Highlights from - A Step-by-Step Approach to the Design of an AC or DC Marine Electrical System

One of the questions most frequently asked by boat owners during visits to our boat show booths over the years is "How do I go about designing a safe, compliant marine AC or DC electrical system that will meet all of my present and future power requirements?" Unfortunately, there is no simple answer to this question. However, after 25 years of listening attentively to customers, we have developed the following useful step-by-step approach to marine AC and DC electrical system design.

The marine industry is fortunate to have a boating standards organization. The American Boat and Yacht Council or ABYC is a consortium of boaters, marine surveyors, boat manufacturers, and the U.S. Coast Guard, working together to establish marine safety standards and recommended practices. Paneltronics is proud to have direct involvement in ABYC electrical standards development. Since 1988, we have actively participated on the ABYC Electrical Project Technical Committee. We design and manufacture our products to comply with ABYC standards, and we encourage you, as a potential customer, to do the same. Since we will be referring to ABYC Standard E-11, **AC and DC Electrical Systems on Boats* throughout this text, you should obtain a copy. Excerpts from ABYC E-11 can be found on our website www.paneltronics.com.

ELEMENTS OF A SAFE MARINE ELECTRICAL SYSTEM

Step 1 - Safety First:

Although every Paneltronics panel is completely pre-wired for ease of installation, we recommend that if you are not comfortable working with electricity and you want to avoid possible exposure to shock or electrocution, hire a qualified and experienced marine electrician. An ABYC Certified Marine Technician would be a great place to start. For a list of certified technicians, visit the ABYC website at www.abycinc.org, go to Certified Technicians and follow the screen directions.

A safety issue that must not be overlooked is fire. In an article "Why Boats Catch Fire," published in the July 2003 issue of *Seaworthy* magazine, a Boat U.S. Marine Insurance claim study revealed that 55% of all boat fires start onboard vessels in the AC or DC wire harness, or in related appliances. Once ignited, electrical fires are difficult to extinguish unless the fault can be isolated from the power source, since heat generated from shorted wiring can re-ignite a totally extinguished fire. To minimize the possibility of damage, injury, or loss of life caused by boat electrical fires, you must design your electrical system to both isolate and limit the current in each appliance circuit. Obviously, the related costs required to isolate individual circuits in marine electrical systems will be greater than those incurred for similar residential wiring. The justification for this additional margin of safety on boats is that an open window or door can provide an easy escape from a burning house, but walking away from a burning boat may not be an option. By isolating individual circuits, there is a greater likelihood that critical electrical appliances will function during a fire emergency.

Overcurrent Protection:

It is our view that the magnetic circuit breaker is presently the most reliable and cost effective device for use in the marine environment to isolate and limit the current in an individual appliance circuit. Although it is common practice to use single rating circuit breakers (i.e. 15 Amps) for all loads, this may, at best, provide only conductor (wire) protection. Proper circuit breaker selection and sizing is critical. By selecting the proper amperage rating for each load (ABYC E-11.10.2.2), both the conductor and the individual appliance connected in the circuit will be isolated and current limited.

CIRCUIT BREAKER SELECTION CHART

1. CIRCUIT BREAKER FULL LOAD AMP RATING:
Circuit breaker must be rated not to exceed the current rating of the load (F.L. AMPS), and must protect the smallest conductor in that circuit (ABYC E-11.10.2.3).

2. CIRCUIT BREAKER VOLTAGE RATING:
Circuit breakers must be rated for a maximum voltage (MAX V) not less than the voltage of the power source AC or DC (ABYC E-11.10.1.5.2 and ABYC E- 11.10.2.4).

3. CIRCUIT BREAKER FREQUENCY:
Circuit breakers must be rated AC - (50/60 HERTZ), DC, or AC/DC - (DC/60Hz) (ABYC E- 11.5.2.2.7).

4. CIRCUIT BREAKER TRIP DELAY:
Circuit breaker must have a (DELAY) rating that is compatible with the power source AC or DC and tolerant to the inrush characteristics of the load (motor, lamp, resistive, inductive).

5. CIRCUIT BREAKER TRIP AMPS:
Circuit breaker must have a (TRIP AMPS) rating that indicates the current level where the breaker will trip.

6. CIRCUIT BREAKER INTERRUPTING CAPACITY:
Circuit breakers must have an ampere interrupting capacity (AIC) that is compliant with ABYC E-11.10.1.5.5 and ABYC E-11.10.2.1.2.

7. CIRCUIT BREAKER IGNITION PROTECTION LABEL:
Circuit breakers installed in fume areas must be tested and labeled "IGNITION PROTECTED" (ABYC E-11.5.2.2.8) and (ABYC E- 11.10.1.5.1)

Note: UL 1500 tested units will be marked with "IGNITION PROTECTED" and units tested to SAE J1171 will be marked "SAE J1171". ISO 8846 is not presently an approved ABYC rating.

**Copies of Standard E-11 AC and DC Electrical Systems on Boats are available from the American Boat and Yacht Council, 613 Third Street, Suite 10 , Annapolis , MD 21403 , Phone (410) 990-4460*

Step 2 - Load Calculation:

Before considering battery ratings, generator outputs, or wire gauges, you should first establish the total AC and/or DC requirements for your electrical system. For DC systems, refer to ABYC E-11.8.1.1 and complete Table II. For AC systems, see ABYC E-11.8.2 and complete all the sections through E-11.8.2.2.5. Remember to plan for future expansion. The addition of spare circuits now will save you considerable time and money in the future. Once you have determined your power requirements, you can then consider power source options.

Table II – Electrical Load Requirement Worksheet

Column A		Column B	
Load	Amperes	Load	Amperes
Navigation Lights		Cigarette Lighter	
Bilge Blower(s)		Cabin Lighting	
Bilge Pump(s)		Horn	
Wiper(s)		Additional Electronic Equipment	
Largest Radio (Transmit Mode)		Trim Tabs	
Depth Sounder		Power Trim	
Radar		Toilets	
Searchlight		Anchor Windlass	
Instrument(s)		Winches	
Alarm System (standby mode)		Fresh Water Pump(s)	
Refrigerator			
Engine Electronics			
Total Column A		Total Column B	
		10% Column B	
		Largest Item in Column B	

Total Load Required:
Total Column A:_____ Total Column B: _____
(The largest of 10% of Column B or the Largest Item)
Total Load: _____

Step 3 - DC System:

The most widely used DC power source is the battery. Other sources of DC power include solar panels, wind generators, and alternators, but for the purpose of this article we will only concentrate on batteries. The most popular DC voltage rating found on vessels is 12VDC, although 24VDC and 32VDC are also popular ratings on larger boats. Paneltronics offers DC panels in 12VDC, 24VDC, and 32VDC.

Engine Starting Batteries:

Engine cranking batteries are similar in construction and function to automotive batteries, but the materials used in automotive batteries will limit their longevity in a marine environment. Engine cranking batteries are designed to deliver a short burst of power, followed by a quick recharge. The Marine Engine General Data Sheet supplied by the engine manufacturer will specify the minimum Cold Cranking Ampere (CCA) battery rating required to ensure a reliable engine start (see ABYC E-11.4.3 DEFINITIONS Battery cold cranking performance and ABYC E-11.6.1.1.1).

House Batteries:

Unlike cranking batteries, house batteries are constructed with thick lead plates designed to be discharged over a long period of time. They may be discharged to about 50% of their capacity, and then recharged. These deep cycle batteries, so called because of this characteristic, are the batteries of choice for running appliances during long cruises. To select the proper rating for your deep cycle batteries, first refer to Table II in Step 2, and expand the data by multiplying each appliance load current (in amps) by the number of hours you plan to operate the appliance (in a 24 hour period). The sum of these amp-hour requirements represents Part 1 of the total DC Daily Load. Part 2 is calculated if an optional inverter is installed on your AC system, and is explained in the inverter section later in this article.

With the exception of cranking motor circuits, please note that overcurrent protection is required in all conductors connected directly to the batteries. (See ABYC E-11.10.1.1.1 and FIGURE 15 for placement requirements). It is important to remember that overcurrent devices placed in fume areas must also be ignition protected (ABYC E-11.10.1.5.1).

Step 4 - AC System:

AC represents Alternating Current. In marine electrical systems, the most common sources for alternating current (AC) are shore power from utility company generators, onboard generators, and inverters.

Shore Power:

In the United States, the 3 most readily available marine shore cord configurations are 120VAC- 30 Amps, 120VAC- 50 Amps, and 240VAC- 50 Amps (ABYC E-11.6.3.1.1 through E-11.6.3.2.3). AC shore cord systems rated at 220VAC- 50Hz are commonly used in Europe and other parts of the world. Paneltronics offers panels for all these electrical systems, including panels with circuit breakers having the required European CE approval. When selecting shore power cords, check the quantity and ampacity of the inlets available on the dockside stanchions where your vessel will be docked. Then evaluate the physical weight and cost of each available shore power cord set that will power the maximum number of AC loads calculated in Step 2 above (ABYC E-11.8.2.1 through ABYC E-11.8.2.1.2).

Shore Power (Continued):

Leakage Currents caused by defective wiring or defective electric appliance onboard a vessel present a significant shock hazard to personnel. In order to significantly reduce the risk of electric shock hazard to personnel in the water near a vessel, boarding a vessel, or onboard a vessel that is connected to shore power, effective July 2009 each 120VAC 60Hz or 240VAC 60Hz shore power cord set, or feed, must be protected by an Equipment Leakage Circuit Interrupter (ELCI) (see ABYC E-11.11.1). The ELCI may be a stand alone device or part of the Main Shore Power Disconnect Circuit Breaker located on the AC distribution panel.

If the distance from the shore power inlet mounted on the vessel is greater than 10 feet, measured along the conductor from the location of the Main Shore Power Disconnect Circuit Breaker, an additional overcurrent protection device and the ELCI is required within 10 feet of the power inlet (ABYC E-11.10.2.8.3 through E-11.10.2.8.3.1). ELCI devices installed in fume areas must be mounted in enclosures that are "Ignition Protected" (ABYC E-11.5.3.1) and ABYC E-11.4.15). In addition, ELCI devices mounted in locations subject to rain, spray, or splash must be weather proof (ABYC E-11.4.31).

Another dangerous condition that can create a shock hazard for personnel in the water near a vessel, boarding a vessel, or onboard a vessel is Reverse Polarity. This is the unintentional backward connection of the hot (ungrounded/black), the neutral (grounded/white), or grounding (grounded/green) AC shore conductors. ABYC requires that a visible indicator of reverse polarity be present near the AC shore main circuit breaker (ABYC E-11.6.3.3.1). As an additional safety feature, Paneltronics provides an AC Shore Main Circuit Breaker that includes a Reverse Polarity trip coil. This "smart" circuit breaker trips automatically upon sensing a potentially dangerous reverse polarity condition.

It is our opinion that the installation of Isolation Transformers should be considered for all shore power circuits (ABYC E-11.7.1). They are designed to prevent galvanic corrosion and the hazard of electric shock caused by reverse polarity in the dockside stanchion. Personnel who are boarding, onboard, or swimming in close proximity to an unprotected vessel connected to an improperly wired dockside stanchion are exposed to potentially lethal electric shocks. Properly installed, isolation transformers magnetically couple a vessel's AC system to shore, and at the same time, they isolate shore ground from the floating grounded neutral AC system onboard the vessel (ABYC E-11.17.4) and (ABYC E-11.17.5).

Note: Isolation Transformers should be mounted on a non-conductive surface. Mounting hardware should not come in contact with any vessel metallic structural members. Finally, to insure that total isolation from shore ground is maintained, ground connections from telephone lines and cable TV must also be isolated by transformers.

AC Generators:

Generators are machines for generating AC electricity. To determine the size of the proper AC generator required for your application, multiply the total AC load calculated in amperes in Step 2 above (see ABYC E-11.8.2.2.5) by the AC system voltage, and divide by 1000. This result is the minimum KVA generator output rating required for a single-phase system (ABYC E-11.8.2.1.3).

Note: The AC system onboard vessel is a polarized grounded neutral system (ABYC E-11.5.5.1), (ABYC E-11.5.5.2), and (ABYC E-11.5.3.2.1); therefore, the generator neutral must be grounded at the generator (ABYC E-11.5.5.2.3).

Observance of the 7/40-inch rule for the placement of overcurrent protection devices may require their placement within a gasoline fume area near engines or generators (ABYC E-11.10.2.8.1), (E-11.10.2.8.4), and (ABYC E-11.4.15 DEFINITIONS Ignition protection). These overcurrent protection devices must be ignition protected. Paneltronics manufacturers circuit breaker panels with ignition protected (UL 1500) two-pole C-Frame circuit breakers that will bring your generator installation into compliance (ABYC E-11.10.2.7.1).

Inverters:

Inverters are devices that convert DC battery power to Alternating Current (AC) for powering household appliances. These devices are very popular on smaller boats, or as back-up to generators. Larger inverters may be used in place of generators. Inverter advantages include quiet, pollution free AC power on demand. However, larger inverters require larger battery banks to sustain their operation.

Note: Inverters are a major consumer of stored DC battery power. Consider this when calculating your total battery requirements. To determine the battery requirements for an inverter, use this simple calculation. Multiply each AC appliance power rating in watts by the number of hours you plan to operate the device for a 24 hour period (watt-hours); then add the sum of all AC appliances powered by the inverter and divide by the DC system voltage (12, 24, or 32VDC). This total should be added to Part 1 of your previous DC calculations for Daily Load. Finally, multiply 4 (diversity factor) to obtain the total Amp-hour rating of the required battery bank.

Single Power Source Selection:

Cogeneration, powering a load by multiple power sources at the same time, does not presently meet ABYC standards (ABYC E-11.8.2.1.4). Therefore, single source selection that isolates all power sources must be assured with the use of a break before make switch or lockout device (ABYC E- 11.5.5.6.1). Paneltronics panels offer these for safe selection of up to 6 power sources (i.e. shore power, generators, or inverters) (ABYC E-11.5.5.7).

Wire Sizing:

The construction of insulated conductors (wire) used in marine AC and DC systems is very different. Conductors approved for AC use may also be used for DC, but the converse is not true. The insulation temperature rating of most marine wire available today, AC or DC, is 105°C. By selecting 105°C rated insulated wire apposed to 75°C rated wire, higher currents can be transmitted safely using thinner, lighter wire. The markings on individual marine wire conductors must include type/style, voltage rating, gauge, and temperature rating (ABYC E-11.14.1.1). The minimum wire size permitted for marine use is 16 American Wire Gauge (AWG); however, there are several exceptions (see ABYC E-11.14.1.2). The possibility of strain hardening caused by low frequency vibration present on vessels mandates the exclusive use of stranded copper wire (ABYC E-11.14.2.4. and ABYC E-11.14.3.6). Tinned, stranded copper wire is the preferred wire conductor for use in marine electrical systems because it offers maximum protection against corrosion. At junctions, this wire is galvanically compatible with tin plated terminals. This compatibility helps prevent high resistance connections, overheated junctions, and fires.

DC Wire:

DC wire must have a minimum 50-volt insulation rating (ABYC E-11.14.2.1), and this insulation must meet the temperature rating requirements of the Society of Automotive Engineers (SAE) J378 and SAE J1127, or J1128 (ABYC E-14.2.1.1 through ABYC E-11.14.2.1.1.4). Wire types that conform to these requirements, such as GPT (PVC marine engine and component wire) and Boat Cable (UL 1426), are readily available. To calculate conductor size, see ABYC E-11.14.2.2 through ABYC E-11.14.2.7.1).

AC Wire:

AC wire must have a minimum 600-volt insulation rating (ABYC E-11.14.3.1), and flexible cords must have a minimum 300-volt insulation rating (ABYC E-11.14.3.2). This insulation must also meet the flame retardant and moisture resistant requirements of UL 83 (ABYC E-11.14.3.4). Wire types that conform to these requirements, such as AWM 1230, AWM 1231, and Boat Cable (UL 1426), are also readily available. To calculate conductor size, see ABYC E-11 AP TABLE 1 and ABYC E-11.14.3.5 through ABYC E-11.14.3.7.2.

AC and DC Power Distribution Panels:

The primary considerations in the selection of an AC or DC power distribution panel are DESIGN, QUALITY, FUNCTION, and STYLE. Although many panels appear to be similar, a close inspection may show practical and functional differences.

Design Elements to be considered:

- Custom Configurability - Does the panel offer you the option to select the appropriate circuit breaker amperages to isolate and limit loads?
- Physical size - Does the panel fit in the space that you have available?
- Modularity - Does the panel offer you horizontal or vertical layout options?
- Flexibility - Does the panel offer you an option for future expansion?
- Ergonomics - Does the panel have a user-friendly layout?

Functional Elements to be considered:

- LED Indicator Lights - Color-coded LED's can be very functional.
- Backlighting - Meters and Labels should be easily read in low light conditions.
- Function Labels - Labels should be easy to add and change.
- Meters - Meters should be accurate with easy to read scales or digital displays.

Quality features to look for:

- Tinned stranded copper wire rated at 105°C
- Bus Bars
  Properly rated for total ampacity
  Solid Copper/Tin Plated
  Conveniently Panel Mounted
- Panel should be made of a corrosion resistant material such as aluminum
- Durable surface finish such as polyurethane or powder coat finish
- Quality Components
- Superior Workmanship

By now you should have determined the total number of circuit breakers, the ampacity for each load, and all of your power inputs. In addition, you should have considered the design, function and quality elements that you want to incorporate in your panel. By coupling this information with the physical size available for your installation, you should be able to select the proper AC and/or DC power distribution panel. Paneltronics offers you over 180 modular panel designs. Each model is pre-wired for a simple installation. For additional product information, please visit us online at www.paneltronics.com or call us toll free at 1-800-36-PANEL. Factory trained technicians are available to help you design a safe, compliant marine AC or DC electrical panel system that will meet all of your present and future power requirements.