Advanced Topics:

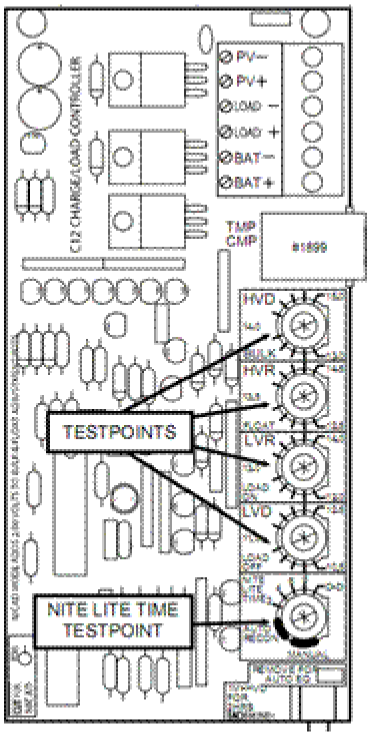
The technician's corner. Most readers will not really want to read this part and might feel "embarrassed" that they don't know or understand the details given here. Not to worry; simply skip this part if you are a normal OWL and well, you rely on the technicians in your life to set up custom solar systems. This section is for the ones who like to make and design there own solar systems with bits and parts from other suppliers, and connect the various sub-systems together. If this doesn't sound like you, dear reader.... skip this section completely.

Setting Up Solar Controllers for Optimum Performance

Various recommened controller settings can be discussed here with battery issues based on chemistry and thoughts about optimum LVD settings and more. Why you want to setup and test a specific way. This topic is for those with a technical background, in support of others on the field.

Xantrex Model C-12

With a much larger physical dimensions (16.5 x 11 x 4 cm)[4] and a discrete circuit board with easily serviceable electronic parts[5] the more expensive Xantrex C-12 controller (approx US$ 80) has significant advantages in ease of service, should something fail in the system. However one of its greatest and most desirable features is a programmable LVD cut-out of the netbook “load” when the operating voltage of the AGM battery falls below a user setting. This means that we can set the LVD to anything we want, and would suggest no lower than 12.5 volts as the maximum “depth of discharge” point. 12.6 volts would be much better.



Inside the Xantrex Model C-12 Notice too, the field serviceable standard components on a conventional Printed Circuit board.

Note in the drawing (right), the five user setting controls, specifically the Low Voltage Disconnect and the Low Voltage Re-Connect. Best of all, the control knobs themselves can be removed to further discourage changes later.

Convenient Digital Voltmeter (DVM) probe points are provided to make accurate threshold settings.

Unlike the Morningstar Controller, it is now possible to compensate for field conditions. In reality, many users are not using a proper gauge wire, running from roof-top to controller, and especially from controller to battery. There can be a significant difference between the recorded voltage at the battery terminals and what is “sensed” by the controller, even for short wire run lengths. As high as 3 tenths of a volt. So for a desired LVD of 12.5 volts at the battery, the controller might have to wait for 12.2 volts at its terminals. Finally, we can accurately set the solar controller to maximize run times for the netbook, while at the same time, using the minimum Depth of Discharge (DoD see section below) to greatly extend useful life of the relatively expensive batteries. Once proper settings are established by an expert (consultant), the control knobs can be removed and front panel sealed, reducing “tinkering” later.

Typical Charging Cycles

The Xantrex solar charge controller, like the older Trace Inverter chargers, follow a typical three phase charging method in three distinct phases: “Bulk, Absorption, Float”. The battery voltage will vary during the three stage charging process, as follows:

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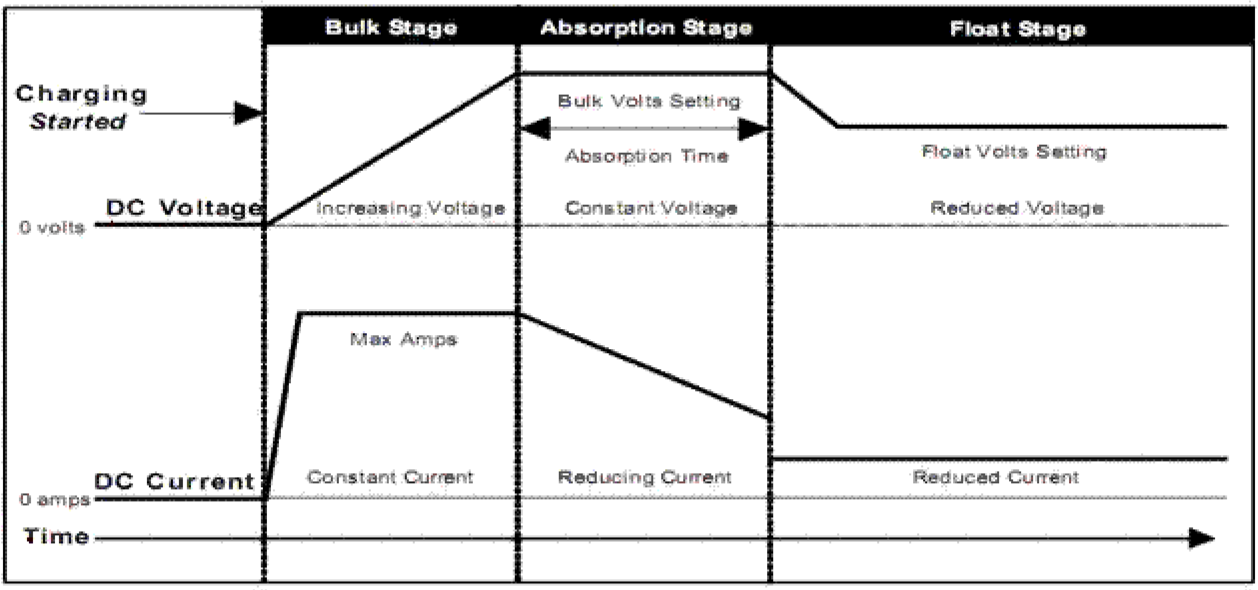

{cke_protected}{C}%3C!%2D%2D%3Cstrike%2D%2D%3E~~>>->>>>->>>>>- end tiki_plugin >>BULK— The first stage of 3-stage battery charging. During this stage the PV (solar) array is allowed to charge at its full output. Once the voltage of the battery reaches the BULK voltage setting, the controller goes to the next stage. Current is sent to batteries at the maximum safe rate they will accept until voltage rises to near (80-90%) full charge level. Voltages at this stage typically range from 10.5 volts to 15 volts. There is no “correct” voltage for bulk charging, but there may be limits on the maximum current that the battery and/or wiring can take.~~

- ~~ABSORPTION— The 2nd stage of 3-stage battery charging. During this stage the voltage of the battery is held at the BULK voltage setting until a timer accumulates 1 hour (C-12). Voltage remains constant and current gradually tapers off as internal resistance increases during charging. It is during this stage that the charger puts out maximum voltage. Voltages at this stage are typically around 14.2 to 15.5 volts.~~

- ~~FLOAT— The 3rd stage of 3-stage battery charging. During this stage the voltage of the battery is held at the FLOAT voltage setting. Full current from the PV array can still be delivered to the loads during this stage during the day powering the netbook. After batteries reach full charge, charging voltage is reduced to a lower level (typically 12.8 to 13.2) to reduce gassing and prolong battery life. This is often referred to as a maintenance or trickle charge, since it's main purpose is to keep an already charged battery from discharging.~~[6]
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~~Both controllers here use PWM, or “pulse width modulation” where the controller or charger senses tiny voltage drops in the battery and sends very short charging cycles (pulses) to the battery. This may occur several hundred times per minute. It is called “pulse width” because the width of the pulses may vary~~

from a few microseconds to several seconds.

If the voltage of the battery drops below the FLOAT setting for a cumulative period of one hour, a new BULK or ABSORPTION cycle will be triggered (C-12). This typically occurs during each night. If the battery is full at the start of the day, it will receive only an ABSORPTION charge for 1 hour and then be held at the FLOAT setting for the remaining period of the day unless the battery is discharged.[7]
{cke_protected}{C}%3C!%2D%2D%3Cstrike%2D%2D%3E>>->>>>->>>>>- end tiki_plugin >> Note that the voltage levels of both the Bulk Mode and the Float mode are settings one can control, unlike with the less expensive Morningstar SS-10L model.

Typical Battery Charging Voltages by Type

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Battery Type Ca=Calcium Sb=Antimony	Absorption Charging Voltages	Float Charging Voltages	Equalizing Charging Voltages
Wet Standard (Sb/Sb) Deep Cycle	14.5	13.2	15.5
Wet Low Maintenance (Sb/Ca)	14.4	13.2	15.8
Wet "Maintenance Free" (Ca/Ca)	14.8	13.2	15.8
AGM (Flat Plate) VRLA	14.3	13.6	15.6*
AGM (Spiral Wound) VRLA	14.6	13.6	Not Applicable
Gel Cell (Ca/Ca) VRLA	14.1 or 14.4*	13.8 or 13.2*	Not Applicable

Typical Battery Charging Voltages at 80 Degrees F (26.7 Degrees C) Asterisk marks say: "Verify with Battery Manufacturer"

{cke_protected}{C}%3C!%2D%2D%3Cstrike%2D%2D%3E>>->>>>->>>>>- end tiki_plugin >>There are many different chemistries and construction types for lead-acid batteries. For the best information on your particular battery, please consult the manual from your particular manufacturer. Be particularly careful with Gel Cell models, since they have the largest variance from “normal” and are often abused, fail, overheat or worse, if not charged properly.

Sadly the chart on the right doesn't included “flooded lead acid” batteries, or the kind one typically finds in automobiles that need refills with distilled water from time to time. As of this writing, we are not sure what the correct charge voltages are for such a battery. See chart at right.[8]
{cke_protected}{C}%3C!%2D%2D%3Cstrike%2D%2D%3E>>->>>>->>>>>- end tiki_plugin >> (Sb= Antimony; Ca= Calcium)

It is our opinion that SLA AGM batteries should not be equalized which means you should turn off the “auto-equalize” function on the Xantrex C-12 controller if you are using that style of battery. See “Battery Technologies” section.

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1. Far more than you ever wanted to know about “insolation” can be found at http://en.wikipedia.org/wiki/Insolation

2. Solar Buzz. See http://www.solarbuzz.com/technologies.htm

3. See AltE store: http://www.altestore.com/store/Solar-Panels/1-to-50-Watt-Solar-Panels/Global-Solar-Energy-Global-Solar-3

~~0W-12V-Framed-Solar-Panel/p5573/ Download spec sheet here as well.~~

~~4. www.xantrex.com/web/id/405/docserve.aspx (Brochure)~~

~~5. www.mrsolar.com/pdf/xantrex/C12.pdf(Manual)~~

~~6. Elements of this text taken from the very nice solar reference: “WindSun Deep Cycle Battery FAQ”; See http://www.windsun.com/Batteries/Battery_FAQ.htm~~

~~7. From the Xantrex Manual: “C12 Charge/Load/Lighting Controller Owner’s Manual” – March 2005; 975-0130-01-01 Rev. D; www.xantrex.com~~

~~8. From the web site: http://www.batteryfaq.org See section 9: “How do I charge (or equalize) my battery?” which has considerable specific charging cycle graphs by lead-acid battery type.~~

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Lead-Acid (Pb) Battery Issues

AGM or Absorbed Glass Mat Batteries

A newer type of sealed battery uses “Absorbed Glass Mats”, or AGM between the plates. This is a very fine glass mat composed of Boron-Silicate fiber. These type of batteries have all the advantages of gelled, but can take much more abuse. Panasonic, Lifeline, PowerSonic, Yuasa and all the rest manufacture AGM batteries. These are also called “starved electrolyte”, as the mat is about 95% saturated rather than fully soaked. That also means that they will not leak acid even if broken - very important to the aviation industry, and therefore considered “non-hazardous” cargo. Therefore they are more easily transported.

AGM batteries have several advantages over both gelled and flooded (liquid filled), and were more expensive than gelled in the past. But recently prices have fallen such that now they are completely replacing gelled altogether, and rapidly closing in on “flooded” batteries.

Advantages of AGM

Since all the electrolyte (acid) is contained in the glass mats, they cannot spill, even if broken. This also means that since they are non-hazardous, the shipping costs are lower. In addition, since there is no liquid to freeze and expand, they are practically immune from freezing damage, which is admittedly more important in northern Canada, not sub-Sahara Africa.

Nearly all AGM batteries are “recombinant” - that is - the Oxygen and Hydrogen recombine INSIDE the battery. These use gas phase transfer of oxygen to the negative plates to recombine them back into water while charging and prevent the loss of water through electrolysis. The recombining is typically 99+% efficient, so almost no water is lost.

The charging voltage profiles are the same as for any standard battery - no need for any special adjustments or problems with incompatible chargers or charge controls as with the older Gel Cell type batteries. And, since the internal resistance is extremely low, there is almost no heating of the battery even under heavy charge and discharge currents. Amazingly the AGM batteries have no charge or discharge current limits (not sure that one should test this however).

AGM's have a very low self-discharge rates - from 1% to 3% per month is usual. This means that they can sit in storage for much longer periods without charging than standard batteries. AGM batteries can be almost fully recharged (95% or better) even after 30 days of being totally discharged (but please don't do this, nonetheless, as discussed more fully in this paper).

AGM's do not have any liquid to spill, and even under severe overcharge conditions hydrogen emission is far below the 4% max specified for aircraft and enclosed spaces. The plates in AGM's are tightly packed and rigidly mounted, and will withstand shock and vibration better than any standard battery.

Even with all the advantages listed above, there is still a place for the standard flooded deep cycle battery. AGM's will sometimes cost 2 to 3 times as much as flooded batteries of the same capacity, although recently we have seen a dramatic price reduction. In many installations, where the batteries are set in an area where you don't have to worry about fumes or leakage, a standard or industrial deep cycle is a better economic choice. AGM batteries main advantages are no maintenance, completely sealed against fumes, Hydrogen, or leakage, non-spilling even if they are broken, and can survive most freezes. Not everyone needs these features.

No Equalization Charging. Unlike the more “Flooded” type batteries, equalization charging to extend the life-time of the batteries that some charge controllers allow for “automatically” are not to be used. In fact, this will decrease the lifetime of AGM batteries due to electrolyte loss via the vented valves supplied. Once electrolyte is expelled it is lost forever. However, this is one less maintenance headache that the user has to concern themselves with. Plus there is no need to ever refill the batteries with distilled water, for the lifetime of the battery.

So when considering solar systems for our national colleagues to use, the combinations of increased safety, easier transport, no-refilling and no equalization charging are considered great advantages.

Consider Manufacturing Date Codes

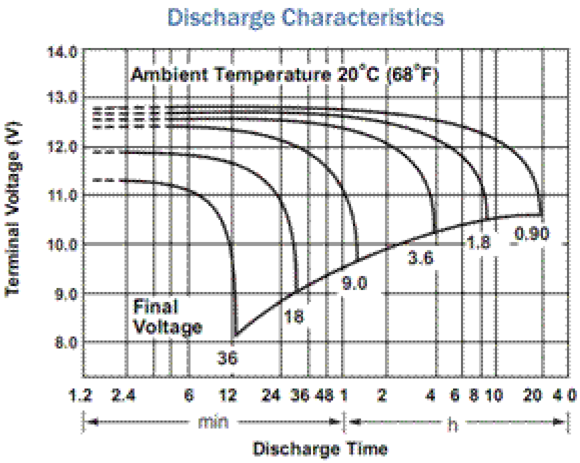
Each manufacturer of lead-acid batteries has their own system of stamping on the unit the date of manufacture. This becomes important for AGM style batteries especially as their capacity generally degrades in time “just sitting around” on the shelf. This can be an important factor in a third-world setting, where the supplier in a port town, has had stock sitting around for a very long time, and the store-reseller has not taken the time to maintain a trickle charge of the batteries while waiting for sale.

If possible, contact the manufacturer of the given part directly on email and convince them (if possible) to tell you their system of date code stamping. Then you can easily verify the claim that the given stock you are about to purchase indeed has been manufactured recently.

Valve Regulated Batteries

All gelled (Gel Cell) are sealed and are “valve regulated”, which means that a tiny valve keeps a slight positive pressure. Nearly all AGM batteries are also sealed valve regulated (commonly referred to as “VRLA” - Valve Regulated Lead-Acid). Most valve regulated batteries are under some pressure - 1 to 4 psi at sea level.

Amp-Hour Capacity

“All deep cycle batteries are rated in amp-hours. An amp-hour is one amp for one hour, or 10 amps for 1/10 of an hour and so forth. It is amps x hours. If you have something that pulls 20 amps, and you use it for 20 minutes, then the amp-hours used would be 20 (amps) x .333 (hours), or 6.67 AH. The accepted AH rating time period for batteries used in solar electric and backup power systems (and for nearly all deep cycle batteries) is the “20 hour rate”. This means that it is discharged down to 10.5 volts over a 20 hour period while the total actual amp-hours it supplies is measured. Sometimes ratings at the 6 hour rate and 100 hour rate are also given for comparison and for different applications. The 6-hour rate is often used for industrial batteries, as that is a typical daily duty cycle. Sometimes the 100 hour rate is given just to make the battery look better than it really is, but it is also useful for figuring battery capacity for long-term backup amp-hour requirements.”10) g"> 

Power-Sonic's expected performance for a typical 18Ah AGM battery. Some working conditions might necessitate a 35 Ah battery instead. This chart is based on the "20 hour rate" of discharge. Note the logarithmic axis. Power-sonic Model PS-12180

So what is our expected performance per average netbook? How long can we reasonable expect to supply power to a netbook while in use in the day? Consider this graph from Power-Sonic (right).11) Reading the chart to the right, let us consider a typical low power Asus 1101 HA netbook, that is running at 0.80 amps and while in use during the day. To reach the LVD point of 12.5 volts (see "depth of discharge"-next section) one would expect a "run time" of approximately 6 hrs. But this assumes that there is no supplemental solar energy also going to power the device even during heavily overcast days. Reality can yield much better performance than indicated in this pure load chart. With some of the new third generation solar panels, the "shade" performance is quite exceptional. It is not uncommon to see on an "overcast" day, enough solar energy to be completely sustaining a netbook, via the solar charge controller alone, while leaving a small "trickle charge" left over for charging the battery at the same time.

So, does one need to specify an 18 Ah battery, or a 35 Ah battery for everyday use? The answer depends upon the number of expected work hours for the end user, and also the number of expected "totally overcast" days, per average week. If the realities of village life means that one can only expect 4 hours of good day-time work, due to village level obligations to family members, then probably an 18 Ah battery would suffice. If the user is going to truly work 8 hrs a day, and perhaps 3 of those hours will be into the evening, then certainly consider purchasing a 35 Ah battery instead. If 12 volt house lights are in the equation, then go further, but also go for larger solar panels than 40 watts.

Remember that if one constrains the work to only during the day, it is possible with a 30 or 40 watt solar panel to completely remove the battery from this circuit entirely (in theory). The panel, even in overcast conditions, would charge the netbook's internal battery, and certain netbooks are capable of running 8-10 hours now on their internal Lithium Ion batteries. Such a "battery eliminator" circuit might be advantageous to fight off potential familial demands to use the battery elsewhere, a perennial problem in the field.

Lead-Acid Battery Life Issues

Depth of Discharge

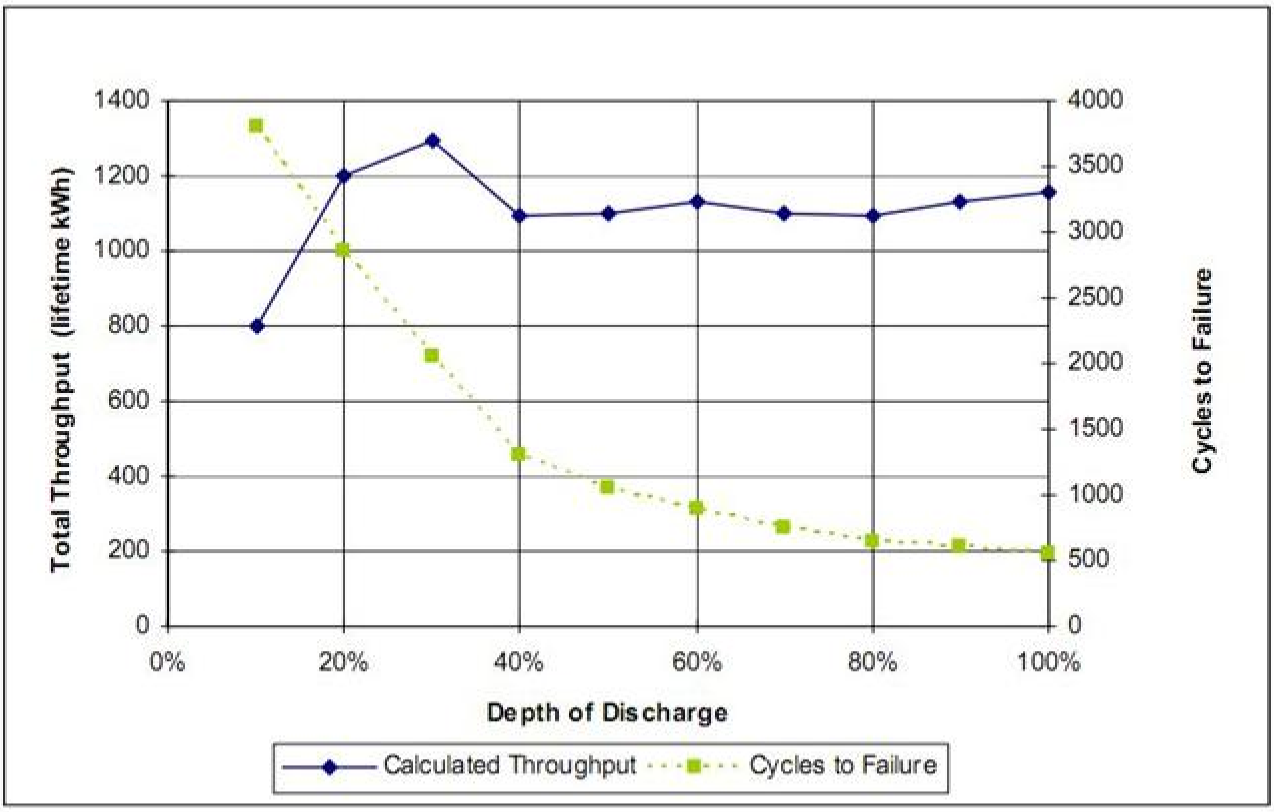
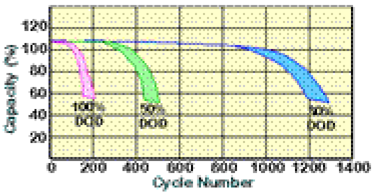
A very important factor for battery lifetime is the average level of discharge over the lifetime of the project. Basically lead-acid batteries are designed to be fully charged at all times. While using the batteries, the overall level of discharge should be keep to a minimum, and still achieve daily work goals that are practical for the given work conditions. Consider this chart: 12) g"> 

Figure 7 Cycles to Failure and Total Throughput for a Flooded Flat Plate Battery based on data supplied be the manufacturer

g"> 

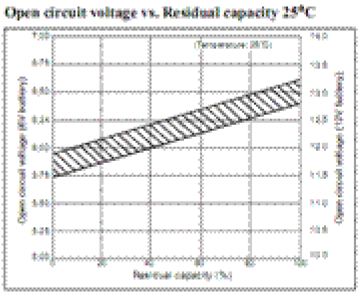
Another chart showing battery lifetime in relation to use. Here 30% DoD goes beyond 1200 cycles or four years if worked every day.

A consistent “depth of discharge” (DoD) of 50% (above) will yield a standard lifetime of 1000 charge/ discharge cycles per battery. If the user is constantly using the system each day, and recharging via solar, one would only expect their lead-acid batteries to live for approximately 3 years. This discharge level corresponds to 50% of the usable electrolyte solution and an operating voltage at the terminals of 12.5 volts.

However, if the user consistently discharges to the 30% level, or approximately 12.7 volts then the battery lifetime jumps to 2000 charge/ discharge cycles. Suddenly lifetime moves out to 6 years without the need for battery replacement.

Since the price of solar and netbooks is rapidly decreasing, but lead-acid batteries are not, this DoD issue needs to be monitored closely. Note too that “total lifetime kWh” peaks at the 30% discharge level.

Capacity Monitoring

g"> 

Battery Capacity chart Source: Panasonic

The goal of the solar controller is to protect the lead-acid battery, while allowing useful work to be done as required from the battery. As we have seen, the total number of solar cycles for the lifetime of the battery is dependent upon the average LVD cut-off (there are other factors as well). “Capacity” or the ability to store a given amount of energy is 100% for a newly acquired battery, but diminishes over time. Capacity can be monitored in the evenings for a “no load” situation. Using a Digital Voltmeter (DVM) at the battery terminals, turn off all loads including the netbook, any lights and anything else attached to the battery (you can leave the solar controller connected), and then refer to this chart on the right to see your present battery status.13)

So if my battery was held at a float voltage of 13.7 volts during the day in good sunshine, but at dusk with no load, the voltage at the terminals was found to be 13.0 volts or less, then one can conclude that your battery is at 80% of its normal capacity. It has “aged” that much, where age is relative term here, and not based on the actual number of days of use. Note that temperature has an effect here too, but is beyond the scope of this particular paper. See reference for such details.