HOW TO SIZE & USE YOUR BATTERY BANK

Introduction

Glacier Bay manufactures a complete line of AC, DC, engine and hydraulically driven refrigeration systems. Unlike manufacturers who specialize in one type of system, Glacier Bay can provide whatever is most appropriate for the application. From experience, we have found the best system for the vast majority of cruisers to be a DC driven system coupled with a properly designed battery bank and charging system.

We encourage you to ignore some "conventional wisdom" on energy management, gain your own clear understanding of DC storage and charging systems and apply that knowledge to your boat. By doing so, you can reduce the engine run time required by your refrigeration system to 50% to 80% less than would be needed with a direct engine-driven system.

Also remember, the money and effort you put into your battery and charging system benefit the entire boat, not just the refrigeration system.

What size battery bank should you have?

If you are a cruiser the answer to this one is quite simple - the largest one you can afford in terms of space, weight and money. This is equally true no matter what the electrical load is! To see why, let's take a look at two different approaches to estimating the "correct" battery capacity.

Energy Analysis — the conventional wisdom

It is common practice among the energy gurus to perform an energy analysis of a cruising boat and advise a battery bank capacity based on the results. To perform such an analysis, assumptions are made about the length of time the lights, appliances, navigational equipment, water maker, etc. will be operating and the amount of current they will draw while they are on. An amp-hr (current draw x operating time) total over a 24 hour period is then calculated for every device which consumes electrical energy. For example:

Assumption	**Calculation**	**Usage per 24 hrs**
Three reading lights drawing 1 amp each will be used an average of 3.5 hours per day.	(3 x 1) x 3.5 = 10.5	10.5 amp-hrs
The refrigerator draws 6 amps while it's running and runs an average of 18 hrs per day.	6 x 18 = 96	96 amp-hrs

Making accurate estimates for some items is relatively easy, for others such as electric autopilots it is nearly impossible. Nevertheless, to complete the analysis, the total estimated energy consumption of all such devices is added together to provide an estimated average total daily energy consumption in amp-hrs. As you can imagine, the totals vary tremendously from boat to boat. However, for illustration purposes, let's assume that our particular cruiser calculates a total estimated use of 140 amp-hrs per 24 hours.

In the next step of the analysis it is assumed that our cruiser will not want to discharge their batteries more that 50% since it is commonly believed that doing so will disproportionately shorten their life span. The cruiser must now decide how often they wish to run their engine or generator recharge their batteries. This, in combination with their estimated daily energy consumption then forms the basis for calculating the battery bank size required. For example:

Recharge Frequency Desired	**Bank Size Required**
twice per day	140 amp-hr
once per day	280 amp-hr
once every two days	560 amp-hr
once every three days	840 amp-hr

So it is seen that, by using the energy analysis method, the calculation of appropriate battery bank size is made purely on the basis of energy usage and the frequency of recharge cycles. Sounds good. So what's the problem?

Why energy consumption is irrelevant when sizing your battery bank

While it can be helpful to have an idea of how much energy you are likely to use in a day, it should not form the basis for sizing your battery bank. Why? Because it leaves out the single most important consideration in battery bank sizing - the recharge, or acceptance, rate. The energy consumption analysis gives you an idea of how often you will need to run your charging engine but gives no indication of how long the engine will need to be run. For most cruisers, particularly those who have already had the experience of sitting in their island paradise amidst the diesel fumes waiting for their batteries to recharge, minimizing their engine run time is the top priority.

The proper size alternator for the battery bank

To fully appreciate why the acceptance rate is so important it is first necessary to gain an understanding of the relationship between alternator size battery bank size. It is only possible to select right alternator(s) after the capacity and type of battery bank have been determined.

Capacity

While the power output of a battery is rated in several ways, the only rating generally useful to the cruiser also happens to be the most common and is referred to as the 20 hour amp-hr rating. This number represents the total amount of energy that the fully charged battery can release when discharged at a stable rate over a 20 hour period. A good quality 8D size (20"x11"x10") lead-acid type deep cycle battery would have a 20 hour rating of 220 amp-hrs @ 12 volts. Gelled electrolyte type batteries (gel cells) and absorbed glass mat batteries (AGM) are usually slightly less with about 200 amp-hrs in an 8D size. Remember, when determining the capacity of your battery bank use the manufacturers ratings and add the amp-hr rating of all batteries which are connected in parallel and discharged and recharged as a single bank. If you choose to use multiple house banks (not recommended) count only those banks which are discharged and recharged simultaneously. Do not simply add up the ratings of all the batteries on your boat.

Type

This is not a question of brand name but one of electrolyte type. Your choice here is common lead-acid, gelled lead-acid (gel cell) or absorbed glass mat (AGM).

Calculating your battery bank's acceptance rate

The acceptance rate is the maximum rate at which a battery bank can be recharged. The acceptance rate of the bank is determined by it's capacity, type and state-of-charge. Since we know (or can determine) the capacity and type of the bank, we will need to make an assumption as to it's average state of charge under cruising conditions. Batteries which are deeply discharged have a higher acceptance rate than those which are more fully charged. Surveys have shown that cruisers typically cycle their batteries between 50% and 80% of full charge under most conditions. Cruisers who have large capacity banks in comparison to their energy needs tend to cycle between 70% and 90%, while those with small banks tend to cycle between 40% and 70%.

For the sake of this exercise, we will estimate at the average acceptance rate when cycling the batteries between 50% and 80% of full charge. Under these conditions lead-acid batteries have been shown to have an acceptance rate equal to 25% of their total 20 hour amp-hr rating. Stated another way, a lead-acid battery bank consisting of three 8D size 12 volt batteries @ 220 amp-hrs each (660 amp-hrs total) would have an acceptance rate of 165 amps.

One advantage in gel cell type batteries is that they have a higher acceptance rate than do the common lead acid type. Acceptance rate calculations made with gel cell batteries should be based on 40% of their 20 hour amp-hr rating rather than the 25% figure used with lead acid.

Because of their lower 20 hour rating, the bank of three 8D batteries described in the example above would have a total capacity of only 600 amp-hrs (rather than 660 with lead acid). However, they would have an acceptance rate of 240 amps instead of 165 amps.

The highest acceptance rate is obtained with absorbed glass mat batteries (AGM). Acceptance rate calculations made with AGM batteries should be based on 100% of their 20 hour amp-hr rating rather than the 25% figure used with lead acid or 40% used with gel cells. Our bank of three 8D batteries (as described in the other examples) would have a total capacity of 600 amp-hrs just as would the gel cells. However, they would have an incredible acceptance rate of 600 amps instead of 165 amps (lead acid) or 240 amps (gel cell).

As you can see, once you know the capacity and type of your battery bank you can calculate it's acceptance rate. Simply multiply the total capacity by 25% for lead acid batteries, 40% for gel cells or 100% for AGMs.

What about the alternator?

Since the acceptance rate described the maximum rate at which a battery bank can be recharged, it stands to reason that the proper size alternator can only be selected once the acceptance rate has been determined. It is wasted money to charge a battery bank that has an acceptance rate of 70 amps with a 165 amp alternator. Likewise, using a 100 amp alternator to charge a battery bank with an acceptance rate of 240 amps is pointlessly slow and inefficient. The goal is to get the output of your alternator (under actual charging conditions) to match the acceptance rate of your battery bank as closely as possible. Most alternator manufacturers will provide you with the output curve of the alternator you are considering under hot conditions and at a variety of speeds. An alternator rated at 150 amps will likely only put out 130 amps once it gets hot and will only do that running at full speed. Under realistic charging conditions, you may only be running your engine at 1100 - 1200 rpms. If your alternator is belted at a 2 to 1 ratio it will be spinning at twice that speed, or 2200 - 2400 rpms. It is quite possible that 150 amp alternator is now only going to putting out 80 amps or so.

Given this, how is it possible to get 200 to 300 amps of real charging capability? Sometimes it isn't, but don't give up too quickly. Very large alternators with outputs 200+ amps are now quite common. Additionally, it is often very practical to use two or more alternators to charge a single bank. Some boats are already set up to have one alternator charge the engine start battery and a second to charge the house bank. Usually the engine start battery needs little if any charging. An automatic battery bank combiner can be used to allow both alternators to charge the house bank.

How much difference does this approach to battery sizing make?

Occasionally none, but often the results are surprising. Take a look back at our very first example where our cruiser was required to replace 140 amp-hrs of energy per day. Let's assume that, using the energy analysis approach, he determined that running the engine once per day would be ok. He would then be advised to install a lead-acid battery bank of 280 amp-hrs capacity (ie. 50% max discharge).

Now, using your knowledge of acceptance rate calculation, you know that the maximum rate at which this bank can be recharged 70 amps (bank capacity x 25%). Therefore, it will take two hours of engine run time per day to replace the electricity that the cruiser is using (70 amps x 2 hours = 140 amp-hrs).

If, on the other hand, the cruiser wants to minimize their engine run time, they could increase their battery bank to far in excess of that recommended by the energy analysis approach to, say 600 amp-hrs. With this bank the acceptance rate would now be 150 amps, making it possible to replace the same 140 amp-hrs in less than one hour, or only ½ the time required by the smaller bank. If all that sounds great but you don't have room for that many batteries, use gel cells or AGMs. You'll be able to get that high charge acceptance rate in a much smaller bank.

By gaining a good understanding of battery acceptance rates, it is clear how large house battery banks can be used to reduce the engine run time. It is equally easy to see why the popular practice of separating house batteries into multiple banks is not the most efficient use of energy.

Battery life

One cannot really discuss "battery life" without first defining the term. The same energy gurus who promote the energy analysis method of battery bank sizing usually describe battery life by the number of cycles (ie. discharge and recharge) which can be done before the battery fails. Through their efforts, most people now recognize that depth of discharge has a direct impact on the number of discharge/recharge cycles a battery can do. As a result, many cruisers endeavor to cycle their batteries as "shallowly" as possible.

However, the number of cycles is only one measure of a battery's life and probably not the best. Another way to look at battery life is by looking at the total number of amp-hrs which a battery will store before failure. When viewed in this way, quite a different picture emerges as can be seen in the chart below.

Typical Cycle Life
(100 amp/hr Trojan Deep Cycle Battery)

Depth of discharge	Number of cycles	Total amp-hrs provided during service life
10%	6,200	62,000
20%	5,200	104,000
30%	4,400	132,000
40%	3,700	148,000
50%	2,900	145,000
60%	2,400	144,000
70%	2,000	140,000
80%	1,700	136,000

From our previous look at acceptance rate we know that batteries can be recharged much faster when they are permitted to cycle down to 50% and below. From this chart it is obvious that doing so extends the useful life of the batteries as well.

Conclusion

By first calculating how much energy your Glacier Bay DC refrigeration system will use (use our published guidelines to get an accurate idea), and then applying the principles discussed in this paper to your battery and charging system, you will see just how much better off you are with the DC system rather than an direct engine-drive. For those who do not mind engine running, there is still a place for engine-driven refrigeration. However, as you will see once your calculations are complete, they rarely make sense on a cruising sailboat. At Glacier Bay, we manufacture both types of systems. Correctly set up, our DC system will use typically require 1/2 to1/4 the daily engine run time of an engine-driven system. By properly planning and setting up your DC system, and combining it with energy efficient appliances such as refrigeration and watermakers, battery charge concerns really can become a thing of the past.