AJ's Technical Tips:

Protecting the Battery from Problems Caused by Deep Discharge

By Arne Jacobson

I wrote an article earlier this year about the problems that can be caused by over-charging the battery (see Solarnet, May 2005). This time I will talk about another problem for lead acid batteries. This is the problem of deep discharge. Deep discharge of a battery occurs when electric current is drawn out of the battery until it reaches a very low state of charge. When the battery is drawn down very low, it can be damaged in a way that shortens its lifetime. The battery voltage at which deep discharge occurs depends on several factors, including the battery type as well as the rate at which current is being drawn out of the battery. In general, though, it is safe to say that a battery in a small solar PV system is deeply discharged when the voltage falls below 11.8 volts.

Deep discharge damages the battery, so it is best to avoid drawing the battery voltage down below 11.8 volts. If a battery is discharged deeply on a regular basis, its life will be much shorter than if it is maintained at a higher state of charge. Deep discharge is therefore very costly for solar PV system users, as it means that batteries must be replaced more often.

In order to understand how and why deep discharge damages the battery, it is important first to discuss the way that a lead-acid battery works. Standard 12 volt lead-acid batteries have six cells, and each cell has two sets of plates. The negative plates are made out of lead, and the positive plates are made out of lead oxide. Lead oxide is a compound that consists of lead and oxygen. The chemical abbreviation for lead is Pb, and the abbreviation for lead oxide is PbO_2.

The liquid in between the plates in the battery is a mixture of sulfuric acid (abbreviated H_2SO_4) and water (H_2O). This mixture is called the electrolyte for the battery. The battery works because of chemical interactions that occur between the two sets of plates and the electrolyte. When the battery is discharged one reaction occurs, and when the battery is charged the reaction is reversed.

In order to explain these reactions in more detail, it is useful to discuss changes that occur in the electrolyte during normal battery operation. When the battery is fully charged the sulfuric acid (H_2SO_4) is at its highest concentration. During battery discharge part of the sulfuric acid molecule is transferred to the lead plates. The reaction that occurs during discharge breaks the sulfuric acid into two parts. One part (H_2) combines with some of the oxygen from the positive plate (PbO_2) to form water (H_2O). The other part (SO_4) is transferred to the plates to form lead sulfate ($PbSO_4$). The lead sulfate is formed on both the negative and the positive plates. As the battery discharges, more and more of the sulfuric acid (H_2SO_4) is converted to water (H_2O). At the same time, more and more of the surface area of the plates is converted from either lead (negative plate) or lead oxide (positive plate) into lead sulfate ($PbSO_4$). This is part of the normal operation of the battery, and without this formation of lead sulfate ($PbSO_4$) on the plates no electric current could be drawn out of the battery.

When the battery is recharged, this process is reversed. In other words, the sulfate group (SO_4) is removed from the plates, leaving lead (Pb) on the negative plate and lead oxide (PbO_2) on the positive plate. At the same time, water (H_2O) in the electrolyte is converted into sulfuric acid (H_2SO_4). Again, this transfer of the sulfate group (SO_4) from the plates to the

electrolyte is part of the normal operation of the battery.

The problem that occurs during deep discharge is related to this transfer of the sulfate group (SO_4) back and forth between the plates and the electrolyte. Under certain conditions some of the lead sulfate ($PbSO_4$) on the plates becomes permanently attached. In other words, the SO_4 does not come off of the plate during recharging. Once this permanent bond is created, the part of the plate with the permanent bond is no longer available as an active area in the chemical reactions associated with charging and discharging the battery. The storage capacity of a battery is related to the amount of area on the plates that is available for these reactions, so the creation of these permanent $PbSO_4$ bonds reduces the battery's storage capacity. This process is called sulfation. If the battery experiences a lot of sulfation, it will not be able to hold a charge.

The main cause of this sulfation problem is deep discharge of the battery. That is, the lead sulfate bonds ($PbSO_4$) that form on the plates are much more likely to become permanent during deep discharge. The problem is especially bad when the battery is left to stay at a low level of charge for a long time.

There are, therefore, two things that you can do to prevent permanent sulfation in a battery. First and most importantly, you should avoid discharging a lead-acid battery below 11.8 volts whenever possible. Second, if the battery is drawn down below 11.8 volts, you should recharge it FULLY as soon as possible.

I know that there are times of the year when there is very little sun, and it can be difficult to recharge a battery in a solar PV system fully. In these cases I recommend the use of a battery charging shop. If you do use a battery charging shop, you want to make sure that the shop has a high quality charging machine and that your battery gets a full charge. If the battery is the standard “wet cell” lead-acid battery (that is, if it is not a sealed battery), the electrolyte will start bubbling and fizzing when it has reached a full charge. After a deep discharge, it is good to charge the battery for at least an hour after the electrolyte begins to bubble.

Deep discharge and the sulfation that it causes are a very serious problem for batteries in Kenya and elsewhere in Africa. Detailed data that my research team collected over a period of six months in 2003 to 2004 from a representative sample of 15 household solar PV systems provide information about the deep discharge problem in Kenya. Maina Mumbi of Off-Grid Energy Alternative Technologies played a very important role in this effort, and I want to acknowledge his contribution here. I am additionally grateful for data analysis work done by two Humboldt State University students, Stephen Kullmann and Douglas Saucedo. I also thank Peter Ndegwa Thuo, Paul Philip Chaura, Christopher Ongeri Adundo, and the 15 families who participated in the study.

Figure 1. Battery charging stations can be used to give batteries a full charge at any time of the year.

One of the important results from this study is presented in Figure 2. This figure is a type of graph called a cumulative probability distribution, and it shows the percentage of the time that the voltages of the batteries in the 15 systems were below a given voltage level. For example, the data show that the voltage of the batteries was below 11.8 volts approximately 40% of the time. This information is indicated by the red arrows on the graph.

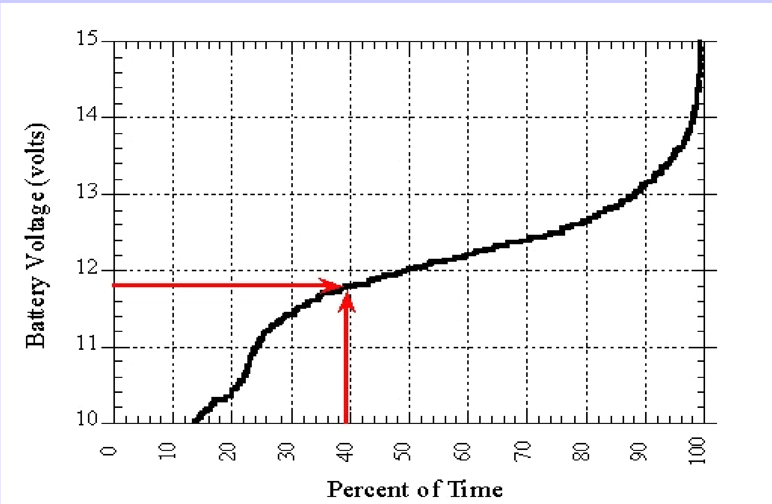

Figure 2. Cumulative Probability Distribution of Battery Voltage for 15 Household Solar PV Systems in Kenya

The fact that the battery voltage in the 15 systems was below 11.8 volts for about 40% of the time during the six months that we collected the data shows that the batteries in many of the systems have a <u>*very serious*</u> deep discharge problem.

Deep discharge shortens the useful life of a battery. Batteries that are discharged deeply on a regular basis must be replaced much more often than batteries that are maintained at a higher state of charge. Most of the batteries in the 15 household study had been damaged after only one or two years in service. Battery replacement costs money, so deep discharge has important economic consequences for solar PV system users. In other words, the overall cost of operating a solar PV system can be reduced significantly if deep discharge problems can be minimized.

Families that are careful with their energy use can extend the life of their battery. For example, one of the 15 families that I worked with was very careful to keep their battery at a high state of charge whenever possible. Figure 3 shows the cumulative probability distribution of the battery voltage for their system. If you look carefully, you can see that the voltage was below 11.8 volts less than 2% of the time. This is a very big difference when compared to the batteries in the other households in the study. The battery in this careful household is currently 7 years old, and it should continue to work well for a few more years. The long life of this battery is directly related to the fact that the family is very careful not to discharge the battery deeply.

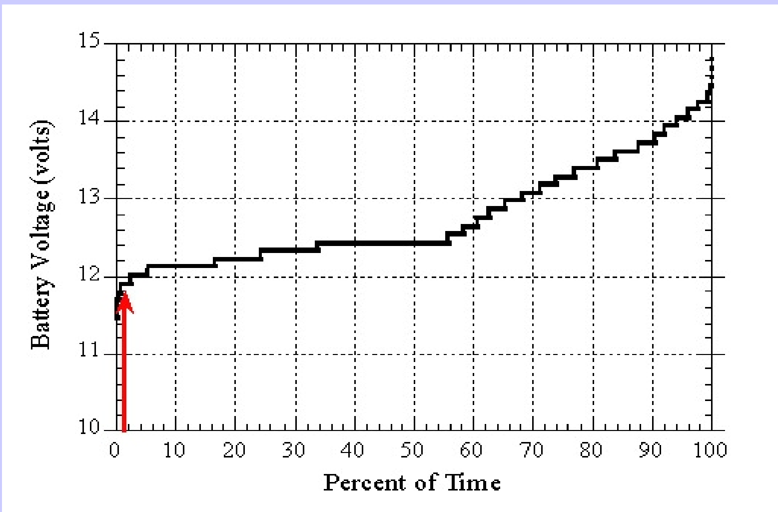

Figure 3. Cumulative Probability Distribution of Battery Voltage for One Well Managed Solar PV System in Kenya

So, what can people do to avoid the problems of sulfation and deep discharge?

First, I should mention that some batteries are more resistant to deep discharge problems than others. It should come as no surprise that true deep cycle batteries are the best, followed by good quality "solar" type batteries. Automotive style batteries are very sensitive to deep discharge problems, and can be damaged very quickly. As I have said before, I do not recommend automotive batteries for use in solar PV systems (see Solarnet, Vol. 4, No. 2).

A charge controller that includes a low voltage disconnect (LVD) provides another important part of the solution. However, some charge controllers are better than others, so it is important to get a good quality unit. See my Solarnet article on charge controllers for more information on this topic (Solarnet, Vol. 6, No. 1). In any case, I recommend charge controllers that have a LVD with a set point of 11.8 volts. If you cannot find a suitable unit with this set point, then a controller with an LVD set at 11.5 volts or higher is the next best choice. I do not recommend charge controllers with LVD settings that are below this level.

Voltage indicators can also play an important role in good battery management practices. Most charge controllers include a set of indicator lights that show the level of charge in the battery. It is also possible to install a meter in the system that gives the battery voltage. These indicators are important, as they provide solar PV system owners with information that they can use to manage the state of charge of the battery. Without good information, it is very difficult to know when it is OK to use energy and when it is necessary to cut back in order to avoid deep discharge of the battery.

Of course, many solar system users do not know how much damage can be caused by deep discharge. This is an area where solar technicians and solar equipment vendors have an important role to play. This role is in educating customers about the dangers of deep discharge and the importance of good battery management practices. I encourage all technicians and vendors to work hard to explain these issues to their customers. Once they understand, they will be much more likely to purchase a charge controller and to take good care of their battery.

Until next time, *kwaherini.*