Deployment Guide
Solar Power for Rural PCs

June 2011

By:
Bob Marsh, VP and co-Founder
bob.marsh @ inveneo.org

with valuable assistance from:
Bernd Nordhausen, Intel Corporation
Jen Overgaag, Sam Perales & Stephanie Seale, Inveneo
# Table of Contents

**Basic Solar Power Theory** ............................................................................................................................... 3
- How solar power systems work .......................................................................................................................... 3
- Solar panels ......................................................................................................................................................... 4
- Batteries ............................................................................................................................................................. 5
- Charge Controllers ........................................................................................................................................... 6
- Inverters ............................................................................................................................................................. 7
- Wiring ............................................................................................................................................................... 8
- Safety ............................................................................................................................................................... 8

**Important factors you must consider** ............................................................................................................... 8
- The Sun .............................................................................................................................................................. 9
- Local climate .................................................................................................................................................... 9
- Type of usage & reliability ............................................................................................................................... 9
- Size of the electrical load ................................................................................................................................ 10
- Time duration per day ...................................................................................................................................... 10
- Site characteristics .......................................................................................................................................... 10
- Availability of necessary materials .................................................................................................................. 10
- Cost .................................................................................................................................................................. 10
- An important note about printers ..................................................................................................................... 11
- Optional features ............................................................................................................................................. 11

**How to design a solar power system** .............................................................................................................. 11
- System design process steps ............................................................................................................................. 11
- How much power is needed? .............................................................................................................................. 11
- How many hours per day? ................................................................................................................................. 12
- Deciding system voltage and AC vs. DC operation ............................................................................................ 13
- Component availability .................................................................................................................................. 13
- Reading the component specifications ............................................................................................................ 13
- Finding the local insolation value ...................................................................................................................... 13
- Calculating the needed battery capacity .......................................................................................................... 14
- Calculating the number of solar panels needed ............................................................................................... 14
- Calculate the maximum charge current ........................................................................................................... 15
- Choosing the charge controller capacity .......................................................................................................... 15
- Calculating the optimum wire size ................................................................................................................... 15

**Conclusion** ....................................................................................................................................................... 16

**About Inveneo** ................................................................................................................................................. 17

**Appendix 1 - Insolation Values** ....................................................................................................................... 18

**Appendix 2 - Wire size & resistance tables** ................................................................................................... 20

**Appendix 3 - Example battery specification** .................................................................................................. 21

**Appendix 4 - Example solar panel specifications** ............................................................................................ 22

**Appendix 5 - Example projects** ..................................................................................................................... 23
- Burkina Faso, West Africa -- CEG Komtoega ................................................................................................. 23
- Zambia, Southern Africa -- Jonathan Sims-Chikanta High School Computer Lab ......................................... 24

**Appendix 6 - Basic electrical theory** ................................................................................................................ 25
- Ohm's Law ......................................................................................................................................................... 25
- Circuits .............................................................................................................................................................. 25
- Series connections .......................................................................................................................................... 26
- Parallel connections ....................................................................................................................................... 26
- Series-parallel connection ............................................................................................................................... 27
Overview

Many people believe that solar power is too expensive to use for powering computer installations in remote or rural areas that are without a connection to the AC grid. However, there have been two recent developments that have significantly lowered the cost of solar. First, the power consumption requirement of low-cost computers and peripherals has come down considerably. Second, the cost of solar panels has dropped dramatically, with some panels selling in the US for as much at 70% less than typical 2008 prices. If you are thinking about deploying computers in remote rural locations or in countries with erratic grid power, the cost of reliable, long-term, low-maintenance power has never been lower.

This guide will show you how to specify, design and build your own small-scale self-contained solar power system. The guide’s purpose is not to make you a world-class expert on solar technology. Rather, we will take a “hands-on” approach, emphasizing a step-by-step method to designing and building truly practical solar systems. As there are a large number of “tricks of the trade” involved when installing a solar system, we do not usually recommend a do-it-yourself approach for beginners. It is better to work with an experienced solar installer, especially if you have never worked with solar or other power systems before.

After reading this guide, you should be able to estimate the size, level of complexity and cost of small to medium-sized PC installations, and you will understand the basic theory and practice. This guide is focused on completely battery-operated PC and network installations. It does not discuss battery backup systems for generator- or AC-grid-powered locations.


Basic solar power theory

It would be difficult to understand the reasoning that lies behind many of the choices that need to be made as part of this guide’s step-by-step design process without some understanding of certain basic principles. So, if you are not conversant with basic electrical theory or could use a few reminders, please refer to the brief refresher in Appendix 6.

How solar power systems work

In the simplest case, as shown in Figure 1 below, photovoltaic solar panels convert sunlight into DC electrical current that flows through wires to a solar charge controller. The charge controller regulates the amount of current that flows into the batteries and usually also controls the current to the user’s equipment. Optionally, the battery’s DC output can be converted to the standard 120VAC or 230VAC used by most common electrical appliances and IT equipment. Normally, the power system also incorporates safety devices such as fuses, circuit breakers and lightning protection.

Solar power systems comprise four key elements, as shown in Figure 1:

- One or more photovoltaic (PV) panels, usually called "solar panels"
- An array of one or more deep-cycle rechargeable batteries
- A charge controller to regulate the charging of the battery array from the panel’s electricity
- The wiring and safety devices that connect these elements and the powered equipment
Solar panels

There are three types of commonly available materials used to manufacture solar panels:

1. Mono-crystalline silicon – panels made from this material have the highest efficiency in terms of W/m² (Watts per square meter), but they have a greater loss of power output at higher temperatures than other materials. Additionally mono- is a bit more expensive than poly-crystalline material.

2. Poly-crystalline silicon – these panels are somewhat less expensive, and less efficient than mono-crystalline panels, although the cost and efficiency differences have shrunk recently. Both types of crystalline panels can lose quite a bit of power generation capability at temperatures higher than the standard rating of 25°C.

3. Thin film – there are several material combinations used to make thin film panels, ranging from Copper-Indium Selenide to amorphous silicon. Thin film panels are currently considerably cheaper, but most are also quite a bit less efficient, requiring significantly greater area to generate the same power output. Many thin film panels, however, are much less sensitive to high temperatures and are made to tighter tolerances than crystalline panels, making thin film the better choice in hotter, harsher locations.

Panels come in various kinds of packaging, ranging from small, lightweight roll-able power packs designed for carrying and portability to strips of roofing tiles that blend into the appearance of adjacent normal tiles, to very large, 300W rigid panels in aluminum frames.

Most rigid panels use an outer layer of protective tempered glass, and that is the type of panel we will use in the following design examples.

Solar panel temperature effects

An inherent effect of silicon’s elemental physics is that silicon-based devices operate more efficiently at lower temperatures. The drop-off in efficiency is quite dramatic and some low-quality panels may lose a significant portion of their rated capacity when operated in hot climate conditions. If your site is in a hot location, like most of North Africa or the Southwest of the USA, for example, it is very important to check the power temperature coefficient of the panels you are selecting. A value of greater than -0.5 %/°C might be problematic.
Batteries

Types of batteries

As of 2011 there is only one battery technology that is economically viable for use in solar power systems, and it is one of the oldest battery types, Lead-Acid. There are two major types of Lead-Acid batteries, “flooded” or “wet” cell, that require fluid and usually regular maintenance, and sealed batteries that may be called “gel cell,” “SLA” (Sealed Lead-Acid), or “VRLA” (Valve-Regulated Lead-Acid). A high-reliability variant of SLA technology is “AGM” (Absorptive Glass Mat).

Within both wet and sealed types there are two usage models, one for starting motors and the other for deep-cycle applications. Auto or truck batteries are not designed for the constant regular charging/discharge cycling that is characteristic of power systems. Instead they are designed to deliver a powerful surge of current for a few seconds or minutes, and then have a constant charge applied while the engine is running. If car or truck batteries are used in solar applications, they will last only a short time as the daily, slow charge and discharge will dramatically shorten their lifetime. Only deep-cycle batteries should be used for solar power systems.

We normally recommend only sealed, maintenance free batteries for use in developing countries or rural environments, as wet batteries require regular checking (and often topping up) by a trained person who is consistently available.

If they are available, AGM (Absorptive Glass Mat) sealed batteries should be used, even if they cost a bit more than non-AGM models. AGM technology is much more rugged and resistant to damage from dropping, or over- or under-charging, often giving these batteries a longer real-world lifetime. AGM batteries provide the most reliable service and cost-effective solution over the long term.

Battery specifications

Battery capacity is measured in “Amp-hours,” commonly abbreviated to “Ahr” or “Ah”. Amp-hours refers to the amount of current in Amperes that can be drawn from the battery over so many specified hours. The relationship is not quite linear, that is, a 100Ahr battery can be drawn down at 20A for 5 hours, but if the current drain is 30A, it will not last for 3.3 hours. Most sealed lead-acid batteries are rated at the 20-hour discharge rate, or 5% of the rated capacity in Amps per hour, such that if the drain current exceeds the 20-hour rated value, the effective capacity is reduced. Refer to the data sheet in Figure 9 in Appendix 3 for a chart that shows the change in capacity ratings at varying discharge rates.

All makes and models of sealed batteries come in many sizes and capacities. Generally, 12V models are the easiest to use and most commonly available. 80Ahr to 240Ahr are the most commonly available capacities and are therefore often the most cost effective.

Battery temperature effects

Lead-acid batteries lose much of their storage capacity at low temperatures, in particular near or below freezing. Each battery manufacturer gives its own specification for temperature coefficient. However, if that information is not available, a factor of 1% per °C below 20°C (68°F) should be subtracted from the rated capacity.

Battery discharge factors

Lead-Acid batteries should never be discharged by more than 80% of their capacity, or permanent damage may result. However, in actual usage, if batteries are routinely discharged by more than 50-60%, the life of the battery will be shortened. So it is much better to limit the maximum discharge to about 50%. Under this operating scenario, i.e. maximum 50% discharge, typical deep-cycle batteries should provide a useful lifetime of at least 4 to 6 years over hundreds of charge/discharge cycles.

Battery charging factors

Charging batteries is not a perfectly efficient process, so we need to assume that the charger will have to put in about 20% more power than the battery can actually store. Once the battery is fully charged, the charger should reduce the charging current to a very small value sufficient to maintain the full charge state. This state is called “float charge.”
Charge Controllers

There are several commonly available charging technologies that control the rate and duration of battery charging.

The simplest charge controllers use a voltage-controlled cut-off switch. Basically, this simple charge controller drives a constant current into the batteries until the controller detects that the battery voltage has reached a certain pre-set value, the switches off until the battery voltage falls to a different pre-set value when it starts charging again.

A slightly more efficient variant of the simple charge controller is one that changes the charging current in fixed stages, dropping the current in two or three stages until the shutoff voltage level is reached. This method is often used in the auto/truck battery chargers.

However, two technologies that more effectively monitor battery’s condition during charging have become the most often used:

- **Pulse Width Modulation (PWM) controllers** – these continuously vary the amount of current to the battery by monitoring the charge condition. With PWM, the current is adjusted digitally, by switching the current on and off very quickly while varying the percentage of time that the pulses of current are turned on. The Xantrex® shown below, Phocos® and Morningstar® controllers are examples of different implementations of PWM charging.

The Phocos® CML-20 shown at the left of Figure 3 is perhaps the simplest-to-use form of charge controller. It can handle up to 20A charge current, and uses a few simple green, red & yellow LEDs to indicate battery charge level and system status. It has only one adjustment, a selection between wet and gel cell batteries. The Morningstar® PS-15M, shown on the right of Figure 3, is also very simple to install and configure. Both devices incorporate several features to protect batteries and load equipment from fault conditions.
Multi-Point Power Tracking (MPPT) – this is the latest and most efficient charging technology. MPPT uses clever algorithms and a DC-DC converter to match the optimum voltage and current from the solar panels to the battery array’s state-of-charge. MPPT controllers can be as much as 98% efficient, and they have a major advantage in that panel voltage does not need to match the battery voltage. In fact, some MPPT chargers, such as the Outback Flexmax series shown in Figure 5, can accept up to 96VDC from a series-connected array of panels, but charge battery arrays at 12V, 24V, 36V, 48V or even 60VDC.

If using higher voltages, these controllers minimize external system losses due to the much lower currents passing through the panel and battery wiring. (Ohm’s Law again!)

Most charge controllers have additional important features besides just charging the batteries, for example:

- **Load Switching** - with this the controller can act as a master power switch to shut off power to all the attached equipment.
- **Low voltage disconnect (LVD)** - if the batteries are drained excessively for any reason, LVD will shut off the output current to all the equipment.
- **Reverse polarity protection** - prevents damage if the batteries or solar panels are connected by mistake with positive and negative terminals reversed.
- **Static and over-voltage protection** - in hot dry environments in particular, the internal electronics can be damaged by static electricity. This feature can also protect against nearby lightning strikes.

### Inverters

Inverters electronically convert the battery’s DC voltage to a higher AC voltage. The quality of the AC waveform output is the primary differentiator among inverters, as normal AC grid power is a “pure sine wave” with a stable frequency of 50 or 60Hz, depending on country standards.

- **Very small and cheap inverters** output AC voltage in a “square wave,” which may be ok for use with light bulbs. However, this type should not be used with electronic equipment or appliances that use AC motors.
- **The “modified sine wave” output inverter** is relatively inexpensive to manufacture and can be used with most electronic devices.
- **“Pure sine wave”** gives an AC output that is closest to high quality grid power. Pure sine AC power can be used with any type of equipment, and is recommended for appliances with motors, such as refrigerators, air conditioning, fans or washing machines. This is the most expensive type of inverter.
Wiring
The most significant and common power loss is caused by the use of wire that is too small in size to carry the current put through it. Smaller diameter wire always has a relatively higher resistance. Ohm's Law is quite inflexible; the higher the resistance, the higher the voltage drop and power loss.

The most important wire is the connection between the charge controller and battery. This wire must always be of relatively large diameter and short length, as the controller must be able to read the battery voltage as accurately as possible to correctly adjust to changing battery state of charge.

The wires running from the outdoor solar panels to the charge controller are almost always going to be rather long, so it is also important to select an appropriate wire gauge to keep the voltage drop to an acceptably low level. Refer to Appendix 2 for a table that shows the resistance for each common size of copper wire. We’ll discuss selecting wire sizes in more detail later in this document.

Safety
There are two major dangers that need to be alleviated with safety features, over-currents and lightning:

Over-current protection
The battery array stores an enormous amount of energy, and if a wire or metal tool were to be dropped across positive and negative terminals, very high currents would flow through the short circuit thus created. These high currents could severely damage the batteries, and (in the worse case) result in an explosion or fire. So it is very extremely important to insulate the battery terminals with plastic or other non-conductive insulation. In addition, it is essential to use a high current DC circuit breaker or fuse in the positive battery lead to protect against short circuits elsewhere in the wiring to the charge controller. This breaker or fuse should be located as close as is practical to the battery end of the wire that connects to the charge controller.

It is also a good idea to install a circuit breaker and/or switch on the output of the charge controller to the equipment to assist in maintenance and for additional circuit protection.

Lightning protection
A nearby lightning strike could severely damage the entire solar installation, so it is important to use a good earth ground and heavy-duty copper wire to the outdoor solar panel array (i.e. at least 5mm diameter or 4ga.). The earth grounding wire should be solidly connected to the metal mounting of the solar panels.

Important factors you must consider
Every power system has limitations. In the case of solar, the primary limiting factors are in nature, i.e. factors like the amount of the Sun’s energy that is available at the site, the local cloud and fog weather patterns, and the presence of trees or hills that might block sunlight. There are many factors that need to be taken into account before design or implementation of a solar power system can begin. Let’s examine these various factors one by one.
The Sun
The amount of sunlight that shines on any given location is called "insolation" and the location’s insolation value is the most important design factor. Insolation can be stated in two ways for use in power system design calculations:

1) As equivalent power over an area per unit of time, e.g. Watts per meter² per day (W/m²/d), or
2) As hours of peak sunshine per day, i.e. as if each day, the sunlight is either full maximum brightness or completely dark.

Generally, in order to make it easier to design a system that will work reliably in any season, these insolation values are given for the day of the year with the lowest amount of sunshine.

Due to the 23 degree tilt of the Earth’s rotation relative to the plane of its orbit around the Sun, the amount of solar energy at most places on Earth varies significantly throughout the year as the Earth revolves around the Sun. This variation is virtually zero at the Equator, but increases the greater the distance from the Equator. Every person living in the temperate zones of the Northern or Southern hemispheres notices the change in day vs. night hours from season to season. The maximum difference in daylight hours between June and December may be small in Sudan, but is extreme in Sweden. As an example of an in-between location, Inveneo’s offices in San Francisco in the USA are at approximately 38 degrees latitude North of the Equator and the seasonal difference in daylight is over 5 hours.

When we are designing a reliable solar power system, we need to know the minimum amount of daylight that our site will experience on the day of the year with the least sunlight. This information can be obtained from maps such as the one shown in Appendix 1 – Insolation Values, that include the effects of both latitude and regional weather patterns.

Local climate
Local weather conditions can vary considerably over short distances. In particular, sites that are close to oceans, large hills or mountains, or that are in low lying valleys, may experience more clouds and fog than sites that are in relatively wide, flat or inland areas. These weather variations across small areas are called micro-climates. Here in the San Francisco area, for example, there are several micro-climates. The cold waters of the Pacific Ocean are nearby, and there are several large hills and mountains, ranging from 200m to 1200m elevation. Inland there are large low-lying valleys that can be very hot from May to October. The combination of the hot inland areas and cold ocean water creates strong winds and many areas of morning and afternoon fog up to 4k from the ocean. It is common for temperatures to vary up to 25C only a few kilometers apart.

In micro-climates, it is very important to obtain insolation data that is specific to the location, as the maps that cover large regions may be inaccurate, and typically will show more solar energy than is actually available in some parts of the region.

Type of usage & reliability
The decision to design for higher reliability or lower cost is an important design factor. Some facilities may need 100% reliability, but others may not. A hospital or health clinic needs a highly reliable power source to guarantee that the lights stay on and equipment keeps working while doctors are operating on a patient, for example. But a school may have a stronger need to save money. Often quite a bit of money can be saved by allowing for shorter equipment working hours on the few worst insolation days of the year. On very sunny days, the school’s computers can operate for 10+ hours a day, but perhaps it is sufficient for the computers to operate for only 6 hours on the shortest day with the stormiest weather.

It is rarely necessary to provide more than a few hours of battery power capability, as we can count on the Sun to rise every day to provide energy for recharging our batteries.

At the beginning of the design process, it is up to the system designer and client to make the decision to design the power system to ensure 100% operation under all conditions, or to achieve a lower cost.
Size of the electrical load
It is important to know the power requirements of each piece of equipment to be powered by the solar power system as accurately as possible. The labels on most electronic equipment overstate the normal power requirement, as the label values give only the absolute maximum value for regulatory purposes. In order to obtain reasonably accurate values, it is therefore often necessary to measure by oneself the actual DC or AC power consumption of each device under typical operating conditions.

Time duration per day
It is also important to decide on the number of hours per day that each item will operate. Usually, two factors, operating power and power-on-time, are multiplied together to calculate a design goal in Watt-hours (abbreviated as "Whrs" or "Wh"). It is this Watt-hour requirement that primarily determines the size and number of solar panels and batteries needed.

Site characteristics
There are a number of very important elements to consider when choosing the exact location of the various parts of the solar power system.

First, there needs to be enough area on which to mount the solar panels. If the panels are to be placed on a roof, the roof's structure must be strong enough to hold the weight of all the panels. Also, the structure must have enough internal supports to attach the panel mounting hardware to. Many rural roofs are built with relatively thin support beams that are placed far apart, and this can present a problem for larger, heavier solar panel arrays.

Second, solar panels are quite valuable and desirable virtually everywhere, so it is important to mount the panels in a secure location. On rooftops, it is often necessary to bolt down and lock the panels to prevent theft. If the panels are mounted on the ground, it may be necessary to install a fence around the panels and wiring. The copper metal in the wires going from the panels is also quite valuable and often must be protected.

Third, the solar panels should be placed away from trees or man-made structures that would block the sun's rays from reaching the panels for all or part of the day. If it is impossible to completely avoid shading of the panels, then a mounting location should be chosen that minimizes the minutes or hours of shading.

Availability of necessary materials
It is extremely important to understand what materials and power devices can actually be obtained in the country and region of the solar project. Availability of the many makes and models of power components varies widely from place to place, so a list of components that are available for purchase in-country and their costs should be put together before beginning an actual power system design.

Wire and other electrical hardware can also be obtained almost everywhere, even in may rural towns, but generally solar panels, deep-cycle batteries, charge controllers and special battery cables must be obtained in large cities or the capital.

Batteries are heavy and solar panels are usually large and bulky. While these sound like obvious facts, that weight and bulk make these two components difficult to transport safely and inexpensively. The only safe and relatively affordable way to transport batteries and panels is to do it in significant quantities in sealed containers. Unless your organization intends to install a large number of sites, it is impractical to purchase such large quantities of equipment. In addition, to keep costs low, it can take several weeks to transport the items to the country and location of the installation. For these reasons, Inveneo nearly always obtains these items in-country, even though, theoretically, the basic purchase price may be less in the US or Europe.

Cost
Cost is always an important factor, but it should always be kept in mind that the higher initial cost of a solar power installation gives a virtually zero long-term operating cost when compared to diesel or gasoline-powered generation in rural locations. Inveneo has written a white paper on the topic of power costs that is available on our website: http://www.inveneo.org/solar
While there are a number of suppliers of very relatively inexpensive solar panels, the buyer should be careful to choose only those from manufacturers with a good reputation for quality. Cheap, low-quality panels made from "off-spec" cells may supply considerably less power than advertised, or last for a much shorter period. High quality solar panels have a power tolerance of ±5% at most, and should keep generating power reliably for 20 years or more with less degradation over time than their low-quality counterparts.

An important note about printers

There are several advantages and disadvantages to both major types of printers and multi-function printer/scanner devices. However, there is one major problem with laser-based printers, i.e. the laser printing process uses a heating element to heat up the carbon toner and then fuse it to the paper. The heating element and motor drives use a lot of power. Very few laser printers use less than 300W when printing, and that high power level often requires 50% to 100% more investment in the total solar system capital cost. Inveneo always recommends using ink-jet printers or multi-function devices when operating from solar power and battery.

A typical inexpensive HP All-in-One®, such as the Officejet® Pro 8500A model, needs only 24W maximum when printing or scanning and only ~2W when in sleep mode. Compare this with an equivalent laser multi-function, the Laserjet® Pro M1212NF, that requires 375W when printing.

Optional features

Some charge controllers incorporate a valuable feature as an option, i.e. the ability to output real-time data so that the user or solar installer can monitor the amount power from the system and battery condition.

An even more useful feature on some systems is the ability to shunt excess power to additional devices whenever the battery array is fully charged. As most solar designs use the insolation value on the least sunny day of the year, this feature can be very useful in sunny weather for additional charging car batteries, cameras, cell phones etc that are not normally part of the site’s standard complement of devices. Some charge controllers (for example, Phocos) allow for an optional shunting controller to be added in conjunction with the primary controller.

How to design a solar power system

This section outlines a step-by-step procedure for designing your solar power system. With Inveneo’s several years experience in designing and building for schools, health clinics and community centers in Africa and Asia, we’ve been able over time to simplify the design method and to minimize the time required to analyze and calculate values.

System design process steps

1. Determine power needs of each piece of equipment
2. Determine the hours/day that each piece of equipment will run
3. Decide which system voltage to use, and decide AC vs. DC operation
4. Determine which solar panels and batteries are available
5. Obtain performance specifications for the available panels and batteries
6. Find how much solar energy is available, by looking up the insolation value for the site location
7. Calculate the amount of battery storage capacity needed
8. Calculate the wattage number of solar panels needed
9. Calculate the capacity of the charge controller
10. Calculate the minimum wire size and voltage loss

How much power is needed?

Once you have determined exactly which items you want to run from the battery array make a list describing each item and the numbers of each that will be installed. From the datasheet specifications of each item, add the typical power consumption in Watts. As mentioned earlier, the specs for many types of equipment overstate the power usage.

In order to avoid over-designing the solar power system and thus raising its cost unnecessarily, it is important to know real power consumption. For example, the Inveneo LCD 15" widescreen display monitor with LED
backlight uses only 8W, but its external power brick that supplies 12VDC is rated at 3A output. So, even though the external power brick can supply up to 36 Watts, the actual, real-world consumption of the monitor is only 8W (approximately ±1W).

The importance of low-power choices for equipment cannot be overemphasized. In typical rural IT projects, the solar power system components cost more than computing and networking devices. Choosing computing or networking equipment with low power consumption directly translates to a lower total project cost.

Table 1 below shows a sample format for listing the equipment that will run from the solar system. The list includes all of the types of equipment most commonly used in rural deployments. Note that this list does not include the hours of operation (yet) and its primary use is to give you an idea of the maximum peak power that will be needed at the site. The batteries and charge controller must be able to supply at least this much power (223W in this sample list) in case every item is turned on simultaneously.

<table>
<thead>
<tr>
<th>List of equipment items</th>
<th>Typ. Power each (W)</th>
<th>Qty.</th>
<th>Total Instant Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-power Server (e.g. Inveneo® R4)</td>
<td>28</td>
<td>1</td>
<td>28</td>
</tr>
<tr>
<td>Low-power PC (e.g. Asus® EB1007 with Inveneo® 15” LCD monitor)</td>
<td>22</td>
<td>5</td>
<td>110</td>
</tr>
<tr>
<td>Intel®-powered classmate PC or similar netbook</td>
<td>15</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Long-range WiFi radio (e.g. Ubiquiti® NSM5)</td>
<td>7</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Network Equipment (e.g. Cisco Linksys® LAN switch)</td>
<td>5</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Misc. Equip (ink-jet multi-function printer, etc)</td>
<td>20</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Light bulbs (e.g. high-efficiency 12VDC CFL)</td>
<td>11</td>
<td>3</td>
<td>33</td>
</tr>
<tr>
<td><strong>Total peak power:</strong></td>
<td></td>
<td></td>
<td><strong>218</strong></td>
</tr>
</tbody>
</table>

Table 1 - Sample Equipment Power List

How many hours per day?

You need to carefully consider the number of operating hours per day for the rural IT equipment. Remember that power usage is measured KW-hours, i.e. power over time. For example, a 50W PC that runs for two hours uses as much power as a 100W PC that runs for 1 hour. Since more time translates to more power needed, each extra hour of operation adds to the size and number of batteries and solar panels, which in turn, translates to higher total system cost.

If possible, it may be better to regulate the operating hours of the entire installation than to eliminate equipment that would enhance the capabilities of the facility. Inveneo’s experience is that many schools or community centers can provide adequate IT services when “open” for an average 5-6 hours per day.

Daytime operation gives more efficient use of solar energy, as a properly designed solar system can charge the batteries and power all the equipment at the same time. In effect, with daytime-only use, the batteries are cycled less fully and less often, extending their useful life.

The simpler Table 1 was used to better show the sequence of calculation steps, but the following Table 2 below is the one that should normally be used where both individual items’ power level and operating hours are multiplied at the same time to derive the total Watt-hours needed by the entire installation per day.

In this example battery and solar panel calculation, we will assume that the entire computer center is operated for 10 hours each day, and that the insolation equivalent peak-hours value is 4 hours. Therefore, the center must continue operating on battery power alone for 10 - 4 = 6 hours.
## Deciding system voltage and AC vs. DC operation

DC operation is the most efficient mode, especially for smaller installations of just a few PCs where the distance from battery bank and charge controller to the PCs is relatively short. With completely DC operation, no DC-AC inverters are required and charge controllers are simpler and less expensive.

For larger installations, and especially where the IT equipment must be placed more than about 25m (~80ft) from the power source, it is better to choose AC for distributing power. Due to Ohm’s law again, when the current is greater, it is better to use a higher voltage, so using 120 or 240VAC wiring dramatically drops the voltage loss from long wiring runs.

Generally for DC operation, there are three choices of system operating voltages: 12, 24 or 48VDC. It is better in principle to use a higher voltage, as higher voltage results in lower current at the same power level, which results in less losses due to resistance (remember Ohm’s Law). 12V operation is usually the simplest and cheapest choice, especially for small installations with just a few PCs. Some low-power PCs can operate directly from a 12VDC battery source.

## Component availability

As mentioned earlier, you need to determine which components can be obtained locally before beginning design work. In particular, you need to find a source for good quality deep-cycle batteries and solar panels.

## Reading the component specifications

Solar panel specification can be rather arcane and confusing, and the same holds true for some batteries. The most common rating system for solar panels is called STC (Standard Test Conditions), but this rating is always greater than the real power output. A more realistic rating is PTC (PVUSA Test Conditions) Refer to [http://www.inveneo.org/solar](http://www.inveneo.org/solar) for a more detailed explanation of solar panel specs. The PTC value is usually 5% to 8% less than the STC value for power output.

## Finding the local insolation value

Using maps like the ones shown in Appendix 1, Figure 7 or Figure 8 it is easy to determine the insolation value for your location. We have found that the method based on peak-hours per day is easier to understand and use than irradiance values in kW/m²/day. However, if only the power irradiance value is available for any location, it is easy to convert to peak insolation hours:

\[
1kW/m²/day = 1 \text{ peak insolation hour}
\]

If you are in a region in a developing country with several micro-climates, it can be difficult to obtain accurate data. In this case, especially if you are certain that the solar project site definitely has more fog, clouds or rain that the broader region, it makes sense to adopt a more conservative design approach. This means starting with the

### Table 2 - Sample Power/Hours of Battery Operation per day List

<table>
<thead>
<tr>
<th>List of equipment items</th>
<th>Typ. Power each (W)</th>
<th>Qty.</th>
<th>Total Instant Power (W)</th>
<th>No. hours operating</th>
<th>Watt-hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-power Server (e.g. Inveneo® R4)</td>
<td>28</td>
<td>1</td>
<td>28</td>
<td>6</td>
<td>168</td>
</tr>
<tr>
<td>Low-power PC (e.g. Asus® EB1007 with Inveneo® 15” LCD monitor)</td>
<td>22</td>
<td>5</td>
<td>110</td>
<td>6</td>
<td>660</td>
</tr>
<tr>
<td>Intel-powered classmate PC or similar netbook</td>
<td>15</td>
<td>1</td>
<td>15</td>
<td>6</td>
<td>90</td>
</tr>
<tr>
<td>VoIP Phone</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Long-range WiFi radio (e.g. Ubiquiti® NSM5)</td>
<td>7</td>
<td>1</td>
<td>7</td>
<td>6</td>
<td>42</td>
</tr>
<tr>
<td>Network Equipment (e.g. Cisco Linksys® LAN switch)</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>Misc. Equip (ink-jet multi-function printer, etc)</td>
<td>20</td>
<td>1</td>
<td>20</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>Light bulbs (e.g. high-efficiency 12VDC CFL)</td>
<td>11</td>
<td>3</td>
<td>33</td>
<td>2</td>
<td>66</td>
</tr>
</tbody>
</table>

Total Watt-hours per day for battery only operation: 1096

Minimum Watt-hours per day of power during Insolation peak (4 hours): 730
more general regional data like that shown in the sample maps, and then designing for 10-20% more hours of usage per day or more power per day than will actually be used.

**Calculating the needed battery capacity**

In our example from Table 2 above, the total peak power requirement is 218 W and the Watt-hours needed for the battery-only operation period are 1126 Whrs. First, for simplicity let us assume that we have decided to use 12VDC as our system and battery array voltage. The following table lists the sequence of calculations to compute the battery Amp-hours capacity needed to power the example installation:

<table>
<thead>
<tr>
<th>Step</th>
<th>Description of this calculation step</th>
<th>Formula for this step</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Starting point: Watt-hours used under battery power only</td>
<td>1096 Whrs</td>
</tr>
<tr>
<td>2</td>
<td>Extra margin for inefficiency/losses (esp. if using inverter)</td>
<td>1096 Whrs + 10% = 1205 Whrs</td>
</tr>
<tr>
<td>3</td>
<td>Compensation factor for temperatures as low as 12°C</td>
<td>25°C-12°C = 13 degrees, so 13% derating</td>
</tr>
<tr>
<td>4</td>
<td>Add extra capacity for low temperature conditions of 12°C to get the total battery power used</td>
<td>1205 Whrs + 13% = 1362 Whrs</td>
</tr>
<tr>
<td>5</td>
<td>Battery capacity needed divided by maximum allowed discharge percentage (usually 50%)</td>
<td>1362 Whrs ÷ 50% = 2725 Whrs</td>
</tr>
<tr>
<td>6</td>
<td>Total battery capacity for all items for 6 hours /day operation</td>
<td>2725 Whrs ÷ 12V = 227 Ahrs</td>
</tr>
<tr>
<td>7</td>
<td>Select number of batteries</td>
<td>Under est. &gt; 2 x 110 Ahr = 220 Ahrs; Over est. &gt; 3 x 79 Ahr = 237 Ahrs</td>
</tr>
</tbody>
</table>

**Table 3 - Calculating battery capacity needed**

*Notes: Step 3 - refer to the section on “Battery temperature effects” above for an explanation of temperature effects above or below 25°C. As an example, the low temperature of 12°C was chosen as typical of nighttime conditions at moderate elevations in East Africa in the coldest month.*

*Step 4 - this resulting value (1362 Whrs) is the total power needed from batteries during the non-peak-insolation hours.*

*Step 5 – refer to the section on “Battery discharge factors” above for details about the 50% factor.*

As batteries do not come in every capacity, it is usually necessary to round up or down, based on the battery sizes that are locally available. In the example above two common 12V battery sizes are shown:

a) 2 x 110 Ahr capacity batteries can be used when rounding down, giving 220 Ahrs total, or

b) 3 x 79 capacity batteries can be used when rounding up, giving 237 Ahrs total. Inveneo generally recommends rounding up slightly to increase capacity and reliability.

**Calculating the number of solar panels needed**

First, the battery calculations above do not take into consideration the inherent inefficiency of the charging process. Batteries vary but it is usually safe to apply a rule-of-thumb value of 20% for this factor, and we will add in this factor in the solar panel calculations that follow.

We can now move on to figuring out the number of solar panels needed to power the system and re-charge the batteries. First we have to choose solar panels, and for this example, we will assume using the Sunwize SW-S130P model.
<table>
<thead>
<tr>
<th>Step</th>
<th>Description of this calculation step</th>
<th>Formula for this step</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>To calculate minimum total battery power that must be recharged each day, add factor for charging inefficiency</td>
<td>1362 Whrs + 20% = 1634 Whrs</td>
</tr>
<tr>
<td>2</td>
<td>Power needed for operating the equipment during insolation peak solar hours (see last row in Table 2 above)</td>
<td>730 Whrs</td>
</tr>
<tr>
<td>3</td>
<td>Total power needed for operation and battery charging</td>
<td>730 + 1634 = 2364 Whrs</td>
</tr>
<tr>
<td>4</td>
<td>Add Power output tolerance factor from datasheet</td>
<td>2364 + 5% = 2483 Whrs</td>
</tr>
<tr>
<td>5</td>
<td>Compensation factor for local temperatures as high as 40°C</td>
<td>0.5%/°C × (40-25) = 7.5% de-rating factor</td>
</tr>
<tr>
<td>6</td>
<td>Add temperature factor</td>
<td>2483 Whrs + 7.5% = 2669 Whrs</td>
</tr>
<tr>
<td>7</td>
<td>Divide by insolation value (from map) to find total power need</td>
<td>2669 Whrs ÷ 4 hrs = 667 W</td>
</tr>
<tr>
<td>8</td>
<td>Round up to give higher reliability, or down for lower cost</td>
<td>Either 5 or 6 panels needed (generally, rounding down to 5 is ok)</td>
</tr>
</tbody>
</table>

Table 4 - Calculating solar panel capacity

Note: Step 5 - refer to the section on “Solar panel temperature effects” above for an explanation of temperature effects above 25°C. As an example, the high temperature of 40°C was chosen as typical of afternoon conditions at moderate elevations in East Africa in the warmest month.

For 12VDC system operation, either 5 or 6 panels will do. If you were to choose 24VDC operation with AC output as a different approach, it would be necessary to choose an even number of panels, as the 130W/12V panels for this example would have to be configured as 3 pairs of panels in parallel. Within each pair, the 2 panels would then be connected in series.

Calculate the maximum charge current

Referring to the example Sunwize solar panel of Appendix 4, we can find that the peak rated current (I_{mp}) is 8.1A, so we multiply that by the number of panels to determine the maximum charge current:

5 panels × 8.1A = 40.5A

Choosing the charge controller capacity

While the 40.5A value we just calculated is right at the maximum of value of typical 40A charge controllers (like the Phocos shown above), it is possible for the peak charge current to exceed this if the panel happens to be at maximum positive tolerance, so it is advisable to choose a controller with a maximum current rating of 50A or 60A. A number of manufacturers make controllers in this range.

Calculating the optimum wire size

Copper is a fairly expensive metal, so larger diameter wire with lower voltage loss can be significantly more expensive than smaller wire. While in theory we want to have the lowest voltage loss possible, in practice it is necessary to compromise between low loss and reasonable cost for wire. As a rule of thumb you should not exceed about 5% power loss in the wire cable that connect the solar panels to the battery.

Remembering Ohm’s Law, given a fixed resistance (i.e. in this case, a fixed wire size) higher amperage current means more voltage drop. Thus, switching from 12VDC to 24V or 48V system operation will cut currents through both panel and battery wires by 50% or 75%, respectively. In addition, a lower current charger often becomes possible when using a higher voltage. This is a particularly good approach in situations where 120VAC or 230VAC from an inverter will be the main power source for the IT equipment.

Example panel wire calculation:

Solar panel output voltage = 17.4VDC (from spec sheet in Appendix 4)

length of cable from panels to charge controller = 10m (33ft)

length of both wires (combined) from panels to charge controller = 10m × 2 = 20m (66ft)

1st try: resistance of 20m using 6mm wires = 0.0031ohms/m × 20 = 0.062ohms
voltage loss: 0.062ohm \times 40.5A = 2.5V drop. 2.5V is 14% of panel voltage, so let's try bigger wire...

2nd try: resistance of 20m using 16mm wire = 0.00115ohms/m \times 20 = 0.023ohms

voltage loss: 0.023ohm \times 40.5A = 0.93V drop. 0.93V is only 5% of panel voltage, so this is a workable solution.

Note: 6mm diameter wire is roughly equivalent to American 10AWG wire size, and 16mm wire is equivalent to American 5AWG wire.

nominal battery voltage = 12VDC

length of cable from batteries to charge controller = 1m (3.3ft)

length of both wires (combined) from panels to charge controller = 1m \times 2 = 2m (6.6ft)

1st try: resistance of 2m using 6mm wires = 0.0031ohms/m \times 2 = 0.0062ohms

voltage loss: 0.0062ohm \times 40.5A = 0.25V drop. 0.25V is only 2% of battery voltage, which doesn’t sound like a large percentage. However, it is a large enough drop to confuse some charge controllers, as controllers rely on accurate battery voltage measurement to properly regulate charging... so let’s try bigger wire...

2nd try: resistance of 20m using 10mm wire = 0.00183ohms/m \times 2 = 0.00366ohms

voltage loss: 0.00366ohm \times 40.5A = 0.15V drop. This is a low enough voltage drop.

**Sample Parts List**

Now that we have made the above calculations we can make a list of the major components that are needed for this example solar power system:

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>130W Sunwize solar panels</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>110Ah 12VDC AGM deep-cycle batteries, Universal</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Charge controller, e.g. Phocos CXN-40</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>DC circuit breaker, 100A (for battery positive lead)</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>12VDC to 230VAC 300W inverter, e.g. Morningstar Suresine 300</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>enclosure and AC circuit breakers for equipment power</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>mounting hardware for solar panels</td>
<td>1 set</td>
</tr>
<tr>
<td>8</td>
<td>battery rack or container and misc. wiring hardware</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>battery connecting cables</td>
<td>1 set</td>
</tr>
<tr>
<td>10</td>
<td>length of wire from solar panels to controller</td>
<td>TBD</td>
</tr>
<tr>
<td>11</td>
<td>length of grounding wire 20mm dia.</td>
<td>TBD</td>
</tr>
<tr>
<td></td>
<td>grounding rod for outside burial</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table 5 - Sample Parts List**

It would be a good idea to compare your parts list with quotations supplied by solar installers in your area.

**Conclusion**

The process of designing or evaluating a solar power system may have seemed complicated at first, but when looking back on all the steps described in this document, none are complex or difficult. Hopefully, you are now able to execute these steps with relative ease, and then use this knowledge to more readily implement IT projects in remote and rural areas.

Inveneo always recommends using experienced solar installers, as they know all the "tricks of the trade" that are needed to quickly install and efficiently install reliable, reasonable-cost systems.
About Inveneo

Inveneo is a not-for-profit social enterprise working to bring ICT tools to the organizations that need them most; those working in rural and remote parts of the developing world. Inveneo designs and delivers integrated ICT solutions, including low-power-consuming hardware, open source software and connectivity, that are designed to be sustainable in these settings. Our clients are primarily NGOs, governments and private sector organizations that deliver critical education, relief, healthcare, microfinance and other services to underserved communities. In addition to designing sustainable ICT solutions, the Inveneo Certified ICT Partner Program (ICIP) trains and certifies in-country ICT entrepreneurs to be capable of installing and supporting projects in low-resource settings. More detailed information about Inveneo may be found at: http://www.inveneo.org.

A list of Inveneo’s local partners, including solar installers, may be found at: http://www.inveneo.org/ictpartners

This document is covered by Creative Commons copyright license terms:

http://creativecommons.org/licenses/by-nd/3.0/
Appendix 1 – Insolation Values

Figure 7 - Africa Insolation in kWh/m²/day, and optimum tilt angle
A "Peak Hour" of sunlight is based on supposition that each 24-hour day’s insolation can be modeled as either complete darkness or full, maximum brightness. In the model used to create Figure 8 above, there is no in-between level of solar brightness or twilight; it is either dark or light. So, for purposes of solar power calculation, we can assume that coastal Accra, Ghana, for example, has approximately 3.5 hours of full daylight and 20.5 hours of nighttime darkness every day. On the other hand, desert-like Bamako, Mali has over between 5.0 and 5.5 hours of full daylight and from 18.5 to 19 hours of darkness.

This model makes it easy to calculate the power that a solar panel array can deliver, and it is based on the insolation values for the worst day of the year with the cloudiest weather. In other words, the actual amount of peak sunlight should always be more than these values.

This map shows the number of daytime hours of peak sunlight across climate zones of North-West Africa. The darkest red-colored area has the most sunlight, i.e. >6 hours/day. The lightest yellow-colored areas, for example along the coast of Ghana, Nigeria and Cameroon have between 3.0 and 3.5 hours/day.

Figure 7 above shows similar color-coded data in kWh/m²/day form. This form can be converted to peak-insolation hours with the assumption that 1.0 kWh/m² = 1 peak-hour. The figure also shows the optimum angled tilt for solar panels at each degree of latitude on the African continent.
Appendix 2  - Wire size & resistance tables

RESISTANCE-METRIC WIRE SIZES
COPPER CONDUCTORS AT 20° C (68° F )

<table>
<thead>
<tr>
<th>Conductor Size (1)</th>
<th>Resistance (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm²</td>
<td>per 1000 ft ohms</td>
</tr>
<tr>
<td>.5</td>
<td>11.03</td>
</tr>
<tr>
<td>.75</td>
<td>7.35</td>
</tr>
<tr>
<td>1.0</td>
<td>5.52</td>
</tr>
<tr>
<td>1.5</td>
<td>3.69</td>
</tr>
<tr>
<td>2.5</td>
<td>2.26</td>
</tr>
<tr>
<td>4.0</td>
<td>1.41</td>
</tr>
<tr>
<td>6.0</td>
<td>.939</td>
</tr>
<tr>
<td>10.0</td>
<td>.558</td>
</tr>
<tr>
<td>16.0</td>
<td>.351</td>
</tr>
<tr>
<td>25.0</td>
<td>.222</td>
</tr>
<tr>
<td>35.0</td>
<td>.160</td>
</tr>
<tr>
<td>50.0</td>
<td>.118</td>
</tr>
</tbody>
</table>

(1) Nominal cross sectional area/mm²
(Ω) Maximum resistance allowed may vary with different copper wire standards.

Table 6 - Metric wire sizes

<table>
<thead>
<tr>
<th>AWG</th>
<th>Area CM²</th>
<th>Resistance per 1000 ft (ohms) @ 20 C</th>
<th>Diameter (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>211600</td>
<td>0.049</td>
<td>0.46</td>
</tr>
<tr>
<td>000</td>
<td>167810</td>
<td>0.0618</td>
<td>0.40965</td>
</tr>
<tr>
<td>00</td>
<td>133080</td>
<td>0.078</td>
<td>0.3648</td>
</tr>
<tr>
<td>0</td>
<td>105530</td>
<td>0.0983</td>
<td>0.32485</td>
</tr>
<tr>
<td>1</td>
<td>83694</td>
<td>0.124</td>
<td>0.2893</td>
</tr>
<tr>
<td>2</td>
<td>66373</td>
<td>0.1563</td>
<td>0.25763</td>
</tr>
<tr>
<td>3</td>
<td>52634</td>
<td>0.197</td>
<td>0.22942</td>
</tr>
<tr>
<td>4</td>
<td>41742</td>
<td>0.2485</td>
<td>0.20431</td>
</tr>
<tr>
<td>5</td>
<td>33102</td>
<td>0.3133</td>
<td>0.18194</td>
</tr>
<tr>
<td>6</td>
<td>26250</td>
<td>0.3951</td>
<td>0.16202</td>
</tr>
<tr>
<td>7</td>
<td>20816</td>
<td>0.4982</td>
<td>0.14428</td>
</tr>
<tr>
<td>8</td>
<td>16509</td>
<td>0.6282</td>
<td>0.12849</td>
</tr>
<tr>
<td>9</td>
<td>13094</td>
<td>0.7921</td>
<td>0.11443</td>
</tr>
<tr>
<td>10</td>
<td>10381</td>
<td>0.9989</td>
<td>0.10189</td>
</tr>
<tr>
<td>11</td>
<td>8234</td>
<td>1.26</td>
<td>0.09074</td>
</tr>
<tr>
<td>12</td>
<td>6529</td>
<td>1.588</td>
<td>0.0808</td>
</tr>
</tbody>
</table>

Table 7 - America gauge wire sizes
Appendix 3  - Example battery specification

Figure 9 - AGM deep-cycle battery specification

Take a look at the Characteristics/Capacity section above to see the decrease in total capacity with an increase in discharge rate. Capacity falls from 100Ahrs at a 20-hour rate to only 60Ahr if the battery is discharged at a rate that would empty it in 1 hour.
Appendix 4  - Example solar panel specifications

http://www.wholesalesolar.com/solar-panels.html

SunWize® SW-S130P Solar Module
High performance for industrial applications

The SunWize SW-S130P solar module delivers top-quality performance for all photovoltaic applications including telemetry, communications, security, rural electrification, water pumping and general battery charging. The SW-S130P can be used in single-module and multiple-module installations. Each module consists of 36 solar cells connected in series providing sufficient voltage for battery charging under extreme high temperatures. The modules are manufactured according to the strict requirements of international and US quality standards. 25-year limited warranty.

Features include:

- The glass surface is impact resistant and allows maximum light transmission.
- Polycrystalline solar cells are encapsulated and bonded to the glass in multiple layers of ethylene vinyl acetate (EVA) and laminated with a white Tedlar™ backing insuring long life in severe environmental conditions.
- A weather resistant junction box accommodates all wiring methods including moisture-tight strain relief connectors and electrical conduit. Bypass diodes insure reliable operation.
- Anodized aluminum tubular frames add strength and durability. Frames come with predrilled mounting holes.

<table>
<thead>
<tr>
<th>Model</th>
<th>Rated Power (Watts)</th>
<th>Rated Voltage (Vmp)</th>
<th>Rated Current (Imp)</th>
<th>Open Circuit Voltage (Voc)</th>
<th>Short Circuit Current (Isc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW-S130P</td>
<td>130</td>
<td>17.4V</td>
<td>7.4 A</td>
<td>22.0V</td>
<td>8.1A</td>
</tr>
</tbody>
</table>

Standard Test Conditions (STC): 1000 W/m², 25ºC, AM 1.5

<table>
<thead>
<tr>
<th>Model</th>
<th>Rated Power (Watts)</th>
<th>Rated Voltage (Vmp)</th>
<th>Rated Current (Imp)</th>
<th>Open Circuit Voltage (Voc)</th>
<th>Short Circuit Current (Isc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW-S130P</td>
<td>130</td>
<td>17.4V</td>
<td>7.4 A</td>
<td>22.0V</td>
<td>8.1A</td>
</tr>
</tbody>
</table>

Electrical / Thermal Parameters

- Max System Voltage: 600Vdc
- Series Fuse Rating: 15 Amps
- Voltage Temperature coefficient (Voc): -0.35%/C
- Current Temperature coefficient (Isc): 0.065%/C
- Power Temperature coefficient (Pmax): -0.5%/C
- Peak Power Tolerance: +/-5%

©2010 SunWize Technologies • 1155 Flatbush Road, Kingston NY USA 12401 • Tel: 845-336-0148 • Fax: 845-336-0457 • www.sunwize.com

Figure 10 - Example solar Panel specification
Appendix 5 - Example projects

Burkina Faso, West Africa -- CEG Komtoega

CEG Komtoega is a secondary school in East-Central Burkina Faso, where the nearest AC grid access is 15km away. The school's computer lab includes 20 low-power workstations, a server, printer and VSAT terminal, all powered by 8 Kyocera 130W solar panels charging 9 - 100Ahr 12VDC AGM batteries. The high-efficiency 11W light bulbs, printer and network equipment are powered by the Fronius 500W inverter, running from a separate subset of solar panels and batteries.
Zambia, Southern Africa -- Jonathan Sims-Chikanta High School Computer Lab

Jonathan Sims-Chikanta High school, located in a remote part of Southern Zambia, is the only high school within a 70 miles radius, yet thanks to the funding efforts of Hoops of Hope (http://www.hoopsofhope.org), it now sports a state of the art computer lab. Far away from the electrical grid but blessed with plenty of sunshine, solar was an obvious energy choice to power this 20-PC lab.

The overall design of the lab followed the guidelines described in this paper, but also includes some innovative design features. First, a 40ft retired shipping container was refurbished to house the lab. The layout of short benches along either side allow for 20 desks with ample of space to walk around. The charge controllers and battery bank are housed in a wooden cabinet at the far end of the container.

Second, dual AC/DC wiring with power sockets at each desk (see ) provides a choice of energy efficient DC and standard AC power. A majority of the equipment, including 20 Intel®-powered classmate PCs and four DC-powered ceiling fans, run directly on 12VDC. Other equipment, such as a printer and a full sized energy-efficient teacher laptop, runs on AC power.

A 1,440Watt array of solar modules charging a 1,000AHr battery bank provides enough energy to power the lab continuously during the day plus several hours of operation at night. Thus, using innovative design, this well-used shipping container now enjoys a second life providing educational opportunities for students in a remote part of rural Zambia.
Appendix 6 - Basic electrical theory

To make sure the reader understands one of the most important electrical principles, we'll give a brief reminder here about the theory of Direct Current (DC) circuits.

Ohm's Law

Most importantly, as it affects every aspect of solar power system design and implementation, Ohm's Law defines the relationship among the 3 basic elements of electric circuits. Ohm's law says that, in a DC circuit, the voltage (Volts) is proportional to the current (Amperes) multiplied by the resistance (Ohms). The modernized form of this Ohm's law equation is: \( \text{Volts} = \text{Amps} \times \text{Ohms} \) (or \( V = A \times \Omega \))

- Volts (V) = the potential energy of a power source such as a solar panel or battery
- Amps (A) = the amount of electric current flowing through a circuit
- Ohms (Ω) = the resistance to the flow of electric current of individual or multiple circuit elements

Power, expressed in Watts, is the measure of the work that is being done by the circuit, is defined as proportional to the voltage multiplied by the current: \( \text{Power} = \text{Volts} \times \text{Amps} \) (or \( P = V \times A \)). Power is only created or used when current flows through a circuit.

Circuits

Diagram 1 shows a very simple circuit consisting of a battery acting as power source (on the left) with two wires (top and bottom) connecting the 24 Volt battery's output to a load consisting of a single resistor (on the right). Because the 12ohm resistance of the resistor is known, it can be used to calculate the current flow of 2 Amps, as well as the power used by the resistor, 48 Watts.

![Diagram 1 - Simple circuit](image_url)
Series connections
When two circuit components are connected end-to-end, they are said to be "connected in series." In a series connection of batteries, for example, the total voltage is doubled, as shown in Diagram 2. If the components were resistors, the resistance would also be doubled.

![Diagram 2 - Series connection](image)

When 2 batteries are connected in series, the total voltage output is increased: \( V_1 + V_2 \)
in this example, 4VDC total.

However, the current output remains the same.

Therefore, this resulting battery array gives 4VDC @ 3 Amps

Parallel connections
When two circuit components are connected side-by-side, they are said to be "connected in parallel." When two batteries, for example, are in parallel, the voltage stays the same, but the available current is then doubled.

![Diagram 3 - Parallel connection](image)

When 2 batteries are connected in parallel, the total voltage output is the same, 2VDC

However, the current output is increased: \( A_1 + A_2 \)

Therefore, this resulting battery array gives 2VDC @ 6 Amps

Each cell = 2 VDC
capacity = 3 Amps
Series-parallel connection

When two sets of serial-connected components are then connected in parallel, this is said to be a "series-parallel connection." In the example of Diagram 4, as there are four batteries, the total capacity of the battery array is 4x the capacity of one battery, and in this configuration, both the voltage and available current are doubled.

Each series pair of batteries will source 4V. Then the output of both series pairs is combined, so that the total current output is increased.

Therefore, this resulting battery array gives 4VDC @ 6 Amps

Diagram 4 - Series/Parallel connection