African Energy™

Africa's Source for Renewable Energy

Technical Primer

A Practitioner's Guide to the Solar Energy and Power Backup Business in Africa

Welcome to the world of renewable energy - the most enjoyable industry on Planet Earth! Yes, it is possible to make a good living from renewable energy and to have fun doing it.

INTRODUCTION

You will find that people use renewable energy for many reasons: some feel it is a contribution to improving the environment; some want to appear trendy; some are techno-geeks and think it is fun; some use it because subsidies make it financially attractive. In Africa, we use it because we need it.

First, let's discuss what today's commercially available renewable energy equipment can do - and can't do. The equipment and systems discussed here generate electricity and are not used for heating water or air. Heating is done by solar thermal systems - here we are discussing solar and wind electric systems. Solar electric panels (also called photovoltaic modules) create electricity from light, not from heat.

So, if we are generating electricity, then can we power any electric device? Yes and no. Yes, technologically it is possible to power any load (that's what we call any device that uses electricity), but there are some loads that are not economically feasible. For example, to power a house full of split-unit air conditioners in Lagos or Luanda with solar would be prohibitively expensive (even by Nigerian or Angolan standards). And in 99% of African situations, solar and wind are not cheaper than the electricity available from the grid (meaning the state-run electric utility--NEPA, KPLC, ESKOM, Sonalec, etc.)

As a point of reference, the cost of electricity from your utility would usually need to be above US$0.30/kwh, in order to consider solar as a cost saving measure in your country. Your country's cost is probably less than US$0.15/kwh. So, we don't suggest selling solar as a replacement for utility power.

However, you can sell a **power back-up system** as a very good solution for places where the grid is not reliable. These systems store grid electricity when the grid is working and then provide power to the loads when the grid fails. And these are very practical solutions for places like Luanda and Lagos (except for powering air conditioners).

What Is Electricity?

Now, let's learn more about electricity. Electricity is the movement or flow of electrons creating an electrical current. **AC electricity** is alternating current and is the kind most frequently used - it is the kind of electricity your utility or generator provides. AC electrons change polarity (alternate forward and backward) many times every second. These magnetically charged electrons are seeking to mate up with electrons of an opposite polarity to neutralize their charge. Well sort of…to be honest, electricity is a phenomenon that no one truly understands. Most African countries, like European countries, use 50hz electricity (usually at 220-240 volts) meaning these electrons alternate 50 times per second. AC electricity cannot be stored in a battery - it must be used when created.

DC electricity is direct current - the kind found in your car battery, in static discharges, and in lightning. DC electrons move in one direction -from positive to negative, and can be stored in batteries. Solar modules produce DC electricity.

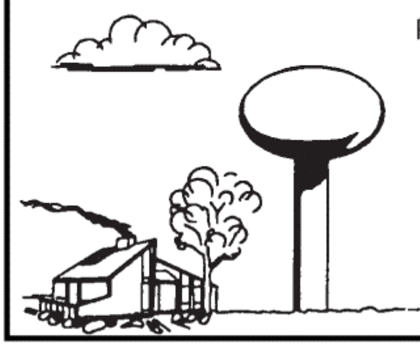
Solar modules produce electricity through the **photovoltaic effect (PV)** that causes a flow of electrons within the silica sealed inside the module. The electrons are excited by particles of light striking the silica and travel through the electrical circuits attached to the face of the silica cells in order to reach an opposite charge and neutralize themselves. This flow of electrons from positive to negative is, by definition, electricity.

Solar panels produce DC electricity, and in most cases we store the power in a battery, and then draw it back out either to DC appliances, or through an inverter that will convert it to AC power. The battery, therefore, becomes the heart of the system. The only times your renewable energy systems won't use batteries is if they are directly powering a DC device like a solar water pump that works only while the sun shines.

<u>Electrical Terms and Calculations</u>

The building blocks of an electrical vocabulary are voltage, amperage, resistance, watts and watt-hours. Electricity can simply be thought of as the flow of electrons (**amperage**) through a copper wire under electrical pressure (**voltage**) and is analogous to the flow of water through a pipe. If we think of copper wire in an electrical circuit as the pipe, then voltage is equivalent to pressure and amperage is equivalent to flow rate. To continue with our electricity to water analogy, a battery stores energy much as a water tank stores water. Since a column of water 2.31 feet tall produces 1 psi at the base, the taller the water tower, the higher the pressure you get at the base. As you can see from the picture below, the mushroom shape design of a water tower allows it to provide a large volume of water at between 40-60 psi. Once drained below 40 psi, which occurs near the neck of the tower, continued water usage will rapidly

Many water towers are physically shaped like a mushroom. Electrically speaking, batteries are mushroom shaped as well. A tower designed to produce 50 p.s.i. for household pressure might be built like this.



PSI	FEET	VOLTAGE
60	139	12.70
50	115	12.57
40	92	12.43
30	69	12.30
20	46	12.17
10	23	12.03
0	0	11.90

deplete the water supply at an ever decreasing pressure.   Although a 12 volt battery is not physically shaped like a water tower, it has most of its stored electricity available between 12 volts to 12.7 volts. When drained below 12 volts, little amperage remains and the battery voltage will decrease rapidly.

In a simple system, a power source like a solar module provides the voltage which pushes the amperage through a conductor (wire) and on through a load that offers resistance to the current flow which in turn consumes power (watts). Power is measured in **watts** and is the product of voltage multiplied by amperage. Energy is power (watts) used over a given time frame (hours) and is measured in watt-hours or **kilowatt-hours** (1 kilowatt-hour equals 1000 watt-hours). For example, a 100 watt light left on for 10 hours each night will consume 1000 watt-hours or 1 kilowatt-hour of energy. A kilowatt-hour is the unit of energy measurement that the utility company bills you for each month. Electrical appliances are rated in terms of how many watts (or amps) they draw when turned on. To determine how much energy a particular appliance uses each day, you need to multiply the wattage by the number of hours used each day.

Now that you know the formula for power (**watts = volts x amps**), be sure to remember that different voltages (ie: 12, 24, 48) do not necessarily mean any change in total power. For example, 6 amps at 12 volts is the same amount of power as 3 amps at 24 volts or 1.5 amps at 48 volts. It is still 72 watts. A watt is a watt is a watt. For our purposes, changes in operating voltages do not change overall power. A 24 volt battery bank of 300 amp hours is equivalent to a 12 volt battery bank of 600 amp hours.

MARKETS

Now that you have an idea of how these systems work, let's talk about how they can be useful in Africa. There are several distinct markets that seem to develop in most African countries:

1. Solar Home Systems (SHS) and Lanterns

These are small systems intended for homes without grid electricity and with no AC wiring. Typical systems include a solar module ranging from 7w to 50w, a charge and load controller, several DC lights, and a small 12v battery (usually an automotive starting battery bought in the local market). Often these systems include a small inverter to power a television or a fan.

This market segment also includes self-contained solar lanterns that have their own batteries and solar modules. As you might guess, price is very important in this market. And because the systems are small and prices are low, you need to generate significant volumes in order to make this market attractive. That can and is being done, and experience has shown that once a market opens, the volumes can be surprising.

Educating consumers is a major factor in building this market. Evaluate what has been done already in your country, because it will take more than just one company in a country to really create a market. Usually these markets grow out of a combination of aggressive solar companies, promotion by government, and assistance from donors (although donors can also spoil your market with subsidies if they are not careful).

We suggest that, as quickly as possible, you get yourself out of the position of installing these systems. There needs to be enough local expertise, and your systems need to be simple enough for them to be installed at the village level without your direct involvement. The availability of traditional or imported finance and public acceptance of solar are important factors to consider. To be successful in this market, you need to have stock (product) on hand at all times, as SHS customers will generally buy when they are ready, and won't want to wait while you import stock.

2. Inverted and Communication Systems

This is a market that will use larger systems - systems that will primarily produce inverted AC electricity. These include remote office systems, health clinics, schools, camps and farm or bush residences. The target market for these systems is much smaller, but their ability to pay is much greater. You will normally be installing and servicing these systems directly. Power sources for these systems in Africa will be primarily solar, with many hybrids using wind and generators also.

This market segment also includes communication service providers such as mobile phone, wireless, and radio providers. Very large build-outs by mobile phone companies will normally be contracted out to major manufacturers like Kyocera or BP, but you can be successful in designing and installing systems for smaller tenders.

Your technical abilities and your ability to attract significant clients in your country will determine your success in this market. It will be more difficult to hold stock (product) for this market, as the systems will vary in components required. Have enough on hand to do a few simple systems and to demonstrate to clients, but then you can plan on ordering any other necessary components in by air once you have confirmed orders.

To compete well in this market, you should consider that you will need the basic tools of a commercial electrician or air conditioning installer. That means a few technicians, a vehicle, a workshop, and some tools.

3. Power Back-Up

This is a market you can develop in any city where grid power is available but unreliable. These systems act as UPS (un-interruptible power systems) and in places where power is unreliable, every office should have one. You can also sell these wherever people are using generators, because power back-up systems can reduce their generator run times. The simplicity of the systems means that it is easier to keep stock, especially of good deep cycle batteries. Education is also a key in developing this market. Your clients may include banks, telecom companies, and government services, as well private companies and individuals. You will need good AC/DC technical abilities and either your own stock or access to a stock of good batteries.

4. Water Pumping & DC Motors

This market gets its own heading because it is the only one that is PV direct (direct solar load without batteries). Although solar water pumping comprises 99% of this market now, there may be an untapped market for other DC motor applications, such as grinding mills or cooling equipment in your country.

Water pumping systems in Africa are commonly sold to institutional buyers such as government, donors, or NGO's. Private buyers are usually not frequent enough to sustain a market solely on water pumping. Most of your sales will probably include installation, so you will need the ability to travel to rural areas and get the work done.

CONCLUSION

So, finish reading this training handbook while thinking about the markets that best fit your circumstances. We have found that there are three essential factors that determine success in this business:

1) A concentrated effort and desire to make it work
2) Technical and marketing ability
3) Access to at least some capital.

We have seen hardly anyone fail in this business in Africa if they possessed those traits.

SYSTEM SIZING

This is the most important thing to learn in the business. You must know how to calculate the amount of energy required by your clients and the amount of equipment they will actually need to meet that requirement. Africa is littered with the remains of solar "entrepreneurs" who never learned or cared about this crucial part of renewable energy. They said they "weren't technical" and promised what they couldn't deliver and left their clients believing that "solar doesn't work." As a consequence, all of us in the industry suffer. Please be diligent and avoid this mistake.

So, first - understand the **load**. That means knowing how to calculate the amount of power your client requires. Since you know the formula for power, this is easy. Simply list out the various appliances or loads that your client will run - together with their consumption in watts and hours of run time. If you don't know the wattage of an appliance, read the label, check the sample sheet on the back of this manual or test it with a meter.

Here's a typical example for a small home system:

Load	Quantity	Watts	Connected Load	Hours	Total Watt Hours	System Loss	Watts Required	Charging Voltage	Amp Hours Required
Light	3	15	45	3	135	1.15	155	13	11.92
Fan	1	50	50	5	250	1.15	288	13	22.15
Total			**95**		**385**		**443**		**34.07**

- **"Connected Load" gives the total number of watts connected at any one time, and will be used for sizing your inverter.**

- **"Total Load" tells how much power your loads are using.**
- **"System Loss" compensates for the power lost in transmission (remember resistance?) and in and out of the battery.**
- **"Watts Required" tells you how much power you need to put into the system (or down the wire) in order to yield enough for your "Total Load".**

Now that you know how much power you will use in a day, you can think about your available power sources and you can start to select a system voltage. Most small systems are done at 12 volts; medium and larger systems are done at 24v or 48v. Because it takes more than 12 volts to charge a 12 volt battery (remember the water tower example), we can use 13/26/46 volts as the sizing voltages in our calculations. Dividing the wattage by the voltage gives us the total amp hours required to run our system for a day. We are now ready to talk about the heart of your system - your batteries.

BATTERIES

Batteries are the heart of your system because they store all of the energy you produce. (Unless you are doing a water pumping system, in which case you must have a water tank to store your daily production-very similar in concept to a battery.) If you use poor quality batteries, or you don't use enough batteries, your systems will always have problems - and your clients will blame you and the technology. Since batteries are usually the cheapest components in the system, it makes perfect sense to spend a little more and build a successful system by not cutting corners on the batteries.
In renewable energy systems, we commonly use lead acid batteries. This is the same technology that you find in your car battery, and in fact, automotive batteries will work in renewable energy systems for a limited time. The problem with automotive batteries is that they are shallow-cycle, meaning that the lead plates within the battery are thin, and are designed for supplying almost all of the battery's energy in a very short time (5-10 minutes). This is exactly what your car engine needs to start, but your renewable energy system needs to draw energy out of the battery over a much longer period of time (20 - 100 hours). If you use automotive (also called shallow cycle) batteries in your system, they will not run as long, the thin plates will soon give out, and your batteries will fail.

Deep cycle batteries have thicker lead plates, which have less overall surface area as compared to an automotive battery. Because of the lessened availability of surface area for chemical reaction, deep cycle batteries produce less current than a shallow cycle battery but can produce that amount of current for a much longer period of time.

In battery language, a **cycle** on your battery bank occurs when you discharge your battery and then charge it back up to the same level. A lead acid battery is designed to absorb and give up electricity by a reversible electrochemical reaction. How deep a battery is discharged is termed **depth of discharge (DOD)** while the **state of charge (SOC)** is 100% minus the DOD. This means that a 25% DOD equals a 75% SOC. A shallow cycle occurs when the top 20% or less of the battery's energy is discharged and then recharged.

So, our suggestion is to use **deep cycle batteries** whenever possible and cycle them as low as possible.

Flooded - The most common type of deep-cycle battery is a flooded lead acid ("plomb ouvert" in French). These battery's vent caps can be opened allowing you to add water to extend their life. Since they are not sealed, they also discharge hydrogen and oxygen when charging, meaning that you should provide a way for the batteries to be vented to the outside. Because these batteries are not sealed, they will need to have distilled water added to them every 2-3 months. Remember that we only add distilled water and not electrolyte (battery acid/sulfuric acid) since only the components of water have escaped (oxygen and hydrogen). These batteries will also need an equalization charge, which means a charge at a higher than normal voltage occasionally to re-mix the sulfates.

Flooded batteries will give the longest life of any lead acid battery and have the best price, but do require periodic (and correct) maintenance.

Another advantage of flooded batteries is that they can be manufactured "dry", meaning without electrolyte (acid) in them. This is important in Africa because batteries start to lose their charge as soon as they are charged. Flooded batteries have the highest self discharge rates. For example, within 6 months of manufacture they could be almost 100% discharged if they are left sitting without a charge. And once a battery becomes fully discharged it can suffer irreparable damage - in fact, even allowing it to sit too long at a partially discharged state can cause damage. So, "dry" shipped batteries allow you to avoid that problem by only adding electrolyte and charging them when you are ready to use them.

(You may also find sealed lead acid batteries in your markets. They are simply flooded batteries that can't be opened. These are "maintenance-free" meaning they can't be maintained because you can't add water. We don't recommend them, because they will have a very short life in a renewable energy system.)

AGM - Absorbed Glass Mat batteries are the newest type of sealed (maintenance-free) battery. Their electrolyte is absorbed in a glass mat, as the name implies. AGM batteries have a low self-discharge and are generally good performers, although they won't last as long as a maintained high quality flooded battery. AGM batteries can also be used even when tipped on their side and emit no gases. AGM batteries are more expensive than their equivalent flooded battery.

AGM and all sealed batteries need to be charged at a lower rate (to keep them gassing) and most charge controllers and inverter/chargers have a setting for sealed or flooded batteries.

Gel - Gel batteries are similar in many respects to the AGM batteries. Their electrolyte is fixed as a gel - they are also maintenance-free. They are the best performers in hot environments, but have the slowest charge rate of any battery. They are slightly more expensive than AGM batteries but can give twice the cycle life. Historically, they have been the best performers in Africa.

So, remember that maintenance is essential for flooded batteries - if they are going to be installed in a place where distilled water can't or won't be added- your system will fail. In Africa, AGM or Gel batteries are often a better choice because of the problems of maintenance.

A Battery's Life

Battery **state of charge** is determined by reading the static (i.e. not charging or discharging) battery voltage or the **specific gravity** of the electrolyte. The density or specific gravity of the sulfuric acid (H2SO4) electrolyte of a lead acid battery varies with the state of charge and temperature. The density is lower when the battery is discharged and higher as the cells are charged. This is because the sulfates are suspended in the electrolyte when the battery is charged. Specific gravity is read with a hydrometer, which will tell the exact state of charge. A hydrometer cannot be used with sealed or AGM or Gel batteries.

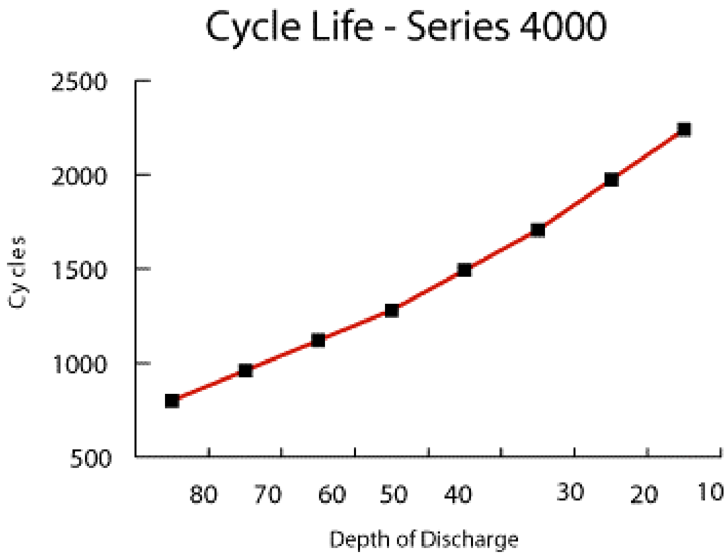
Voltage meters are used to approximate the battery's state of charge. They are relatively inexpensive and easy to use. The main problem with relying on voltage reading alone is the high degree of battery voltage variation through the working day. Battery voltage reacts highly to charging and discharging. In a PV system at any one time, we are usually either charging or discharging the batteries, and sometimes we are doing both at the same time! As a battery is charged, the indicated voltage increases and as discharging occurs, the indicated voltage decreases.

These variations may seem hard to track, but in reality they are not. A good accurate digital meter with a tenth of a volt accuracy can be used with success. The pushing and pulling of voltage, once accounted for by experience, can also help indicate the amount of charging or discharging that is taking place.

By comparing voltage readings to hydrometer readings, shutting off various charging sources or loads and watching the resulting voltage changes, the system owner can learn to use indicated voltage readings with good results.

It is worth repeating: the most important factor in your battery's life is the depth of discharge. This means how much of your battery's available energy you draw out in each cycle (before re-charging it). The deeper the discharges, the shorter the life (the less cycles) in a battery.

So, let's go back to your sizing worksheet. We determined that we need 34.07 ah per day. If we selected a 43ah battery, we would be cycling it to 80% depth of discharge each day (34 / 43 = 80% - almost). Look at the sample chart below (for Surrette Batteries) to see what this implies about the number of cycles a battery would provide at that depth of discharge before dying.



Now what if we used a 110ah battery? We normally recommend that a battery system be sized for no less than 50% depth of discharge. Clients always use more power than they anticipate, so it is a good idea to add a cushion to your calculations. And with solar systems, a planned 20-30% depth of discharge leaves you a few days of safety (autonomy) in case of heavy cloud cover for a few days.

Battery sizing in power backup systems is typically more aggressive - 50% to 80% depth of discharge - in order to reduce cost. Be sure to inform your clients of the number of cycles they can expect at their chosen depth of discharge. Then let them chose whether to spend a little more now or a lot more later, depending on their cash flows. In Africa, the customer will almost always choose to discharge more deeply now and replace them more often.

<u>Cable Sizes</u>

It is absolutely essential that you use the correct size of cables and wires for every part of your system. The bigger the wire, the less resistance and the more efficient your system will be. Wires and cables that are too small will overheat, cause fires, and decrease efficiency. In fact, your inverter may not even start some loads if your battery-to-inverter cables are too small. Remove the wire sizing chart in Appendix A, laminate it, and use it every time you size a system. If you can't find big enough cables on your local market, order them from African Energy or use several smaller cables together in parallel.

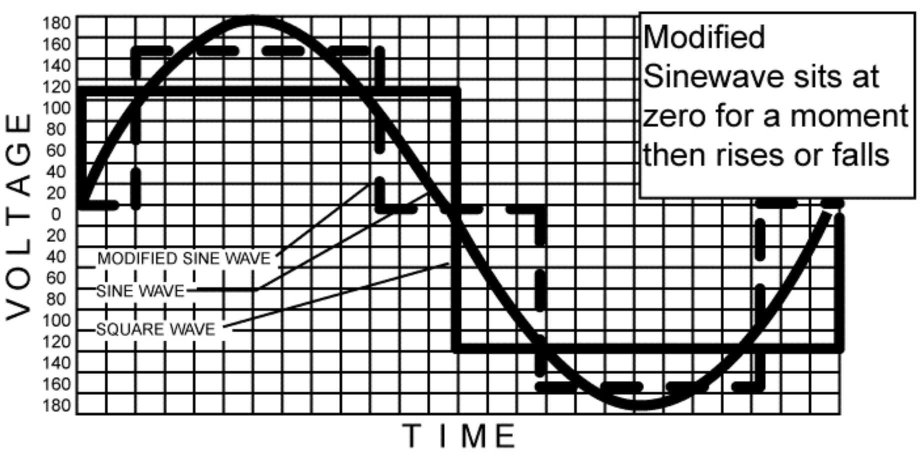
<u>Inverters</u>

Remember that DC electricity is stored in you battery, but AC electricity is needed to power most of your loads. An inverter is the piece of equipment that gets your power from DC to AC. Inverters come in all quality grades and capacities. Most small (100w-1000w) cheap inverters on the market are of the high frequency type. They are lightweight and are not intended for frequent use or high surges. They work for running a small television, a cell phone charger, etc. However, they are not appropriate for running larger loads on a continuous basis. For larger loads we use transformer-type inverters which can handle surges (when your client plugs in loads that exceed the inverter's normal rating) and can also run continuously without burning out.

Waveforms

Unfortunately, in the world of alternating current electricity, not all waveforms are created equal. When we talk about waveforms, what we are interested in is the shape of the wave that an AC signal traces with relation to time as it switches directions. It is a question of how smoothly the switch occurs.

The three most common outputs for inverters are square wave, modified sine wave (sometimes called a quasi sine wave), and sine wave outputs. Here, we will look at these waveforms, and how different types of loads behave when operating from them.



The sine wave smoothly increases to its peak and smoothly decreases in a perfect S shape. Modified sine waves and square waves shoot straight up, level off at peak voltage, and then drop straight down as the current changes directions. The modified sine wave also sits at zero (neutral) for a short period, giving an extra step. This is the main difference between it and the square wave.

Most devices with variable speeds such as electric drills, or devices with chargers such as cordless drills or screwdrivers, can behave irrationally when operating with modified sine or square wave inverters. These types of units use one of two types of solid state "switches" in them, SCR's (Silicon Controlled Rectifiers) or Triac's.

The basic theory is that a timing circuit looks at the point where the waveform crosses zero volts and uses this point as a reference to start its clock. On a drill for example, depending on how much the trigger has been moved, a certain amount of electricity will be allowed through based on this time. Think of it as a water wheel that has been mounted under a faucet that you control. If the water always comes out in smooth rising and falling surges, you could count when the surge hit zero pressure and then by delaying how much of each surge gets to the wheel you can control its speed. If you let the entire surge from zero up to peak pressure and back to zero pressure through the faucet, the wheel will spin the fastest. If you only let the portion of the surge from zero pressure through peak pressure through the faucet, the wheel will run about half speed.

If there was no way to time this process it would be impossible to know exactly when to turn the faucet on and off to achieve a desired speed.

Since a sine wave has a sloped "zero crossing" (the point where the voltage passes through zero volts), the timing circuit will work. It knows when to turn the switch on or off. However, if the wave passes through zero too fast or sits at zero for a period of time, the timer gets confused. It doesn't know where zero is. The reason is that it looks for the rate of change or the slope of the zero crossing point. A modified sine or square wave has no slope. Therefore, the timing circuit can't figure out when to let power through and when not to. Since the timer never starts, no power passes through to the device at all. When the trigger on the drill is pulled all the way to high speed, the whole SCR and timer circuit is bypassed and the drill runs at full speed. This explains why all or none is available in some drills. Others will run erratically and won't be variable.

Battery chargers experience the same problems. The Triacs (switches) don't know when to let electricity through since they can't find the zero crossing. Therefore, inadequate (if any) charging will take place. Some chargers will react opposite and allow full power through, possibly overheating them. Small wall-based chargers will often have overheating problems with modified sine or square wave inputs.

Sensitive stereo equipment or PBX phone systems will also hear some static on the line from a modified sine signal. We have also found that some fan motors tend to overheat and have shorter lives when running on a modified sine.

Unfortunately, it is hard to predict what exact models of equipment will have problems with modified sine wave and square waveforms. The only way to know for sure is to try it. As a point of reference, the most popular inverters in Africa are the Xantrex (Trace) DR series which produce a good modified sine. They power most loads, with the exceptions noted above.

INVERTER/CHARGERS

The recent development of high quality inverter/chargers with fast automatic transfer switches has opened a whole new market for back up power in Africa. These units act as giant UPS (un-interruptible power systems) that can handle the loads of offices, homes, etc. In designing these systems, size your inverter for the "connected load" from the sizing worksheet - and then add a bit more for future loads. You must also take into account any loads with surges. For example, electric motors typically have a starting surge which is 2 to 3 times their rated consumption. Be sure to leave enough room in your inverter sizing to allow for these loads. You can assume that Trace/Xantrex and Outback inverters will surge momentarily to twice their rated capacity for motor starts, etc.

Also pay attention to the charging capacity of each unit. A general rule of thumb is that charging rates should not be set above 20% of the battery bank capacity. Be sure you have a big enough charger to match your battery bank. This is also a good time to discuss multi-stage battery charging.

Battery Charging

A typical 12-volt lead-acid battery must be taken to approximately 14.2-14.6 VDC before it is fully charged. (For 24-volt systems, double these figures - for 48 volt, multiply by four.) If taken to a lesser voltage level, some of the sulfate deposits that form during discharge will remain on the battery's lead plates. Over time, these deposits will cause a 200 amp-hour battery to act more like a 100 amp-hour battery, and battery life will be shortened considerably. Once fully charged, batteries should be held at a lower float voltage to maintain their charge – typically 13.2 to 13.4 volts. Higher voltage levels will "gas" the battery and boil off electrolyte, requiring more frequent maintenance.

Most automotive battery charger designs cannot deal with the conflicting voltage requirements of the initial “bulk charge” and subsequent “float” or maintenance stage. These designs can accommodate only one charge voltage, and therefore must use a compromise setting – typically 13.8 volts. The result is a slow incomplete charge, sulfate deposit build-up, excessive gassing and reduced battery life.

The charger available in Xantrex/Trace and Outback inverters automatically cycles batteries through a proper three-stage sequence (bulk, absorption and float) to assure a rapid and complete charge without excessive gassing. Factory battery charger settings on most inverter-charger combinations are optimal for a lead acid (liquid electrolyte) battery bank of 250-300 amp hours in a 70°F environment. If your installation varies from these conditions, you will obtain better performance from your batteries if you adjust the control settings.

The Maximum Charge Rate in amps should be set to 20-25% of the total amp-hour rating of a liquid electrolyte battery bank. For example, a 400 amp-hour bank should be charged at no more than an 80 -100 amp rate. Excessive charge rates can damage batteries and create a safety hazard. The Bulk Charge Voltage of typical liquid electrolyte lead acid batteries should be about 14.6 VDC. There is no one correct voltage for all types of batteries. Incorrect voltages will limit battery performance and useful life. Check the battery manufacturer’s recommendations.

The Float Voltage setting should hold the batteries at a level high enough to maintain a full charge, but not so high as to cause excessive "gassing" which will "boil off" electrolyte. For a 12-volt liquid electrolyte battery at rest, a float voltage of 13.2-13.4 is normally appropriate; gel cells are typically maintained between 13.5 and 13.8. If the batteries are being used while in the float stage, slightly higher settings may be required.

Charge voltage guidelines used here are based on ambient temperatures of 70°F. If your batteries are not in a 70°F environment, the guidelines are not valid. Temperature Compensation automatically adjusts the voltage settings to compensate for the differences between ambient temperature and the 70°F baseline. Temperature compensation is important for all battery types, but particularly gel cell, valve-regulated types which are more sensitive to temperature.

ESSENTIAL ACCESSORIES

Every inverter installation should have a way to disconnect the inverter from the battery (other than pulling the cable off the battery) and should also have **over-current protection**. "Over-current protection" means a device such as a breaker or fuse that will disconnect the line if too much current (amperage) tries to pass down it. This will protect your inverter in case your batteries should have a fault (short circuit) and vice versa. You can accomplish this with a **DC breaker/disconnect** installed in the positive cable from battery to inverter. Remember to tape those cable together, as well. This reduces impedance and improves efficiency of your power transfer. Also remember to connect an earth/ground cable to every component of your system (ie: inverter box, disconnect, controller, etc.) and to bond it with your AC ground & DC negative at only one point in the system. You may also want to consider a **battery temperature sensor** which will connect to your Trace or Outback inverter/charger and regulate the battery charge rate to keep your batteries from overheating. This is particularly important if your batteries will be installed in a hot place or if you will be charging at a high rate. A **battery capacity meter** of some sort will also help your clients to better manage their energy use by showing the amp hours left in their battery bank.

POWER GENERATION - SOLAR (PV)

Now that you have an understanding of storing and inverting power, the study of generating it will be easy. Let's consider solar as a generating source first. Remember that light striking the silicon cells within a module excites the electrons in the silica molecules, causing them to move down the conductive tabs and out the wires of the solar module. In a typical solar module, this electricity will leave the module at between 16 and 18 volts under load. The voltage and amperage of each module is determined by the size and number of "cells" or thin slices of silicon that make up the module.

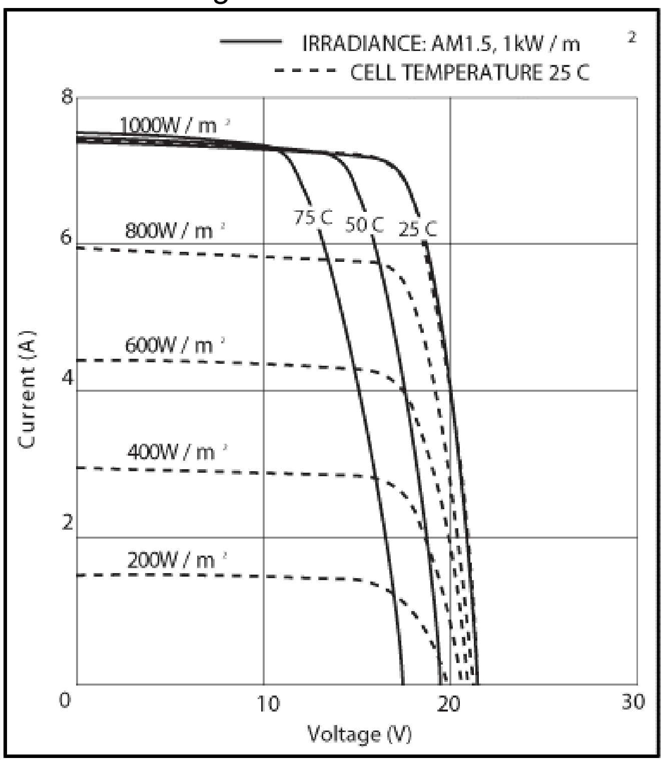
Solar is universal and will work virtually anywhere, however some locations are better than others. Irradiance is a measure of the sun's power available at the surface of the earth and it peaks at about 1000 watts per square meter. With typical crystalline solar cell efficiencies around 14-16%, that means we can expect to generate about 140-160W per square meter of solar cells placed in full sun. Insolation is a measure of the available energy from the sun and is expressed in terms of "full sun hours" (i.e. 4 full sun hours = 4 hours of sunlight at an irradiance level of 1000 watts per square meter). Obviously different parts of the world receive more sunlight than others, so they will have more "full sun hours" per day. The solar insolation zone map at the end of this guide will give you a general idea of the full sun hours per day during the summer for your location.

The current and power output of photovoltaic modules are approximately proportional to sunlight intensity. At a given intensity, a module's output current and operating voltage are determined by the characteristics of the load. If that load is a battery, the battery's internal resistance will dictate the module's operating voltage.

A module which is rated at 17 volts will put out less than its rated power when used in a battery system. This is because the working voltage will be between 12 and 15 volts. As wattage (power) is the product of volts times amps, the module output will be reduced. For example: a 50 watt module working at 13.0 volts will produce 39.0 watts (13.0

volts x 3.0 amps = 39.0 watts). This is important to remember when sizing a PV system.

An I-V curve as illustrated below is simply all of a module's possible operating points, (voltage/current combinations) at a given cell temperature and light intensity. Increases in cell temperature increase current slightly, but drastically decrease voltage.



Maximum power is derived at the knee of the curve. Check the amperage generated by the solar array at your battery's present operating voltage to better calculate the actual power developed at your voltages and temperatures.

So now you can see why a 50 watt solar module doesn't put 50 watts of power into your battery. Because of the gap between the operating voltage of the module (17v) and the charging voltage of your system (13v), not all of the electricity that the module produces can be used in a battery system. That is why we size in amp hours (Ah). Remember that our sizing worksheet told us the Ah we would need. You should learn the amp ratings (Isc Max) of each solar module - for example, the KC-50 could be renamed a "3-amp module". It gives you 3 ah of battery charge per hour of full sun. And remember that an hour of full sun is not what it seems - it is 1kw of potential energy falling in the form of light on one square meter of Earth.

Most African countries enjoy 12 hours of sunshine per day, but only average 4-6 sun hours. Perhaps we should rename sun hours to "kilowatt hour-meters" to avoid the confusion. So, taking our sample system's daily requirement of 34 ah, how much PV (solar) would we require in a typical African country with an annual average of 5 kWh-meters (sun hours)?

34 ah / 5 sun hours = 6.8 amps.

We need a module, or collection of modules that will provide 6.8 amps at max current. A 120 to 125 watt module will do nicely. Or we could use two 60 watt modules wired in parallel.

This sizing would guarantee performance on an average. But since the 5 kWh-meters or sun hours was an average, we know that some months were probably better and others were worse. If we need to guarantee maximum performance, we should size to the worst average weather conditions.

Modules should be installed in completely un-shaded areas - remember that the cells are wired in series and even partial shading can cut your module's power in half. Pole mounted modules are popular in Africa, but if your array exceeds four modules, you will probably want to use a ground or roof mount. You can buy ready-made mounting structure at African Energy, or have it made locally. Remember that north of the equator your modules should tilt at 15 degrees south, and in the south, face north. Tilt your modules at not less than 15 degrees, and up to your actual latitude. The 15-degree minimum tilt ensures that water and dust run off the module. You can also adjust to latitude minus 15 degrees in the summer and latitude plus 15 degrees in the winter, but never below 15 degrees.

Use a compass or magnetic declination chart to find true north. Remember to earth (ground) your racks and connect your modules with toothed or burred washers that will dig into the module frame and create a good electrical connection so that they can share your rack's ground. For large arrays of several series strings (for example, 4 series strings of 4 modules each in a 48 volt system) you should use a PV array combiner that will allow you to fuse or break each string and combine it efficiently into a 2 wire output.

CONTROLLERS

The power from your PV array is higher than your battery voltage, and is erratic depending on weather. A charge controller regulates your array's output and reduces the voltage as the batteries become more fully charged, allowing them to get completely charged. There are several different technologies used in today's charge controllers. The best employ pulse width modulation (PWM) and the really expensive ones use maximum power point tracking (MPPT) to follow the knee of the PV power curve and convert excess voltage to useable amps and vice versa. These can provide up to 20% more useable watts and start to make economic sense on systems exceeding 600 watts of PV. Most charge controllers can also act as load controllers for your DC loads, providing a low voltage disconnect (LVD) to keep your batteries from becoming too deeply discharged. Some also have features allowing a timed disconnect and an on/off function based on light levels, such as for street lights.

WIND

Wind turbines are a viable source of energy in some parts of Africa. But before you waste any of your own or any else's time thinking about wind, first determine average wind speeds for your area. Check records at your nearest airport or with your country's meteorological society. If you have average speeds above 10 mph (4.5 meters per second) during at least several months, then wind may make sense as a supplement to your PV system. This is especially true if the wind occurs during your worst solar months.

Electricity produced by wind generation can be used directly, as in water pumping applications, or it can be stored in batteries for household use when needed. Wind turbines can be used alone, or they may be used as part of a hybrid system, in which their output is combined with that of photovoltaics, and/or a fossil fuel generator. Hybrid systems are especially useful for rainy season backup of home systems where cloudy weather and windy conditions occur simultaneously.

The most important decision when considering wind power is determining whether or not your chosen site has enough wind to generate the power for your needs, whether it is available consistently, and if it is available in the season that you need it.

The power available from the wind varies as the cube of the wind speed. If the wind speed doubles, the power of the wind (ability to do work) increases 8 times. For example, a 10 mile per hour wind has one eighth the power of a 20 mile per hour wind. (10 x 10 x 10 = 1000 versus 20 x 20 x 20 = 8000).

One of the effects of the cube rule is that a site which has an average wind speed reflecting wide swings from very low to very high velocity may have twice or more the energy potential of a site with the same average wind speed which experiences little variation. This is because the occasional high wind packs a lot of power into a short period of time. Of course, it is important that this occasional high wind come often enough to keep your batteries charged. If you are trying to provide smaller amounts of power consistently, you should use a generator that operates effectively at slower wind velocities.

Installation of turbines should be close to the battery bank to minimize line loss, and 30 feet (10 meters) higher than obstructions within a 300-foot (100 meter) radius. The tower should be well grounded to dissipate lightning.

A FEW LAST WORDS

Renewable energy is a fairly new idea in much of Africa and consumers judge its worth by its results. We have seen the industry significantly harmed in some countries by low quality work and low quality equipment. We have also gained many customers who have tried the "cheap" products and found that they don't work. The solar business is highly competitive and there are no real shortcuts to quality products. For example, all world-class modules are usually priced within 10% of each other, and their costs of production are probably as similar. Labor costs usually comprise less than 15% of modern solar module production, so moving to low wage countries for module assembly usually turns out to be more expensive. In fact, because crystalline solar modules last for 30 or more years, ***the cheapest way to do solar is to do it right the first time***.

Doing it right means mastering the sizing formula and knowing how much energy is really required and how much equipment you will need to generate that energy.

Doing it right also means managing your customer's expectations and helping them understand what the system can do.

And finally, your systems need to be installed right so that they work well, look good, and keep running.

Africa is the world's most exciting market for renewable energy today. There are probably 50 years of work to be done in bringing energy to Africa's 700 million people. We hope this guide is helpful to you in that task and that you find this industry as rewarding as we do. Wishing you sunny days ahead!