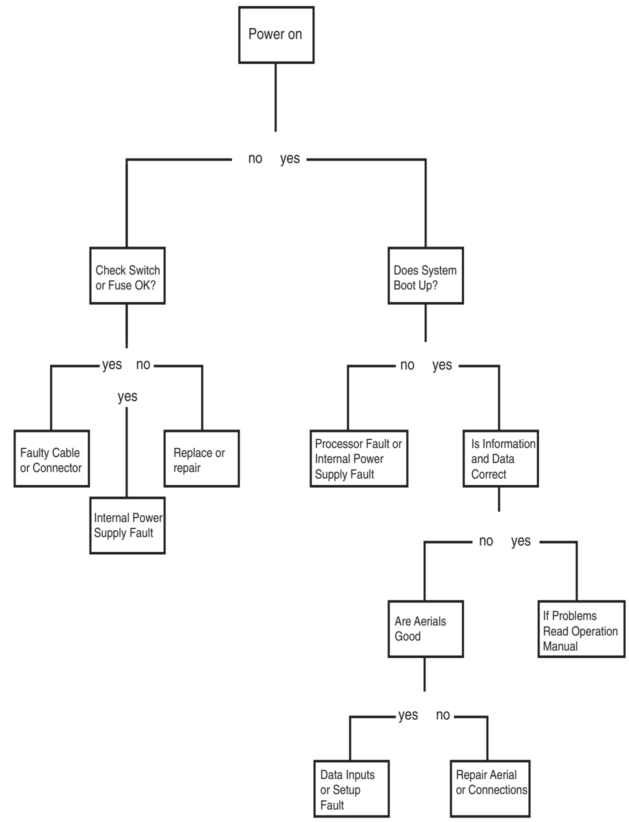

professional help, ask yourself the following questions and consider the related tasks.

Did I operate the equipment properly? Read the manual again and go back to basics. When you are sure that you have operated the equipment properly and it doesn't work then call a pro.

Are all the plugs in and power on? It's amazing how many people forget to plug in an antenna or put on the power. If power is on at the breaker and not at the equipment double-check that the circuit connection on the back of the switchboard is not disconnected. Check that the equipment fuse has not ruptured.

What were you doing immediately prior to the problem? Numerous faults occur immediately after working on often unrelated systems. The inadvertent disturbance of connections can and does occur regularly so check again.

Clearly document the sequence of events before the failure and the symptoms at failure. Building a profile may point to some other factors. This assists the technician and may also assist you in resolving the problem and avoiding the service call. Keep a current technical file onboard. If possible obtain copies of all needed technical manuals. This helps the service person and saves you time (and money) if you supply the information. When you contact a service person, ask for credentials and references. Technicians who have earned an ABYC certification in their field are usually top shelf.

Dealing with Technicians

Far too many boaters surrender control to a service person and elevate them to supreme status. It's better that you are present during the service call, if possible. It's your boat and your money, so be proactive. Here are some helpful pointers when dealing with tradespeople.

Be at the boat at the appointed time. I have lost count how many times I'm left waiting at the dock. Just like a taxi driver, wait time is extra. Have everything opened up and provide good access, where required. I have often wasted hours, while lockers are emptied, panels are removed and so on. If you are a liveaboard get everyone up and out of their bunks. I have had several occasions where I literally had to wake someone up and request access to the area under the bunk.

Pre-clean the working area. It's quite unfair to expect service people to work on filthy engines or dirty bilges and elsewhere. Consider laying down drop cloths to prevent grime being tracked through the boat; if you don't mind, then ignore this advice. Have a good tool kit ready. It's impossible to carry a complete tool set onto every boat. Such assistance is greatly appreciated and saves both time and money.

Don't waste time drinking coffee and "jawboning." It's costing you money. Likewise don't keep asking if they have found and fixed the problem. You'll find out soon enough. Stay out of their way but be ready to provide help with any required tasks. Watch and listen. This is a valuable opportunity for you to develop some additional skills.

Be sure you receive a properly completed service sheet, along with a listing of parts replaced and why. Question what is unclear; unfortunately, there are unscrupulous people around, with less than the required skills, who simply keep changing parts until the device works.

AC System Troubleshooting

Fault finding in an AC electrical system is not so different from troubleshooting a DC electrical system but it does require extraordinary and diligent attention to personal safety.

By John Payne

The scorching is a symptom. Replacing the cable end fitting and/or the outlet is not the solution. There's a bigger issue here.

AC electrical current is potentially lethal and you must take every precaution to ensure that onboard systems are properly and safely installed and maintained. There are some basic tests you can do to troubleshoot AC power systems without calling in a specialist. However, if any of these exercises give you the jitters, consult a qualified marine electrician. While a licensed electrician should be generally well versed in electrical systems of all kinds, marine electricians are specialists, especially those who hold ABYC certification. Unintentional contact with live circuits can seriously injure or kill you so, before troubleshooting your boat's AC electrical system, there are some fundamental safety rules you must adopt to ensure your safety.

Never work on AC equipment, connections, wires or the service panel when the system is energized, i.e., "live." All power sources must be disconnected before touching any part of any circuit. Isolate and lockout circuits and equipment before opening them up. Before even opening the AC electrical panel always remove the shorepower supply plug from the boat's inlet fitting, make sure the generator is shut down and locked out and disconnect an inverter, if one is installed.

Voltage Connection

The nominal AC electrical system voltage configurations in common use in North America are 120/240 (single phase and Delta three phase) and 120/208 (Wye three phase). Though lower voltages reduce electric shock hazards to life and limb, special caution is still required. Though the standards that apply to marine electrical systems are the bare minimums, compliance with them saves lives and you should, at all times, follow the recommendations contained within the U.S. National Electrical Code (NEC) and the American Boat & Yacht Council's (ABYC) group of "E" standards.

In 120-volt systems, the shorepower is normally supplied through a 30-amp circuit. This electrical configuration provides for three wires; the black wire is "hot" or energized; the white wire is the neutral conductor and the green wire is the ground conductor. In a 120/240-volt system, there are some differences: namely, the red wires are "hot" but the ground and neutral wires remain the same as in the 120-volt arrangement. To add to the confusion, many other countries use IEC standard color codes and, in 240-volt systems, a brown wire is the "hot" conductor, a blue wire is the neutral and the grounding conductor is a green/yellow stripe wire.

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About Circuit Protection

An understanding of the basics of circuit protection is essential successful troubleshooting. Most boat AC installations have a circuit breaker on the marina distribution pedestal along with a ground fault circuit interrupter (GFCI) to detect and isolate ground leakage conditions. The GFCI is an important safety feature. If your dock power pedestal is not so equipped, it should be. The main circuit protective device is the circuit breaker. You should also have an AC main circuit breaker at your control panel with individual circuits also protected by circuit breakers.

There is a lot more to selecting and installing circuit breakers than meets the eye. The interrupting capacity of the circuit breaker must be able to break any prospective fault current levels. The important thing to understand is the breaker is there to protect the circuit wiring and not the connected equipment.

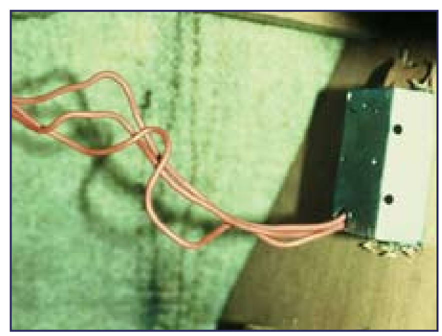
The main purpose of the protection system is to prevent currents from rising to a value above that of the wire rating. Overcurrent protection devices, i.e., fuses and circuit breakers, also protect the wires and connected equipment from the potentially destructive and excessive currents that happen under short circuit conditions.

This is an electrical stew recipe from a shade tree electrician: a little AC; a little DC; some electronic cables; and a fuel hose.

Troubleshooting this wiring spaghetti is an electrical nightmare. This is a candidate for a "do over."

AC System Commissioning

Most AC faults begin with improper installation and testing and the latter is also the foundation of troubleshooting. The following is the accepted practice for all shore installations (including your home). Step one is to check the ground resistance and continuity. The maximum resistance should be no more than 2 ohms between the main ground and between any other grounded points. Next, check the insulation resistance of an AC circuit using a 500-volt, DC-insulation tester (also known as a megger). Before doing this, always disconnect all the connected electronics and appliances and switch off all power sources. Turn on all switches so that all parts of the circuit are interconnected. The insulation resistance measured between the ground and all live conductors must have a minimum insulation resistance of 1 megohm (1 million ohms). Consider hiring a professional electrician with a meter to do these checks.



All red wires in an AC outlet? You could die laughing if you fiddle with this while it's energized.

One check you can safely do yourself is to perform a polarity check using a standard polarity tester. All of the switches, the circuit breakers and the equipment terminals must all be at the same polarity. You cannot have any crossed neutral and active conductors. Also, check for conductor short circuits. Use your ohmmeter and check between active and neutral conductors to ensure that only load resistances are present. With all switches set to the on position, check that there are no short circuits that are often caused by cable damage or possibly incorrect equipment connection.

Troubleshooting Ground Leakage Protection

A much more reliable and acceptable way to protect circuits and people, both on shore and on the boat, is to install ground leakage protection devices. Many marinas now have these installed on each circuit. Ground leakages are relatively common and nuisance tripping does happen at marinas (they do at mine), usually when someone plugs in an extension cord and power tool. If a GFCI trips and then trips immediately again when switched back on, then you should investigate and troubleshoot a more serious fault condition. The main and common causes of nuisance tripping are as follows: a connection between the neutral and ground downstream of an GFCI; crossed neutral between protected and unprotected circuits, often caused by extension leads with incorrectly wired plugs and sockets; damage to the cable insulation, a popular fault with old extension leads; water and moisture in a junction or terminal box or plug and socket (very common); cumulative leakages from several sources with many small leakage paths; absorption of moisture into heating elements; some tracking across dirty and moist surfaces to ground commonly caused by condensation and salt, particularly in a shorepower receptacle, where water ingress causes tracking. Never ignore any of these.

Circuit Troubleshooting

Most AC faults manifest themselves at the main switch panel. A circuit breaker "trip" is often the first clue to where to start your troubleshooting. The main criteria in any troubleshooting exercise is whether you have voltage or not and what current demands are being made. It's important to know that around 95% of all problems in AC power systems are due to failing or failed connections. When a connection becomes loose, it develops a high resistance. This is aggravated under load as current flow increases and the connection may simply melt or generate enough heat to cause a fire. The connection failure points include the source at the switch panel or, more commonly, within junction boxes or termination boxes at the connected equipment.

You get a small tingle or shock when you touch the case of any connected equipment. Any fault that occurs on an ungrounded or inadequately grounded equipment may lead to any exposed metal, e.g., the case or equipment cover, to be "live" up to rated voltage. Any person who contacts this equipment, even intentionally, may suffer a electrical shock, resulting in serious injury or even death. The purpose of safety grounding is to provide a low resistance path to carry any fault current and, during fault conditions, extremely high currents often flow. In normal practice, this high current ruptures fuses or trips circuit breakers.

The source of a shock or even a tingle needs immediate investigation. Immediately, turn off and disconnect all power and check the main grounding point first. Then, check the ground connections in the power outlets that supply the affected equipment. If you have a galvanic isolator, it should be checked. Always check your shorepower lead plugs and sockets and replace if they show signs of charring and burning. Remember that these conditions are symptoms of a problem. Just replacing the cable end fittings will not fix that problem.

The circuit breaker trips immediately after being activated. If you have a panel ammeter, it generally shows an off-the-meter full-scale deflection. This indicates a high fault current condition. Check if it's a load short circuit. To diagnose this fault, you need to find out whether it's within the load on the circuit or the circuit supply wire. Disconnect the load and recheck again. In most cases, it's the connected load, such as a light fitting, an appliance or a motor. If the fault is localized to the circuit cable, then the most common cause is a cable connection, in particular a junction box. Cable failures are relatively uncommon but, when they do happen, it's often due to chafe of the cable where it runs through a bulkhead transit point.

AC Jargon

What is a short circuit?

A short circuit occurs when two points of different electrical potential (positive to negative) are connected. In this condition, extremely large currents can flow, causing heat that can lead to fire. While a short circuit can be created intentionally, it's the unintentional one that causes the big problems.

What is an overload?

An circuit or current overload occurs when the circuit current carrying capacity is exceeded due to the connection of an excessive load. This conditions arises when too many electrical devices are attempting to operate on a circuit or a condition such as a stalled cranking motor or other electrical motor that creates excess load on a circuit. Current overload should cause an overcurrent protection device, such as a fuse or a circuit breaker to "trip" and interrupt the current flow until the overload condition can be corrected.
— JP

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The circuit breaker trips off several seconds after activation. The panel ammeter will show a slower increase in the current to a high value before tripping the breaker. This is typical of an overload condition. Check that any connected motors or pumps are not seized or whether the bearings themselves have seized. In some cases, a damp terminal box can lead to a slow and gradual breakdown in the insulation between terminals and a slow increase in fault current.

There is no power after the circuit breaker is closed. The first thing is to verify that you have power at the switch panel. If you have power, check that the circuit connection has not loosened, come off or burned the back of the circuit breaker. On many switch panels, the buss bar is soldered to one side of all distribution circuit breakers, so check solder joints. In many panels, the circuit breakers have a buss bar strip connected between them. Check that the breaker screw terminals are tight. It's also good to operate the circuit breaker several times. Some times the breaker mechanism makes poor electrical contact and several on/off operations often solve the problem. If all your tests show that the positive electrical supply is present, check that the negative wire is secure in the negative connection block.

Whenever you troubleshoot an AC system, always consider your safety as the highest priority. Once you have checked for voltage on a live system, remove the power and isolate before you continue troubleshooting. All electrical systems require a logical approach to isolating faults. The most common faults are always the most simple and often easily identifiable.

Safety with AC Power

- ***Before working on AC circuits onboard, disconnect the AC power from its source. Take your time and observe correct polarity. Have a reverse polarity indicator on board, either integrated into your AC panel or in a hand-held model. Check for correct polarity every time you plug into shorepower. Dockside AC with reverse polarity (the hot and neutral wires are crossed) can damage onboard AC equipment and be a definite safety hazard if the neutral and ground wires onboard ever become shorted, carrying hot AC current through the ground wiring.***
- ***Use GFCI receptacles on each circuit. A GFCI at the head of a branch circuit can protect outlets downline in the same circuit.***
- ***Install an indicator light that clearly shows that live AC power is present onboard.***
- ***Make sure your boat is wired by a competent marine electrician and adheres to ABYC recommendations.***

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Most electrical problems are the result of poor connections, accidental wire penetrations or chafing, or the use of substandard components that fail. By using high-quality components and good wiring techniques, you'll save yourself many headaches down the line. If you do encounter a problem in a circuit, first check all connections, including at switches and circuit protection devices, for corrosion and tightness. If everything seems okay, begin checking the continuity of the circuit with a multimeter or test lamp. Start at the battery positive terminal and work your way toward the loads. Do the same for the negative run. Continuity will be disrupted at the source of the problem. Isolate the problem area and repair or replace electrical components or wire as necessary.

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Troubleshooting Engine Electrical Systems

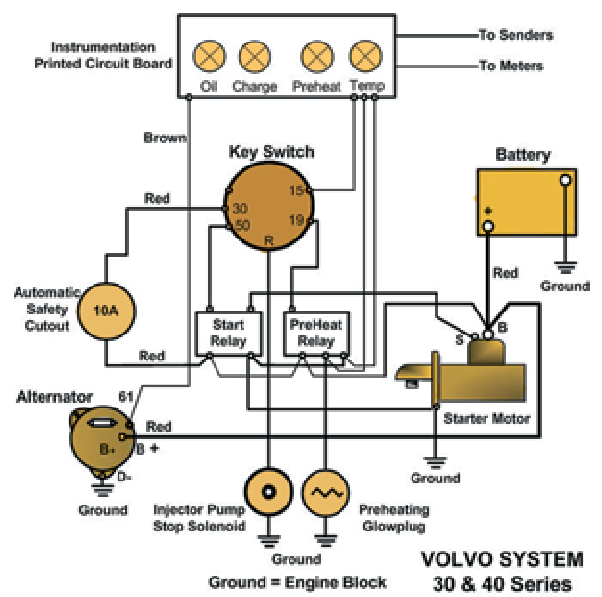
When your engine won't start, a systematic approach to diagnosing your often-ignored engine's electrical system can often get you underway again. Here's how.

By John Payne

At first glance, a circuit diagram appears to merge into a mass of wires and components. This looks intimidating when you're trying to troubleshoot problems and failures. Before you can troubleshoot, you need to know the sequence of electrical functions that take place to start an engine.

In some engines, the key is turned to a preheat position and the preheat time is either automatic through a timing relay or at the user's discretion. When the key switch is then turned to the "On" position, the engine control circuit is energized. When the key switch is turned to the "Start" position, the start solenoid is energized and pulls in to supply current to the start motor.

Image of a typical Volvo engine electrical system



The starting circuit is frequently cited, along with the associated control circuitry, as the main cause of engine failure. Other systems that take the blame include instrumentation and monitoring and charging and are not discussed in this article. This system comprises the starter and the preheating system and the control system for starting and stopping the engine. Various subsystem components and sub-systems that make up a starting system include a starting battery, engine control panel, wiring loom, preheating system and starter motor.

In the average starting system there are up to 16 possible single failure points. Failure of any single point brings down the entire system. A typical starting circuit consists of the DC positive circuit, which includes the battery, the battery connections, the battery isolator or a changeover switch, the cables from battery to engine, the solenoid connection and solenoid contacts, the starter motor and the various starter motor components such as the brushes, brush gear, commutator, bearings and windings. The DC negative side of the circuit also includes the battery connections, the engine block that is often part of the return path, the cable back to the battery and an ammeter shunt, if installed. The engine control system from the panel includes the key switch, stop and start buttons, wiring harness, harness connectors, control system fuses and engine stop solenoids.

Fault: Voltage Drop

High resistance that results in excess voltage drops in starting circuits is the most common fault. In most cases, this is caused by loose connections or, less commonly, corrosion at cable terminations. Battery changeover switches are also a big cause of starting problems with contact problems resulting in high resistance. Installing high quality switches is important to avoid failure.

The main start cables should be rated to have minimal voltage drop at full rated current. The starting cables should be kept as short as possible and as large as possible to minimize power losses and maximize the power availability to the starter. As an indication of the start current levels, the instantaneous stalled condition short circuit currents can be

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up to 3,500 amps in large engine starters before the load drops to a few hundred amps. Even very small values of resistance and resulting voltage drop can have significant effects and prevent starting.

Loose or corroded main engine fuses, multi-pin plugs, socket assemblies and engine control wiring loom harnesses are the most common reason for engine electrical failure.

Fault: Key Switch

There is nothing quite so unnerving as that deafening silence that follows when the key is turned and nothing happens. Failure to start is usually caused by circuit failures rather than reduced voltage conditions. Key switch connections and start buttons are not actually a frequent cause of problems, although, on some boats, water ingress and corrosion can cause failure. The terminal connecting the circuit from the key switch to the solenoid is a common failure point. They are relatively small and tend to work loose or even break. Some are actually slide-on connectors that can vibrate loose. Some circuits may also have a fuse protecting the ignition circuit and, in some cases, this may have poor connections or even blow and prevent starting.

Fault: Relays and Harnesses

Some engines use relays for operations and all relays should be checked. It is not uncommon to have relays work loose and they also may be affected by vibration that causes poor seating of contacts in the relay base. Several multi-pin plug and socket assemblies usually connect the main engine control wiring loom to the control console extension loom. As these are usually prone to heat and vibration, they should be disconnected and reinserted to ensure a good pin contact. Corrosion of pins is also a possible failure point, although it is less common.

Fault: Low Voltage

Low voltage at the battery starter terminals is the most common reason why engines crank over slowly without reaching the needed rpm to start. The usual assumption is that the starter battery is at fault, however starting batteries are generally less the cause than might be expected. This can be easy to verify by checking the voltage with a meter.

If the battery reads 12 volts and above, then it can be presumed to be charged, although some batteries may fail under load. Under starting loads a battery voltage should not drop below 9.5 to 10 volts. The principal failure mode is the battery connections and is the very first place to look if the voltage is correct. Taking off, refastening and tightening a battery terminal is usually enough to rectify the problem. This is only half the circuit and the negative terminal also must be checked. In poor connections with high resistance, it is not uncommon to simply feel the connection and it can be warm or even hot. In some cases, smoke can be seen rising after a start attempt.

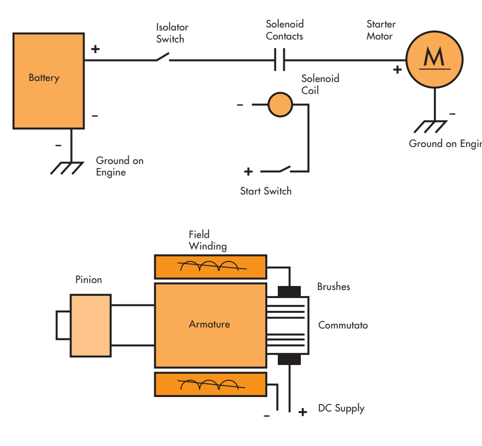

Image of typical single engine starting circuit layout.

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Fault: Start Terminals

The ominous click when an engine fails to start or the start solenoid chatters away without a start signals trouble with the starter motor and solenoid. Terminals often work loose or make inadequate contact. Many people try and torque the connections up with an adjustable spanner; however, there is no substitute for a socket or ring spanner to do it properly.

Fault: Engine Negative

A final electrical area to check is the engine negative connection. Loose bolts are a common cause of failure and must be tightened onto a clean surface to avoid high resistance. Remember the negative side of the circuit is as important as the positive and voltage drops occurring in both sides of the circuit will cause voltage drop and cause the starter to crank over slowly.

Fault: Glow Plugs

Partial or complete failure of the preheating glow plugs on direct injected engines is also a reason for slow starts. In most boats, the plugs are interconnected and even the loss of a single plug can cause problems. The connections on plugs need to be inspected and damage is often a cause of failure. Bad connections also cause voltage drop to the plugs with reduced heating.

Fault: Motor Failure

It's common to burn out starter motors from too many starts or excessively long start attempts, causing the overheating of starter windings. The bearings in starter motors may seize up causing slower rotation, although this is comparatively less common. [Ed: A step-by-step diagnostic guide and bench testing of starter motors and solenoids appears in DIY 2000-#1 issue.]

Use a voltmeter to test the start battery and replace if voltage drops below 9.5 volts under starting loads.

Maintenance Tasks

Preventive maintenance is essential to the reliability of your engine's electrical system. The first task is to ensure that the starter is mechanically secure. Engine starters on boats are, by default, generally located relatively low down towards the engine bilges. They are subject to leakages from seawater cooling systems; seawater injection points into exhaust elbows as well as any unexpected high bilge water level. Also check that the attached cables are of the correct rating and that the terminal nuts are properly torqued so that they do not work loose.

Faulty wiring connections are the most common reason for failure. Regularly examine every wiring connection, remove and check them, clean and refasten. Check loom connection plugs for damage. Visually check the cable looms and look for signs of chafe or damage. Check the pre-heating glow plug connections. Check that the plug connections and the insulators around the connections are clean and not causing tracking to ground.

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Breaking the Ground Circuit

This article on bonding, corrosion and grounding systems discusses galvanic corrosion and the steps to protect metal components immersed in seawater from damaging corrosion-producing voltages and currents.

By Susan Canfield

Any boat that spends a lot of time plugged into a marina's shorepower system is susceptible to galvanic corrosion induced by neighboring boats. Every boat that plugs into the marina service connects to every other boat plugged into that system via the green AC grounding wire. The effect of this situation creates a giant battery or galvanic cell **(Figure 1)**.

Figure 2 illustrates two boats moored side-by-side in a marina. Each is correctly wired with the AC grounding conductor connected to the off-engine DC negative bus and to the bonding system (if installed). Metal fittings on the bottom of the boat on the left are bonded and protected by an external zinc anode. The underwater hardware on the boat on the right is not protected. The zinc on the first boat is the negative plate in our giant battery. The running gear on the second boat

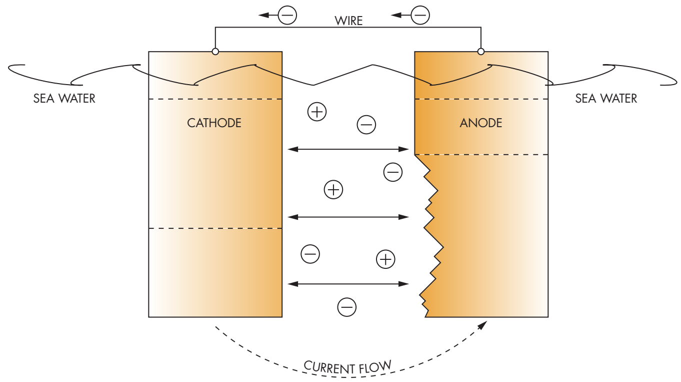

Figure 1

The Galvanic Cell: Galvanic corrosion occurs when two different metals are immersed in an electrolyte, in this case seawater, a conductor of electricity, and are in electrical contact either directly or via an external conductor. The electrical interaction between the dissimilar metals results in the corrosion of the less stable metal (more electro-negative potential), and protects the more stable metal (more electro-positive potential) from corroding. The combination of metals is known as a galvanic cell. In the electrolyte, the resultant electrochemical reaction causes negative ions to flow from the cathode to the anode, and positive ions from the anode to the cathode. Thus, the anode corrodes, while the cathode is protected.

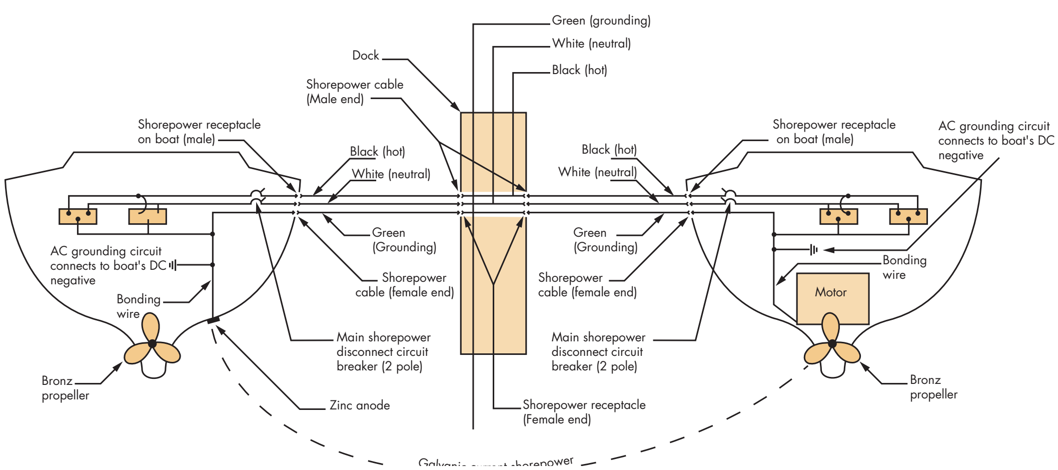

Figure 2

Galvanic Activity: When boats plug into a marina's shorepower system, the green AC grounding wire is the external conductor in a giant galvanic cell. Galvanically generated DC current flows along the AC grounding wire and between the underwater hardware via the electrolyte (seawater). The resultant galvanic activity causes the zinc anode to corrode first. When the zinc is depleted, the next least stable metal will start to corrode.

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forms the positive plate. When both boats plug into shorepower, the green AC grounding wire completes the circuit between the battery's two terminals. Galvanically generated DC current flows along the AC grounding wire and between the underwater metals via the electrolyte. The zinc anode — the least noble, which is, the most galvanically active metal — corrodes first. Powerboats with aluminum outdrives are particularly vulnerable. As a least noble metal, the aluminum outdrive becomes the sacrificial anode for surrounding boats without adequate zinc (anodic) protection. In this galvanic cell, the wetted surface of the aluminum, one of the least noble metals, is the anode, for surrounding boats with inadequate zinc protection.

Cutting or simply disconnecting the green AC grounding wire will eliminate the risk of galvanic current caused by other boats, but doing so creates a dangerous, potentially fatal shock hazard for anyone onboard and for swimmers who may be nearby while the boat is plugged in. Stray AC currents as low as 5 milliamps can cause muscle seizure and drowning. Don't cut or disconnect the green AC grounding wire. There is a better solution.

A galvanic isolator installed in the boat's shorepower grounding conductor breaks the grounding circuit. Mercury Marine's Quicksilver Galvanic Isolator kit (Part 18478a3, US$189) is UL listed and ignition protected, with a current rating of 60 amps. It uses a capacitor, which passes AC but not DC, so that a diode failure does not disconnect the grounding wire, a potentially lethal condition.

Corrosion Control

Fortunately, you can effectively block the galvanic cell created when a boat plugs into a marina's shorepower system (and the galvanic corrosion that it induces) by installing a galvanic isolator **(Figure 3)**. These devices are designed to protect a boat from passing or receiving low voltage galvanic current (up to 1.2 volts), while permitting dangerous AC voltage to pass safely via the green wire to the shore ground. Isolators contain one pair of diodes connected in parallel with a second pair conducting in the opposite direction. Diodes must be heavy duty to carry short-circuit amperage long enough for the circuit breaker to trip. Unfortunately, some isolators lack this capability. Other isolators parallel a capacitor — an electronic component that passes AC but not DC — so that a diode failure does not disconnect the grounding wire, a potentially hazardous condition.

When shopping for a galvanic isolator, look for one that meets the American Boat and Yacht Council (ABYC) standard and is labeled to indicated that it has been tested by an independent laboratory, such as Underwriters Laboratories, for compliance with that standard. Be sure that the current rating of the isolator you choose is at least the same as your boat's main shorepower

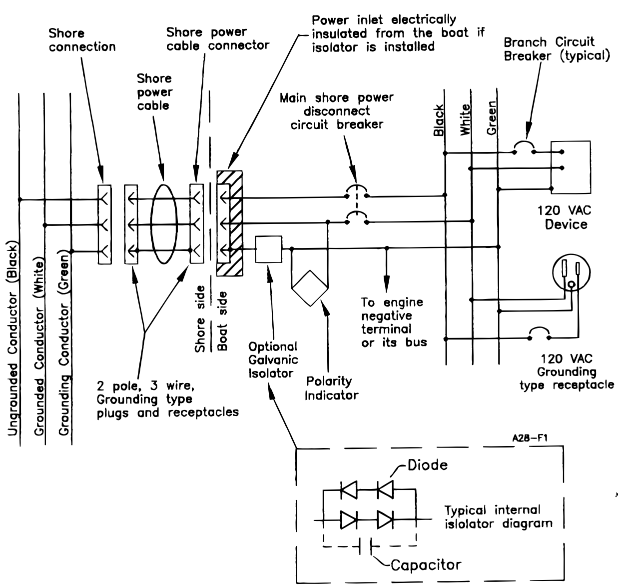

Figure 3

Typical Isolator Hookup:
When installing a galvanic isolator, ABYC standards require that it be placed in series in the incoming AC grounding wire immediately downstream of the shorepower inlet. If your boat has two shorepower inlets, you will need two separate galvanic isolators, one for each inlet. It's important that an isolator be installed in a ventilated, dry, and accessible location.

disconnect circuit breaker. When installed in a compartment containing a gasoline fuel tank or a gasoline-fueled engine or generator, the isolator must also be labeled as "ignition protected." All other factors being equal, galvanic isolators with a capacitor in addition to the usual diodes perform better than an isolator with diodes alone. They also cost two or three times more, but this difference becomes insignificant when weighed against the potential costs of galvanic corrosion.

If you already have a galvanic isolator installed in your boat, check to be sure it meets the ABYC standard. If in doubt, call the isolator's manufacturer. If your isolator doesn't measure up, upgrade to one that does. The vast majority of galvanic isolators currently installed in boats give no visual indication of diode failure. It's critically important to periodically check isolator function using a circuit tester or multimeter. Refer to the owner's manual for information on testing your galvanic isolator.

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