All Light and No Power

Solar Technology in The Gambia

A Complete Do-It-Yourself Guide

David Mills, PCV 2000-2003

ALL LIGHT AND NO POWER: SOLAR TECHNOLOGY IN THE GAMBIA
PEACE CORPS, THE GAMBIA

DAVID MILLS, PCV 2000-2003
davidmillspcv@yahoo.com

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ACKNOWLEDGEMENTS

I will put here my **disclaimer**. I am not an electrician, an expert, or a professional with any degree (real or imaginary), certificate, or diploma on the topic of solar power. I am just a guy who likes to take things apart and is interested in new technologies, gizmos, and gadgets. My father taught me to be inquisitive yet know when to seek proper help, when to open up the manual, or know at which time to make the phone call to a certified 'professional.' In other words, do your own research, ask your own questions, and do not take *my* word for it. Oh, and if it is not too dangerous or costly, and it *is* your own equipment, try your own little experiments and have fun.

I would like to thank the following people for their inspiration and help along the way. Michael Grossman whose brain I picked and who had a mind (and language) for these kinds of things; Matt Coles for his attention to detail, diplomacy, and sanity; and Yamai Secka-Jack for sharing her rays of sunshine with me when the clouds came in.

To those volunteers who actually have degrees in this sort of thing, I know you will have a lot to offer The Gambia. There is a great potential using locally available materials, especially in the area of wind power, provided you can solder and read schematics. Feel free to modify and update this information, for new technology is being created everyday in this exciting field. In the meantime, just and relax and enjoy the sun.

David Mills
Peace Corps, The Gambia
2000-2003

CHAPTER 1: INTRODUCTION AND HISTORY OF SOLAR POWER

The sun is unlimited and is the source of all life. In nature, the sun is the power plant that allows plants to convert sunlight into energy by a process of photosynthesis. With technology, man has been able to harness the suns power and turn it into electricity by the Photovoltaic (PV) Effect, first discovered in 1839 by Becquerel. After the oil crisis in the 1970s, photovoltaic panels were being developed for terrestrial use, building on the early applications gained from space industry. ***It is unlimited free power, but it does have its limitations***.

Solar isn't good for everything. It is excellent for use in small systems here in The Gambia for lights and DC fans, mobile phones, and televisions in the compound. For schools, it is excellent for computer labs and audio/visual equipment. It however not good for anything that takes up a lot of energy. These items are typically those that heat up or cool down (air conditioners, refrigerators, freezers, washers, dryers, or coffee pots). Each of these items requires a lot of watts, or power, over an extended period of time (like the AC or Fridges) to keep things either hot or cool. Power (P) is measured in Watts. Voltage (V) is measured in Volts. Current (I) is measured in amps. Watts equals Voltage times Current. In a mathematical formula, this is:

$$P = V\,I \quad \text{or} \quad \text{Watts} = \text{Voltage} \times \text{Current}$$

*Conservation is key…*If one wishes to use solar power, and promote it in the village to set an example, your lifestyle may have to change. Unlike America, where you are connected to the grid and the power always comes out of the walls (unless you are living in California during the summer where blackouts do occur), here you produce your own electricity and store it for use. Suddenly when you are producing your own power, you know that it is not unlimited, for you are away of your storage capacity. Your lifestyle may change and your conservation methods may be altered. Suddenly you are really conscious of light bulbs being left on even if you are only leaving the room for 2 minutes—you turn out the light. If a computer is on where nobody is sitting and working with it, at least the monitor is turned off (most monitors are the largest consumers in a typical desktop system.) No longer will it flow freely from the wall only for you to receive a bill at the end of the month. With solar you do pay for it initially in one lump sum (a major hurdle for individuals and schools to produce under the current economic system) although there are options like budgeting and planning which might allow a venture into alternative energy possible. Solar components also happen to be modular, which means that you can start small and add on as both the funds allow and the demands for power increase. As for availability in The Gambia, there are various levels of quality parts. For this I say you pay for what you get. And as with any technology or project here in the Gambia, maintenance will play a role in how long your solar project will last.

Often at times people are looking for a quick fix or can only afford to pay for the quick solution, and too often the choice is a generator. PV systems are more economical than conventional generators for low consumption. Before a decision is made either way, I urge you to read through this book to see the different options. With no moving parts to be lubricated, the time and energy spent on maintenance with solar energy is minimal compared to other energy solutions. With solar the main factor that affects its longetivity is following the simple maintenance schedule. Because it is so clean and quiet and efficient, maintenance duties tend to be overlooked, and once a problem arises within the system, quick action must be taken before serious damage can occur to the components. *Solar is unlimited free power, but it does have its limitations*.

Current Applications

Current applications include personal calculators, remote telephone, radio, and railroad relay stations. In the Gambia, the newest Senior Secondary Schools on the North Bank (Essau, Njabba Kunda, Kaur) as well as a handful of Upper Basic Schools were equipped with DC Lighting systems in their school blocks in 1997 as a part of President Jammeh's Education Initiative. These towns are not supplied with local power from NAWEC (National Water and Electricity Company) and the decision was made to supply light for evening studies and campus security. There are also PV installations in use at Gamtel's remote telephone relay stations, and NAWEC's remote water tower pumping facilities (Ndugu Kebbeh, NBD-West and Jattaba, Kiang-West).

There are vast potential uses for solar power as it relates to individual, autonomous systems. There is a need for community centers for women's groups, which would allow work into the night for women who have obligations during the day. Tailors would be able to work with better light during the high traffic seasons of Koriteh and Tobaski, when they often work well into the night using candles and lanterns. Children who are going to school, after fulfilling their compound duties, often settle down at night when things quiet down to do their studies. Children, for quality studying, require their own candle. Gambian woman have on average over 7 children, and this could mean many candles per night being burned for the sole purpose of reading. Also candles and lanterns are dangerous open sources of heat that can cause fire. Remote medical regions that need refrigeration for vaccination and anti-venom doses could use small refrigerators that are surfacing in the world markets. From what I hear they are economical running directly off batteries and do not require inefficient inverters. In this case I am not talking of the massive ones you store 6 crates of cokes, 4 boxes of chicken, and last night's leftovers).

Solar can even be used here in the cities, where the quality of power which is provided is often poor, dropping at very low AC levels (sometimes 150VAC, where it is supposed to be 220VAC) causing lights to dim, restarting computers, and, for the most part, damaging delicate electrical systems. You all see it: the welder on the next block starts his work and all of a sudden, the problems start.

Instead of having back-up generators, have back-up solar systems. Use city power or grid power to charge batteries through a battery charger while the power is on, and use the batteries when

NAWEC is not running. This option was not discussed in depth (prices, sizes) for I did not have any projects within the cities. In this system, you don't need panels because you use a battery charger to charge your battery bank, running your AC items off of an inverter.

Why Use Solar: Advantages and Disadvantages

Advantages

- Long term cost saving
- Efficiency and economical than conventional generators for low power consumption.
- Environmental soundness
- Minimal transportation (one-time), simple, low cost maintenance, and easy to operate
- During the dry season is when school is in session. This makes the use of solar power in schools idea, since during these nine months there are minimal overcast days.
- Users can control their power as it is decentralized. You don't have to worry about fuel shortages, NAWEC being out, or political situations.

Disadvantages

- Initial Cost
- Limited suppliers of good quality products and minimal human resources base for maintenance and installation.
- Not suitable for large devices which require a lot of energy. This includes refrigerators, AC, or other motor driven or compressor containing electrical devices.
- Systems need often expensive and short-lived batteries for most applications.

Computer Lab: Long Term Generator Vs. Solar Power Comparison

This was adapted originally from an old IT Newsletter produced by Marc Maxson (PCV/TG 1999-2001) in September 2000. It was adapted from an example from **www.mrsolar.com**.

The question was asked: How much would one expect to pay for parts in a solar array? Here are some numbers in dollars looking at cost over time.

Solar power purchase for a small computer lab (12 computers for 12 hours a day)

Trace C-40: 40 amp charge controller	$134
Concorde PVX-12105: 105 amp hour battery	$129
Solarex SX-55U: 55 Watt panel	$237
XP (1100W) 12VDC to AC Inverter	$710
Total Cost:	$10,000

Prices are from **www.mrsolar.com**. Cost includes 30 panels (1650W), 1 controller, 6 batteries, and 2 inverters to provide continuous daily power during the dry season. Estimates exclude consideration of air conditioners but allow the use of multiple electric fans and a desk jet printer.

This array should last 10 years, if maintained properly. There is ongoing research, however, that it may be that the solar panels themselves could operate with relative high efficiency for 15 to 20 years. So only the batteries, in effect, would need replacing.

This cost can be compared with using a generator:

Generator purchase for small computer lab (12 computers, 4 hours a day)

Generator purchase	$200
Minimum monthly fuel cost (4 hours a day for 20 days)	$50
Total cost after 10 years	$10,000

(Estimates are from the Essau DHT, and includes a 9% inflation adjustment and a second generator purchase after 5 years. Fuel at the time of this comparison is D6.75/liter, with 5 liters consumed each 4 hours.)

In comparing the two forms of energy, both spend approximately the same amount of money over a 10-year period. However, notice how the generator only provides power to the 12 computers for 4 hours per day, whereas the solar array provides power for 12 hours a day. If the cost is the same, then the solar array can produce 12/4 = 3 or 300% more power. Moreover, we still have not considered the transportation of the fuel to and from the generator. This adds up to more wasted time, more energy, and increased cost. Best of all, it is clean, quiet, and abundant. Set it, simply maintenance it, and you won't have to worry about where you next batch of fuel is going to come from. Likewise, there is less of a chance that with solar power this energy is likely to be misused. It is difficult to divert energy like solar to, say, a different building or residential house. With fuel, bought in large 20-liter containers, is sometimes bought in bulk and stored. It could easily be mismanaged, siphoned to a different container and sold or used by those who have access to the fuel. I have heard of this first hand in my own community, where the government establishment purchased fuel for their generator, only to have the 'generator man' take a percentage for himself, for he was not running the generator during the entire designated times. Whatever was left over, or skimmed from the top, was kept to himself. At the beginning of the month, a new shipment of fuel was purchased. Hum…

Conventional sources of energy often have a low start-up cost, and a larger operational and maintenance cost over the course of time. With PV systems, there is a large start-up cost with minimal maintenance and repair cost over time. Also, as was recorded earlier, there is less likely the chance that energy from conventional energy sources can be mismanaged (misallocation of fuel). The transportation system in the Gambia is still rather poor, which adds to transportation costs of the overall system. And the current economic system, with the deflation of the Dalasi in relation to other hard currency, has seen the exchange rate plummet in the past 3 years. Now is the best time to invest in solar. Soon, however, if the Dalasi continues to plummet (a liter of gasoline today was D20/liter, compared to D6.75 when the above comparison was done) it is going to make it difficult for any types of energy installations to be purchased and maintained. Retailers and suppliers alike mark their goods on the foreign exchange rate, even if it is old stock having possibly been purchased at a lesser cost.

The immediate and short-term fix is not the best answer. Planning, budgeting, and possibly financing could be a way for those who do not have the immediate resources available to them may still be able to be achieved in the long run.

HISTORY OF SOLAR POWER

Solar power harnesses the sun using photovoltaic (PV) cells. The cells of a PV array are made up of silicon crystals, which when are exited by photons (the suns rays) create an electric current. This electricity is either used directly (i.e. to operate a DC water pump) or stored in a battery for later use.

Commercial solar power energy, like a lot of technology, was born from the U.S. space program. In 1954, Bell Laboratories in the U.S. discovered that single crystals of silicon could be made into practical but expensive photovoltaic (PV) cells. Engineers were looking for an economical, efficient, and lightweight way to power satellites and space stations. The U.S. Government donated a lot of funds for solar power research. The cost however for the common home user was still too costly, since production of the silicon wafers was still energy intensive. The amount of pure silicon needed at the time was still costly to manufacture for common terrestrial use. If it were not for the space program, photovoltaic electricity probably would have been put on the back burner. However, when the oil crisis came about in the mid-1970, renewed interest was sparked. It was at this time that major international developers from the U.S., France, Germany and Japan continued to tune the manufacturing process, creating more interest and demand for efficient modules. With advances in telecommunications, increased demand for isolated research facilities, and the need for cleaner energy, PV has remarkably decreased their production costs. Silicon is one of the purest commercial materials used, energy intensive and expensive to produce, even though silicon (the main component of sand) is the second most abundant element on earth.

The first PV panels were composed of monocrystalline cells. These panels, made up of single crystals of silicon, were heavy, required a lot of refined silicon, and were minimally efficient per square meter. Research of the 70's and 80's led to a refining of the manufacturing process, producing polycrystalline cells that had an increased surface area of silicon within the same amount of space. New technology has led to amorphorous, or flexible PV panels, which use less silicon (lower cost), are lighter in weight, and are much more durable for rigorous environmental conditions. Overall, the PV panels of today are becoming smaller, more efficient, and now, are having built in technologies to make sure the maximum amount of power is provided to the battery bank. Other technologies like MPPT systems, which tracks the maximum power point of a PV array numbers in the charge controller, increases a panels efficiency. PV tracking mounts, which make sure the panels are perpendicular to the sun from early morning to late evening, have the ability to increase the efficiency of a systems total power output by 50%.

Each of these technologies, however, comes at cost. Do you invest in something that will give you a larger amount of power with the equipment that you have, or do you buy more equipment? The answer to this question is to look at the available technologies in country. My suggestion is high quality components (PV panels, deep cycle or solar batteries, and quality name-brand charge controllers and inverters) will prove more reliable, be better able to withstand the difficult environmental conditions, and hold their value for a longer time. The re-sale values from many high-quality devices, like PV panels, are about the same whether you purchase them new or used.

There was indeed a potential for use not only in the space program, but also for other industries like telecommunications, transportation, and portable electronic devices. I am talking about powering remote phone and communication towers, warning signals such as navigational beacons, railroad switchboxes, and my high school favorite, the personal solar powered calculator. Typically these systems are stand alone, isolated, or require a small amount of energy (such as the calculator). For residential or commercial systems that might already be tied to the grid, however, the cost per kilowatt-hour for PV systems still is not as inexpensive as current energy sources like oil, and more recently, natural gas. Although the cost per kilowatt-hour has come down for PV, they are only most cost competitive with conventional electrical energy during high demand peak times.[1] With oil often being the target of war and conflict, and with many wells across the world not producing as much as they have in the past, the cost of gas prices are continuing to rise. It is predicted that in the next 50 years the worldwide oil reserves may soon begin to dwindle, increasing its cost. Solar is being looked at, along with other cleaner energies like hydrogen.[2] The 1998 Kyoto Agreement led green companies to promote environmental awareness, and consumer interest and increase demand has continued. Many aid and donor organizations, especially in developing countries where there is need for small and independent electrical systems, are switching gears to turn away from the traditional generator, and look to longer term, lesser maintenance devices. Here in the Gambia, with the majority of the country with either no or poor quality power, we too are searching for better ways to receive our power. Anywhere there is not a current power source, or anyplace that is not connected to the electric grid, solar power has stepped in to play a role.

Long term, in the current economic situation in the Gambia, with the Dalasi continuing to decline and oil prices continuing to increase, now is the time to move to alternative, clean, reliable, and low maintenance alternative energy systems.

[1] http://www.ecoworld.com/Home/articles2.cfm?TID=259
[2] "The Energy Squeeze"Fred Guterl Newsweek April 8/April 15,2002. Pages 52-56

CHAPTER 2: BASICS OF ELECTRICITY

The following section of Electrical Resistance, Ohm's Law, and Electric Power was taken directly from: **http://physics.bu.edu/~duffy/PY106/Resistance.html**

Electrical Resistance

Voltage can be thought of as the pressure pushing charges along a conductor, while the electrical resistance of a conductor is a measure of how difficult it is to push the charges along. Using the flow analogy, electrical resistance is similar to friction. For water flowing through a pipe, a long narrow pipe provides more resistance to the flow than does a short fat pipe. The same applies for flowing currents: long thin wires provide more resistance than do short thick wires.

The resistance of a material depends on its length, cross-sectional area, and the resistivity (the Greek letter rho), a number that depends on the material. Resistance is measured in ohms, or Ω.

Ohm's Law

In many materials, the voltage and resistance are connected by Ohm's Law:

$$V = IR \text{ or } Voltage = Current \times Resistance$$

Electric Power: The Mathematical Information

Power is the rate at which work is done. It has units of Watts. 1 W = 1 J/s

Electric power is given by the following equations (where P = Power, V = Voltage, I = Current, and R = Resistance):

$$P = VI \qquad P = V^2 / R \qquad P = I^2 R$$

The power supplied to a circuit by a battery is calculated using **P = VI.**

Power = Volts x Current or **Watts = Voltage x Amps**

IT IS THIS EQUATION, **P = VI**, WHICH WILL BE USED THROUGHOUT TO DETERMINE HOW MUCH POWER YOU NEED IN YOUR SYSTEM.

Even though this equation is used strictly for determining DC, it is still useful for calculating the maximum power consumed by AC.

Batteries and power supplies supply power to a circuit, and this power is used up by motors as well as by anything that has resistance (also called the **LOAD**). The power dissipated in a resistor goes into heating the resistor; this is known as Joule heating. In many cases, Joule heating is wasted energy. In some cases, however, Joule heating is exploited as a source of heat, such as in a toaster or an electric heater.

The cost for power that comes from a wall socket is relatively cheap (About 10 cents per kilowatt-hour.) On the other hand, the cost of battery power is higher. One example of a 2000-Watt system I saw on the Internet was approximately 26 cents per kilowatt-hour over the estimated 25-year life of the system.[3] With solar, however, this cost is spread over a period of years and is not subject to the inflation of increased oil costs (which has been happening here in the Gambia). In a sense, you are locked into an energy rate at the purchase time of your system. With oil you do not know the situation of the cost of oil production or even availability in 1, 5 or even 10 years. And with the way nations are currently fighting over oil-rich areas (Mid-East), it is my opinion that those who invest in alternative forms of energy even now will be in a much better situation come crisis time.

Although power is cheap, it is not limitless. Electricity use continues to increase, so it is important to use energy more efficiently to offset consumption. Appliances that use energy most efficiently sometimes cost more but in the long run, when the energy savings are accounted for, they can end up being the cheaper alternative.

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[3] http://www.nmsea.org/Curriculum/7_12/Cost/calculate_solar_cost.htm

Direct Current (DC) vs. Alternating Current (AC)

AC/DC. Yes, it was a rocking band in the 80's and 90's. It also is the common two types of electricity that we as consumers use on a daily basis.

DC or Direct Current A battery produces direct current; the battery voltage is constant, which generally results in a constant current flowing one way around a circuit. In this simple type of system, there are positive and negative terminals. Energy flows from out of the positive terminal, goes through a load or object of resistance (i.e. a light) and back into the negative terminal. If you connect positive and negative terminals without a LOAD, you will create a short circuit, and things will 1) heat up 2) generally spark 3) potentially start a fire (if there is enough power in reserve). In a DC system, if you plug in the components incorrectly (say you put the positive terminal battery into the negative terminal of the charge controller) you are reversing the circuit. Again, this will spoil the system if you reverse the polarity.

Generally **RED** is positive (+) and **BLACK** is negative (-). Examples of DC systems include anything that is powered with a battery (portable walkmans and cd-players, flashlights—each battery, A, AA, C, D, are 1.5 V DC) and car radios. Car radios have car batteries, and this and example of a 12V DC system. Each battery has a plus and a minus sign—line them up properly

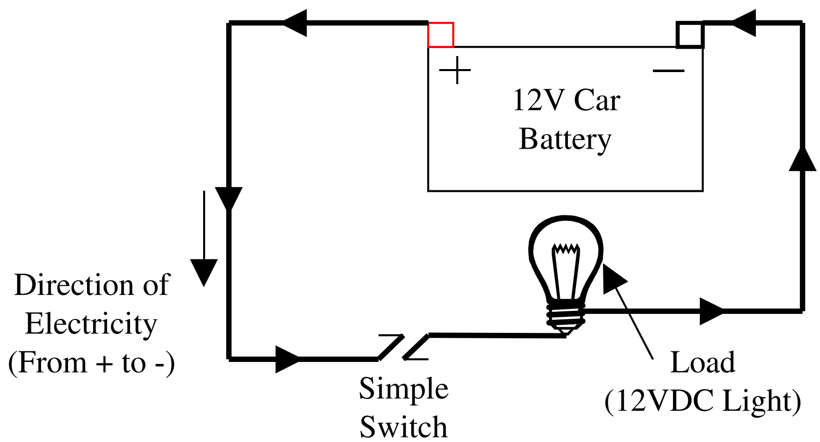
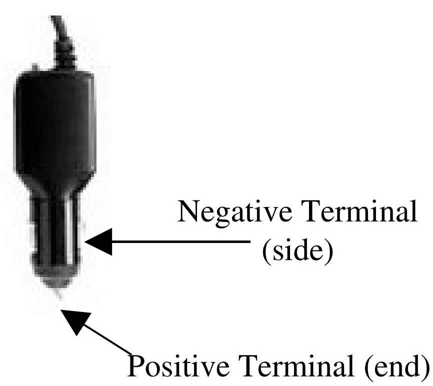


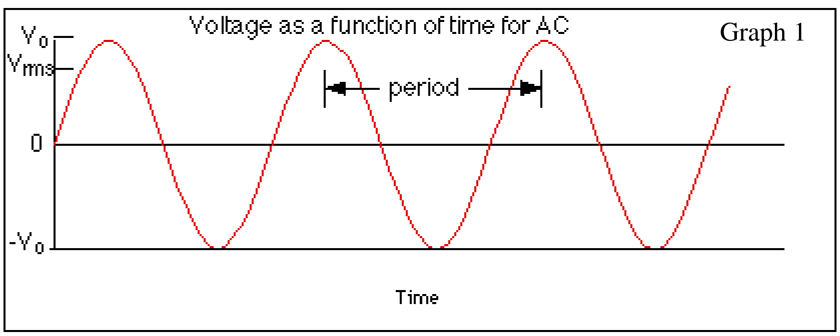
FIGURE 1: Example of a simple DC circuit that includes 1-12V DC battery, a simple toggle switch, and a load (a 12V DC light). When the switch is closed, the light is on (complete circuit). When the switch is open, the electrons cannot complete the circuit, and the light is off (open circuit).

FIGURE 2: If you are using a DC light or something that plugs into a car cigarette lighter, and you are not sure which is positive or negative, do not guess (and possibly reverse poles). Before you hook anything up, identify the positive end as the middle or bottom portion and the side or outside as negative. Sometimes only one of the negative sides will be connected, so try the other side. Use small alligator clips to make the connection if you are unwilling to



AC or Alternating Current There are two types of AC power that power companies produce around the world. 110 Volts AC (North America/China) and 220Volts AC (basically the rest of the world.) In the Gambia, all appliances (unless they come from America) run off of 220VAC power. This is what is considered WALL CURRENT or CITY POWER or GRID POWER. Each of these terms can be used interchangeably. In micro-power systems, AC power can be produced from either a generator or an inverter.

If you look at a picture of the voltage coming out of the wall in North America at its peak, it hits about +170 V, decreases through 0 to –170 V, and then rises back through 0 to +170 V again. (You might think this value of 170 V should really be 110 – 120 volts. That's actually a kind of average of the voltage, but the peak really is about 170 V.) This oscillating voltage produces an oscillating electric field; the electrons respond to this oscillating field and oscillate back and forth, producing an oscillating current in the circuit.



GRAPH 1: The graph above shows voltage as a function of time, but it could just as well show current as a function of time: the current also oscillates at the same frequency. There are 50 periods of oscillations (50 Hz Frequency) in each second.[4]

Breakdown of AC power includes the **voltage** and the **rate of alternation**. Because this type of electricity is alternating, it turns back and forth at around 50 or 60 times per second. This is measured in the amount of **Hertz (Hz)** that a device needs. Also, because the electricity changes from positive to negative and back again many times per second, it is not necessary that you plug the plug into the wall in a certain direction.

Also, AC power can travel much farther without loosing efficiency as compared to DC power. With DC power, there is always caution as to the distance one wishes to run a wire as well as the thickness of the wire. Small wires over long distances have a lot of resistance. Think of a hose trying to pass water. A long hose with a small diameter will have more difficulty in moving the water through its distance. A shorter hose with a thicker diameter will be able to move more

4 http://physics.bu.edu/~duffy/PY106/Resistance.html

water faster, longer, and with the least amount of resistance. In electricity, especially with solar power where you are producing your own electricity, you want your system to be as efficient as possible. I will get more into efficiency when I talk about the individual components.

For some reason, 220VAC power is 4 times more efficient than 110VAC over long distances. Why does the U.S. use 110VAC when 220V is more efficient? The answer is not known. Would it be great if all devices internationally used the same type of current? Yes. Will it change? Probably not.

How do you know: AC or DC? 110V or 220V?

When dealing with electronic devices, it is important to know whether or not something requires AC or DC current. Light bulbs and fans, for instance, can be both. And just because there is an American Plug on the end, doesn't mean that the device cannot run on both 110 and 220VAC. In reciprocation, just because a plug can fit into a certain power strip or outlet on the wall (FIGURE 3) does not mean that the device is that particular voltage.

FIGURE 3: **Multiple Plug Adapter.** This particular power strip (left) is to be plugged into a 220VAC wall outlet (see chord). If it is plugged into 220VAC on one end, you can be sure that each plug on the strip will also be 220VAC. Multi-ports like these are responsible for many devices being destroyed by the incorrect input voltage of electrical devices, especially those taken from overseas. Similar is the single plug adapter (right) that can accept both 220V and 110V plugs. Check the Power Specification to avoid trouble.

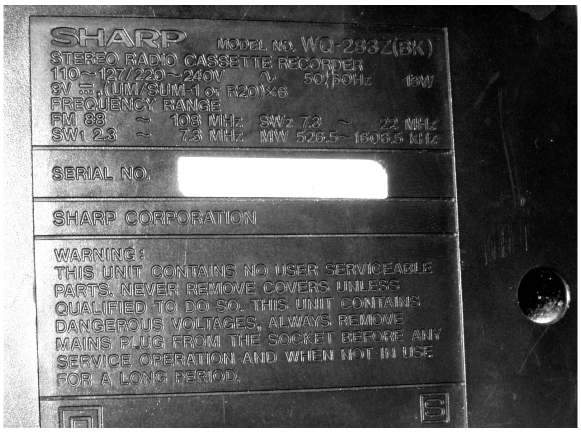
To understand just what type of power you need, locate the power specification data. Usually it is either a sticker or a molded part of the back or bottom of a device that gives the energy requirement specifications. Usually found near the plug, it will look something like this:

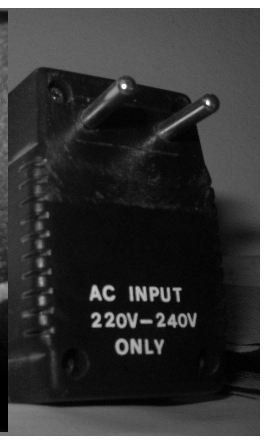
HSF INPUT CHARACTERISTICS

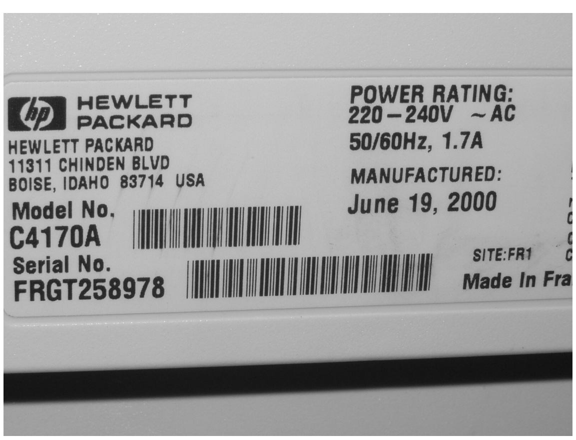
SPECIFICATION		RATING		CONDITION	
		50W, 100W, 150W	350W	50W, 100W, 150W	350W
a-c Voltage	rated nominal	100/120/220/240V a-c		Single Phase	
	min-max range	95-264V a-c	85-264V a-c		
Power Factor		—	0.99 typ	—	EN61000-3-2
d-c Voltage	min-max range	125-370V d-c(1)	110-370V d-c(1)	Polarity insensitive	
Brown-out Voltage	min	85V a-c 110V d-c	80V a-c 110V d-c	Ripple, source & load effect increase	Ripple, stabilization increase
Frequency		50-60Hz		Single Phase	
		47-440Hz(2)			

The main area of concern is the A-C VOLTAGE. The input power voltage for this particular device is rated at 100/110/220/240VAC. This means that it can be plugged directly into the wall either in the US (110V) or Gambia (220VAC).

Other power specification labels could either be molded into the plastic (top left) or just a sticker attached to the bottom of the device (fan, right). Other times it is actually on the box either within the chord (like this chord from a Dell Laptop). Other times, it is right on the plug (bottom right.

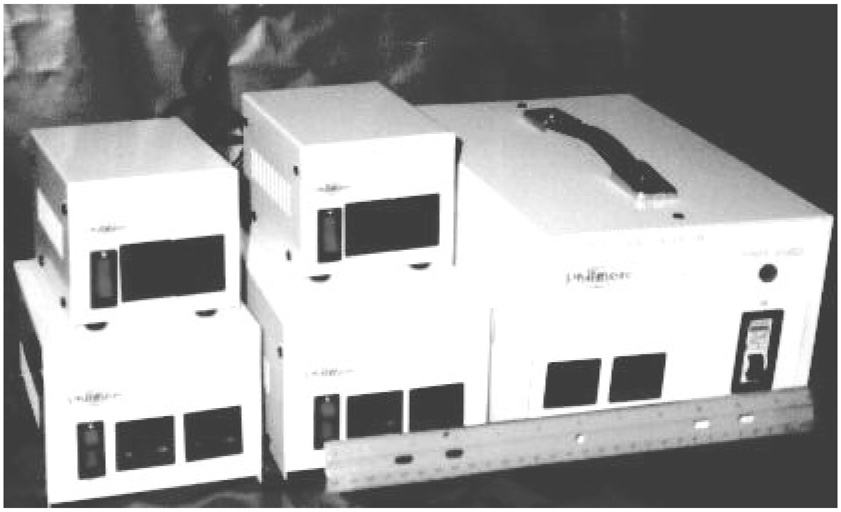






The Power Rating on the left shows that this printer can only be plugged into 220-240V AC Power. The '~' means that it is AC power. If you see something like
‾‾‾‾‾
it means that this power requires — — -
direct current (DC). You will often find this symbol with those devices that run off batteries, or could potentially run off batteries (personal CD-players, laptops, etc.)

<u>**Power Transformers**</u>



If you do have a device from America with a power rating of 110VAC, and you would like to plug it into a 220VAC power source here in the Gambia, you need a **step-down transformer**. This basically cuts the amount of voltage from 220V in half to 110V. The transformer is placed between the wall and the device. Step-up and step-down transformers are rated in Watts. Your transformer should be able to safely run the device with room for additions at its rated Peak Power Watt (PPW), or the maximum amount of watts the device might require at a given time. For example, a computer that requires 110VAC requires approximately 165 watts for both the monitor and tower. A safe transformer for this equipment would be 200 watts minimum. You can always have excess, especially if you want to add on at a later time. If your transformer is too small, you risk destroying either the transformer or possibly the device itself.

If for some reason you have a 220VAC device and you would like to run it off of 110VAC (say, you have an American inverter which supplies 110VAC) then you need a **step-up transformer**. This doubles the amount of voltage from 110VAC to 220VAC.

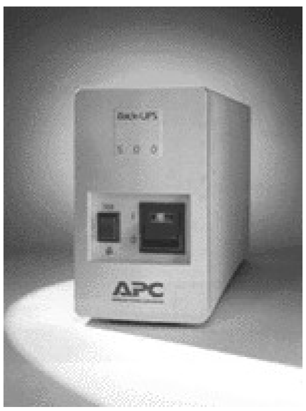
If you are lucky, you will have a device (like most modern computers and cameras) that has a self-altering plug. This INPUT power would read something like 110-240VAC. If you see this, you can plug it into any AC source around the world. They produce these devices so that people can travel, and not have to worry about lugging around heavy transformers.

Lastly, some devices you manually have to switch the INPUT from 110V to 220V or visa versa. Many newer computer power supplies, hairdryers, and other devices have this option.

110VAC / 220VAC switch
Make sure that Input Voltage (voltage from wall) matches this setting before you plug in the power chord

UPS: Uninterrupted Power Supply

A UPS is used especially with computers to maintain power to your device. It is not to be used as a source of power, but rather provide a limited amount of reserve so that your power is not interrupted and you have enough time to properly turn off your device.



The basic components of a UPS are a small battery (usually less than 10 Amp-Hours) and an inverter. When the power cuts out from the wall, the battery supplies power to the internal inverter to convert the DC battery power to AC wall power and along to your device. Since these batteries are small, they are not to be abused by allowing devices to be plugged into them for long periods. For more information about battery stress and discharge rates, see the section titled BATTERIES. Like transformers, UPS are rated in Watts and should be correctly sized for the device that is attached.

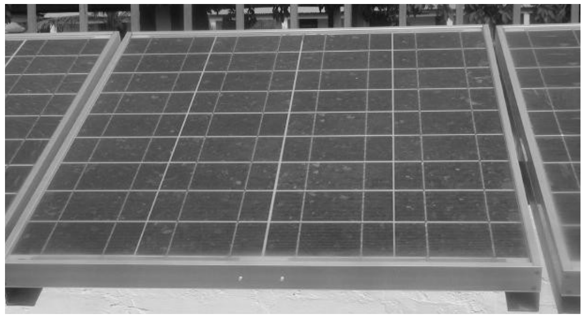
If you are running off of solar power, it is not necessary that you have a UPS in your system. In a sense, your entire solar array is a large UPS. Your battery bank is the battery component of the UPS, and your external inverter supplies the power to the entire system of devices. The only thing that you have to make sure is that you watch your battery level meter (see section Charge Controllers) to know when your battery levels are low. If the LED meter on your charge controller shows dark orange or red, then it is time to turn off the components and allow time for your batteries to recharge.

Multimeter

A **multimeter** (or locally known as a 'machine') is an electrician's tool used to read voltage,

amperage, and resistance. Unless you are an electrical engineer, you will probably only use the machine for voltage readings, either AC or DC. Use the DC setting to read your batteries, by placing the correct red and black readings in parallel to the respective terminals on the batteries. Choose a setting that is higher than your expected amount of voltage. For instance, if I want to measure the current out of the wall (~220 VAC) I will not choose millivolts but thousands of volts. If you receive a negative reading (like –224 VAC) you simply have reversed the poles. If you are going to measure the current of something, be careful: if you put in too much current, it is possible you might either blow the fuse or the machine if you hook it up wrong.

CHAPTER 3: SOLAR PANELS / PHOTOVOLTAIC (PV) MODULES



Photovoltaic Panels, or PV Panels, are the main component in a solar power system. Also called solar panels, these convert sunlight directly into (DC) electricity. A 55-Watt panel only produces that much energy in full sunlight. In weaker light, the panel may only produce half to a third of its stated capacity.

The panels should not be directly connected to the batteries, but connected to a charge controller. See the next chapter.

Panels are rated in watts (W) and come in a number of different sizes. Typically the larger the panel, the more watts it might produce. Unless otherwise stated, most panels are 12 Volt DC. You need uniformity of your voltage throughout the system. Smaller systems are usually wired in a 12VDC arrangement while larger systems are usually 24VDC (though they can increase to 36 or 48 VDC, depending on the size of the system). The higher voltages are to allow for higher current to pass through a system.

> If P = VI, doubling the voltage (V) will half the amount of current (I). A large current passing through a wire can be as dangerous as a large amount of water under high pressure passing through a small hose.

For example, if we have a 600-watt system arranged in 12V, there will be 600/12 = 50 Amps of current. If the same 600-watt system was arranged in 24V, there will only be 600/24 = 25 amps of current. A safe range of current going through any one wire has been no more than 40 Amps (or about 1000-Watts of power coming from the panels in a 24VDC system). Anything larger than 40-amps you run the risk of fire. If you are going to go above 1000-watts of power from the panels, it is probably recommended that you step the system to 36VDC or break the panels into sections, with half running though one charge controller and the other half running through another charge controller. Still, all the power from your panels is going into the same battery bank. By splitting up the current, the amount of power running through any one wire can be handled safely.

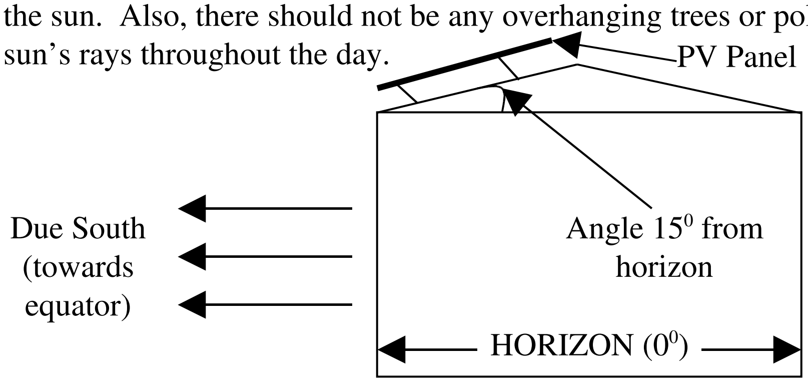
Typically however in small-scale power systems the voltage is 12VDC. On the market in the Gambia is a 14-watt solar panel, which measures about 80cm x 30cm, from a no-name manufacturer. If P = VI, then the amount of amps that this panel supplies is approximately 1.16-

amps for every hour of peak sunlight. In both the mornings and the afternoons, when the sun is no longer perpendicular with the panel, the amount of current being produced (in amps) could be 1/3 to 1/2 the rated wattage, or 1/3 to 1/2-amps/hour. It all depends on the quality and manufacturer of the panel. Spending more money now on better quality panels will be best for the long term. The larger companies like Siemens (supplied by VM) and Isofoton (supplied through GamSolar) sometimes even guarantee their panels to produce a certain amount of energy for up to 15 years. These lesser quality no-name manufacturers don't usually come with guarantees, so in 5 to 7 years you could possibly see a reduction of panel output. Simply put, you pay for what you get.

<u>How Many Panels?</u> People ask me how many panels they would need. Basically, the more watts you have the larger the current and the more electricity you are able to put into your batteries. You may have 4 panels, but it depends on their size. Don't look at the number of panels but rather the total number of watts. For instance, one 55-watt panel can produce more electricity than three 14-watt panels (42-watts). It all depends on your electricity needs and how fast you need the panels to recharge the batteries. Theoretically you could hook up a small solar panel to a really large battery, but if the amount of power taken out (power in amps used) is far less than the amount of power going in (amps from panels), there will be a large recharge period. More on correct PV-sizing in *Chapter 8: Putting It All Together.*

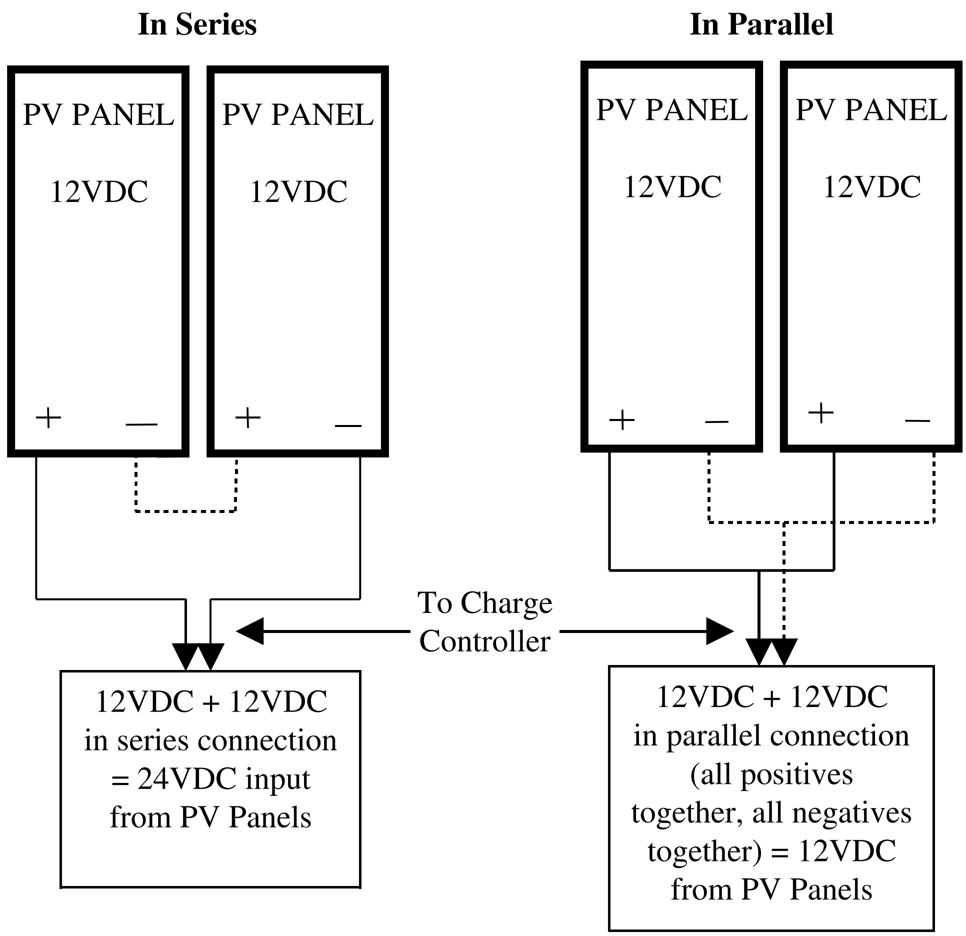
The only main concern about panels is that they should be clean, especially during the dry season months. **A large percentage of power (up to 50%) is lost for even a mild coating of dust.** Recommendation is a weekly cleaning of the panels either by getting up on the roof to wipe them clean, or do as I do: take a few cups of water and toss them onto the panel from the ground. Monthly I do get up on the roof to properly clean them, but just to get the thick stuff off, a few cups of well placed water will do. Also, make sure that the PV frame and glass covering the panel is intact and leak proof. If the glass on a panel is cracked, it is possible to get it replaced. For water sealing, especially around the boarders where the glass meets the frame, a thin coat of silicon glue (silicon dioxide) does wonders to keep the water, insects and dust from damaging the silicon wafers underneath. Lastly, if there are any exposed or fraying wires coming out of the panel, they should either be covered with electrical tape or replaced so as to not cause a short circuit or loss of efficiency.

<u>Positioning</u>: The best place to mount a PV panel is on a rooftop, directly above the battery bank. The bottom of the panel should be directly facing south, at a 15^0 angle from the horizon. This is because in The Gambia we are approximately 15^0 North of the Equator, and at this position, throughout the year, the face of the panel is maximized for the most direct perpendicular angle to the sun. Also, there should not be any overhanging trees or poles that might interfere with the sun's rays throughout the day.



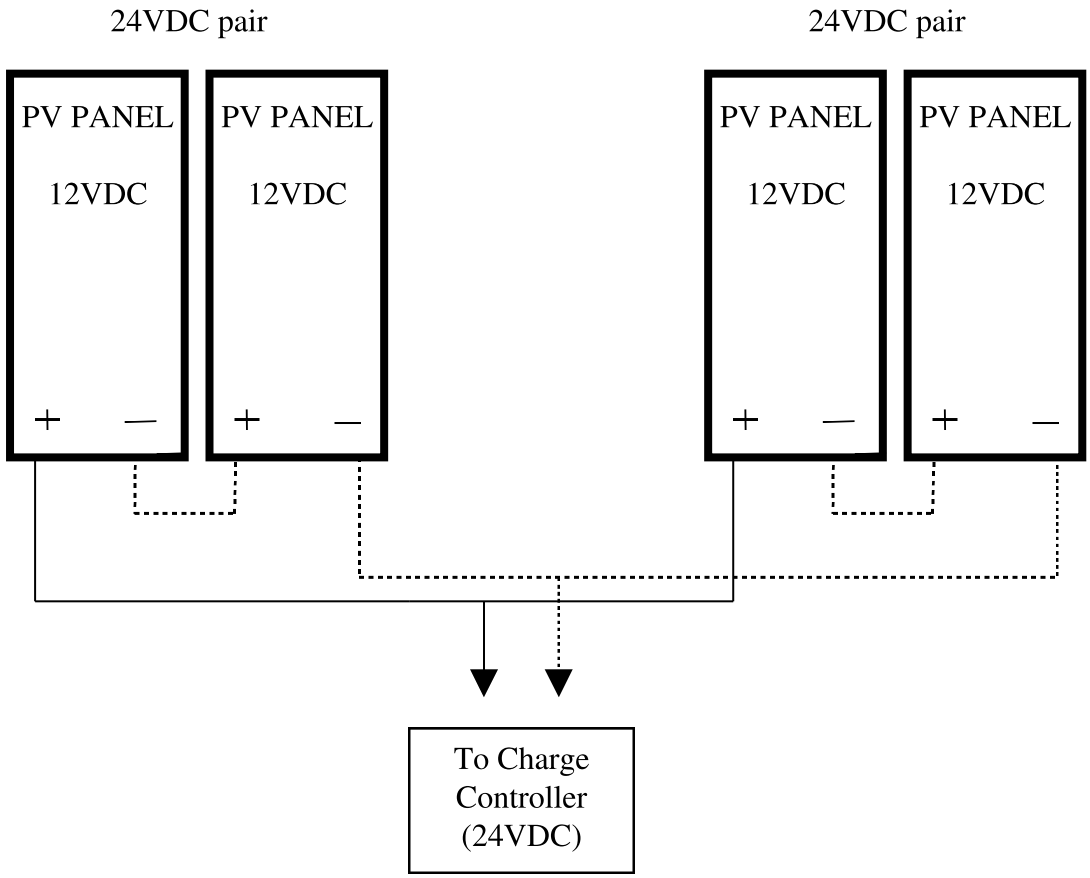
Since The Gambia is 15^0 north of the equator, we face our panels at a 15^0 due South. In Lilonwe, Malawi, 14^0S latitude, their panels would be mounted at a 14^0 angle, facing due North.

Wiring: Being that panels are modular (made up of different components that can be added a bit at a time), they can be connected in either series or parallel to achieve the required amount of Volts. The number of watts is the sum of the total number of watts from each panel and is constant. Only the voltage (V) and current (I) changes.



In the diagram above, there are two 12VDC panels arranged in both series and parallel. When things are arranged in **series**, it alternates positive/negative from panel to panel. At the ends of the two extreme panels, the remaining positive/negative wires feed directly into the charge controller. If two panels are arranged in series, then it is 24VDC; three panels arranged in series, then it is 36VDC and so on. If all the positives are wired together, and all the negatives wired together, then the arrangement is in **parallel**. Remember though the total current can get quite high, especially if you are dealing with high-output solar panels. Be careful and ask advice from either VM or GamSolar if you have any questions.

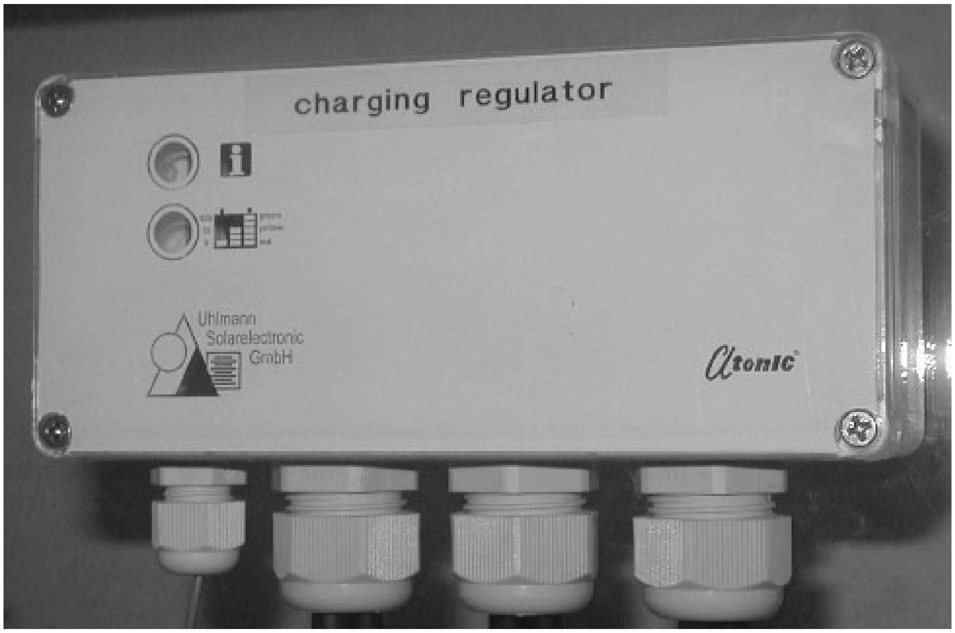
It is possible to have both an arrangement in series and parallel. This type of arrangement would be necessary if you have 4 or more panels (in pairs by 2) in a 24VDC arrangement. The panels would be broken into two sets, with each set wired together in series to create two 24VDC pairs. The leads from each of these sets would be brought together in a positive/positive and negative/negative formation (parallel) to keep the total incoming voltage at 24VDC. See the next diagram.



In a series connection, the number of panels can be even or odd (depending on your required voltage). If parallel, panels can only be added in groups of 2, like that of a 24VDC arrangement. In other words, you cannot have two panels in series and a third panel joined to them in parallel, for the two voltages (12VDC and 24VDC) do not match (if all panels are 12VDC). Remember, there must be uniformity of panels and their arrangement throughout the system. See Chapter 8.

Lastly in this chapter it should be known that the incoming voltage must be higher than the battery bank voltage for any charging to occur. You cannot charge a 24VDC battery bank with panels that are arranged in 12VDC. On the flipside, you can charge a 12VDC battery with a 24VDC panel arrangement, however only 12 volts will actually enter the battery. The rest is lost in heat (bad…bad). This setup is both inefficient (50% loss) and not recommended.

CHAPTER 4: AMP CHARGE CONTROLLERS / REGULATORS



Charge Controllers, or charge regulators, are an often overlooked component of a solar array. They are responsible for making sure that 1) the batteries do not overcharge 2) the power from the batteries does not leak back out into the panels at night time. It is imperative that batteries are not allowed to overcharge.

Once a battery is full, the charge regulator shorts (or crosses) the positive and negative leads of the incoming panel. This stops the flow of electrons into the battery, and therefore, stops the charge. The controller continues to monitor the **State of Charge (SOC)** of the battery, and will turn back on the current if the battery level drops back below the threshold. The usual cut-off value for a charge controller with solar batteries is around 13.6 volts. After the battery voltage reaches this level, the charge controller steps in and stops the flow of current.

Charge Controllers are specific for PV panels only. Shorting a PV panel is not dangerous—the electrons are dissipated in heat within the panel and the wire. They are not to be used in conjunction with other things like wind generators or even a gasoline battery charger. If you short the leads to these devices there will be a lot of heat with no place to go. If a wind generator were shorted, the motor will be put into undue stress and possibly spoil. They do make charge controllers for wind generators, but they are arranged in a different formation. Instead of being between the wind generator and the batteries, it is an external device connected directly to the batteries that allows for massive heat dissipation. Instead of controlling and stopping the flow of current, these devices take the excess energy and passes it along in the form of heat.

Charge controllers are measured in **amps (I)**. The more panels you have in any given system, the larger the size of the controller you will need. To figure out how much you will need, look at the arrangement of the panels (12V? 24V?) and how large your PV array is. In our example, we have ten 50-watt panels, which could be arranged in either 12VDC or 24VDC arrangement. Let's crunch some numbers if *Power = Volts x Amps*:

12 V Arrangement	**24V Arrangement**
P = VI	P = VI
500w = 12V x I	500w = 24V x I
I = ~ 42 amps	I = ~ 21 amps

In both arrangements, the total input wattage will not change (500-watts). The current (I) is dependant on the panel arrangement. If you have all the panels in parallel (12V) going into one charge controller, all the watts (500) through the one box. When you double the voltage, you half the current. Of the two arrangements, the 24V arrangement would probably be better, since it is easier and cheaper to find a charge controller under 30-amps and the amount of current going through any one wire is not too large. In our example, I would recommend the 24V panel/ battery arrangement, a 25-amp charge controller, and at least 6.5mm wire.

If I wanted my panels to have the 12V arrangement, I could split the panels in half (5 and 5) and run half the panels through one 25-amp charge controller (250w/12V = ~21-amps) and the other half through a different 25-amp CC. Of course, you could also find a 45 or 50-amp charge controller, but remember that this is a lot of current going through one wire. If this is the choice, there will be a MINIMUM size wire recommended by the manufacturer for the connections.

Siemens Solar Charge Controller: The side of the controller gives the power specifications. This particular controller can be used either in 12V or 24V systems, and is self regulating which means that you don't have to change anything—it's plug and play. The maximum amount of current that can be both brought in or taken out is 20-amps. This corresponds to 480-watts of panel (in a 24VDC arrangement) or 240-watts (in a 12VDC arrangement).

Maintenance: There is simple maintenance of charge controllers.

1) Keep them clean from corrosion build-up that might occur on the terminals.
2) If the charge controller has air vents and is in a room where debris tends to congregate (basically anywhere in the Gambia, and especially during earwig season) make sure that debris (insects, dust, dirt, cobwebs, etc.) do not congregate inside near the circuit boards. This can be said with controllers, inverters, or any equipment that has electrical circuitry. Earwigs like to find the most obscure places, and a nice dark charge controller can lead the insect into a tight squeeze, one that simulates the electric chair. We lost 2 charge controllers in our school this way: insect infestation. The little buggers decided to do the congo line between a capacitor welded to the board. Lets say that the insects got the chair, and our principal placed an order for two new charge controllers without the ventilation holes.

3) Make sure they are mounted in a way to allow proper airflow for cooling. On a wall is preferable, as they tend to get a little hot when the batteries are full.

CHAPTER 5: BATTERIES

"Most batteries do not die a natural death…most are murdered."

A quote from an unknown industry representative from the Sunelco Planning Guide that describes batteries as being the life-blood of alternative energy systems

Picture to the left shows two 105 AH Solar Batteries arranged in series (12V + 12V = 24V) that are linked by a parallel connection to 3 other groups of batteries for a total amp-hour storage capacity of 440 AH at 24V. Total number of batteries: 8

Arrangement: The description above right sounds a little complicated. Yet series and parallel connections are the same as described in *Chapter 3: Panels*. Only this time instead of watts being the cumulative figure as they are in panels, the amount of amp-hours (AH) will be dependant on the voltage arrangement. If a 12V battery has 50-AH storage, total **storage capacity** (battery capacity) is 50-AH. If two 50-AH batteries are arranged in parallel (positives together, negatives together) the voltage remains the same but the total storage doubles (50AH + 50AH = 100 AH @ 12V). If the same two batteries are arranged in series (see picture above), the voltage doubles (12V + 12V = 24V) but the storage capacity remains the same (50-AH). Quick reference:

Series wiring increases voltage but NOT amp/hour capacity.
Parallel wiring increases capacity but NOT voltage.

If you are adding two batteries whose AH capacity is different (say a 50-AH and a 80-AH battery) arranged in parallel, the total AH capacity is approximately the average of the two (~ 65-AH). From what I understand from some of the online correspondence with members of **www.otherpower.com**'s message board, two batteries together in a battery bank should have approximately the same size capacity of AH so when charging one battery does not fill up faster than the other.

If you are going to add two different kinds of batteries together, it is best if they are approximately the same age or condition. One poor battery in a system can bring the entire system down. In the case of batteries, the storage capacity and efficiency of a system is based on the weakest battery; in other words, you are only as fast as your slowest teammate.

Within the DC connections (between panel and charge controller, charge controller and battery, between batteries that are connected either series or parallel, or the distance from battery to inverter) all should be kept as minimal as possible. In wiring systems there is a 2% rule:

> "Voltage drop is the amount of voltage lost over the length of a circuit. Voltage drop changes as a function of the resistance of the wire and should be less than 2%, if possible. If the drop is greater than 2%, efficiency of the equipment in the circuit is severely decreased and life of the equipment will be decreased. As an example, if the voltage drop on an incandescent light bulb is 10%, the light output of the bulb decreases over 30%!" [5]

If you wish to know the formula for voltage drop (nerd), go get one of those small black little Pocket Reference books which list information like the wire area in circular mils, resistivity in ohms, and circuit level capacity. What I recommend is go big or go home. The larger the wire, the more likely you will not breach this 2% rule which might lead to decreased equipment efficiency. Understand that a lot of current is coming through and attached to one battery or group of batteries (if you have a 24V arrangement). This current, through other series and parallel connections, has to move to the other sets of batteries. If the wire between the two is too small, there will be too much resistance and the electrons will bump into each other too much as they make their way from battery to battery, battery to inverter, etc.

Types of batteries: Battery technology of lead-acid batteries is basically the same as it was 50 years ago, but improvements on internal plate design has increased their durability somewhat.

Lead-Acid Car Batteries: These are made for **cars**, not solar power systems. When the ignition key in a car is turned, the battery supplies a lot of power in a short amount of time to enable the starter to start the car. The battery spends the rest of the time sitting being recharged by the alternator once the engine has been started. When you use these batteries within your system, they are instead providing a small amount of power over a long period of time. These batteries cannot handle this abuse. They are not designed for it, and may fail in a short amount of time (less than 6 months), especially if they are allowed to drain below their 50% capacity. Actually, if a car battery is used in a system, it should only be drained to no more than 80% capacity if you want them to last for more than a year or so. These batteries, if not abused, can allow a volunteer to have cheap storage during their two-year service. When fully charged, the voltage should measure **12.8 Volts** across the terminals of a shallow-cycle (car) battery.

Deep-cycle or Solar Batteries: These batteries are designed to output a little amount of current over a longer period of time. The plates on the inside are more porous, allowing for this 'trickle' event. Like all batteries, they cannot take the abusive pounding of deep-cycling below 25%, but they are designed to resist damage from repeated discharges (50 to 80% capacity used up) and

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[5] Glover, Thomas J. Pocket Ref. 2nd Edition. 1997 by Sequoia Publishing, Colorado. p. 120.

will still last significantly longer if discharged by only 20%. When fully charged, deep-cycle batteries should read **13.4-13.6 Volts** (depending on the manufacturer).

Sealed Lead Acid or RV/Marine Batteries: Both of these batteries are designed to be minimal maintenance components, for since the cells holding the acid (or sometimes gel) are sealed, there is minimal corrosion on the battery terminals. Also by being sealed this allows them to be used around salt water, for regular acid batteries and salt water could create poison gas or explosion.

Placement: If the batteries are lead acid flooded, then they should be kept in a ventilated area. When these kinds of batteries are charged, there is a byproduct of Hydrogen (H_2) gas. If you know about the Hindenburg, you know that hydrogen gas is explosive. It is this gas that causes the sulfate build-up on the battery terminals. Also, when arranging them in the room, I like to get them off the floor and up on either a piece of wood and some cinderblocks or on chairs placed next to each other. This way the batteries are at least knee level, and allow for easy cleaning and maintenance.

Caution: Batteries can put out a huge amount of power in a short time: Be careful about metal tools and wires that could span between and short-circuit a battery. For instance, if you are using a wrench to tighten the terminal screws on the battery, make sure when tightening the bolts that the positive and negative terminals are not in any way bridged. I heard of one story of a heavy-duty wrench becoming liquefied after spanning a 48-Volt arranged battery system. The wrench became molten metal and melted the plastic encasing of the batteries, and both the hot metal and sulphuric acid messed up the person pretty good. Batteries can dish out a large amount of power in a short period because electrons which are stored always look for the path of least resistance.

Battery Abuse*:* As was mentioned with car batteries, no battery should drop below the 50% mark if they are expected to last. **Deep-cycling**, or draining the battery below 50% and recharging it to full capacity, can damage a battery even if it is a 'deep-cycle.' One chart that I saw for Tojan L-16 batteries (a popular type of battery used in PV systems) shows that this 50% mark is when the battery voltage is approximately 12.20V. From what I have seen in the field, this will depend on the type of battery, and unless otherwise listed, a battery does not show its maximum state of charge. Car batteries or other shallow cycle batteries are anywhere from 12.6 to 12.8 Volts. A deep-cycle battery is said to read around 13.4-13.6 volts when fully charged. These numbers are good to know so you don't abuse a battery by taking it to the recharge guy, pay your D30, and have him spoil your battery by overcharging it. The other reason I bring it up is because charge regulators seem to regulate at different rates. Some charge to 13.4 Volts, but it is possible, since you are using a car battery, it is getting way too much power and is being constantly overcharged. You are doing the right thing by protecting your batteries by a charge controller, and yet your charge controller is not even doing its job because it thinks that the maximum level at which to turn off is 13.4V, where your battery is designed to be at a 100% **State of Charge (SOC)** at around 12.8V. All this time the controller is continuing to charge when it will never get to this level, and you are limiting the life of your battery. The only suggestion I can make is size your battery to the correct type of charge controller by reading though the documentation that is provided either on the box or in the manual.

Since I never know what kind of charge controller or battery will be available in country, the recommendation is to take a reading of the battery the first time it is used and charged, and make a mental note of its maximum as its 100% SOC. Then make a note when its levels cause equipment to turn off (inverters) or lights start to dim or hum. This I would mark as the lowest allowable SOC (0%). Your 50% cut-off should be around the average, and your schedule, if you do not wish to stress your batteries, should allow proper recharge periods. If you are finding that there is not enough storage for what you need, get more batteries. If you find that there is not a fast enough recharge period, get more panels. Or as I say, call the experts in the first place to design the correct system for you and don't take my word for it.

Maintenance: A large issue as with any mechanical or electrical device is maintenance. All too often, especially here in West Africa maintenance is overlooked…It is true even more so with PV systems, whose all too quiet, clean, and efficient manner leads people to believe that all is working well and no routine maintenance is needed. Quite the opposite is true. When dealing with batteries, maintenance is the one way to protect your investment. Batteries that are abused do not last long. Deep-cycling a deep-cycle battery is still not permissible, although they allow for you to be a little sloppy. This abuse comes down to need and ignorance. I am guilty, for sure. I have let my batteries drop below 12 volts, yet I need just one small thing charged, just one small fan for a couple of hours, just a little bit of power. That is okay and fine for my personal system, which can take a little abuse because I won't own it forever. I am not worried about its value 3 years from now because I won't be here. A school, however, has decided to make a rather large investment with some idea that you brought to the table. Training them the proper way on maintenance is key for the system to last.

Online material from **www.otherpower.com** talks about battery maintenance only 4 times a year. I recommend maintenance more often, because conditions here in West Africa test routine maintenance schedules to the limits. Environmental conditions like heat can cause mild problems to turn worse in a shorter amount of time. The importance of regular and routine check-ups more than 4 times a year is necessary. For instance, with flooded lead-acid batteries, it is important to make sure that the electrolyte levels in the battery cells do not fall below a certain level exposing the plates. If the batteries plates are exposed when charging then the batteries will be damaged.

The best part of PV maintenance is that it is simple

One item recommended **6 times a year** is to **equalize the battery bank**. This is to be done with regular flooded acid batteries (not gel). "Equalization is basically a controlled overcharge that extends your battery life by knocking deposits off the plates. It's usually easiest to do this with a generator. Charge the batteries at a normal rate, but don't stop when the meter shows full. Keep charging for 2 or 3 hours longer." It was also said that if you wanted to monitor this process, you could take specific gravity readings 30 minutes apart until there is no more increase in the readings. We at our school have not done this because we don't have a generator with a 12/24V DC output (or a generator with a battery charger). This just came to me: I guess we could do the same process without a generator by charging the batteries for a period on a sunny day by removing the charge controller from the system (bypass it) and hook the batteries directly to the panels, monitoring the process very closely. Same idea, although I am sure that it will take a little bit longer. The concept is the same and I am sure it will work.

Four times of the year it suggests users to turn off the main power switch (or unhook the panels) and:

1. Check the electrolyte level. Do this when the batteries are not discharged. They should have a low and high level fluid marks—sometimes the full mark is an inner plastic "shelf" with a hole in it to see the electrolyte level. If the levels are low, fill only with **DISTILLED WATER** to the full mark. Do not add more acid, because all you want to replace is the water. Adding more acid adds more acid molecules, creating too concentrated a solution for storage of energy to take place.

2. Clean the battery tops with rags dipped in baking soda and water solution. DO NOT let this cleaning solution to get into the batteries. Be careful of the vent holes in the caps on each cell, as cleaning solution can enter here.

3. Check for corrosion on all battery terminals. If any terminals have the encrusted residue or 'green stuff' turn off the main power (or disconnect inverter and all other items). Carefully disconnect wires from the dirty terminal and clean off gunk with a wire brush. Don't breathe in the dust. Reconnect the wires.

This second maintenance schedule I recommend should be done more than 4 times a year. I have gotten into the habit of doing it at the end of each month, during the time that our administrative office is processing the vouchers for salary payments. Now the rhythm and routine is set, and no longer do I have to coax our caretakers to actually do the maintenance, it is a part of their regular routine, and something handed down by the principal. However, this textbook strategy on how to keep a PV system up and running in harsh conditions did not come easy, and in fact, is still being modified. Moreover, some of these lessons were learned hard with lost equipment, bad vibes from staff members, and downtime we lost from damaged parts. While the lab sat inoperable, I sat around asking myself why.

Some lessons learned out maintenance in a school setting. Everyone really does have to be on the same page: the lab attendant or teacher who is constantly using the system and has an "in-from-the-trenches" perspective, the caretakers who do the actual maintenance, and the principal who is responsible for writing the checks. In the end fingers can be pointed, but one thing has to be: If I did not let all the involved patrons to our PV system know the what, why and how of maintenance, I:

1) Did not do my job correctly properly training all the necessary people and did not follow-up.
2) Have not stressed the importance of maintenance. Some people in this country know a few things about electricity. I call it a backyard electrical engineering degree. These are the type of people who *try* things out to see if they work. With electronics, this cannot be. I have heard people *trying* to bypass a blown capacitor inside of an inverter with a piece of wire, leading to shocks and sparks. These actions can further damage a system, and add additional expenses. In two years of service, you probably will not see too many problems with your equipment because they are still relatively new. In order to get the full use out of solar, the investment has to be protected. It has to have good practices instilled early, when we are learning how to walk within this world of alternative energy. Even more so is walking this path under the harshest environmental conditions, where heat, dust, and insects can deal a nasty hand of cards.

Plain and simple: if these things are not maintained, they will not last. "Sorry, sir, the battery is blown because someone hooked it back into the system with no charge controller." In fact, this is not their fault but my fault. For instance, instead of only working with the caretakers, I should also have worked with the man responsible for writing the checks. I should have been working with everyone involved. The principal needs to know that a well-trained staff is looking after the school's investment properly. All the major players need to be trained properly to know what is going on. This allows dialogue and brainstorming to occur within the group, and keeps everyone on the same page. For more information see *Chapter 9: Sustainability.*

CHAPTER 6: INVERTERS

If you wish to run alternating current (AC) devices, or those that you need to plug into the wall, there is one last component required. In order for the stored energy from your battery bank, which is DC, to provide wall current it must be inverted from DC to AC. For this we use a **DC to AC Inverter**.

Inverters are measured in watts, and they come in different input voltages (most are either 12V or 24V and correspond to meet the local demand, though I have seen a 48V inverter connected to a 48V battery bank in one of Gamtel's remote relay power stations). The correct size will of course depend on your battery arrangement. If the batteries are in 24V arrangement, your inverter must be 24V. It may be possible to run a 12V inverter off of a 24V arrangement (by hooking the inverter terminals to only one 12V battery even though they are being charged in 24V) but the efficiency of this arrangement is greatly reduced. When hooking up an inverter to a battery bank, make sure that the inverter's two terminals (marked + and -) correspond to the batteries positive and negative terminals. Failure to match the positive to positive and negative to negative will result in damage to the inverter. Also, inverters should have marked on them the maximum amount of watts that they can handle. There is a **maximum load** and a **continuous load**. The maximum load is the maximum amount of watts that an inverter can provide FOR A SHORT AMOUNT OF TIME only. Some devices with motors require larger start-up power, but drop back off after the motor is moving. It is like pushing a large box across the ground: it requires more energy to initially move the box, but once it is moving, it takes less energy to push it along. Do not purchase and inverter based on the maximum amount of output. Rather our figures should be based on the **continuous load**, or the constant amount of energy needed to run all the components of your system.

How big an inverter do I need? Well for that, we need to know how much power (watts) you will be running off the system if all components are on at the same time. Take all the devices and write out how much power each of them require using the chart below. Add them all up and make sure you inverter is MORE than the total you will be running at any given time. If the number is large (over 1000 watts) it may be cheaper and more economical to purchase two inverters half the total amount. This will only work in places like computer labs, where 1 or 10 computers might be functioning. There are three reasons behind this idea. A large inverter requires power just to run. Smaller inverters use less energy than large inverters. Most times you are not at full capacity, especially in a school setting where classes are not consecutive 5 days a week, morning till evening. It is during these light use times that a large inverter does not need to be producing power. In other words, you don't turn on a massive generator just to operate a few lights. Moreover, you can use one inverter half the time and switch over to the other one the other half of the time. Here you are limiting the continuous stress of one inverter which would have to be on all the time, no matter if you are using only part of the continuous load or all of the continuous load. Lastly, if one inverter does fail, then a back up can continue to power at least half of the equipment so the entire PV-system does not just sit due to one missing piece of equipment.

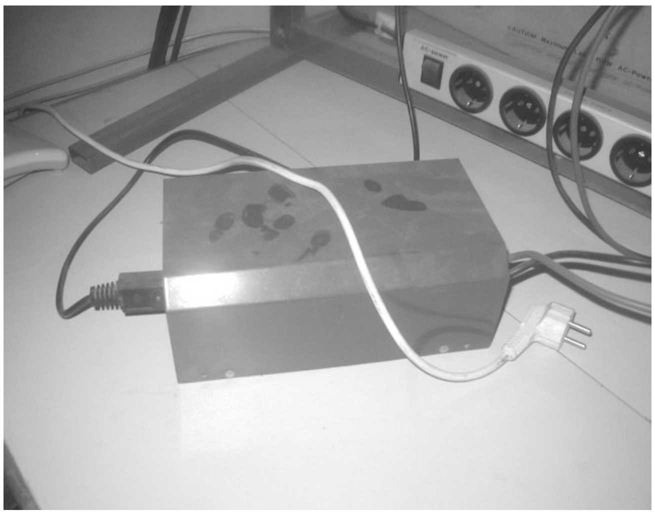
For example, Essau SSS had purchased a large 1500-watt @ 24V, modified sine-wave inverter, made in Lebanon. When it was spoiled, we looked for two 1000-watt inverters (we needed to increase our available power to 2000-watts). In pricing 2000-watt inverters we found that:

1) two 1000-watt inverters were cheaper
2) we were not putting all our eggs in one basket
3) we would only need to turn on one inverter to power 1 or 2 computers, instead of a massive 2000-watt inverter, therefore increasing our overall efficiency
4) we now have a back-up in case one of the two spoils. Inverters are separate components that can feed off of the same battery bank. Turn on those inverters which will be needed, and leave the others off to rest.

Anytime energy is being converted from DC to AC, there is approximately a 20% loss of the available power. This affects the system by decreasing the total available battery storage by around 20%. Example: 300-watt inverter is plugged to a 100-AH battery bank. The total available storage capacity of the system, if all components are running through the inverter, is now 20% less, or down to 80-AH. This is important to know, especially if you want to correctly size your battery bank to meet your energy requirements. For this reason (20% loss) I try to have as many components of my systems running directly from DC. Often these components may cost more, but in the long run (looking at total efficiency and power losses) the extra money spent on equipment could be put to better use.

Computers need AC power, but if you were to look at the inner hardware (specifically the power specifications) we will find that the hard drives, motherboard, disk drives, and other components are either 5VDC or 12VDC. Technically, a 12VDC hard drive could be run from a car battery. Using the correct step-down circuit, we could run the 5VDC components. If this is done, you will no longer need a power supply. There now will be fewer parts to maintain (and blow up due to people's inability to chose the correct voltage), greater efficiency, and overall less cost (no purchase of an inverter). Instead of going from DC (battery) through an inverter (AC) back to DC (components of the system), there is a rather high loss of power. If anyone has the electronic capacity to build this circuit, do it. It should increase the overall efficiency of the PV-system by approximately 30%.

Lights that are going to be placed a far distance are sometimes run through AC, where the 20% loss of using an inverter is less than the losses accumulated using far-distanced DC-lights. Remember, with DC systems, the wire distances from panel to battery, and battery to load should be as minimal as possible for the maximum amount of efficiency. That and the wire used in these connections should have the largest diameter as possible (at least 4 mm).



220 Volt DC to AC Inverter: The inverter to the left has a positive and negative leads that are hooked to their respective positive and negative terminals of the battery bank. The other end (black plug, left) feeds into the power strip (above, right). Here appliances can be plugged in and run, as long as the continual load (total amount of watts) is not surpassed at any given time. The distance between the inverter and battery bank should be as short as possible: remove any excess wire between components to minimize the efficiency lost to DC dynamics.

There are all kinds of inverters in the local suppliers of electronics. Most come in either 12 or 24 volt inputs, but their quality varies. There are 2 kinds of inverters on the market: sine-wave (sinusoidal) or modified sine-wave. Sine-wave modules convert DC-power to a pure 50 or 60 Hz frequency. These are often three times as expensive, and are used to power very delicate devices. Most appliances here can run off of modified sine-wave. Looking at the picture of this type of electricity on an oscilloscope, the lines are not smooth and flowing like a pure-sine wave inverter (see Basics of Electricity, Chapter 2). Rather, they produce rigid peaks and valleys 50 or 60 times a second. They will work with computers, TVs, VCRs, etc. though their quality varies by manufacturer. Both the Germans and Japanese produce good quality inverters but they tend to be a little more expensive (both modified and pure-sine). I recommend buying something in a box with documentation, for our school had a run-in with two no-name Lebanese manufactured inverters that failed after no more than 2 years (the larger one is pictured above). Turns out their design with a large cooling fan and open sided ventilation slots allowed both dust and insects to nest inside which possibly caused a short circuit to some of the internal components. The fact that there was no documentation did not show us the proper ways of maintenance, the important part of any component of PV systems. We neglected to realize that this hidden debris could lead to inverter failure. **Lesson learned**: do not just clean the outside, especially if the inverter is in a room where insects and dust are found. Open it up twice a year both during the dry season and after the rains. Clean equipment does last longer. And remember that you get what you pay for.

CHAPTER 7: THE PERIPHERALS

Peripherals include extra items like wire, lights, and fans. Though these components are often overlooked, they play a vital role in how efficient your system as a whole will perform.

Lights: The three most common kinds of lights sold here: DC to DC-lights, modified DC-lights, and AC lights. They are measured in watts and the stated wattage represents how much power they will consume in one hour. Although I have not worked directly with them and therefore do not know too much about them, LED lights are also available through Gamsolar though they are not featured in the following examples.

DC to DC-lights are the best choice for rooms smaller than 6 x 6m, where the distance from battery to light is minimal. They hook directly to either the battery terminals or the positive (+) and negative (-) leads that are often found on charge controllers (like the Siemens model found within the systems provided by VM—see below photo).

Charge controller showing the three terminals for component connection. Left is the lead for the PV-panels, center is where the battery leads are connected, and right is where the LOAD (in our example, DC-light) is connected. With DC-light, connection can be made either to this terminal, or plugged directly to the battery. Keep in mind this terminal is 12VDC, and items that are only 12VDC should be connected.

The connection distance between the power source (battery or charge controller) should be as short as possible, for with distance, DC loses efficiency. Also, the thickest diameter wire that is affordable should be used to make the connection. Trim off any wire that may be extra. At Essau Senior, three classrooms are provided 6 lights. I would guess that the longest wire for the furthest two lights is 12 meters from battery to light. The wire connecting the two is 4mm.

Modified DC-lights or DC to AC Lights use a 220VAC bulb and a small transformer attached between the battery and socket holder. The input voltage is 12VDC, the transformer steps this to 220VAC, and a conventional light you would find in any grid-connected house is powered. On average these lights (the small double looped halogen ones) are said to have a 9-watt rating, but upon closer inspection, there is a heat sink attached to the small circuit board to dissipate heat. Excess heat is a sign of efficiency loss, and even though the light is rated at 9-watts of consumption per hour, it requires much more. High school physics tells us that energy cannot be created nor destroyed. The excess electrons, instead of remaining in the batteries, are lost into the air in the form of heat. This is the same concept seen in computer power supplies. The 3-

inch fan that cools these boxes is releasing the extra energy not used by the components of the computer. In both situations, energy is lost and both systems are not ideal especially if there are other options (either no power supply in a computer or an efficient DC to DC-light). Also, the modified DC-light's transformer is subject to corrosion by salt water in the air. Anyone either along the coast or a third of the way up the river may have to replace this transformer once the corrosion reaches high levels.

I have both a modified DC-light as well as a common DC to DC-light, both of which are rated around 9 or 10-watts. The problem with the modified light is that it needs at least an 80% charge in the batteries to convert the DC into AC in the small transformer. If the battery level's SOC drops below 80%, the light will seem to squeal and make a high-pitched noise. This is not only annoying but also an audible sign to the user that indeed this light is struggling to keep lit. After this level, the light will start to dim exponentially. Not a whole lot of fun, especially when you are in the last chapter of Harry Potter on a rainy night with nothing else to do.

AC-Lights are used when the distance from battery bank to light is rather large (greater than 10-meters???) In Kerewan there is an NGO called FORUT who light their premises with 7 AC bulbs, with varying distance from battery to light anywhere from 3 to 35 meters. They are spaced throughout the compound, and the wire used was rather thin. In this case, AC-light running through an inverter was the correct choice. Even though you lose efficiency (up to 20%) using the inverter, the loss does not compare to what would have occurred if they used 7 DC-lights connected by the same thin wire. Even better, it would be more efficient if those lights that were close to the battery bank (2 were in the same room with the batteries) were DC, and the rest that were far off were run via the inverter.

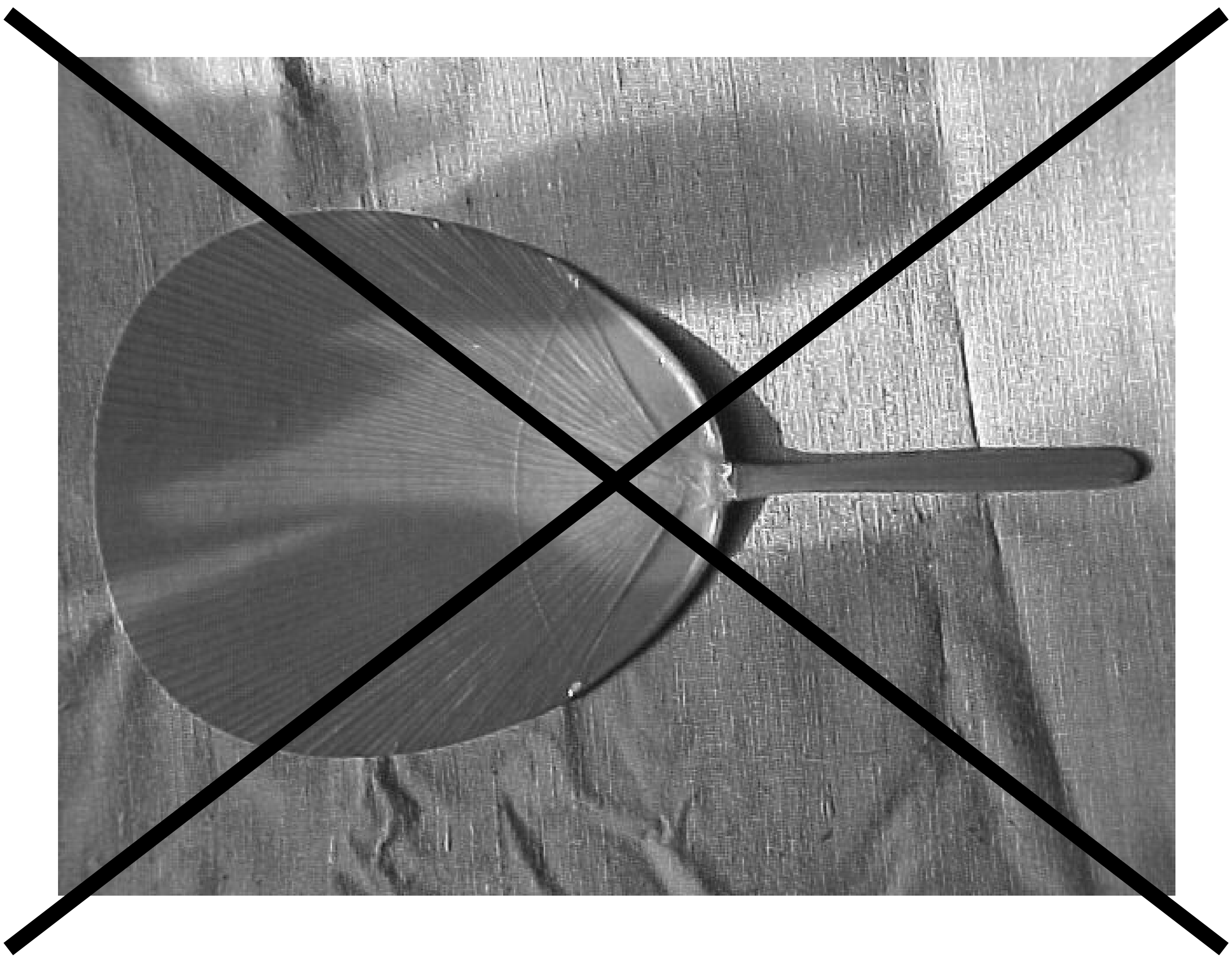
When looking at each option, realize that a little power loss here and there will add up. This is especially true if there are multiple inefficient components. Ask yourself…what is cheaper: paying an extra D150 for a true DC-DC light, or having to purchase and additional battery or panel to make up for the losses accumulated through inefficient components.

Wire is important in any connection that is DC. Basically you would like the largest affordable wire to make your connections from the battery bank to the extra components. The wire that connects the batteries together in either series or parallel connections should be as thick as possible (minimum 8 mm or 0 Gauge A.W.G.) You will notice that the wire protruding from inverters, especially the larger inverters, is rather large. If a 1000-watt inverter only has a small wire coming from it, then it probably is not a good inverter. The designers do not know that this DC connection should be as thick as possible.

Standard copper wire is measured by both its A.W.G (American Wire Gauge) rating or by its actual diameter in millimeters. For example, A.W.G. ratings vary from **0000** (11.7mm) to **40** (.08mm). The most common types in Gambia vary from A.W.G. **0** (8.3mm) to A.W.G. **18** (1mm). In the connections between batteries, I recommend at least 8mm (A.W.G. 0) or better (A.W.G. 00, 000, or 0000).

The smaller the A.W.G. (gauge) number, the larger the diameter of the wire

Fans are discussed here because it is sub-Saharan Africa. It is possible to have a small fan that is equivalent to the amount of air you would get if you fanned yourself. Find an old computer power supply with a 3” fan and take it apart. Be careful because components inside the power supply still hold charge even if not plugged in, so be wary when it says: *CAUTION-opening device may cause severe shock.* Just do not stick any metal tools inside. Anyhow, remove the guts of the power supply and detach the 3-sided section that contains the fan. This section acts like a fan stand, and since it is usually made out of aluminum, it is easy to bend to the correct angle sitting on the floor or laying down on the bed. This fan is 12VDC, with a power rating from 0.05 amps to .5 amps (not a whole lot of juice). Attach the red fan wire to the battery positive and the black fan wire to the battery negative. Rig up a simple switch on one of the wires (to break the circuit) and presto: no more whacking yourself in the face with a hand fan as you try and fall asleep in a pool of sweat during the hot season.



...No More Hand Fans...

CHAPTER 8: PUTTING IT ALL TOGETHER

So, how many panels and batteries will I need? That depends on what you are running and for how long. If you pay a little more for efficient equipment, you may be able to save money on the amount of stuff you need to buy. Either you get 20% more equipment like panels and batteries—often an expensive solution—or 20% more efficient items like light bulbs, which will save you in the long run (although they are a little more expensive).

To determine how much equipment you need, make a list of all the items you wish to run, and for approximately how long per day. Rate each item, by the chart below, on the amount of power (watts) they will use in one hour.

THESE ARE APPROXIMATE VALUES—ACTUAL NUMBERS MAY VARY

Item	Watts / Hour	Item	Watts / Hour
Air Conditioner	1500	Desk Jet /Dot Matrix Printer	5 in standby, 30-50 running
Electric Iron	1500	Old Computer (w/ monitor)	165
Sewing Machine	100	New Desktop Computer (w/monitor)	225
Table Fan	10-30	Lights	Varies due to size
CD-Player	35	TV, 12" B+W	15
Cell Phone	24	TV, 19" Color	60
Stereo @ Avg. Vol.	15	TV, 25" Color	130
Satellite (12' Dish)	45	VCR	40
Radio	10 - 40	Laser Jet Printer	600

Source: **http://www.readymaderesources.com/pdf/solar%20wattage%20use.pdf**

Example: I want one old 486 computer for 2 hours a day, two fans rated at 24-watts for 2 hours, 1 radio for 4 hours, and a 12-watt light for 6 hours. My list is as follows:

Item	Power in 1 Hr.	Total time	Total power consumption	Total Current
486 computer	165-watts	2 hours	330-watts	27.5-amps
(2) 24-watt fans	48-watts total	2 hours	96-watts	8-amps
radio	30-watts	4 hours	120-watts	10-amps
DC-light	12-watts	6 hours	72-watts	6-amps
Total required for each day			618-watts	51.5-amps

To go from total power consumption to total current, divide the power by the battery voltage. Since this is a small system, the batteries (and panels) will be arranged in 12 Volts.

Of the 4 items, only the top two (computer and standing fan) will be needed to run through an inverter, since we were able to hook up both the DC-light and the radio. Our inverter needs to be at least 426 watts. I would recommend at least 500-watts, possibly 700-watts (if you want to add something later like a few mobile phones).

As for the radio, it either requires 220VAC or DC. Its DC requirement is 8 large batteries (Size 'D') that are each 1.5VDC each. 8 x 1.5 = 12VDC (directly to a car battery)). If the radio requires 6 batteries (which many around here do) then you cannot hook this radio (rated at 9VDC) to a 12VDC car battery.

Panels: each day you are using up approximately 620-watts of power (power doesn't know a difference between AC or DC….it is all relative. **Ideally whatever power you take out, you must put back in.**

If you had **(2) 50-watt panels** (allowing for 100-watts to come in at high sun), this means that throughout the day, the approximate amount of power coming in at:

TIME	% of PV Maximum Power Output	Total power produced during the hour
9am	25%	25-watts
10am	50%	50-watts
11am	70%	70-watts
12pm	85%	85-watts
1pm	100%	100-watts
2pm	100%	100-watts
3pm	85%	85-watts
4pm	70%	70-watts
5pm	50%	50-watts
6pm	25%	25-watts
Sum total power produced throughout the day		660-watts

These two panels can produce the required amount of energy you would need daily for this equipment provided that there is full sun, the panels are clean, and the connections are good. This is ideal, however sometimes we cannot afford the ideal system. One PV panel (only rated at 50-watts/ hour of peak sun) then this will produce ½ the power, meaning that it will take twice as long to charge the system. That is what is nice about PV-systems. They are modular and can be bought and added as needed (or as funds allow.)

As for the size charge controller you need depends on panel/battery arrangement. Since we are using two (2) panels arranged in 12VDC parallel, total amps coming through our 12VDC charge controller needs to be at least 8.33 amps:

$$P = VI$$

$$100 = 12 \times I$$

$$I = 8.33 \text{ amps}$$

The recommendation would be a **10-amp charge controller**. This could be purchased either in-country or, if you have the time and means get it, from an online auction like E-Bay® or U-Bid®, and have your family or friends send it to you. Often this is one component that can be bought much cheaper in the States, and have sent due to its size and small weight.

As for **batteries**, since you are running during the daytime, count on the batteries not totally being drained directly but rather are being charged back up throughout the day when using the equipment. If this equipment is being only run at night (when there is no power coming in from the panels) then the storage capacity has to be sufficient enough to provide power in the night. However, the batteries should not go below their 50% SOC threshold if you want the batteries to last.

To figure out how much storage you need (total number of amp-hours) we need to know how much current, measured in amps, will be drawn from the batteries. This is split into DC and AC components:

Total DC current needed: 10 + 6 = 16 amps (radio and light)
Total AC current needed: 27.5 + 8 = 35.5 amps (computer and fans)

Remember that if you are running though an inverter, you will lose approximately 20% of the total available power. Compensate the loss by adding an additional 20% onto the total number of amps needed to run the AC current:

35.5 x 20% = 7.1-amps 35.5 + 7.1 = 42.6 amps required for the AC components taking into account the 20% inverter loss *(adjusted total)*

Total required amps for the day (16amp from DC + 42.6amps from AC) = **58.6 amps**

Theoretically, this means that one 60-amp hour (AH) battery could provide the power for the day. Yet this means that the charge will be taken from 100% all the way down to 0%, a process called 'severe punishing deep-cycling' and the life of the battery system will not last long. Since we want to stop at 50%, double the total required amount of amps for the day (in our case, we will need ~120 amp hours of storage in a 12VDC arrangement.) If we wish for more storage (maybe at night time when there is no more charge coming in from the panels) we can increase this even more to 150-AH storage.

Any combination of 12VDC batteries will do. If they are arranged in parallel, either (3) 40-AH or (2) 60-AH would be sufficient

Be careful not to have the battery bank too big, for it takes longer to charge a big battery bank than it takes to charge a small one. You have to find the balance either through your own research (write the book) or by asking either VM or Gamsolar what they think about your figures.

Once you have shopped around for the best prices on the most quality goods you can afford, it is time to get the equipment to the site and installed. Be careful if you are driving up-country that the delicate items like panels are not on the bottom of the bush taxi's pile of goods. Also, batteries should not be filled with acid until they are ready to be used.

Some Reminders

Panels should be face down or covered with an opaque cloth when being wired together, for if the panels are in the sun, you can believe that they are producing energy.

Batteries should be off the floor to allow for easy cleaning and maintenance.

Charge controllers should be mounted on the wall for correct airflow and voltage monitoring.

Inverters should have enough space around them, being careful not to back the cooling fan against a wall. These things get hot, and the fan is there to cool them down. Do not block it.

Wire should be as thick as possible, and all connections should be as short as possible. Find a room to centralize the battery bank to the rest of the building and to the rest of the devices running on the system. Be very cautious about the DC connections because these suffer the most due to incorrect sizing and excessive distances.


VARTA
THE BATTERY EXPERTS
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CHAPTER 9: SUSTAINABILITY

As with any technology in a developmental aspect, sustainability and best practices should be addressed and met. From the initial research to the implementation, human resources are the key to sustainability. I have learned that proper training and communication of everyone involved within an organization will minimize problems and maximize efficiency. Often at times there is the idea that the *team* players, no matter at which level, will have the "It's not my job" or "This is the problem" mentality. This is something that we wish to avoid.

I believe that solar power within West Africa is still in an experimental stage. The technology is there but the human resource base is still minimal. The temperature and conditions that the equipment is operating is well beyond the normal 25^0C factory tested range. When I first started, there was only one company supplying quality components and providing technical assistance. In the last three years other companies have come in (i.e. GamSolar) with quality equipment and trained staff.

Because there are only a few companies providing equipment and maintenance service, and because organizations do not have the capital to move solar power, I have seen these companies rely on equipment malfunctions to keep their businesses going, even though the system costs should be a one-time. There are maintenance packages offered at an extra cost (% based) for 1, 3, 5, or 10 years. I know that Gamsolar offers this as an option, and I believe that the government used to have a contract with VM for the preventative maintenance of their DC-light systems installed in the schools in 1997. Six years later, through, we realized that the contract was finished and the school had to pay a VM technician to come out and solve a few of our problems. All of our problems could have been avoided had everyone been properly trained. We just did not know.

Basically these people have a knowledge that they are unwilling to part with or share. If they did give advice, they would not be making any money from additional sales. They wait until something malfunctions (due to poor maintenance) and only then they are happily to come out (for a fee) to find the problem and offer a solution (buy more equipment through *their* company). After our first AC-system was installed, there was not one thing mentioned about maintaining the equipment, no manual that talked about troubleshooting, and no expert who would hold our hand when something went wrong. We learned from our mistakes and we wrote the book.

This is the main reason why I created this manual. Although I am not an expert or a technician, I have done the research and asked the correct questions. You too should be doing your own research and look at the conditions, infrastructure, and human resources available within the institution *before* you begin.

Once everyone has committed to using solar power, the organization as a whole must work together to protect the investment. Good leadership and maintenance schedules should be written down and followed. Each player should have a basic understanding of the various components, how they interact within a system, and the potential problems that could go wrong.

In terms of sustainability, these schedules may be designed by the volunteer but should be implemented through the leader of the school or institution. There has to be a point person for the entire project, who makes sure that the job is completed. Follow-up by this person should also occur in a timely and orderly manner.

As a volunteer working with a new technology, I brought in the idea and led the team in the direction of alternative energy. At first I did the majority of the maintenance because I wanted to see it succeed. Yet I cannot be around the school at all times and take care of every problem. My job is to provide the concept, provide the training, and make sure that people's roles are defined. One day I leave this place and unleash my counterparts to a world without my scrutiny, passion, or wish for long-term success. They will be all alone. And if it ever should fall apart, it will be both the fault of my counterparts for not listening or asking the correct questions, but mostly my fault for not showing them the importance of good habits, responsibility, and ownership.

Ah, the harsh reality I think of being a volunteer. What is sustainability, and can it work with PV systems? Sad truth is that it can happen in any sector. I have bought this new technology, and I should be responsible to make sure that in fact these things will be looked after, these practices that I showed by example, these routines that I have done monthly for the last 2 years, will be continued. It is a sad thought to know that some months after you leaving, you hear that your project has fallen. Why? Because maintenance was not stressed enough. The simple remedy is to train as many people within the facility all that you know, as much as you know, then give some space in the remaining months for them to figure it out for themselves, to solve their own problems, to find the lasting and most economical solution. And if they really fall, pick them back up, review either what went wrong or what was not completely understand, and learn from the mistake. Do not totally shut them out of the learning process but rather brush them off and put them back into the field. Enable yourself time to train, and start the process months before you intend to leave. It allows you to fix the problems while you are here, and not just when you are getting ready to go home.

CHAPTER 10: CASE STUDIES

Essau Senior Secondary School: This facility was Gambia's 1st Solar Powered Computer Lab It is the basis for this manual and it is where most of the research on maintenance was written. Initially at Essau were pre-existing DC-lights, with each teaching block having 200-AH solar battery storage, a 20-amp charge controller, 110-watts of PV-panels, and 6 efficient DC-to-DC lights. It was here, with a borrowed 300-watt inverter from America (110VAC), that we plugged 2 computers. You should have seen it. This foreign inverter needed a step-up transformer to power those computer towers that were strictly 220VAC. Half were running from 110VAC, the other half off of 220VAC. We were in a storage closet off of the library that had everything from boxes of cut glass, old circa 50's science books, and a bunch of dust and cobwebs. Not an ideal place for a small computer lab of 2 computers.

During this experiment I worked with 2 other teachers on basic computer literacy, but our capacity of storage and our inefficient set-up gave us only around 2 hours of power per day until the cut-off voltage of the inverter kicked in and the system turned off. This was before I knew anything about efficiency, clean battery terminals, dusty panels, and losses in step-up transformers. Using the generator/PV cost comparisons, I set out for information at VM (at the time, the only distributor of quality products). It took 3 months to research and convince my principal that over a 10-year period we could have 300% more power. Not just power, but clean, reliable, minimally maintenanced power. My approach to the principal had a mathematical slant, since as a former math teacher numbers were his specialty. From there he approached the school board and we were approved for the initial purchase of (8) 50-watt panels, (6) 100-AH solar batteries, (1) 30-amp charge controller, and a Lebanese made 1500-watt/24V input inverter. Total bill was approximately D80,000 (currently US $5000) and included installation costs, wire, switches, and 4 AC lights. The school funded the entire project without outside help.

Now, the installation was OK: packing tape was used instead of electrical tape, two of the AC-lights stopped working after a few weeks, and screws used to attach the PVC pipe to the wall were not long enough, for after 6 months, some of them were falling to the floor. Basically it worked and the only thing I did not like was the cosmetic appearance.

We used this system to power 4 computers for around 6 hours a day during the dry season. When we received ten (10) 486-DX computers from World-Links, we were able to power at most 10 computers (choosing those monitors and towers which had the least amount amperage draw…basically we mixed and matched the most efficient computers) and 2 fans. As soon as the monitor of that 11th computer was turned on, the inverter overloaded and went into stand-by. The inverter was equipped with overload protection that shuts off the system in case of excess demand, a nice option for this environment. ***Ouch!!*** Flipping 10 computers off by cutting their power and not properly shutting them down can lead to disasters down the road.

Older computers require less energy per unit than most of the Pentium I or above computers. The components inside are not as advanced, and do not need as much power. I much rather prefer them because I can turn on more computers with the 1500-watt inverter. If the average draw from an old computer is around 165-watts, I would estimate that a newer computer is somewhere between 200 and 300-watts and varies by manufacturer. The majority of this power goes to the monitor (around 2/3 of the total consumption). If you want to save energy, pick the oldest monitors you have in stock (usually they are rated around 1 to 2 amps), even though the computer may be brand new. Are you trying to do graphic design with a 19" Trinitron monitor (which can draw up to 6-amps) or teach computer literacy? A big expensive Super-VGA monitor I feel is not needed.

The first room we chose to occupy was the 3 x 4 meter closet off the library. With the 1st installation of additional components, we took an existing physics lab, put in windows, added a drop ceiling, and setup up the computers in rows. Since the physics block was at the end, and the principal wanted the equipment separate from the lab, I needed the chemistry teacher (middle room of the 3 in the science wing) to provide the keys for both his classroom and the attached office, where the batteries for both DC-lights and the computers were housed. It was said that the panels needed to be directly over the batteries (which they were) for the panels needed to be on the south roof. I still do not recommend this set-up at all. A person working with multiple computers at any given time needs access to the battery bank 1) to watch the charge controller battery levels; 2) see when the batteries need to be cleaned due to sulfate build-up 3) if the inverter does need to be reset, it can be done without having to track down the man with the keys. We lost a lot of time trying to work with this system. In the new lab that was built by the Department of State for Education, we will have all of our panels, batteries, and inverters within the same room as the computers.

The second installation, around a year later, added three (3) 50-watt panels to the existing three (3) panels in the administration block. They also added one more battery. The lab was able to get four (4) more 50-watt panels and an entire new battery bank of eight (8) 105-AH solar batteries. Here batteries should be the same age and type. The existing 6 that were there were incorporated to other school blocks. We did try to increase our capacity one day by adding 2 older 100-AH batteries that were sitting around. Those two batteries brought the entire system down, where they caused the other batteries to not fully charge. We took them out. Remember:

You are only as fast as your slowest runner

After 2 years our 1500-watt inverter blew up when the caretaker tried to bypass a capacitor with a 16 A.W.G. wire. The capacitor was apparently shorted when an insect climbed between the two leads. As a result, the other 7 capacitors blew up in his face and other internal components were destroyed. Now unfixable (all the replacements are not available in-country) our lab was without power for 3 months while two replacement inverters were ordered from overseas. We did not mess around with any cheap products this time with the inverter. What we should have done is bought the good stuff in the beginning.

Lesson learned from our caretaker playing Electrical Engineering master. Do not trust anyone who tests for current by licking their fingers and touching the leads of a live wire. Also, do not just *TRY* something to see if it will work. That is the way to blow something up. People in this country who claim that they are electricians, science teachers, or other staff that say, "Let's give this a shot," be very cautious about. Take it to a professionals who will keep down the costs in the long run..

Our other Lebanese no-name inverter lasted only a year. This was the 1000-watt that was placed in the office, same manufacturer as the other one. Here the inverter lost the same capacitor, and before we had our ingenious caretaker try a little self-maintenance, we took it to Gambia Electric for servicing. Same problem—they did not have the correct parts in stock (or just couldn't fix the problem). The recommendation is to buy quality products at the beginning.

Albreda Junior Secondary School: I received a call from this small JSS on the North Bank, about 35 km from Barra. They said that their DC lights were not working (they were one of the new JSS supplied by DC-light in 1997) and the batteries could not hold their charge. I did see that some batteries clearly had low levels of acid, and probably some of the batteries needed to be replaced because of neglect. I suggested that they call some professionals (like VM) to come and maintenance their systems, testing the battery's individual cells to see which are faulty. Those that had their electrolyte fall below the minimal mark and allowed to continually charge w probably were damaged and needed replacement. What I did not know was why batteries that had the correct acid levels still would not hold charge. Some months later I read about the sulfate build-up that occurs on the battery terminals. Sure, I had seen it on all kinds of batteries: the green/white calcium-like substance that builds up on the terminals. Seeing my mistake, the next time I ran into the headmaster I notified him that he needed to not only look after the water levels, but also make sure that the terminals are cleaned by soapy water. It is also recommended that the battery terminals be cleaned with a wire brush to allow efficient charging and minimal loss through the battery terminal corrosion.

Brikama Ba Community Internet Café: Action Aid called me up to design a system for Brikama Ba's Internet Café. They wished to run 5 computers, a large DC-fan in the center of the room, 1 light, modem, HUB. Total required watts were a little over 800, so a 1000-Watt inverter would allow for expansion at a later date. Total time per day to run: 6 hours. They also wished to have a photocopier and laser printer, but it was suggested that since they require a lot of energy and are only going to be running when needed, a generator should be purchased. The e-mail went as follows:

Mr. Cham,

I ran some numbers, but the proposal was dependant on the availability of materials in country. Specifically, the fan. I would recommend you go with a large DC fan. If not, then two high-quality standing fans will be fine, though they are not as efficient.

5 computers @ 200 watts each:	1000 w
2 lights @ 10 w each	20 w
DC Celiing fan (guestimate)	80 w
external modem	10 w
HUB for network	30 w

TOTAL WATTS NEEDED: ~1200 watts. Your inverter has to be at least 1200 Watts. Recommend a high quality one--we bought a Lebanese inverter (1500 watts) and it only lasted us 2 years. Modified Sine Wave Inverter should be fine (you don't need a pure sine wave inverter). In fact, I would do two 600-watt inverters so you could switch between the two to limit the stress long term. Also, if one goes down, there is a backup. **Two (2) 600-watt inverters, 12VDC Connection**.

Instead of saying day/night, let's just assume that this system will be on for 6 hours a day (2 in afternoon, 4 in evening). This will use up ~300amps of battery power per day. Since you do not want to drain them 100% each day, double the required amount (600) and add an additional 20%. If arranged in 12V configuration, I would recommend **eight (8) 100 amp-hour solar batteries**.

Panels: Since you are running at night and all your charging is during the day, I would have minimum **twelve (12) 50 or 55-watt panels** (total watts from panels at 12V = 600-watts).

Charge-controllers. 6 panels at 12V arrangement would each go through (1) 30-amp charge controller (300watts/12V = 25amps). 1/2 the panels through one charge controller, 1/2 through the other. They both feed into the same battery bank, so make sure they are the same model, same amperage. **Two (2) 30 amp charge controllers.**

As for the kind batteries, **do not** buy gel or sealed acid batteries. In hot climates, you need to be able to top off the batteries when the liquid levels in the electrolyte fall. Solar Batteries that you top off with distilled water would be best.

Summary:

(8) 100 amp-hour solar batteries (800 amp-hours storage)
(12) 50-watt PV panels (600 watts)
(2) 30-amp charge controllers.
(2) 10 watt lights
(2) 600-watt / 12Vinverters (Mastervolt is a good brand)
(1) DC ceiling fan (most efficient) or 2 standing fans.

WIRE: Can't really say because I don't know how far the panels are going to be. I recommend VERY THICK wire to attach the batteries together (AWG 4, 2, 0, or 00...the smaller the number, the larger the diameter). Use at least 6mm or greater. With wire, when you get a pro-forma from either VM or GamSolar, ask what they are using in terms of size. All DC-connections should be as short as possible (ie: panels should be on roof of lab, directly overhead, inverter as close to batteries as possible, etc.)

Don't forget you need to add in things like power strips and installation costs. That will depend on your equipment. Total the number of plugs (computers = 10 ports) plus modem, HUB, fans (if standing and not DC). Somewhere around (3) 5-port power strips.

In addition to the Internet Café, they wished to have the local radio station have 6 lights. I suggested the same system that VM installed with those schools in 1997: 100-watts of panels (2 x 50-watt), minimal 10-amp charge controller, two 100-amp hour solar batteries arranged in 12V parallel, and 6 efficient 10-watt DC bulbs. Wire distance should be kept to a minimal by centralizing the batteries amongst those lights so that the distances of each are approximately the same distance as the others.

As for the Radio Station for DC-lights I recommended (6) 10-watt lights, (2) 100 A/H solar batteries arranged in parallel, (2) 55-Watt quality PV panels, and a 10 or 12 amp charge controller.

Recommend: GamSolar (460189) and VM (228904) as solar distributors of the Gambia. There are other places popping up, so check around. Make sure it is not cheap goods!!!!!!!

Kuntaur JSS, CRD: Action Aid also came to me to aid the installation of their first rural electrification project for the Department of State for Education, where a small Junior Secondary School located 25 km northwest of Georgetown was the target population. The headmaster approached the organization for a small computer lab (4 computers, 2 fans, and a light) saying that (4) 50-watt solar panels were originally there for DC lighting. Their original batteries were car batteries (not good for long term pounding abuse) and their existing charge controller was a relic out of the mid-80's. The project supplied 6 sealed acid car batteries, an 800-watt inverter, and two large 20-watt fluorescent lights. Before the installation, I wished to have a local counterpart (i.e.: a local electrician from the area) to work with, for I felt as if the project would not be sustainable if I was to install it all myself. When the electrician was notified, and transportation arranged, I headed to Kuntaur. Upon arrival, I noticed a few things. First, the sealed acid batteries in a hot area like Kuntaur were not practical. A sealed acid battery, although they have even lesser maintenance than a regular flooded acid battery, cannot be topped off with distilled water when and if the pressure and heat inside the battery caused the existing water to purge from the pressure valve. In an area as hot as the north bank of CRD, there must be a way to top off these levels. Second, the lights that they chose were both too big and ran offn off of AC current. We know now that if the distance is short, an economical DC-light is the better alternative, and if just the lights wished to be run, the large inverter did not have to be turned on. That and the size of the lamps (20 watts each) were too much for this simple 6 x 4 meter room. We went ahead with the installation of the batteries and inverter, but I suggested after a return to Kombo that the two AC fluorescent lights be switched to one DC 10-watt bulb, plenty of light for a room of that size.

Five months later, I received a call from Action Aid saying that the lab was not functioning. Troubleshooting by phone and working with the electrician which was already familiar with the system, we figured that the relic charge controller had finally ceased to function—a replacement was paid for by the school. I also suggested (after continuing research) that they move their panels from 40 meters away to the top of the roof. At the time, I did not know that DC loses efficiency with distance. 40 meters from panels to batteries is too much, especially with thin 2.5 mm wire. These changes have been made, and last I heard, the project has enabled the lab to move into Internet communications with the addition of a modem and telephone access. As for the batteries, well, I do not know if they will last as long as ones that could be topped off with distilled water.

The only other concern was that the input power from the panels (only 200-watts input power @ 12V = 16.6 amps input power at peak sun, or 12 amps per hour average over 6 hours) was too small for the connected batteries. If 300 amps need to be replaced, the system would need almost 4 days to completely recover, provided that there is full sun. A long turn around period for recharge turned out to be true. The lab had to either cut back on its use (which it did) or purchase more panels (at least 200-watts more) so that the recharge time could be halved (one day full use, 2 day recharge). Due to limited funding, the school cut back on the number of computers it used, though they continue to look for ways to increase the amount of input power available for their lab.

Lessons learned: 1) Be as efficient as possible. A rural school cannot afford the losses that might have occurred with inefficient lighting or poor quality parts. When dealing with an NGO like Action Aid, it is often quite difficult to get things changed once the pro-formas are issued, the funding granted, and the supplies bought. 2) Understand that environmental conditions vary by area, and certain equipment should be avoided: sealed batteries may work in the cooler Kombo areas, but are really unfit for the warmer areas. 3) Work with a counterpart, no matter if you are installing, doing maintenance, or troubleshooting

The following string of text is not exactly a case study, but it teaches a good lesson. It was taken off WWW.OTHERPOWER.COM's message board where one gentleman was asking the real-life battery consumption (real world figures) instead of the theoretical battery consumption. A later posting revealed that one battery was spoiled, and after he took it out of the system, he had a more realistic consumption. The section with the '>' was the original posted message. It shows how helpful the guys at www.otherpower.com can be.

View Thread | Post Response | Return to Index | Read Prev Msg | Read Next Msg

OTHERPOWER.COM Message Board

Re: battery current consumption (real world)

Posted By: Tom Dubya <mailto:earthsourcepowr@oneota.net?subject=Re: battery current consumption (real world)>
Date: Monday, 30 September 2002, at 7:46 a.m.

In Response To: battery current consumption (real world) (Richard Gormley)

Richard:

My battery system is beefier than yours but here are my consumption figures now from 1100 Ah of storage @ 12V:

I'm running PowerMac G4, 21 inch monitor, printer idling, 24 inch TV, satellite receiver, small air circulation fan, 17 Watt floro lite and a couple of "wall warts" off my 1500 watt inverter.

My batteries are a bit on the low side as its been cloudy.

Battery voltage under current load is 11.90 volts.

Current draw is about 22 Amps it fluctuates some depending on what the computer is doing mostly.

In theory with full batteries I could run this load for about 50 hours.

Laser printers are notorious for sucking power. They heat the platen constantly when powered on even at idle.

Just what I'm seeing. And to me your current consumption seems in line with the norm.

Are the bats full of water? Do you have nice, heavy cables connecting them and the inverter?

Have you tested the specific gravity of the acid? A hydrometer is fairly important for checking batteries I suggest you buy one at the auto parts store. They are pretty cheap. Or borrow one perhaps.

3 12V 210 Ah batts [630 Ah total] should supply you with 20 amps for around 30 hours from topped off batteries with no problem.

Other things to consider are loose or ugly connections [corrosion] which can and will drop voltage, a bad battery(s) or the batteries never actually get fully charged or undersized battery cables.

From here I think you have a bad battery but that is assuming they are properly watered, fully charged and well connected.

You could try pulling individual bats out of the bank to see if performance improves and if it does you've found your bad battery. Check water level, specific gravity in all cells and you may find a problem that way. Without more details its tough to call this one.

Also realize that others here are more experienced with batteries than I am.

Cheers. TomW

> Hi all, what kind of battery current consumption are you pulling from your
>batts? I`m concerned that running my Computer, Screen (19") Laser Printer,
>small TV and CF lights all together is puling 20 amps or so from my batts, I
>think the batts must be buggered as even with all 3 batts (210amphour units in

>parr,12v) the inverter (800Watt) will very quickly take the loaded voltage down
>to 10v (inverter shuts down at 10volts) This process will give me power for
>about 3 hours, then that's it till they are recharged. Do I simply need more grunt
>(amphour capacity)? What kind of Amp pull are people taking from there batts?
>(I would like to compare real world figures) Thanks, Richard.

Messages In This Thread

battery current consumption (real world)
Richard Gormley -- Sunday, 29 September 2002, at 9:42 p.m.

- **Re: battery current consumption (real world)**
  Adrian -- Monday, 30 September 2002, at 5:51 a.m.
  - **Re: battery current consumption (real world)**
    Tom Dubya -- Monday, 30 September 2002, at 7:46 a.m.
    - **Re: Batteries**
      DanF -- Monday, 30 September 2002, at 9:06 a.m.

APPENDIX A: Price Lists Of local suppliers (As OF August 2003)

GamSolar: 460189 Kotu: From Shell, go to B+B Junction, make a left, 300 meters down on the left. Mr. Touray is an electrical engineer, and will design systems to provide the maximum amount of sales for his business (for instance, he will try and have a system which will provide power for 4 full days if there is no sun. Yet, this is the Gambia, and there is usually sun at least every 2 days. They have quality equipment from Germany and Japan. They are a little slow at getting back to you, so you have to keep on them for information. The table below is as of October, 2002. To compare with the rest of the other price lists, add approximately 15% to these costs to get an idea.

Description	Price in Dalasi	Description	Price as of Dalasi
PV Modules (in watts)		**Lights and Accessories**	
LGE 12-watt, amorphorous	1600	Solsum DC-light, 11 watt	350
Shell Solar 24V, 95W	9350	Solsum DC-light, 7 watt	300
ISOFOTON 50W	4950	Lamp holder for Solsum light	15
ISOFOTON 110W	9950	Solsum LED	250
ISOFOTON 165W	15540	Rondo halogen DC, 10 watt	125
Charge Controllers (amps)		Spare halogen	60
LGE Regulator 6-amp	750	Labcraft, Batten light (set of 4)	1200
LGE Regulator 10-amp	850	Labcraft light 8-watt	340
Steca 20-amp	2500	Labcraft 13-watt	360
Steca 30-amp	3500	Light switch, 16Amp, DC	125
Batteries (Amp-hour)		DC local light switch	15
Delphi 1000 sealed 60-AH	1600	Outlet and socket plug	125
Delphi 1000 sealed 115-AH	2600	Solumine Street Light	9850
Delphi 1000 sealed 135-AH	2900	**Inverters**	
6V, 130 AH	—	Steca Inverter (12V, 1200W)	26550
battery cable with fuse and clip	600	Solarix Inverter (12V, 550W)	8000
battery cable connector	16	Steca Inverter (12V, 200W)	4100
Cables / Wire per meter		Inverter, Sine-wave 1000W	28000
2 coil, 4mm	35	**Lantern**	
2 coil, 2.5 mm	25	Logic lantern (7W)	1600
2 coil, 1.5 mm	12	Replacement tube (7W)	95
2 coil, 0.75 mm	6	Print card for Logic Lantern	500
1 coil, 4 mm	38	battery for Logic Lantern	300
1 coil, 2.5 mm	26	blocking diode for LL	45
DC Ceiling Fan	4500	PV pump and controller, 6000 lt/day	30500

VM: 228904 Banjul. (Behind Muslim Senior Secondary School) Mr. Camara is a nice and friendly Gambian gentleman who has helped both the school and myself with system design and installation. They also have technicians to service equipment. This is the company that installed all of the DC-Light school systems in 1997 (Essau SSS, Albreda JSSS, Njaba Kunda SSS, Kaur SSS, among others) for at the time, they had a monopoly on quality solar components. Each school block of 3 rooms has on average (6) DC-lights, (2) 100-AH Solar Batteries, and (2) 50-Watt Siemens PV Panels. Administration blocks and libraries usually have more panels and batteries due to the larger energy requirements (3-5 panels per building).

<u>This is the e-mail (08/03) that Mr. Camara sent me including a basic price list and SAMPLE</u>

1. Solar panel 50w		D 10,500	
2. Solar Battery 100A		D 3, 500	
3. Charger Regulator:	8A	D 2,100	
	20A	D 3,700	
	30A	D 4,700	

4. Inverter:	Dutch made	1500w	D 32,000
	Dutch made	500w	D 15,000
	Chinese made	1200w	D 7,000

SAMPLE

A Customer needs a solar system to use the following appliances in his home.

1. One colour television and video
2. 10 lighting bulbs
3. A radio and tape recorder
4. Two electrical fans

This Customer will receive the following invoice from us.:

3 Solar panels 50w	@	D10,500	D31,500
3 Solar Batteries 100A	@	D3,500	D10,500
1 charger regulator 20A	@	D3,700	D3,700
1 Inverter 500w/1200w			D7000/D10,500 option

Installation materials and workmanship (if house is wired)	(If house is not wired)
D6,000	D10,000

Gambia Electric: 227335 (Banjul, near the Guinean Embassy—contact is Maria Ashcroft);
392150 (2 junctions on right from Jimpex Junction, heading towards YMCA)

Gambia Electric can also service electronic components like Inverters, provided they have the parts in the country.

Product	Size	Cost (Dalasi)	Comments

Inverters (Cherokee Brand)	500-Watt	6655	No-name
	1000-Watt	11315	"
Inverter (Sinergex)	1000-Watt	_____	Pure-sine wave
Panel (efficient for 5 yrs)	14-Watt	1800	good for small systems
Marine Battery (sealed gel acid)	100 AH	6050	not good for hot areas

MP Trading (Westfield Branch):

Product	Size	Cost (Dalasi)	Comments
Complete DC Light Set	40-Watt	150	Replacement bulbs are D35
PV Panel (Kyocera, Japan)	60-Watt	10,000	
	75-Wat	12,000	
	120-Watt	15,000	
Inverters (Avg. Quality, Japan)	300-Watt	1250	
	600-Watt	2900	
	1000-Watt	6500	
Car Batteries (Rocket Brand)	50 AH	650	
	75 AH	950	
	100 AH	1200	
	200 AH	2700	
Wire	1.5mm	120 Roll	100 yds., 3 coil
	2.5mm	80 Roll	100 yds., 2 coil
Generators	2.4 KVA	18,000	Honda Engine
	950 VA	5800	"
	2.4 KVA	9000	No-name Mfr.
	6.5 KVA	43,000	Honda Engine

Katib Electronics: 396270 Westfield Junction. Mohammed is a nice guy who knows his stuff about electronics, especially DC-systems. They make a lot of their own modified electronics, and can build circuits provided you supply the layout. Reasonable with costs, though always haggle with the given prices.

Product	Size	Cost (Dalasi)	Comments
PV Panel (Kyocera, Siemens, Sharp; all made in Japan)	60-Watt	10,000	
	75-Watt	15,000	
	120-Watt	20,000	

Car Batteries with Acid (Rocket Brand)	50 AH	750	
	75 AH	950	
	100 AH	1200	
	200 AH	3500	
Modified DC-Light (220VAC from 12V)	9-Watt	150	Not efficient

Dabaakh Malick Energy Centre: Pap Malick Sey is the General Manager, and I never talked to him. Someone gave me the his card and here it it: 390710 or 991931

APPENDIX B: OTHER HELPFUL ONLINE INFO

www.otherpower.com These people rock. They have an excellent discussion board, which answer any electrical question or alternative energy idea you might post. They are all a bunch of alternative power gurus around the world who, in their spare time, build things out of scrap parts (wind generators, mostly). It doesn't matter how 'silly' you might think the question is, they are there to help. Just post a question to the enthusiasts, and let them guide you.

www.mrsolar.com   A good all-around US-based company which has a helpful Frequently Asked Questions (FAQ) section.

Canadian Renewable Energy Network: http://www.canren.gc.ca/default_en.asp. Nice website about Artic Alternative Energy Programs. Specifically, they have an online glossary of definitions, acronyms, and unit conversions in case you come across some terminology that you don't understand. (http://www.canren.gc.ca/glossary/index.asp)

Article that appeared online at http://www.ecoworld.com/Home/articles2.cfm?TID=259

ECOWORLD — NATURE & TECHNOLOGY IN HARMONY

UPWARD trend

BP Solar means Sun Power

By Ed "Redwood" Ring

If the whole world consumed 500 quadrillion BTU's of energy in 2000, and that's only a bit generous, than a square of photovoltaic cells 200 miles on a side would have produced 100% of the world's energy requirements in that year. That's assuming 8 watts of output per square foot of PVs, 6 hours of sun a day year-round, and 70% efficiency after transmission and conversion.

When I visited BP Solar's photovoltaic manufacturing plant in Fairfield, California, I hadn't done the math in time to ask Mac Moore, Director of Building and Utility Markets for North America, how much it would cost to buy a square of PV's 200 miles on a side, capable of producing annually 16,700 gigawatt years (500 quadrillion BTU's)

Mac Moore at BP Solar

of electric power. But if it were up to BP Solar, photovoltaics would be well on their way to producing a substantial share of the world's energy.

Currently the total world manufacturing capacity for photovoltaics, according to Moore, is about 400 megawatts. Of that BP produces 60 megawatts, or 15% of the world output. When the Fairfield plant goes into full production early next year, another 10 megawatts per year will be added to BP's share. Despite dramatic lowering of costs to produce photovoltaics in the last decade, and skyrocketing overall energy cost, photovoltaics remain a minor player in global energy supply.

Photovoltaic cells take their place alongside wind and geothermal energy as "non-hydro renewables." It is the goal of Sir John Browne, the Chairman of British Petroleum, for "renewables to contribute 5% of the world's energy supply by 2020." That seems like a modest goal, until one considers the staggering increases in manufacturing of PVs and wind systems that will be required to achieve it. At the current rate of world PV production, it would take 175 years before photovoltaics supplied just one percent of the world's energy requirements.

Moore did get a chance to answer some questions about prices for more modest systems, because while PVs are not likely to totally replace conventional fuels anytime soon, they are now cost competitive with conventional electrical energy during periods of peak demand. At $10 per watt installed (assuming a 25 year life), PV generated electricity costs $.35 per kilowatt hour, which is under peak costs which frequently exceed $.40 per kilowatt hour and have gone much higher. This means that a relatively small percentage of electrical power from PV arrays can exert a powerful downward pressure on peak prices by contributing power to the grid when demand is highest.

According to BP's Moore, the lowest installed cost right now of PVs for large scale commercial orders is about $6 per watt, which is $.21 per kilowatt hour.

Recent California baseline prices have now gone up to $.15 per kilowatt hour, putting PV costs within striking distance of conventional electrical costs. Ironically, the viability of PVs has increased their price to the end-users, because current demand to purchase PVs is far beyond supply, and there is no end in sight.


BP Photovoltaic Plant

Over the next decade, it appears that PVs and renewables may have to

APPENDIX C: TROUBLESHOOTING FOR DUMMIES

Copy and pasted directly from **http://oneota.net/~earthsourcepowr/t-shoot4dummies.html** and edited for spelling mistakes. Tom is one of the otherpower.com gurus who has answered many of my questions. His e-mail is tom.dubya@in-box.net.

Troubleshooting For Dummies has been visited 361 times since 7.21.02.

TomW's Alternative Energy systems troubleshooting for dummies, version .001 July 2002

This document is and will be a work in progress so it will change as time and inclination permit.

If you have further questions or comments email me and I'll do my best to help. I only check this email account every other day or so and I might take awhile to get you a response.

Copy freely; just don't take credit for my work or the work of others.

Started by TomW [tom.dubya@in-box.net]

Since this document is geared towards the Alternative Energy [AE] and Renewable Energy (RE) fields I will try to concentrate on the systems and components most likely to be encountered in those fields.

Please, please always consider safety in your work. It is much easier to remove an eye or an arm than it is to replace it. Electric current can burn you, sparks can blind you, and heavy items can fall on you. Anything that spins has the potential for enormous kinetic energy; even a lightweight object can be lethal at high speed. Consider the 240-grain (about 1/2 ounce) pistol bullet very light and non-lethal in your hand. The same object traveling at several hundred feet per second (a piece off your windmill blade) and suddenly it becomes lethal.

Batteries can be **dangerous**. Let me repeat, Batteries can be **DANGEROUS**.

Not only do they contain a fairly strong acid that can consume metal, clothing, eyes and flesh but when charging they produce a combination of oxygen and hydrogen in a good mixture of explosive gases. Keep flames, sparks, cigarettes, lighters, welders, etc. well away from the batteries especially when they are charging. Provide plenty of ventilation. Wear eye, skin and clothing protection and flush any spills with plenty of water.

Batteries are able to put out an amazing amount of current [1000s of amps] instantly so keep metal objects well away from the terminals. In higher voltage systems like a 96-volt bank you could draw a spark across a quarter inch of air gap in the right circumstances. I have heard stories of wrenches getting across a big bank like that and the resulting short spewing molten lead from the battery terminals into the guys face and up the wall. Be very aware of this potential for destruction in high current sources, especially at higher voltages.

This document and any suggestions, plans or procedures are intended for adults and those without mental deficiencies that could cause errors in judgment where safety is concerned.

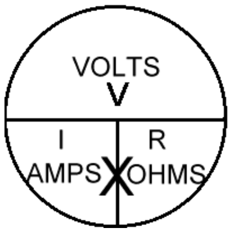
The most basic rule of troubleshooting:

Never assume a part or piece of test equipment is good, even if it is new and unused. Always test your meters, gauges, leads, connections and other components before you chase your tail looking for circuit problems. Miswiring is one big problem with the uninitiated. Always be certain of your connections to be sure that it’s wired properly and your connections are solid. Again never assume its wired right just check it with a clear head and don't rush it.

Even a brand new component can be bad. I like to test new components before I install them or at least before I energize a circuit. This simple step can avoid a cascade of damaged components from installing a bad component and energizing the circuit. It is also critical that you pay close attention to component lead markings and connect them properly. Misconnecting things can lead to circuit damage and weird problems that are confusing to the newbie. When you are using large battery banks the potential for destruction is immense. You can draw enough power from a large battery bank to instantly vaporize even fairly heavy copper cable and certainly kill things like diodes, inverters and controllers in an instant. It is very important that you pay attention and get help if you are unsure of how to connect something.

Basic test equipment needed is simply a volt-ohm-ammeter and I prefer analog [with a needle] because they need no battery to use except to read ohms [resistance]. These can be had new for about $15 or so US. Analog is nice for troubleshooting because you can see the meter move without looking directly at it. Digital meters are nice for precision comparison and can be used to troubleshoot I just prefer an old fashioned meter with a needle.

You can add other equipment as you go but a volt ohmmeter will do for almost everything we do in this field. If you need to measure current [amps] you will need an ammeter. The ammeters in the volt-ohm meters usually measure less than 10 amps and you can kill them with excess current. For use in AE systems you can use automotive ammeters up to 60 Amps you can parallel a couple of identical meters to read higher current by taking the reading times 2. For high current feeding from batteries to an inverter or other large load you will need a current shunt with matching meter these can be had for reasonable prices on Ebay and from electronics supply houses and can read into the 1000's of amps and the meter can be located some distance from the point at which you read the current in the circuit. I have been using a 150 amp shunt with a matching meter I got off Ebay for about $25 delivered. You could home brew a shunt and add a meter but thats beyond the scope of this document.



<u>Some basic facts about electricity:</u>
E= Voltage [volts]; I = Amperes or amps [current]; R= ohms [resistance]

I found this graphic somewhere that shows the relationship of voltage, current and resistance.

Regardless of the form electricity has [AC or DC] the 3 components we use to describe electricity have a mathematical relationship that can be expressed by the formula [E=I*R] or in English "Voltage equals Amps times Ohms". With a bit of high school algebra we can obtain the missing value once we know the other two. Another handy mathematical relationship for finding power either consumed or produced is Watts [P or Power] equals Volts times Amps. [P=i*E]. I have deliberately not included VA or Alternating current power relationships here its beyond the scope of this document. I will note that in an alternating current [A.C.] circuit the voltage and current are slightly out of phase with the amount of phase shift determined by the inductive and or capacitive characteristics of the circuit.

Well that was just some basic info to get you up to speed on that. Lets look at some common questions I have seen on the board with some solutions and how you can answer them yourself.

I have voltage at my mill but when I connect it to my diode or bridge rectifier I don't get any voltage to my batteries?

First. Be absolutely positive your connections are right to the bridge or diode. With a diode a reversed connection will block charging voltage/current and is not likely to damage the diode. With a bridge rectifier you can kill it by misconnecting it if your AC source [generator] has enough voltage and current available.

Assuming your connections are correct [because you meticulously checked] we can now start bugging out what may be wrong. I would start by disconnecting the batteries from the bridge or diodes and leaving the rest of the circuit intact.

With your meter set to DC range greater than your source [genny] voltage check the leads that feed the batteries. You should see DC voltage somewhere close to the source AC voltage but lower. Check for proper polarity on these leads by confirming that the + lead is indeed the + lead. If your meter tries to move backwards then polarity is reversed and no charging can occur. Reverse the leads to the battery leads if this is the case.

If there is no voltage at the DC leads from the diode or bridge then you need to check the AC feeding into the bridge or diode to see if it is there. If the AC is on the input to the bridge or diode and you have low voltage or nothing on the output then it is likely your bridge or diode is bad. If so you need to replace it with a good one. But first see if the AC is present when not connected to the AC leads of the bridge to be certain it is not getting loaded down to zero by the bridge for some reason.

Testing diodes: A diode is simply a one-way valve for electricity, at least for our purposes. Most diodes will drop [use] about .7 volts across its leads when passing current. The most common failure modes of diodes is either shorted [passes the AC like a wire] or open [nothing gets through]. Occasionally a diode will test OK but fail under load so just because it tests OK does not mean it works under load.

Testing a diode is simple. You need an ohmmeter. You simply set your ohmmeter to its highest range and place one ohmmeter lead on each lead of the diode. You should get a high reading in one direction and a low reading in the other direction. Please note that an ohmmeter reads "backwards" and a low reading will deflect the meter more than a high reading. The actual numbers don't matter as long as one is significantly higher than the other. If the meter pegs both ways it is shorted. If the meter does not move either way it is open. To test the ohmmeter, short the leads together and the meter should peg to the right showing 0 ohms.

Testing bridge rectifiers: Testing a bridge is a bit more difficult so I usually just give them a function test. Simply disconnect the + and - connections to the batteries and check for DC on those leads. If there is no DC on those leads then check the AC leads to see if the source voltage is present. As always be certain your meter is set to the proper function and range. If no AC is present try disconnecting the AC leads and check for voltage. If AC is present with the bridge disconnected the bridge may be shorted and loading the voltage down to zero. Before you replace the bridge try connecting a load to the AC lines a light bulb is a good choice but be certain it can handle the raw AC voltage level. If the AC source can light a bulb then your source is likely OK so replacing the bridge may cure the fault.

If the AC is present but no DC is available on the output it is a fair assumption that the diode or bridge is bad.

If everything is OK with the batteries disconnected but you get nothing when you connect the batteries you may have a bad battery bank or a diode / bridge that fails under load. Check to see that your batteries are capable of taking a charge and that they show at least some voltage at their terminals when disconnected from the charging source.

Series and Parallel Circuit Basics: I have seen some confusion about how series and parallel circuits function. I'll try to clarify some of the main points. For simplicity I will not address reactive circuits [containing capacitors and inductors] but only talk about Direct Current resistive circuits.

A series circuit is comprised of components connected + to - to + to - in a string much like people holding hands around a circle. You end up with two ending leads one + and one -.

In a series circuit the total voltage will be the sum of the voltages connected. Total current will be somewhere between the highest and lowest current rated sources. *A formula will go here, one day.*

In a parallel circuit we have components connected with all the + leads together and all the - leads together. Much like two people facing one another holding hands, with 12-volt sources in parallel we would have a 12-volt output. The current [Amps] available would be the sum of all the sources.

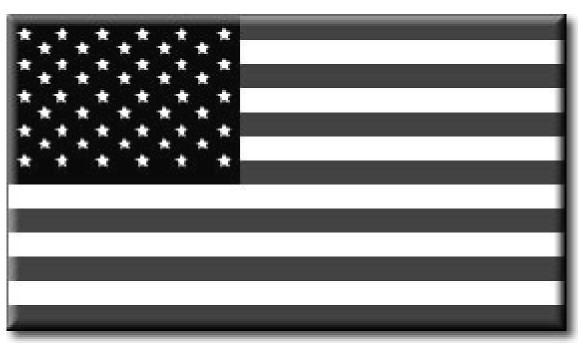
For example say we have 3 solar panels rated at 12 volts. 2 of these panels are rated at 5 amps [60 watts] and one is rated at 10 amps [120 watts]. This leaves us with 2 60 watt and one 120 watt panels. The total will be 240 watts, regardless of how we connect them [series or parallel]. If we connected all 3 in series we would have 36 Volts @ 6.66 Amps and 240 watts. If we connected them in parallel we would have 12 Volts @ 20 Amps and 240 Watts.

Most importantly you need to match your source voltage to your battery bank to be efficient. I do not believe that charging a 12 Volt battery at 36 volts would damage the battery but it would be very inefficient because your battery would load the 36 Volts down to 12 Volts and you would end up with only 6.66 Amps @12 Volts for only about 80 watts or a loss in the wire of 24 Volts @ 6.66 Amps and you would lose 160 Watts as heat in your wire or panels.

Without special equipment or an elaborate switching arrangement you cannot charge a higher voltage battery bank with a lower voltage source. IE: you can't charge a 24-volt [or larger] bank with a 12-volt source. In order to achieve charging you must have a greater voltage from your source than the voltage of your storage batteries.

More to come..

TOMW



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