The Relationship between Battery Bank Size and Charge Capability

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The house battery bank is the electrical heart of most cruising vessels; it supplies all the energy needed for everything from cabin and navigation lights to communication electronics and inverter operation. And, unless your vessel is designed as "generator-reliant", it's likely that the demands placed on the house battery bank will be rigorous indeed and as time passes and more gear is added it's also likely these demands will grow.

In my work as a technical consultant I inspect a variety of cruising vessels, both new and used, all over the world. The vast majority of these vessels have one thing in common, the output of the available charge sources are disproportionately small when compared to the house battery bank. This scenario is indicative of a builders', owners' or boat yards' piecemeal approach toward DC energy management and it's one that causes no end of frustration and disappointment for the folks cruising aboard these vessels. To make matters worse, because onboard energy needs have increased dramatically in the past decade, the size or capacity of house battery banks has grown dramatically in that time. Regrettably, those installing these large banks, be they builders, yards or owners, appear to be unaware of the charging requirements for such a large house bank and the consequences of failing to provide for the bank’s charging needs.

The size of the battery bank is based on the vessel’s house needs as well as its ability to be charged.

Some time ago inspected a new and finely crafted 50 foot single screw cruising vessel whose 12 volt house battery bank possessed over 1000 amp hours of capacity (an amp hour is the typical unit of measure for deep cycle batteries, one amp hour represents the usage of one ampere for one hour, while ten amperes of usage for four hours equals forty amp hours and so on). Just a few years ago this would have been considered huge battery bank, however, by today’s onboard electrical standards it’s moderately sized for a serious cruising vessel. The owners’ complaint was a refrain I’ve been hearing for most of my two decades-long professional career; “the battery bank isn’t big enough”. Although I was certain I knew why this cruising couple was saying this, I inquired as to why they believed this to be so. The predictable response,” the batteries aren’t lasting long enough between charging cycles”, confirmed my suspicion. Indeed, the battery bank required all too frequent re-charging, but not because it was undersized (if anything it was over-sized). The problems lie in the method(s) of charging.

Stock alternators, even ones that appear to have high output, are rarely up to the task of charging large house battery banks.

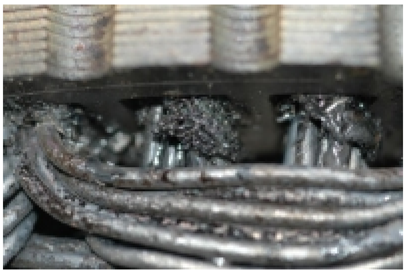
The vessel was equipped with a stock alternator supplied by the engine manufacturer, it’s output was 100 amps. While this may seem like a lot at face value, it’s woefully undersized for the task. Furthermore, because the alternator was internally regulated, as nearly every stock unit is, it was incapable of recharging a large house battery bank with any degree of efficiency. It’s important to note that most marine engines are industrial blocks that are marinized, they are destined for trucks and other industrial applications where the only requirement of their alternator is to recharge a starting battery whose amp-hour capacity is often something less than 100 amp hours. The average engine start cycle requires *less than one amp hour*, thus replacing it requires very little effort or time on the part of a stock alternator.

Internally regulated, standard equipment alternators, regardless of their output, are simply not capable of properly recharging even small house battery banks.

Insidiously, some stock alternators are deceiving in that their output is seemingly high, as in the case of the aforementioned cruiser, offering a hundred or a hundred and fifty amps. The problem with these alternators is two-fold.

First, they are internally regulated and therefore not equipped to deliver the multi-stage charge required by deep cycle house batteries. Second, with few exceptions they are not designed to deliver their full output except for short periods of time. When called upon to do so, by retrofitting one of these alternators with an external regulator as is sometimes done, they often expire prematurely as a result of overheating.

A new alternator (left) and a stock alternator that was externally regulated (right), albeit for a short time. The windings on the alternator on the right have been discolored as a result of overheating (they previously looked like those on the left.



A close up of the overheated windings, note the insulating material has vaporized.

The difference between a continuous duty high output alternator and a high output stock alternator is, to paraphrase Mark Twain, like the difference between lightning and a lightning bug. The trouble, however, doesn't end here. Not only is the stock alternator not equal to the task it's being called upon to carry out, even when externally regulated, its output, contrary to initial perceptions, is simply inadequate. While 100 amps sounds substantial, it's anything but when compared to the massive bulk of many house battery banks. In the case of the 50-foot cruiser, it’s a mere 10% and even if it was a proprietary, continuous duty high output alternator it still would be inadequate.

Purpose made high output alternators are designed to produce nearly their full output for extended periods. They can do so by being able to dissipate heat effectively, in some cases by using diodes mounted in external heat sinks.

Depending upon the battery type, flooded, gel or AGM, the rule of thumb for the ratio of charge output to battery bank size calls for the charge source, an alternator(s) in this case, to be a minimum of 25% of the bank’s amp hour capacity. That is, the alternator output required for this battery bank, in order to achieve reasonable re-charge times, should be approximately 250 amps. Continuous duty alternators of this capacity are available, however, they are not inexpensive and their installation requires careful engineering and often fabrication of heavy duty brackets. In some cases, two alternators (either on a single engine or one each on a twin screw application) may be required to achieve the required output. When dual alternators are used simultaneously, both outputs should be connected directly to the house battery bank, they must be synchronized so they behave as a single alternator.

Twin alternators operating on a single engine. When dual alternators are installed in this manner it's preferable to locate them opposite one another in order to balance the load on the crankshaft.

After my inspection of the 50-foot cruiser I recommended that the stock alternator be replaced by a continuous duty 200 amp unit (the largest that could be accommodated by this engine's mounting design) along with a multi-stage, temperature compensated regulator and a battery bank monitor so the owners could accurately determine how many amp hours had been used by the bank, which in turn would dictate their re-charge cycle. With this gear in place, as well as a little training regarding battery bank monitoring and discharge protocols, the perceived need for a larger battery bank evaporated.

Monitoring the condition of a battery bank as well as the rate of charge and discharge is a critical aspect of onboard power management. Without it the user is flying blind. The cruiser in this story was not equipped with one by the builder.

Although the error was no doubt innocuous, the builder of this vessel never should have installed a mega-battery bank knowing it would be serviced by a mini-charge source. Battery banks, particularly large ones, must always be treated as an integrated package whose design is based on the electrical needs of the vessel/crew, available installation real estate and, most important of all, the charge source. Without this forethought, just one thing is certain, an often misperceived disappointment in the performance of the vessel's batteries.

Alternator Regulators

While the integration of this system is vitally important to its efficient operation, there are a variety of details and ancillary items that must also be considered. Among the most important are the methods by which the alternator or alternators are regulated.

As mentioned above, all alternators are not created equal. Most are designed for short duration high output scenarios, to recharge a start battery or perhaps to supply power to an air intake post heating system for the purposes of reducing smoke upon start up. The solution is to utilize an alternator that's designed for extended high output operation. That, however, is only half of the high output charging equation. To put it bluntly, alternators of this variety are long on brawn and short on brains. While exceptionally robust and capable of delivering amps galore, they typically lack regulation of their own and proper regulation is especially important when it comes to recharging a large battery bank as quickly and as safely as possible.

External, multi-stage, temperature compensated "smart" regulators make all the difference when it comes to controlling high output alternator.

The internal regulator supplied with most stock alternators has a reliable but unsophisticated charge profile or voltage range. In spite of the alternator's rated output, when guided by such a regulator, it's simply not capable of replacing large amounts of energy that have been drawn from a heavily depleted house battery bank. When called upon to do so, after an initially high output, it often tapers back to a modest charge rate. The results are twofold. One, the battery bank becomes chronically undercharged and two, the voltage that the batteries are exposed to is often incorrect, which leads to poor performance and a shortened lifespan.

Stock, internally regulated alternators like this one fail miserably when called upon to control charge on house battery banks.

Fortunately, the solution to the problem is straightforward enough. In addition correctly sizing a proprietary high output alternator for the battery bank that is or will be installed aboard the vessel, it must be controlled by an external multi-stage “smart” regulator. Smart external regulators have been available to the marine industry for many years, I installed my first 15 years ago, and even the earliest models represented a vast improvement over what was hitherto available. External regulators pair precision control with a high output alternator’s brute force, offering the user the best of both worlds.

Stock alternator output typically tapers off shortly after start up, even if the bank is depleted. This is the primary drawback of using a conventional, internally regulated alternator.

The key to effective management of alternator output is to supply it in distinct stages, bulk, acceptance and float. Batteries are able to accept different charge rates as a function of their internal resistance, which in turn is a function of their state of charge. Heavily discharged batteries have low resistance while fully charged batteries possess high resistance. Smart regulators are able to determine and take advantage of these states of charge, tailoring the alternator's output for the greatest charge efficiency and thereby ensuring the shortest possible recharge time.

Bulk is, as the name implies, the highest output stage of the alternator/regulator. It sends a heavily depleted battery bank the greatest possible amount of amperage that it can safely accept (send too much and it will cause the battery to overheat and possibly catch fire). As the bank's state of charge increases, the regulator switches to acceptance mode, which is essentially a throttled back charge rate. Finally, once the battery is fully charged the regulator enters a float mode, keeping the battery bank's voltage high enough to prevent sulfation (an accumulation of energy-robbing sulfate

crystals on the batteries' plates) and low enough to prevent overcharging.
I don't believe it would be an overstatement to suggest that multi-step charging protocols have been to large house battery banks what fiberglass resin has been to boat building. Without this approach using large battery banks and recharging them in a reasonable amount of time would be virtually impossible. Absent this level of charge efficiency, convenience and functionality the plethora of DC gear that's become an integral part of the modern cruising vessel would be simply impractical.

Although deemed optional by some, temperature compensation is, in my opinion, an indispensable part of any multi-step smart regulator system. Because batteries are capable of accepting a higher voltage when cold and consequently incapable of safely accepting the same voltage when hot, temperature compensation plays a vital role in establishing battery charging parameters and increasing longevity. Simply put, temperature compensation is a must for any multi-stage charging system.

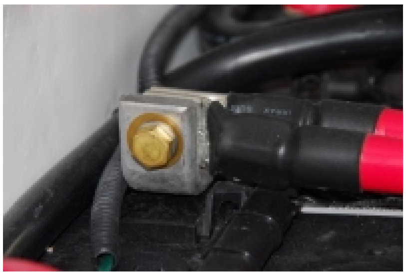
Temperature sensitive probes installed on the battery send signals to the regulator to, which in turn help tailor alternator output based on the battery's ambient temperature.
I recently inspected a battery bank that was (wisely) located in the lazarette as the vessel cruised the Bellingham Channel, where the water temperature was a chilly 53°F. The charge rate was noticeably higher than, say a vessel I inspected the previous month, it was located in the Bahamas, the water temperature was 75°F, and its batteries were stationed in the

engine room. The temperature compensation probe enables batteries living in vastly different environments such as these to be charged safely, efficiently and quickly (or as quickly as possible) while ensuring maximum battery longevity. Typically, the probe is adhered or bolted to one of the batteries in the house bank. It's important that the probe be installed on the house rather than the start bank as the house bank will be heavily discharged and cycling and it's the bank to which the alternators' output should be directly connected. If the house bank is split between two locations, the temperature probe should be installed in the location that is anticipated to be hottest, the engine room rather than the lazarette for instance.

Finally, for vessels equipped with twin propulsion engines, the preferred approach calls for the installation of one high output alternator on each engine with both outputs connected to the house battery bank. In order to operate properly, however, they must be synchronized using a device that will enable them to act in concert rather than in opposition. Left to their own devices, one of a twin independent alternator set up will often prevail, leaving the other in idle mode, essentially nullifying the value of a twin arrangement.

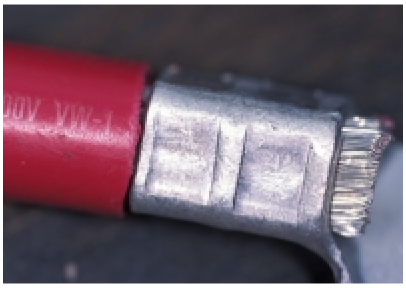
A single regulator controlling two alternators with the help of an intermediate controller.

<u>Battery Bank Wiring Protocols</u>



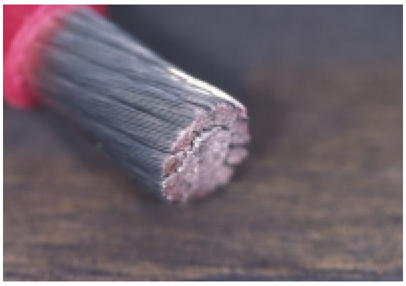
Regardless of how large your battery bank may be, or how powerful your alternator, or how smart its regulator, if these disparate components are not properly connected to each other via sound, secure, properly sized and routed wiring then you are sure to have unreliability, frustration and possibly even fire as your constant cruising companions.

Wire



Wire and crimp terminals are the means by which charge current travels to battery banks, and how current travels from the battery bank to house loads. It's imperative that wiring be secure, reliable and installed in a manner that presents the lowest resistance possible.

Wiring used for connecting batteries to each other and to their respective loads, the house or starters, should be type two or type three. This refers to the number of strands contained within each conductor. For example, a 1/0 (one aught) cable, this is a popular size for moderately sized battery banks and engines, in number two stranding contains 127 individual strands. The same cable in number three stranding contains 1064 strands, a significant difference to be sure and one that has a marked effect on the flexibility of the cable. While not required, where available, type three stranding is preferred, particularly for cabling that is attached to engines and generators. Many fine strands offer greater flexibility and resistance to vibration-induced fatigue. Additionally, flexible cable is considerably easier to install. Cabling used for these applications should also carry a UL 1426 or SAE J1127 (Battery Cable) or J1128 (Low Tension Primary Cable). Additionally, the cable jacket should be rated for a temperature of not less than 167°F/75°C dry (it's most often shown on the cable jacket in Celsius, and 221°F/105°C dry is preferred). Tinned conductors, while highly desirable for their corrosion resistance, are not a prerequisite and not required by ABYC guidelines.



Many fine strands, tinned in this case, make high quality large diameter cable flexible and failure resistant.

Cables that lack the aforementioned nomenclature, or if they carry other unfamiliar labeling, may not be suitable for use in engine compartments or in marine applications for that matter. Welding cable and coarse wire (made up of a few very thick strands) household or industrial cabling should not be used anywhere aboard, and especially not for battery installations. Welding cable, while very flexible, lacks among other things the abrasion resistance necessary for marine installations. When choosing cable, particularly heavy gauge cables, those 1/0 and larger for instance (these have an outside diameter of one half inch and up), look for a bend radius capability of no less than ten times the cable diameter. There's only one thing worse than snaking heavy electrical cable through a boat in the most inaccessible places and that's snaking inflexible heavy cable through those same spaces.

Overly stiff battery cables can place excessive load on connections. Terminals using cast in place studs are especially prone to this type of failure. Al alternative, shown below, us a “military battery terminal”, which uses fastener compression to reliably retain cable terminals.

Le Resistance

Every foot of cable between the charge sources, the alternator(s) and battery charger(s) or charger/inverter creates resistance in the circuit, this is unavoidable. Resistance generates heat, which to some degree is acceptable; however, when electricity is making heat, it’s not charging batteries or reaching appliances. There are a few ways to minimize resistance. The first and easiest is to make sure the connections are clean, corrosion-free and tight. Cable connections should be made using a conductant paste such as Thomas and Betts Kopr Shield, http://www.tnb.com/contractor/docs/shamrock.pdf . This paste is designed to be applied to a wire’s strands before they are inserted into crimp terminals and between crimp terminals and studs, bus bars, battery lugs etc. Do not slather it on the outside of the connection; it will do little good when used in that matter. Instead, in order to minimize corrosion, coat completed connections with a protectant such a CRC Battery Terminal Protectant http://www.crcindustries.com/marine/content/prod_detail.aspx?PN=06046&S=N

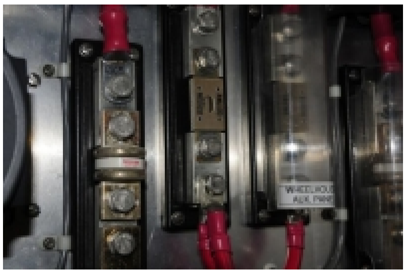
Keep the number of connections at the battery to a minimum, just one or two to a post (four is the absolute limit). Instead, use bus bars that complete connections off of the battery.

Avoid using wing nuts to make battery terminal connections (it’s a violation of common sense and ABYC guidelines).

The next method of minimizing resistance utilizes simple mass, the more copper between a charge source and battery bank or between a battery bank and a consumer the less resistance. Therefore, other than the weight and expense involved, the larger the cable’s gauge the better. The minimum voltage drop that should be tolerated in battery and charging system wiring is 10%, while 3% is preferred. Tables and mathematical formulas used for determining voltage drop are available to all members of ABYC as well as in various marine electrical publications.

Wing nuts are simply inappropriate for securing battery terminals in any application, especially in high output charging scenarios.

OCP



Over current protection, this is simply a fancy term for fuses or circuit breakers. These are necessary for safety sake. In battery bank, charging system and most other onboard wiring the sole mission of OCP is to protect the wire, not the appliance or consumer. That’s right, fuses and circuit breakers are designed to trip or blow in the event of a short circuit, a wrench falls across the terminals of a bow thruster (these should be protected from such accidents), or an overload, the dinghy crane is used to attempt to lift a dink that’s carrying 100 gallons of water. If OCP is not present, or if it’s improperly sized, the cable will overheat and possibly catch fire or cause something adjacent to it, a wood bulkhead or insulation for instance, to ignite.

Over current protection, fuses and circuit breakers, must be installed as close to the battery as possible, within 7 inches for American Boat and Yacht Council Standards compliance.

The value of the fuse or circuit breaker is determined by the ampacity of the cable, its ability to carry current and the cable size is determined by the needs of the consumer or charge source. These three aspects of battery and charging system wiring are inextricably linked where OCP is concerned. They must all be taken into account when determining wire size and OCP. Among other locations aboard, over current protection is required on every positive cable within seven inches, measured along the wire, of the battery's terminal. That distance may be increased to 72 inches if the cable is sheathed in conduit, loom or even electrical tape. Closer is always better. The only exception to this rule is cabling that is or can be used for starting engines and generators. This is among the most often violated guidelines and one I encounter constantly in the vessel inspections I conduct, both new and used. Perhaps the most common area in which this is encountered is on battery charger and inverter installations. In many cases, I find no OCP what so ever or, it's located adjacent to the appliance, the inverter or the charger, rather than close to the battery. Or, OCP is installed adjacent to the alternator, but not at the alternator's battery terminus.

Routing

Battery banks must be wired in such a way as to draw current evenly across the bank, rather than from a single end.

In order to ensure that all of the batteries in a battery bank "wear" evenly, it's important to distribute the load or charge across the bank. That is, the positive cable that either supplies current to the house or supplies charge current to the battery bank, should be attached at one electrical end (not necessarily the physical end) of the bank, while the negative cable is connected at the opposite end of the bank. House supply cabling connections to the bank should mirror rather than parallel charge source connections. This approach allows the bank to act as a buffer when heavy loads are applied while a charge source is present, operating a windlass or thruster for instance while the engine is running and alternator is sending current to the bank. Finally, the output from the alternator(s) should be connected directly to the house battery bank rather than via the start battery, isolators or splitters etc.

<u>Addendum to Wire Size Calculations</u>

The following addition was submitted by my colleague Mickey Smith of Boat Systems, Inc. Mickey is an experienced and knowledgeable systems consultant who specializes in electrical design.

"The value of the fuse or circuit breaker is determined by the ampacity of the cable, its ability to carry current and the cable size is determined by the needs of the consumer or charge source."

While this is generally correct, there are cases when you consider DC motors without any sort of thermal protection (SDA: Bilge pumps for instance) and high power DC loads. Check out the following from the ABYC Standard:

11.10.1.2 Motors or motor operated Equipment

11.10.1.2.1 Motors and motor operated equipment, except for engine cranking motors, shall be protected internally at the equipment, or by branch circuit over-current protection devices suitable for motor current. The protection provided shall preclude a fire hazard if the circuit, as installed, is energized for seven hours under any conditions of overload, including locked rotor.

In this case, the OCP is required to be sized to load without regard to the wire size. Also, in most DC circuits, given the 3% and 10% voltage drop requirements, in many cases, the wire will be more than capable of carrying the required current.

This brings up the point of high powered DC devices, like inverters and some battery chargers. In this case the wire size may be large given the manufactures recommendations for the voltage drop requirements. The OCP device should be sized to the manufactures recommendation and not the wire size.