Big Banks

The demand for battery bank capacity is on the rise, but meeting it isn't as simple as just adding more batteries.

Text and photographs by Steve D'Antonio

__Above—__Large battery banks are becoming a fact of life aboard cruising boats. As demand for onboard power increases, and inverter capacities grow, battery banks are being tasked with keeping up, sometimes unsuccessfully.

There was a time when a 40′ or 50′ (12m or 15m) cruising boat could get by on 400 amp-hours of house battery capacity. Times change, and common now are large house-battery banks supporting myriad electrical accessories and the extended periods that operators wish to use them. I've seen a steady increase in the physical size, electrical capacity, and complexity of banks, often achieved by simply adding more batteries to an existing design or installation. In most cases, little consideration is given to the consequences—physical or electrical—of these changes to the boats and to the battery banks.We'll tell you what to take into account when designing, installing, or maintaining a large battery bank.

To start with, there's no standard definition of a large battery bank. Based on the evolution I've observed in the industry over the past two decades, what was considered large 10 years ago is now simply average, and what passes for a large battery bank today might be standard tomorrow—especially with the increased popularity of hybrid electric propulsion systems. For the purposes of this article, a large battery bank is anything more than 750 Ah at 12V from three paralleled 8D batteries, each of which measurements

When you increase the size of a battery bank, the potential for faults and failures goes up accordingly. Because of the physical size and weight of the batteries, not to mention the electrical energy stored within large banks, failing to properly secure them and incorrectly routing cables can cause serious damage to a boat.

20¾″ x 10″ x 10¼″ (52.7cm x 25.4cm x 26cm) and weighs 165 lbs (74 kg); or 500 Ah at 24V from four 8D batteries in a combination of series and parallel connections. My criteria have as much to do with the number of batteries in the house bank as with the amp-hour capacity or voltage. If smaller case sizes were applied to the above equations, the overall number of batteries and the complexity of a given system would consequently grow.

Many of the suggestions and guidelines that follow apply equally to *all* battery banks, large and small. While larger banks magnify the consequences, any battery adrift in an engine compartment, hydrogen gas accumulation within a battery box, or overheated and arcing connections are of great concern. In addition, large battery banks require more connections, so the likelihood of an accident or fault increases. Most marine electricians and mechanics have experienced the jolt of the arc when a grounded tool made contact with an ungrounded battery terminal, welding the two.

Now consider that the average starting battery possesses a mere 500 to 800 cold cranking amps, while a large house bank might produce over 5,000 CCA. The need for caution is clear. Short circuits of any sort will almost certainly be catastrophic. Tools to service such banks and related wiring should be fully insulated, even if it means simply wrapping exposed metal surfaces in common electrical tape.

When working around any battery, take these precautions: Remove rings and bracelets to avoid shorts to ground and resulting serious burns. Wear safety glasses even when working with sealed valve regulated lead acid (SVRLA) models, which include absorbed glass mat (AGM) and gel batteries. Spilled or splashed acid, or

The temptation to increase a bank's capacity by adding more batteries is strong. Doing so often magnifies issues such as inadequate physical support and security, poor ventilation, and the number of connections and their associated increased resistance.

acid that becomes airborne as a result of an explosion will damage eye tissue; and a short circuit can discharge sparks formed around superheated or molten metal, the smallest particle of which could also cause serious eye damage. Due to their considerable weight and often poorly accessible location, batteries should be installed by crew with healthy backs; or by those who employ cranes or block and tackle with proper hoisting, lifting and skidding techniques and follow safety protocols.

Support and Security

When I inspect a boat or review a systems proposal, I first look at the intent of the boat's design to assess how robust the security of a large battery bank must be for safe, reliable operation. If the boat carries a code, such as an ISO stability standard or rating, which can range from "A—ocean" to "D—sheltered waters," its intended use is clear. In the absence of this rating, assess the boat's overall design and the manufacturer's statements. If it's a sailboat or expedition powerboat designed for offshore passagemaking, consider what will happen when the vessel heels, is knocked down, or fully inverted. If, on the other hand, the boat is designed for inshore or sheltered-water use, the battery bank installation may reasonably reflect less severe sea conditions.

Because of their considerable mass, large battery banks require special accommodations to withstand violent seas. If the batteries are securely fastened to a shelf and the boat encounters tumultuous seas that result in high g-loads or capsizing, the shelf must continue to hold the batteries and their support-and-containment structure, and must resist abrasion, water damage, and attack from acid. It should also be designed to retain spilled or leaked electrolyte.

Designers or repair yards might encounter a problem at this point with installations of SVRLA or flooded batteries when attempting to follow American Boat & Yacht Council (ABYC) standards. The council's guidelines, in section E-10, "Battery Installations," are less than clear on electrolyte containment, especially for SVRLA batteries. The guideline states:

"Provision shall be made to contain incidental leakage and spillage of electrolyte. *NOTE: Consideration should be given to: (a.) the type of battery installed (e.g., liquid electrolyte or immobilized electrolyte). (b.) the boat in which the battery is installed (e.g., angles of heel for sailboats, and accelerations for powerboats).*"

So what constitutes "incidental"? If the battery is an SVRLA, does this guideline negate the need for containment? Does a flooded battery require 100% containment in a box? And just how much electrolyte is it reasonable to expect an installation to retain when a sailboat heels? I've been asked those questions by boatbuilders, professional systems installers, and boat owners. The answers are complex and remain debatable.

Sturdy battery shelves or racks such as these provide excellent support, good case ventilation, and access for mechanics to inspect connections regularly, ensuring long battery and boat life.

The base of this battery shelf lacks the necessary integrity to support the heft of this near 1,000-lb (454-kg) bank, and its unencapsulated timber will rot if routinely exposed to water.

Over-Current Protection

Because of their high potential for generating fault currents, large battery banks add a few twists to standard protection measures. I discussed this subject with Wayne Kelsoe, vice-president of electrical engineering at Blue Sea Systems (Bellingham, Washington). In designing components capable of handling large battery bank current, he has conducted experiments and compiled data on this subject, which will also inform the American Boat & Yacht Council in the standards revision discussion. I've distilled some of that information into a list to keep in mind while designing or installing large battery banks.

- The potential fault current for batteries connected in parallel is nearly cumulative and is mitigated only by the resistance of the related wiring and connections.
- Fault current is often more than four times the cold cranking amp rating, and for a safety margin assume five

Few electrical topics are more important than over-current protection, such as the fuse shown here, and the requirements are doubly important in large battery banks.

Expect that during the life of a boat the SVRLA batteries might be replaced with conventional flooded batteries, making spilled or leaked electrolyte a possibility. I advise builders installing SVRLA batteries to consider such a retrofit in the boat's future, and include trays or liquid-tight cleat assemblies surrounding the batteries, and shelves that are impervious to degradation from exposure to electrolyte and water. These features should be robust enough to resist deformation and the possible failure of their acid-resistant encapsulation. Since resin alone lacks sufficient abrasion resistance for a reliable, long-lasting acid-proof coating, that means shelves of wood or synthetic core should be fully laminated with resin *and* glass fiber; and perimeter cleats should be secured to the shelf with fasteners and adhesives or epoxy bedding.

Battery boxes are ideal for securely retaining and protecting batteries and for containing spilled electrolyte. But boxes also present challenges. Chief among these is ventilation, which prevents hydrogen from being trapped within the box and allows heat to dissipate. These installations receive a failing grade because of inadequate ventilation.

While high-density polyethylene sheeting resists acid, it often lacks sufficient structural rigidity to support large battery bank loads. It is also difficult to make a cleat liquid-tight with HDPE, so batteries installed on HDPE shelves require independent trays or boxes to contain acid.

Commercially available or custom-made battery trays and boxes are ideal for battery support, security, and electrolyte containment, provided they are compatible with the installation. But they must be properly ventilated to release hydrogen gas as well as to dissipate the heat generated during charging.

Wood battery boxes simply coated in resin cannot withstand exposure to acid. A coating applied without fabric reinforcement is too fragile for battery box construction.

At one time I questioned the need for battery boxes, particularly when I considered how they often inhibit inspection and service. Then I saw the result of a battery explosion in which the battery's "shrapnel" and acid were almost fully retained by the stout plastic box. Still, such explosions are rare, and in large banks, the additional space taken by boxes, and the difficulty of installing batteries into them, can make them impractical.

Fasteners that secure boxes, cleats, trays, or shelves must not be installed where spilled or leaking electrolyte can corrode the heads and lead to mechanical failure.

times. Thus, a single flooded 8D battery that typically produces about 1,200 CCA has a potential fault current of 5,000 amps (more for an AGM battery), and requires OCP that carries an ampere interrupt capacity of at least that amount.

• There is a loose correlation between conventional battery weight and fault current (and amp-hours and fault current). Batteries that rely on thin plate pure lead designs can deliver 67A/lb at 12V, while other lead-acid batteries are closer to 37A–45A/lb at 12V. As a rule of thumb, in the absence of other data, multiply the weight of a 12V bank by 50 for an indication of potential fault current. The correlation between fault-current and amp-hours figures ranges from a high of 89A/Ah for TPPL batteries to 20A–25A/Ah for others. This is a rough calculation at best. These ampere figures can be halved for 24V systems.

• Electronic battery testers such as those from Midtronics and Pulsetech can accurately predict fault current by multiplying CCA readings by 4.2, or by 5 for a safety margin (See "Battery Testing," PBB No. 79.)

• Disconnect switches should be located where they will benefit from OCP.

• Banks larger than a single 8D, a pair of GP31s, or six 6V golf cart batteries should rely on a Class-T fuse for OCP. This fuse is rated at 20,000A at 160V and should handle 100,000A at 32V. While circuit breakers can be used provided they carry the appropriate amp interrupting capacity (AIC), a common failure mode after a short-circuit fault is for the contacts to fuse when reset. How many of us have reset a circuit breaker after it trips the first time without investigating the cause? If the fault still exists and the OCP is compromised, a fire *could* result. At the very least, the breaker will be internally damaged and will not reset, allowing the circuit to remain open. Boat operators often carry spare fuses, but how many carry spare primary circuit breakers?

—Steve D'Antonio



Making sure that batteries stay put when a boat is running in rough conditions or heeling excessively is critical for all battery banks, large or small. Because of their weight, large banks can test retainer designs. Many installers don't consider the need to balance retention and ventilation, but these three installations ensure that the batteries are secure and have adequate air circulation.

Attachment

Convention and compliance with ABYC Standard E-10 dictate that batteries remain stable, moving no more than 1″ (25mm) when a force of 90 lbs (41 kg) or twice the battery's weight, whichever is less, is applied. (I recommend that anyone designing, installing, modifying, or maintaining a large battery bank review the complete chapter for details of testing to ensure compliance with the standard.)

While these guidelines set the bar high, I don't think it's high enough. Allowing a battery to move even 1″ after it's considered fully installed is an invitation to a host of maladies, including connections working loose, as well as cable and case chafing. My personal guidelines call for complete immobilization of all battery installations, regardless of size.

Batteries can be secured in a number of ways. Clamp them under insulated-alloy or extruded-FRP channel or box-section strongbacks with threaded through-bolted rod to ensure that they don't move during virtually any conditions, including inversion. Typically, this approach is for batteries installed in trays or on shelves. The clamping strongbacks can be oriented for easy inspection, and water service for flooded batteries. One advantage of installing batteries *without* boxes is that they can be more easily serviced, and casually inspected each time a person walks though the compartment. But remember that all hardware must still be located outside the electrolyte containment area.

Another option is synthetic web straps to secure batteries to shelves or trays. Strap material must be impervious to acid. My preference is the stainless steel positive-ratcheting variety rather than the simple plastic friction type. Plastic buckles are difficult to install with enough tension to immobilize a battery, and some straps with plastic buckles are notoriously difficult to release after they've been in place for months or years.

Straps should attach to the shelf or tray with strap eyes rather than by screws piercing the strap material, unless a backing block distributes the screw's load over a wide area. To secure the straps, fasteners should be through-bolts rather than tapping screws, although in some cases tapping screws can secure smaller batteries if the threads engage the full thickness of the substrate they fasten to, and are of the largest possible diameter the hardware mounting hole will allow.

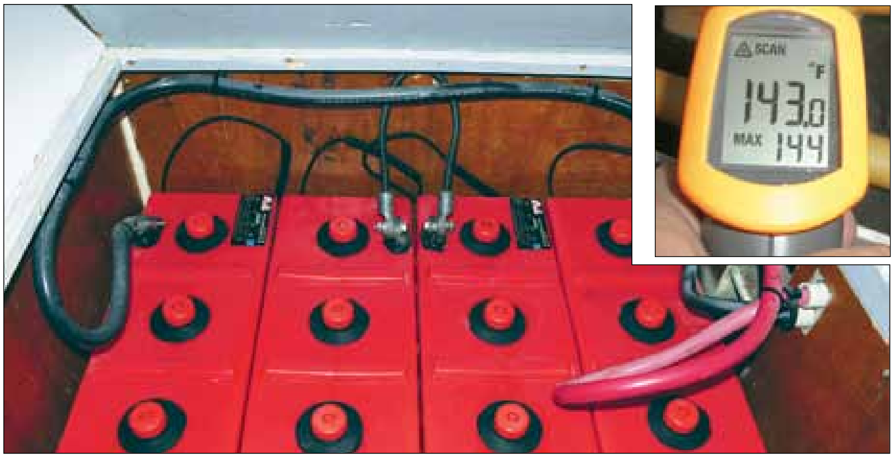

Many straps and strap eyes are not up to the task of securing batteries, much less larger batteries and big banks. These light-duty strap eyes designed for holding down a small runabout battery in a plastic box are inadequate for heavier yacht-sized units.

Ventilation

It is a common misconception that SVRLA batteries do not vent hydrogen gas and therefore require no ventilation. A warning from a popular AGM battery manufacturer: "Even though VRLA batteries are designed to recombine these gasses internally, the recombination efficiency is less than 100%. Small amounts of hydrogen and oxygen are released from the pressure relief valve during charging."

Overcharged or overheated AGM and gel batteries will vent more than just small amounts of hydrogen. And since a concentration of just 4% hydrogen is combustible, batteries must be allowed to safely dissipate this gas. ABYC Standards make no distinction between SVRLA and flooded batteries; all require provisions for dissipation of hydrogen gas, which is lighter than air, for the boat to remain compliant. This means: avoid placing batteries in compartments or lockers that lack ventilation at their highest points. Similarly, remote-vent plumbing must rise continuously to allow hydrogen to escape and to prevent water accumulation, which prevents gas from venting.

Batteries also require ventilation to dissipate heat generated during normal heavy charging. One of the most common mistakes in large battery bank installations involves what I refer to as "the battery sandwich." Typically, the heat generated within batteries is easily radiated to the surrounding air. But in a battery sandwich—a series of batteries packed tightly against one



Batteries tightly stacked "sandwich" style can overheat because no air can circulate around those in the middle. The center batteries in this bank are noticeably hotter than those on the perimeter. Also, the locker is resin-coated wood, and the top of the space is not ventilated. This compartment would benefit from a re-design.

another—the batteries on the outside insulate those on the inside of the pack, and none is adequately ventilated. I've measured batteries in the center of a bank that were as much as 30°F (17°C) hotter than those on the perimeter.

The hotter the batteries get, the faster the reaction rate within them, and the worse the problem becomes, creating what's known as *thermal runaway*. In extreme cases, a runaway can lead to a battery fire and/or explosion. Fortunately, there's a simple preventative: ensure that a gap of no less than ¼″(6mm) exists between any two batteries to allow heat to dissipate.

Access and Service

Make provisions for access when designing or installing large battery banks. Flooded batteries require regular access to inspect electrolyte level and add distilled water (batteries should be maintained with only pure distilled water). The electrolyte in a battery is a diluted mixture of sulfuric acid and water that should be filled no higher than the internal cell liquid-level indicator, typically a tab that protrudes down and into the cell. Overfilling will result in electrolyte splatter during normal gassing; as more electrolyte escapes, the acid concentration level becomes more diluted as it's replaced with water. Once lost, acid cannot be replaced; only water that outgases or evaporates should be added back to the electrolyte mix during regular maintenance. Ultimately, overfilling or underfilling leads to loss of capacity and eventual battery failure. For large banks, recombinant cell caps or permanently plumbed watering systems often make sense, particularly if batteries are difficult to reach.

Even with SVRLA batteries, it's essential to periodically inspect for cable security, evidence of case failures, and venting and corrosion problems. In these sealed batteries, chronic post corrosion indicates that the seal has failed and electrolyte has been lost, shortening battery life. And, of course, a failure, if not caught and corrected, can compromise the entire bank.

Burying batteries under or behind other batteries, in racks whose clearance between levels or shelves is too narrow, or in areas that are inaccessible without tools, means an owner or crew will be less likely to inspect and maintain the bank.

This battery box vent "system" is intended to remove hydrogen gas, but because it dips down, the fumes cannot properly escape. Water has accumulated in the dip, making gas passage even more difficult.

Electrical Considerations

While ABYC standards for over-current protection (OCP) do not yet reflect some specific needs of large battery banks, they are fully applicable to much of the wiring associated with battery banks and DC systems in general.

Those standards require that all cables leading from a positive battery terminal or positive bus bar (starter cables excepted) have OCP within 7″ (18cm) of the source. If cabling is contained within sheathing, conduit, a control box, or other enclosure, OCP may be located as much as 72″ (183cm) from a battery terminal, or 40″ (102cm) from a battery switch or other terminal, bus bar, etc. In all cases, OCP should be installed as close as possible to the power source. This recommendation is for cabling to battery chargers and inverters, two components that often lack such protection or exceed suggested cable length.

Because large battery banks have vast quantities of reserve energy, OCP guidelines are especially important. A short circuit in a heavy-gauge cable connected to a large battery bank positive post(s) or bus bar will generate significant heat and almost certainly cause a fire in the presence of combustible material. With the aforementioned exception for starter circuits, all positive cabling attached to large battery banks *must* be protected with an appropriately sized OCP (see sidebar, page **xx**).

If a large bank plan includes an option for engine start paralleling, install separate cabling for this function to maintain OCP on the other supply cables connected to the bank's positive terminals. There's talk in the industry of recommending OCP on starting circuits. Perhaps with the advent of a variety of easily installed OCP hardware, and more data, the time has come to consider this approach.

If a bank is made up of multiple groups of paralleled batteries, each so-called string should include OCP as well as a disconnect switch that makes it possible to isolate groups of batteries from a large bank for troubleshooting or service, or if an individual battery or cable fails. In addition, a master disconnect is a good option to quickly isolate the

Left—*Carefully install wiring for all battery banks, and mitigate the possibility of cable chafing. While the cables in this bank have been wrapped in an anti-chafe loom, its material is not ABYC compliant, because its design is discontinuous and lacks fire resistance.* ***Right***—*Beyond a certain size threshold, 2V batteries wired in series make good sense because of their lighter weight, smaller size, and more manageable electrical output.*

entire bank from the boat in the event of a fire or other malfunction. It should be readily accessible, preferably outside the engineroom.

Wiring Protocols

In most of the large battery banks I see, multiple batteries are wired in parallel just as they would be in a smaller bank, but with more batteries and more connections. One risk of connecting exceptionally long strings is that it often leads to an intra-bank voltage imbalance.

Perhaps one of the most commonly misunderstood standards is the end versus cross-connection protocol—the method in which a large battery bank is connected to the boat's electrical system. Imagine a series of three or four 12V batteries connected in parallel: the batteries' like terminals are interconnected, positive to positive and negative to negative. At the physical end of the bank, for convenience and to minimize cable length, positive and negative cables from the boat's electrical system are connected to the last battery in line. This can be detrimental to the bank because resistance within it is cumulative, and batteries farther from the main connection point tend to provide power disproportionately because they are cycled less frequently. The result: batteries in the bank "wear" at different rates, creating voltage imbalances that reduce the bank's effective capacity.

The preferred alternative is to make positive and negative connections between batteries at *opposite* ends of the string to reduce the potential for intra-bank imbalances and charge-acceptance problems. Next, the bank's primary charge source should be cross-connected, but the cross should *mirror* rather than parallel the connection for the bank's supply to the house. The protocol allows the battery bank to act as a buffer between heavy loads such as windlasses or inverters and chargers/alternators.

Most battery manufacturers agree that the maximum number of batteries to parallel is between three and four. This is likely the most often violated "rule" for cruising boat battery banks. I've seen as many as eight 12V batteries connected in parallel, and seemingly working well for years. As a rule when paralleling, install fewer batteries of a larger case size, rather than a greater number of smaller batteries. This minimizes potential imbalances and the number of cable connections that invariably increase resistance.

Batteries connected in series behave as one large battery and have no theoretical string limit other than the desired voltage. Interconnecting a greater number of lower voltage individual batteries in series provides an appreciable bank capacity without the risk of intra-bank voltage imbalance. It works well for large battery banks. Perhaps a series bank's greatest single weakness, though, is the old-fashioned Christmas-tree-light-failure scenario: if a single battery fails, the entire bank is brought down. The offending battery cannot be removed from the bank unless a replacement is available, which is impractical because a "spare" would have to be maintained at its parent voltage and

Left—*Two parallel series strings of two batteries each allow for high amp-hour capacity at the desired 12V-system voltage.* ***Above***—*Over-current protection of large battery banks is a critical requirement. Class T fuses are well suited for this role. The fuse shown here is an ANL, which lacks the appropriate ampere interrupt capacity for the large bank it serves.*

Left—*When designing a bank, it's better to employ fewer larger style batteries than to a greater number of smaller case styles. This reduces the number of connections required, simplifying installation.* ***Right—****Battery specifications guide the user in building a bank of the correct amp-hour capacity as well as specifying proper over-current protection.*

be the same cycle age as the rest of the bank.

A practical variation includes strings of series banks, each producing the desired voltage for the boat and connected, in parallel, to a single bus bar. Such an arrangement can produce significant amp-hour capacity while remaining within the four-battery-in-parallel maximum, because each series string behaves as if it were a single large battery.

In larger battery banks with multiple parallel strings it's virtually impossible to judge the health or condition of any given string. Monitoring the temperature of individual batteries can flag an impending problem. An adjunct to some voltage and amp-hour monitors, or a component of whole-boat monitoring systems, can monitor the temperature of individual batteries and banks. Subtle problems are more reliably detected through current monitoring. Multiple Hall-effect current sensors will provide a clear picture of a string's discharge and charge acceptance rates, which can then be compared to other strings in the bank. Ideally, multiple strings should provide and accept the same or nearly the same current to the house and from charge sources, respectively. A disparity indicates a possible failing battery or a corroded or loose connection.

When assembling any battery bank, avoid mixing battery case sizes and ages. In theory, different case sizes present differing internal resistance even when new. These differences can push a bank into imbalance. The same is true of batteries as they age and cycle. Their resistance changes with use, and replacing one battery in a bank that has been cycled hundreds of times will almost certainly create a charge/discharge imbalance.

Ideally, all batteries/banks aboard should be of the same type—i.e., SVRLA or flooded—and the same voltage, including propulsion-engine and generator-start batteries. With this approach, emergency paralleling and charging are simplified and more versatile. Battery types should never be mixed in the *same* bank, because the charge profile, internal resistance, and charge acceptance rate of an SVRLA differs markedly from that of a flooded battery. They can be paralleled *momentarily* for emergency starting.

Deep-cycle batteries are often available with a variety of terminal styles—from posts and flags, which are commonly lead, to threaded inserts and L blades, most frequently copper. Whichever hardware is employed, it's important to make low-resistance connections and ensure that large-gauge cabling does not overload the terminals. No more than two-cable ring terminals should be installed on any single battery post. I prefer copper terminals because they are less prone to deformation, denting, and breakage. Common lead battery posts require some form of conversion to a stud connection that will accept a ring terminal. Avoid adapters that utilize cast-in-place studs. Instead, look for adapter terminals that rely on through-bolt fasteners, which impose compression rather than tension loads on the adapter body. Keep in mind that in some cases it might be necessary to add support to the cables to relieve some of their load on battery terminals. Finally, route cables so they don't impede access to cell fill caps.

Make all connections direct, and avoid intervening hardware and components. Ring terminals should make direct contact with battery terminals.

Left—*Hall effect transducers are valuable sensors for multiple-battery installations. They allow a user to monitor the performance of an entire battery bank, a section of batteries within the group, or even an individual battery.* ***Right—****Stacked ring terminals, even within the ABYC specified limit of four, invites resistance and heat generation, putting an unnecessary drain on an otherwise properly designed bank. A bus bar would better serve this installation.*

Far left—*Fuses, like other positive conductors, must be fully shielded to prevent possible contact with grounded components, which could casue a short.* ***Left***—*As shown here, limit connections at each battery terminal to two ring terminals and avoid interspersing other hardware such as washers and lock washers in the current path. This increases resistance and reduces the overall output of the battery bank.*

The threaded fastener is merely for support and compression; it's not designed to be a current-carrying conductor. A common error made by installers is interspersing stainless steel washers between cable ring and battery terminals (see "Finding Faults," on page **xx** in this issue). Similarly, bus bars and other termination points in such systems should be fabricated from pure electrical-grade copper. (Larger cross-sections of lower conductivity metals can be used if purpose-made and rated for the application.)

Pay careful attention to details when installing ring terminals, battery post adapters, and other hardware and components in large battery banks. Employ a torque wrench to make connections at batteries (most battery manufacturers include torque specifications); apply conductive paste to contact surfaces; and coat completed connections with corrosion inhibitor. Clearly and permanently label fuses/circuit breakers, disconnect switches, and bus bars. Also consider making diagrams of the bank that show the gear installed and the routing of wiring. Provide a copy to the customer, post another at the installation, and keep one in your own files, preferably on a computer so it can be e-mailed if necessary. This information will be vital to the future of a well-designed battery bank, which, no matter how fine the components and safe the installation, will depend on regular maintenance and service for longevity. PBB

About the Author: *For many years a full-service yard manager, Steve now works with boat builders and owners and others in the industry as "Steve D'Antonio Marine Consulting." He is a contributing editor of* Professional BoatBuilder, *and awaits the publication (by McGraw-Hill/International Marine) of his book on marine systems.*