Plan For Implementing Small-Scale Stand-Alone Photovoltaic Systems In Rural Thailand

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Introduction

This document is a guide for individuals and groups who want to install small-scale stand-alone photovoltaic systems in rural areas of Thailand. It includes information on determining whether or not solar power is the most appropriate power-providing solution based on the needs of the end-users, how to go about designing, acquiring, and installing the system, and how to adequately take care of it.

[put a disclaimer]

This plan is the ultimate result of an Interactive Qualifying Project conducted as part of the graduation requirements for Worcester Polytechnic Institute. The aim of the project was to develop a method for increasing the quality of education in hill-tribe schools of Thailand. It was determined that the introduction of educational tools would be a good first step in this endeavor. However, a lack of infrastructure and resources has limited the introduction of electricity into these rural villages. A photovoltaic system was deemed most appropriate for this application.

Many successful and non-successful attempts at utilizing solar power in a rural environment were studied. The results showed that a system in this environment needs to be easily maintained by the users, and adequately designed to suit this need. Instances were discovered where a lack of adequate understanding by the implementers and end users lead to the failure of small-scale stand-alone photovoltaic systems. This plan should act as a guide for installing maintainable and sustainable photovoltaic systems, and can be adapted for many different applications.

Any questions or comments should be addressed to the Interdisciplinary and Global Studies Division of Worcester Polytechnic Institute.

1. An Introduction to Photovoltaics and its Applications

Purpose of Section

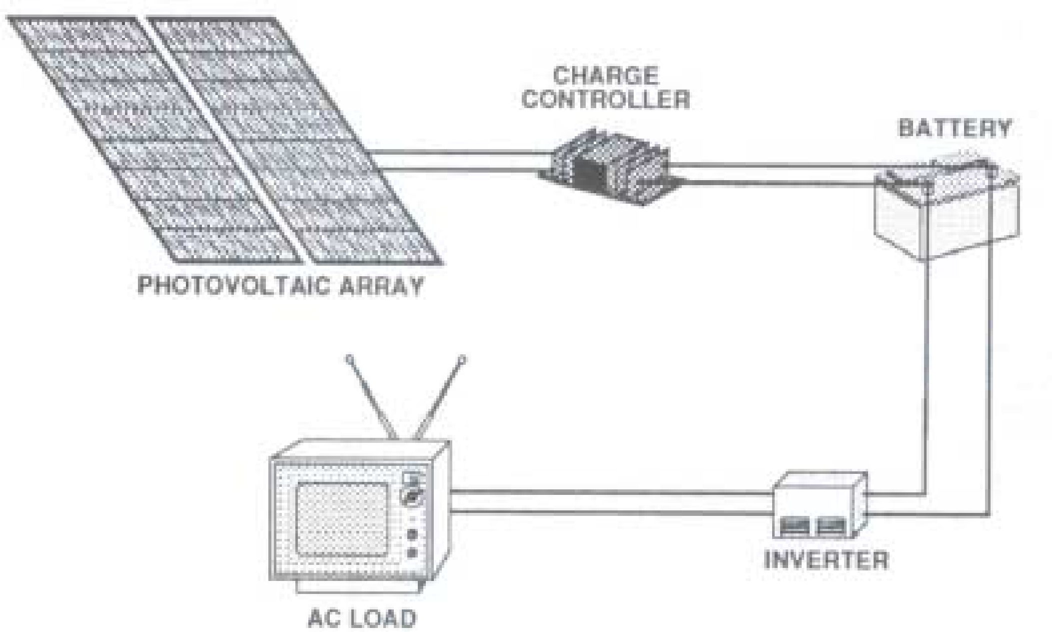
This section is used to determine whether a photovoltaic system is a feasible option for the end-users' particular needs. An overview of solar power systems gives the reader a sense of the scope of what will be required in a PV system installation. This section also includes some of the benefits and limitations of such a system and what a PV system can be used for.

1.1. Solar Power and the Photovoltaic System

DEFINITION
Photovoltaic (PV): pertaining to the process of converting the sun's light into electricity. PV systems are sometimes called solar electric systems.

PV Systems are made up of five main components, whose purpose is discussed in the following sections. Electricity is generated from the sun by solar panels. This energy is then fed to the storage batteries and the inverter by a charge controller. The devices being powered by the system, called the load, are plugged into the inverter. This is illustrated in figure 1.

Figure 1: Simplified Flow of Electricity in a PV System[1]



Solar panels are made up of small PV cells that are wired together. These cells produce energy when exposed to the sun. This energy can then be used to power electronic devices directly, or stored in batteries for later use.

The solar panels are rated in peak watts, which is the amount of energy the panel will produce under peak conditions. Normally, the environment is not constantly at peak conditions, which are set at a certain temperature, sun exposure, and wind speed. By adding more panels the system can produce more power, but it must be kept in mind that peak conditions are usually only met for one hour each day, at mid day.

As the sun shines on the panels, the energy that is produced is brought to the charge controller before it is transferred to the batteries. The main purpose of the charge controller is to prevent overcharging and over discharging of the batteries. The charge controller does this by regulating the level of power that reaches and leaves the batteries. If the batteries are full, the charge controller stops the solar panels from sending energy to the batteries. If the batteries are nearing complete discharge, the charge controller stops power from leaving the batteries.

Battery storage allows the system to be run when the solar panels are not producing enough energy on their own. This includes during cloudy days and at night. There are two types of batteries: deep cycle batteries and shallow cycle batteries. The two types are designed to meet specific needs, with certain benefits and tradeoffs associated with each one.

Deep cycle batteries are batteries that can be discharged to up to 50% of their total capacity. They are then recharged by the solar panels before further discharge can take place, which would damage the battery and decrease its lifespan. These deep cycle batteries, also called deep discharge batteries, last longer than any other type (typically five years) and have the deepest discharge percentage available for a PV system. The main tradeoffs with using a battery of this type are the increased cost associated with them and the lack of availability.

Shallow cycle batteries are only designed to discharge 20 to 30% of their total capacity. This is because they are used in automobiles where they are never discharged below 95%. Attempting to discharge them like a deep cycle battery would cause severe damage and significantly decrease their lifespan. If they are kept charged at 70 to 80% of their total capacity, they will last up to 2 years. The benefit of shallow cycle batteries is their availability and inexpensive cost.

The power that is stored in the batteries can be used by direct current (DC) devices, such as special types of lighting. Most devices, however, require alternating current (AC). An inverter is a device that converts the DC in the batteries to the AC used by most devices. The cost of an inverter varies with the amount of power it needs to deliver to the devices.

1.2. Uses of a Small-Scale Stand-Alone PV System

Small-scale PV systems are used in many different environments for different situations. Their versatility makes them ideal for any area that receives enough sunlight to make the system feasible.

DEFINITION
Stand-alone PV systems: systems that are not connected into a power distribution grid. They are used in an area where power is not being fed in by power lines or any other source of electricity.

These PV systems are often used in rural areas where it is too expensive to supply the area with electricity from the power distribution company. They have been used to power satellite telephones, beacon lights on mountaintops, and in battery charging stations and could potentially used in many other situations as well. PV systems can also be used to generate enough power for small appliances, lights, water pumps, and radios. These devices assist in the day-to-day routines of people in remote areas. Sometimes they are used purely for educational purposes, either by setting an example for renewable energy or by supplying power to schools.

1.3. Is PV the Best Solution?

There are many options for providing off-grid power to a remote area, and solar may not be the best solution. There are a few factors that may have an effect on the user's decision to use PV as the power source. The advantages and disadvantages must be taken into account.

First of all, solar power requires the sun. If the area does not receive a generous amount of direct sunlight each day, the system may not be able to produce enough energy when needed. Excessive shading from surrounding objects and cloud cover are two things that can affect the amount of direct sunlight that strikes the solar panels. These two factors are further discussed in section 2.1.

General knowledge about the environment in which the PV system is being considered for implementation should be taken into account. If the average wind speed of an area is high, or there is a waterfall near to the desired location, a wind generator or hydroelectric system may be more cost-effective powering solutions. These other options should be studied since they can also be cost-effective sources of renewable energy in rural environments.

While PV is not a complicated system to install or run compared with other forms of off-grid electrification devices, it still requires regular maintenance that is not normally associated with grid power. The system components have to be checked on a regular basis to make sure that the system is running optimally.

Like many other off-grid systems, PV systems require basic electrical knowledge in order to be able to install and maintain them in an effective manner. Lack of knowledge of PV systems specifically should not prevent some one from attempting to install a PV system, but a basic knowledge of electricity would be beneficial. The more the end-users of the system know the more likely the system will be installed correctly and properly maintained. Studying this document is a positive start to gaining an understanding of electronics and PV systems.

The advantages of PV include low maintenance, low upkeep cost, no waste or noise byproducts, and easy expansion. The disadvantages include high initial investment, reliance on the sun, and possible danger from the batteries (associated with most forms of renewable energy).

2. Site Analysis and Evaluation

Purpose of Section

This section describes what information needs to be gathered about the location in which the PV system will be installed. It also informs the reader how to interpret the data and make appropriate design decisions, which will be passed along to the PV system provider.

2.1. Site Survey

A site survey involves gathering information at the project site, which necessary so that you can later determine the most appropriate PV system. There are two main phases to the site survey: interviews and physical observations. Interviews must be conducted with the intended users of the system, including anyone who may be affected by its installation. Physical observations are also made around the locations where the system may be installed at the project site.

During the interviews, reconfirm that the need for the PV system exists. Discuss the possible impact it may have, including the advantages and disadvantages. It is important to ensure that the PV system is needed because vested interest in a PV installation contributes to its sustainability. Attempt to find out what effect the installation will have on the location. Look for a positive reaction from the people that you are interviewing. If they are not interested in the installation, then maybe you should reconsider the project.

It is also important to discover the technical ability of the persons at the site. Find out if someone is available to be the caretaker of the system after it has been installed. At a minimum, they should have a basic knowledge of electricity. This needs to be done to ensure the system will be taken care of adequately.

The intended applications of the electricity should be determined, including the types of devices and how often they will be used. If the devices are already purchased, then record their voltage, usually labeled “V”, and amperage requirements, usually labeled “A”, which are located on each unit’s power supply. The power requirements of the load devices determine how much energy the PV system will have to produce. If the users are unsure what they want to power with the system, then they may be disappointed in the future if the system can not produce the energy they require. Likewise, if the system creates too much energy then the expense of the system will likely have been higher than necessary.

Make physical observations about the project site. Find at least two suitable locations for the panels, which have an abundant amount of sunlight. This can be determined by observing the sun’s position in the sky and any possible objects that might shadow the site. Observe the sun at midday; this is when the sun would be in the southern part of sky. Look around the site, keeping in mind that the sun will be at different heights in the sky at different times of the year, but always moving from the east to the west. Note any trees, buildings or other potential sources of shading. Choose the locations that appear to get the most sun during the day and have the fewest sources of shading.

2.2. System Design Specifications

There are some specifications that you have to determine for the PV system before it can be purchased. The two main steps are to synthesize the data collected during the site survey and to use the load analysis worksheet to determine the necessary size of the system. This information is needed by the PV manufacturer.

Table 1: Load Analysis Worksheet

Device Name	Watt Rating	X	Hours Used Each Day	=	Watt*Hours
Video	25	X	3	=	75
Television	85	X	3	=	255
		X		=	
		X		=	
		X		=	
		X		=	
		X		=	
		X		=	
Total watt hours:					330

In the load analysis worksheet, given as an example in Table 1, list the devices with their respective watt rating. This is the amount of power required to run each device that the end-users wish to operate. Multiply each of these watt ratings by how many hours the device will be used each day, which was determined during the interviews with the end-users. The total watt*hours is the amount of power needed to be supplied by the PV system each day.

A typical small-scale stand-alone PV system is capable of supplying up to 100 to 1000 watt*hours per day. If the system required is too expensive, then reducing the hours that each device is used each day, or reducing the number of devices used, can lower the price and the complexity of the system.

One other consideration about the system is the type of mounting that will be required by the solar panels. There are three main options: roof-mount, ground-mount, and pole-mount. The racking structure is similar in each case. They differ in the methods of securing the rack to the mounting structure.

Roof-mounting is the most common method since roofs typically receive a lot of sun and are out of the way from day-to-day duties. There are two factors that could limit the use of a roof. First, the structural integrity of the roof has to be good enough to withstand the weight of the panels and the persons installing them. Secondly, the roof has to be facing within 10 degrees of solar south.

The next option, ground-mounting, is similar to roof-mounting, except that the limiting factors are different. The panels can now more easily be made to face south, and the structural integrity of the ground is presumed to be stable enough to withstand the weight of the panels. However, the areas where ground installations are being considered must be free from shadows and out of the way. A fence is often constructed to keep people and animals away from the panels. Also, ground-mounted systems are susceptible to flooding and washouts, which could damage PV panels.

The third option is a pole-mount system, where the PV panels are mounted on the top of a pole. This pole is placed in a hole in the ground and supported with concrete. If the pole is over 1 meter high, support wires are strung to stop it from swaying in the wind. This is a useful installation technique for small-scale systems since as many as four panels can be mounted on a single pole. Although it is the most difficult mounting technique, pole mounting has the advantage of the added sun exposure of a rooftop without the risk of flooding at the ground level.

For each possible installation location, a place must be chosen for the batteries, charge controller, and inverter. The location for these should be well ventilated, out of the sun, and out of people's way. These components can be potentially dangerous, so keeping them in such a location will make them safer and increase their lifespan.

The distance from where the panels will be mounted to where the batteries, charge controller, and inverter will be located must be measured. Also, how far the devices that will be powered by the system will be from the inverter must be determined. When deciding where to place the panels, try to keep these wires as short as possible to limit energy losses that are directly related to wore length. Minimizing the length of wiring from the panels to the charge controller and batteries is very important because the wires used for this typically have the highest power losses. Minimizing the length of wiring from the inverter to the devices being powered is not so important because this type of wiring incurs little power loss over fairly long distances.

3. Acquiring the PV System

Purpose of Section

This section describes the steps necessary for acquiring and installing the PV system once the preliminary design decisions have been made by doing a site survey, completing a load analysis, and by deciding where the system will be installed. These steps will yield the information that a PV company needs to know before giving a price quote, and that will be needed to find project funding.

3.1. Purchasing

There are companies in Thailand who specialize in designing and selling small-scale stand-alone PV systems. By supplying them with the information gathered during the site survey and load analysis, they can design the most appropriate system for your installation.

Contact a PV company and tell them about your intended installation. A list of PV companies located in Bangkok is provided in Table 2. Inform them that you are prepared to supply them with load analysis data and would like a price quote on a PV system. Communication can be initiated by telephone, email, or fax.

Talk with the company representative about the type of installation that is best for the site. He or she will help you in determining the best location and mounting technique for your system. Be prepared to meet with him or her in person to discuss your options. It is helpful to supply pictures or drawings of the site and also to learn how much information they can provide to you about installation procedures.

Talk with a few different PV companies. Not only will you get different price quotes, but you will also increase the amount of professional input into your system design. Price quotes from different companies can be used to compare different designs. It is important to ensure that, in addition to the panels, batteries, inverter, and charge controller, the quote includes an installation kit, a mounting kit, conductor, and delivery. Not every company will be able to supply an installation kit that includes the tools necessary to set up the system. These might have to be acquired from other sources. See section 4 for more information on installation. Another note to be kept in mind is that by letting the PV company know what the purpose of the project is, they may be able to give a humanitarian discount.

Some PV companies do not keep certain necessary items in stock, so it is also important to find out when they can provide the system. There are a few brand names of solar panels that are the most widely used in the world and are of the highest quality. The companies listed at the end of this section either use BP Solar or Siemens brand panels. There are less expensive options available, but they tend to be unreliable, have a shorter lifespan, and produce less power.

After ordering and receiving the system, all the components should be checked for documentation and any visible damage. If a warranty is available for the system, find out what the terms and conditions are.

Table 2: PV Company List for Bangkok

Solatron Co., Ltd.
38 Chavanice Bldg, 2/Fl., Soi Salinimit
Sukhumvit 69, Bangkok 10110, Thailand
Tel: (662) 3920224
Fax: (662) 3812971

BP Thai Solar Corporation Ltd.
101/47/9 Navanakom Industrial Estate
Phaholyothin Road, Klong 1, Klong Luang
Pathumthani 12120, Thailand
Tel: (662) 5291105
Fax: (662) 5294542

Siam Solar and Electronics Co., Ltd.
62/16-25 Krungthep-Nonthaburi Rd.
Nonthaburi 110000, Thailand
Tel: (662) 5260578
Fax: (662) 5260579

3.2. Funding

There are two main sources of funding available. The first includes government agencies that are set up to provide renewable energy to areas that need it. The other options are non-governmental organizations (NGOs) that raise money for humanitarian causes such as powering rural village schools. When contacting these sources, it is also important to keep in mind that the total amount of needed funds could come from multiple organizations.

The application process will usually involve the applicant supplying a proposal, which describes the project, its short and long term benefits, when it will be completed, and who will supervise it. The organization will want to know what the detailed budget is and how much money is being requested of them. An example project proposal is included at the end of this document.

4. Installation

Purpose of Section

This section describes the steps necessary to install a PV system. It is vital that you review all steps necessary for installation before you begin. This includes exactly how to wire the system together, how to position the panels on the chosen type of mount, and the tools that will be needed to complete the installation. It is worthwhile to have PV company show you as many of these procedures before embarking on an installation.

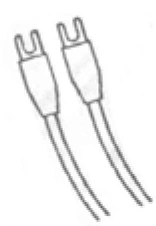
The tools that you will need are given in the following list.

Phillips and Slotted Screwdrivers of different sizes
Wire Cutters, Pliers, and Crimpers
Utility Knife
Bolt Driver Kit
Digital Multimeter
Electrical Tape, Wire Ties, Wire Connectors
Compass, Protractor, Combination Square
Carpentry Tools and Building Materials

There are two separate tasks involved in installing a PV system: structural and electrical. The structural installation involves mounting all of the hardware, while the electrical installation entails wiring all of the components together. These instructions use a system consisting of three solar panels in a single array as an example. They can be easily adapted for other sizes of systems.

When attaching wires, it is important to remember that they must be attached securely and reliably to ensure proper operation of the system during normal wear and tear. However, during system maintenance and troubleshooting it is sometimes necessary to disconnect parts of the system. For this reason, lugs (pictured in Figure 2) that are attached to wiring by a crimping tool are most often used.

Figure 2: Lug Connectors[2]



Positive terminals are marked with a “+” or by red color and negative terminals are marked with a “-“ or black color.

4.1. Solar Panel Mounting and Wiring

Mounting the solar panels is the first step in a system installation. Performing this step correctly ensures maximum power output by the combined panels, often called the PV array. These steps must be taken for all three mounting techniques.

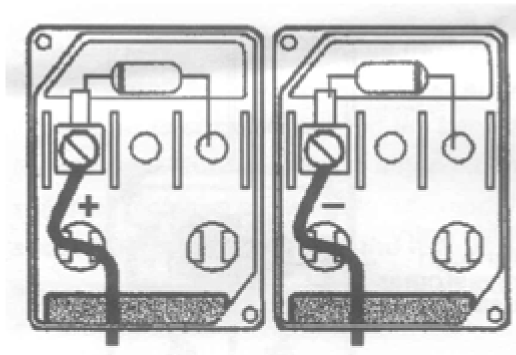
Solar panels are inserted into a support frame that comes from the manufacturer. Secure the frames together with the mounting rails. These rails give added support to the solar panels, as well as provide a method for mounting it. The rails will be attached to the mounting structure.

For a 12-volt system the panels are wired in parallel. This is an electrical term meaning that the positive terminals are connected to each other and the negative terminals are connected to each other. This is represented in Figure 3. The amp-hour rating for each battery is added together in this configuration increasing the storage capacity of the system.

Figure 3: Three Batteries Wired in Parallel[3]

Wire the positive and negative terminals of the PV array together before it is mounted. Each panel comes with two wires for this purpose. Crimp a connector onto the ends of each wire. In our example, this would require eight wires to be crimped. Bypass diodes are installed in the panels to protect the system if one of the panels stops working. This can make the wiring of the panels complicated and because each brand of solar panel might have look different, these details should be reviewed with the PV company before installation. An example of a negative and a positive solar panel junction box can be seen in Figure 4.

Figure 4: Solar Panel Junction Box Wiring[4]

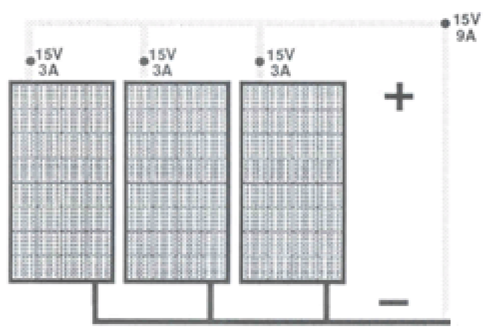


CAUTION

Solar panels produce electricity whenever they are in the sun. Be careful when making battery connections since they are charged before being purchased. Short circuiting battery terminals by connecting the negative and positive terminals together can cause an explosion or a severe electric shock.

Cut a length of DC wire that will reach the batteries from the PV array. Strip the positive and negative wires on each end and crimp on connectors. Attach one end to the PV array, connecting the positive wire to the positive terminal of one of the panels and the negative wire to the negative terminal of the panel. The other end will be attached to the charge controller later. Figure 5 shows three solar panels wired together in parallel. Notice how the currents add and the voltage remains the same.

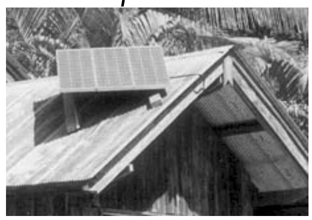
Figure 5: Solar Panels Wired in Parallel[5]



Once the panels are wired together they can be attached to the mounting structure. This is easiest to do before the structure is secured on the roof, on the pole, or on the ground. Ideally, the panels should face due south and be tilted 15° from the horizontal. However, if they are different by as much as 20°, the power output will be decreased only slightly. Use a protractor to measure the angle from the horizontal. A compass is used to determine solar south, which less than is 10° west of magnetic south in Thailand.

In a rooftop installation, shown in Figure 6, the solar panels are mounted through the roofing material, into the roof's support structure. If this is not adequate for the solar panels, an additional structure of supports can be built onto the roof first. This can be made of wood or metal, taking the structural integrity of the roof into account.

Figure 6: Solar Panels Mounted on a Roof



The support structure can also adjust the angle of the solar panels. If the panels are not facing south and tilted at the correct angle, larger legs can be added on the bottom, or on the top of the structure. This structure also increases air circulation, thus lowering the heat absorbed by the panels and increasing their efficiency.

Mounting an array on the ground is similar to roof-top mounting, where the support structure is buried into the ground and secured with concrete. Be prepared to build a fence around the array to keep out unnecessary animals and individuals.

The pole-mount technique requires more engineering than the other two methods if the pole is installed over 1 meter tall. Securing the pole is necessary to stop wind from knocking it over. You can use either wood or galvanized metal for the pole. Use concrete to secure the pole in a hole at least two foot deep. Anchor wires should also be attached from the top of the pole to a spot on the ground at least 2 meters away from the base of the pole in order to keep the pole from swaying. Adequately mark these wires so that people know that they are there. If the pole is less than 1 meter tall, the anchor wires are not needed. To attach the panels to the top of the pole, a pole-mount kit provided by the PV company should be used. This includes the hardware that attaches to the pole, so make sure it matches the pole's diameter.

Secure the mounting structure in place after you have attached the array. String the leads from the array to the charge controller location, making sure there is a few feet of slack.

4.2. Charge Controller, Inverter Mounting, and AC Wiring

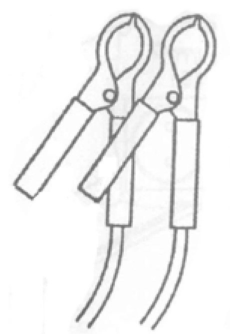
The charge controller and inverter should be placed in a convenient location, close to the batteries and solar panels. This is because the length of wires that connect these devices should be as short as possible in order to limit power losses. However, these components should not be too close to the batteries in case of accidental leakage of flammable gasses or acid.

These devices need to be kept in a cool, dry location. Although housing for these devices is not necessary, it is recommended. They should be accessible for maintenance at all times. Since they usually have various indicator lights on them, they should be highly visible.

Mount the charge controller on a surface with at least two inches of clearance above and below the unit, allowing adequate ventilation for cooling purposes. This is usually accomplished by screwing the controller into a wall with hardware supplied by the manufacturer.

The inverter does not need to be physically mounted to a surface. In some applications it is better to keep it portable, such as if the load is being plugged directly into it. It should be in a cool, dry location to increase efficiency. Connecting the inverter to the batteries is recommended only when the load is being used. Attach the lug connectors to the DC input terminals on the inverter with a screwdriver. The other end of the connecting wire has alligator clips on it (see Figure 7), which can be easily clamped onto the poles of the last battery, as described in section 4.4.

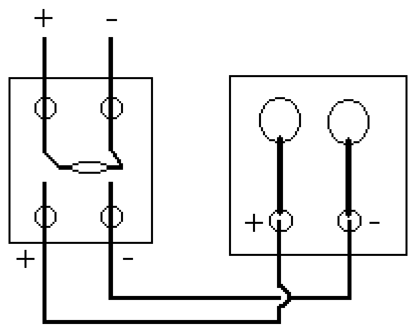
Figure 7: Alligator Clips[6]



The AC output terminals of the inverter can either be connected directly to the load device, or wired to an electrical outlet. For this option, AC conductor, a two-prong plug, AC switch, and an outlet are needed. They are most often not supplied by the PV manufacturer so they must be purchased in an electronics store. Using these devices will allow the electricity to be taken from the inverter to anywhere where it will be used. However, it is important to remember that longer distances will lead to more power loss.

It is best to wire the outlet and switch first, and then run the conductor back to the inverter. Cut a short length of the cable that is long enough to reach from the switch to the outlet. Strip the positive and negative leads on both sides about an inch. Using a screwdriver, wire the positive and negative output terminals of the switch to the terminals on the outlet together, as illustrated in figure 8. Then take the end of the spool of AC conductor and strip off an inch at both leads, connecting the positive and negative leads to the input terminals on the switch.

Figure 8: AC Switch and Plug Wiring Diagram



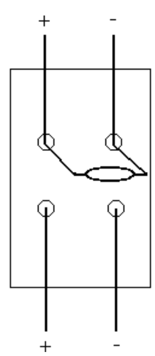
After the switch is wired, run the AC conductor to the inverter and cut the wire, giving yourself a few feet of slack to work with. Secure the conductor onto walls, ceilings, or whatever is available. Once the wire is in place, attach the plug. This is done by stripping the positive and negative leads coming from the AC switch about an inch. Remove the cover of the plug, secure the wires under the terminal screws, and replace the cover. The AC portion of the wiring is now complete.

4.3. Setting up the Batteries

The storage batteries need to be wired in parallel, just like the solar panels. Place them as close to the solar array as possible, making sure it is a cool, dry, and ventilated location. Since it is dangerous to for the positive and negative terminals of the batteries to touch, create all of the connecting wires before attaching them to the battery leads.

A DC battery disconnect switch, modeled in figure 9, is wired between the charge controller and the batteries to easily and safely disconnect the panels from the batteries. Cut a length of DC wire that will reach from the charge controller to the switch. The wiring of the switch will vary with the type purchased. It is often best to attach connectors to the wire, and then attach the connectors to the switch. Make the connections on both ends and attach the wire to the charge controller and the switch.

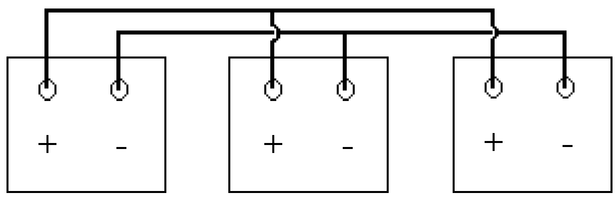
Figure 9: A Simple Switch



The next step is to cut a length of DC wire that will run from the switch to the first battery, giving yourself a few feet of slack. Strip the ends of the wire that will go to the switch, and attach connectors. Wrap black electrical tape around the negative lead and red electrical tape around the positive lead. Make sure the switch is open, as seen in Figure 9, so that no current can flow through the switch.

Cut a length of wire that will connect the positive terminal of the first battery to the positive terminal of the next battery. Cut another length of wire for the negative terminals. If the system only requires one battery, as determined by the PV manufacturer, skip this step. However, if multiple batteries are installed, wires need to be cut to connect the subsequent leads together, as illustrated in figure 10.

Figure 10: Top-down View of Battery Wiring



Terminal lugs are labeled either positive with a plus sign or negative with a negative sign. Connect the positive wire that will go to the switch from the first battery to a positive terminal lug, along with the positive wire that will go to the second battery. Do the same for the negative wire, attaching them to a negative terminal lug. For the second battery, connect both the positive wire coming from the first battery and the positive wire coming from the third battery. Continue with this for the rest of the batteries. The last battery will only have one wire connected to each o its terminal lugs.

Once all wire connections have been made to the terminal lugs, it is time to connect the lugs to the batteries.

CAUTION

The positive and negative terminals at the battery and at the charge controller must be connected in a particular order to reduce the possibility of electric shock. Follow these steps carefully.

First, connect the positive terminal lug to the positive pole on the last battery. You will need an adjustable wrench and/or socket to tighten the bolt on the lug around the pole. Repeat this process for the other batteries, attaching only the positive lugs.

Second, connect the positive wire from the first battery to the positive terminal on the switch intended for the battery input. This can be done with a screwdriver.

Third, connect the negative terminal lug to the negative pole on the last battery. Once again, this will probably require a wrench or socket to tighten the bolt. Repeat this for the rest of the batteries.

Lastly, connect the negative wire to the negative terminal on the switch intended for battery input. This can be done with a screwdriver. Once again, make sure the positive lead from the batteries does not come close to the negative lead because if they touch, all the batteries you have wired will discharge all of their energy very rapidly, causing an explosion and/or fire.

Do not deviate from this battery connection procedure. When disconnecting the batteries, reverse the procedure step by step.

4.4. Making Final Connections and Testing Installation

Wrap electrical tape around all leads to identify polarity and to secure the connection. Use black electrical tape for negative connections and red electrical tape for positive connections. Label all devices and all terminals with a marker that won't wash off or fade.

Reconfirm that the voltage coming form the PV array is close to 17 volts when the sun is shining on it. Measure the voltage across each battery. Connect the positive and negative wires coming from the solar array to the charge controller. The correct location for making the connection should be labeled. The array is now able to start charging the batteries. Close the DC battery disconnect switch. The voltage across each battery should increase, since they are receiving energy from the array. Confirm this. If the battery voltage level does not change, then recheck all connections.

Once the charge level in the batteries is close to 100%, which can be checked by following the procedure in section 5.1, attach the inverter's positive alligator clip to the positive lead on the last battery and the negative alligator clip to the negative lead on the last battery. Turn on the inverter, allowing the DC energy stored in the batteries to be converted to AC. Plug an AC device into the wall outlet and close the AC switch. The device can now be turned on.

5. System Maintenance and Troubleshooting

<u>Purpose of Section</u>

This section describes the steps necessary to take care of the PV system after it has been installed. This includes regular maintenance and the troubleshooting of system problems in order to keep the system running through its intended lifetime. Much of the maintenance of PV systems is composed of cleaning, checking connections, and monitoring performance.

5.1. Maintenance of System

Maintaining the PV system properly will ensure its functionality throughout its intended lifetime. The tasks associated with maintaining the system should be carried out on a regular basis. This ensures sustainability in the rural environment, a common failure of PV systems. A system that is adequately maintained should operate correctly for the lifetime of the components.

<u>Charge Controller</u>

Visually check the controller for any loose wires or connections. The location in which it is installed should be cool and dry, and not near the battery ventilation area, as sparks could cause the hydrogen gas normally released by the batteries to ignite.

Visually inspect all of the system wiring. Look for loose, broken, or corroded wiring, terminals, or connections. Pull firmly on all connections to make sure they are tight. Check all conduits for damage from moisture or animals.

<u>Batteries</u>

Open the DC battery disconnect switch and wait 5 minutes before performing any maintenance on the batteries.

Clean the battery terminals with a cloth or brush. First use a baking soda and distilled water solution, then rinse with distilled water and dry with a clean cloth.

Remove the caps from all the cells and check the electrolyte level of every cell in each battery. If the level is too low, add distilled water. The recommended level is usually indicated by a line on the battery. Replace all of the caps securely by hand.

WARNING
Distilled water is the only type of water that should be added to the battery. Any other types of water will destroy the battery.

Repair any corroded, loose, or burnt connections and tighten all wiring connections. It may be necessary to replace one of the terminal lugs, which connect the wire to the poles on the batteries.

Remove any shelves, hooks, or hangers located above the batteries. Make sure that the area around the batteries is well vented, and that a "No Smoking" sign is visibly posted.

Check the charge level of the batteries. Do this by setting the multimeter to measure voltage on a ten or twenty-volt scale. Connect the positive lead on the multimeter to the positive pole on one battery, and the negative lead to the negative pole on the same battery. The voltage level measured is comparable to a certain percentage of charge, as given in the following table.

Table 3: Battery Charge Level[7]

Open Circuit Voltage	Stage of Charge
12.72 or more	100%
12.60 to 12.72	75-100%
12.48 to 12.60	50-75%
12.12 to 12.48	25-50%
11.70 to 12.12	0-25%
11.70 or less	0%

If the battery charge is below the rated discharge level for the batteries (50% charge for deep cycle batteries and 70% charge for shallow cycle batteries), then the batteries do not have enough charge. Use of the system should then be stopped until the panels have been given enough time to recharge the batteries and another test of the battery voltage results in an acceptable voltage level.

If the battery voltage is found to be below rated discharge almost every day, then it could indicate a more serious problem. This would mean that the batteries are being depleted faster than the solar panels can recharge them. The system could be being over used. In this case, the amount of time that electrical devices are used should be decreased. This could also mean that the wiring is disconnected or damaged and should be checked.

<u>Solar Panels</u>

Use a soft cloth, and either plain water or mild dishwashing detergent and water to wash the surfaces of the PV modules at least once a year.

Check and tighten all mounting system fasteners. The frames should be straight with no serious corrosion.

Determine if the panels will be shaded during any day of the year. Try to remove objects that will cast a shadow on the PV array. Shading is most often caused by growth in vegetation such as trees and bushes.

Measure the open circuit voltage of the panels. Open the DC battery disconnect switch or disconnect the panels from the charge controller so that the connection from the panels to the battery is broken. Set the multimeter to measure volts, and place the positive lead on the positive terminal coming from the array. Place the negative lead on the negative terminal from the array. These should be labeled as attached to the charge controller by red and black electrical tape. The number of volts measured should be within 10% of the system voltage, which is typically 17 volts. Only perform this test under regular sunlight conditions.

<u>Load Devices</u>

Make sure all devices being powered by the PV system are operating correctly, as this increases the efficiency of the system. If any devices are not working, check their fuses and make sure that they are properly connected to the inverter.

Be sure no new loads have been added that will overload the system. If new devices have been added, rework the load analysis from section 2.2 and determine the number of hours that the devices can be run with the current system and consider reviewing additions to the system with your PV company.

<u>Inverter</u>

Check all inverter wiring for loose, broken, corroded, or burnt connections or wires. Look for possible sources of accidental short circuits or ground faults – where the positive terminals could be exposed to the negative or grounding terminals directly.

The inverter must be stored in a clean and dry place, with adequate ventilation. If it not placed in such a location, it could be overheating and automatically turning off.

5.2. Troubleshooting Problems

Troubleshooting must be performed when the user knows there is something wrong with the PV system, but they don’t know what the cause is. The bulk of troubleshooting relies on the user checking the connections between components. Everything must be checked since it is possible that more than one component is malfunctioning. Regular maintenance can cut down on the need for troubleshooting, but unforeseeable circumstances can lead to component failure. Proper identification of these problems at an early stage will allow the user to repair or replace the faulty components, and keep the other components from being damaged in the process.

There are two main types of troubleshooting. The first relies on interpreting visual observations of the system. The other is based on a digital multimeter, which gives you readings on what the parts of the system are actually doing. Comparing these numbers to what the system is designed to be doing can help in determining what may be wrong.

If a problem occurs, the first step is to conduct all of the maintenance steps described in section 5.1. If no obvious cause for the problem is found and the system is still malfunctioning, then start to troubleshoot the system, beginning with the panels. If any connections are found to be faulty, replace them and see if the system improves. Continue with the rest of the maintenance and troubleshooting steps even after faulty connections have been located and repaired.

If the panels are working adequately, and the battery charge level is too low, then decrease the load on the system. If the batteries are within acceptable discharge levels, and the panels are working properly, but the load is having trouble operating, then check the inverter.

The inverter usually has an internal fuse, a device used to safeguard the system from supplying a dangerously high amount of power. It breaks the connection of power from the batteries to the load through the inverter if the load attempts to draw to much power such as if a 300 watt computer tries to draw power off a 100 watt inverter. This is the easiest problem to fix with the inverter. If the fuse is found to be broken, then you can replace it. However, you still need to determine why the fuse blew.

5.3. Contacting Technicians

If a problem cannot be identified, or a problem has been identified that cannot be addressed at the location, a technician can be contacted who works with photovoltaic systems. Any information gathered during maintenance or troubleshooting should be on hand when talking with a technician. Before contacting anyone, review the warranty data of the system components. It may be possible to have part of the system replaced that is still covered under a warranty.

A general electrician can be consulted if the problem is associated with wiring, connections, or load devices. They will also be able to replace fuses and switches. Anything directly affecting the PV system should be reviewed by a PV technician. The best place to talk with one is at the company at which the system was purchased. The contact information should be made available at the system site.

The technician should be told as much as possible during the telephone, fax, or email conversation. In remote environments, it is often necessary for field technicians to be prepared to replace any portion of the system without requiring a return visit. They can be better prepared if they know what the circumstances of the problem are.

Before they travel out to the site, find out how much they will be charging for the work. Sometimes it may be cheaper to bring a component to them then for them to go to a rural location. For example, if the inverter is not working properly, it may be easier to simply disconnect it from the system and bring it to a PV field office, or even to simply replace the device rather than for a technician to travel our to the location.

Sample Project Proposal

This contains the description of the project in response to the question:
PURPOSE and DESCRIPTION OF PROJECT: (include origin, reasons for its undertaking effects long and short term, beneficiaries, # of people who will benefit, start and completion dates, supervision. If an income generating project, explain in detail and provide your business plan, use additional sheet if necessary)

The Interactive Qualifying Project (IQP) is part of our graduation requirements at Worcester Polytechnic Institute (WPI) in which we attempt to bridge the gap between technology and society. WPI has a project center in Bangkok that facilitates about eight IQP's each year. Tip Ruchaitrakul is a Karen native who works with TBCAP (Tak Border Community Assistance Program) who contacted WPI with a project idea. He wanted to find a way to improve the quality of education in the rural village schools that are not funded by the Thai Ministry of Education. His suggestion was to implement a solar system at each school to be used to power devices that would assist the teachers.

We have visited three Karen villages along the Burmese border in the Tak Province and have confirmed both the need to improve the quality of education in the rural schools and the feasibility of utilizing solar power to reach the goal. An NGO called TOPS, the Taiwanese Overseas Peace Service, set up schools in two of these villages three years ago. Because the villages are remote, there are some subjects which are much harder to teach than in the city. First, the teachers are less educated than those in the city. The village elders and teachers all expressed interest in using multimedia devices such as a television and video equipment to assist the children's education. Having the capacity to show videos will help the teachers as well as the students understand the subjects. Second, the teachers said they have a hard time putting the theory to practice. It is hard to learn about cars or cities without ever seeing one. The teachers indicated that being able to show these concepts would make the children more interested in learning. Finally, and most importantly, Thai language would be easier to learn. Because the teacher's native language is Karen, they themselves have trouble speaking Thai, and they do it with an accent. By allowing the children to see and hear Thai's speaking Thai they can learn the language properly. Also, when they proceed on to government schools, where only Thai is spoken, the students will not be behind native Thai speakers.

The short term effect is the improved education of the children. In the long term the lives of everyone in the villages will be improved, because they will have the ability to relate better with the world outside their villages. One problem the villages face is communicating with the Thai government for aid. Without an understanding of Thai, they cannot properly explain their needs and are unable to get the help they need. This will help ensure that the rights of the villagers are protected by having a voice in the government. Villagers who speak Thai will be able to solve problems with the knowledge they have gained through their education. For example, Sokaykla village (with a TOPS funded school) is having a food shortage due to mice eating too much of their rice. If there is an answer to this problem already, they would have to locate the information. Learning to speak Thai being able to understand the world outside the village is the first step in bringing the villages closer to other parts of Thailand. As one elder said, "We want to share knowledge" but they cannot if they cannot communicate in Thai to outsiders.

By installing one solar powered system as part of our project we will be able to show how effective multimedia equipment can be and develop an effective plan which can be followed time after time in any of the hundreds of other villages in need of schools and electricity. The school which we propose to install the first system contains five classrooms up to grade five and provides education for seventy-five students, some of whom come from neighboring villages to receive their education. The school is well established and has existed for sixteen years with the aid of Catholic missionaries. The students at this school still have a difficult time learning Thai, however. The teachers expressed a need for multimedia in this situation too, even after sixteen years of being in existence.

The project will start February 8th and end March 1st. If the funding is available, we will purchase the system from a solar company in Bangkok and install the equipment in the village, under the supervision of our liaison. The installation will act as a guide for future implementations. From this experience we will complete a plan for others to follow to be used in other villages with similar situations.

Table 4: Sample Proposed Budget

Item Description	Quantity	Unit Price	Discount	Amount
55 Watt Solar Module (SM-55)	3	17,000.00	20%	40,800.00
Charge Controller (Sun Saver-10)	1	4,500.00	10%	4,050.00
300 Watt Inverter (G12030)	1	4,500.00		4,500.00
DC Wiring	50 m		100%	0.00
Module Interconnect Cables	1		100%	0.00
12 Volt Battery, 150 amp-hour	2	3,379.00		6,758.00
Digital Multimeter (UniT UT30)	1	480.00		480.00
Airfare, Roundtrip from Bangkok to Mae Sot	4	3,250.00		13,000.00

Sources:

"Backwoods Solar Electric Systems", 2000

Photovoltaic Energy Systems, Matthew Buresch, New York, 1983

Maintenance and Operation of Stand-Alone Photovoltaic Systems, Naval Facilities Engineering Command, Southern Division Photovoltaics Review Committee, Department of Defense, 1991

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[1] From "Maintenance and Operation of Stand-Alone Photovoltaic Systems", Naval Facilities Engineering Command, Southern Division, Photovoltaics Review Committee, Department of Defense, 1991, p. 12
[2] From "DC to AC Power Inverter Instruction Manual"
[3] Naval Facilities Engineering Command, op cite, p. 62
[4] From "General Installation Guide for Siemens Solar Electric Modules", Siemens Solar Industries
[5] Naval Facilities Engineering Command, op cite, p. 24
[6] From "DC to AC Power Inverter Instructions Manual"
[7] Naval Facilities Engineering Command, op cite, p. 106