Ample Power Company

Ample Power Support

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For any specific energy need, a common and logical question arises ...should a combination of series and/or parallel batteries be used? In this issue of Power News we investigate the question with the intent to understand the limitations and advantages of series and parallel batteries.

We touched on some of the issues regarding series and parallel connections in our first book, Living on 12 Volts with Ample Power. We have not changed our opinion ...our reasons for preferring parallel battery systems are stronger today. Within limited time, we can't answer all questions about the issue of series and parallel battery connections. But we can put a framework around the subject that is broad enough to draw some important conclusions. To construct this framework, we'll review battery failure mechanisms, their consequences, and finally compare some attributes of parallel versus series systems.

First a little background. Lead acid batteries are made up of individual cells which have a nominal potential of 2 Volts. Thus, 3 cells make a 6 Volt battery, and 6 cells make a 12 Volt unit. The amount of lead in a cell determines its capacity to deliver power to a load. Capacity is usually specified in Amp-hours, that is, capacity is the ability of a battery to supply a specified number of Amps for a given number of hours. A battery generates voltage by an electrochemical reaction between the positive and negative plates and an electrolyte. Current may be drawn from the battery as long as the electrochemical reaction continues. The model of a battery has an equivalent series resistance, (made up of interconnecting conductors, separator porosity, plate grids, and the electrolyte), and an equivalent parallel resistance (impurities in the plates and electrolyte) that slowly discharges the battery as it sits unconnected.

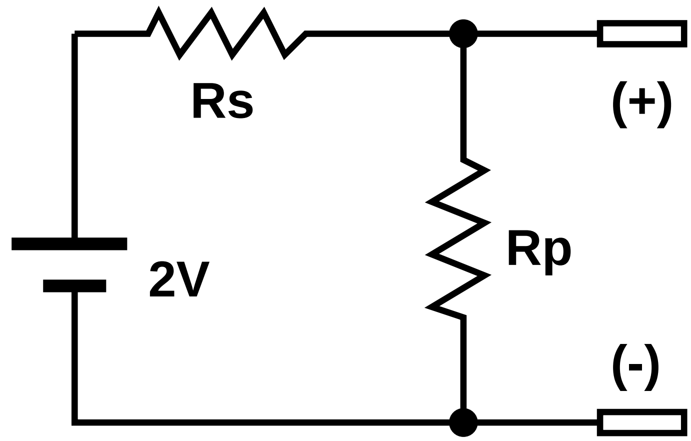

Figure 1: Battery Model

Figure 1 shows a simple model of a cell. As mentioned, a battery slowly selfdischarges through the electrolyte. The rate of selfdischarge is dependent on the composition of the plate material, the specific gravity of the electrolyte, and temperature. Plates grids in deep cycle batteries that use liquid electrolyte, are made with antimony to stiffen the plate. Antimony causes a higher rate of selfdischarge than plates made with pure lead, or lead-calcium alloy. Some sealed lead acid batteries use the later types of plates. In Figure 1, the resistance Rp is a lower value for batteries with antimony alloy, than it is for lead-calcium plates. As expected, liquid batteries selfdischarge faster because of a lower parallel resistance.

Now, since the amount of lead in a cell is a prime determinant of cell capacity, it stands to reason that larger, heavier cells will offer higher capacity than smaller, lighter units. Batteries are manufactured in all sizes, including those that need forklifts to move. Generally, a single battery large enough to satisfy a particular need is most economical, and will offer the best service.

On boats, however, there is a practical limit as to how much space and weight can be given to batteries, particularly in one location. This gives rise to the use of multiple batteries that are physically distributed. As a result, the question arises, should the desired capacity be attained by series connection of 6 Volt batteries, or is it permissable to parallel two or more 12 Volt units? How do we go about making an intelligent engineering decision?

First, we need to define the scope of the problem. The common 8D battery provides about 200+ Amp-hours at 12 Volts. It weighs 150+ pounds, so it may be quite a ballet to move it in and out of a tight compartment. If that were a frequent chore, we might choose two 6 Volt batteries of the same capacity, despite the fact that the two will cost more than the single battery. Adding the cost of interconnections for the two 6 Volt batteries further raises the cost. With the life expectancy of high quality batteries which are properly maintained, we may have no objection to a 150 pound battery and a little assistance every few years.

Small boats may not be able to accommodate an 8D, particularly where existing battery space is inadequate by design. For these situations, the scope of the issue takes lesser dimensions. How best to get 100 Amp-hours? At this level of capacity, should two 50 Ah, 12 Volt batteries be connected in parallel, or two 100 Ah, 6 Volt units be connected in series?

For larger boats, the weight limit is still a problem. At 350 Ah, the 6 Volt cell is large and heavy, and higher capacity units are not readily available. If more capacity is desired, then parallel batteries are a necessity.

The issue then, is applicable to small and large systems, but not necessarily for intermediate capacity systems. Beyond 350 Ah, there are two choices; use parallel batteries, or use 2 Volt cells in series. Two volt cells are made in huge capacities, even in sealed technology. Such cells usually have a small footprint, gaining volume in the vertical dimension. If a vessel is originally designed for 2 Volts cells, perhaps making up part of the ballast in a sail boat, then they may be an appropriate choice. Sealed 2 Volt cells can be used effectively by laying them along the hull of either a sail or power craft. If you can't afford the 2 Volt solution, then the choices are limited ... parallel batteries.

Let's leave the argument of scope and pursue the issue of failures. To gain a toehold on the subject, we pose the questions; what are failure mechanisms of parallel batteries, and what are the consequences of those failures? The failure mechanism of most significance is the one that has the most hazardous consequences.

Failure mechanisms of deep cycle batteries are described on pages 14-97 thru 14-98 of reference 1. Grid corrosion and plate shedding are the predominant failures. Neither is a result of parallel connections. Grid corrosion, a function of normal discharge and overcharge, causes a high resistance or open circuit, such that the battery will not power a load.

The other major failure mode of deep cycle batteries, is shedding of active material which results in a gradual loss of capacity. Shedding is most severe at a great depth of discharge, something that the prudent mariner avoids. Shedding is not normally a problem with sealed batteries because their plates are pressed together within the case, and there is no liquid to slosh about under way.

Curiously, (or perhaps not so,) reference 1 does not list plate shorts as a failure mechanism of deep cycle batteries. Cell shorts are a significant failure in starting and lighting batteries, but not in deep cycle batteries which use better plate separators. Cell shorts are possible, however, and as reference 2 points out on pages 30-31, cell shorts can occur when a cell has been allowed to selfdischarge too deeply and the lead sulfate become soluable enough to diffuse through the separator. A dendrite is then formed on recharge which conducts most of the current through the cell.

Cells which short rarely do so with a low resistance. A cell is made up of alternating negative and positive plates having an intervening separator. Shorts between adjacent plates, are usually a dendrite or a local failure of the separator. It's fortunate that cell shorts are not normally low resistance. Consider a 200 Amp hour cell. Suppose that the cell developed a short that allowed 100 Amps to flow. At that current, a 2 Volt cell would be producing 200 Watts of power across the short. A 200 Ah cell could support 100 Amps of current for about 30 minutes. During that 30 minutes, in excess of 340 Btu of heat would be generated. There is 25-40 pounds of active material in a 200 Ah cell, which will rise to the boiling temperature of water in about 10 minutes. The cell probably ceases to be a battery before boiling is reached. Assuming that it doesn't, we would have enough Btu left, (210), to boil about 1/2 cup of electrolyte. That's a lot of steam!

Obviously, if cells did short with a low resistance, batteries would be much more hazardous than they are. We'd have to mount batteries in special cases that could deal with the heat and acid steam. And given such dangers, there would be regulatory limits on the size of cells that could be manufactured. To get any reasonable capacity a large number of small cells would have to be paralleled. Hmmm.

As mentioned, a cell rarely, if ever, shorts with a low resistance. Some people would have us believe that a shorted cell in one battery of a multi-battery bank will cause a fire. The argument goes that the remaining batteries will rapidly discharge through the cells of the defective battery. Such huge discharge, the story continues, will create an inferno with batteries boiling like a Boston tea kettle, spewing hell infinitely in all directions. Battery cases will blow gaping holes in their sides leaving a rather untidy mess for the maid. It makes us want to wear our rain gear every time we inspect our batteries to find out if any unauthorized cold fusion experiments are occurring.

Luckily, the simple tools of algebra are at our disposal. Assume that we have a topped off battery bank of 6 cells that reads 12.8 Volts. Now short a cell in one of the batteries to create a 5 cell battery. Those 5 cells will have 12.8 Volts impressed across them by the good 6 cell batteries in parallel. Divide 12.8 Volts by 5 to obtain 2.56 Volts per cell. A 6 cell battery with 2.56 Volts per cell would be at 15.36 Volts. That isn't such a high voltage per cell. For instance, when a battery is equalized, as much as 2.7 Volts per cell is applied.

In view of the fact that a fully charged 12 Volt battery needs about 16.2 Volts for equalization, its unlikely that 15.36 Volts is going to cause anything more than 5-7current level will cause some acid bubbling, as it does during equalization, but nothing that is imminently dangerous in a system designed for performance charging. In fact, equalization is a process that applies 5-7extremes, 35remaining 5 in the defective battery to get more than 35less voltage is available to overcharge the one with the shorted cell.

It is our opinion based on reference 1 and 2 that disastrous cell shorts are not a major failure mechanism, and the consequences are, in any case, no more than what happens during equalization. Since the early 1960s when we designed our first battery charger, we have witnessed no dangerous situation that resulted from a cell short.

As an aside, we might suggest that any designer who persistently witnesses spewing and exploding batteries might study the failure mechanism of thermal runaway under charge, with special attention given to the role of regulators that lack battery temperature sensing.

Besides the shorted cell failure mechanism, there is the issue of slow degeneration of the cells due to accelerated selfdischarge. Is this a particular problem with parallel batteries?

Before we examine the battery model again for illuminating clues, let's first quote from reference 2, page 91. "With sealed lead batteries, there are no major problems with parallel connections." Do the manufacturers of liquid batteries make this claim, or do liquid batteries cause problems when paralleled?

The operant element in Figure 1 is the resistance, Rp, which acts as a discharge path for the electrochemical reaction. To be sure, placing two equal resistors in parallel makes an equivalent resistance half that of the original. That means twice the current will flow. On the other hand, we now have twice the capacity to supply that current, so the rate of discharge has the same ratio as before.

Suppose we tinker with the electrochemistry. Can we induce a discharge of one battery into the other? Yes. A good way to do this is to use batteries from different manufacturers. Another effective means is to connect an old battery in parallel with a new one. A more precise way to tinker with the electrochemistry is to alter the specific gravity such that one battery is higher than the other. No one interested in battery longevity would do such an act consciously, but every time water is added to a wet cell, the likelihood is great that the electrolyte level won't be maintained equally. What happens when one battery boils more than another? Does the specific gravity remain equal?

The manufacturers of sealed batteries can make a broader claim about the consequences of parallel batteries than the manufacturers of liquid electrolyte batteries. The sealed battery manufacturer not only gets to control the initial specific gravity of each cell with precise process control equipment, but they don't have to contend with spotty and inaccurate electrolyte maintenance later. The sealed battery manufacturer doesn't have to contend with the addition of impurities into the electrolyte either.

Up to this point, we have attempted to define the scope of the issue, and examine the failure mechanisms and their consequences to parallel configurations. We find nothing alarming about such practice in either liquid or sealed battery systems, as long as the batteries are properly instrumented and prudently cared for. We do favor sealed batteries over liquid batteries for parallel systems because of the consistency of cell chemistry, and the fact that we can't tamper with it accidentally. We don't promote an unlimited number of batteries in parallel. One limit is indicated by the answer to the shorted cell question that was asked above. There are other features of parallel systems that are attractive.

First, a parallel system allows more convenient sizes which yields a greater range of systems. For instance, a 100 Ah battery can be placed in parallel with a 200 Ah unit to obtain a total of 300 Ah. Charging proceeds as expected, with each battery receiving its share of the charge current, and each reaching a full charge at the same time. On discharge, each battery supplies current according to its relative capacity, and both batteries maintain the same percent depth of discharge.

Contrast this with two 6 Volt units. With series connected units, each battery must be of equal capacity. That means that you can only build banks in the capacities that the manufacturers decide to build. Despite close manufacturing tolerances, each supposedly identical battery has different capacity and when the specific gravity is different in each, capacity is further affected. Deep discharges of series cells can cause the weaker cell to be reverse charged. A weak cell in a series string can cause other cells to be overcharged. An open cell in a series string results in a total power loss. For best results, 6 Volt batteries should be periodically charged individually and should definitely be equalized individually with equalizing resistors across each 2 Volt cell. This argument extends to 2 Volt cells when they are packaged individually.

In a series connected bank, an open circuit would mean the total loss of power, but a parallel bank will still function, albeit with less capacity. You'd still have enough power for an emergency call on the radio with a parallel bank. In fact, the failure might be transparent in a poorly instrumented system until a prolonged heavy discharge occurred.

The consequence of a cell short in a parallel bank will be a partial discharge of the remaining batteries in the bank. Even so, a parallel bank with one shorted cell has enough capacity to use the radio, or crank an engine.

The battery failures that we've seen are generally the result of neglect or mistreatment that is predicted or explained by the listed reference books. We urge you to examine the issues personally, and hope you will consult these modern textbooks:

Reference 1: David Linden, "Handbook of Batteries and Fuel Cells", McGraw-Hill Book Company: New York, 1984.

Reference 2: General Electric, "The Sealed Lead Battery Handbook", Publication BBD-OEM-237, General Electric Company: Gainesville, Florida, 1979.

Reference 3: M. Barak, "Electrochemical Power Sources: Primary and Secondary Batteries", First Edition, Institute of Electrical Engineers (IEE) Series 1, The Institute of Electrical Engineers: London and New York, Peter Peregrinus Ltd., Stevenage, UK, and New York, 1980.

For alternate viewpoints, you should refer to the March 1, 1990 issue of Practical Sailor.

There are engineers at the major battery manufacturers who know their products better than anyone. We might hope that each of them would give us the benefit of that knowledge regarding the suitability of paralleling their products.

Parallel Batteries - An Experiment

Any singular experiment is fraught with procedural errors. A well designed experiment attempts to isolate all imaginable distortions with counter tests. Drawing conclusions from an experiment where chance can be a significant factor is equivalent to believing in elves. We report the data in Table 1 without claiming any significance.

On March 7, at 2010 we removed three parallel batteries from the charger. They had been charged for 2 hours at 14.2 Volts. Two of the batteries were left in parallel, while the other, B1, was separated. The batteries are Sonnenschein gel units. The data is the voltage reading of the two banks. All measurements were taken with a new Fluke 87 digital meter. Batteries were left in an office where daytime temperatures are about 70 F, and nightime temperature drop to the low 60s.

Date	Time	B1 Volts	B2/B3 Volts
3–07–90	2010	13.39	13.41
3–08–90	0015	13.08	13.12
3–08–90	0910	13.00	13.04
3–09–90	0930	12.93	12.98
3–13–90	1730	12.84	12.88
3–16–90	1540	12.80	12.84
3–18–90	1915	12.78	12.82
3–21–90	1015	12.75	12.80
3–26–90	1110	12.73	12.77
3–28–90	0930	12.72	12.76
3–31–90	1230	12.70	12.74
4–02–90	1105	12.70	12.74
4–05–90	1740	12.68	12.73
4–07–90	1224	12.67	12.72

Voltage Decay with Time