Batteries and PV Systems

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Battery management and maintenance are significant concerns in off-grid PV systems. Many of the user problems associated with these systems can be traced to improper treatment and misunderstanding of battery performance.

Modern battery chargers use three charging stages—bulk, finish (absorption), and float. Bulk brings the batteries up to the high voltage regulation point; finish holds it at this high voltage regulation point based on time. In the absorption stage, the voltage is constant, and the current tapers off as the batteries are filled. Float trickle charges the battery to a lower, user-determined voltage to keep it full.

From my experience, the most common battery problem is undercharging, leading to sulfation, loss of storage capacity, and shortened service life. Sandia National Laboratories recently published “PV Hybrid Battery Tests on L-16 Batteries” (see Access). Their tests represent several years of systematic testing of a PV-generator (hybrid) system.

The Sandia report is very thorough. Four different brands of batteries were tested. They were all flooded, L-16 type batteries, the most common battery used in residential-scale RE systems. Tests were repeated so that the data represents good averages, and the conclusions are based on good data and methodology. The study has four conclusions:

1. The finish voltage (sometimes called the absorption voltage) for a flooded lead-acid battery operating at 12 VDC nominal should be about 15.3 volts (2.55 per cell) rather than the customary 14.4 volts.
2. Finish charge time should be at least 3 hours and often longer.
3. The maximum interval between finish charges should be about five days.
4. Not all brands of L-16s are the same (though the report names no names).

The general conclusions of the Sandia report are consistent with the number one problem experienced in off-grid PV systems—undercharged batteries. Richard Perez has for many years advocated higher finish voltages for PV-engine generator systems. As he says, “I like to run them hot.”

Home Power technical editor Joe Schwartz adds some good advice regarding flooded lead-acid batteries:

- Higher finish charge rates result in significantly more gassing and potential for hydrogen buildup. Before you crank up the finish voltage to 15.3 VDC (for a nominal 12 volt system), make sure that the battery containment is well ventilated. The use of powered battery vents is recommended.
- Batteries charged to a high finish voltage produce a significant amount of waste heat. Depending on the type and location of the battery containment, in warm climates or seasons active ventilation may be required to keep battery temperature in check. Optimal operating temperature for lead-acid batteries is 78°F (25°C). Higher battery temperatures (90°F plus; 32°C) result in increased self-discharge. Temperatures over 120°F (49°C) can damage lead-acid batteries.
- Batteries charged to a high finish voltage consume a lot of water. Compared to charging at the traditional 14.4 VDC finish voltage, the time period between battery watering can easily be cut in half. Automatic battery watering systems greatly simplify the process.
- Use temperature compensation on all charge controllers and inverter/chargers.

Finish Charging Is Inefficient

There is one significant downside to the battery management strategy presented in the Sandia report. Due to battery charging characteristics, efficiency is very low during the finish charge phase. Very long engine generator run times were reported, sometimes from 6 to 20 hours. These long run times were required to completely refill the batteries to the manufacturers' stated ampere-hour capacity.

The state of charge (SOC) of a battery is most accurately measured with a hydrometer, and is indicated as specific gravity (SG). Most RE users rely on amp-hour meters to provide convenient (although slightly less accurate) battery SOC information. During the Sandia tests, full batteries had a SG in the range of 1.290. The long, engine generator run times needed to achieve this SG translate into dollars and pollution (both audio and atmospheric). Perhaps there is a "middle way" that preserves the lifetime of the batteries while reducing the time and cost of engine generator finish charging.

Revisit the Assumptions

The batteries tested at Sandia were discharged by 60 percent of capacity (to 40% SOC) and then charged back to rated capacity. In these tests, the rated capacities were determined empirically, and in most cases were close to the manufacturer's stated value (in the range of 350 AH for an L-16).

These two points require comment. First, this depth of discharge is not typical of most well-designed, stand-alone PV systems. This point is clearly stated by the author of the study. Most stand-alone PV systems, by design, cycle batteries by about 25 percent daily, not 60 percent.

Second, the manufacturer's rated battery capacity and the way it is determined should be understood. All manufacturers recharge batteries on the grid. Using the grid, they can finish charge the batteries for long periods (on the order of 8 to 12 hours), cramming maximum ampere-hours into them. For a manufacturer, this method makes sense because it results in greater AH capacity figures for their product.

The long engine generator run times required by PV hybrid systems must mimic the finish charge conditions the manufacturers use to rate the battery's capacity. Perhaps batteries should be rated based on their application. For instance, a battery used in a standby application (such as utility backup system with grid recharging) might specify a full charge SG of 1.290. The same battery used in an application that regularly cycles the batteries (such as a PV system with engine generator backup) might have a recommended SG of 1.250 to be considered full.

It is true that a battery with a SG of 1.290 holds more charge than the same battery with a SG of 1.250. However, the shorter finish charge time required to achieve the lower SG reduces the engine generator runtime. Keep in mind that most of the fuel consumed by the engine generator is wasted during the late stages of finish charging.

A Comparison

Consider two systems. System A is designed and operated along the lines of Sandia's test. It might be characterized as an undersized PV array with batteries that are cycled deeply (50 percent) and recharged to the manufacturer's recommended SG of 1.290. System B is designed to provide the same functional capacity (daily AH consumed, in this case 350 AH), but the batteries are only cycled by 25 percent, and the engine generator finish charging takes the batteries to a SG of 1.250.

According to Sandia's findings, system A would need about six hours of finish charge every five days, due primarily to the deeper cycling. Because system B is only discharged by 25 percent and the target SG is lower, it would require less finish charge time of about three hours every five days. Over a ten-year period, the difference between the two engine generator run times is about 2,160 hours.

A conservative assumption is that it costs US$1 per hour to operate an engine generator. The ten-year savings of system B over system A (US$2,160) is reduced, however, by the fact that B's battery bank is twice as expensive. If both systems used L-16 batteries, the respective capacities in this comparison would be 700 AH (A) and 1,400 AH (B). System B would have an initial battery cost of about US$800 more than system A (based on US$200 per L-16). Subtracting the increased battery cost from the engine generator savings (US$2,160 - US$800) gives a net savings by system B of US$1,360. System B also realizes further savings because of longer battery life due to the lower depth of discharge.

Modified Conclusion

Finish (absorption) voltage needs to be about 15.3 volts (for a nominal 12 volt system). Batteries need to be fully charged (finished) about once a week. If the depth of discharge is moderate, and a modest SG of 1.250 is chosen, the finish charge time can be reduced from six hours to three hours.

These choices will reduce the engine generator run costs. On a life cycle cost basis, the reduced engine generator run time more than pays for the larger battery bank. Other benefits include reduced local air pollution, longer engine generator life, and reduced noise pollution, battery watering, and maintenance.

Don't Undersize the Array

Though Sandia's tests were specifically done on L-16 batteries, based on my field experience, the results are generally true for all lead-antimony flooded cell batteries. In very general terms, we can say that the finish charge time is inversely related to the average state of charge.

Finally, one of the easiest ways to increase battery life, in addition to limiting the depth of battery discharge, is to add more PV to an existing array. Doing so increases the average state of charge and reduces the need for long engine generator assisted finish charges.

UL vs. Xantrex—The Aftermath

Last November, Underwriters Laboratories (UL) withdrew its listing for the Xantrex SW series inverters and posted a public safety alert and press release on its Web site. Though the SW inverters have been relisted by the Canadian Standards Association (CSA), and Xantrex is taking measures to upgrade all affected units, UL's unprecedented, heavy handed, and punitive behavior leaves many questions.

No one has ever been hurt by an "islanding" inverter. Other well-publicized, UL-approved products that actually killed people were not treated in the same manner. For instance, I saw no mention on the UL Web site of the UL-listed halogen lamps that started several house fires.

Why would a company (UL) treat one of its clients (Xantrex) so poorly? Was there ever a real safety issue involved? Was this public "shaming" of Xantrex and the damage to their reputation commensurate with the severity of the problem?

I do not have detailed answers to these questions. However, UL's pattern of behavior, and anecdotal comments from those who have worked closely with UL, suggest an attitude of arrogance and tyranny.

A Short History

UL is not the only U.S. electrical product testing agency, though it is the oldest. Founded in 1894, UL touts itself as holding "the undisputed reputation as the leader in U.S. product safety and certification." UL was able to attain that reputation, in large part, by maintaining a near monopoly on the certification business.

Prior to 1983, only two testing organizations were authorized by the Occupational Safety and Health Administration (OSHA) to certify electrical products nationally for safety. They were UL and Factory Mutual Research Corporation (FMRC). In 1983, a private testing company, Electrical Testing Laboratories (ETL, now ETL Semko) sued OSHA, since under federal law OSHA enforced safety regulations and technical standards. As a key element of that lawsuit's settlement, OSHA set up the Nationally Recognized Testing Laboratory (NRTL) program, breaking UL's nearly century long monopoly.

Since 1988 (it apparently took five years to establish NRTL), more than twenty companies have been "recognized." OSHA recognizes a company based on an evaluation of the company's ability to perform a specific test. OSHA does not set the standards for testing. Rather, OSHA determines whether or not a company has the technical, staffing, and administrative resources to conduct a specific test. If this is the case, that company becomes an NRTL for that test.

Quoting from OSHA's Web site, "The NRTL determines that specific equipment and materials ('products') meet consensus-based standards of safety to provide the assurance, required by OSHA, that these products are safe for use in the U.S. workplace. Given that each NRTL has met the same requirements for recognition, OSHA considers NRTLs recognized for the same product safety test standard to be equivalent in their capability to certify to that standard."

Choices Are Available

Today OSHA recognizes several electrical testing organizations, including the well-known UL, ETL, and the Canadian Standards Association (CSA). All three are NRTLs, and are legally equivalent. In large part, UL's continued dominance of the testing market today is based on almost a century's momentum gained from their near monopoly. Consumers have grown to accept UL almost as a quasi-governmental agency.

This consumer expectation that UL is the only "official" certification mark, influences many manufacturers to go with UL rather than ETL or CSA. Engineers working in RE have indicated to me that they prefer working with ETL and CSA. They end up working with UL only because their marketing departments fear consumer rejection if a lesser known but legally equivalent testing agency was used.

Clearly, customer attitude (or at least perceived attitude) is key here. Once customers understand and accept that other testing agencies exist and that they can provide legally equivalent testing services, manufacturers may choose to have their testing done by an agency other than UL.

Access

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Quarterly Highlights of Sandia's Photovoltaics Program, "PV Hybrid Battery Tests on L-16 Batteries,"
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