DC Charging System Design

A compilation of information and tips from
Rick Young, Steve Dashew, George Walner, and Bob Gayle

Batteries - Depth of Discharge (DoD)

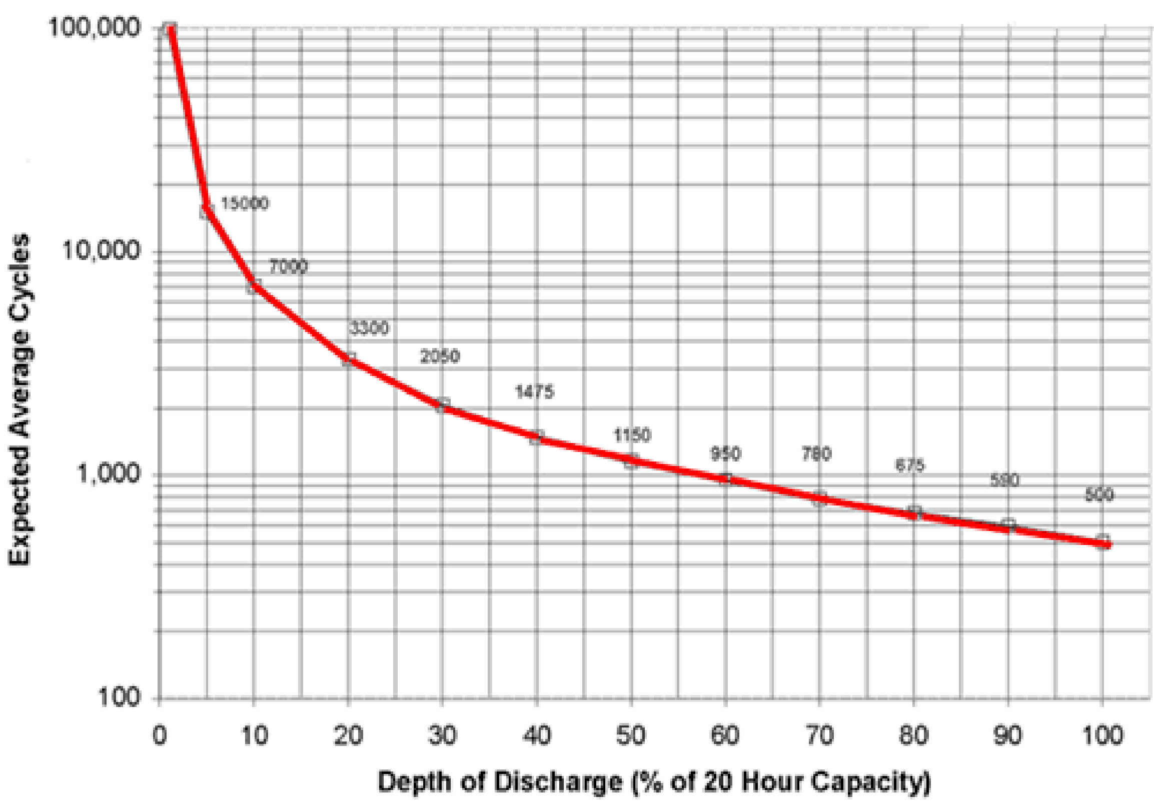


Figure 1

The relation between the cycle life of a battery and its DoD is logarithmic as shown in Figure 1. In other words, the number of cycles yielded by a battery goes up exponentially, the lower the DoD. This holds for most cell chemistries, (eg. flooded, AGM, and gel).

There are lessons here both for designers and users. By restricting the DoD, the designer can improve the cycle life of the battery. For example, look at the difference between 50% and 30% DoD - the life cycle almost doubles. The important point to understand here is that you can get longer life out of your bank of batteries by either having more than the minimal daily capacity required, or by topping the battery up before it becomes completely discharged. The down side of installing greater battery capacity is the weight and space they require, so typically a compromise is necessary. Most people that write about this subject will tell you that a cruiser should not allow their batteries to drop below a 50% DoD because the life expectancy will diminish rapidly, which is true. They'll also tell you that you shouldn't charge beyond 80%, because the cost of charging is greater, (actually it takes longer), and thus will offer diminishing returns and that as it turns out is less true

How to Kill Your Batteries

> *"In the industry it is estimated that about 85% of lead-acid batteries die prematurely by being under charged. For example, if you fail to reach a proper minimum acceptance voltage for a sufficiently long period of time the battery continually degrades and looses capacity on repetitive cycles. This is true for flooded-cell, AGM, and gel cells; that are killed by permanent sulphation due to undercharging, and includes standing for long periods short of a full charge."*
>
> *"Most cruising boats are short of a full charge, typically only charging to 80%, and most cruisers have little knowledge of proper care for their batteries. I suspect that the number for cruisers killing their batteries exceeds 85% under repetitive undercharged cycling."* ***– Rick Young***

There is a simple reason most cruisers stop charging when the batteries at 80% capacity. Most charging is done with the propulsion engine's alternator, a separate generator or shore power, supplemented by wind or solar. Since marina space is more expensive than fuel most cruisers anchor out and use one or more of the other alternatives to generate power. The ability of a battery bank to accept current varies depending on its state of charge, after 80% a battery's ability to accept current (amperage) decreases and slows down dramatically; so getting that last 20% of charge takes hours, which if you're using an engine or generator becomes a noisy, expensive and inefficient use of fuel.

Battery Monitoring

A good battery monitor is the cornerstone of a good charging system; it will measure kW-hours in addition to Amp-hours consumed and returned. This makes monitoring the battery bank and maintaining proper charge much easier.

Ideally you would perform a live test operating as you might over a 24 hr. discharge time and measure exactly how much energy is used, but an estimate can be used to roughly determine the size the battery bank and determine the space to accommodate it and determine hwo the weight will effect trim.

Knowing the kW-hour number one can then decide whether or not to go with flooded, AGM or Gel-cell batteries (Amp-hour numbers will not tell you that because the three types of batteries having all the same Amp-hour rating, will not have the same kW-hour rating). Those cruisers using non flooded-cell constructed batteries, where you are not able to replenish lost water ***require*** a monitor such as the Link 10 or Link 1000 for the longevity of the batteries

A real battery monitor is one that not only shows the usual Amp-hour status but actually measures true energy into and out of a battery bank (kW hours) and one whose measurements are stable for long periods of time and over a wide temperature range. It should be capable of displaying battery status in a simple, easily understood way that itself doesn't drain the battery bank. Dollar for dollar the best real battery monitor is the Link 10 or the Link 1000 ($250). They display battery status using LEDs. The LEDs are in a row of green followed by yellow and finally red LEDs that act like a "gas gauge" for your batteries. The milliamp load of the LEDs is far less than a digital or analog meter, though a digital meter is integral to the monitor, switch selectable for different displays, but remains off until desired. The Link 10 has an optional battery temperature sensor (otherwise you enter the ambient temperature manually). The Link 1000 is temperature sensor "ready" yet I do not know if Xantrex is making the temperature sensor for both of these products, since it wasn't originally designed by them.

The Amp-Hour Law and 3–Stage Charging

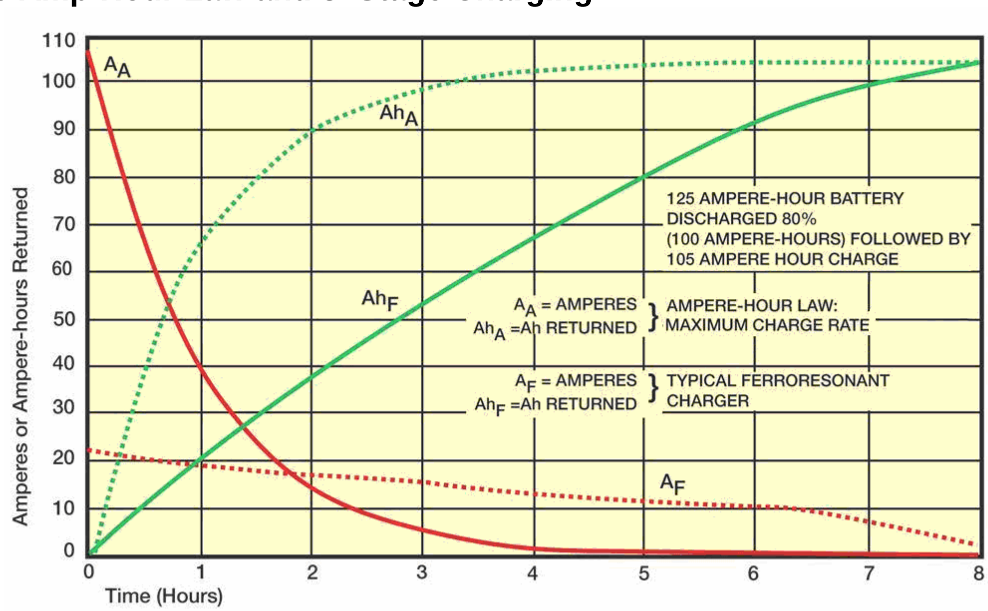


Figure 2. The Current Acceptance and Charge State of the Amp-hour Law [2]
Also graphed is the 8 hour charge cycle for a Ferroresonant (AC)Charger

“As good as Nigel Calder is he is wrong regarding the maximum charge rate not exceeding 25% of battery capacity for flooded cells and 33% for AGM, about how fast and how much current, as well as how much lead-acid batteries can safely charge accept.”

“A charging current equal to the value of the number of Amp-hours “missing” from the battery will not excessively gas or heat the battery. This is the "Amp-hour Law" which was proposed many years ago by G.W. Vinal in “Storage Batteries”, before the technology existed to implement it (1920’s). The charge curve following this "law" forms an exponential curve of E, with an ever decreasing curve of charge current ***– Rick Young***

The Amp-hour Law is shown in Figure 2. Notice that the state of charge of a battery being charged to the Amp-hour Law (**A_{HA} the dotted green line**) mirrors the battery’s charge acceptance (**A_A the solid red line**) in that the current lost roughly matches the current supplied. For example, a 450Ah battery bank discharged to 50% can accept 225A current initially, which then tapers down as the battery charges. Following this curve you can safely recharge a 100% discharged battery in about 3½ hours (AGM and gel cell) to just under 4 hours (flooded-cell) batteries. All lead-acid batteries designed to deliver heavy discharge currents, like those you need for cruising, will be capable of following the Amp-hour Law.

Now compare the Amp-Hour charging curve to the charge curve of a typical ferroresonant (AC) charger (**A_F the solid green line compared** to **A_{HA}**). It takes 8 hours for the AC charger to do what Amp-hour charging does in half the time. If you’re using shore power to do this it’s no big deal, power is abundant and available - it’s only the marina space attached to the power cord that’s expensive. Anyone contemplating using an AC generator to provide power for battery charging however should realize they’re accepting the chargers 8 hour charge cycle not the generator’s output. You’ll be spending a lot of time running your generator unless you look for a 3-step charger, with as high an amperage as your generator will support.

3-step regulators were the first attempt to achieve a charge curve approximating the Amp-hour law. To approximate Amp-hour charging requires more than just a fancy regulator, you also need a sufficiently large bulk charging source to replace those missing amps. 3-stage charging is roughly divided into bulk, absorption, and float stages. Bulk charging handles all but approximately the last 20% of the batteries charge state. . Bulk charging is dependent on availability of sufficient charge current and the batteries ability to accept that current; the closer the amperage of the charge source “matches” the amperage lost, the less time bulk charging will take. In Figure 2, the first 1½ hour of bulk charging, restores about 80% of the battery’s total amperage capacity. The time this takes is largely dependent on the amperage your charge source can provide. For the high current demands of bulk charging one of the best alternatives is a high output alternator on your propulsion engine; the engine is already there and has an alternator so little additional expense is involved in improving this element of the charging system. In any case, you'll also need this charge source to meet your energy demands while on passage.

As battery voltage approaches the charging voltage, the charging current required begins to rapidly decrease, and the state-of-charge increases much more slowly. This is the absorption phase of the charge cycle, and note that the solid red line indicating current acceptance drops from 20% to >5% of the battery's capacity. About 4 hours into Amp-hour charging this fully discharged battery, the number of ampere-hours returned to the battery is back to 100% of its rated capacity. However, the battery will still accept additional amperage up to about 105% at a greatly diminished current. This is the so-called "trickle charge" of the float charge cycle. Beyond about 105% virtually all amp-hours supplied to the battery are consumed in electrolysis and in heating the electrolyte.

> *"All types of lead-acid batteries, including AGM and gel cell, when subjected to Amp-hour-law charging almost never need equalization."* **– Rick Young**

Temperature Effects

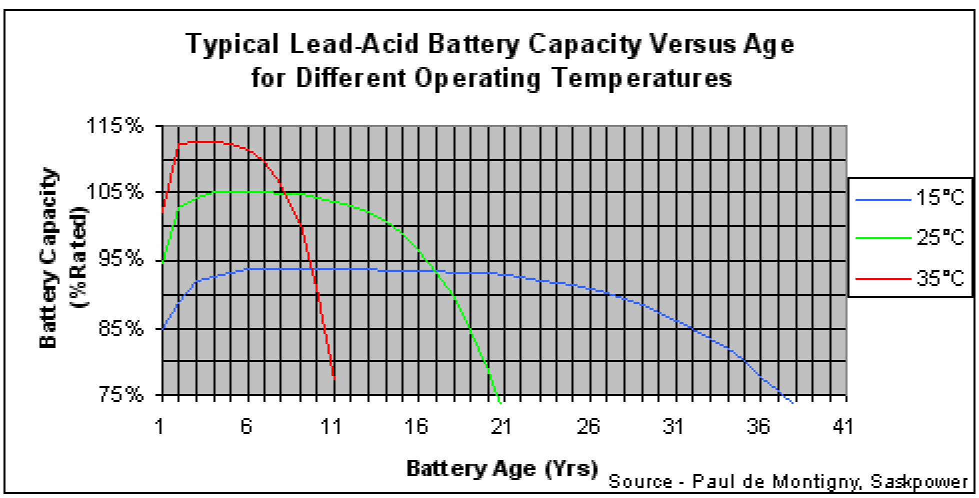


Figure 3

The shelf life and charge retention depend on the self discharge rate and self discharge is the result of unwanted chemical reactions in the cell. Chemical reactions internal to the battery are driven either by voltage or temperature. The hotter the battery, the faster chemical reactions will occur (see Figure 3). High temperatures can thus provide increased performance, but at the same time the rate of the unwanted chemical reactions will increase too resulting in a corresponding loss of battery life. Similarly, adverse chemical reactions such as passivation of the electrodes, corrosion and gassing are common causes of reduced cycle life. Temperature therefore affects both the shelf life and the cycle life as well as charge retention since they are all due to chemical reactions.

Maintenance - Adding Water to Flooded Cell Batteries

The electrolyte in lead acid batteries is a dilute solution of 25% sulpheric acid in water. As the lead-acid cell reaches a full state of charge, the water in the electrolyte is broken down into hydrogen and oxygen gasses by the recharging current. These gasses, along with some acid, escape from the vent on the top of each cell. This process, called "gassing", accounts for the water lost from the cells. High temperatures (>90^{o}F), high rates of recharge, and elevated voltage limits (>2.44vdc per cell) all increase the amount of gassing that can occur during the recharging process. If all the cells in a lead-acid battery are to be fully charged, then a certain amount of gassing will take place. It's up to us to deal with this situation. We add distilled water to the cells to make up for the water hydrolyzed into hydrogen and oxygen.

Never top off the water of cells that aren't fully charged. This presents a dilemma to cruisers who often only charge to 80% of the battery's capacity. There is a product on the market that *constantly* maintains water level in the cells of the battery from a reservoir, and touts its *convenience* for the user. Really it's just a convenient way to shorten battery life, because overfilling with water will inevitably lead to acid spills and loss of electrolyte when you do fully charge.

Ideally we would like to capture any water/acid that boils off the cells, condense it and return it directly to the same cell, as this would keep the cell chemistry as stable as possible over time under all conditions. There are products that help do that.

Water Miser caps and Hydrocaps replace the regular cell vent cap on a battery. When the cell is gassing, the hydrogen and oxygen gasses are vented into the cap, which captures and condenses the gases returning the recombined water to the cell. Hydrocaps use a catalyst to recombine hydrogen and oxygen gas back into pure water. (A chemical catalyst is a substance which facilitates a chemical reaction in other substances, in this case hydrogen and oxygen, without actually participating or being consumed in that reaction.) The resultant water is then dripped back into the cell. This reduces both the danger posed by out gassing explosive hydrogen and the frequency of replenishing water in the cells. The catalyst used in Hydrocaps is effective for about 8-9 years before prolonged acid exposure causes the catalyst to deteriorate requiring replacement.

Water Misers trap water and acid vapor reducing water loss by 50-80%, Hydrocaps recombine the gasses and reduce water loss by 90%. Hydrocaps do get hot when the charging cycle causes out-gassing, heat being a by product of the chemical reaction taking place. Hydrocaps should be removed when equalizing, but proper equalization needs to take place with abundant shorepower and with the proper test equipment. Actually improving your charging system may almost eliminate the need for equalization charging.

> *"We've been using Hydrocaps for 15 years to reduce battery water consumption and help keep the battery tops and terminals clean of acid buildup. This will cut down on water consumption and gas emission."* ***- Steve Dashew***

In an independent test of an off-grid home solar system; a battery bank of Trojan L-16s had their caps changed to Hydrocaps and after 2 months operation required no additional water, this despite previously consuming 1.5 gallons in a similar period without Hydrocaps, (http://www.ibiblio.org/london/alternative-energy/homepower-magazine/archives/11/11pg37.txt). Off-grid homeowners, RV owners, and cruisers that use Hydrocaps report only adding water annually or semi-annually when they clean the tops of the batteries of any acid deposits, dirt and dust. This is a significant improvement that avoids getting you in trouble with your maintenance regimen.

Connecting Your Battery Bank - Avoid Multiple Parallel Strings

The ideal battery bank is the simplest, consisting of a single series of cells, sized in amperage capacity for the job, with power taken off at each end, (eg. negative on one end and positive on the other end). Higher capacity batteries tend to have thicker plates, and therefore greater longevity too. Having fewer cells reduces the chance of randomly occurring defects, and reduces charge equalization problems within cells. Suppose for example, that you require a 600 amp-hour bank. Since the best price per Ah available in the battery market is the flooded cell golf cart battery (6v, 200-225 Ah) most cruisers will arrange their battery bank in a series/parallel string to get 12volts at the desired amperage. You can approximate the 600 amps by using 3 series/parallel strings of T-105 golf-cart batteries (225 Ah each) as shown in Figure 4, or 2 series/parallel strings of the larger L-16 deep cycle batteries (390 Ah each) or by a single series string of large 2v, industrial traction batteries of 600 Ah capacity per cell.

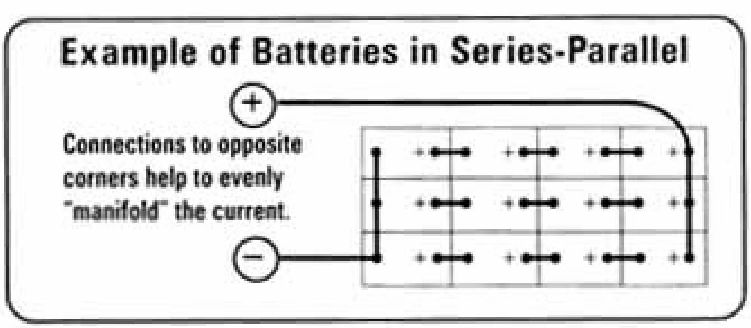


Figure 4

Using parallel strings invites problems in maintaining equalization within the battery bank unless they're connected correctly. ***Under no circumstances is it***

advisable to install more than three parallel battery strings. The resulting bank will tend to lose its equalization, resulting in accelerated failure of any weak cells. Weak cells will be difficult to detect because they will "steal" from the surrounding cells, and the system will suffer as a whole and will cost you more in the long run.

Here are some precautions to take when wiring two or more strings of batteries in series/parallel.

- The goal is to maintain all of the cells at an equal state of charge. Cells that tend to receive less charge are likely to fail prematurely. This can take years off of the effective life of the battery bank. A fraction of an ohm of added resistance in one battery string can reduce the life of the entire string so measure it and juggle batteries and/or cable lengths to get them as close to equal as possible.
- Connect the two main cables to opposite corners of the battery bank, and maintain symmetry in wire size and lengths. This will help to distribute current evenly through the bank.
- Arrange batteries to maintain even temperature distribution throughout the bank. Avoid uneven exposure to heat sources. Leave at least 1/2 inch of air space around each battery, to promote even cooling.
- Apply a finish charge at least every 3 weeks (bring every cell to 100% charge).

Preventing Corrosion

In flooded battery installations, corrosion of terminals and cables is a nuisance that causes resistance and potential hazards. Once corrosion gets hold, it is hard to stop, but luckily it is easy to prevent. Apply a non-hardening sealant to all of the metal parts of the terminals before assembly. Completely coat the battery terminals, the wire lugs, and the nuts and bolts individually. A sealant applied after assembly will not reach all around every junction. Voids will remain, acid spatter will enter, and corrosion will begin as soon as your installation is finished.

Special compounds are sold to protect terminals, but you can have perfectly good results using common petroleum jelly (Vaseline), which will not inhibit electrical contact. Apply a thin coating with your fingers, and it won't look sloppy. If a wire is exposed at a terminal lug, it should be sealed airtight, using either adhesive-lined heat-shrink tubing or submersible rubber splice tape. You can also seal an end of stranded wire by warming it gently, and dipping it in the petroleum jelly to liquefy, and wick it into the wire.

It helps to put the batteries over a floor drain, or in a space without a floor, so that they can be rinsed with water easily. Washing the battery tops semi-annually will remove accumulated moisture, acid spatter, and dust. This will further reduce corrosion, and will prevent stray currents from stealing energy. Batteries installed using these simple protective techniques show very little corrosion, even after 10 years without terminal cleaning.

Energy Audit - Efficiency First

> *"Very often I have calculated battery system "size" to be in the region of 400 Amp-hours for a 40' cruising yacht, but only if the customer would change the fridge to a high-efficiency unit."* ***– Rick Young***

The first design parameter is to find is your daily amp requirements by making a preliminary energy audit of at anchor and on-passage needs. (It's not unusual BTW for on-passage energy needs to exceed those at anchor, because you'll be using GPS, electronic charting, AIS, and autopilots etc. on-passage) Initial investigation should reveal where you could use more efficient equipment, like compact fluorescents, evaporator plate DC refrigeration, LED anchor lights, etc. The approximate number of kW-hours that may be consumed over 24 hrs provides the parameters for sizing the battery bank.

AC appliances consume enormous amounts of battery power (110v x amperage x hours of operation), and need to run off inefficient inverters. Replace AC appliances where DC alternatives are available. Try to limit the AC appliances operated by inverter to those that run for short time periods, (eg. coffee grinders, hand blenders, microwave ovens). Look at alternatives (propane or diesel) to electric appliances for heating water or cooking which demand high current for long periods, or plan on powering them directly with a small AC generator when they're in use.

A spendthrift approach to efficiency will quickly drain even a large battery bank, forcing you to depend on shorepower or running a separate generator for long periods. From your daily energy needs you can begin to design a charging system that will return that energy to your battery bank.

Battery Decisions - 12 or 24 Volts

If you're building a boat and don't have an existing electrical system installed this is an important decision that will effect your wire sizing and selection of equipment. If you have an existing boat and decide to switch to 24 volts you probably don't need to rewire since your existing wiring will be carrying less amperage, but you'll probably want to change out much of the DC electrical equipment to 24 vdc. Some appliances aren't available in 24 volts, but lighting, fans and pumps are and will have the same power demands, but at 24volts require about half the amperage. Often 24vdc equipment is a bit more expensive, sometimes it isn't.

Power in watts = Volts X Amps
12v x 10A = 24v x 5A

Many cruisers base their decision to use a 24vdc system on the use of an electric windlass or bowthruster, because the high current these demand requires very heavy gauge wire on a long run from the battery to the front of the boat. 24volts halves the amperage and reduces the wire gauge required. I would suggest that there are other good, even better reasons for using a 24 vdc system on today's boats. These have more to do with the nature of the marine market itself, and the increasing use of electronic equipment on board.

> *"There are but two ways to build truly reliable electronics: large volume or high cost, either of which are challenging in the small, fragmented marine world."* ***– George Walner, electrical engineer and designer/owner of 'Electra'***

The marine market is really tiny especially compared to the automotive and truck markets, where R&D costs can be spread over millions of units or where volume and the demand for reliability have improved the product. ***Always*** look for alternatives from larger more demanding markets before buying anything with the word "marine" on it.

Here are my reasons for deciding on a 24vdc system:

- Electronic equipment is very sensitive to voltage fluctuations, which are typical in a nominal 12 volt battery bank, (voltage varies from about. 11.2-14.4 volts). The military is dependent on an extensive array of on-board electronic equipment in their vehicles and have standardized on 24v electrical systems. To power electronic equipment they use DC-DC converters, that can withstand extremely harsh environments, to step down from 24v to 12v so any voltage fluctuations at the battery bank can be virtually eliminated at the 12v electronics. Since the DoD paid for the R&D and obtains this equipment from COTS (common off the shelf) contracts, the result is reliable cost effective commercially available converters [3]

- Telecommunications systems that are off-grid, (ie. antenna and cell-phone towers), are typically based on either 24 or 48vdc systems. DC to AC inverters designed for use in cell phone towers are rugged, modular (combining to supply higher amperage), hot swappable and very reliable. The cell phone companies that operate them demand high reliablity.[3]

- Generating DC electricity using a high output alternator on the propulsion engine is often the cheapest and most cost effective charging source. We can dramatically improve the efficiency of the typical truck alternator by operating it at 24 volts. It turns out that using 12 volts places an efficiency limit of about 50% on the typical "claw-pole" automotive alternator. This was considered acceptable in the 60's when fuel prices were low and the switch to alternators was motivated by the need to generate higher currents at idle to power accessories. Running a 12 volt alternator at 24 volts can improve its efficiency dramatically. (More about this when I cover alternators and how they work.)

Battery Bank Sizing – Making a Compromise

Steve Dashew is very smart and he's been working on and refining solutions to charging systems on cruising boats for a long time. I was always intrigued by his choice of "traction batteries" (used in forklifts) and the high amperage he typically selected for his battery banks, (800Ah on *Beowolf*, 1400Ah on *Windhorse*, and recently 1200Ah on the FPB64). This isn't just overkill; there is logic at work here. Traction batteries unlike golf cart batteries are designed to be discharged regularly to 20% rather than 50% of their capacity, giving him an extra 30% of capacity available for use should he want it. (In other words, this increases his ***flexibility*** in staying longer in an anchorage without charging.)

Dashew's battery banks are composed of individual 2 volt cells, which can be used to create a simple series string; that is more reliable than a series/parallel arrangement. Though very heavy in total, and quite tall, each 2v cell is separate, so lifting a single cell is within the capability of one or two fit men (depending on size). The cells are available in a variety of amperages so he selects the size to equal his desired amperage for the entire battery bank. Like off-grid solar powered homes, he sizes his battery bank to power the boat for multiple days. On the FPB64 he has 80% of 1200 Ah available (960 Ah) or enough for a daily load of 320 Ah for 3 days. He plans on powering to a different anchorage or running his generator every third day to recharge his batteries. The generator also provides power for electric cooking and doing laundry along with battery charging. (Some small generators can drive a separate truck alternator for battery charging.) To recharge his batteries when powering, Dashew uses twin nominal 150A 24v alternators with electronic controllers to equally divide the output needs. His is the kind of compromise you almost never read about in boating magazines, but makes perfect sense.

I have to admit being puzzled by the fact he didn't use the large roof area of the FPB series to mount solar panels, which could provide the area to supply some of his daily needs, toping off the batteries regularly at absorption and float current levels. That would make it very much like an off-grid solar home with generator back-up. His boats have the space for a large battery bank and he mounts them so as to balance the boat's trim.

You're probably wondering what this high dollar example has to do with the much smaller, less demanding and hopefully cheaper electrical system on your boat. It is illustrative of how you can make compromises in electrical and charging system design to achieve a particular cruising goal. In Dashew's case, he wants his average 3-day stay in an anchorage to be largely free of the noise and attention demands of a generator, but doesn't want to give up much in creature comforts, including a washer/dryer and DC air conditioning, so he developed a compromise to suit.

Let's use Rick Young's typical 400 Ah 12v battery bank on an efficient 40' cruising boat, to look at an alternative compromise. Figuring that the bank is sized for a daily load of about ¼ the size of its capacity (which is typical) it suggests about 100-150 Ah daily load @ 12 volts. Let's work these hypothetical numbers to try to achieve a different compromise. We'll start by switching to a 24 volt system, so our daily load will change to about 50-75 Ah. Ideally, we'd like to restore much of that load using solar power, but we know we'll never have the area available for bulk charging; for that we'll rely on a high output engine driven alternator which we'll need anyway on passages to recharge the batteries.

What if we increased the Ah capacity of our battery bank so that our daily load could be supplied by solar panels at absorption cycle current levels. That would reduce our solar charging system to about 20% of the battery banks capacity. What size bank would we need?

75Ah / 0.20 = 375 Ah

Let's use a battery bank of L-16s (390Ah). 4 L-16s in a series string is taller and heavier than T-105's but has about the same footprint. How many days can we operate without charging?

390Ah * 0.50 DoD / 75Ah per day = 2.6 or about 2½ days

Suppose we change to 420Ah 2v traction batteries. Will their ability to handle an 80% DoD extend our days without charging?

420Ah * 0.80 DoD / 75Ah per day = 4½ days

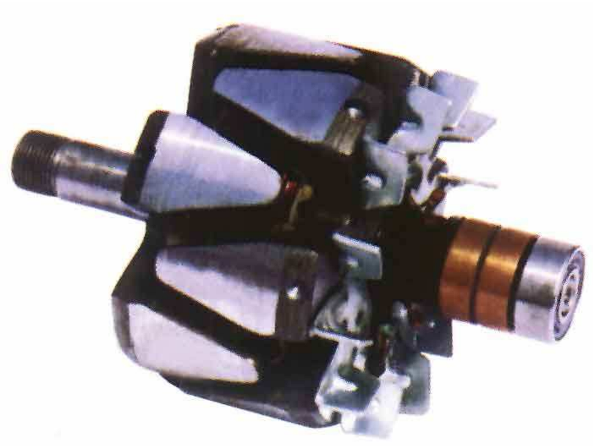
We still have two unanswered questions:

1. Can we design a bulk charging system that can provide the 200-320 Ah needed to bring a 400 Ah battery bank up from 50-80% DoD?
2. Can we fit a solar array on the boat to provide about 75Ah@24volts?

Let's try to answer those questions in that order alternators first…

Alternators and Regulators

How alternators work – The typical automotive "claw-pole" alternator uses a magnetic rotor (turning element) consisting of either permanent magnets or more commonly electromagnets with a field current in their windings. A stator is placed around the spinning rotor. Within limits, the stator wiring determines the amperage output of the alternator. An alternator generates 3-phase alternating current (AC). The AC current comes off in three legs and then a group of 6 diodes (rectifier) are used to convert the AC to DC. "P" type alternators use electromagnets in the rotor and have two field brushes that pass the field current to the spinning rotors. The voltage regulator monitors the battery voltage and varies the field current to alter the amount of current and voltage supplied to the battery.



Rotor with copper slip rings for brushes   **Stator with 3 Phase Output**

The USCG has seen fit to certify as “marine” only brushless permanent magnet alternators, to avoid sparking and fire on gasoline powered boats. Diesel engines don’t have fumes that ignite and so non-marine alternators work fine; indeed to achieve an Amp-hour or 3-step charging regime requires altering or interrupting the field current and is the simplest way to control the output of the alternator. Dropping the “marine” designation also allows us to take advantage of the economies of scale permitted by the truck market.

Truck alternators aren’t designed to charge banks of deeply discharged batteries. Instead, they’re designed to maintain them against a given load. Take an emergency vehicle, as an example. It might have 100 amps of load with various devices in operation, with the engine idling. Supplying the current to recharge after starting isn’t demanding, so the battery never really gets deeply discharged and the alternator loafs along, with the field current cycling on and off, which helps keep the alternator cool. In fact the voltage regulator is built into automotive and truck alternators, and actually monitors alternator temperature to keep them cool since diode failure from heat is the #1 cause of alternator failure. The internal regulator that comes with the alternator can’t do 3-step charging, so it gets tossed out in our application.

Now come on board a boat with a large battery bank and an intermittent charging regimen. When the alternator starts up, it has to go to full output, sometimes for hours on end, to get the batteries back up to their charged state. This means the current flowing to the alternator field is on constantly - what is called full field operation. There is no chance for the alternator to cool down, except via the air being pulled through it by its own fan. (Tip – Always match the fan assembly to the direction your engine turns, though bi-directional fans are available for many alternators they’re much less efficient than a directional fan.)

To meet the current needs for bulk charging on a cruising boat, a high output alternator will spend much of it's time in full field operation. Two small frame high output alternators (90-100A) will not be as reliable or as efficient as one 160A large frame alternator. The large frame truck alternator has much more volume with which to accommodate magnetic flux saturation of the field, better cooling and bearings that are about 4 times "stronger" than those of small frame alternators; all these advantages in a package only 1.5 inch larger in diameter.

Alternator Heat Management - The majority of the heat from an alternator comes from the rectifier diodes, which convert the alternator's AC power to DC. Most alternators draw air from back to front. Unfortunately, the air behind the alternator in most installations is typically beside the exhaust manifold of the engine - the hottest place in the engine compartment. Alternators with internal rectifiers can get so hot, you could fry an egg on them, and many can get hot enough to melt the epoxy insulation on the stator wiring when operated at full-field current.

This is the rectifier board on Steve Dashew's FPB64, taken from his *Setsail* website. It shows the two remote mounted (fan cooled) rectifiers for the Electrodyne alternators. These are installed remotely outside the engine room. The Smart voltage regulator is mounted between the rectifiers.

Heat reduces output, and shortens the life of the alternator. Removing the rectifier diodes from the alternator body, and putting them in a fan-cooled box removes the heat source from the alternator body and the diodes from the hot engine compartment, greatly increasing the durability and life of both. There are kits available to do this (http://www.alternatorparts.com/quicktifier-remote-bridge-rectifier.html), or you can just remove the alternators rectifier and replace it with an aluminum spacer (with holes for cooling) if necesssary, and mount the rectifier in a fan-cooled enclosure outside the hot engine room.

Here's a photo from Dashew's FPB 64. Instead of the solid belt guards that come with the Luggar engine, they've built expanded metal guards in front of the engine …

and around and in front of the belt of the alternator that permit cooling air flow

We thus far have stripped our truck alternator of everything but the rotor, stator and field brushes. If you buy a new high output alternator, the rectifier and regulator are often mounted internally or in some cases on the back of the alternator. An even cheaper alternative would be to buy an alternator core from a wrecking yard, clean it up, strip out the rectifier, toss the regulator, replace the brushes and bearings and any defective parts (if necessary). ***Warning – It is very important when stripping an alternator of these electrical parts to make sure that all electrical connections are well fastened, free from contact with the moving rotor and insulated from the alternator casing. This is particularly true when removing the rectifier diodes. An alternator repair shop should be capable of performing this for you if you explain what you intend to do and why.***

Alternator Selection – About the most amperage you can get reliably from a 12vdc alternator is 160A, which makes the Leece-Neville 110-555 “triple nickels” one of the better off-the-shelf alternatives on the market. (Leece-Neville was purchased by Prestolite who changed the part no. to 8LHA2070JHO for a typical 12/6 mounting lug arrangement or 8HLA2070PHO for a pad mount.) These are frequently used by the manufacturers of motorcoachs and large RVs. The large frame Delco CS144 140A alternator was used for many years in delivery vans and ambulances and has a good reputation also.

DC refrigeration systems often trigger the need for larger battery banks. Many cruisers turn to generators as a charge source, but as we’ve seen selecting a typical AC charger can double the time to charge over a 3-step charging regime. Most AC chargers are made to be connected to shorepower so often provide much lower amperage than a high output alternator can, which also increases the time to charge. Running a generator for long periods in most anchorages certainly won’t make many friends among your fellow boaters.

If you intend to recharge a large battery bank you can resign yourself to longer charge times or use some ingenuity to come up with a better solution. One option is to temporarily split the typical series/parallel battery bank into two independent 12v banks for charging and thus cut the current demand of each bank by half. A split charging regime can work especially well when using two battery chargers with a small generator for power, as long as the charger and battery split are completely independent.

Another alternative is to mount twin alternators on the engine. Boats with twin engines do this using an electronic controller to balance the alternators output, like Ample Power’s Dual Alternator Controller (DAC). (If you attach both alternators without an electronic controller to balance the load, one alternator will work at full output and the other will loaf along – it just doesn’t work). Where fuel consumption and engine operating hours are important this doubling of available charge current can keep the time for bulk charging short and still do it with truck alternators (cheap).

Another option, particularly for people building their boat, is to decide to install a 24vdc system. Bob Gayle wrote a white paper[4] about improving the efficiency of a typical truck alternator and thus its power output. He switched a Leece-Neville 110-555 alternator to charge at 28.8vdc. The measured output for this alternator were 130A @ 14.2v (1.85 kW) at 3400 rpm. With the regulator fooled into using a 28.8 volt setpoint for output, the alternator produced the same 130A @ 28.8v (3.74kW) at 3400 rpm at full field current, almost doubling its power output just by allowing it to operate at the higher voltage. No rewinding was needed since the windings are running the same current. Bob used an old 12v Balmar regulator monitoring voltage from the middle of the battery bank, so the regulator thought the alternator was generating 14.4v; instead of the actual 28.8 volts being delivered across the entire battery bank, (this works easier using a regulator that allows a 28.8v setpoint).

Such a configuration can easily provide the bulk charging for a 24v 225Ah bank, or even a 24v 390Ah bank composed of L-16 batteries. Two alternators with the Next Step regulator and Dual Alternator Controller can charge even large traction battery banks. We know this because Dashew uses a similar arrangement to charge the 1200 Ah bank on the FPB64. The difference is just one of Dashew's two Electrodyne alternators retails for $1,242, while 2 L-N "triple nickels", the Next Step regulator and DAC would retail at $954 and you can find "triple nickels" for a lot less.

Selecting the Pulley Ratio – The pulley ratio is determined by the following equation:

Pulley ratio = Crankshaft Pulley diameter / Alternator Pulley diameter

Notice that the output curve in Figure 5 varies with speed in RPM and that to run the alternator near its peak output requires a shaft speed of 3500-4000 RPM which is much faster than most diesel engines will turn at cruising speed. The cut-in speed for this alternator is 1000 rpm for 12v, (2000 rpm if run at 24v), and the manufacturer has an 8000 rpm continuous rating for this alternator

For example: I've determined that the cruising speed of the Isuzu 4LE2 engine should be about 1800 rpm. The Isuzu's maximum speed is 3000 rpm. The alternator needs to reach the cut-in speed of 1000 rpm for 12v (2000 rpm for 24v) at an idle speed of 800-900 rpm for a ratio of 1.25:1 or greater (2.5 to 2.67:1 for 24v). I would want to turn the alternator at 3400-4500 rpm alternator speed at 1800 engine rpm - a pulley ratio of 1.88:1 for 12v (2.5:1 for 24v). At 3000 rpm the alternator would be turning 5640 rpm (7500 rpm for 24v), still below its 8000 rpm limit.

The power requirements of big alternators put big strains on the drive belts, alternator brackets, and pulley tensioning devices. Add in the power pulses which are inherent in all diesel engines, and it takes muscular engineering for all of this gear to stand up over time. Switch to dual V belts is mandatory, or using "poly-V" or ribbed belts and a serpentine drive is a better idea that can also reduce tension requirements. They're more reliable and better at power transmission.

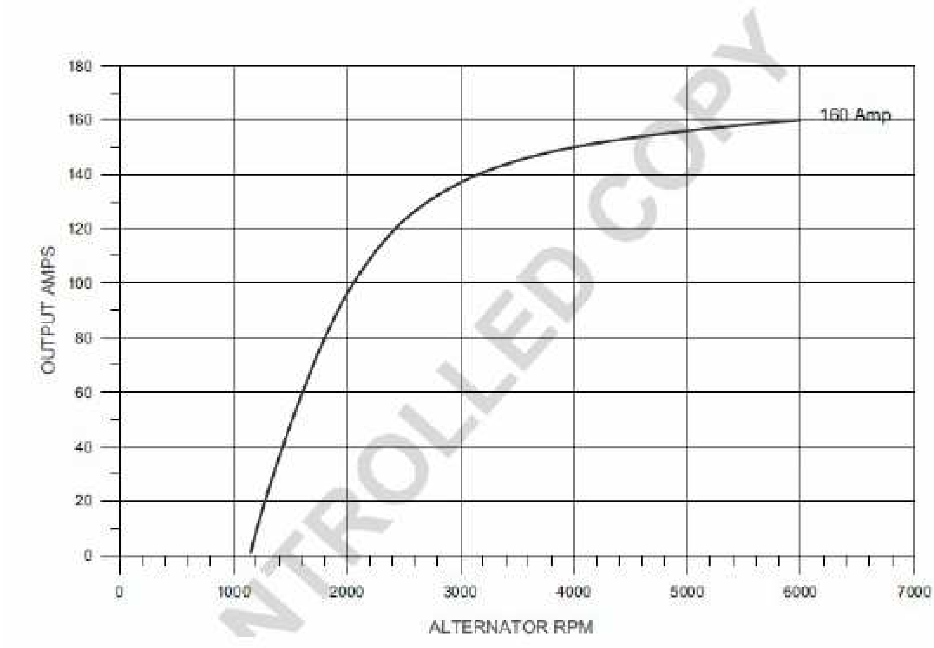
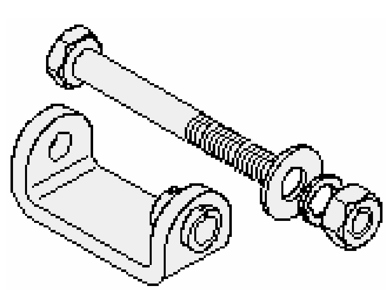


Figure 5 Prestolite 8LHA2070 / Leece Neville 110-555

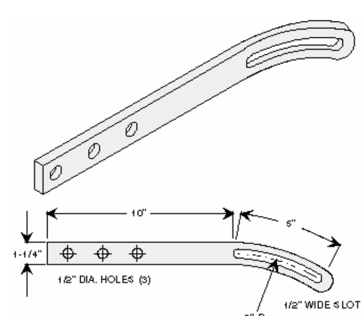
Alternator Mounts Should be Made in Steel – Should you decide to add a second alternator you'll need to make mounts. Steel is used by every engine manufacturer to build alternator mounts for two reasons:

- Steel has vibration resistance that provides years of trouble free service.
- Steel matches the engine's galvanic voltage potential, thus preventing rust. Dissimilar metals and should not be mixed in a marine environment.

Delco makes universal welding brackets for alternators, (2" mount – unplated for welding). It should go without saying that you should measure your alternators mounts and compare them to the brackets before buying them. These can be welded to a custom supplied engine bracket, and the heavy duty curved belt tension extension bracket, (3/8" thick x 1-1/4" wide, unplated)



Delco Part # A300 $17



Delco Part # A220 $29

Finding the HP and Torque Required for a High Output Alternator

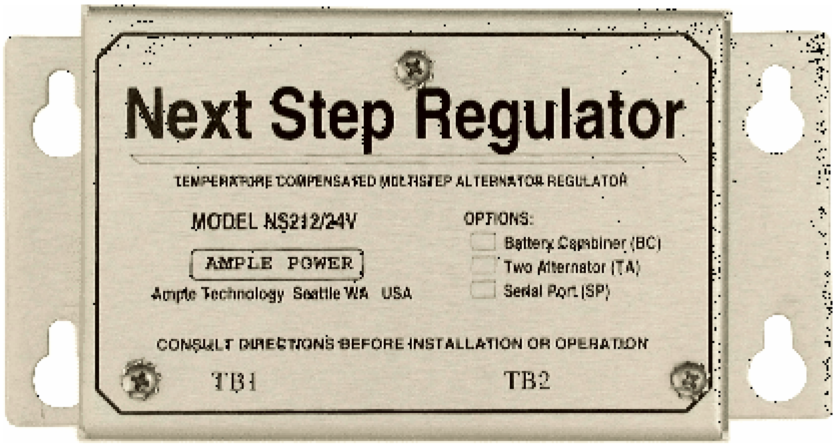
130 amps (@3400 rpm) x 14.4 volts = 1872 watts
1872 watts / 745.7 watts/hp = 2.5 so figure 3 hp
3 hp x (5252 / 900 rpm) = 17.5 ft./lbs.
The same current @ 28.8v or twin alternators would take 2.5hp *2 or 5 hp

Voltage Regulator - During the bulk charge step, the battery can accept most of the alternator current and convert it back to available capacity. Once the battery nears a full charge, excess charge current becomes heat. Small at first, the heat begins to accumulate in the mass of the lead plates. As the heat accumulates, temperature of the battery begins to rise. The current through the battery begins to double for every 18^{o}F increase in temperature. That means more power is dissipated in the battery which means more heat is generated, which means more current flows, which means more heat – all leading to **thermal runaway**. If you're lucky you won't be looking at the battery when the caps blow off with acid following. To avoid this absolutely requires a voltage regulator to control the alternators output.

The voltage regulator monitors the battery’s voltage; if the battery needs more power the voltage regulator changes the field current to the rotor coils. If the regulator senses a large discrepancy between the battery voltage and its setpoint, it sends maximum power to the rotor. If the regulator senses a small need at the battery it will send minimal power, causing the alternator to produce less. The better regulators will also accept battery temperature sender input to prevent thermal runaway.

Unlike the rectifier, the alternators output amperage never goes through the voltage regulator. The area of concern when changing to a high output alternator is the amperage draw of the rotor and consequent change in the field current amperage. The voltage regulator is also sensitive to heat and should be mounted outside the engine compartment, the length of the cable run and the current determine the wire gauge required for the field current. Voltage regulators do have a field amperage rating and because it has direct contact with the rotor you should be concerned with the amperage draw of the rotor in order to size the wiring accordingly. If the amperage draw of the rotor is greater than the rating for the voltage regulator the regulator will fail. Some alternators have the brush mounts built into the body of the regulator, on others they’re separate and permit easy removal of the regulator.

A separate switch for the field wiring can be used to “shut down” the alternator. The field current controls whether the alternator is turned on and generating AC voltage. A dry cell battery, appropriate for providing the field current, can also be wired up to the switch as a backup to insure that the alternator will charge a dead house battery bank if you can get the engine started. (This is problematic if your engine has common-rail injectors or “glow-plugs” which require a lot of current).



Ample Power's Next Step Regulator 12 or 24vdc ($299)

3-step voltage regulators that emulate the Amp-hour Law are few and unfortunately expensive. Ample has a good reputation for reliability; the Next Step 2 w/ battery temperature sensor is both 12/24v capable ($299), and the V3 (12v -$449, 24v $499) has better field current protection.   Balmar have only fair reliability with several SSCA members reporting replacing multiple units or "losing programmed settings after a few days", wire size may play a role in programming loss (?), and the mounting location may play a roll in failures (heat sensitive). Ample and Balmar both accept battery temperature sensor and alternator temperature sensor input to control field voltage. The best 3-step alternator regulators are ones which allow you to set the absorption voltage, the float voltage, and the time-to-float independently and accept a battery temperature sensor to prevent thermal runaway.

Procedure for Adjusting Absorption Charging Voltage

During absorption charging the voltage remains constant and the current gradually tapers off as internal resistance increases, so the charger needs to put out a higher voltage. Voltages during this stage are typically between 14.2 - 15.5 volts in a 12 volt system, (28.2 – 31 volts in a 24vdc system) and being able to make small 50 millivolt changes can dramatically change the charge current supplied. Our goal during absorption charging is to vary the charge voltage until the charge current matches the "missing" amp hours from the battery. Like a fuel tank you use the battery monitor to determine the desired amount of current at any given moment; if you're down 90Ah then you want to feed the batteries 90A of charging current. Adjusting the absorption voltage to match the missing amps will result in a closer approximation of the Amp-hour curve. This can recover lost battery capacity in batteries that have only been partially charged and degraded. Here is the procedure to follow:

1. Pick a time when the number of Amp-hours missing is slightly less than the maximum charge current capability of your charge source.

[**Note:** We know that the battery charger should be sized to deliver approximately 25% of the Amp-hour rating of the bank to guarantee sufficient current density to the discharged plates for uniform conversion of the sulphate formation to oxide formation. Such "good" charging may make a life difference from as little as one year to 10 years.]

2. Increase the charge voltage to as high as possible. Note the charge current. If the current is say 40A and you have 38Amp-hours missing then leave it there, ***it doesn't matter what the voltage is***.

   [**Note:** Be sure to check that your shore charger or alternator regulator can allow the user to set the upper voltage range well above 14.4v, 14.6v is a minimum. Also check to see just how easy it is to make such changes.]

3. Keep watching the charge current versus the number of missing Amp-hours and if the charge current exceeds the number of missing Amp-hours by say 10% or more then consider lowering the voltage again to make the numbers match. If the decreasing charge acceptance current "tracks" the missing Amp-hour number within 10% or so you are in luck

   [**Note:** On succeeding charge cycles the voltage might have to be set slightly lower because the battery has already recovered lost capacity due to a better acceptance charge. As the battery heads towards full the charge current acceptance of the battery decreases tending to not make you have to change the charge voltage perhaps at all.]

Adjusting Float Charging

Once the battery is back to near 100% the charging system switches to float charging. Float voltage is determined by the acid concentration and temperature period; 13.7-13.9v is a good float value for 12v. There is a simple formula describing the at-rest cell voltage as a function of the specific gravity of the electrolyte. The time to transition to float is when you are almost full and you will note a complete lack of tracking:

- For example, the charge current is 5A and you are only missing 2Ah.
- You should note at this time that ***no significant temperature rise has occurred in the battery***. If it has then on the next cycle go to float earlier.

Once you have attempted Amp-hour law charging and the battery has been on float, say overnight for shorepower chargers, (or all day for solar), put the charger back on at the same drive level that you used to get maximum current from your charger.

If the capacity of the battery has been recovered then the charge acceptance current will be near zero - about 100mA per 100 Amp-hour rating of the battery or less. If you observe this then the internal resistance of the battery is minimum and the capacity is likely to be maximum.

- Manually zero out any accumulation in your battery monitor, if it doesn't zero automatically.
- From here you begin your discharge cycle and the end reading will be accurate.

You can repeatedly get away with bulk charging only to approximately 80% capacity, if you periodically (once a month min.) fully charge the battery bank as described above, you'll increase its service life by years.

Time of Recharging

The math involved solves this equation:

$$Ic = Im(e^{-t})$$

Where:
Ic = the charge current available
Im = the number of Amp-hours "missing" from the bank
T = charge time

One integrates Ic versus time to get the total accumulation of Amp-hours for a time period. One quick way to visualize this is that one can get about 63% of Im in the first hour and one can get 63% of the value of the remaining value of Im (at the end of the first calculation) in the next hour. This will give you a very close approximation assuming that the battery is charge accepting, knowing when the charger becomes voltage limited, thereby not being able to put out rated current.

AC Battery Chargers

Iota DLS-90 (12v) and DLS-27-40 (24v) Battery Chargers with an internal IQ4 Charger control that does 3-step charging ($185 - $400)

I suggested earlier that for AC battery chargers powered by a generator one way to reduce the charge time was to split a series/parallel battery bank into two 12 volt banks, which halves the amperage required for each bank, and use two high amperage 3-step chargers. Join your two independent banks with a battery selector switch; wiring one charger to each bank. This way each charger will have the best opportunity to deliver rated current.

Chargers for use with a Honda EU2000 Generator – The small Honda generators are small, light, relatively quiet, and have a fuel pump capable of drawing gasoline from a larger tank or Gerry can, all of which makes it more acceptable to cruisers running them in an anchorage. Using Iota DLS-75 chargers the absolute maximum current draw is 18A at the low end of the AC input voltage range. That is the approximate output of a Honda EU2000 generator. Each charger is connected to a separate 20A AC power circuit. (You use an external IQ4 controller with the Iota chargers to make it into a 3-stage charger. The IQ4 controller adds about $30 to the cost of the chargers.)

The charging voltages on the Iota can be changed, but not independently. There is a single screw which lowers/raises voltages used for all 3 steps. On the older Iota chargers, the screw is accessible from the outside of the charger, and for the newer Iota chargers one needs to open the charger to access the screw.

> *Rick (Young) is the person who helped me to understand how to hook up my two Iota chargers. Here is how it is set up:*
>
> *4 Trojan T-105's are wired up in series/parallel arrangement to give 2 banks of 12vdc. I have a 5kw diesel genset that can power two 120vac 30A circuits . I have each Iota DLS 90 hooked up to a single bank (2 Trojan T-105s wired in series). During charging, I isolate the battery banks and run both Iota chargers at the same time, allowing each DLS-90 to independently charge its own battery bank. When charging is complete, I then put both banks in parallel and drain them as a single bank, enjoying the benefits of a slower drain rate since I'm drawing from all four T-105s at the same time.*
>
> *The system has worked flawlessly for us. The batteries, surprisingly, are behaving like new still, a year later.*
>
> *Everything is working very well now, these are well-built switching power supplies. They don’t get very hot. Thank you all for helping me to select the proper equipment at a price that didn't break the bank. I am very satisfied with the setup.*
>
> *I wired one Iota 90 into each of my 30amp circuits. This allows me to run both chargers and turn on an item or two during bulk charging on either 30amp circuit. More flexibility than having them both on one circuit.*
>
> *Iota stands behind their products as well. I bought a DLS 55 w/IQ4 from a member here and it quit a month later. Iota replaced it with a brand new unit - no questions asked even though it was bought second hand. Now there's a*

company that really stands behind what they make! I wouldn't hesitate to recommend or buy again.

The whole idea is that both chargers work at the same time on the separated banks. Keep in mind that even with the battery selector switch in "both" the chargers can still be operated at the same time with their outputs essentially in parallel, you just have an overall reduced number of Amp-hours being delivered compared to operating with the two chargers because their outputs won't be balanced.

One other way to charge batteries with a generator is by using it to drive a truck alternator. This was what Bob Gayle was investigating in his white paper[4]. He had a small Chinese Chagfa S195 IDI diesel engine mated to an ST 7.5 AC generator and he drove an L-N "triple nickel" alternator off the front pulley for battery charging. This works much better for DC battery charging than any arrangement of AC battery chargers, as your existing 3-step regulator can be switched between the propulsion engine's alternator or the generator's alternator for operation.

Alternative Charging Sources – Solar, Wind and Towed Water Generators

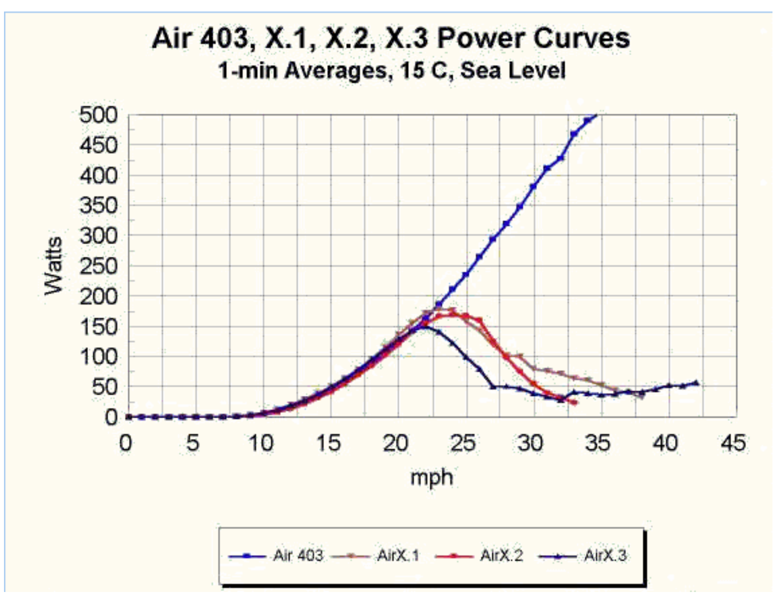
While engine driven alternators can provide your bulk charging needs, few independent charge sources work better for absorption and float charging than solar panels. Photovoltaic (PV) solar provides it's charging over a long time period (about 4 hours/day from 10am to 2 pm), but with limited current, so solar is an excellent charge source for the higher voltage/lower current demands of absorption and float charging, which also needs to be supplied slowly over an extended charging period. If your daily current draw can be topped off during the day by solar you'll not only increase your quiet time at anchor, you'll improve your battery life dramatically (remember the DoD chart). If you reduce your draw periodically by doing some shore based sightseeing a solar array can replace the current draw of a refrigeration system and give your batteries a long trickle charge to 105% capacity to improve their life, all without demanding attention, or annoying your neighbors, while you're off enjoying yourself. The biggest problem with this rosy picture is finding the area (and the money) for the solar panels needed to generate the power.

Unless you have a large catamaran you may have difficulty finding sufficient area on a boat to mount enough solar panels to meet your absorption charging needs, but getting sufficient area to provide the demands of DC refrigeration is easier. This may change in the near future. The solar photovoltaic (PV) industry is undergoing a change from silicon panels to thin film CIGS panels, which should significantly reduce the cost/kW for generating power down to $0.50/kW. Firms like Nanosolar have developed a PV "paint" that is printed onto thin sheets of aluminum using large printing presses. The cells are then placed in a sandwich of insulating glass. All of Nanosolar's current production from their San Jose plant is being shipped to Canada for utility sized installations. Konarka is another firm making flexible CIGS panels using heavy mylar insulation, all their current production is going to produce “utility” sized panels. It will be awhile before we see these panels trickle down first to the residential grid connected and then the off-grid markets. Flexible CIGS panels have the potential to be incorporated into awnings, which will go a long way toward increasing the area that can be utilized on a boat for electrical charging at anchor. So the future may be bright, but won’t be around to help us for awhile.

Pulse Width Modulation (PWM) Charge Controllers were developed jointly by Sandia National Laboratory, Morningstar and Digital Solar Technology[5] to charge batteries using PV solar arrays. To improve solar battery charging, they operate on a different principle of pulsing the charge current. The charger is periodically isolated from the battery and battery open circuit voltage is measured. If open circuit voltage is above a preset limit, the charger remains isolated (shunted); when open circuit voltage decays below that limit the charger is reconnected for short periods - pulsation. The open circuit voltage, charging current and the pulse period duration are chosen so that when the battery is fully charged, the time for the open circuit voltage to decay is the same as the pulse duration. When the charger controls sense this condition, the charger is automatically switched over to the finish rate current, where short charging pulses are delivered periodically to the battery to maintain it at full charge.

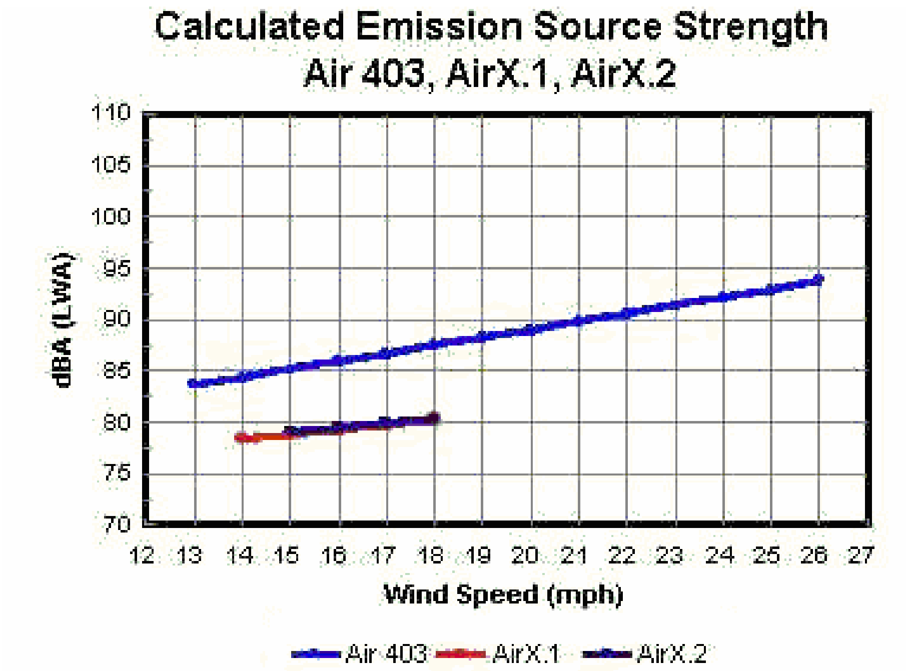
Wind Power – Despite the fact that wind generators with a decent 15-20 kt wind can generate electricity for battery charging, they have not been as widely accepted amongst cruisers for several reasons:

- Average measured power output is typically less than advertised[6]



- For them to work you need to anchor in a windy, more vulnerable anchorage.

- The perceived threat of what might happen if a bird flew into the fragile blades that are madly spinning over your head, and the resultant flying shrapnel.
- The noise of the fan blades. An Air-X wind generator can generate 80dB of noise, compared to the 56dB of a Honda generator, (Remember that decibels are a logarithmic scale, so every 3dB doubles the noise output). It's no wonder then that George Buehler once wrote he had to be physically restrained from throwing an oar blade in a nearby wind generator.



There is nothing to mitigate the need to anchor in windy places or a "perceived" threat of flying shrapnel - you have to live with those. The noise you can improve by sanding all the casting flash off the propeller, and reshaping the leading and trailing edges to be smooth. If you look at the surface of the blades with a magnifier you'll see tiny "craters" caused by air bubbles in the mold process, each of which will tear air and make noise. You can fill these micro-holes with wax or varnish to reduce the noise level.

A German firm (Spreco LDA at http://www.silentwindgenerator.com/) started making blades for the Air-X wind generator based on wind tunnel refinements to the propellers used in the *Gossamer Albatross* solar airplane. They now offer a version of the Air-X generator with all their aerodynamic improvements for 1,140 euros (about $1,600 or roughly a $300 increase over the standard Air-X marine. generator). One of the chief improvements touted is a reduction in noise and improvement in efficiency in light winds.

Towed Water Generators are described by Francis Kinney in "*Skene's Elements of Yacht Design*" (1973) and by Steve and Linda Dashew in *"The Circumnavigator's Handbook"* (1983). *Intermezzo II* his first Deerfoot design had a separate through hull for a prop powered alternator. Some people today are pushing the idea of hybrid (electrical) propulsion by touting the idea of "regenerative sailing" using the propulsion prop to generate electricity. Anyone considering this should note that Dashew never used one on any of his subsequent designs. Anyone attempting this will discover as I'm sure he did that in practice it just doesn't work well.

Luckily for us a group of enthusiasts on the Yahoo Electric Boats Group (http://groups.yahoo.com/group/electricboats/) have investigated this extensively. One of the first facts they discovered was that for a towed water generator to work the pitch of the propeller has to be the exact opposite of a prop designed for propulsion, (try reversing the propulsion prop around in mid-ocean when the wind picks up). They also found that the output was far less than they anticipated, because the water chooses the path of least resistance and moves around the towed prop like a rock in a river. Though everyone in this group approached this application with enthusiasm and ingenuity they found that electric propulsion is limited to day sailing on small boats with the batteries sized to get you in and out of the marina, where you use abundant shorepower to recharge them.

Given the choice between these alternative charging sources I'd choose to invest in solar every time.

Electrical Installation –The appropriate wire varies depending on the voltage and amperage output of the alternator and the distance to the externally mounted rectifier and are shown in the chart on the next page. Check the alternator output at the battery at full charge with a clamp amp. You should be able to trace all the way back from the alternator. The issues start when the alternator is producing 125A, but the battery is only receiving 10A, because the charge is leaking along the way through a parallel path via other devices. Clamp the propeller shaft also since this is often a source for electrical leakage and consequent corrosion problems. Ensure that the output cables are adequately supported and that nylocks (preferably) or lock washers are used on the studs. Only used tinned copper wire for the cables.

When upgrading to a higher output alternator you should always install a larger wire between the alternator and battery. Even with a standard output alternator you will get better performance and life out of your alternator if you upgrade the main battery wiring. The original wire just isn't large enough for proper power transfer. If you are using your alternator to its maximum output or when you upgrade to a higher output alternator you must increase the wires size. An alternators ability to send the power it is making to the battery is directly related to the wire size and quality of connection between the alternator and battery. A wire that is too small when used on a high output alternator can cause the alternator to overheat, burn up and fail.

Another area that receives little attention is the ground. You must also improve the ground as well. A poor ground will hinder the alternators ability to send power to the battery and can burn an alternator up just as fast as an inadequate alternator to battery wire. You should isolate the casings from the negative output terminals, ***never ground through the engine block***. The engine head or block isn't designed to carry large amperage. ***Grounding through the engine is the #1 cause of diode failures, not to mention stray current corrosion out through the prop shaft.*** Your ground may be fine when you first install your alternator but over time corrosion and resistance builds up in the ground connections. This is why it is best to run the ground directly from the rear of the alternator to the battery. Be careful to allow for flexure in the cables leading to the engine and also provide chafe protection for all cables.

When installing a high output alternator to replace an existing one you don't necessarily need to rip out your old wiring. You can piggy back a second wire between the alternator and battery. The main battery wire connected to the back of the alternator has power to it at all times, even when the vehicle is shut off. You connect this wire like normal then you run a second wire between the alternator and battery. The power coming out of the alternator will treat the two wires as one, power following the path of least resistance.

Volt	Amps	< 2m	2-3m	3-5m	5-7m	7-8m	8-9m
12	100-150	4	2	2/0	2/0	2/0	3/0
12	150-190	4	2	2/0	3/0	4/0	4/0
12	190-250		2/0	2/0	4/0	4/0	4/0
12	250-300	0	2/0	3/0	4/0	4/0	4/0
24	100-125	4	4	4	2	2	1
24	125-150	2	2	1	1	0	0

Run the alternator cables directly to the batteries through a 250A fuse on the positive side of the battery. This allows you to pull the fuse to isolate the alternator for service.

Physical Installation - Ensure lock washers and Locktite or use Nylocks on all the bolts used. Pay attention to the belt tension. Too tight and you will prematurely wear the water pump bearings. Too loose and you get excessive belt wear and heating on the alternator pulley which transmits to the alternator. Use this test; when the engine is cool and place a rag on the alternator fan and rotate the pulley so that the engine crank rotates (yes, the pulley ratio mechanical advantage will enable you to do this). If the belt slips the tension is too loose. Tighten the pulley JUST so that it doesn't slip with this test and you will be fine. Keep checking the tension over time.

Battery Selector Switch - Be judicious when choosing a battery selector switch for use with starting motor currents. Some diesel start motors have locked rotor currents of 900-1800 Amps and most switches will not reliably carry that load for years. Cole Hersee has good switches that have proven to work over time even with loads above their ratings. Perko switches, however, have failed (in my experience) even with motor loads within their ratings. Other switches also may not fare well over time.

Sulphation, Internal Resistance and Battery Aging

The Internal Resistance of a Battery can be calculated by measuring the "open circuit" (E) voltage of the battery. This is simply the voltage at the battery terminals when no current is being drawn. It's hard to measure voltage without drawing some current, but most quality digital voltmeters have a high enough input resistance that it can be overlooked for mathematical purposes.

We need to load down the battery and measure the voltage at the battery terminals again (V). Let's call the load resistance RL. A word of caution: be careful when using low value resistors with good batteries, as the current draw will be high enough to heat up the resistor (and the battery!). Given all those values, the equation for the internal resistance (Ri) of the battery is:

$$Ri = (Eo - Vl) / I$$

or

$$Ri = (Vs / I) - RL$$

or

$$Ri = RL \times (Eo / Vl) - 1$$

derived from $Vl = Eo \times RL / (Ri + RL)$

where
Ri = Internal Resistance (Battery)
RL = External Load Resistance
Eo = Open Circuit Voltage (Battery not loaded)
Vl = Loaded Circuit Voltage (Battery under load)
I = Current (when Battery loaded)

Expect very small numbers (< 0.01 Ohm) for a new fully-charged battery. Expect a non-linear increase in Ri, as the battery discharges. As noted, you'll want a chart of numerous Ri calculations, at varying state-of-charge.

References

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[3] "E.E. Owner - How a gifted electrical engineer set up his dream boat", by Ben Ellison Nov 2007, Power & Motoryacht ,

http://www.powerandmotoryacht.com/boat-electronics/electra/

[4] "Operation of the Lundell Clawpole Alternator at High Power Density and Efficiency"; by Bob Gayle; Three Cedars Research and Development Bob Gayle's white paper on high output alternator efficiency is only available by joining the Society of Micro-Cogeneration R&D/Microcogen.info Forum (it's free). Here is a link to the thread where the paper is: http://www.microcogen.info/index.php?topic=157.0

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[6] "AirX Fails Power Curve Tests", by Paul Gipe, January 29, 2003 http://eduhosting.org/windpics/airx.html