The Small Computing on Solar (SCOS) Handbook Volume II

Tools for National Language Workers

"The Age of Lithium Ion"

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Abstract:

This is an support volume to the original SCOS Handbook, 2010, primarily in response to the incredible changes in solar technologies that have transpired in the last three years, plus an SIL hosted workshop called "The Asia-Pacific Language Tools" workshop, held at Chiang Mai, Thailand, Feb. 2013.

As before the principle goal of the handbooks are to educate advisors and mentors that oversee language work performed by Asia-Pacific Mother Tongue Language Workers (MTLW). This can be realized in a relatively cost-effective manner whereby whole communities can support their best people by obtaining affordable, yet robust technologies that will work in harsh environments. This handbook primarily concerns itself with solar equipment issues. Since adequate training is of primary concern one section of the handbook will address curriculum ideas that will help get difficult concepts across to national coworkers who did not have access to a good education, and yet are quite adept once trained. It is meant as a "handbook" or a guide to collect in one place all the relevant technical issues useful to SIL administrators who want to set up unassisted, long term, national coworker projects with adequate mentor contact. Volume I focused on "older" conventional Lead-Acid based solar systems; Volume II here, concentrates on the new Lithium Ion battery chemistries, and LFP in particular. Plus the newer, lighter, less-prone-to-breakage, thin-film flexible solar panels that have made their debut in the Western world.

Picture: *Josep Aputa (Barupu language, PNG) assists as mentor, a fellow student at the "Paratext for National Workers" workshop held at the SIL / BTA National Training Centre, Aiyura Valley, Eastern Highlands Province, Papua New Guinea. The typical "low power consumption" notebook is shown here, easily supported by small Lithium solar systems, as outlined in this handbook. Adequate training must be provide. to understand the software tools related to Language Development, as well as the basics of maintaining a viable solar system. Josep is a member of the Aitape West Multi-Language translation project, north coast, Papua New Guinea (11 languages in progress).*

Introduction

In years 2011-2013, the marketplace literally exploded with new solar technologies, particularly new light-weight flexible “roll out” solar panels. Prices continued to plummet to the point where we witnessed quantity one pricing of small form-factor panels at around $1.5 per watt. This is/was a major factor in the rapid escalation of domestic solar installations and the rise of companies to provide that service within the USA, Australia, New Zealand, and Europe. A 68 watt thin-film solar panel (or greater) could now be “rolled out and glued” to make a new roof-top surface in the USA. Combined in sections on modern metal roofs, considerable domestic power could be generated and even fed back to the local grid network in some regions, obviating the need for any batteries whatsoever.

At the same time huge advances occurred new Lithum Polymer and Lithium Ferrous Phosphate chemistries fueled by the relentless pursuit of newer and better Hybrid and total Electric Vehicles, principally the automobile. The huge advances in the manufacture of Li-Ion technologies in this marketplace greatly reduced costs and retail sales of LFP type batteries, also plummeted, making systems much more affordable.

This handbook represents the state of the art for SIL workers/ advisors/ mentors considering the merging of these two powerful trends in the industry and toward new Third-World applications. Successful application of these new technologies could lead to sustainable and affordable hardware, would empower third-world national citizens to consider doing portions of the language development task, by themselves (usually by teams), without increasing their dependence financially on outside funding agencies. But the key, as with any new technology is adequate training. Without training all technology applied in the third-world is meaningless and will fall to ruin. Without the full backing of local level communities behind the task, and contributing their own resources, outside funding agencies are continuing to waste assistance monies even to seemingly worthwhile causes. To adequately equip these communities, systems must be affordable as well.

Summary: SCOS Goals and Objectives

> **“Define a complete system of hardware, a tool, suitable for third-world national coworkers to consider doing language development work *in groups*, for themselves and by themselves. To build reliable, self-contained, and low maintenance hardware systems, where there is no readily available mains power.”**

> “SCOS defines a sustainable platform by which suitable national language tools can be implemented by laymen in the field”

. . . . — Brian Chapaitis

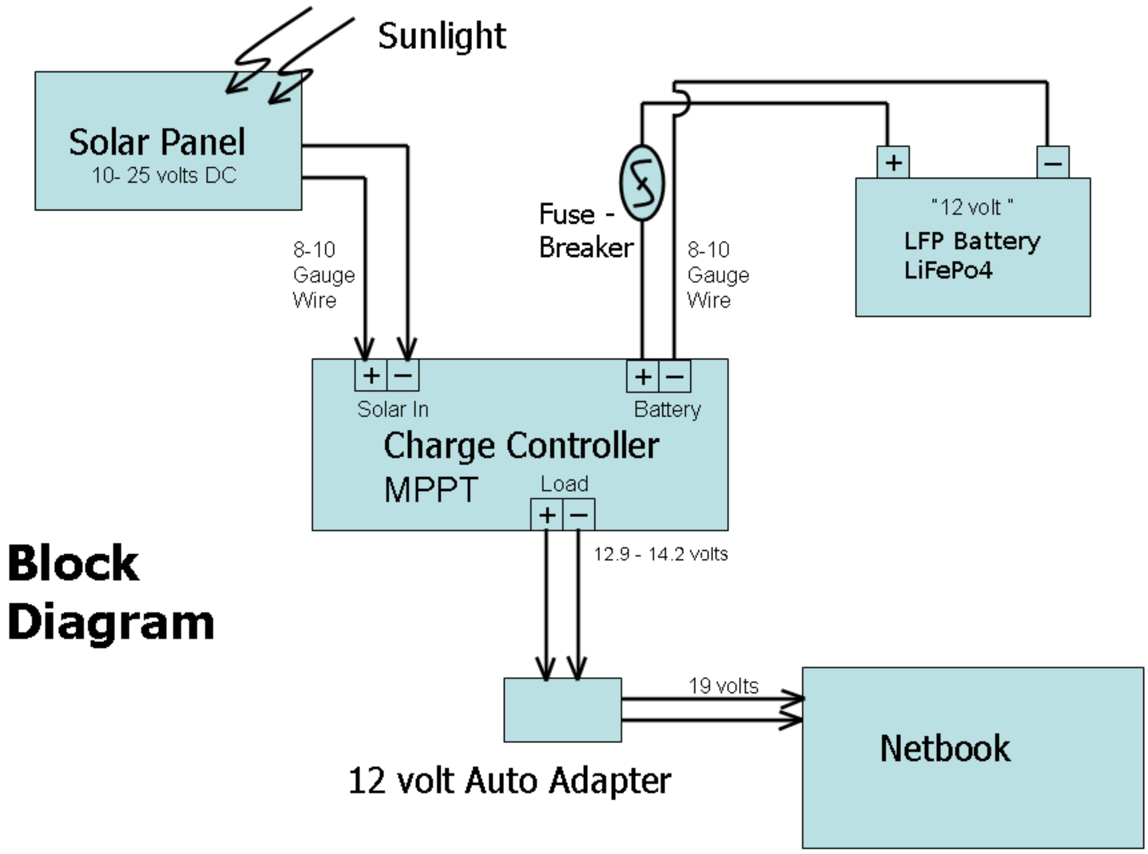
Summary: Main Points

For those who want to read the main points (and not the reasons why):

- *Best small-scale Solar Controller: Genasun GV-5 designed for LFP batteries.*
- *Best battery pack: EV systems 12v, 20Ah LFP battery.*
- *Best lighting technology: LED based units and modules in a variety of form-factors.*
- *Good Battery Lifetime while in use. Unknown but theoretical is now up to 10 years without replacement.*
- *Best representative solar panel. 12 v, 68 watt, roll-out panel, Unisolar PVL-68 or EQUIVALENT; xunlight-xrn10, at 50 watts.*
- *Village solar systems are designed to run a small notebook computer (8 watts), charge mobile phones and tablets, and run two LED lights for a total of 8 watts, for four hours a night.*
- *Best low-power-consuming notebook: AMD dual core, Lenovo model x131e (8 watts; high res screen)*

System Overview

Block Diagram of a Complete Solar System



Description of Components

Note: Although the manufacturers of the solar controllers below say the order of connection of parts does not matter – the general wisdom says that under full sunlight, the converted energy of the sun's radiation should have a good place to go. Therefore always connect the battery first, or disconnect the battery last during assembly of the parts.

Solar Panel:

A flat device, sometimes called a photo-voltaic (PV) panel that converts incident solar radiation into electrical energy. Manufacturers include Xunlight, Gold Peak (GP), Global Solar (GS), Unisolar, others.

Solar Charge Controller:

Due to rapid changes in solar radiation possible, the solar panel voltages fluctuate dramatically. The purpose of the controller is to condition the power coming from the solar panel and make this power acceptable for LFP battery chemistry to store electrical power, and without premature damage to the batteries, shortening their useful life. The newer design, Maximum Power Point Tracker (MPPT) is superior to the older Pulse Width Modulation (PWM) designs of before.

Battery:

An electro-chemical energy-storage device. Many battery chemistries exist including Lithium Ion used in mobile phones, and laptops and Nickel-Metal Hydride, often used in older laptops and LED flashlights. All can be re-charged. Lead-Acid is a very old technology, well understood, but with the wrong characteristics for a solar system and considered extremely fragile.

Fusible Link:

A circuit component, that is designed to break, or burn, when a relatively high current is applied (as in a short-circuit) and thus save further damage to equipment attached to a power source. Examples are an automotive in-line fuse (which must be replaced when used once) and a mechanical circuit breaker which can be reset by the user. Please do not skimp here and not bother with some sort of fuse or breaker in your solar setup. There is more than enough energy stored in a typical solar setup to create a spark that burns a village house down, or a direct sustained short of battery terminals leading to a battery explosion. The price of an automotive style fuse holder and fuse is very inexpensive insurance.

Automotive Adapter:

Actually a voltage conditioner and regulator, notebooks would normally use these to condition the electrical transients or “noise” found in automotive 12 volt electrical systems, saving the notebook power supply from undue stress. In solar notebook applications these devices protect the notebook input power supply from voltage swings present from the solar controller charging the battery. These range from 12.8-14.2 volts DC for LFP systems, where the given notebook wants a steady 19.5 volts supplied at all times. These adapters are very energy efficient and superior to use in comparison to an AC inverter.

Notebook or “notebook”:

A new class of notebook computer that can run a major Operating System like Linux or Windows, but consume 10 watts of power or less. These range in size from the early Asus 701 series at 7 inches wide – all the way to the Lenovo x131e, dual core AMD processor, which is 11 inches wide. 11 inches is about optimal size for touch typists. Many manufacturers are getting out of the “notebook” business, in lieu of tablets, however Lenovo is still in the low-power game with it's x131e notebook. “notebook” appears to be a moniker controlled by Intel.

LED Lights:

These come in a variety of shapes and sizes, but we want the 12 volt variety since they do not require smallish inverters producing 120 volts or 240 volts AC. They are therefore more efficient and less expensive. Particularly nice are high intensity bulb clusters that have standard GU-10 or MR-16 connectors and plug into regular lamp fixtures. In the diagram above, these lights would be connected by wires in parallel (see below) and then strung around the village house. Lighting should have independent switches, to easily adjust loading, or permit “load shedding” when desired.

Language Software:

Briefly mentioned here, but designed with national lay-workers in mind, these would include the OS environment and application suite called Balsa (Basic Language Software Appliance). Applications like WeSay, Paratext, Libre Office, Thunderbird eMail, and Bloom (literacy) would be included and most are “Free Libre”, or Open Source software. In this manner, community funds can be spent more on hardware issues, than on software ones.

New Thin-Film Solar Panels

Example of a Thin-Film 40-60 watt solar panel from Sinotech. These are extremely light-weight and note the corner grommet holes for ease to mount or string up via ropes. They can be easily taken in at night for security purposes.

Different Solar Technologies

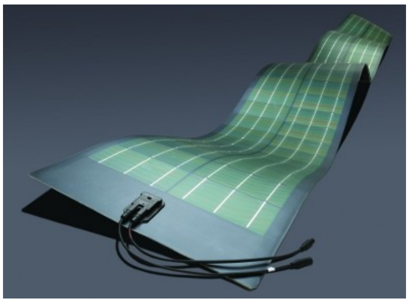
The ***maximum energy*** we could ever expect from average solar radiation to the ground (or insolation) would be around 1,000 Watts/m^2 on the earth’s surface perpendicular to the Sun's rays at sea level on a clear day. But of course that would be in the ideal since there are many other factors involved where one is located. Insolation from the words *in*cident *sol*ar radi*ation* is often expressed regionally on maps as kilowatt-hours per square meter per day ($kW \cdot h/(m^2 \cdot day)$). Look for insolation maps for your region which can be quite helpful for planning purposes. Obviously this has a bearing on photo-voltaic (PV) or “solar” panels, but solar panels are never 100% efficient.

Thin Film technologies can sometimes reach 18% and “multiple junctions” higher than that. Most of the commercial production of thin film solar is based upon another compound CdTe (cadmium telluride) with an efficiency of 11%. These are of interest today because of greatly reduced manufacturing costs, and you notice their rectangular nature when placed on a substrate of some kind, or perhaps a flexible roll.

“The selected materials [of thin film] are all strong light absorbers and only need to be about 1 micron thick, so materials costs are significantly reduced. The most common materials are **amorphous silicon** (a-Si, still silicon, but in a different form), or the **polycrystalline materials**: **cadmium telluride** (CdTe) and **copper indium (gallium) di-selenide** (CIS or CIGS).

Each of these three is amenable to large area deposition (on to substrates of about 1 meter dimensions) and hence high volume manufacturing. The thin film semiconductor layers are normally deposited on to either coated glass or stainless steel sheet, or some on a flexible poly-laminate layer”[1]

The flexible plastic substrates (rolls), reduced costs further, and made for very light-weight panels as shown here. Perfect for reduced shipping costs to third-world countries.



New, durable, lightweight solar panels like this Unisolar PVL-68, literally roll out onto a surface. They are easily transported if not fixed down. They will not easily break since there is no glass. Prices as low as US $99 have been seen in some on-line stores.

Triple Junction Thin Film Technology

This technology gets it's name from sealed laminate layers that also are translucent and allow photos to penetrate to multiple levels in parallel. So there is a flexible sandwich of materials, and the overlap means that reasonable power levels can be achieved. We have managed to get a few of the Unisolar PVL-68 panels which are designed with an adhesive backing to glue down on modern metal roofs on USA dwellings. They bond with the roofs making them sealed from the elements and yet generate electricity. The trick of course is to have your roof line facing the correct direction for the most part.

Wondrously light weight (4.4 lbs; 2 kg), these Unisolar panels are very easy to ship by small aircraft as they roll into a near cube. They are virtually unbreakable since there is no glass, and just one panel is enough for a village system.

Best of all, these panels have great “low light” or shade performance. It is not uncommon to be generating a suitable charge for the solar system even when skies are completely overcast, or it is raining.

The Ideal Solar Panel

We have found these 68 watt panels excellent “low light” performers but since the requirements for a village notebook system and LED lights is more like 55 watts... these are over-performers anyway. It means that on the darkest of days, one can expect to recharge the house battery pack completely. One no longer really worries about the weather, which for national training purposes is what we want. solar systems that just “plain work”, and we don't really have to teach others how to maintain them all that much. In other words, systems that represent a “low training” load in our “language tools” course work.

Operating Procedure Notes

It might be helpful to note here, that while ***charging*** a typical notebook’s ***internal*** batteries, that this appears to be a most power ***inefficient mode*** of use. Charging currents go quite high, up to 4-5 amps at times, (nominal use current would be 0.8 amps) and somehow the energy conversion efficiency drops dramatically inside a typical notebook. If this scenario of charging and recharging the notebook’s internal batteries is required for daily use in the language programme, then we would suggest larger or more solar panels than 50 watts. Again, this makes something like the Unisolar panel highly desirable. But the better scenario is simply to never really use the internal notebook batteries at all. Use your new external LFP battery pack instead as explained more fully in this handbook. This obviates the gross inefficiencies of the internal chargers in notebooks and laptops. Inefficiencies in the labs for all makes and models of netbook-class computers has been observed as low as 40% to 60%. (Instead of 95%)

Conventional solar panels were not designed to operate well at high temperatures, but we note that the Unisolar panel is a stellar performer all the way to 130 degrees F (55 deg C). This makes sense for a design that is normally glued on top of metal roofs, and not in an elevated frame that allows air to pass underneath the panel. Normally panels mounted on metal roof-tops may get very hot and this condition will decrease panel output for mono-crystalline type panels. Sandia Laboratory reports: “The voltage of crystalline cells decreases about 0.5 percent per degree centigrade temperature increase.”[2] A crystalline solar panel could decrease its power output by as much as 12% overall. This effect does not appear to be an issue with the Unisolar panel as it appears to be designed for “hot” use.

Blocking Diodes. In the old days, charge controllers were not that sophisticated and a series-blocking diode was placed in the solar panel wiring such that during the night, the fully charged batteries would not discharge back through the panel. This is not a problem with modern solar charge controllers since their circuitry typically disconnects the solar panel at night.

However, there is discussion about the new solar panel technologies, like CIGS and Thin Film technologies and whether two panels wired in parallel need blocking diodes or not. The issue is during a brilliant sunny day, and if shade from a nearby tree were to cover one panel, while the sun illuminates the other. The fear is that a high enough potential energy will flow back through the shaded panel, and might overheat this panel with damage.

However, note that the Sandia National Labs Solar Technologies Department (US government) says that this is not an issue in their excellent report.[3]

What size solar panel do I really need. The general rule of thumb is that during the worst-case overcast or rainy conditions that you expect in your locale, that the energy output of the panel equal the energy consumed by the notebook. This also assumes that an 8 hours "solar day" is equal to an 8 hours of working time, including any time spent working at night within a 24 hr period. In our labs in the Highlands of PNG, that spells out to about a 40 watt panel for a 10 watt notebook, or a factor of four (4x). But what about lights at night? Two LED spot-lights at 4 watts each (total 8 watts) is worth about another notebook in "load" to the system. Fortunately these are turned on usually for only 4 hours at night, more or less. So with lights included in our "average" system, we are working about 50% more, and therefore a **60 watt panel** is more robust.

This works because language workers typically do not work constantly all day on their machines, and a typical day does indeed have patches of great sunshine to recharge batteries. Overcast sometimes means "bright" overcast, producing 2x more power than what is needed to run the notebook.

Can one make a 50 watt solar panel suffice (with lights). Yes, especially if using one of the more modern MPPT type solar controllers. As stated before, the goal of this handbook is to obviate expert training, by having superior systems, and yet the cost of the systems is not too exorbitant and becomes un-affordable by the local language communities themselves. (Or to be more practical about it – we want to reduce subsidies and increase the proportion of "buy-in" for their own affairs for their own projects)

Solar Charge Controllers

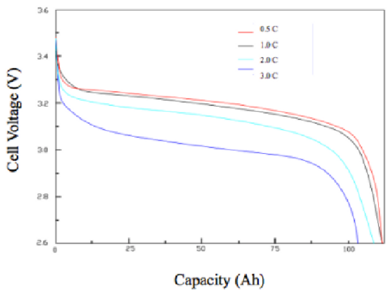
Purpose

The reason for the solar controller is to condition the power from the solar panels (sometimes called a Photo Voltaic (PV) Panel) to be acceptable for Lithium batteries. All solar panels have a Maximum Power Point (MPP) and manufacturers proudly give specifications for this. It is the "knee in the power curve" where the total power is maximized at a certain specific voltage and certain specific current output *for a given amount of sunshine*. This point changes with different solar panel technologies. Also, the *state of the battery* is changing as it charges back up again, while the incident solar radiation is changing by the minute. Finally the notebook or "load" may or may not be in use to do active work. The controller then makes new and different decisions about the charge voltage and current applied to the battery. All this to help your battery live a much longer and healthier life before replacement while performing its work function as well.

The old Morningstar and the Xantrex controllers discussed in Volume I, are not actually trying to hold the solar panels at that optimum point for max power. They are called “Pulse Width Modulated” (PWM) controllers and mostly just regulate the charge current for what their lead-acid batteries really need at the moment.

Controllers such at the Genasun GV-5 mentioned below are called “Maximum Power Point Tracking” controllers, or MPPT. These are actively seeking to keep the panel voltage at the optimum point for power for the given solar conditions (a cloud might have passed). Decisions are made in fractions of seconds, say 20 times a second, all the time.

Low Voltage Disconnect Issues (LVD/LVR)



The typical discharge curve for a LFP battery. Note the long mid period that is relatively flat with the steep fall off of terminal voltage just before the end of capacity. If 80% (used) is the maximum depth of discharge allowed then setting the LVD at 12.5 volts is reasonable here. Note these curves are under reasonable loads.

The Low Voltage Disconnect (LVD) should be set in a manner that protects the notebook user from overusing the battery and potentially discharging the battery too far for a given daily charge/ recharge solar cycle. Once the load is disconnected with a hard-worked battery, the user must be further “blocked” from continuing to drain the battery further. Otherwise damage will occur. A reconnect occurs (LVR) when the system detects that the battery has been sufficiently recharged to give the “go ahead” to the user, if they really, must continue working.

For classic Lead-Acid batteries this LVD or “disconnect” point by necessity must be set way higher than one would normally suspect. As outlined in Volume I, if longevity of the battery is of high value, then the terminal voltage at rest should be no greater that 75% of a full-charge condition. And we saw in Volume I that for lead-acid this ideal point was around 12.3- 12.5 volts depending upon the setup and conditions.

But the chemistry of LFP batteries are completely different. One can expect to do a deep, deep discharge.... as much as 80% or rather a condition of 20% of total storage capacity... and not damage an LFP battery. Discharge characteristics of LFP are rather flat in use with a fierce drop-out when approaching that final 20% of energy capacity. Therefore, under load conditions the designers of the Genasun GV-5 place their “standard” level at 11.5 volts and this is both adequate, and not necessary to really adjust, as with the Xantrex C-12 discussion in the Volume I handbook.

The Genasun GV-5 LFP MPPT controller. It costs around US$ 130, and is well worth it.

Note however, that in the “labs” in the PNG Highlands... running a 55 watt solar panel, and a mere 20 Ah LFP battery and the Genasun MPPT controller.... that even on the worst of rainy days, the ending capacity of the battery is probably still 40-50% of the total capacity of the battery. We have never actually witnessed the LVD point being reached.... ever... that would represent the 20% full capacity minimum level. This also means that we can expect a battery longevity or lifetime on the order of a true 2000 cycles, which would work out to be around 5.5 years before replacement. The typical Lead-Acid battery, is so easily abused, that typically they are replaced in a mere 1.5 years at least in our PNG context.

The Genasun GV-5 LFP Controller

The Genasun company makes a broad line of both lead-acid and lithium battery controllers and in a variety of sizes. At the very small end of their product line is what we want for our affordable national village systems, and is totally adequate for the relatively small loads that we are entertaining here.

http://genasun.com/products-store/mppt-solar-charge-controllers/

In the complete line-up the controller we would want for LFP batteries and LVD is listed as US$ 115

Note the different model types here. Look for the 5 Amp, designed for a LiFePo4 battery, composed of 4 cells for a terminal voltage of 14.2 volts.

In the "labs" our Genesun controller was purchased and sent over by JAARS Solar Department, JAARS Inc. and they can certainly help you locate this part. Email: solar_power_jaars@sil.org

Back to Past: Remember the Xantrex Model C-12?

The popular Xantrex C-12 controller was discussed back in Volume I in great detail. It is exclusively designed for lead-acid battery types and follows the now common "four-phase" charging profile including the "bulk charge" phase for lead-acid chemistries. The C-12 is unusual in that it is entirely adjustable in many parts of the multi-phase charge cycle.

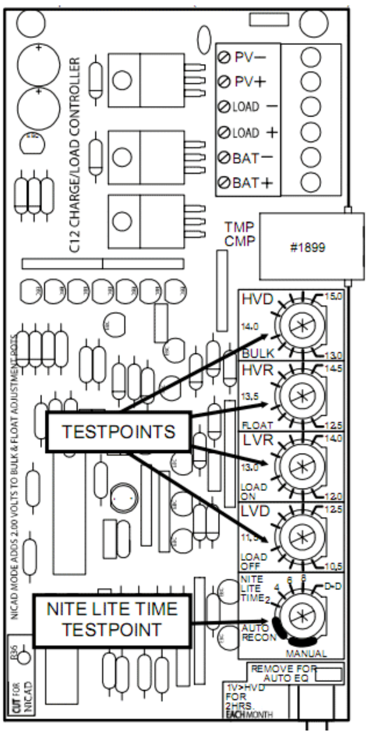
Could this less expensive charge controller be adjusted to handle well the characteristics required for LFP batteries? The answer looks quite hopeful and our teams in Buka, Bougainville are making such plans today.

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 less. expensive Xantrex C-12 controller (approx US$ 85) has significant advantages in ease of service, should something fail in the system.

As with the lead-acid batteries we want the same LVD point (but for a totally different reason) set at around 12.5 volts. For the LFP battery this would correspond to about a 20% full capacity discharge (80% DoD).

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

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



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

C-12 Settings for Lithium Batteries??

Typical suggested settings for the EV-Power LFP 20Ah battery pack.

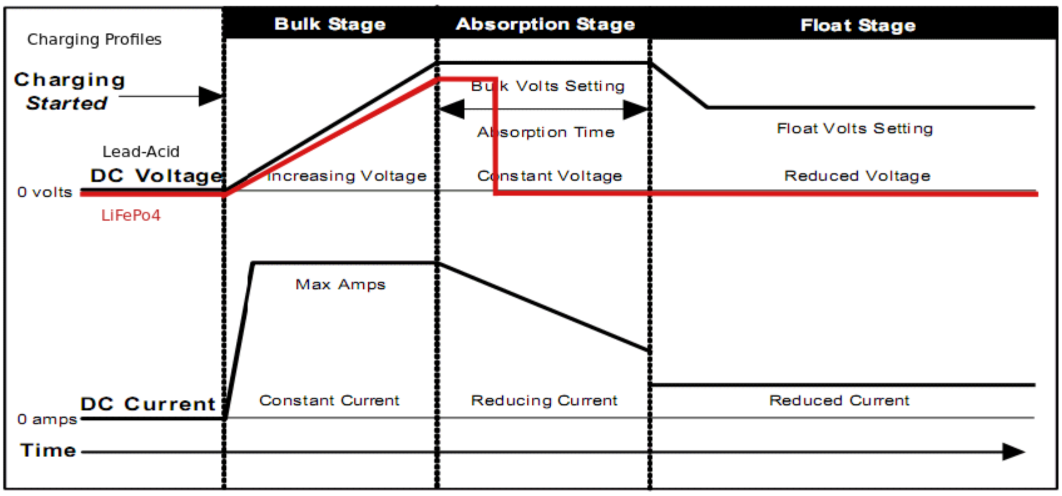
C-12 Pots	*Desired Voltage*	*Test Point Setting*
HVD	14.2	1.2 V
HVR	13.0	1.5 V
LVR	12.8	0.8 V
LVD	12.0 **	1.5 V
NLT	Auto-Recon	

HVD was the “bulk mode” voltage and was a linear current ramp up, much the same as an LFP battery would require, but we don't want the charging voltage to exceed 14.2 volts. We really want **NO trickle charging after about one half hour**, but the Xantrex doesn't know about the care and feeding of LFP batteries. So our compromise here is to set the terminal charging voltage down low enough that trickle charging might stop altogether. Therefore the HVR or the “float” voltage is set to 13.0 volts. LVR is the “Low Voltage Re-connect” is fine at 12.8 volts. and finally the LVD is the “Low Voltage Disconnect” is set at 12.0 volts, or nearly the same by which the Genasun would normally switch off due to the very steep discharge rate (11.5 v); NLT is “Night Light Time” (not used)

** Note: The desired voltage at the battery TERMINALS is actually 12.0 volts, however, due to resistive losses in the wires to the C-12 controller, (as with any controller) this setting could be reduced by 0.2 volts, which is a compromise at best. It all depends upon the work being done, or the active load at the time of the LVD switch off. It is always best to measure at the terminals and observe what is really happening at a typical LVD event.

Typical Charging Cycles

For the LFP battery we basically want a constant current linear charging profile, but once full charge is obtained, then we simply shut-off the charging all together. The new charging profile for LFP is indicated here in red. As one can see below, the Xantrex C-12 controller doesn't normally shut down additional “trickle charging” which is the desired characteristic for LFP batteries.



However, if we lowered the LVR point low enough, then it is possible that no further charging would occur to the LFP battery anyway. The absorption phase is too long, and we don't really have control over that. Only time will tell with real field users whether their LFP batteries using the Xantrex C-12 give the desired life-time results, but such trials are planned for in Bougainville, North Solomon Islands. Unfortunately we have to wait a few years to observe premature failure or not.

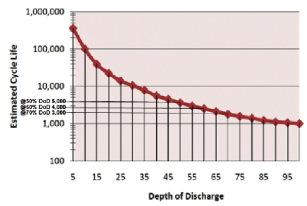
Note too, that one does not get the benefit of the MPPT function of the Genasun by using the older Xantrex controller. On the other hand, a Genasun GV-10 (10 amp controller) comparable to the Xantrex C-12, is twice the price of the GV-5, at approximately US$ 250[6]. We get by with the GV-5 because the typical village setup with notebook and lights is quite adequate with the less expensive, GV-5 controller. But the maximum solar panel size for the GV-5 should not exceed 65 watts, typically.

The LFP Battery Life Advantage

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. Since the source of energy is so variable, and subject to daily weather and night-time patterns, lead-acid is actually the worse chemistry for typical solar applications. To do their job they must be discharged readily all the time; to do their job they might have to wait hours (or even a day) before adequate solar energy is available to recharge to full capacity.

As we saw in Volume I, the overall average “depth of discharge” for lead-acid batteries greatly affects their longevity. If you only discharge your lead acid battery to 75% total full capacity each day, then you can expect your battery to live for around 1300 or more cycles. That would be around four years before replacement. Some batteries of course are better constructed than others.



Relationship of battery cycle life as a function of Depth of Discharge for the considered LifePo4 battery

LFP life-time chart showing battery cycles expected in relation to depth of discharge. The logarithmic Y axis is too hard to read here, but in the 50% to 70% range this researcher indicates a life-time of 5000 to 3000 cycles.

LFP batteries and their chemistry, “love” to be exercised. They are designed to be discharged, even rapidly without damage. They are designed to discharge to 20% their full capacity. The “depth of discharge here can be as far as 80%, without harm to the battery. Perfect also for HEVs too (Hybrid Electric Vehicles).

Not all Lithium batteries are the same, but for the LFP battery we can expect up to 3000 daily cycles over a good life-time of use. This translates to over 8 years!

In the Labs of Papua New Guinea, even in the worst of weather, we observe a discharge under normal loads to 50% of full capacity. This is indicated by a terminal voltage of approximately 13.1 volts each morning. The worst terminal voltage ever seen was approximately 12.9 volts and that event never repeated itself ! (A 16 hour computer work day/ night and in bad rainy weather).

Comparing “Apples” and “Oranges”

Two types of batteries shown here. They are about equivalent in energy storage capacity. One is designed for thousands of deep cycles; the other one is fragile. The Pb one weighs three times the other (LFP). Which battery type is really the least expensive to operate? With shipping costs so high, the lighter weight LFP might actually be less expensive.

So which is really the more expensive battery type to purchase. This is a difficult question to answer because the solution is not found in the initial purchase price of the system, but rather the overall life-span of the project.

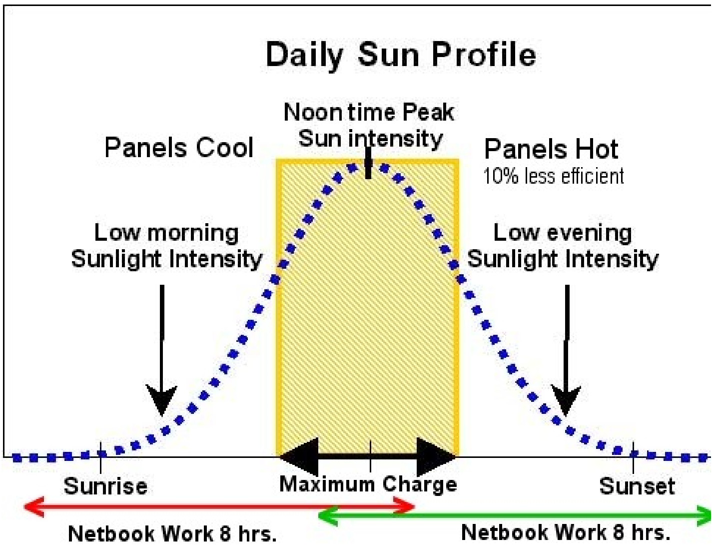
If the LFP 20 Ah battery is equivalent to an 80 Ah lead-acid AGM battery in USABLE capacity, then is it really the more expensive battery? Consider that that lead-acid battery weighs about three times as much, and that can translate to much higher shipping costs by truck, plane, or sea vessel. And since one can only reasonably discharge to 75% of full capacity, the end user typically under-specifies their capacity need, over-stressing the battery in use. This under-estimation leads to dangerously deep discharge levels, and then premature battery failure. It is not uncommon for users to report replacement of their lead-acid batteries in around 18 months. Some research teams even plan for an 18 month replacement cycle on their batteries.[7]

The EV Power 20Ah LFP battery shown here cost around US$ 130 to purchase and then a mere $32 to ship by air, to our center in the Highlands of Papua New Guinea. It weighs a mere 3.5 kg (7.7 lbs). Compare this to a typical automobile starter battery of 19 kg (41.8 lbs).

Typical Work Day Cycle

Repeated here from Volume I, it is important to state again (especially when teaching others) that solar energy is erratic and changing all the time. It is not relatively constant, like our mains power supply (normally) is, although some workers in the third-world would argue this point as well.

How one works during the day can have a profound effect on battery longevity, beyond the depth of discharge issue. Basically ALL Lead-Acid batteries are designed to be fully charged at all times. This means that how one works is important for battery life. And the warning in Volume I was to start work early in the day, and take advantage of the sun-rising in the day. Minimize your work at night, because basically discharging the sensitive lead-acid battery to it's maximum usable capacity, and then waiting perhaps 4 or more additional hours, just to recharge..... is a terrible scenario for longevity. Lead-acid was simply not designed for this kind of work.



Daily sun radiation pattern with peak solar energy around noon-time. Note that for LFP, it really doesn't matter when in the 24 hr. work period you work for 8 hours. Part of the time can be at night.

In direct contrast, the LFP battery is perfectly content to wait around being partially discharged for the next day's charge cycle, and it is much more forgiving about when the user actually works. Night-time is an acceptable time to exercise the battery and do useful work. Then the next day there is time enough to recharge and "top up" the battery cells.

It is this "delay" to recharge, that is probably the most important reason for premature lead-acid battery failure. It is not strictly a "depth of discharge" issue. ***All the lead-acid battery manufacturers expect the user to immediately recharge a discharged battery after use.*** A clear example of this is an automobile that discharges its battery during starting (200A) but the rest of the trip this same battery is receiving an immediate recharge cycle. Lead-Acid batteries cannot wait around to be fully recharged. It is for this reason that one should consider <u>other</u> battery chemistries for the <u>standard solar powered</u> application. ***Lithium battery chemistry to the rescue here.***

Is Lithium-Ion Safe?

As of this writing, there was a recent world-wide incident in January 2013, with Boeing aircraft grounded, due to a problem on an ANA jet and related to an on-board fire with Lithium-Ion batteries. Two aircraft reported incidents, grounding an entire fleet of 787 Dreamliners.

This gives rise to the logical question: "Is Li-Ion safe". In the news we see:

> *"In a little-noticed test in 2010, the F.A.A. found that the kind of lithium-ion chemistry that Boeing planned to use —* ***lithium cobalt*** *— was the most flammable of several possible types. The test found that batteries of that type provided the most power, but could also overheat more quickly."*
> *– NY Times, January 2013*

There are many different types of Li-Ion batteries. To the best of our knowledge so far, the LiFePo4 chemistry is reported to be the safest Lithium technology and the least likely to cause a fire if mistreated.

However, if one is still concerned, then we would recommend an enclosed metal container with holes for wiring surrounding the ev-power 20Ah LFP battery pack. The battery units in the Boeing aircraft are all placed in metal enclosures for safety reasons, but an on-board aircraft fire is much more serious than a fire in a hybrid or electric car on the ground, or a fire in a house dwelling at rest.

Many millions of hybrid and electric cars are in use to today, traveling on a thousand roads, and are not having fires, so this concern over Lithium-Ion may be unwarranted. On the other hand, even a miss-handled Lead-Acid battery, shorting and arcing a spark, could easily start a fire in a village house made from common bush materials. All the more reason for excellent training of individuals on the setup, care and maintenance of such systems.

"Phosphates are not prone to thermal runway and will not burn even though abuse occurs. Therefore lithium ion batteries made by phosphate as cathode are safer as compared to other lithium ion batteries. Batteries made from LiFePo4 technology have good shelf life, long cycle life and is maintenance free. LiFePo4 batteries are environment friendly as compared to o LiCoO2, LiMn2O4 and Li(NiCo)O2. LiFePo4 batteries can work in temperature range of -20C to 70C. LiFePo4 technology does not contain heavy metals and does not have the memory effect like nickel cadmium and nickel metal hydride batteries. Safety devices along with good electrode design can reduce the risk of fire or explosion."[8]

Also see the last paragraph for LFP on Wikipedia:

http://en.wikipedia.org/wiki/Lithium_iron_phosphate_battery

Which under the topic "Safety" makes a distinction between LFP and Lithium-Polymer or (LiPO) which are commonly used in hobby environments. This is still another type of Lithium-Ion chemistry and with different characteristics.

"[LFP] A. Safest and the most environmental friendly

The Lithium Iron Phosphate Battery has been proven as the most environmental friendly battery. The primary concern with Li-Ion batteries is safety. Overcharging and overheating can cause fire and

explosions. The ***exception*** *to this is the LiFePO4 battery."*
– Globe Light and Water Systems[9] (Emphasis mine - BHC)

One thing to note is that of all the Lithium-Ion chemistries, the LiFePo4 is the least energy dense. The other chemistries carry considerably more energy per kg than LFP. This might explain why LFP is actually safer but the technical explanations all revolve around the design of the cathode and the controlled release of electrons.

All our readings continue to confirm that Lithium-Cobalt (remember Boeing) is extremely "poor" in safety. All articles continue to suggest this. The appeal of that chemistry is its extremely high energy-storage density.

If you are still concerned:

A suggested and practical solution is to simply place the battery inside a large open metal bucket in the village, since the actual ev-power LFP package is rather small. If there were a fire this would give occupants time to contain it.

There is a big difference between Lithium "primary" batteries and Lithium "rechargeable" batteries. The former can be purchased in small sizes at a local store shop and are used once and then disposed of. This type of battery has solid Lithium metal inside and it would be foolish to extinguish a solid-metal battery with water. Sand is the best option.

However, Li-Ion **rechargeable** batteries do **NOT** contain solid Lithium metal. These batteries, like the LFP rechargeable, can indeed be extinguished with water and in fact there is a youtube.com video put out by the FAA on how to extinguish this type of fire, with water.

"If the fire occurs in an airplane, FAA tells flight attendants not to use fire extinguishers but specify water or pop (soda). Water cools the adjacent material and prevents the fire from spreading. Many research laboratories and factories also use water to put out battery fires."[10]

In the event of a fire....

The idea is to cut off all oxygen. The recommended practical solution is "sand" (as with any chemical fire). Or with a rechargeable Li-Ion like LFP, water is acceptable practice. Water has the additional benefit of cooling adjacent cells in a multi-cell battery about to self-ignite from a neighboring cell.

Where to Purchase Parts

In a Hurry ..... Read this Section First .....

At the time of writing this Volume of the SCOS Handbook, JAARS Solar was about to release their "Half-Pint" system (84Wh, LFP based) and their "Full-Pint" system (240Wh, LFP based). The latter system is based on the research found in this handbook. I would suggest, starting in April 2013 and beyond that you contact the industrious people at JAARS Solar Department, to get the latest on system availability including any nice solar-panels that they might have to offer.

Email contact: solar_power_jaars@jaars.org

for more details, or perhaps they will have a web-site up and running for this.

If you want to "make you own" DIY system, then continue reading below, but the material below will be dated fast.

Solar Panels

Since the Asia-Pacific Language Tools workshop (Summer Institute of Linguistics, in conjunction with Palaso University, Chiang Mai) has now passed, there have been many queries about solar parts suppliers, from many parts of Asia as well as the Pacific region. Most are interested in getting into Li-Ion chemistries and particularly the LFP style batteries.

Xunlight Model: XRN10

115.9 × 11.9 × 0.006 in (1.5 mm); 4.4 pounds (2.0 kg); 53 Watts; Max Power Voltage (Vmpp): 16.7 Volts; Max Power Current (Impp): 3.18 Amps

This is a perfect match for the Genasun GV-5 controller, can easily maintain a notebook, charge a phone/ tablet, and run 2x LED lights at night.

Our favorite panel, the thin-film Unisolar model PVL-68 was sold on sale in early 2013 for around US $99 at quantity 2 (min.) purchases. That was the principal unit I would have sent the reader but these wonderful panels seem to be "out of print" for now. They would have been found at "Solar Blvd" in California, US. See:

http://www.solarblvd.com/Solar-Panels-&-Systems-12-Volt-Solar-Panels/c1_269/index.html

Here you will find great price points for 12 volts solar panels suitable for use on the Genasun GV-5 controller. Strictly speaking we want a max solar panel power out of 60 watts for the Genasun and we were pushing the design limits of the controller which states a maximum of 60 watts. The company engineers unofficially say: "It can handle it".

However, I can clearly state with great success that a standard mono-crystalline, HQRP 55 watt panel works flawlessly in our labs supporting a 10 watt notebook, a 5 watt tablet, a 2.5 watt smart-phone and approximately 8 watts of LED lighting, quite well, and with full recharge of the 20Ah LFP battery (see below) even in the worst-case weather days.

Therefore you may consider any of the panels listed at Solar Blvd in the 50 watt to 60 watt range, and you will be extremely pleased with the results.

If you are on an extreme budget and forgo any external systems, only powering a 10 watt notebook (nothing else) then feel free to reduce the solar panel size to 40 watts... but remember... no other loads please added to your system.

At the time of this writing, please note these panels:

- *Solar Cynergy   PV-SC060J12   Polycrystalline   US$ 87*
- *W Solar   SA-65Mx 9   Mono-crystalline   US$ 78*

Panel suppliers, particularly at quantity 1 sales, are often hard to come by. By the time you read this report, the situation will have changed. Please do not be afraid of mono-crystalline panels. I actually prefer their performance, at least modern panels currently being produced.

www.amazon.com is also an excellent source for solar panels, but usually the stores are situated in the USA and some do not attempt overseas shipments at all. Once again JAARS Inc. P & S Department may be a shipping resource to use with such stores, since they ship all over the world, and are situated in North Carolina, USA.

HQRP (Osprey-Talon) makes an excellent solid aluminum frame panel at 55 watts. Mono-crystalline. US$ 124

At the time of this writing, please note these panels:

- *HRQP   55W   ASIN: B004LLZIOC   Mono-crystalline   US$ 124*
- *LiteFuse   50W   LF-SP50W   Mono-crystalline   US$ 140*
- ***Epcom   WK50-12   Polycrystalline   US$ 99***

Note that the LiteFuse shipping weigh is 10.6 lbs (4.8 kg) which seem lighter than most. The Epcom shipping was 13 lbs (5.9 kg); usually polycrystalline panels are physically larger. Don't forget that shippers use “dimensional weight” and charge what whatever is higher. Aluminum frame panels often have a higher dimensional weight than physical weight.

Thin Film Flexible Panels

I am constantly on the lookout for the best suppliers in this type of panel, but if they fall to reasonable price points, it seems that everyone instantly purchases them and stores get “sold out”. The wonderful Unisolar PVL-68 panel is no longer for sale at Solar Blvd, and is increasingly hard to find (since it is now “out of print” in the world).

However, a competitor can be found at www.civicsolar.com these days:

http://www.civicsolar.com/product/xunlight-xrn10-53-watt-thin-film-laminate

In the Xunlight brand:

- *Xunlight 53W US$120*
  Model: XRN10 4.4 lbs (2.0 kg) Thin Film Laminate

However, one caveat is that you must purchase quantity 2 parts.

http://www.civicsolar.com/product/xunlight-xrn10-53-watt-thin-film-laminate

Advantages of this type of panel are extreme portability at 2.0 kg, and relatively unbreakable in comparison to a conventional glass fronted aluminum frame solar panel. I could not determine shipping costs however with Civic Solar unless I went as far as an actual purchase on their on-line fulfillment system, therefore I cannot report here about shipping costs.

Also note that since this panel can roll up, the dimensional weight issue goes away for shippers. Most likely the shipping weight will be the physical weight, or in this case a mere 2.0 kg.. This is VERY important when shipping a solar panel to a third-world allocation.

Xunlight Manufacturing Photo

Thin-film lends itself to easy economy of scale as demand progresses forward for more photo-voltaic sources.

One big advantage to thin-film is that the result is not fragile. It does not require a tempered glass front which is easily shattered, plus it is lighter.

If you are still looking for the Unisolar PVL-68 panels, then consider what www.ebay.com has to say. Search "Unisolar PVL-68 solar":

- ***Sun Soldon 68W US$139 4.1 kg***

http://www.ebay.com/itm/Peel-Stick-68-watt-Uni-Solar-Laminate-Solar-Panel-Flexible-12v-Unisolar-/271171326641?pt=LH_DefaultDomain_0&hash=item3f231212b1

However, world-wide shipping costs are high with this company. They wanted US$ 103 to Papua New Guinea, and I would ship overseas via JAARS Inc. P & S department, instead via their DHL services. This panel weighs only 9 lbs. (4 kgs)

Xunlight Model: XR12

Xunlight makes a variety of sizes, so if your design needs exceeds the purpose of this handbook, there are many other solutions available.

This is an example here. It is quite possible that less expensive offerings can be purchased via Hong Kong and Mainland China and we are pursuing such contacts today.

Also consider Lensun www.lensunhk.com

- ***Lensun 50W US$169 2.0 kg***

http://www.ebay.com/itm/50W-100W-150W-200W-250W-flexible-solar-panel-12V-Mono-thin-light-for-boat-car-/321042942578?pt=LH_DefaultDomain_0&var=&hash=item4abfa68a72

Free shipping to USA, UK and Australian addresses. Contact for International shipping rates.

www.amazon.com has some interesting flexible panel possibilities.

- *HQRP 45W ASIN: B005AWVQEM Mono-crystalline US$190*

This is at the bottom of our power range at 45 watts, and seems expensive, but not if it is light-weight to ship to where you are. Note that there are many flexible panels for sale here, but most are at exorbitant prices, and so ignored here.

Don't Overlook Direct from China

Often if one prowls the ebay.com.au website (Australian) you will quickly land on Hong Kong direct suppliers of solar panels. In the 50 watt light-weight, flexible category (2.0 kg) consider:

Discount Solar, From the Exeter, California, USA, but really "Sacred Solar" China.

http://www.ebay.com.au/itm/Semi-Flexible-Bendable-60-Watt-Solar-Panel-12V-High-Efficiency-Sunpower-/140921817442?pt=Battery_Chargers&hash=item20cf984962

60 Watts US$152 + US$45 shipping= US$197 (to exotic Papua New Guinea) Weight: 1.4 kg Has grommet mounting holes

Green Solar, from Fujian, China

http://cgi.ebay.com/ws/eBayISAPI.dll?ViewItem&item=261111051473#shId

50 Watts US$155 + US$30 shipping= US$185 (for example to India) Model: ECO-MPS-50W Weight: 1.85 kg Polycrystalline on Aluminum substrate. The same company also sells mono-crystalline on aluminum for US$175

http://www.ebay.com.au/itm/50W-mono-semi-flexible-solar-panel-flexible-solar-cell-module-for-yacht-boat-RV-/261092881762?pt=LH_DefaultDomain_0&hash=item3cca593562

Sun Gold Power, from Shenzhen, China

50 Watts AU$180+ AU$25 shipping= AU$205 (large variety of countries) Model: ? Substrate: ?

http://www.ebay.com.au/itm/50W-Semi-Flexible-solar-panels-panel-for-car-boat-varavan-CE112161-/330795307244?pt=AU_Boat_Parts_Accessories&hash=item4d04efd0ec#shId

Finally the big Chinese manufacturers have store presence in major countries, so for example in the Pacific, we look to Australia.

Solar Power 2005, (really HK Lensun Solar), but in NSW, Australia (limited shipping to other countries)

50 Watts AU$198+ AU$0.00 shipping= AU$198 Mono-crystalline on an aluminum laminate substrate.

http://www.ebay.com.au/itm/50W-Semi-Flexible-12V-MONO-solar-panel-for-motorhome-boat-car-FAST-SHIP-/121005941291?pt=AU_Solar&hash=item1c2c84222b

Others... many others..... check again in a month.

Solar Controllers

There may be other Li-Ion MPPT solar controllers out there, but few in the "low end" for small-scale systems, which is what a village-class system represents. A 5 to 10 amp controller is all that is required here, and to move to a 20 amp system, increases the system cost beyond what some third-world communities can afford.

As of this writing, the best LiFePo4 (LFP) controller would be the Genasun GV-5 unit found here:

http://genasun.com/products-store/mppt-solar-charge-controllers/

The relative small size of the Genasun GV-5 controller. Be sure to order the model specific for a 4-cell, LFP battery, not the model for Lead-Acid chemistries.

Listed for a "4 cell LFP battery" with standard LVD as $115. It can be ordered directly with additional shipping costs to overseas locations. However I would suggest that you check with JAARS Solar for this part, since they have tested this part in the USA, and shipping overseas is not difficult for them as they service so many third-world situations.

Batteries

As with the search for Li-Ion solar controllers, it is easy to find relatively large battery packs using LFP technology, say 12v 100Ah units or greater. But when it comes to a small-scale unit suitable for a village-level system, that could be affordable for communities... the best choice appears to be by ev-power systems:

http://ev-power.com.au/webstore/index.php/12v-lifepo4-batteries/12v-lifepo4-batteries.html

On the web page, look for the left hand battery pack at AU$ 127.50. We believe this is for sale also in the USA, and again, JAARS Solar Department would be a good resource here.

The ev-power 4 cell, approx. 12 volt, battery pack, which tops out at 14.2 volts when fully charged. The true usable capacity of the ev-power pack is 16 Ah (at 12 volts), vs 5 Ah for the Lead-Acid AGM style battery (12 volts) shown to the right.

The travel weight is around 1/3 the weight, due to the very high energy-storage density of LFP products.

Low-Power "notebook"-Class Machines

The term "netbook" is really a trade-marked name by Intel and represents a class of low-power-consuming notebooks, that were also extremely popular for a few years, due to their relatively inexpensive cost. As of this writing, the "netbook" has been eclipsed by the rise of tablet class computers.

However, there are still notebook companies that make low-power-consuming computers and still at reasonable prices. The best choice at this point in time would be the Lenovo x131e, with dual-core AMD processor core. This machine has been tested with both Windows OS and Linux OS. Compared to the older x120e it is a full 2 Watts less "heavy" for a total of 8 watts, while running with wifi on, and screen at half-brightness. Complete with a dual-core processor, it is reasonably speedy with say, normal Word Processing type applications, and better still it has a higher resolution screen at 1366 x 768 pixels than the older "netbook" class machines of olden days, and purposely limited by Intel. **Special note:** The screen is also the coveted anti-glare, matte type coveted by users working in difficult lighting situations.

Lenovo x131e is the latest version (2013) of a low-power consuming notebook. With it's dual core AMD processor, it runs applications relatively fast and consumes a mere 8 watts. A higher resolution (than normal), anti-glare screen is a big plus.

So as of this writing, the x131e can be purchased directly from the Lenovo web-site:

www.lenovo.com

There are many extra options that can be "dialed" in on the Lenovo site, and this would include extra memory, size of hard drive, and size of internal battery pack. Then once you have determined your "ideal" system configuration, quickly run over to:

www.amazon.com

And search for "Lenovo x131e". Here will be many "hits" from many potential stores (since Amazon is mostly an aggregator of stores). But most likely you will find your identical configuration that you specified before, and perhaps for US$ 50 less. Personally, I only order from "big" stores and ones that I have a prior relationship with, for the most part.

Summary

Lithium Ion is the Future of Solar Systems

This handbook, Volume II, was originally inspired by a meeting in Chiang Mai, Thailand for the "Asia Pacific Language Tools" workshop, February 2013.

Hopefully the reader can see the supreme advantages of moving to Lithium Ion battery technologies, over the older and frail lead-acid batteries so commonly in use today.

Training Trainers

Part of the workshop is an effort to teach and train others to do the same for national colleagues in our work. It is hopeful that the latter half of this handbook will give some useful classroom activities to help train up language workers who will be both using and maintaining such equipment in the village context, while the "experts" in technology may not be readily available to assist when things go wrong.

About the Author

Brian Chapaitis originally studied electrical engineering at Cornell University, USA. He is comfortable with programming embedded micro-controller systems, and thus is a "hardware and software" man, although he considers "real programmers" to only work in assembly code.

Together with wife Helen (physician), they have served in a variety of positions in the SIL Papua New Guinea Branch for over 25 years.

Brian presently works out of the Language Software Services office in the SIL LCORE department building at Ukarumpa, in the Eastern Highlands Province, Papua New Guinea. He can often be found way off center, ministering within the church in the local village context. He shares the growing vision of empowering national counterparts to do aspects of the Language Development task hitherto thought impossible, with self-sufficiency, using the latest new appropriate technologies, both hardware and software.

Brian Chapaitis,
SIL PNG Branch, Papua New Guinea

Email: brian_chapaitis(at)sil.org   use: @ (this reduces spam)

Appendix

Making “Electricity” Simple

Pacific Islanders

Many Pacific Islanders and those living on the “big island” of Papua New Guinea have very high Intelligence Quotients (IQs) and are extremely fast learners. Their number-one problem is their lack of educational opportunities that normally abound in the Western world.

This means that adequate training can produce interesting results with both the maintenance of “high tech” solar systems, as well as the proper care of notebook computers, including the ability to run software applications on such systems. This is why a major thrust in the Pacific is national training courses for our national colleagues.

The Problem:

A major challenge in explaining how solar systems work, is a lack of understanding of “basic electricity” concepts. Power and electricity are really abstract, if not “magical” concepts to some. You cannot really “see” electricity, but you can see it's results, as in a nearby lightning strike on top of the hill-side ridge. If you go to town, you can see electric lights at night. But where does all the light come from? What is electricity really?

The human solar controller. With raised water pitcher, one can pour energy into a cup and make a wheel turn. The “paddle wheel” is shown on the overhead. The new style flexible solar panel is laid out on the floor.

So introducing a solar system into village life and culture does demand a certain amount of training if one expects the village worker to keep such a system running and in excellent condition.

Lack of a suitable understanding of the various parts of a solar system can lead to premature failure of batteries. One student in one of our training courses proudly announced. “I know all about solar panels and batteries and how they work”, he said. “But I have a question for you: Why are my batteries dead? They charge up instantly, and then they don't work very long after that. Why is that?”, he wondered.

When I inquired further about his procedures he simply told me that he attached the solar panel leads to the (lead-acid) battery terminals correctly and then left everything in the sun. He didn't understand at all the necessity of the “controller” part we have outlined here. How the box makes all the very necessary decisions to try to protect the battery. Otherwise you “break” the battery beyond repair. But, “it doesn't look broken”, he said. These students need some series of visual aids or metaphors to make things a bit more clear.

The Water Metaphor

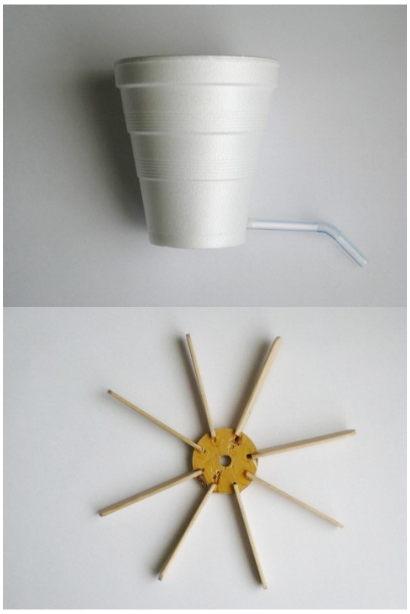
Materials:

- *A small plastic cup*
- *A flexible straw*
- *Waterproof glue*
- *A liter or quart pitcher with spout*
- *A wooden dowel or something round with center hole*

- *Some old flat sticks, like ice cream sticks or tongue depressors*
- *Some wood pieces and a large nail.*
- *2 small nylon tie-wraps, or very tiny "o" rings*

Construction:

Construct a wooden paddle-wheel from the ice-cream sticks and the dowel. Use your imagination here, but you want around eight or more "paddles" in the small wheel that you create. Other wooden parts can make a stand, with an upright member, and the nail can be the final axle for the wheel to spin upon. Small nylon tie-wraps can be used as guides.



The simple "wooden paddle-wheel" constructed from common wooden parts. The cup with straw represents the storage of the battery in the system, which can only do work at a certain rate. The cup is filled well and never over-flows by the controller (person with pitcher of water). The size of the cup represents the capacity of the battery.

Application:

A good lesson that has met with some success is the "classic" water metaphor. Electricity is likened to a stream that flows down hill (energy) and can do useful work. Fast or slow "flows" represent high or low currents. High mountain-tops can represent increased voltage, or "push" behind the water. When work is accomplished, say by turning a paddle wheel, the water meets a certain amount of resistance, impeding its general flow.

But what about the "battery"? It can be represented by any storage container, say a bucket or a plastic cup in the classroom. One can have a plastic cup with a straw in place in the bottom become a useful illustration for a "battery" that both liberates energy to do work, and also receives energy from the sun at the same time.

In class, we can show a person with raised pitcher, filling a cup, with straw spout that then drives a paddle-wheel, representing a notebook, doing work. If I regulate the flow of "water" energy into the cup, then I can propel the water wheel, which can only run at the speed that the spout allows. However, if I fill the cup with spout too fast, then it fills up and water overflows onto the floor. This is a "damaging" situation for the battery... this overcharging... and leads to greatly reduced capacity in real batteries.

Then by punching holes in the cup with spout, we can show that the capacity to store and hold water (energy) had diminished. With enough holes in the cup (battery) there is no storage at all. So at night, our lights and the notebook basically cannot do any more useful work, or they run down the battery way too soon.

But the "holes" in the battery are invisible to the user. He cannot see them. This is the situation of our village student who directly connected his solar panel and then totally overcharged and damaged his very fragile batteries.

(As an aside here, it is said that LFP batteries can handle much higher re-charge currents and are rapid-charge devices. It is possible that one could "manually" recharge them by "direct connection", but I am not one to experiment this way with expensive equipment.)

So, by overfilling the cup/ spout and then declaring "holes" in our battery, we can physically punch holes in our illustration. Now the controller does its best to "fill" the battery to original capacities, but all that formerly usable energy spills through the holes and onto the floor. The paddle wheel will turn so long as the "sun" is up. but rapidly dies at night, when the sun goes away, or fails when the clouds roll by in the daytime.

The person with the pitcher in this illustration is actually the “smart” controller... constantly making micro-decisions to keep that container just full enough, but not too full, to do useful work. If the “battery” is full, then we stop filling it up for a while. The solar energy flow is regulated, preserving the life of the container/ battery.

Other Useful Exercises

What if due to cost considerations, one started with a small system with one 20 Ah LFP battery, but one wanted to add a second battery to the system. How should one do this. We want to maintain a 12 volt system, but increase storage capacity. Or we want to increase the usable current output of our system. How should we hook up the wires for this?

The answer of course is to teach the concepts of series and parallel circuits, which can be confusing at times. In the rest of the handbook, we hope to give ideas of basic experiments with batteries and lights that can get the concepts across of compete circuits, short-circuits, and broken circuits and why a solar system might be failing at the moment.

The “Muli” Battery

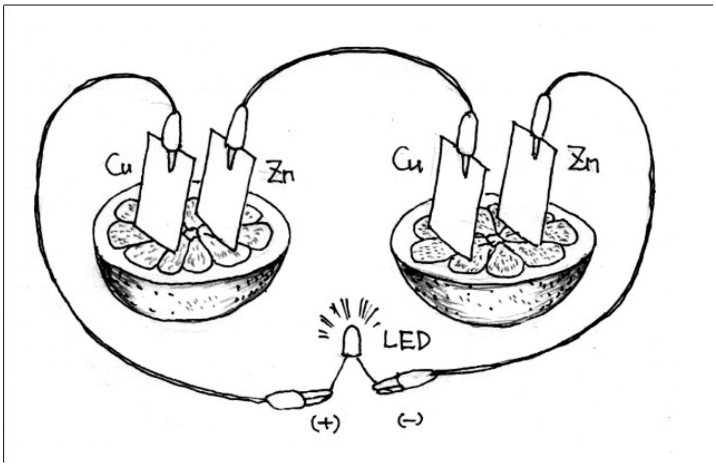
A very entertaining exercise in the classroom is showing how an ordinary citrus fruit, called a “muli” in PNG's trade language, “Tok Pisin”, can be turned into a true battery delivering enough energy to light a small light bulb or an LED light. The key is gathering the right local materials. We will not go into the actual chemistry as to why this all works, but basically you need certain oxidation and reduction agents in the presence of an acid or base (alkaline) solution, to liberate enough free electrons that can then form a useful circuit with wires. For the current to flow however, one needs a “complete” circuit to be maintained, or “a circle”.

Materials:

- *Something made of copper: old coins; stiff copper wire.*
- *Something made of aluminum: aluminum pop rivets; strips of an old coke can.*
- *A small LED or tiny 3v light bulb*
- *Some conductive wire to make a complete circuit.*

Application:

Roll or squish the citrus fruit to help break down the membrane cells inside that would separate the fluid parts. We want that all connected. An alternative is to extract the juice which is acidic[11] and place in a glass jar of some kind. But the skin can be our container here. Insert the aluminum part and the copper part which are our electrodes called the “anode” and the “cathode”.



A battery made from fruit. Basically it is the acid solution that we want as electrolyte. There is not a lot of power here, but it gets the idea across as to what is inside those mysterious things we call batteries. You don't have to cut a fruit in half, here, and you can simply insert the metal parts through the skin, but cutting a fruit will yield twice as many “cells” in your “muli” battery. This circuit is a series connection and usually you need three or more for a LED to light up.

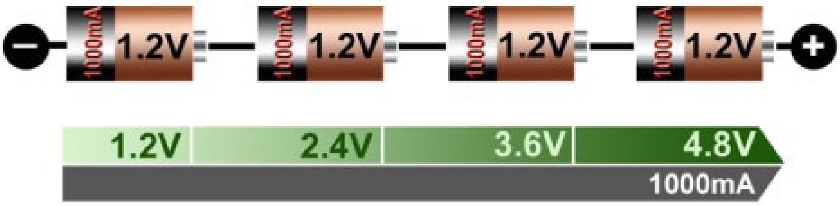
If you make more than one of these and with conductive wire connect into a “series” circuit then with three “muli” cells you should be able to make a small LED light glow, or a tiny light bulb glow. A special note: LED lights have a polarity, so you must connect one specific way. If it does not light as expected, then reverse the leads. Also, a LED light will not glow very brightly... just barely.

Parallel and Series Circuits

This might seem like an advanced concept and why would one bother training villagers about such ideas, but the reality is that in the future someone is going to want to "add" another battery to the existing system. If so, then how do you connect the wires correctly. And maybe there are four LED lights suspended from the ceiling, but now you want to add one more? What circuit is used to add the light? The ideas of adding something new in parallel or series is rather important.

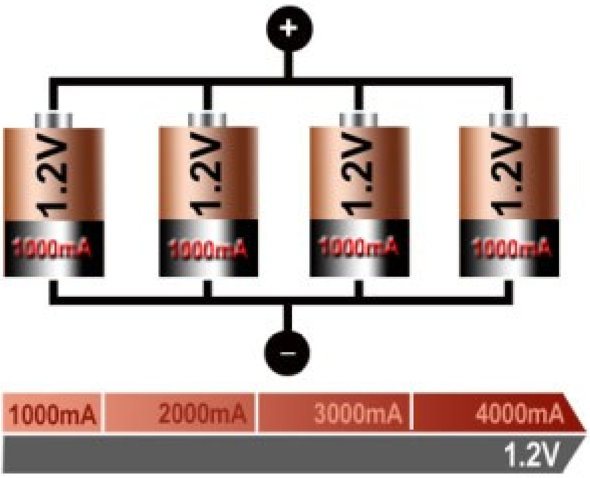
Inside our 20Ah LFP battery is really four cells. Often you see six cells in a typical lead-acid automobile battery. The voltage of the cell is determined by the electro-chemical reaction and the materials used.

So to get to our 13-14.2 volt LFP battery each cell is around 3.3 volts, but it depends upon the state of charge. They are arranged in a line and this is called a **series** circuit:[12]



Note that the voltage is additive, but not the "current" or energy flow in mAh units. So fully charged, our "battery" composed of four cells totals 4.8 volts as shown above. But note that each cell has the same energy "flow" of 1000 mA, or 1A (amp) here. (For LFP this total should be 14.2 volts.).

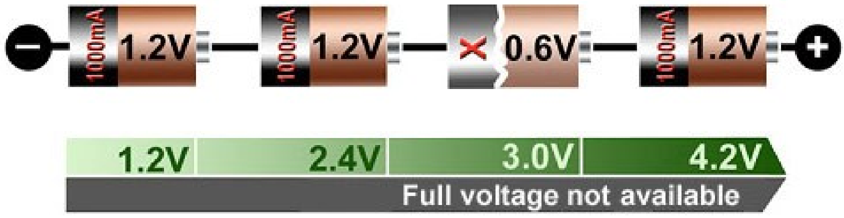
So what if we arrange our battery cells differently, say in a parallel circuit. Here like-minded electrodes are tied together:



Note that the total voltage of the new "battery" is much lower, or the value of one given cell, (1.2v) but the flow is four-times as much now, or 4A.

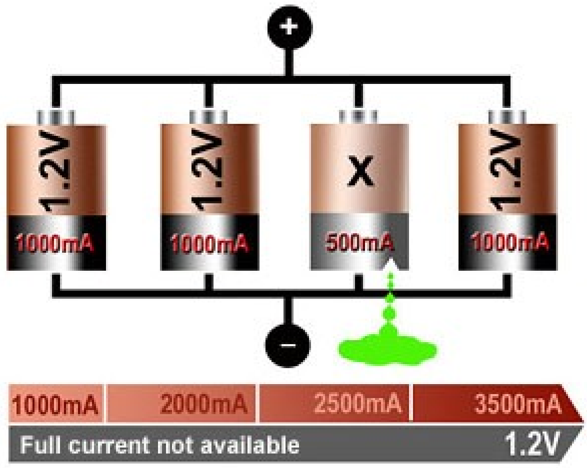
Both configurations have actually the same amount of energy stored, however there is a big difference in what you can drive with a 1.2v source versus a 4.8v power source. As in anything in life, there are trade-offs. You can have four times the voltage, but at the expense of running that device you want to power at 4.8v, with ¼ the current ability as otherwise.

So what happens when one "cell" goes bad in comparison with the others.? One bad cell can drag down the performance of the others in total. Consider:



This "battery" has one bad cell, and cannot reach it's desired full potential. The voltage of the cells adds up in this series circuit, but now is reduced by 0.6 volts. The expected voltage at the terminals is only 4.2 volts.

How about for parallel circuits:



The overall terminal voltage is maintained by the stronger cells, but the current ability of the whole is hampered. Instead of the expected 4 A of current, we are only going to see 3.5 A of life.

[1] Solar Buzz. See http://www.solarbuzz.com/technologies.htm
[2] See http://photovoltaics.sandia.gov/docs/PVmodules.html third paragraph.
[3] See: http://photovoltaics.sandia.gov/docs/PVmodules.html "Photovoltaics Modules" 4th paragraph. Apparently parallel configuration of whole solar panels is fine. The issue is on a cell-by-cell basis within a panel, and we cannot control that anyway. Problems occur only with higher voltage configurations above 24 volt systems.
[4] www.xantrex.com/web/id/405/docserve.aspx (Brochure)
[5] www.mrsolar.com/pdf/xantrex/C12.pdf (Manual)
[6] The GV-10 listed on their web-site may be discontinued, but it is reported by JAARS Inc. that placing two GV-5 units in parallel will work, and therefore the extra cost would be twice or approximately US$ 250 again.
[7] "Advanced Technology Products", serving PNG with sustainable equipment for villages for over 37 years in the country, includes solar lighting systems in their catalog. They report a replacement schedule for their lead-acid batteries of a mere 18 months in villages. Their DoD was to a terminal voltage of 11.5 volts, which is way too low. Of course, the initial cost is lower too, with smaller batteries installed, and such is the cost-benefit ratio that they have chosen to use.
[8] University of Southern California, "A Comparitive Study of Lithium-Ion Batteries", Mehul Oswal, Jason Paul and Runhua Zhao, 2010
[9] See Faq and comparison chart: http://www.globelws.com/battery.html
[10] Battery University, http://batteryuniversity.com/learn/article/safety_concerns_with_li_ion "Safety Concerns with Li-ion", 7th paragraph down.
[11] For more fun, but more expensive, try "Diet Coke", but not sugared Coke or Pepsi products.
[12] See the excellent web-site on battery technologies.
http://batteryuniversity.com/learn/article/serial_and_parallel_battery_configurations