GGGI

Module 8 - **Trainers Guide**

Solar Operation and Maintenance Basics

ENGLISH - FIJI ISLANDS

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Cover photo: Solar demo kit used in Vanuatu pilot community training. Source: GGGI Vanuatu.

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GLOSSARY

AC - Alternating Current is the type of electricity that "alternates" or is always changing, typically produced by inverters, generators, and larger power systems.

Charge controller - A component that controls the charging of a battery and stops it from overcharging.

Clamp Meter - A device that is used to measure current in an electrical circuit, though most can also do other measurements as well.

Current - An electric current is a flow of electric charge in a circuit or wire.

DC - Direct Current is a type of electricity is constant and is typically produced by solar panels and batteries.

Electrical power - Is the rate at which energy is used or produced in a circuit, measured in Watts.

Electrolyte - This is the chemical liquid found inside lead acid batteries. These is very corrosive acid and dangerous.

Inverter - A device that converts DC electricity to AC electricity

Load - Anything that consumes power or uses electricity to operate, such as lights, fans, etc.

Mounting - Something used to hold a component in place. For example, the components and fittings that are used to install and secure solar panels on the roof or on the ground.

Multi-Meter - A device that is used to do tests and measurements on a electrical circuit, such as measuring voltage, continuity tests, etc.

Overcharge - Condition where a battery is continuously charged even after it is fully charged. This can short the battery life or damage it.

PV Array - It means many solar panels connected together.

Short circuit - When live wires of opposite polarity come into direct contact with each other, it is called a short circuit. For example, when the positive and negative terminals of a battery touch. Short circuits can damage your components and cause fire and serious injuries.

Solar Panel - Also called 'PV module' or PV panel, is the device that produces electrical energy when exposed to sunlight.

Terminal - Electrical connection posts meant for connection of wires to a device. For example, batteries come with positive and negative terminals to allow for connection of battery to other circuits. Normally there are and bolts on the terminals to tighten the electrical connections.

Voltage - Is the potential difference between two points in a circuit and is what causes current to flow in a closed circuit.

The "Solar Operations and Maintenance Basics" training module is meant for technical learners who wish to know more about solar installation and maintenance.

Upon completion of the course, the learners will achieve the following learning outcomes:

- Describe the various types of Solar PV Systems.
- List the components used in Solar PV Systems.
- Explain the requirements of components used in Solar PV systems.
- Identify tools used in solar PV system installation and maintenance.
- Describe procedures for installing and maintaining solar PV Systems.
- List the safety requirements for solar PV systems.
- Identify and resolve common faults in Solar PV Systems.
- Demonstrate the use a Solar PV System maintenance checklist.

HOW TO USE THIS GUIDE

The trainer guide is provided with the class notes and includes activities which need to be done after each section of the course. The guide acts as a recommendation only. After seeing the situation on the ground in each community, the experienced trainers may use their judgment to modify their delivery and assessment techniques to achieve better results.

The Trainer Guide provides detailed notes written in the form that can be directly delivered to the learners. However, the very detailed notes are intended to broaden the knowledge of the learner as well. You are not required to read each paragraph from the Trainer Guide, but you are expected to know the materials sufficiently to train others. Firstly, you must know what key concepts the learners need to learn. These are normally called learning outcomes. The learning outcomes are all listed at the start of the Trainer Guide, and you must ensure that at minimum, every learner achieves those 8 learning outcomes. You are required to take at least a week to go over the TG and go through the activities in the Learner Workbook. During the actual training you can refer to the Trainer Guide and explain it to the learners in your own words. If you are unsure of something always refer to the TG notes. Also note to take heed of the time recommended for each session and activity.

In case where learner literacy levels are low, trainers are advised to adapt to the situations and modify activities as appropriate. It is advisable to keep a continuous record of competencies of learners. All competencies are achieved when learners fulfil all learning outcomes.

HOW TO CONDUCT ACTIVITIES

- Activities are best done in groups or pairs. It is recommended that in each group there is at least one who is more literate or a more active learner who can help to translate and explain the training contents to learners who are slower to understand.
- You may divide the learners into groups of at least 2 and preferably 3-4 learners and ask them to carry out a rigorous discussion within the group. Some activities can be given to the groups for overnight preparation. The trainer needs to be aware of the dynamics of relationships in the community when dividing learners into groups. Sometimes women and youth are not free to share their views when the men from the communities are present. The trainer should ideally ask learners for their guidance when organising them into groups for discussions.
- Ideally the learners may present the results of their activities to the class and have a class discussion based on their findings.
- It is not necessary that all groups present in the same activity.
- However, it is important that all groups are given opportunity to present or verbally discuss their answers.
- At all times, encourage learners to be interactive and participative in class.
- Learners must be encouraged to be vocal and to contribute actively in class discussions.
- To better improve learning, the learners must be encouraged to strongly inquire about the topics through questions.
- The activities allow trainers to observe if the learners have achieved the learning outcomes. If possible, do keep record of the learner's achievement of learning outcomes so that you can help them learn better. A sample record table is given in this guide.
- Adapt existing activities and/or alternative suitable activities in case the desired literacy levels of learners are not met or the desired resources are not available.

TEACHING TOOLS

<u>The following tools/items may be required to enhance learner learning:</u>

- Laptop/ computer and projector to play videos or present notes to the whole class. This will depend on availability. In case this is not available, you are recommended to take large prints of the key concepts and display to the learners while teaching.
- Provide each learner with pen or pencil, and paper to allow them to participate.
- Whiteboard and markers or black board and chalk can be made available to allow both facilitator and learner to state a point
- The Learner Progress Record sample given below can be used to observe learners, note their feedback, and assess if they have achieved the specific learning outcome. This recording is useful for both the learner and trainer so you can focus on those who are falling behind. Note there are no marks to be awarded and the record is only to improve learning. This is entirely optional.

TABLE 1: **Learner Progress Record – (optional for trainers to use)**

Learner Progress Record (Optional):	Date:
Learner Name:	
Learning Outcome	**Achieved Outcome (Yes or No) and Comments**
1. Describe the various types of Solar PV Systems.	
2. List the components used in Solar PV Systems.	
3. Explain the requirements of components used in Solar PV Systems.	
4. Identify tools used in solar PV System.	
5. Describe procedures for installing and maintaining solar PV Systems.	
6. List the safety requirements for solar PV System.	
7. Identify and resolve common faults in Solar PV Systems.	
8. Demonstrate the use a Solar PV System maintenance checklist.	

LESSON PLAN AND TIME

TABLE 2: **Lesson Plan and Timing of each session**

Chapter	Lesson Type	Recommended Time
1. Ice Breaker - Introductions	Theory and Activity 1	30 minutes
2. Components of Solar Power Systems	Theory	30 minutes
	Activity 2	30 minutes
	Activity 3	10 minutes
	Activity 4	10 minutes
3. Solar PV Component Requirements	Theory	30 minutes
	Activity 5	10 minutes
	Activity 6	20 minutes
	Activity 7	10 minutes
	Activity 8	20 minutes
4. Types of Solar PV Systems	Theory	40 minutes
	Activity 9	10 minutes
	Activity 10	10 minutes
5. Tools used in Solar PV System	Theory	30 minutes
	Activity 11	10 minutes
6. Installing Solar PV Systems	Theory	40 minutes
7. Safety Requirements of Solar PV Systems	Theory	20 minutes
	Activity 12	60 minutes
8. Identifying and Resolving common faults in solar home PV Systems	Theory	40 minutes
	Activity 13	30 minutes
9. Solar PV Maintenance checklist	Theory	30 minutes
	Activity 14	30 minutes

1

Ice Breaker Introduction

Trainers must understand that the learners who are attending the module have taken time from their usual daily activities which sustains their livelihood. Most will also be very nervous and unclear regarding what the module is all about. Hence the trainer must ensure that the learners are comfortable and not too nervous. It is important to make them feel at ease so that they can focus on the module and absorb as much knowledge as possible.

Tell them that this is an informative module and there will be no tests or marks in this. You must inform them that this module is being run so that they can take the information to help themselves to transition to renewable energy. Even if they do not use it, they can always use the knowledge to help others. In any way this module will better equip them to help grow their communities. Tell them to be at ease and focus on enjoying the day and asking as many questions as they want. Also tell them to not worry too much about complicated things as you will guide them through this.

ACTIVITY 1

Introduce yourself briefly to the learners. Ask if they are all comfortable at the venue. Once by one ask them their names and tell them to give some details about themselves – such as what they would normally be doing at that time and what they hope to gain from the module at the end of the day. In addition, if time permits – ask them what they think about solar energy. There is no correct answer, and the goal of this activity is simply to get them relaxed and engaged into the session. You may crack few light jokes as laughter always lightens the mood and helps learners relax. Ask the learners about their prior experiences in solar energy and how much they know about the topic. Also ask them what they wish to gain from this training session and record their answers on paper so that it helps the trainer in setting a direction to the course. For example, if learners expect to know more about installation and less about repair or maintenance, the learners can be taught more about their primary interest. This input will help the trainer direct the training to the learners needs.

2

Components of Solar PV System

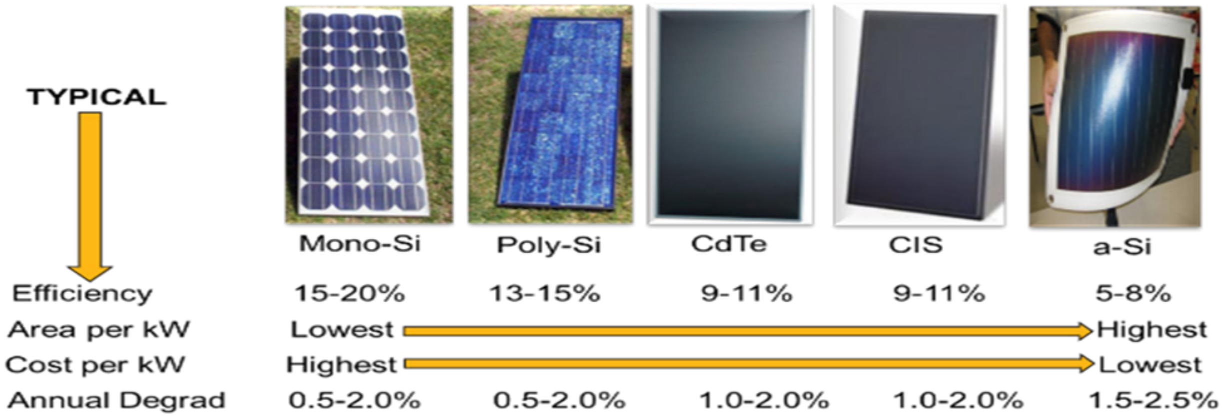
There are different types of components used in a solar PV system. A change in each component usually changes the characteristics for the system.

2.1 Solar Panel (PV Module)

A Solar PV Module produces electricity by converting sunlight into energy. There are different types of PV module, and each has its own applications and performance characteristics.

FIGURE 1: Solar Panel[1]

FIGURE 2: Different types of Solar Panel (PV Module)[2]



Full names of PV Modules:

- Mono-Si: Monocrystalline silicon
- Poly-Si: Polycrystalline silicon
- CdTe: Cadmium telluride (CdTe). This is thin film technology
- CIS: Copper indium gallium selenide solar cell. This is thin film technology
- A-Si: Amorphous silicon. This is thin film technology

It can be seen that Mono-Si (monocrystalline silicon) has the highest cost per KW and lowest area per KW. This means that with a low area exposed to sun, Mono-Si can produce more power thus the efficiency is also more. However, it should be noted that PV module must not be installed in a location that has shade in parts of the day as this will affect the power output of the PV module and will drop the system efficiency significantly.

1 Source: Audio Digital, http://www.audio-digital.com/tag-produk/sound/

2 Adapted from the System Components- PV Modules, Arizona State University (VOCTEC), http://voctec.asu.edu

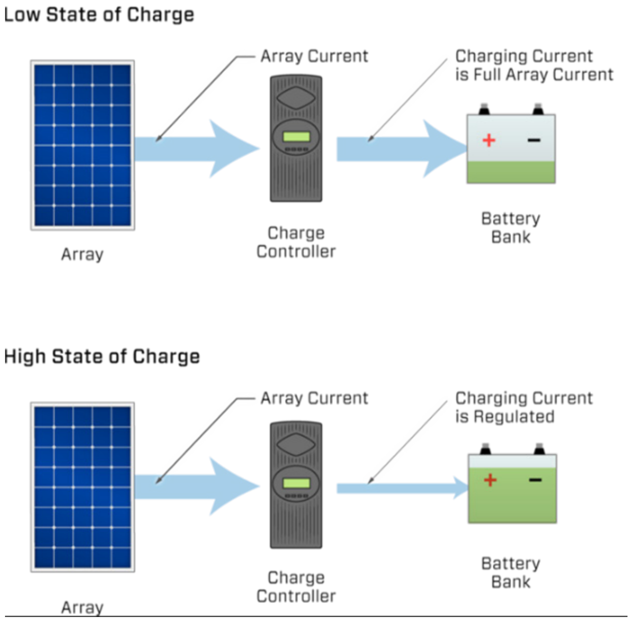
2.2 Charge Controller

A charge controller is connected between the solar panels and the battery to control the rate at which electric current is added to or drawn from electric batteries. It prevents overcharging and may protect against overvoltage and excessive discharge.

FIGURE 3: Different types of controllers[3]

- Over-charge protection
  - When battery voltage is low, the charge controller continues to connect the PV module to the battery to charge it.
  - When battery voltage is high, the charge controller automatically disconnects the PV module from battery to stop charging, thereby protecting the battery from being damaged by overcharging.

FIGURE 4: Over-charge protection[4]



3 Adapted from System Components: Charge Controllers &Inverters, Arizona State University (VOCTEC), http://voctec.asu.edu

4 Photovoltaic Systems, Dunlop,2nd Ed.

- Over-discharge protection
    - When the battery voltage is high, the charge controller automatically connects the load to the battery.
    - When the battery voltage gets low, the charge controller automatically disconnects the load from the battery to prevent damage to the battery from excessive discharge.
    - This following circuit configuration within the controller is recommended to prevent both over charging and over discharging of the battery. Note that most commercial controllers include both the charge controller and the load controller in the same package

FIGURE 5: Over-discharge protection[4]

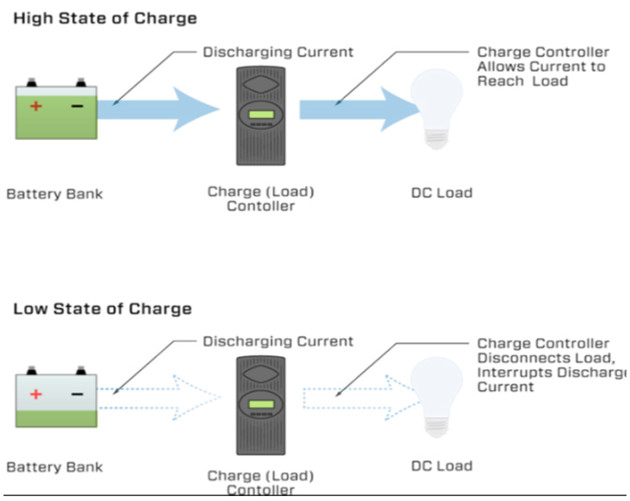
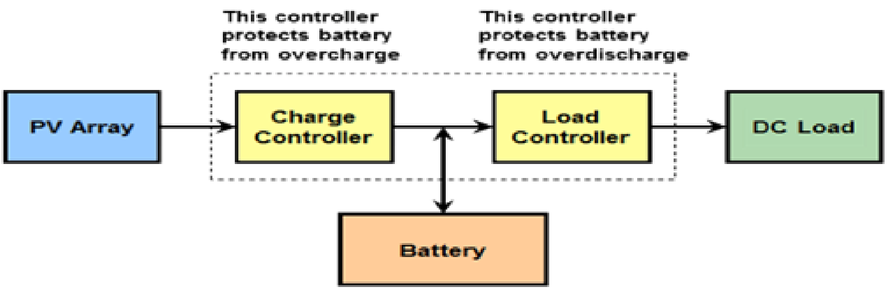


FIGURE 6: Recommended configuration[5]



2.3 Batteries

A battery is a device that is able to store electrical energy in the form of chemical energy and convert that energy into electricity.

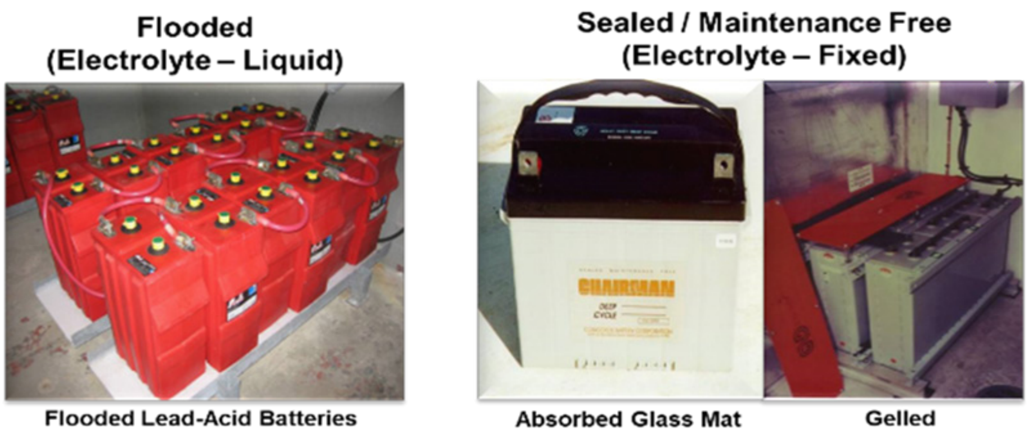
FIGURE 7: Battery[6]

- Batteries are commonly constructed using Lead and Lead Oxide electrodes and contains diluted sulfuric acid inside.
- Other types of batteries are also available, such as Nickel-Cadmium, Lithium, etc. and the controller used must be specifically for the type of battery that is installed since each has different electrical characteristics.
- In a solar system, the batteries are charged by the solar panel during daytime and the charged batteries then supply power during the night-time and when it is cloudy and there is little power coming from the solar panels.
- Automotive batteries are not recommended for solar. They are designed to give a large amount of current over a short amount of time.
- Solar batteries are the opposite. They are designed to give a small amount of current over a longer amount of time.
- Sealed batteries have a maximum voltage of 14.1 V, flooded batteries (batteries that have caps that can be removed to add more water) can be charged up to 14.4V and even higher for short periods when cells need to be equalized.

5 Source: Jim Dunlop Solar.

6 Source: JICA.

FIGURE 8: Different types of batteries[7]



- Battery Capacity:
  - Capacity is a measure of the stored electric charge or stored energy that a battery can deliver under specified conditions
  - An ampere-hour (Ah) is the unit of measurement for lead acid battery energy storage capacity and is equal to the transfer of one ampere for a period of one hour. Lithium and other types of batteries usually have their unit of energy storage as Watt hours or kilowatt hours (Whr or kWhr) for large batteries)
  - Capacity depends on the battery temperature, discharge rate and cut-off voltage as well as the size of the electrodes themselves.
- The battery has the highest failure rate among all the components in a DC or AC solar installation and requires routine replacement at regularly scheduled times.
- The flooded lead-acid batteries have liquid electrolyte, while the sealed batteries may have gel type electrolyte.

2.3.1 Flooded Batteries

This is the traditional engine start, tractor, and deep cycle-style battery. The liquid electrolyte is free to move in the cell compartment. The user has access to the individual cells and must add distilled water as the level of electrolyte falls. Popular uses are engine starting and deep cycle designs for general use.

2.3.2 Sealed Batteries

This term can refer to several different constructions, including only a slight modification to the flooded style. In that case, even though the user does not have access to the cell compartments, the internal structure is still basically the same as a flooded battery. The only difference is that the manufacturer has ensured that enough acid is in the battery to sustain the chemical reaction under normal use throughout the battery warranty period. Other types of lead acid batteries are also sealed, as explained below. Very popular uses are engine starting and limited starting/deep cycle applications.

2.3.3 AGM Batteries

The Absorbed Glass Mat construction allows the electrolyte to be suspended in close proximity with the plate's active material. In theory, this enhances both the discharge and recharge efficiency. Popular usage includes high performance engine starting, power sports, deep cycle, solar and storage batteries.

2.3.4 GEL Batteries

The Gel Cell Battery is similar to the AGM battery style because the electrolyte is suspended, but different because technically the AGM battery is still considered to be a wet cell. The electrolyte in a gel cell battery has a silica additive that causes it to set up or stiffen. The recharge voltages on this type of cell are lower than the other styles of lead acid battery. Gel batteries are best used in VERY DEEP cycle applications and may last a bit longer in hot weather applications.

7 Source: Adapted from "System Components- Batteries", Arizona State University, VOCTEC, http://voctec.asu.edu

2.4 Cables

FIGURE 9: Cables[8]

Electrical cables are used to connect two or more devices, enabling the transfer of electrical signals or power from one device to the other.

Circuit breakers have different amperage ratings such as 10A, 16A, 32A etc. The breaker will automatically disconnect the circuit if the amps through the breaker reach the specified amps. For example, if you are using 10A breaker and if you have connected 12Amps load, the breaker will disconnect (commonly known as "trip"). This is to protect against overcurrent in the circuit for safety.

FIGURE 10: Circuit Breaker and Isolator[9]

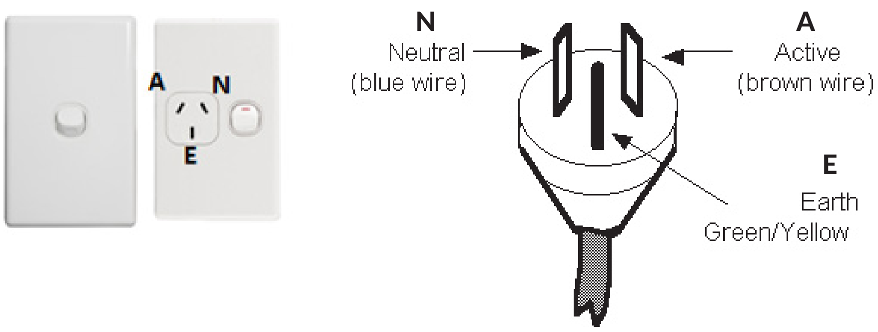
2.5 Circuit Breaker/Isolator

A circuit breaker's basic function is to interrupt current flow after a fault (short circuit) is detected. An isolator is a mechanical switching device that, in the open position, disconnects a device and allows for isolation of the input and output of a device.

2.6 Switch and Power Socket

A switch isolates a component from the electricity supply and a power socket is used to connect/disconnect an appliance to an electricity source.

FIGURE 11: Switch and Power Socket (Australian Standard Configuration)[10]



8 Source: Global Market, http://newimg.globalmarket.com/PicLib/group0/5e/73/c477defc613ecc9a0e47b82452f4_l.jpg

9 Source: Wave inverter.co, https://waveinverter.co.nz/shop/solar/solar-connectors/pv-dc-isolator-switch-mc4/ and POSO.com, http://poso.com.vn/wp-content/uploads/2020/04/1-2.png

10 Source: University of Newcastle Australia, "Electrical General-Purpose Outlets", https://www-eng.newcastle.edu.au/eecs/ect/oh&s/Hazards/ElectricalGPOs.html

2.7 Inverter

An inverter is an electronic device or circuitry that changes direct current (DC) to alternating current (AC). There are different types of inverters for different functions. Selecting an inverter for stand-alone systems is based on the following specifications:

- Battery input voltage (12, 24 or 48 V)
- AC output voltage (120 or 220V)
- Highest AC power required for cumulative load (in Watts)
- Surge current (e.g., motors) requirements, if any (in Amps)
- Additional features (battery charger, etc.)

FIGURE 12: Inverter[11]

FIGURE 13: Function of an Inverter[12]

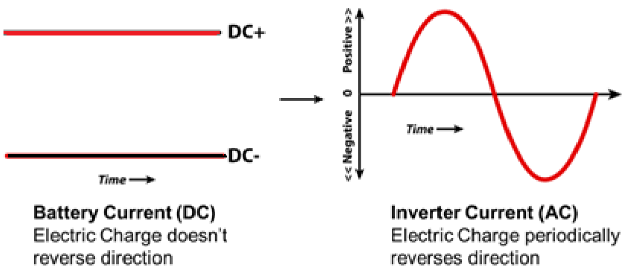


FIGURE 14: Different types of Inverters[13]

	Stand-Alone Inverter	Operate from **batteries** and supply power independent of the utility grid
	Interactive Inverter	Operate from **PV arrays** and supply power in parallel with the utility grid
	Bi-Model Inverter	Transfer PV system operation to a stand-alone mode and provide backup electric power to critical loads when the utility grid is not energized

For the purpose of this training module, we will only focus on the stand-alone inverter, as this is the most common one used in solar home systems.

2.8 Solar Panel Mounting Systems

FIGURE 15: Mounting brackets[14]

Photovoltaic mounting systems are used to fix solar panels on surfaces like roofs, building facades or on the ground. These mounting systems generally enable retrofitting of solar panels on roofs or as part of the structure of the building. The solar array of a PV system can be mounted on rooftops, generally with a few inches gap (for cooling) and parallel to the surface of the roof. If the rooftop is horizontal, the array is mounted with each panel aligned at an angle to best receive solar rays.

11 MorningStar, May 2021, https://www.morningstarcorp.com/products/suresine/

12 Adapted from System Components: Charge Controllers &Inverters, Arizona State University (VOCTEC), http://voctec.asu.edu

13 Adapted from System Components: Charge Controllers &Inverters, Arizona State University (VOCTEC), http://voctec.asu.edu

14 Source: Shopping.co, https://shopee.co.th/Utilizing%E2%9C%BF%E2%9C%B2-Solar-Panel-Mounting-Bracket-End-Mid-Clamp-Kit-Adjustable-For-19Mm-55Mm-Framed-i.188349769.7409094766

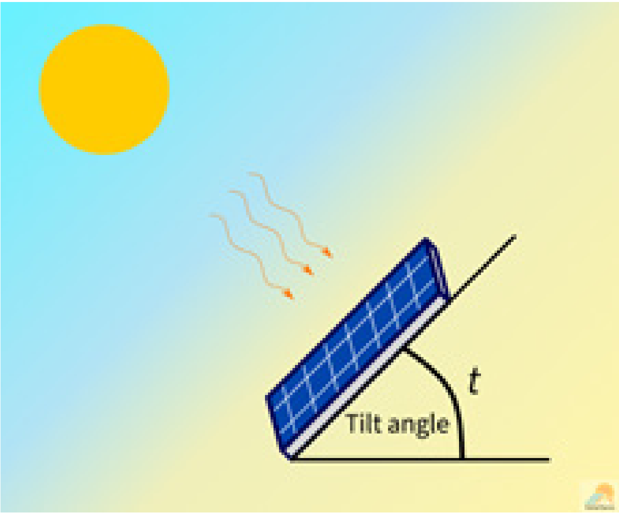
Generally, for rural communities, due to the varying types of roof structures, that may also include thatched roofs or other types that may not be structurally suitable for mounting panels on top, the ground mounted systems are usually preferred due to their various advantages. This will be discussed in more detail later in this training module.

2.9 PV module orientation

Regardless of which mounting structure is chosen, the primary purpose of the mounting system is to enable a safe and secure fixture to mount the PV modules on to. However, apart from this, it is also equally important to tilt the solar panel and face it in the direction that will ensure maximum energy generation from the sun, while also avoiding shading throughout the day.

A poorly oriented or shaded solar panel will produce less solar energy than what it is capable of, and this can cause energy shortages, lead to system shutdown issues and can result in premature battery failures.

FIGURE 16: Solar Panel Orientation[15]



As already covered in detail in the "Solar in the Community" module, one should understand the location and movement of the sun, in order to be able to optimally orient the solar panel. The mounting structure should allow for this optimal orientation.

In general, for Fiji, all PV modules should ideally be tilted between 15-20 degrees and facing towards North direction[16], in order to ensure maximum PV power generation from the modules throughout the year.

2.10 Earth and Grounding components

It is required to ground all PV systems as a properly grounded system will help protect maintenance personnel from unintentional shocks and possible deaths (even during any surge and lightening). It can also help prevent fires in the system post-installation. In other words, properly grounding your PV installation protects you.

The figure 17 shows that the frames of the PV panels, as well as the negative terminal of the system is grounded.

Whether the positive (+) or negative (-) wire is grounded, depends on the installation instructions provided with the equipment. In all cases, the aluminum frames of the solar panels need to be connected to the same ground used by the electrical wiring in order to protect against lightning strikes that can cause fires or serious damage to system components. The grounding wire finally gets connected to a grounding or earth rod outdoors, which is usually driven deep underground, as shown in the figure 18.

15 Solar Sena, "Optimal Solar Panel Tilt Angle Calculator", May 2021, https://solarsena.com/solar-panel-tilt-angle-calculator.

16 Adapted from the Grid- Connected PV Systems (System Installation Guidelines), by PPA and SEIAPI Technical communities, 2019, https://www.ppa.org.fj/wp-content/uploads/2019/08/Grid-Connected-PV-Systems-Installation-Guidelines-V4-250719.pdf

FIGURE 17: How to ground equipment[17]

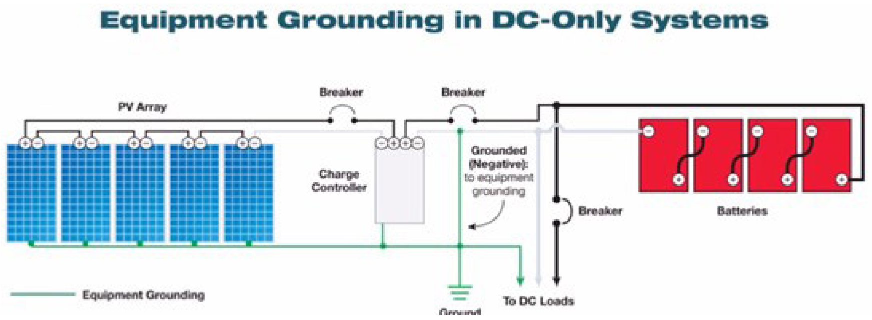
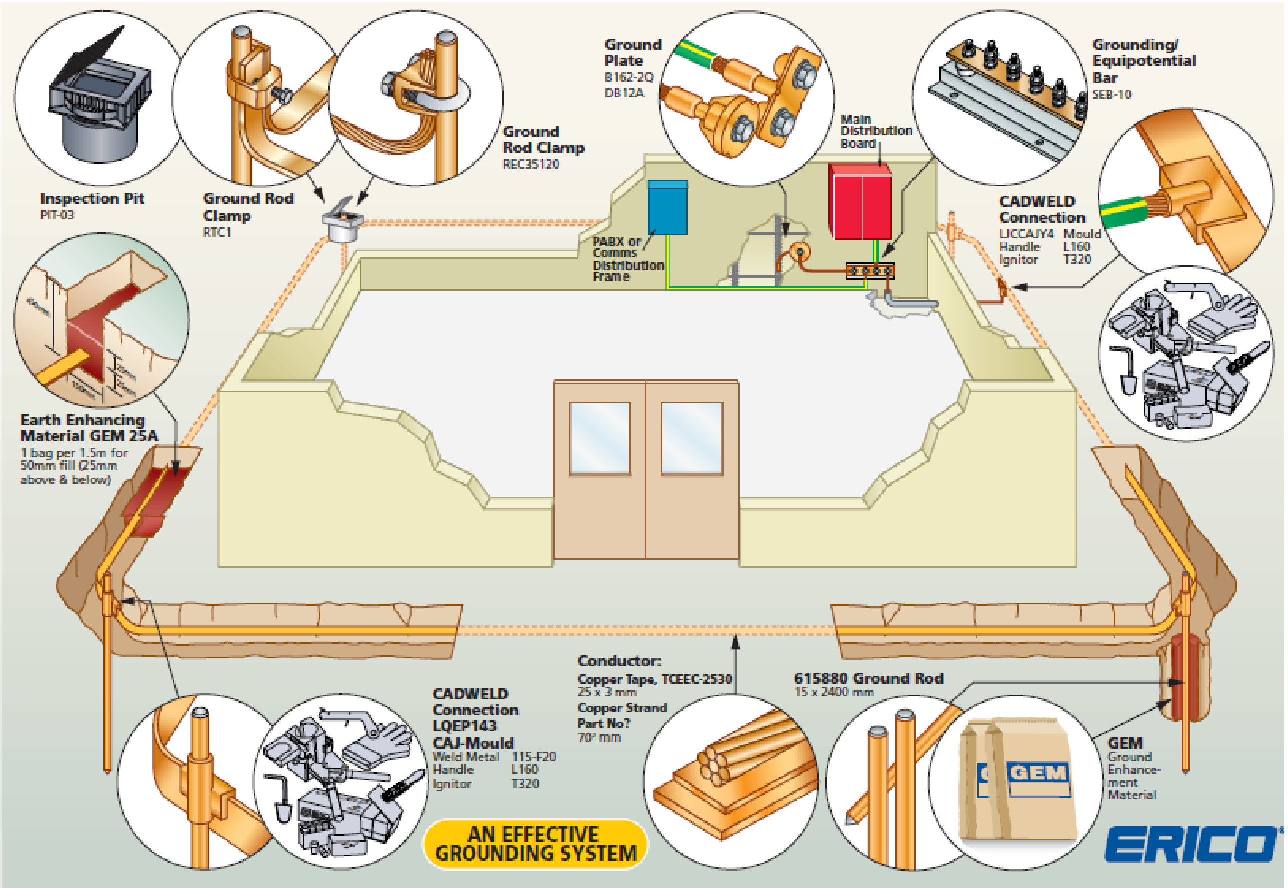


FIGURE 18: Grounding components[18]

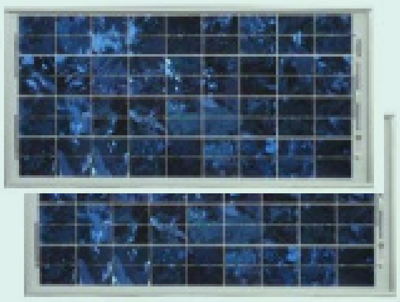
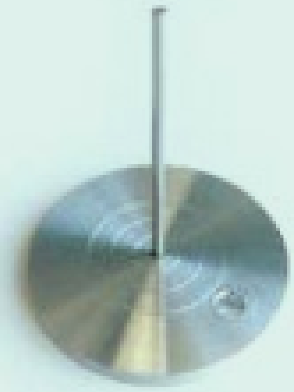


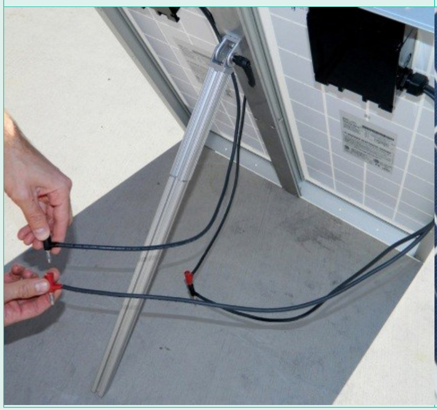
17 Source: Jim Dunlop Solar.

18 Source: Erico, Components to an effective grounding systems, http://wapp.com.au/2018/03/components-effective-grounding-system/

ACTIVITY 2

Demonstrate how shading affects the performance of a PV Module. Measure Voltage (V_{oc}) and Current (Isc) under different shading patterns by connecting PV modules into Series and Parallel connections

Test Set-up		
1. PV Modules (2x)	2. PV Array Mounting Rack	3. Sundial
		
4. Digital Multimeter	5. Cardboard for shading	6. Assemble PV Array as described in MTT Quick Start Guide
		

Test Procedure: Measurement of Voltage		
1. Connect PV modules in series	2. Measure Open Circuit Voltage (VOC1) without shading	3. Shade one cell of PV array
		

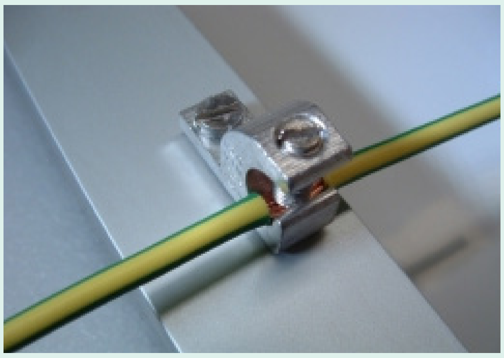
4. Measure Open Circuit Voltage (VOC2)	5. Shade one half of PV array	6. Measure Open Circuit Voltage (VOC3)
		
Test Procedure: Measurement of Current		
7. Repeat measurements 2 - 6 for Short Circuit Current (I_{SC1})	8. Repeat measurements 2 - 6 for Short Circuit Current (I_{SC2})	9. Repeat measurements 2 - 6 for Short Circuit Current (I_{SC3})
		
Recording and Observation of Voltage and Current: (Sample Calculations in black)		
Array not shaded: One Cell shaded: Half array shaded:	Open Circuit Voltage (VOC) *VOC1 = 41.1V* *VOC2 = 41.0V* *VOC3 = 34.4V* **Observation:** VOC3 is higher than expected 20.5V (Voc of a single module) due to partial light transmittance through and around the cardboard	Short Circuit Current (ISC) *ISC1 = 1.88* *ISC2 = 1.84* *ISC3 = 0* **Observation**: I_{SC3} is 0 because these modules do not have by-pass diodes (the shaded module is acting like a huge resistor causing the module to operate at near open- circuit condition)
Practice: Help and allow learners to do the setup in teams of 3 and record/measure the values.		

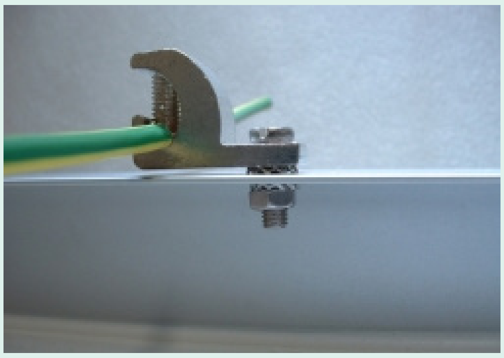
ACTIVITY 3

Why should we earth the solar PV system? Do one earth connection on the PV module.

Answer

- It is required to ground all PV systems as a properly grounded system will help protect you from unintentional shocks and possible death. During lightning and component failure, it protects from shocks.
- Provide learner with grounding Lug (as shown in the picture). The learner should be able to connect (similar) as follows:





ACTIVITY 4

Why should we use proper mounting brackets?

Answer

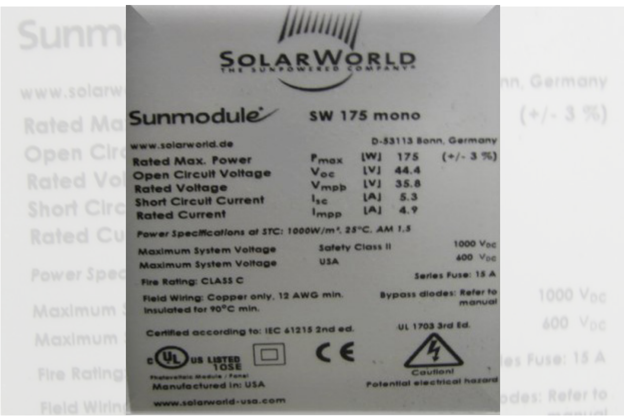
- To protect the PV module from moving and getting damaged.
- To protect the PV module from flying away in high wind.
- To ensure the angle of incidence (Panel facing the sun) does not change.

3

Solar PV Component Requirements

Now that you have been introduced to the components used in a solar system, this chapter will take a more detailed look at each of the component in terms of how it operates and what are the requirements for its operation. It is critically important to have components which are of good quality and meet the minimum requirement of having a safe and durable solar power system. Each component is provided with the manufacturer's specification or features. The specification provides specific details on that particular component or appliance. The following are some of the requirements for each component.

FIGURE 19: Nameplate data on the solar PV module[19]



3.1 PV Module (Solar Panel)

It is extremely important to be aware of the requirements of PV Module. Some of the important requirements to be aware of:

- What is the operating voltage?
- What is the maximum power?
- What is the operating current?

All PV modules must be marked with the following information (if not, then they might not be from a reputable source):

- Open-circuit voltage (Voc)
- Short-circuit current (Isc)
- Operating voltage (Vmp)
- Operating current (Imp)
- Maximum power (Pmax)
- Polarity of terminals
- Maximum permissible system voltage

It should be noted that the higher the irradiance, the higher the output of power and current but the voltage of the PV panel changes little between 200-1000 W/m^2.

3.2 Effect of Temperature

The cell temperature plays critical role in the performance of monocrystalline and polycrystalline PV modules.

- Voltage decreases 1% for each 2°C increase in temperature.
- Current increases 1% for each 12°C increase in temperature.
- Power decreases 1% for each 2.2°C increase in temperature.

In general, the hotter the solar pane gets, the lower will be its power output. As you will see later in this module, it is important to ensure good ventilation of solar panels during its installation.

3.3 Charge Controller

The charge controller should:

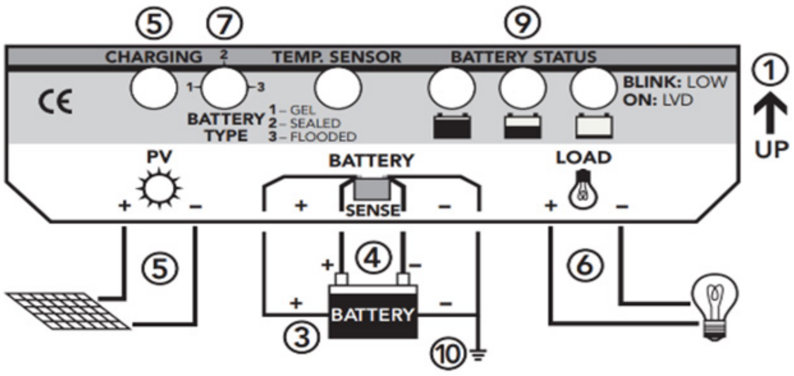
- Have an adequate current capacity for both charging (amperes from solar PV) and for operating the loads (load current).
- Accommodate both the PV input voltage and the battery voltage.
- Have the peak DC power required for cumulative load.
- Be flexible to work with different battery types (flooded or sealed lead-acid battery).
- Be reliable - simple controllers are more reliable than complicated ones (avoid complex extra "features" such as LCD screens, micro-processor programmed control, etc.).

19 Adapted from the System Components- PV Modules, Arizona State University (VOCTEC), http://voctec.asu.edu

Some specific features:

- 3-position battery select: gel, sealed or flooded.
- Temperature compensated charging.
- LED's to indicate battery status and faults.
- Remote battery voltage sense terminals.

FIGURE 20: Specific features of Charge controller[20]



Note: You can use multiple solar charge controllers in case you have more solar arrays. You may connect different arrays through the controller to the same battery bank. Since the array currents are normally lower than the battery current in most cases, let us see how you can simply size a charge controller using a simple approximation.

3.4 Batteries

Batteries only store electricity and do NOT generate electricity:

- One cell of a lead acid battery is 2V
  - 2V means nominal voltage. Voltage range is around 1.85V to 2.40V
  - 12V battery has 6 cells connected in series
  - 6V battery has 3cells connected in series
- Material
  - Electrodes: Lead and Lead oxide
  - Electrolyte: Diluted Sulfuric Acid
- Parallel connection sums capacity (Ah)
- Series connection sums voltage (V)
- Total energy storage remains the same (Wh)
- Do not mix different types, models, and age of batteries

Batteries have the highest failure rate of all components in a solar power system.

FIGURE 21: Typical battery Specification[21]

SPECIFICATIONS

Nominal Voltage		12 Volts	
Amp Hour Capacity		115 (C20)	90(C5)
Reserve Capacity Minutes		170 @ 25 Amperes	
Physical Characteristics	Length	13.13"	334 mm
	Width	6.75"	171 mm
	Height	9.38"	238 mm
	Wet Weight	58 Lbs	26.4 Kgs
Terminal Options		BCI Type M	

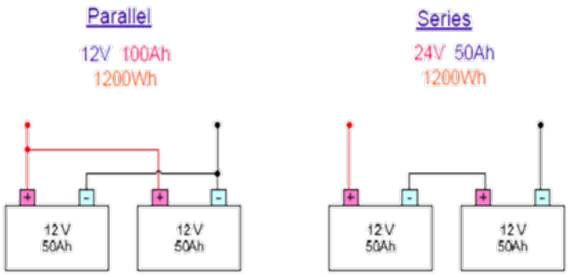
ELECTRICAL SPECIFICATIONS

Amp Hour Capacity	20 Hour Rate	5.75 A	115 Ah
	10 Hour Rate	10.30 A	103 Ah
	5 Hour Rate	18.00 A	90 Ah
	2 Hour Rate	33.50 A	67 Ah
Internal Resistance	80 F	27 C	7.6 mOhm
Capacity affected by Temperature (20 Ah Rate)	104 F	40 C	102%
	80 F	27 C	100%
	32 F	0 C	65%

20 Morning Star, June 2021, https://www.keoghsmarine.com.au/morningstar-prostar-solar-charge-controller-30a-12-or-24v-pwm-4-stage-charging-led-charge-indicators-sr--ps-30

21 Source: Waveinverter, co.nz, https://waveinverter.co.nz/wp-content/uploads/2017/12/products-CR325-1.png

FIGURE 22: Typical Battery Connection[22]



Some key points:

- Parallel connection sums capacity (Ah).
- Series connection sums voltage (V).
- Total energy storage remains the same (Wh).
- Ideally, DO NOT parallel more than 2 batteries (as this may cause unequal battery charging and discharging, which can cause pre-mature battery failures and most manufacturers will not honor warranties if more than two batteries are operated in parallel). However, it is accepted that for some systems it is unavoidable, though as a rule, the more batteries there are connected in parallel, the shorter the battery life. As an absolute maximum, never have more than 4 batteries in parallel.
- DO NOT mix different types, models, and age of batteries, as this can cause premature battery failures.
- Batteries must be mounted in a well-ventilated place and protected from sun and rain. Avoid placing batteries inside the living area of the house.
- Battery charging equipment should be hard wired, do not use a temporary "clip on" type connection.
- Battery terminals should be insulated with plastic or rubber to prevent inadvertent short circuits.
- Ensure sufficient clearance between battery terminals and metal walls.

Use insulated tools during any battery work.

3.5 Inverter

The table shows some key features and specification of an inverter. Usually, inverters are single phase and 3 phase. In this module, we will only focus on single phase 220-240V, 50Hz output and 12V input.

FIGURE 23: A Suresine 300W standalone inverter[11]

TABLE 3: Sample specification and feature of an Inverter

Specifications & Features	
Continuous Power Rating (300 Watts at 25°C)	Total Harmonic Distortion (< 4%)
Peak Power Rating (600 Watts at 25°C)	Low Voltage Disconnect (LVD) (11.5V or 10.5V)
DC Input Voltage (10.0V – 15.5V)	Low Voltage Reconnect (12.6V or 11.6 V)
Waveform (Pure sine wave)	LVD Warning Threshold (11.8V or 10.8V)
AC Output Voltage (220V or 115V +/- 10%)	LVD Delay Period (4 minutes)
AC Output Frequency (50 or 60 Hz +/- 10%)	High Voltage Disconnect (15.5V)
Peak Efficiency (92%)	High Voltage Reconnect (14.5 V)

22 Adapted from "System Components, Batteries", Arizona State University (VOCTEC), http://voctec.asu.edu

ACTIVITY 5

What is the requirement you should look at when selecting a PV module?

Answer

- Open-circuit voltage (Voc)
- Short-circuit current (Isc)
- Operating voltage (Vmp)
- Operating current (Imp)
- Maximum power (Pmax)
- Polarity of terminals
- Maximum permissible system voltage

ACTIVITY 6

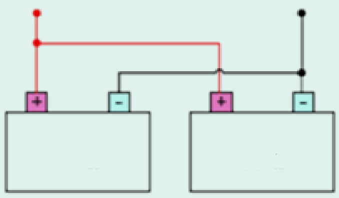
Get two batteries and connect them in series and parallel. Measure the total voltage for each setup.

Battery (x2)	Cables	Multimeter
		

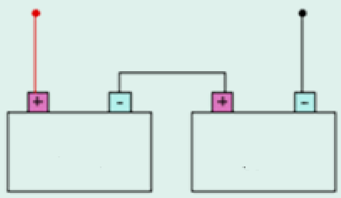
Answer

- Provide the learner with two 12V batteries.
- Provide the learner with a Multimeter set to measure voltage.
- The learner should connect the batteries as shown.

Parallel
12V 70Ah
840Wh



Series
24V 35Ah
840Wh



ACTIVITY 7

What will happen to PV power and current if the temperature of the solar cells increases?

Answer

- Power will decrease and current increases slightly.

ACTIVITY 8

Provide the learner with all components discussed above (PV Module, Controller, Battery, Inverter and 12 DC light with fixture. Ask learner to identify the name plate data (Specification & Features) on each component. The learner is expected to read/identify all information written on the components as per notes above.

4

Types of Solar PV Systems

Having covered the different components and their requirements in previous chapters, this chapter will put all components together to discuss the various types of solar PV systems. There are three types of solar power systems:

1. Standalone solar power system.
2. On-grid solar power system.
3. Hybrid solar power system.

4.1 Standalone solar power system

Stand-alone systems are not connected to the electricity grid and are typically installed in remote rural communities where there is no or limited connection to the grid, or areas of low electricity demand. This system produces DC power, but an inverter can also be added to power AC appliances. We will cover both types in this module.

4.1.1 Standalone solar (DC) power system

Unlike their grid-connected counterparts, these systems must have batteries to provide the power supply at night. The available power is DC 12V typically, but other voltages such as 24V, 48V etc. are also used depending on size of systems.

FIGURE 24: Standalone DC power system[23]

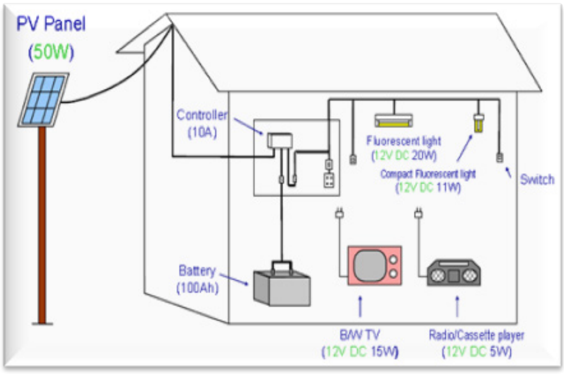
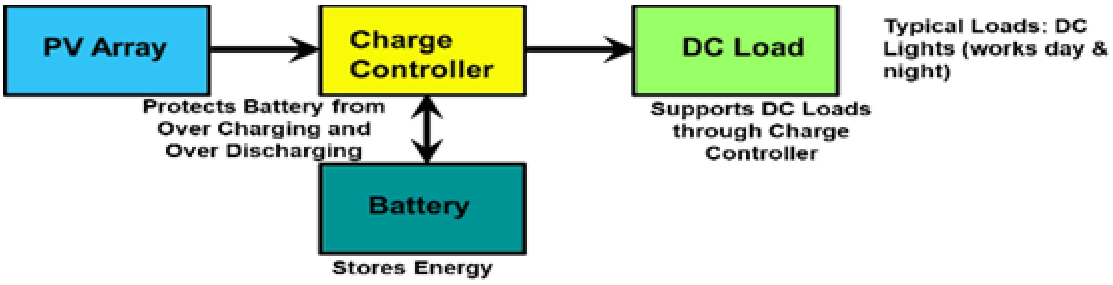


FIGURE 25: Typical standalone DC power system with battery[24]



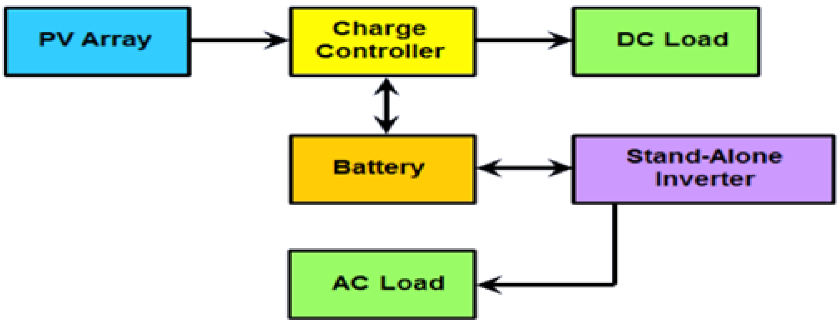
- Works Day and Night, due to presence of battery, typically only supplies DC loads, mostly lights.
- Can have other DC loads like DC fans, mobile phone charging via USB port, etc.
- DO NOT add extra lights or loads to a SHS system, as this will cause system malfunction, overheating, damage, or shutdowns due to energy deficits.
- Mostly used for a smaller home that only requires lighting and phone charging features.

4.1.2 Standalone solar (DC+AC) power system with battery

- Works Day and Night, due to presence of battery.
- Same system as "DC load only", but has additional inverter to allow powering of AC loads also.
- DO NOT interchange AC and DC loads. DC loads MUST be powered by DC supply ONLY. NEVER POWER DC LOADS WITH AC SUPPLY. **There is GREAT RISK of equipment damage, serious injury or even death.**
- Mostly used for medium sized homes that have lighting, phone charging and small AC appliance needs.

23 Source: JICA
24 Source: Jim Dunlop Solar

FIGURE 26: Standalone solar (DC+AC) power system with battery[25]



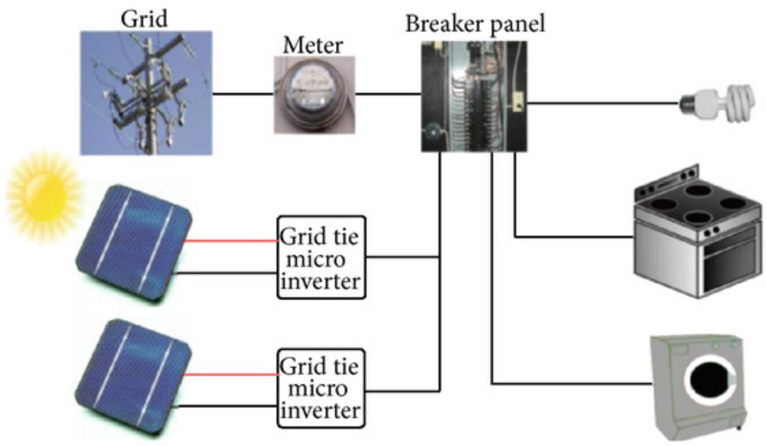
4.2 On-grid solar power system

This type of system is not applicable to remote rural communities who do not have access to grid electricity. This training module will not focus on this system, hence only minimum information is provided here for the learners understanding.

These types of systems are most common in areas where the grid infrastructure is suitable. The inverter converts the electricity generated by the solar system – which is direct current (DC) – into AC electricity so that the power generated is compatible with the grid. These systems cannot create their own grid, as they can only connect to an existing grid to supply power to that grid.

Houses with grid-connected solar systems use solar power first before sourcing electricity from the grid, hence causing a saving on the electricity bill. When the panels are not producing electricity at night, electricity is provided solely from the electricity grid. This type of system is not used in rural communities where either grid electricity is not available or to avoid complexity and instead, they can keep a simple standalone system.

FIGURE 27: On-grid setup[26]



25 Source: Jim Dunlop Solar

26 Source: Hindawi, "Journal of Renewable Energy", June 2021, https://www.hindawi.com/journals/jre/2013/785636/fig1/

4.3 Hybrid solar power system

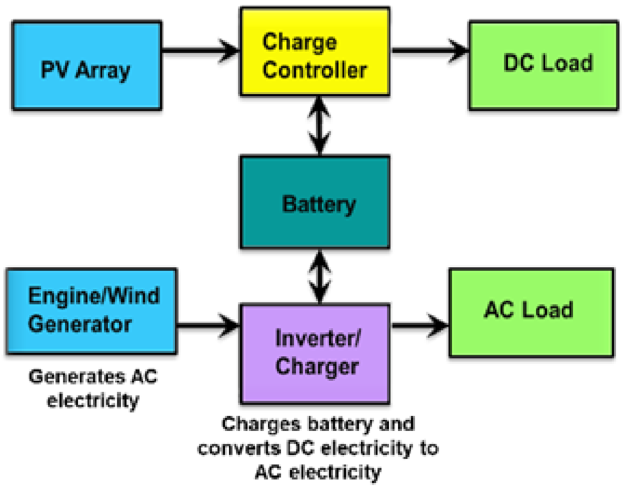
This type of system, can operate both on-grid and off-grid, can supply large amounts of power and is expensive, therefore is not common in remote rural communities. This training module will not focus on this system, hence only minimum information is provided here for the learners understanding.

Hybrid solar PV systems are becoming increasingly popular. These types of systems are suited where attractive feed in tariff is provided to grid connected consumers by utility companies. Battery back-up systems can be a viable alternative as consumers use the electricity stored during the day to run their house at night. They also have the advantage of being able to supply power during power outages, via the use of other sources of energy such as that stored in the batteries, using a backup generator, or other Renewable Energy sources, such as wind, pico-hydro etc.

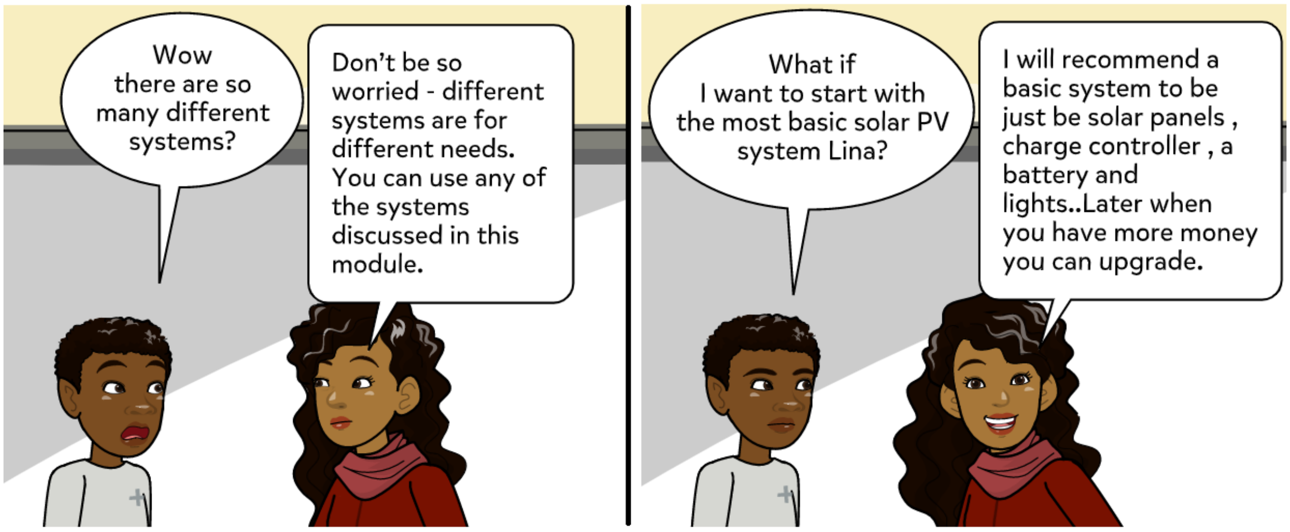
- Works Day and Night, due to the presence of a battery
- Same system as "DC + AC load" system, but has an additional charger function in the inverter to allow charging of batteries via use of Diesel/Petrol Generator/ Wind turbine etc. This allows for backup power to avoid overload or energy deficit situations.

Mostly used for larger sized homes which have lighting, phone charging and luxury AC appliance needs (TV, washing machines, refrigerators, etc.)

FIGURE 28: Hybrid setup[27]



Cartoon Break



27 Source: Jim Dunlop Solar

4.4 Solar system sizing

As a technician, your focus, is usually on the installation, maintenance and troubleshooting aspects of a solar power system. However, you may be interested to also know how a solar system is designed and sized up, since most of the time, customers do tend to ask questions regarding this.

The design of a solar system is usually done by qualified or accredited technicians or engineers with the aid of computer design software, which allows for a more detailed and accurate design.

While this detail design is beyond the scope of this training, provided in Annex A is a simplified method of sizing up a Standalone DC solar system for the basic knowledge of interested learners. Using a set of assumptions, this method is able to provide general sizing of components used in a solar system and can also be used if a customer is interested in upgrading their system to run more loads.

ACTIVITY 9

Draw any 3 major types of solar power system and label each of their components.

Answer

- The learner is expected to draw on-grid, standalone DC, Standalone AC+DC and Hybrid. Some of them may draw standalone system with batteries and without batteries. Put more emphasis on the standalone systems.

ACTIVITY 10

Discuss in class which system you will prefer and why?

Answer

- The learner most likely will prefer either Standalone DC or standalone AC/DC system. The most likely reasons will be the access or availability to use various AC and DC appliances. Expect many different answers.

5

Tools used in Solar PV System

Installation of any solar PV system requires the use of various tools. This chapter will discuss some of the common tools that are required in the installation of Solar PV system.

While there are many types of tools available, not all of them will are required for installing simple solar home systems.

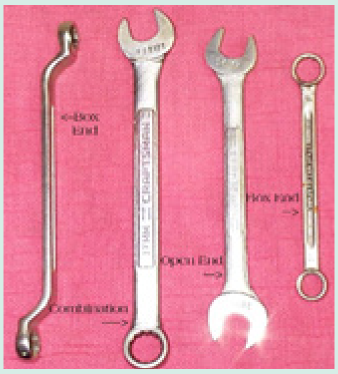
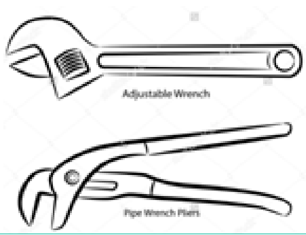
FIGURE 29: Common tools[28]

5.1 Specific Tools and its functions

Pictures of Tools	Names of these tools	Uses and functions of these tools
FIGURE 30: Clamp meter[28] 	Clamp meter	Clamp meters measure any of these: AC current, AC and DC voltage, resistance, making them perfect for electrical work. Good for higher and easy current measurement. Annex B shows how to use a clamp meter.
FIGURE 31: Multi-meter[29] 	Multimeter	A typical Multimeter can measure voltage, current, and resistance. Has higher resolution. Current can only be measured if the meter is connected in series with the component being measured (without special adapters). Annex C shows how to use a multimeter.

28 Quora, "What type of tools and fasteners are required to install a solar panel", https://www.quora.com/What-type-of-tools-and-fasteners-are-required-to-install-a-solar-panel#!n=12

29 Source: Jim Dunlop Solar

Pictures of Tools	Names of these tools	Uses and functions of these tools
FIGURE 32: **Flat screwdriver**[30] 	Slotted or Flat screwdriver	Open screws.
FIGURE 33: **Philips Screwdriver**[31] 	Philips Screwdriver	Open screws.
FIGURE 34: **Solar Irradiance Meter**[32] 	Solar Irradiance Meter	Measure solar intensity or irradiance.
FIGURE 35: **Different types of wrenches**[33] 	Offset Box wrench, Combination wrench, Open end wrench and Normal box wrench	These are tool used to provide grip and mechanical advantage in applying torque to turn objects—usually rotary fasteners, such as nuts and bolts—or keep them from turning.
FIGURE 36: **Wrenches**[34] 	Adjustable wrench Pipe wrench pliers	These are tool used to provide grip and mechanical advantage in applying torque to turn objects—usually rotary fasteners, such as nuts and bolts—or keep them from turning.

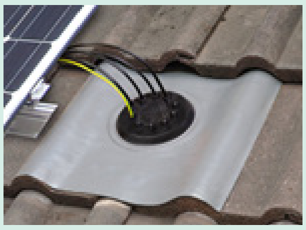
30 Source: Galco, www.galco.com

31 Source: Conceptdraw.com, "Manufacturing and Maintenance", https://www.conceptdraw.com/examples/diagram-of-screwdriver-and-its-specific-use-in-maintenance

32 Solar Panel Store Blog, June 2021, https://www.solarpanelstore.com/products/daystar-ds-05-solar-irradiance-meter

33 Mechanical Engineering, https://mechanical-engg.com/gallery/image/2209-wrench-typesjpg/

34 Source: Pinterest.com, "Different types of wrenches", https://www.pinterest.com/pin/147352219031480866/

Pictures of Tools	Names of these tools	Uses and functions of these tools
FIGURE 37: Lineman Pliers[35] 	Lineman Pliers	Linesman pliers are a type of pliers used by electricians and other tradesmen primarily for gripping, twisting, bending, and cutting wire and cable.
FIGURE 38: Needle nose pliers[36] 	Needle Nose Pliers	are both cutting and holding pliers used electricians, and other tradesmen to bend, re-position and snip wire.
FIGURE 39: Flashings[37] 	Flashing	Flashings are used to avoid any water leaks through the opening.
FIGURE 40: Module connectors[38] 	Module connectors	Module connectors are used to connect each solar panel in series with another solar panel.

35 Source: AmPro, https://ampro.fr/en/shop/pliers/wire-cutting-pliers/71-2-high-leverage-diagonal-pliers/

36 Source: DORNO, Rubber Grip Long-Nose Pliers, https://www.olo-7.top/products.aspx?cname=rubber+needle+nose+pliers&cid=40

37 Source: Alternergy Solar Pv and Storage solutions, https://www.alternergy.co.uk/dektite-lead-multicable-solar-flashing-tiled-or-slate

38 Source: CED Greentech, https://www.cedgreentech.com/article/pv-connectors-what-you-need-know

These are different types of screw heads that solar technicians may can come across. Each head has a specific screwdriver.

FIGURE 41: Screws with different heads[39]

Handling and carrying tools are also very vital in solar PV system work. The following methods can be used to carry tools:

FIGURE 42: Ways to carry tools in tool belt safely[40]

FIGURE 43: A-frame ladder[41]

There are three (3) types of ladders:

- **Step Ladder (A-frame)** - Step ladders are versatile free-standing ladders. Step ladders are designed to be used in the fully 'open' position. Step ladders are not designed to be used to gain access to another level such as a rooftop and should never be used for this purpose. Nor should step ladders ever be used in the folded position leaned up against a wall or other structure.

39 Source: UU-99, https://www.hindawi.com/journals/jre/2013/785636/fig1
40 Source: Pinterest.com, https://www.pinterest.com/bambulancemania/work-apparal/
41 Source: Total Tools, https://www.totaltools.com.au/2-4-4-0m-extension-ladder

- **Platform ladder** – is similar to A-frame step ladder however it provides safe working environment. It provides a better platform to step and work on. It also has some sort of rail or barrier which provides bit of fall protection.

FIGURE 44: Platform Ladder[42]

- **Straight or Extension ladder** - Extension ladders are similar to straight ladders and are normally used to reach higher areas. Extension ladders have a 'base' section and a movable 'fly' section. When used properly, extension ladders can be used to work from or to gain access to various levels and rooftops.

FIGURE 45: Extension ladder[43]

Choosing a proper ladder length is very important. Choose the ladder length based on the contact point where your ladder touches the roof line or wall. Keep in mind that the 'size' of the ladder is not the 'working height' of the ladder. For example, a typical 24-foot extension ladder should only be used on a roof line of 17 ft or lower. Three primary issues regulate the ladder working height:

- Overlap for extension ladders.
- The safe standing level on the ladder.
- The extension of the ladder above the roof line when accessing the roof.

SAFETY TIP: When selecting a straight or extension ladder, choose a length that extends a minimum of 3 ft above the rung you need to stand on to work from. When using extension and straight ladders, the fourth rung from the top is the highest rung to climb to or work from.

SAFETY TIP: Never use a metal ladder near a electrical lines or equipment. Always look up prior to raising a ladder to ensure no overhead powerlines are present.

ACTIVITY 11

What is the major difference between a clamp meter and a multi-meter?

Answer

- Multimeter - does not have clamp jaws to measure current across the cable and must be connected in a circuit to be measured.
  - It provides higher resolution.
- Clamp-meter – has clamp jaws to measure current across a cable and needs no connection into the circuit being measured.
  - Able to provide higher currents.

42 Source: Total Tools, https://www.totaltools.com.au/2-4-4-0m-extension-ladder

43 Source: Swallow Tail Inn, http://www.swallowtailinn.com/when-should-replace-your-siding/

6

Installing Solar PV systems

Installation of Solar PV Systems are to be done by trained electricians. There are several design and installation standards to be followed in order to ensure correct and safe installation that follows industry best practice.

With a mission to create an enabling environment for the growth of sustainable energy business entities and sustainable energy equipment and/or energy services in the Pacific Islands, The Sustainable Energy Industry Association of the Pacific Islands (SEIAPI), provides very useful guidelines on the design and installation of different types of Solar PV Systems for the Pacific, that follow the relevant Australian and New Zealand standards as well as industry best practice. This chapter aims to cover the basics of such installation practices.[44]

In all the Solar PV examples so far, we have seen the use of single solar panels and batteries. However, as a technician, you will be faced with systems that came with multiple solar panels and batteries.

Or a customer might be looking at upgrading their existing system by adding more solar panels and batteries.

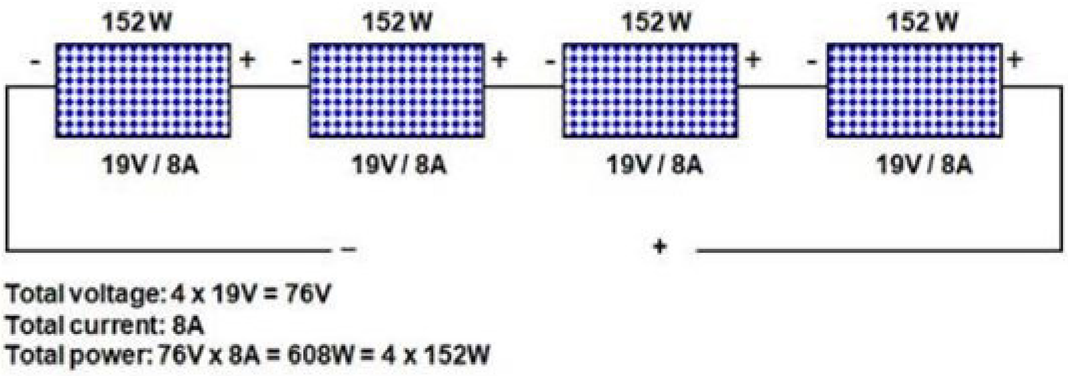
How will you wire up the extra panels and batteries?

- The answer lies with parallel and series connections.

6.1 Series Connection

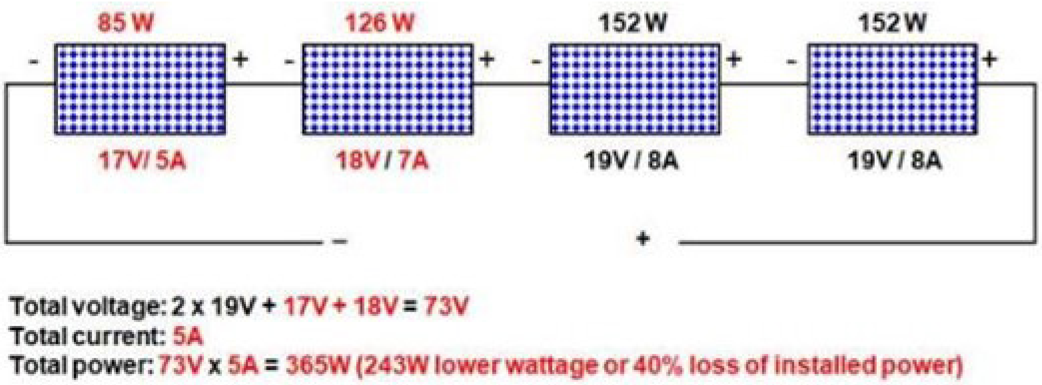
PV modules are connected electrically in series to increase the voltage output (current output remains same). In a series connection, the positive terminal of one solar module is connected to the negative terminal of the other module. The load connects to the positive end and to the negative end of this string. For the best performance, all of the modules in the string should be identical.

FIGURE 46: Series Connection[45]



When dissimilar PV panels are connected in series, the voltages get added up, but the current is limited by the panel with the lowest current output panel in that series connection.

FIGURE 47: Series with mixed sizes[45]



44 Source: SEIAPI Sustainable Energy, http://www.seiapi.com/guidelines/, May 2021

45 Photo credit: https://solarpanelsvenue.com/

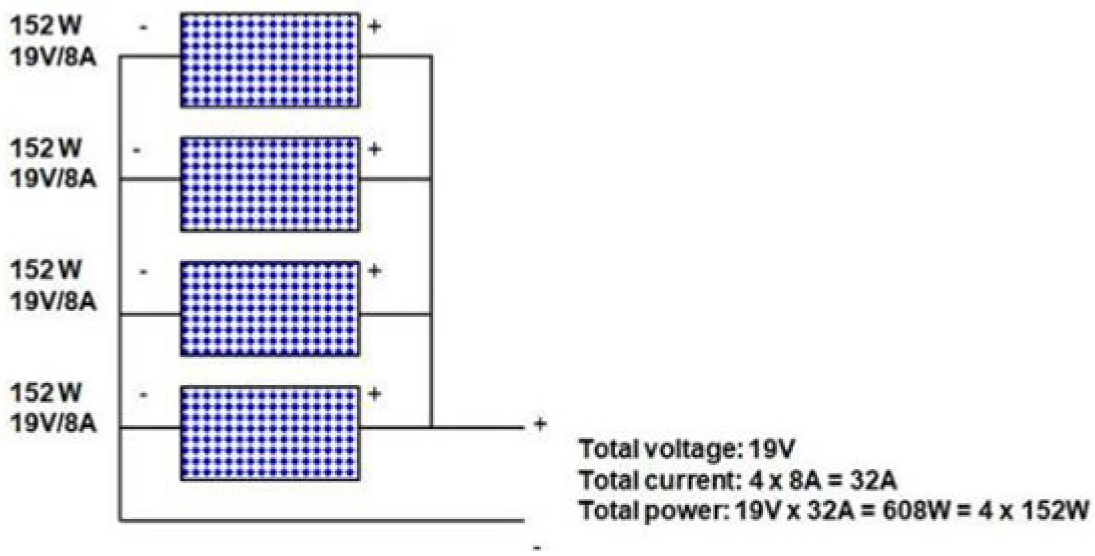
As you can see, while adding more panels in series to an existing system might seem like a good idea, it only has benefits when you add similar type of panels. Mixing different types of panels, especially those with very different current and voltages, will cause you to lose a lot of power, primarily because of the smallest panel in that series string.

6.2 Parallel Connection

PV modules are connected electrically in parallel to increase current output (voltage output remains the same). In a parallel connection, the positive terminal of one module is connected to the positive terminal of the other panel, and negative terminal of one module to the negative terminal of the other panel. The load connects to the common positive and to the common negative connections of the modules. For the best performance, all PV panels should be identical.

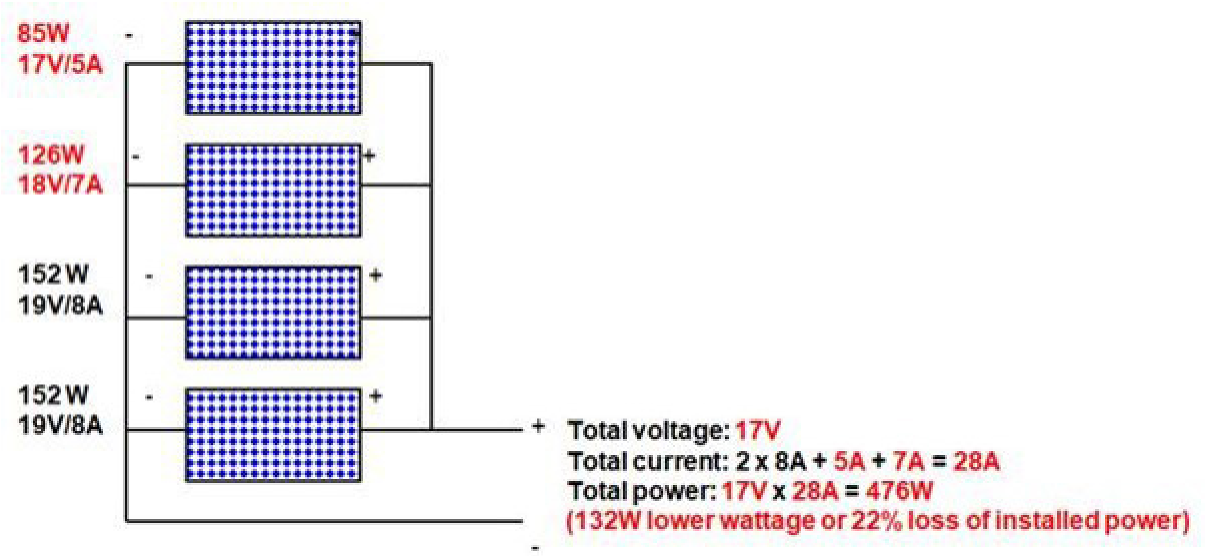
Remember that putting panels in series increases voltage. Hence if an existing system is 12V, you will probably be jumping to 24V or 48V by doing series connections. This will require you to upgrade your charge controller and batteries as well to match all the voltages accordingly!

FIGURE 48: Parallel Connections[45]



When dissimilar PV panels are connected in parallel, the currents still get added up, but the voltage is limited by the lowest voltage output panel in that parallel connection

FIGURE 49: Parallel with mixed sizes[45]



As you can see, while adding more panels in parallel to an existing system might seem like a good idea, it only has benefits when you add similar type of panels. Mixing different types of panels, especially those with very different current and voltages, will cause you to lose a lot of power, primarily because of the smallest panel in that series string.

Remember that putting panels in parallel increases current but does not change voltage. Hence if an existing system is 12V, it will remain as 12V by doing parallel connections. However, since the current is now larger, this will require you to upgrade your charge controller, electrical cable, switches, circuit breakers and in some cases, batteries as well to be able to handle the extra current accordingly!

6.3 Preparing for installation

Before you start installation, you must plan the installation and gather all the required material before proceeding. Clearly decide if series or parallel connections will be made and foresee any safety issues that may arise. Be equipped with the required PPE (personal protective equipment) before you start solar installations. In addition, you may want to ensure the correct size and number of components are being taken to the site for installation.

Ensure to have a talk with the customer regarding the installation, for example, where they want the system components to be installed indoors, preferred location of the solar panel outside, routing of the wires and if there will be a need to make any holes on the walls, ceilings etc. The customer must be made fully aware of the installation process and provided with general recommendations of good practices to avoid any issues later on.

6.4 Solar PV Module mounting

While your electrical knowledge may be very good, the one thing that may be new to you during solar installation is probably the mounting of solar panels on different types of roofs or ground mounting to withstand all weather conditions. Regardless of the mounting type chosen, the installation must ensure that the mounting is strong, safe and does not affect the proper operation of the solar module.

6.5 Roof Mounting PV Modules

Since solar panels are often installed on top of existing rooftops, there are important considerations to take note of before proceeding with roof top installation. Some of these are :[46]

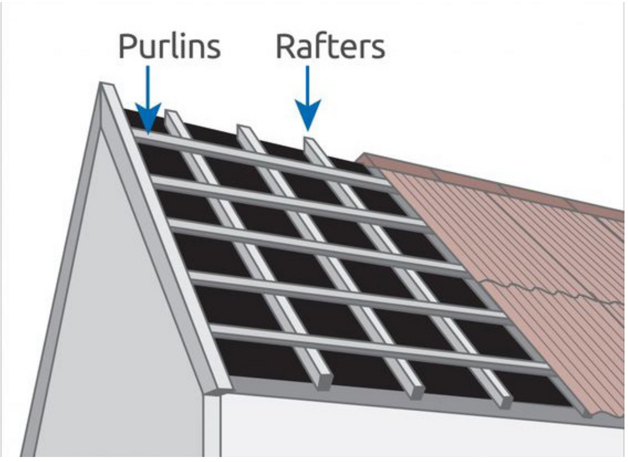
- Have at least 50mm (2 inches) of gap below the modules for cooling by natural ventilation and prevent leaves and other debris from building up underneath.
- If fauna (e.g., rats) are a problem in the vicinity of the installation, then consideration should be given as to how to prevent them gaining access to the cables.

46 Off Grid PV Power Systems – System Installation Guidelines, SEIAPI, 2019

- The array structures shall be designed to withstand the aggressively salty atmosphere. All array supports, brackets, screws and other metal parts shall be of low-corrosion materials suitable for the lifetime and duty of the system and use materials that do not increase their rates of corrosion when mounted together in an array or when mounted on the surface of the underlying structure.
- Where timber is used it must be suitable for long-term external use and fixed so that trapped moisture cannot cause corrosion of the roof and/or rotting of the timber.
- Any roof penetrations must be suitably sealed and remain waterproof for the expected life of the system
- For metal roofs the array frame structure should be attached to the roof using brackets that are screwed through the ridges of the roof into a purlin or rafter below.

Let's look at roof mounting PV modules on a corrugated iron gable style roof and look at where the support members are below the roofing iron.

FIGURE 50: Wood structure in roofs[47]



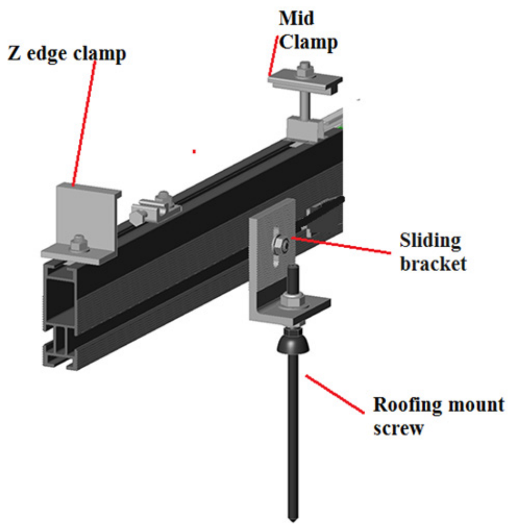
The first thing to do is to setup a mounting base (sometimes called L-feet) which is fixed onto the roof's purlin using the roofing screws (DO NOT use nails even if the metal of the roof is nailed to the purlins, always use the proper roofing screws.) You must take care to use screws with fiber/rubber washers or use silicone sealants to prevent roof leakages.

FIGURE 51: Solar Rails on corrugation[48]

Next, solar rails are connected to the L-feet. Solar rails are recommended as standard practice when putting up several roof solar panels. Even for a single panel it is very useful and allows future extension very easily. Not only does the use of L-feet and rails allow for air gap under the solar panel for cooling, there are mounting system available that also help to properly tilt the solar panels for maximum solar energy harnessing.

For best performance in Fiji, the tilt should be no more than 20 degrees and preferably closer to thr latitude angle (around 15 to 20 degrees for Fiji). They also should be pointed toward the equator, which is towards North for the Southern hemisphere. Unfortunately, most existing roof slopes are rarely sloped correctly in tilt and direction for the best solar reception, hence pole mounted solar panels are a better alternative.

FIGURE 52: Edge and mid clamp for solar mounting[49]



47 Source: Pinterest.com, March 2021, https://www.pinterest.co.uk/pin/539446861598727570/
48 Source: Sun for Son, http://www.solar-mount.com/solar-mounts/high-quality-tile-roof-aluminum-alloy-pv.html
49 Source: Solar Gain, June 2021, https://www.solargain.ca/product/fast-rack-10-panel-mounting-kit/

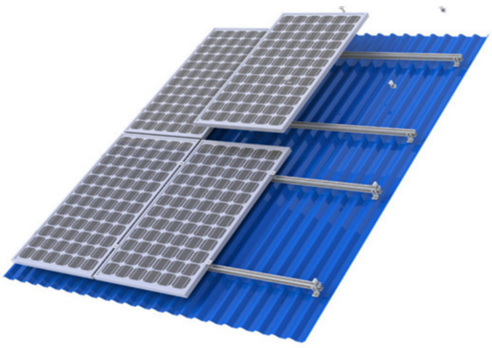
Once the rails are secured, the Solar panel is then installed and secured on top the rails using various types of clamps.

FIGURE 53: Solar panels mounted on rails[50]

Note that the above-mentioned roof mounting systems are examples only, as there are numerous types of mounting available.

Since most remote rural communities might not have access to proper rails, the following diagram shows how to use timber rails and then screwing the z bracket to the timber to hold the solar panel in place. In the case you cannot find a z bracket, you can always build one by carefully bending a flat bar. Avoid using steel as it will rust faster. Recommended metal parts would be aluminum or galvanized steel. Always use treated timber meant for external use to avoid frequent replacement. Regularly check solar panel mounting frame especially before cyclone season.

FIGURE 54: Mounting solar in Pacific island roofs using z clamps and timber[51]



Many of the remote rural communities also have thatched type roofs. There are numerous issues in installing solar panels on thatched roofs and it is not generally considered appropriate or strong enough. Due to the native style structure, any mounting will cause a leak in the roof if it is not sealed properly. Also, the thatching may collect moisture under the panel and not be exposed to sunlight to dry out. This may cause the thatch and the supporting structure to rot over time. Additionally, placing a solar panel with 2 Amps or more current passing through it when mounted on dry thatched roof material creates a fire risk in case of shorting or a spark from a loose connection. Therefore, except for very small solar panels, you must mount the module on a separate frame attached to a stand or pole instead.

FIGURE 55: Pole mounted solar is better option due to unsuitable roof structures[52]

6.6 Ground/pole mounted PV Modules

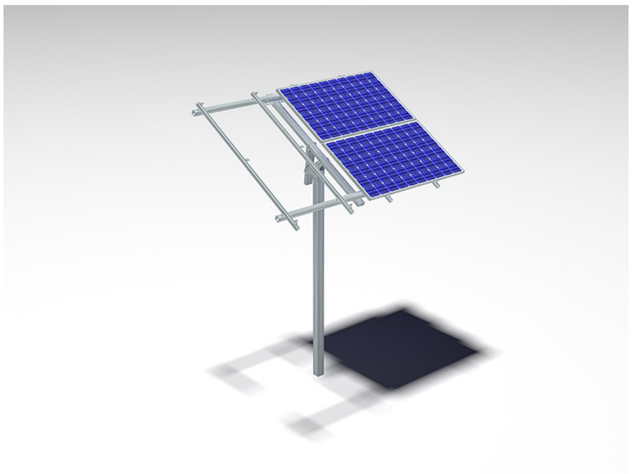
If roof mounting of solar modules is not suitable or possible, then ground mounted systems can offer a very good alternative, especially for rural remote communities. It has to be noted, however, that ground mounted systems are generally more expensive then roof mounted types, mainly due to the use of standing structures and the required footings for strength.

50 Source: ClayEnergy, Fiji.

51 Source: Able Solar, "Tin Roof Mounting System", https://www.ablesolar.co.nz/shop/Solar+Panel+Array+Frame/Roof+Mounting+Frames/Tin+Roof+Mounting+System.html

52 Source: Fiji Department of Energy

FIGURE 56: Example of pole mounted solar PV mounting system[53]

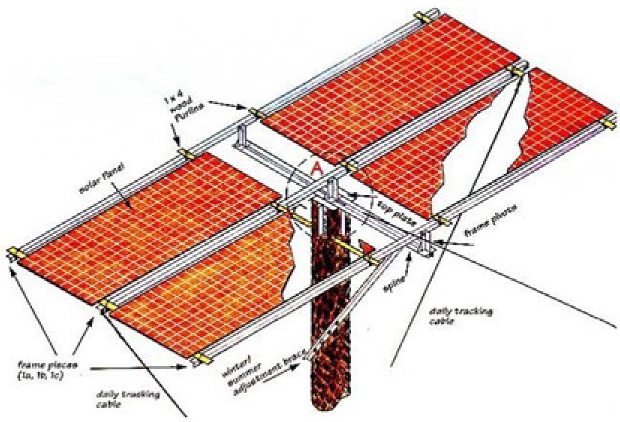


The advantages of pole mounts for one or two panel installations include:

- can locate away from shade,
- proper tilt and direction can be set,
- cooler for the panel since the bottom of the panel is clear for ventilation,
- no worries about leaves and debris collecting between the panels and the roof,
- better access for maintenance,
- no problems with roof leaks due to mounting panels on the metal roof.

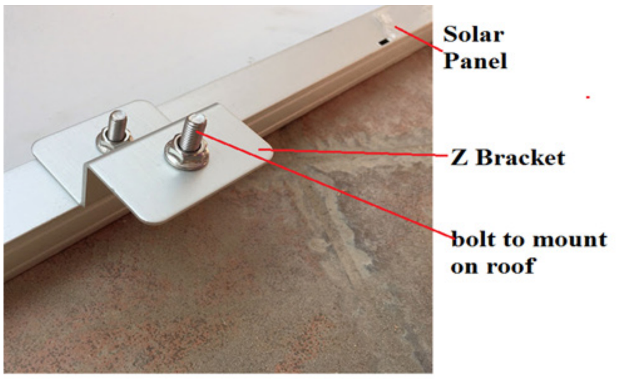
Mountings made of wood attached to wooden poles or metal poles are also adequate for single panels though they must be sufficiently strong to survive tropical storms and need to be bolted securely to the pole. Pole mountings are also required if the house roof is shaded by trees at some time during the day. Remember that in the tropics, the sun spends some months in the northern part of the sky (and any trees to the north may cause shade) and some months in the southern part of the sky (and any trees to the south may cause shade).In case you need to build a solar panel rack on a pole, below is an example to help guide you. You can also fabricate similar wooden structures according to your particular panel dimensions. The figure below may easily hold one 100W panel. The specific dimensions will depend on your panel sizes. You may need the help of a welder fabricator to construct the pole mount. Proper footing will also be required to give strength to the pole. Concrete reinforced footings are generally used for this.

FIGURE 57: Pole mounting can also be fabricated locally[54]



In some cases, the standard slotted rails may not be available. In this case you will need to improvise and use a Z bracket. While this is not the best way, it is an alternative to mount directly onto the roof with z brackets. Z brackets are normally used for mounting solar on camping trucks or on flat surfaces etc. But it can work easily for solar installation on corrugated roofs. Below is a Z bracket connected to the back side of the solar panel.

FIGURE 58: Z clamp mounting details[55]



In case you use a z bracket only without a slotted rail, you will still need to use a timber rail to avoid drilling a hole in your solar panel or if your panel is not large enough to sit across two purlin lines.

53 Source: Mibet Energy, May 2021, https://www.mibetsolar.com/

54 Source: Mother Earths News, "How to Build a Manual Solar Tracker", https://www.motherearthnews.com/diy/manual-solar-tracker-zmaz97amzgoe

55 Source: Engineer Solar, June 2021, http://engineer-solar.com/Products/solar-panel-z-bracket.html

6.7 Installing Batteries

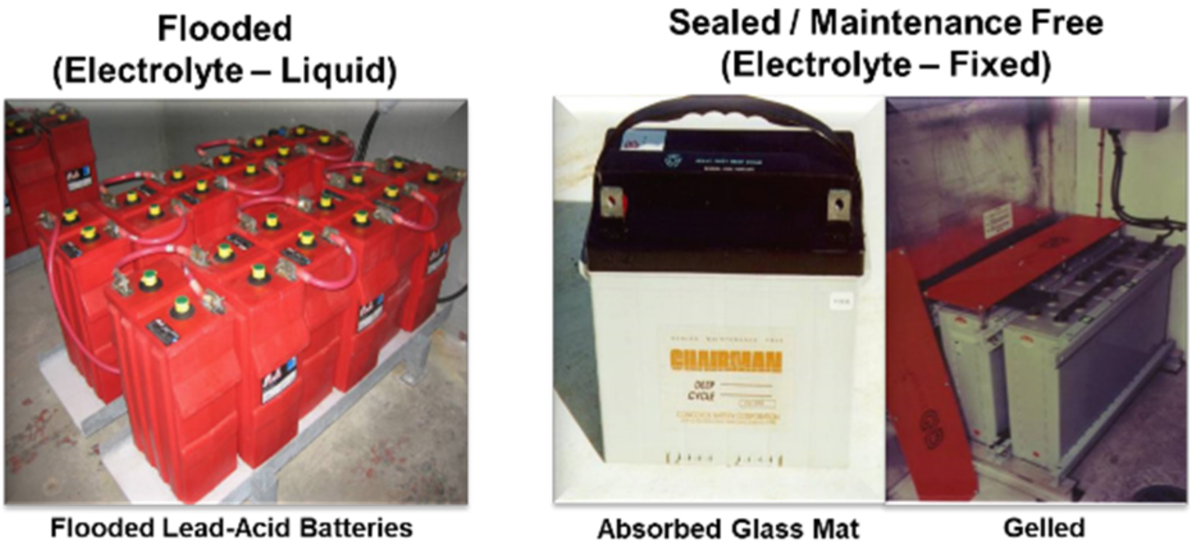
Batteries are used to store energy for use later. They are commonly constructed using Lead and Lead Oxide electrodes and contains diluted sulfuric acid inside. Other types of batteries are also available, such as Nickel-Cadmium, Lithium, etc. with Lithium batteries having many advantages but are more costly than similar sized lead-acid batteries.

In a solar system, the batteries are charged by the solar panel during daytime and this battery then supplies power during night-time and during periods of cloudy weather. For long life, the lead-acid batteries need to be a type that allows deep-discharging (deep cycle) over a period of several days and must not be intended for engine starting (automotive batteries).

While starting batteries will work initially, their life will be greatly shortened when used for solar applications instead of for engine starting. Likewise, the batteries intended for solar use should not be used to start engines, they can be internally damaged in that case.

The longest life lead-acid batteries are flooded units, but they must have distilled water added regularly because some of the liquid in the cells evaporates during charging. Most household units are not maintained properly and do not last very long. So, maintenance free (sealed) batteries are best for home use and good ones can last 5 or more years if not abused by excessive discharge cycles.[56]

FIGURE 59: Types of Battery[56]



As discussed earlier, the battery/batteries are one of the components of a solar system that has the highest failure rate and is one of the components that is very costly to replace, especially in remote rural locations. Hence it is extremely important to take greater care of the batteries, which starts with following correct installation techniques. Some of the key points to note with regards to proper battery installation are.[57]

- The battery/batteries must be installed in a dedicated battery room or an enclosure.
- The location and/or enclosure selected must ensure that mechanical protection is guaranteed and access to the batteries is restricted to those people who are authorized to be in proximity to the batteries.
- Sufficient space should be available within the enclosure to allow for ease of battery installation and maintenance, and no metal objects should be in the vicinity such that one could fall across battery terminals and cause a short circuit.
- If the battery enclosure is a dedicated room and part of an occupied building, then the access should be from the outside and for batteries that emit explosive fumes (e.g. open-cell lead-acid type batteries) the internal walls should not have any vents/penetrations to the inside of the house and there must be venting to the outside.
- No electrical equipment shall be mounted above explosive and/or corrosive gas emitting batteries
- The location where the batteries are installed should be dry.

56 Source: Adapted from "System Components- Batteries", Arizona State University, VOCTEC, http://voctec.asu.edu

57 Off Grid PV Power Systems – System Installation Guidelines, SEIAPI, 2019

- Batteries must be raised off the ground or concrete floor. (If left on the ground, the lower sections of the batteries will adopt the temperature of the ground, which is generally lower than the ambient temperature adopted by the upper sections of the battery systems. With certain chemical-based battery systems, this can lead to stratification of the electrolyte and premature failure.
- The enclosure should not be located in direct sunlight and should be in a location that keeps the batteries as cool as possible.
- Adequate ventilation should be available to assist in temperature control and if necessary, to avoid the build-up of hydrogen or other gases associated with charging.
- Batteries are typically heavy and the area under the batteries shall be capable of bearing the weight of the batteries without distortion.

6.7.1 Installing Charge Controller and other components

The remaining components of a Solar Home System, such as the charge controller, loads, Inverter (if the system is AC type) and cabling and protection equipment, are usually installed on a mounting board and fixed to a wall as seen in the figure below.

FIGURE 60: Engineer showing wall mounted SHS system[58]

The general guidelines for installation of these components are:

- Components to be installed according to the manufacturer instructions.
- All spacing requirements around each component should be followed to allow for proper clearances and ventilation of that component.
- Installation of the charge controller and inverter (if present) should be as close as practical to the battery to reduce long cable lengths and reduce voltage drops.
- Components should not be installed in direct sunlight and should be installed in a dust free location.
- Since the components, especially the inverter, can be heavy, it is important to ensure that the mounting board is strong enough to bear the weight.
- All DC (and AC cables if inverter in present) must be routed and support safely. AC cables must be separated from DC cables and have mechanical protection to avoid exposure to other cables or personnel.
- All cables used must have a greater voltage and current rating than the maximum voltage and current expected in that circuit.
- All protection and switching components shall be appropriately rated to operate safely when required.

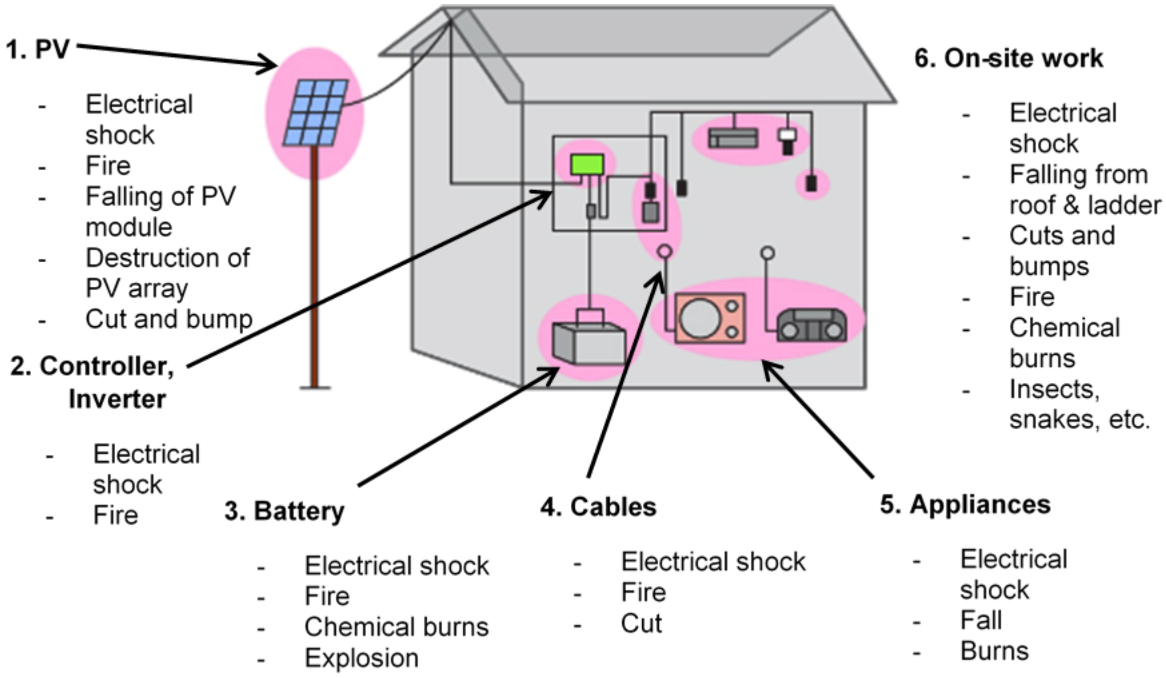
58 Power Solutions, May 2021, https://www.worldbank.org/

7

Safety Requirements of Solar PV Systems

Safety is of utmost importance in a Solar PV installation or maintenance exercise. There are numerous health hazards that can be present in Solar PV Systems. Some of the safety risks are highlighted in the figure below.

FIGURE 61: Safety risks in Solar PV System[59]

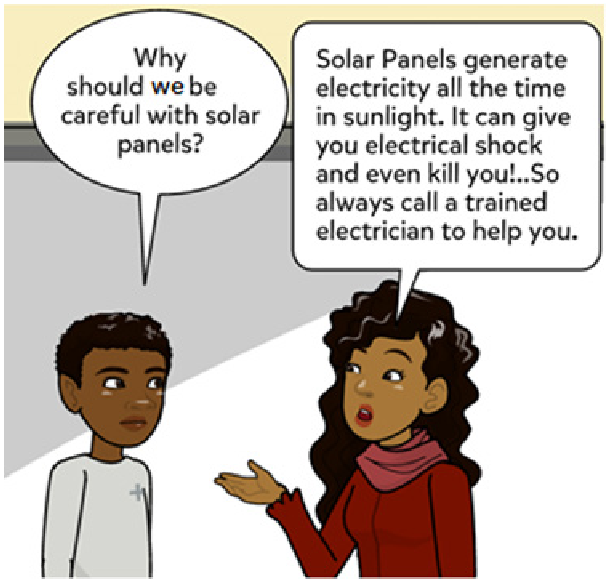


Here are some general safety rules that you must abide by during solar PV installation or repair. As trained technicians you must have been told about safety rules in electrical or mechanical systems and you must follow all safety rules that apply. You must note that your safety is the most important thing, and you must not attempt to do any work where you know your safety is compromised.

Do note that the safety points covered below are generic practices and a few points may not be compulsory, depending on the type of solar system you are working on. For example, wearing all of the listed personal protective equipment (PPE) when working on a small solar DC system may not be strictly required, due to the lower voltage levels. However, when it comes to safety, a technician should take all necessary precautions, regardless of if it is not a strict requirement, in order to ensure maximum safety for everyone involved.

7.1 Safety Rules to follow

FIGURE 62: Always seek help from a solar technician[60]



59 Source: JICA
60 GGGI, Fiji.

1. Always notify owners of the household and turn the power off before making any connections or adjustments. Never attempt to work on a circuit which is still live (active with power). The amount of current that will flow is determined by voltage and resistance in the circuit. If current greater than 20mA (pronounced as milli-Amps) passes through a person's body, it can cause serious damage. Always check the voltage between any conductor and any other wires, and to ground. Use insulated tools and avoid short circuits that may cause sparks.

FIGURE 63: Warning Sign[61]

2. Always ensure you conduct installation or repair only on circuits for which you have training. Do not attempt to modify solar PV systems unless you understand the system completely.

FIGURE 64: Wear Insulated gloves[62]

3. Always wear PPE (personnel protective equipment) such as insulated gloves, eye goggles and safety footwear. Never touch live exposed wires even with insulated gloves.
4. Never attempt to repair faulty batteries on your own. Batteries contain dangerous chemicals which can cause serious harm.

FIGURE 65: Acid Warning[63]

5. Never store batteries near a fire or inside living rooms – some batteries give off flammable or toxic gases even if we do not see them.

FIGURE 66: Fumes warning[64]

6. Never store batteries in confined spaces or near fuels as they can cause a fire from sparks. Always place batteries in well ventilated areas.

61 Source: AviationPros, https://www.aviationpros.com/tools-equipment/safety-equipment/article/11148860/ground-handling-safety-signs
62 Source: Safety workblog.com, https://safetyworkblog.com/assets/understanding-the-2015-edition-of-nfpa-70e-the-arc-flash-hazard.jpg
63 MSDS online, https://www.msdsonline.com/2014/07/22/sulfuric-acid-safety-tips-sulfuric-acid-msds-information/
64 Source: National Safety Signs, https://nationalsafetysigns.com.au/wp-content/uploads/2020/02/D10332-Toxic-Fumes-sign.png

FIGURE 67: Battery Warning[65]

7. Always wear a harness which is connected to the roof of your house when working on installing solar PV panels on roofs. When working on roofs always work in pairs if possible. Note that roof surfaces become very slippery after rain. For safety it is recommended only to work on dry roofs.

FIGURE 68: Connect harness to roof always[66]

8. Note that a solar panel starts generating electricity in any amount of sunlight. Ensure not to touch the wires at any time or attempt to connect live wires. Always get help to carry heavy panels, even light panels if there is much wind.

FIGURE 69: Be careful carrying the panels in heat[67]

9. Solar panels and their mountings and even the roof may get extremely hot in the sun so take care to wear gloves and other PPE when handling those hot surfaces. Also ensure you are aware of appropriate precautions when using electrical equipment such drills etc. for mounting and wear eye projection when using drills or hammers.

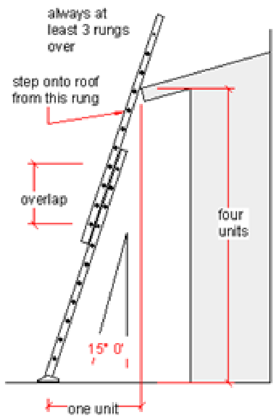
65 We Need Signs.com, "Ansi Battery Charging Safety Signs", http://www.weneedsigns.com/home.php?cat=403

66 Source: Solar Power World, https://www.solarpowerworldonline.com/2016/01/how-to-stay-safe-on-top-of-metal-roofs-when-installing-solar/

67 Adapted from Barefoot college Annual Report (2016-2017), https://www.barefootcollege.org/wp-content/uploads/2018/10/Barefoot_annualreport_2016-17_v7_online.pdf

FIGURE 70: Wear PPE and connect harness on roofs[68]

FIGURE 71: Ladder to make at least 75 degree angle with ground[69]



10. Always ensure you practice ladder safety rules when using a ladder to reach roofs for dealing with solar PV systems. Ensure the ladder has at least a 75-degree angle with the ground. Ensure the ladder is stable on flat ground. Ensure someone holds the ladder and prevents it from slipping.

ACTIVITY 12 - MANDATORY

Part A: Discussion on safety precautions

Ask the learners to get into groups and imagine they have to install 2 x 50-watt panels with 3 x 30Ah batteries including a 20A charge controller, 2 x Dc lights and 1 x 100W inverter with one single AC light bulb as a load.

The learners are required to first discuss all the safety precautions that they need to take while making this installation. Let them discuss orally or even write it down. Also ask them how they will go about installing the system. After this help them install a DC and an AC standalone system using the VOTEC Kit.

Answer: The safety rules are given in the notes above (rules 1 – 10):

1. Always turn the power off before making any additional connections or adjustments. Never attempt to work on a circuit that is still active with power. The amount of current that will flow is determined by the voltage and resistance in the circuit. If a current greater than 20mA passes through a body, it can cause serious damage. Always check the voltage between any conductor and any other wires, and to ground. Use insulated tools and avoid short circuits that may cause sparks.
2. Always ensure you conduct installation or repair on circuits for which you have training. Do not attempt to modify solar PV systems unless you understand the system properly.
3. Always wear PPE (personnel protective equipment) such as insulated gloves, eye goggles and safety footwear. Never touch live exposed wires even with insulated gloves.
4. Never attempt to repair faulty batteries on your own. Batteries contain dangerous chemicals which can cause serious harm.
5. Never store batteries near a fire or inside living rooms – some batteries give of toxic or flammable gases even if we do not see this.
6. Never store batteries in confined spaces or near fuels as they can cause a fire from sparks. Always place batteries in well ventilated areas.
7. Always wear a harness which is connected to the roof of your house when working on installing solar PV panels on roofs. When working on roofs always work in pairs if possible. Note that roof surfaces become very slippery after rains. For safety it is recommended only to work on dry roofs.

68 Source: Pacific Prime Singapore, https://www.pacificprime.sg/blog/covid-19-lockdown-singapores-quarantine-measures-for-foreign-workers/
69 Source: Builder Bill, https://builder-bill.com/diy-help

8. Note that a solar panel starts generating electricity in any amount of sunlight. Ensure not to touch the wires at any time or attempt to connect live wires. Ensure to carry heavy panels with the help of other technicians.
9. Solar panels and their mounting and even the roof may get extremely hot in the sun so take care to wear gloves and other PPE when handling hot surfaces. Also ensure you are aware of using electrical equipment such drills etc. for mounting and wear eye projection when using drills or hammers.
10. Always ensure you practice ladder safety rules when using a ladder to reach roofs for dealing with solar PV systems. Ensure the ladder has at least a 75-degree angle with the ground. Ensure the ladder is stable on flat ground. Ensure someone holds the ladder and prevents it from slipping.
11. ALWAYS CONNECT the BATTERY and PANELS LAST in the SYSTEM to avoid making the circuits live.

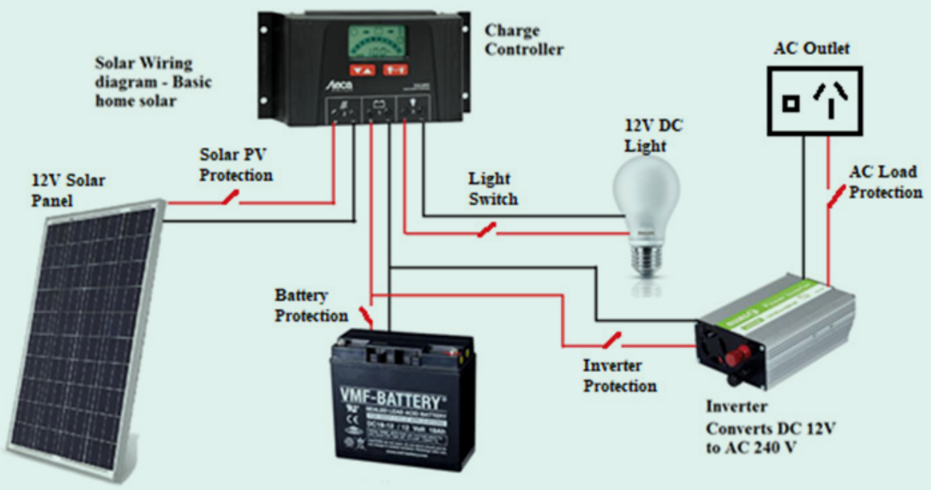
Part B: Installation of a Solar standalone DC+AC System

Supply the learners with a solar PV system containing the following:

- Solar panels.
- Battery.
- Charge controller.
- Inverter.
- DC light bulbs (about 10W) with a switch as AC load.
- AC light bulb (about 10W) with switch.
- Solar Panel mounting kit.
- Electrical wire.
- Pliers, screw drivers, multi-meters.
- PPE – insulated gloves, goggles, insulated tools, helmets, roof harness.
- Wire connectors and DC circuit breakers.

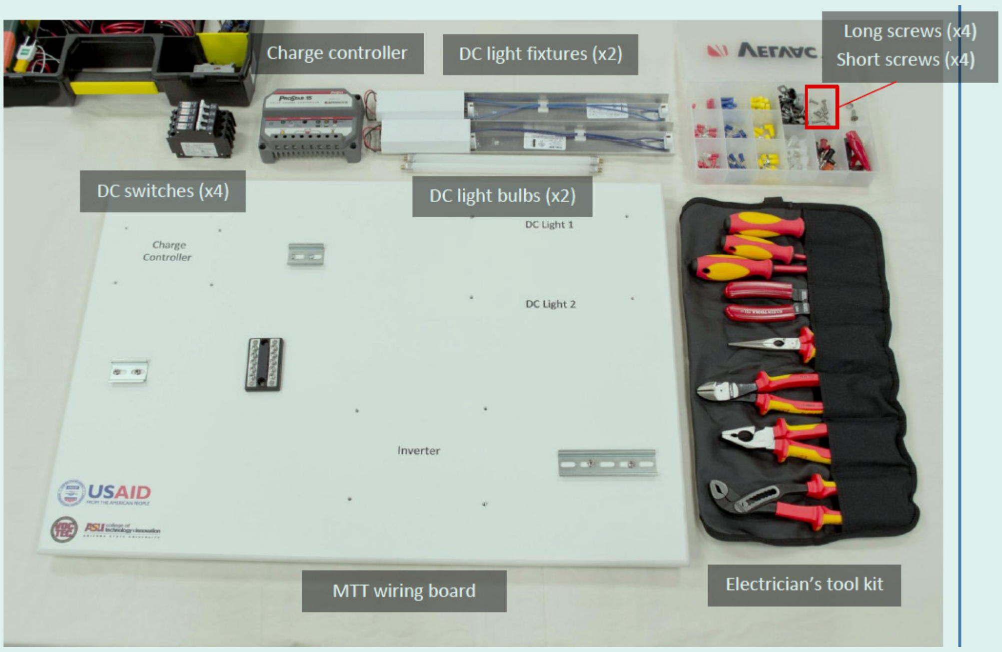
In this activity the learners will attempt to install an actual solar PV system with the typical circuit diagram as follows:

FIGURE 72: Connection diagram of DC+AC Solar PV System[70]

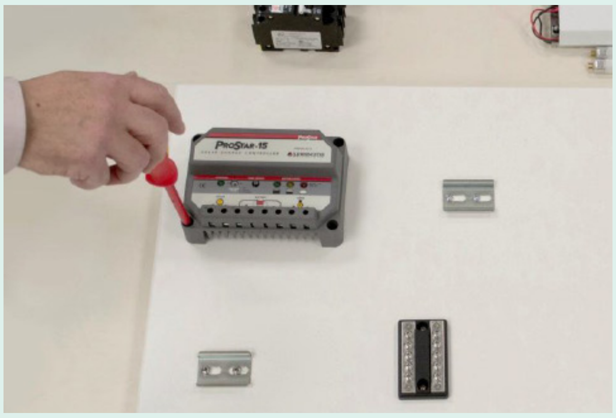


The learners must orally be able to explain how the installation will be done. If there are teams, they may take turns doing this. Hence, be present with them at all times, to ensure they are making the right connections. We start by doing a DC setup on the MTT board.

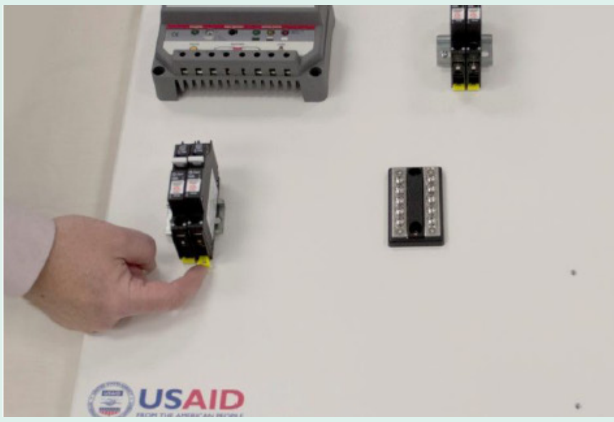
DC Setup Materials Needed



1. Attach charge controller with long screws to four threaded screw inserts on upper left corner of the wiring board.



2. Snap on four DC switches to DIN rails by pushing in yellow tabs at the bottom of the switch.



3. Attach DC light fixtures with small screws to threaded screw inputs on upper right corner of wiring board (DC light fixture with wires labeled 1 should go above DC light labeled 2).

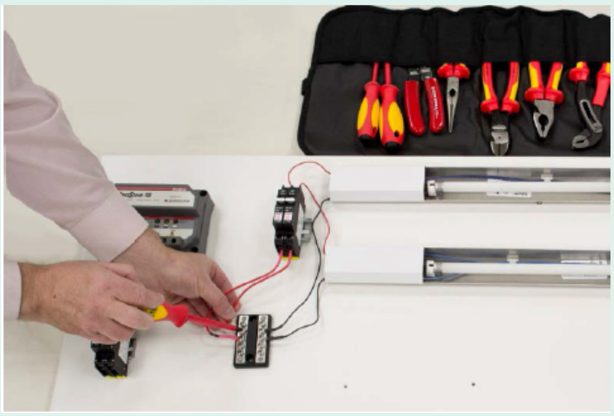
4. Snap in DC light bulbs to fixtures by gripping the metal ends of the bulb. (Insert bulbs into fixtures and gently rorate bulbs until they snap into place).

Now we wire the components of the DC system.

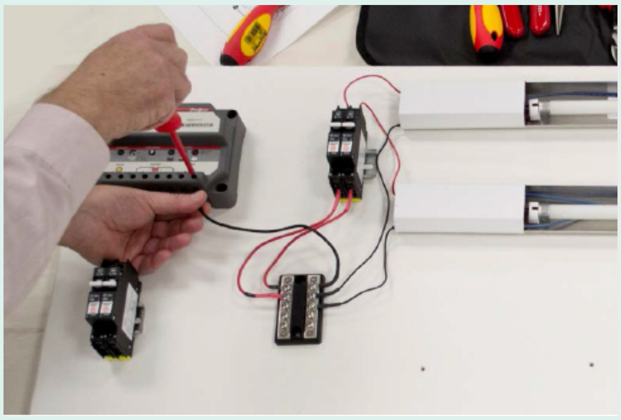
1. Insert **red wires** labeled 1 respectively 2 of DC lights 1 and 2 to upper screw terminal inputs of DC switches.

2. Connect **black wires** #1 respectively #2 the DC lights 1 and 2 to right side of distribution bar.

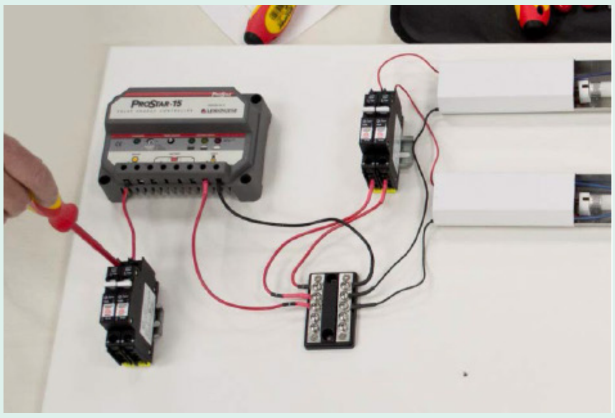
3. Connect both DC switches to the left side of distribution bar with short **red wires** #1 and #2 (Flat terminal end goes into lower terminal input of DC switches).



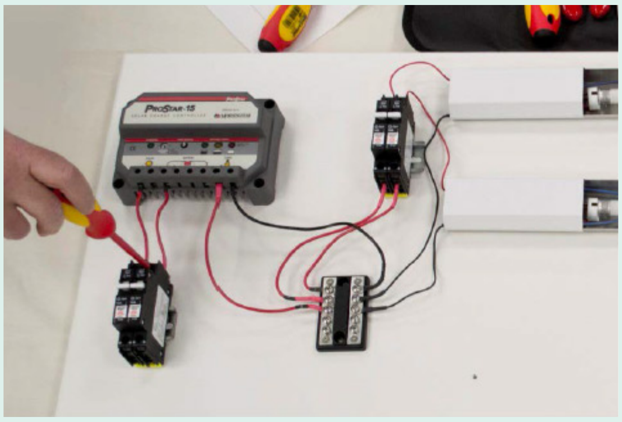
4. Connect charge controller to distribution bar with one **black** and one **red wire** #3. (Red and black pin terminals go into charge controller's load positive respectively negative terminal input).



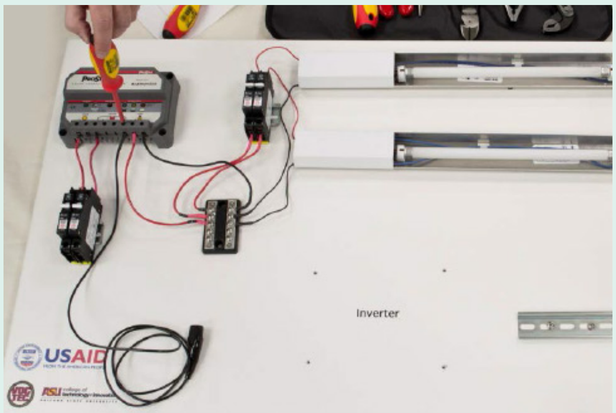
5. Connect charge controller to left DC switch with short **red wire** #8 (**Red** pin terminal goes into charge controller's solar positive terminal input).



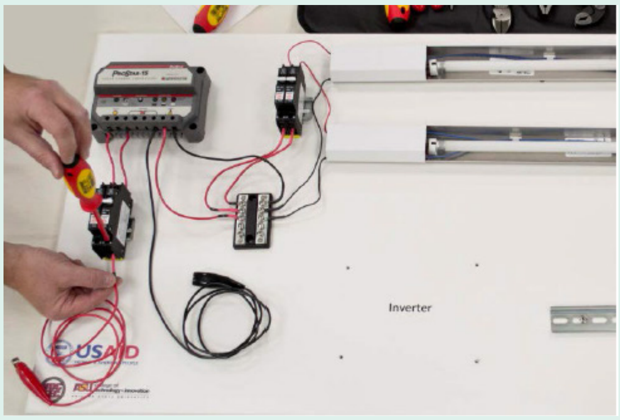
6. Connect charge controller to right DC switch with short **red wire** #7 (**Red** pin terminal goes into charge controller's battery positive terminal input).



7. Connect long **black wire** #7 into charge controller's battery negative terminal input (Black pin terminal end goes into charger controller).

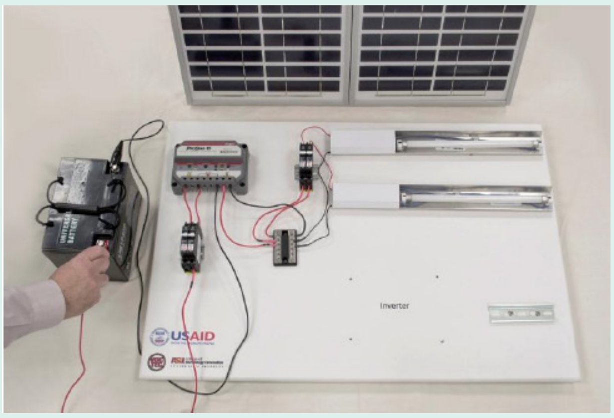


8. Connect long **red wire** #7 into right DC switch terminal input (**Red** flat terminal end goes into DC switch).

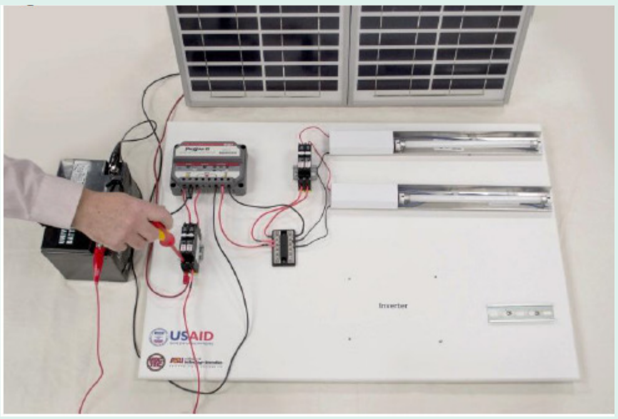


In the next steps we connect the battery and panel.

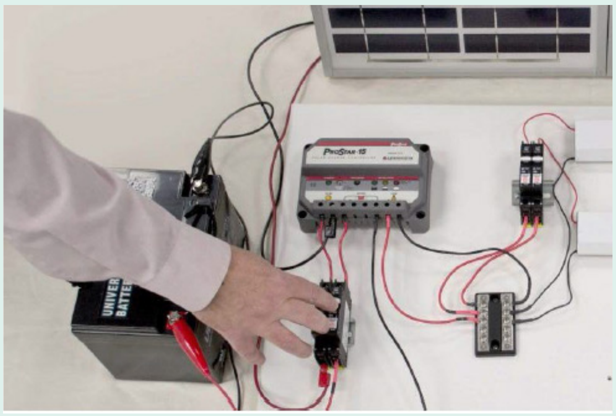
1. Connect **red wire** #7 to positive pole of battery and **black wire** #7 to negative pole of battery (make sure switch is in off position)



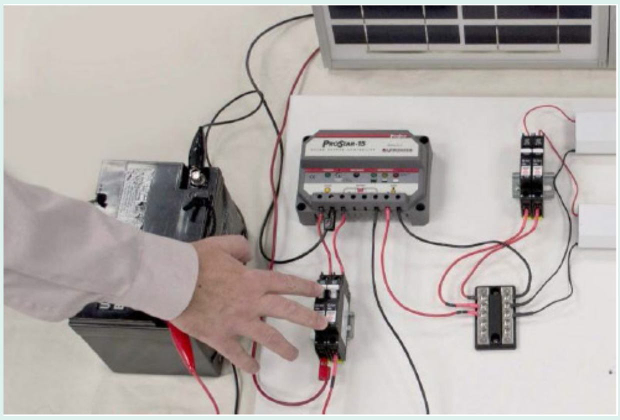
2. Connect PV array's negative connector (**black**) to charge controller's negative input terminal and positive connector (**red**) to left DC switch terminal input.

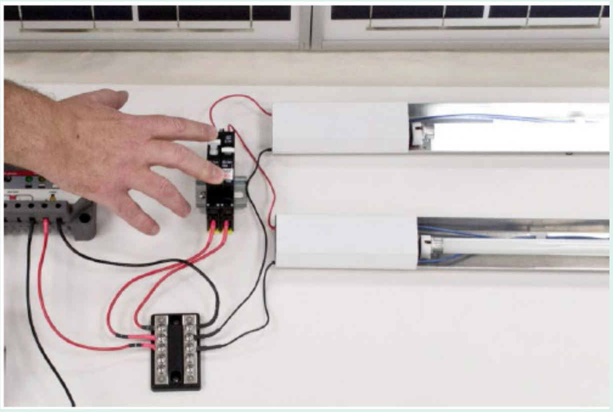
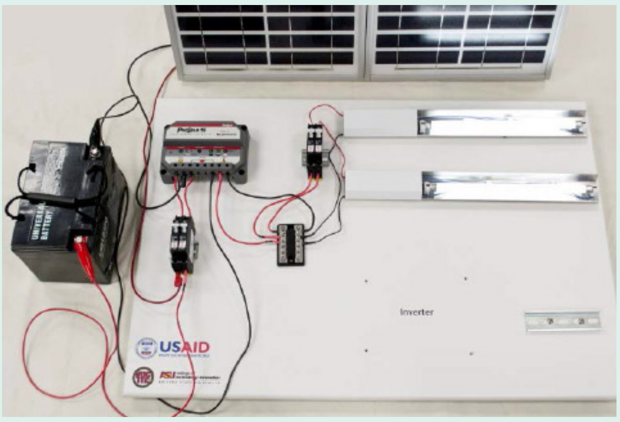


3. Switch on the right DC battery disconnect switch (charge controller will power up and battery lights will flash green, yellow and red).

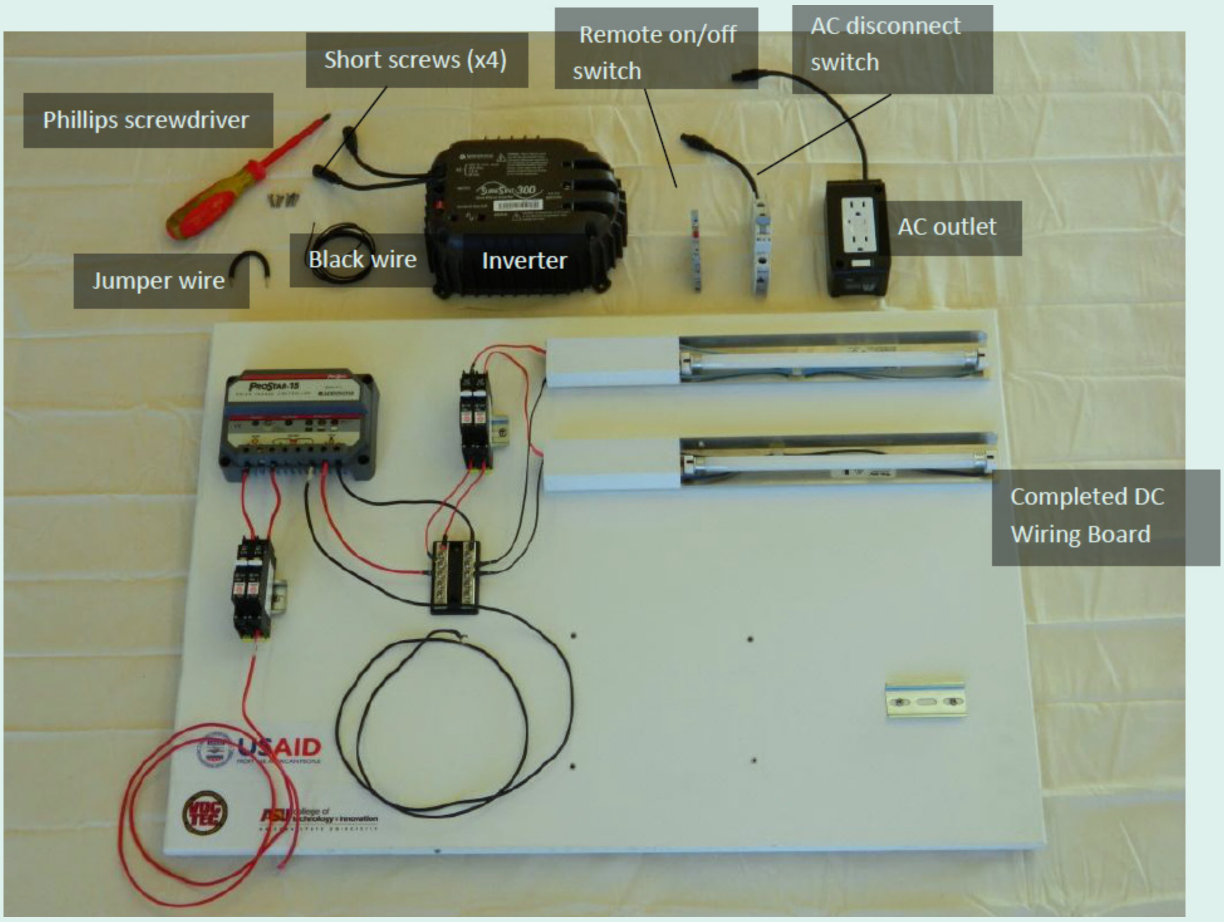


4. Switch on the left PV disconnect switch (if sunlight is incident on PV modules, green charging light on the charge controller will turn up).



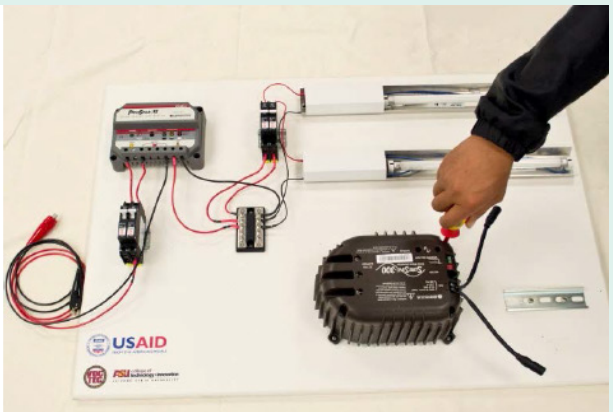
5. Switch on DC light disconnect switches (DC lights will come on).	6. Completed DC System.
	

Now that we have the DC system done let's move to the AC system. Here some more components you will need.

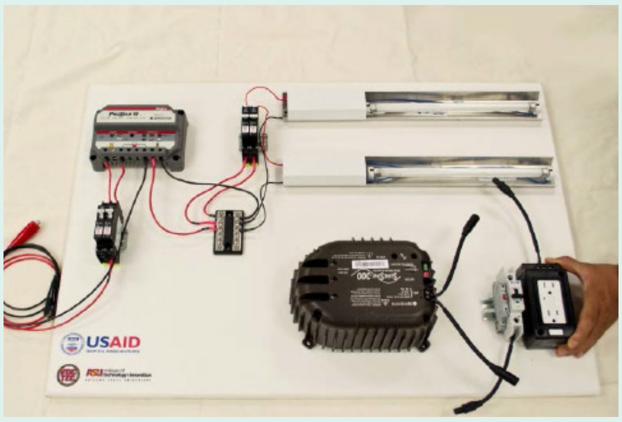


Now let's install the inverter.

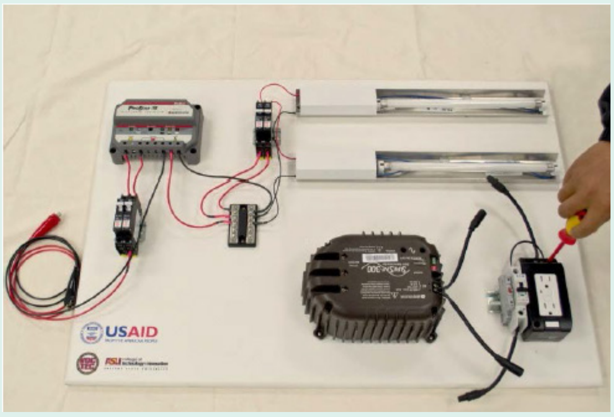
1. Attach inverter upside down with short screws to the threaded screw inserts in the lower middle of the wiring board.



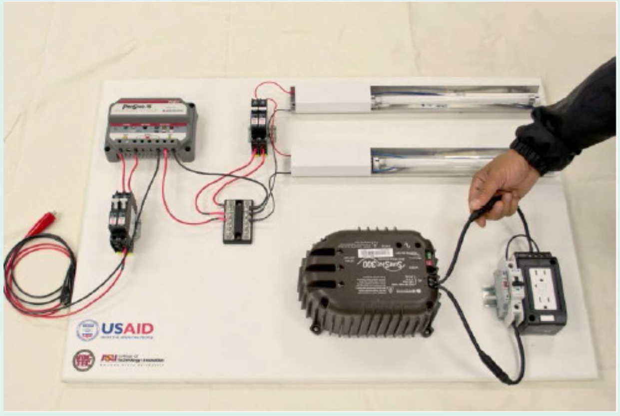
2. Snap the remote AC on/off switch, AC disconnect switch and AC outlet to DIN rail on lower right side of the wiring board.



3. Connect **black jumper wire** #5 from upper terminal input of AC disconnect switch to input of AC outlet.

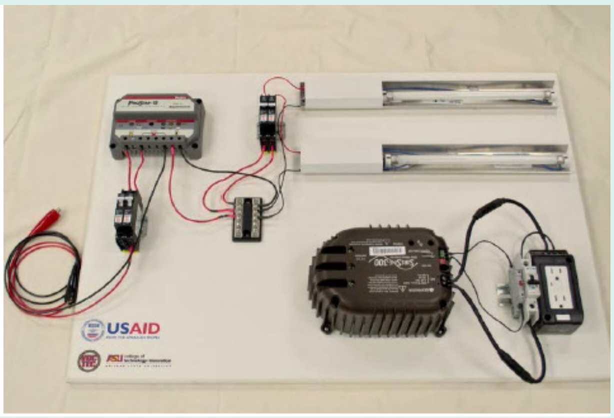


4. Connect AC output plugs of inverter #5 to input plugs of AC switch and AC outlet.

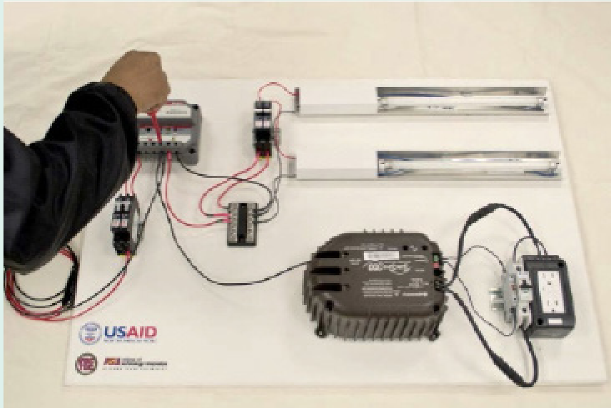


5. Connect remote on/off terminal inputs of inverter to remote on/off switch with thin **black wires** #4

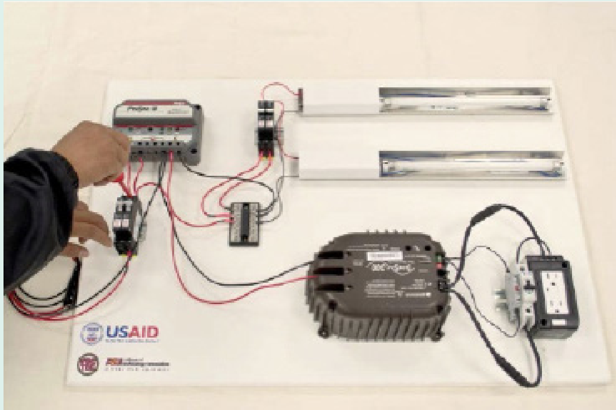
6. Inverter AC output is off when switch is open circuit and on when switch is short circuit.



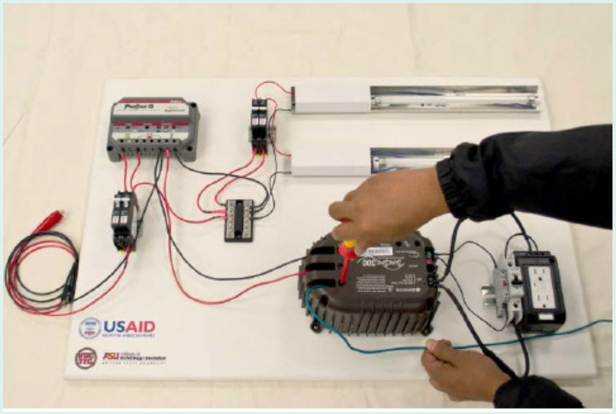
7. Connect flat terminal ends of **black wire** #6 to negative 12 Vdc battery input of inverter and pin terminal end to C/C's battery negative input terminal.



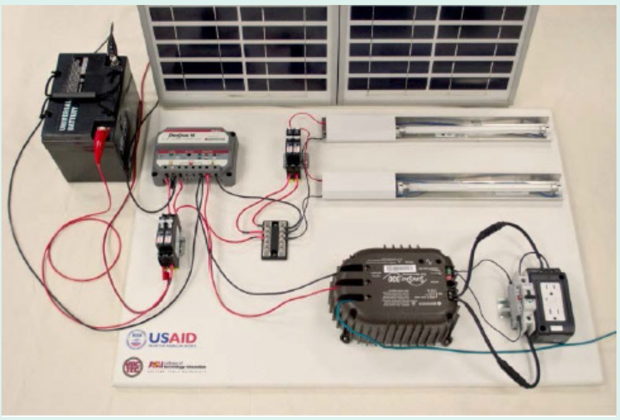
8. Connect flat terminal end of **red wire** #6 to positive 12 Vdc battery input of inverter and pin terminal end to battery DC disconnect output terminal.



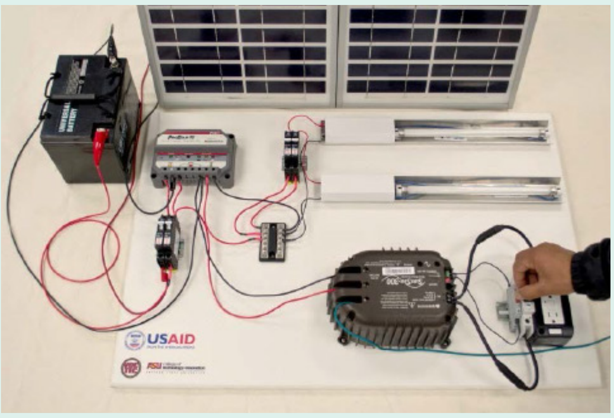
9. Screw **green ground (earth) wire** #6 to ground terminal inverter and securely fasten the opposite end of ground rod (if available).



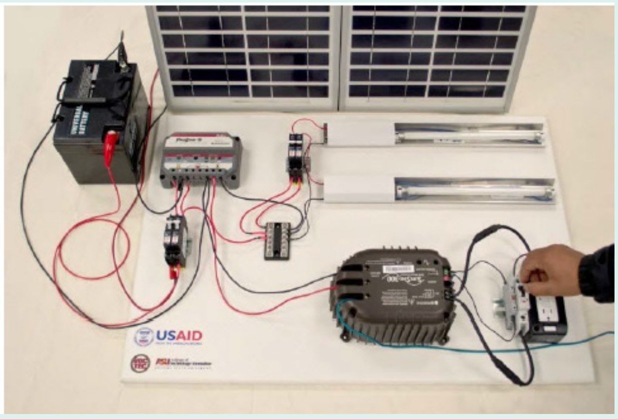
10. Follow steps 1 to 4 of Section D of this guide to connect battery and PV array and to switch on battery and PV disconnect switches.

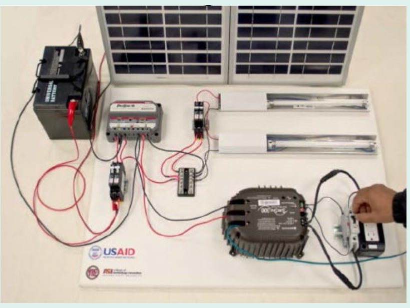
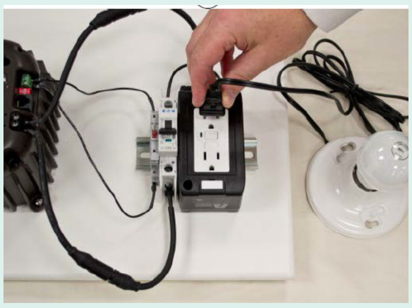


11. Switch on remote on/off switch (this will activate the AC output of the inverter).



12. Switch on AC disconnect switch and connect AC local.



1. Carefully assemble MTT board by following steps 1-5 of the MTT Five-Step Quick Start Guide	2. Plug in AC load (e.g. AC light bulb) into AC outlet.	3. Turn on all switch.
		

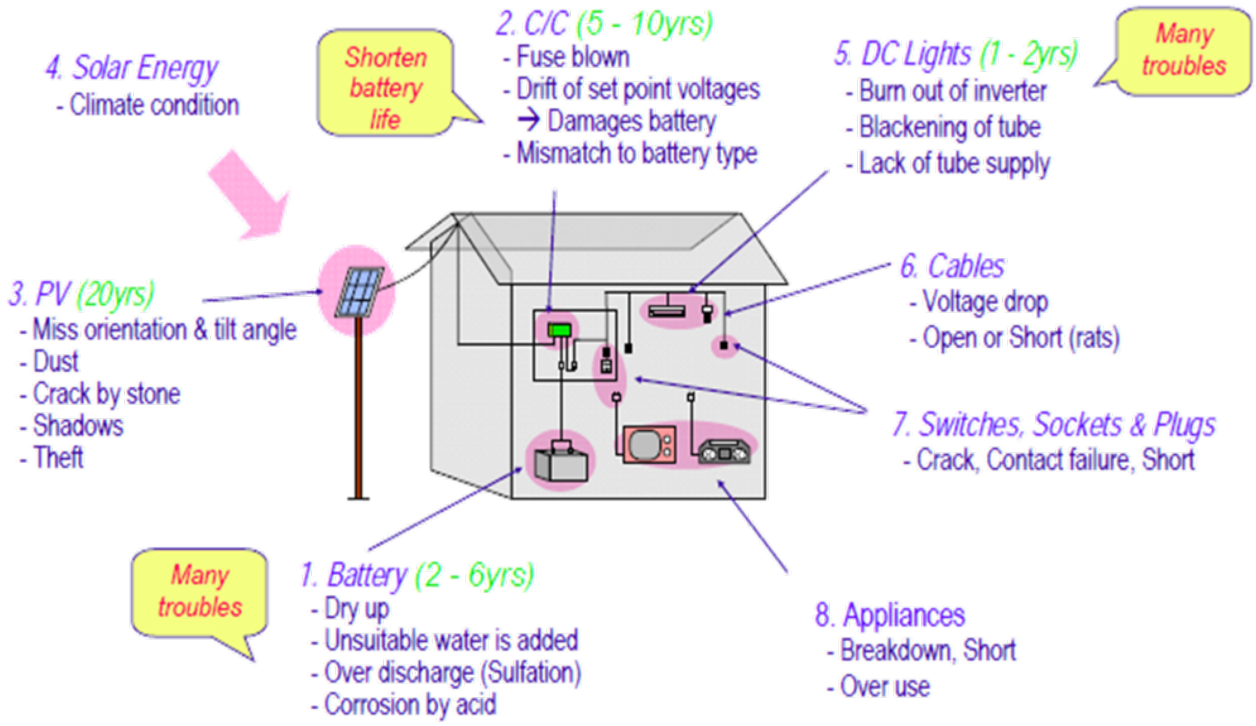
8

Identifying and resolving common faults in solar home PV systems

Note: Below common faults can be discussed during Activity 12 above, while the learners are still with the hardware kit wired up.

Most of the faults experienced in a Solar Home system are abrupt and can cause the system to shut down while some faults can be found during routine checks. The following figure shows the common types of faults that can be experienced in a solar home system, while the rest of the chapter covers component level faults, checks and remedies.

FIGURE 73: Common component faults[71]



8.1 Charge Controller Faults

In a solar PV system, the charge controller is the brains of the entire system, and it is the first place you can look to for faults. Here are some common faults on charge controllers.

Fault 1: Charge controller does not show full state of charge by the end of the day.

Reason: Accidental overuse (cloudy, rain, special TV program).

Remedy: Reduce load usage time by half for a day to allow batteries to charge properly.

Fault 2: Charge controller cuts-off load and lights.

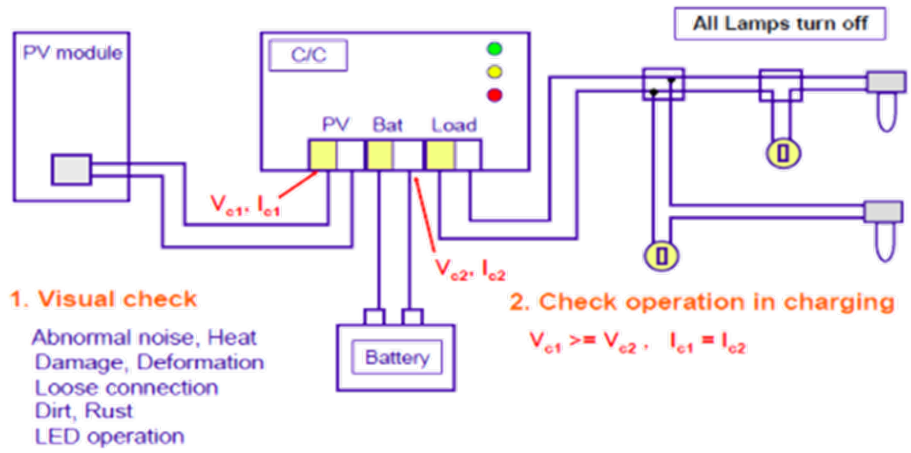
Reason: Daily overuse (battery is discharged):

Remedy: Reduce load usage time by half till C/C shows full state (at least for a week) to allow batteries to charge properly. Reduce the time appliances are used daily.

The above mentioned are the two most common faults you will see in charge controllers. Most solar charge controllers will also cut – off power to loads in case of accidental short circuit. The charge controller needs to be reset after the short circuit is removed. Most charge controllers give battery voltage and solar output voltage too which you can use to troubleshoot. Some controllers' flashes lights or give error codes. Keep your charge controller manuals on hand for reference when error messages occur.

71 Source: JICA

FIGURE 74: Controller fault finding[72]



Fault 3: No current is flowing to battery, or it signals battery is fully charged even though battery has just begun charging or it keeps charging battery even when full.

Reasons: Blown fuse, loose connection of wires or malfunction of internal controller circuit.

Remedy: Tighten loose connections, replace blown fuse, check LVD and HVD settings.

8.2 Solar Panel Faults

Solar panel faults can be found especially when there are power losses or when you make measurements. Display of solar panel voltage can also be seen on some charge controllers.

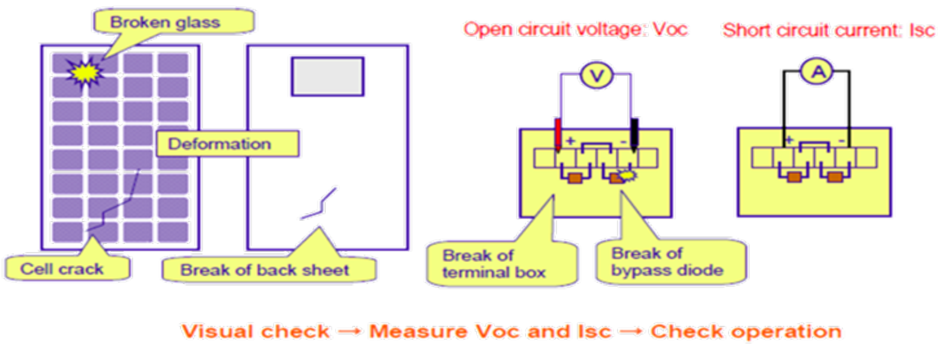
Fault 4: Low or no power output from solar panel.

Reason: Wrong orientation (wrong tilt angle and/or direction), Accumulation of dust, Crack in the glass lamination, Shadow over the panel, poor sunlight cloudy conditions, Short circuit of bypass diode, Loose or broken wire connections, theft of panels.

Remedy:

- Rectify orientation and tilt angle (tilt angle must not be less than 10o and should be facing North).
- Check presence of dust and cracks.
- Clean PV with water, detergents not needed.
- Tighten loose connections at the terminal box.
- Remove blockages and prevent shadowing at PV module between 9am – 3pm.
- Replace Bypass diode.

FIGURE 75: Panel Fault[73]



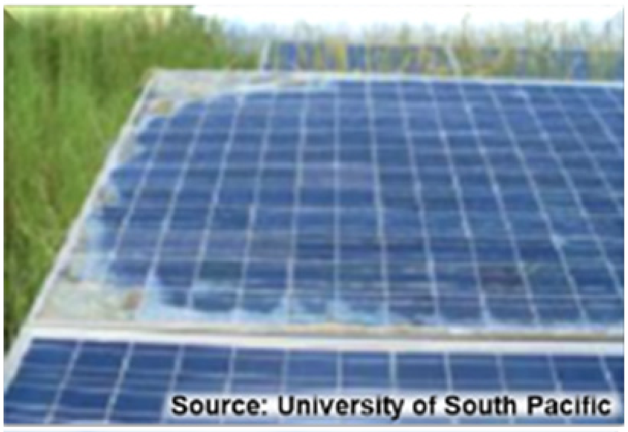
Other common reasons of power loss:

Delamination: this is when the laminate material on top of the solar panel gets detached. Delamination could lead to electrical shock, and it leads to dramatic power loss

72 Source: JICA

73 Source: JICA

FIGURE 76: Panel Surface damage



System Browning: This is when the sunlight and chemical reaction of the panel layers cause sit to change color to yellow or brown. Browning may not lead to electrical shock, but it will lead to dramatic power loss

Both Browning and Delamination cannot be treated easily and may require new and better-quality panels as replacements.

8.3 Battery Common Faults

Fault 5: Battery is very quickly charged or cannot be charged properly because the cells have unequal voltages.

Reasons: Sulfation (chemical change in the lead electrodes), loss of electrolyte, stratification (when electrolytes in the solution concentrate at the bottom), loose terminal connections, high battery temperature or leakage of electricity due to acid on the outside surface between battery terminals.

Remedy:

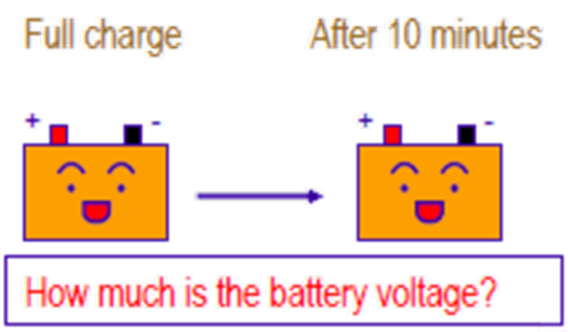
- Loosen connection at the terminals.
- Clean terminals with steel brush, replace terminals and then apply grease (e.g., Vaseline or lithium grease) to inhibit terminal corrosion.
- Level of battery electrolyte is low, top up when necessary.
- Use appropriate terminal lugs/clamps only.
- Remove corrosion at the terminals with a wire brush.
- Slightly shake battery (not more than 10 degrees from the floor line at side) to clear up stratification.
- The installation conditions are poor (too hot, lack of ventilation, etc.), relocate if necessary.

8.4 Checking battery voltage

After fully charging a 12V battery, turn off all loads and stop the charging. After a minimum of 10 minutes (but better if you wait 1 - 2 hours), measure the battery voltage. If the voltage is lower than 12.5V, the battery has almost reached the end of its usefulness *[this is not a valid test for all types of lead-acid batteries, though it does give some indication of its condition]*.

It is important to replace severely malfunctioning batteries to avoid damaging other batteries in the battery bank if there are multiple batteries connected together.

FIGURE 77: Battery charging – always monitor voltage[74]



74 Source: JICA

8.5 General Balance of Equipment Faults

Faults:

- BOS (cables, switches, lights, etc.).
- No light even when battery is fully charged.
- Under-voltage at load end.
- No power at load end.

Reasons:

- Open or short circuit or grounding.
- Inappropriate/undersize cables (large voltage drop).
- Burned-out DC light tube/inverter.
- Loose connection at the terminals.
- High resistance on the switch contact.

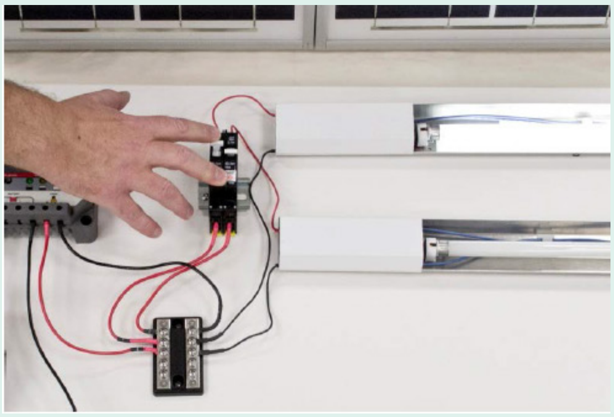
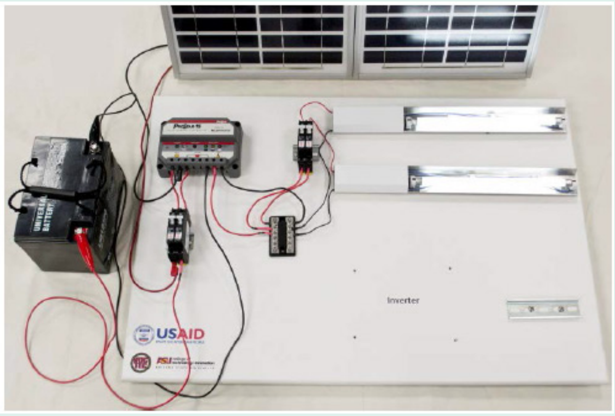
Remedy:

- Check voltage level at load end and voltage drop with the light switched to on.
- Tighten loose connections at the terminals.
- Check size of cable if the installed cable is the appropriate size, replace as necessary.
- Check Continuity of cables, when open circuit, trace the line and correct the open circuit.
- Check and rectify possible short circuit and inappropriate grounding in the line, re-insulate short-circuited/grounded line.
- Check operation of switch and voltage drop between input to the switch and output from the switch when it is turned on.

ACTIVITY 13 – CONTINUITY TESTING

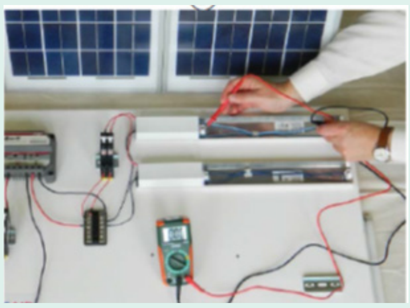
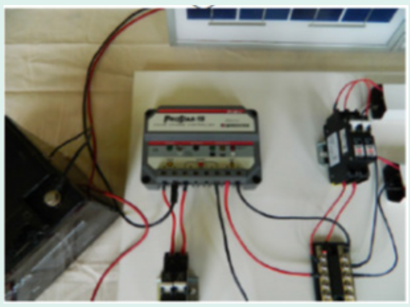
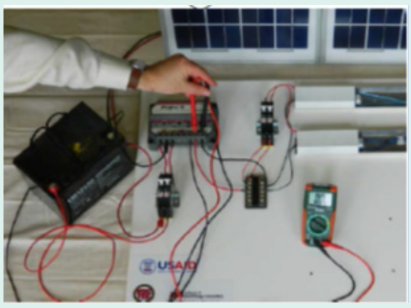
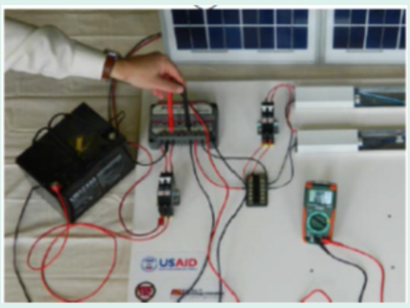
For this activity a faulty wire will be connected between the battery and charge controller for the learners to detect and correct using continuity tests.

Setup the DC Solar PV System and show that it is working.

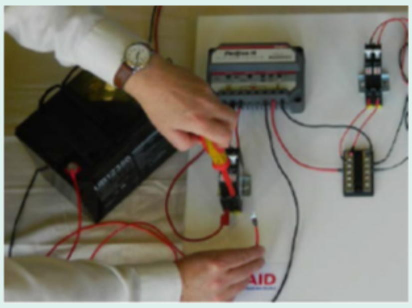
5. Switch on DC light disconnect switches (DC lights will come on). 	6. Completed DC System. 

Once the learners see it is working – replace one good wire with the faulty wire as shown below.

You May demonstrate the fault finding and correction activity using the following instructions.

1. Conduct visual imperfection of system. 	2. Remove DC light bulb(s). 	3. Measure voltage at light fixture terminals (voltage should be 0V). 
4. Check indication lights at charge controller (all light should be off). 	5. Measure voltage at charge controller's load output (voltage should be 0V). 	6. Measure voltage at charge controller's battery input (voltage should be 0V). 

7. Measure voltage directly at battery terminals (voltage should be above low voltage reconnect LVR). 	8. Problem is identified as “broken continuity” between battery and charge controller. 

1. Switch multimeter to continuity setting and check connection between negative battery terminal and negative charge controller battery input. 	2. If multimeter beeps, the circuit is continuous. Measure continuity between positive charge controller battery input and disconnect switch (DMM should beep). 	3. Measure continuity between input and output terminals of disconnect switch (DMM should beep when switch is on). 
4. Measure continuity between disconnect switch and positive (red) battery terminal (DMM will **NOT** beep). 	5. Problem is detected as discontinuity between battery positive terminal (red) and disconnect switch. 	6. Check connecting cable for faultiness. Cause is identified as wire insulations **not stripped** at battery connector. 

You may demonstrate the fault finding and correction activity using the following instructions.

9

Solar PV Maintenance checklist

While most of the maintenance aspects have already been covered in previous chapters already, this chapter provides a summary of all the PV maintenance required for solar home system, ending with a checklist for technicians. In some sections, more details may be provided on maintenance of larger systems as well, for information purposes only.

9.1 Planning Maintenance

Routine maintenance is the best way to increase the life of your solar PV system and its components. Routine maintenance is normally done as a check which has a list of items of each component that needs to be ticked off. The checklist ensures that the components are inspected, cleaned, evaluated, and serviced on time so they last longer. Here are some tips on how to do routine maintenance.

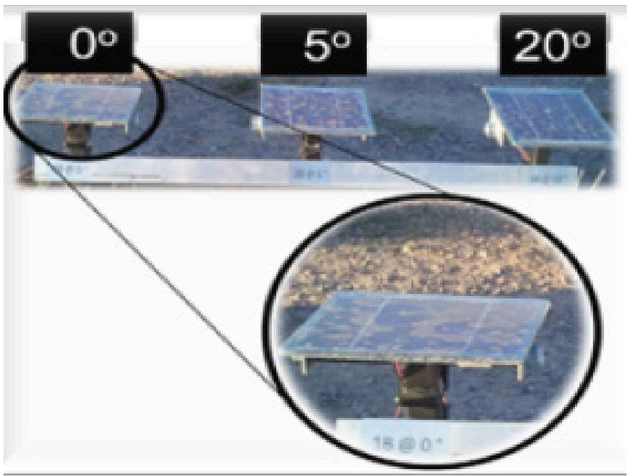
9.2 Solar Panel Maintenance

- Inspect PV arrays for any signs of physical damage, such as impacts or fractures.
- Surface must be clean, un-damaged, clean any dirt or debris both on top of the panel and underneath if it is mounted on the roof.

FIGURE 78: Damaged Panels[75]

- Soiling loss increases as tilt angle decreases. Ensure that panels are not flat and have some tilt. For Fiji, this should be ideally tilted between 15-20 degrees, facing North, but no less than 10 degrees to allow for self-cleaning during rain.

FIGURE 79: Effect on dirty panels[76]



9.3 Battery Maintenance

Batteries are the most common component to fail if not looked after properly. Battery maintenance involves various tasks depending on the type of battery and manufacturer requirements, including:

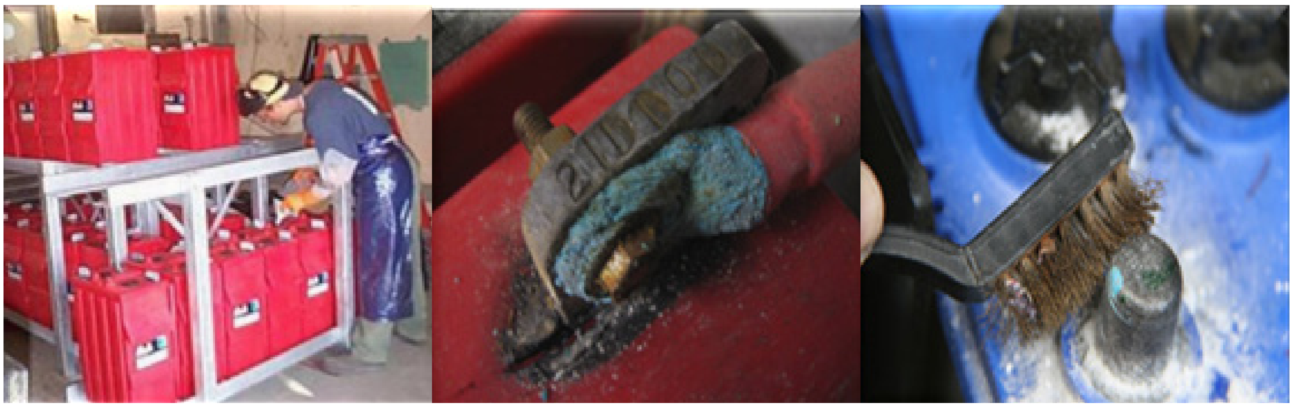
- Inspecting and cleaning battery racks, cases trays and terminations.
- Inspecting battery disconnects, overcurrent devices and wiring systems.
- Measuring voltage.
- Battery load testing applies very high discharge rates for a few seconds, while measuring the decrease in battery voltage. This is used to indicate weak or failed cells by significantly greater voltage drop. This should not be done without rigorously following the manufacturer's instructions for this test. Damage of the battery can occur if done improperly.
- Battery capacity testing involves discharging the battery at nominal discharge rates to a prescribed depth-of-discharge. This evaluates available energy storage capacity for the system. Again, this should not be done unless recommended by the manufacturer and using the manufacturer's instructions. If done incorrectly the battery may be damaged.

75 Jim Dunlop Solar

76 ASU PV/ Reliability Laboratory

- Replace the poor batteries in a series string. The performance of a series string battery bank will be dominated by the poor performing batteries. In general, it is best to replace all batteries at the same time though changing a known bad battery in a bank of batteries may be reasonable due to budget constraints.
- Discourage Frequent Over-discharges of the System - Overuse and over-discharging reduce battery lifetime due to a high depth of discharge (DOD).
- Measuring specific gravity and adding distilled water when low (for flooded lead-acid batteries only!).
- Periodic battery maintenance should include checks of all terminals for corrosion and proper tightening.
- Use a steel brush to clean oxides at connections. Wear insulation gloves at all times.

FIGURE 80: Battery care[77]



SAFETY TIP: Use safety goggles and rubber gloves when servicing batteries. Wear old clothes because you can get acid on them (if batteries are of flooded type).

Keep an open box of baking soda and a plastic pan of water nearby while servicing your batteries—in case of a spill, you can dump the baking soda in the water, stir it, and use the mixture to quickly neutralize any spilled acid.

Low voltage isn't a shock hazard, but high current is. A wrench dropped across terminals can quickly burn your hand and possibly explode the battery. Be careful!

9.4 Measure battery state of charge

The state of charge SoC is a measure of battery health and battery capacity. There are two ways to measure this – by open circuit voltage and by measuring the specific gravity (SG) of the electrolyte (only possible for flooded type batteries).

9.5 Voltage Method

Battery specific gravity (flooded battery type only) and open-circuit voltage are measured during maintenance to evaluate battery health and estimate battery state-of-charge. Open-circuit voltage should be measured after the battery has rested for a few hours. This table below gives the state of charge:

FIGURE 81: State of Charge[78]

State-of-Charge	Specific Gravity	Open-Circuit Voltage (V)
100%	1.265	12.6
75%	1.225	12.4
50%	1.190	12.2
25%	1.155	12.0
0	1.120	11.8

For typical lead-acid battery at 25°C

77 Source: Jim Dunlop Solar
78 Source, Pinterest.com, https://www.pinterest.com/bambulancemania/work-apparal/

9.6 Hydrometer method (for flooded batteries only)

Hydrometers measure electrolyte specific gravity (SG) by extracting electrolytes from the battery cell into a chamber. Archimedes hydrometers use a float and buoyancy principles to measure SG. Refractive index hydrometers use a prism and optics to measure by the angle that light refract SGs through a droplet of electrolyte. After reading the SG the above table can be used to estimate the SoC.

FIGURE 82: Hydrometer usage[79]


Archimedes Hydrometer

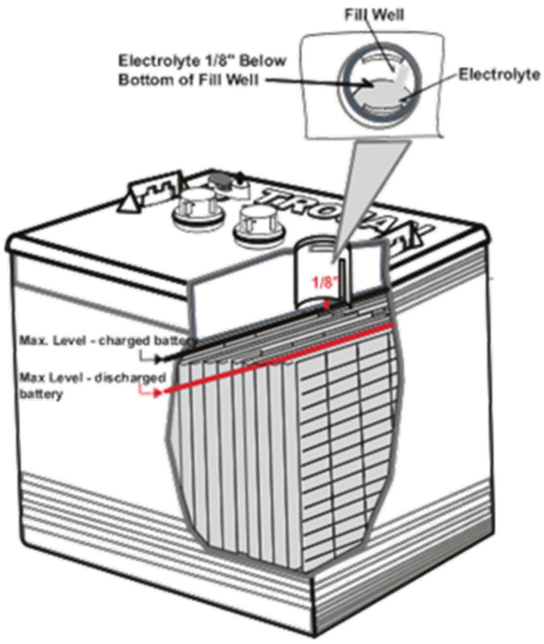

Refractive Index Hydrometer

Source: Jim Dunlop Solar

Adding Distilled Water to Battery (flooded battery only):

- Open vent flooded batteries loose water due to electrolysis and gassing during charging.
- Water loss increases with temperature, charge rates and age of battery.
- Use distilled water to prevent contamination of the battery and do not overfill.

FIGURE 83: Battery structure[80]



You may use a battery maintenance checklist given below to carry out routine checks on batteries.

Batteries (may be part of a backup system)	
Check electrical connection	Weekly
Check for corrosion and clean terminals	Weekly
Check water level and top up for lead acid batteries	Weekly
Ensure that batteries are fully charged on a regular basis	Weekly
Replace the battery bank	Typically, every 3-5 years (lead-acid) and 5-10 years (sealed gel) if well maintained
Manage hazardous materials storage and disposal: recycle spent batteries, manage electrolytes spill for lead-acid batteries	As needed

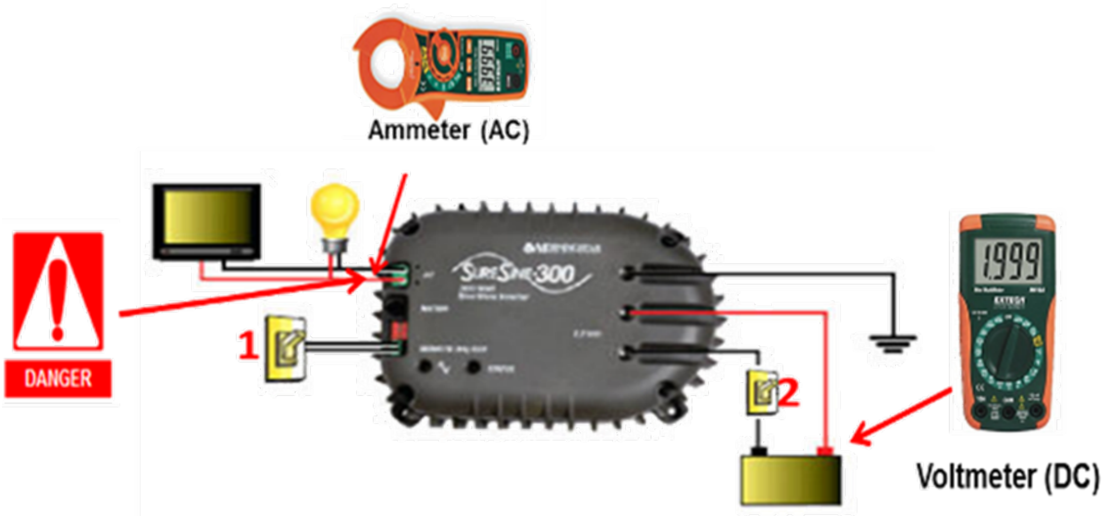
79 Source: Jim Dunlop Solar
80 Source: Jim Dunlop Solar

9.7 Inverter Maintenance

- Verify if the inverter is receiving DC voltage from the battery using a voltage meter set to DC voltage measurement.
- Verify if the inverter is producing AC voltage to the AC load using voltage meter set to AC voltage measurement.

SAFETY TIP: Inverter generates dangerously high AC voltage of 220-240V. Wear electrical insulation gloves and follow all safety procedures.

FIGURE 84: **Inverter wiring**[81]



Do NOT remove any wiring, do the monitoring in the following sequence:

- Turn off the disconnect switches 1 and 2 (see image).
- Use clamp-on ammeter (AC) on the AC side.
- Connect the voltmeter (NOT ammeter) to the battery. terminals (remember: Ammeter will short circuit the battery and it will blow the fuse on the meter!).
- Turn on the disconnect switches 1 and 2.
- Observe if voltage is present and current is flowing to the load. If yes, the inverter is working.

FIGURE 85: **Charge controller**[3]

9.8 Charge controller Maintenance

Charge controllers are normally robust and should not give a lot of trouble unless they are overloaded.

- Check loose connections.
- Check display voltages and check for error messages.
- Check fuse is not blown.
- Check mountings of controller.

81 Adapted from "Operations &Maintenance of Stand-Alone PV Systems, Arizona State University, VOCTEC, http://voctec.asu.edu

9.9 Creating and using checklists

You can easily overlook a few things during your routine check. It is useful to keep a weekly or monthly checklist in a logbook where you can check each component of you clients solar PV system easily without overlooking anything. A checklist is a very useful record for this routine maintenance. It also provides evidence to your client's that you have done the inspections. A sample monthly master checklist is given below, and you can always add more to it or remove some that do not apply.

TABLE 4: **Checklist**

Check list items	OK	Comment
General Visual Inspection		
Inspect PV modules for defects that can appear in the form of burn marks, discoloration, delamination, or broken glass.		
Check modules for excessive soiling from dirt buildup or animal droppings.		
Ensure that the module wiring is secure and not resting on the roof, hanging loose and exposed to potential damage, bent to an unapproved radius, or stretched across sharp or abrasive surfaces.		
Inspect the PV mounting system for defects including rust, corrosion, sagging, and missing or broken clips or bolts.		
Inspect conduits for proper support, bushings, and expansion joints, where needed.		
In roof-mounted systems, check the integrity of the penetrations (water tightness).		
In ground-mounted systems, look for signs of corrosion near the supports.		
Check to make sure that any cabinets (if available) penetrations are properly sealed and there is no evidence of water ingress.		
Perform a visual inspection of the interior and exterior of the inverter. Look for signs of water, rodent, or dust intrusion into the inverter.		
Inverter Check		
Clean any filters.		
Clean the inside of the cabinet.		
Test any fans for proper operation.		
Check fuses.		
Confirm warning labels are in place.		
Look for discoloration from excessive heat buildup.		
Check continuity of system ground and equipment grounding.		
Check mechanical connection of the inverter to the wall or ground.		
Record all voltage and current readings from the front display panel (if available).		
Check appearance/cleanliness of the cabinet, ventilation system, and insulated surfaces.		
Check for corrosion/overheating on terminals and cables.		
Tighten the connectors and/or bolts as needed.		

Record ambient weather conditions, including the temperature and whether the day is cloudy or sunny.		
Check the operation of all safety devices (circuit breakers, surge arrestors, etc.).		
Battery Check		
If batteries are flooded type, check for signs of any electrolyte in the safety trays (if provided) or on the floor, indicating a possible battery leak or overfilling;		
Check condition of battery containers.		
Check battery voltage level - record voltage levels.		
Check condition of battery terminals - ensure no corrosion, remove corrosion if any.		
Check battery electrolyte levels (not required for gel/ sealed batteries).		
Check for any breaks in wires and uncoated wires - report any breaks in wires.		
Ensure that all connections are tight and properly covered.		
Check for loose or hanging wires.		

ACTIVITY 14

Print out the solar PV sample monthly master checklist and give it to each team of learners or let them use the checklist in their workbooks. Also provide them with insulated gloves, multi meter, clamp meter, eye goggles, and other relevant tools and PPE. They must try to wear safety shoes for the activities.

Ensure everyone puts on the PPE and takes their checklist around the solar PV system which they had installed in the previous activity. Since there are many activities, you may ask them to do the ones which are faster to do as an activity. You must continue to observe them and make sure they tick off and comment on the checks they are doing. The final checklist must be collected and checked orally to give feedback on some checks. It is important they use this checklist to learn how to do routine maintenance. During the checking – allow for questions and answers.

Additional Role Play: (optional)

Two grandmothers from a rural village have just returned from training on Solar O&M Basics and are having a conversation

Tima: I am so happy I was able to attend that training – I thought that at my age I had nothing else to learn – but I was wrong.

Anna: Yes, I feel the same way – there was so much to learn, and I was amazed at how I was able to follow along especially with understanding the technical information.

Tima: The mind is amazing – once we open our minds to learning a new thing – we are able to do it. I had to keep telling myself that I could do it and my children and grandchildren have been very encouraging as well.

Anna: I know that I would not have been able to do it without the support of my family – now we are solar technicians... hahaha

Tima: In order to make sure we remember everything; we should meet once a week to go through what we have learned. What do you think?

Anna: Yes, I agree. Even though we still have the cash power system from EFL a lot of homes in the village are using solar and that's where we can help.

Tima: And with the amount of power outages lately, I think a lot more families are going to choose solar systems. These solar home systems are going to become more popular.

Anna: Yes, you're right. The battery powered solar systems will allow the homes to store the electricity during the day from the sun and use it in the evening to power up the house and the appliances.

Tima: I am so glad we are doing this together to support our children, grandchildren and the rest of the village and also support the environment.

10

Annex

10.1 Annex A: Simplified Solar System Sizing Exercise[82]

Step 1: Load Analysis

We first need to list out all the loads that needed to be powered by the solar system and find out the energy need by each one of them. To determine the amount of energy consumed by each DC or AC load in kilowatt-hours (kWh), it requires information on the number of watts the load draws and the amount of time it runs (operating hours). Certain loads run daily, while others may run a few times a week, so the operating hours can be per day or per week depending on its usage pattern. The weekly energy consumption can be converted into daily energy consumption using the following equation:

Daily Energy Consumption (in watt-hours) =
(Watts× Hours per day × Days per week) / 7 days per week

For this example, we will assume that we are designing a solar system for the following loads:

- 4 x 12V DC LED lights. Each is rated for 3W of power and is used for 6 hours per day, 7 days a week.
- 1 x 12V DC TV, rated for 15W of power and is used for 4 hours per day, 7 days a week.
- 2 x 12V DC FAN. Each is rated for 15W of power and is used for 6 hours per day, 7 days a week.

Analysis of DC/AC loads should be carried out using a spreadsheet as shown in the example below. The spreadsheet will also enable a quick comparison of Energy Efficient appliances with standard ones, for example, LED lamps produce the same amount of light as CFLs but they consume less power. Ultimately, the less energy the loads consume, the less expensive the solar PV system will be.

FIGURE 86: **Example of Load Analysis spreadsheet[83]**

Load Description	Quantity	Watts	Total Watts	Hours/ Day	Days/ Week	Total Wh/ Day
LED DC lamps	4	3	12	6	7	**72**
24" DC TV	1	15	15	4	7	**60**
24" Pedestal DC Fan	2	15	30	6	7	**180**

Adding up all the energies, we get a total daily energy consumption of 312 Wh or 0.312kWh. This will now be used to size up the solar power system components needed to run these loads.

Step 2: Sizing the battery

A battery is required to store electrical energy produced by the PV modules during the day and supply it to the electrical loads at night. The storage is also needed during long period of cloudy weather.

The daily energy consumption will be used to calculate the battery requirements. The three important considerations in calculating the number of batteries needed in a standalone off-grid PV systems include: Days of Autonomy; Depth of Discharge (DoD); and Operating Temperature.

Days of Autonomy: This is the number of days a battery bank is expected to provide power to the system without receiving an input from the solar array or when there is little or no sun to recharge the battery. In case of more days of autonomy there will be larger battery bank and that will be costly. A larger battery bank will need a large PV array to recharge the battery bank on a regular basis. Three to five days of autonomy is a good compromise.

Depth of Discharge (DoD): DoD is defined as how much of the rated capacity of battery has been used or the percentage of energy drained from the battery. The battery life is mainly determined by the use cycles of the battery. Similar to a mechanical device that wears out faster with heavy use, DoD determines the cycle count of the battery. The smaller the discharge (low DoD), the longer the battery will last. If possible, avoiding full discharges and charge the battery more often between uses to prolong battery life. Selection of the battery should be a balance between the longevity, cost, and problem of replacing batteries. In the system design 50% DoD is normally used, although actual DoD during sunny weather is often less than 20%.

82 Renewable energy and energy efficiency guide for rural bungalow operators in Vanuatu, Global Green Growth Institute, 2018

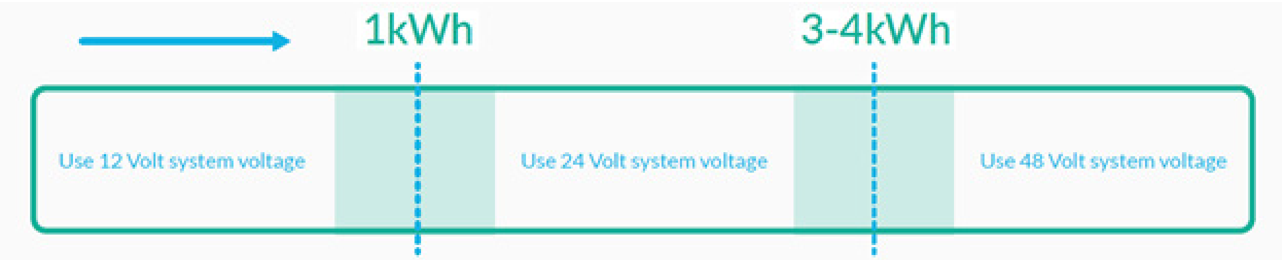
83 Source: DEV Community, "Solpad, all you need to know", https://dev.to/simplystaking/solpad-all-you-need-to-know-4pbl

Operating Temperature: The colder a battery is, the less capacity it can deliver. This is because the efficiency of the chemical reaction occurring inside the battery increases and decreases at different temperatures. However, at higher temperatures, the battery tends to shorten life. In general, the battery performs best in moderate temperatures. With the above considerations, sizing of the battery can be carried out using the following formula:

Battery Capacity (Ah) = (Daily Energy Consumption x Days of Autonomy) / (DoD x Temp & Discharge Rate Derating Factor x Nominal Battery Voltage)

The Off Grid PV Power Systems Design Guidelines developed for PPA and SEIAPI recommends a minimum of 3 days of autonomy (with no generator as back-up) and 5 days of autonomy is preferred for remote sites because battery life may be significantly increased relative to a 3-day period of autonomy. Long battery life is important for remote sites because battery exchanges are easily the most expensive on-going cost in operating a remote off-grid electricity system. The guidelines also recommended 50% DoD for some residential sized lead acid batteries. As temperature in the Pacific is usually over 20°C, the guidelines recommend a conservative 5% reduction of the battery capacity (or 95% derating factor). As for the nominal battery voltage, the recommended battery voltage increases as the total daily energy usage increases. For small daily loads, a 12V system voltage can be used. For intermediate daily loads, 24V is used and for larger loads 48V is used.

FIGURE 87: Guideline for selecting battery voltage[84]



Since our daily energy consumption is less than 1kWh, we will be using 12V battery. Using the 312Wh of daily energy consumption from step 1, we size the battery as:

Battery Capacity (Ah) = (312 Wh x 3 Days of Autonomy) / (50% DoD x 95% Derating Factor x 12V Nominal Battery Voltage)

Battery Capacity = 164Ah

Step 3: Sizing PV Modules and Solar Charge Controller

The main functions of solar charge controllers are to: prevent battery over-charge; and prevent battery over-discharge. The two common types of solar charge controller available are: Pulse Width Modulated (PWM) controller and Maximum Power Point Tracking (MPPT) controller. For simplicity, we will be using the PWM controller in this example. In general, PWM solar controllers are always chosen for small solar PV systems due to their low costs. Sizing solar PV modules and PWM solar controller will be based on current rating of both PV modules and controllers.

Sizing PV modules will be based on the computed daily Ah and battery efficiency. Based on the already computed total daily energy consumption of 312 Wh, calculation of daily Ah is described below.

Daily Ah = 312 Wh/ 12 V = 26 Ah

Allowing for 80% battery efficiency, the solar array needs to produce the following daily Ah:

26 Ah / 0.8 = 32.5 Ah

We now need to assume the **Peak Sun Hours (PSH)**, which represents the amount of peak sunshine available at your particular location. Note that the PSH is dependent on the country and location of the solar system installation, which is usually derived from online databases. For this example, we will assume a PSH for your location as 4.7. Using this the required PV module derated output current is:

32.5 Ah / 4.7 = 6.9 A

84 Off-Grid PV Power System Design Guidelines, The Pacific Power Association (PPA) and the Sustainable Energy Industry Association of the Pacific Islands (SEIAPI), 2018

The PPA/SEIAPI guidelines recommend 20% oversize for the Pacific, so the PV module/array shall have the output current:

6.9 A x 1.2 = 8.3 A

When using a PWM solar charge controller, solar modules that have a nominal voltage rating that is appropriate for the battery voltage (in this case 12V), must be used. Assuming the solar PV modules with the maximum power voltage (Vmp) of around 18V as outlined in the table below will be chosen for this PV system.

FIGURE 88: Electrical characteristic of a 95W module[84]

Eletrical Characteristics	95W PV Module
Maximum Power Voltage (VMP)	17.6V
Maximum Power Current (Imp)	5.4A
Open Circuit Voltage (Voc)	22.2V
Short Circuit Current (Isc)	5.71A

The output current of each PV module is computed in two steps as follows: 1) Average output current based on Isc and Imp; and 2) Derate output current due to manufacturer tolerance (0.97) and dirt (0.95).

For this 95W PV module:

Average module current = (5.71 + 5.4)/2 = 5.56 A

Derated module current = 5.56 x 0.97 x 0.95 = 5.12 A

With the required module current of 8.3 A, the number of PV modules connected in parallel is computed by dividing 8.3 A with derated module current of 95W PV module.

Number of 95W PV modules in parallel =
8.3 A/ 5.12 A = 1.62 round up to 2

Once the PV modules are selected, the PWM solar charge controller will then be chosen based on the array short circuit current and the open circuit voltage of the array. Unless the controller is a model that is internally current limited, it should be sized so that they are capable of carrying at least 125% of the array short circuit current and withstanding the open circuit voltage of the array.

For an array of 2 x 95W PV module:

Isc = 5.71 x 2 = 11.42 A

Voc = 22.2 V

PWM Controller Current Rating = 1.25 x 11.42 A = 14.28 A (15A, 12V PWM solar charge controllers are available and would be ideal for this).

In summary, in order to run the specified loads, the resulting solar power system needs to have:

- 1 x 164Ah, 12V Deep Cycle Battery.
- 2 x 95W, 12V Solar Panels connected in Parallel.
- 1 x 15A, 12V PWM Solar Charge controller.
- Balance of System (BoS) components (cables, fittings, mountings, switches, circuit breakers, etc).

10.2 Annex B: How to do basic measurements using a clamp-meter

This section shows how to do basic measurements using a clamp meter. Note that some meter brands might not have all the features shown.

10.2.1 Measuring DC Voltage using probes

FIGURE 89: DC Voltage measurement schematic[85]

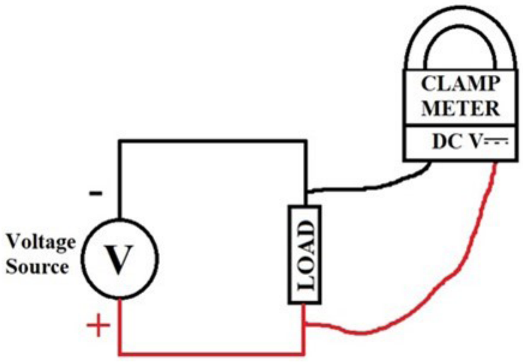


FIGURE 90: DC Voltage measurement on clamp-meter[86]

Steps:

1. Set Clamp-meter dial to DC Voltage mode (DCV or V=).
2. Ensure probes are connected to "V" and "Com" ports of the clamp meter.
3. Touch the end of probes across the load in the circuit to measure its voltage. Voltage measurements are done in parallel to the load. Clamp-meter screen with show measured voltage.

10.2.2 Measuring AC Voltage using probes

FIGURE 91: AC Voltage measurement schematic[87]

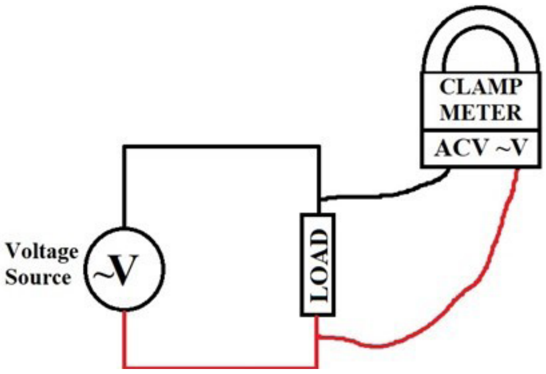


FIGURE 92: AC Voltage measurement on clamp-meter[88]

Steps:

1. Set Clamp-meter dial to AC Voltage mode (ACV or ~V).
2. Ensure probes are connected to "V" and "Com" ports of the clamp meter.
3. Touch the end of probes across the load in the circuit to measure its voltage. Voltage measurements are done in parallel to the load. Clamp-meter screen with show measured voltage.

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10.2.3 Measuring DC Voltage using probes

FIGURE 93: Continuity testing schematic[89]

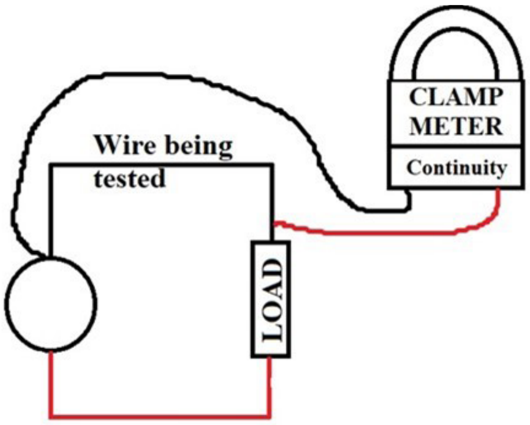

FIGURE 94: DC Voltage measurement on clamp-meter[90]

Steps:

1. Turn OFF power supply in the circuit when doing this test.
2. Set Clamp-meter dial to Continuity mode "). If this mode is not available, you can also use resistance (Ω) mode.
3. Ensure probes are connected to "V" and "Com" ports of the clamp-meter.
4. Touch the end of probes across the wire in the circuit to test its continuity. The clamp-meter will "beep" or show "0" if the wire is continuous. If the wire is not continuous or open, the clamp meter will "not beep" or show "1".

10.2.4 Measuring AC Voltage using probes

FIGURE 95: DC current measurement schematic[91]

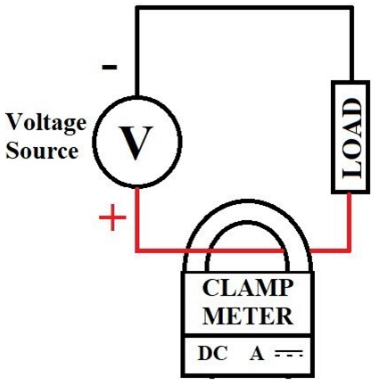

FIGURE 96: DC current measurement on clamp-meter[92]

Steps:

1. Set Clamp-meter dial to DC current mode (DCA or A=).
2. Open the clamp and put the wire inside the clamp.
3. The clamp-meter screen will show the measured current in the wire. The clamp-meter probes are not used in this test.

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10.2.5 Measuring AC current using clamp

FIGURE 97: AC current measurement schematic[93]

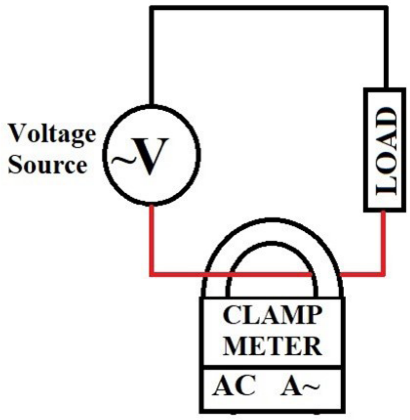

FIGURE 98: AC Current measurement on clamp meter[94]

Steps:

1. Set Clamp-meter dial to AC current mode (ACA or A~).
2. Open the clamp and put the wire inside the clamp.
3. The clamp-meter screen will show the measured current in the wire. The clamp-meter probes are not used in this test.

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10.3 Annex C: How to do basic measurements using a multi-meter

This section shows how to do basic measurements using a multi-meter. Note that some meter brands might not have all the features shown.

10.3.1 Measuring DC Voltage using probes

FIGURE 99: DC Voltage measurement schematic[95]

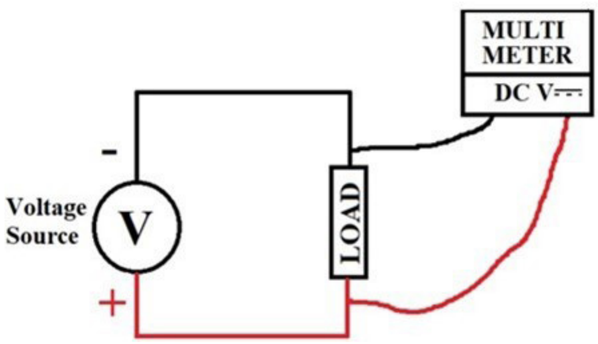

FIGURE 100: DC Voltage measurement on multi-meter[96]

Steps:

1. Set multi-meter dial to DC Voltage mode (DCV or V=).
2. Ensure probes are connected to “V” and “Com” ports of the clamp meter.
3. Touch the end of probes across the load in the circuit to measure its voltage. Voltage measurements are done in parallel to the load. Multi-meter screen with show measured voltage.

10.3.2 Measuring AC Voltage using probes

FIGURE 101: AC Voltage measurement schematic[97]

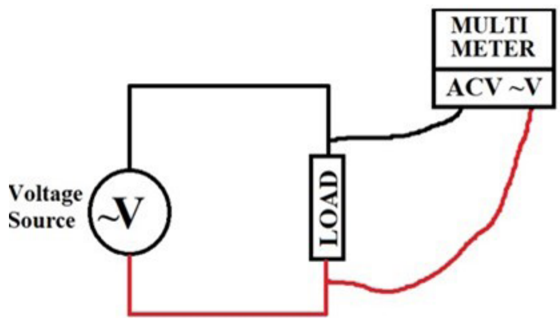

FIGURE 102: AC Voltage measurement on multi-meter[98]

Steps:

1. Set multi-meter dial to AC Voltage mode (ACV or ~V).
2. Ensure probes are connected to “V” and “Com” ports of the multi-meter.
3. Touch the end of probes across the load in the circuit to measure its voltage. Voltage measurements are done in parallel to the load. Multi-meter screen with show measured voltage.

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10.3.3 Continuity testing using probes

FIGURE 103: **Continuity testing schematic**[99]

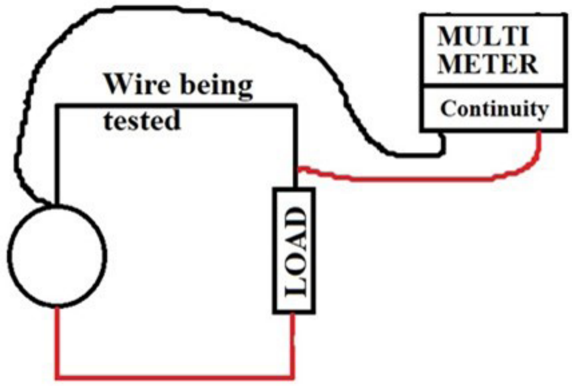

FIGURE 104: **Continuity testing on multi-meter**[100]

Steps:

1. Turn OFF power supply in the circuit when doing this test.
2. Set multi-meter dial to Continuity mode ")))". If this mode is not available, you can also use resistance (Ω) mode.
3. Ensure probes are connected to "V" and "Com" ports of the multi-meter.
4. Touch the end of probes across the wire in the circuit to test its continuity. The multi-meter will "beep" or show "0" if the wire is continuous. If the wire is not continuous or open, the multi-meter will "not beep" or show "1".

10.3.4 Measuring DC current using probes

FIGURE 105: **DC current measurement schematic**[101]

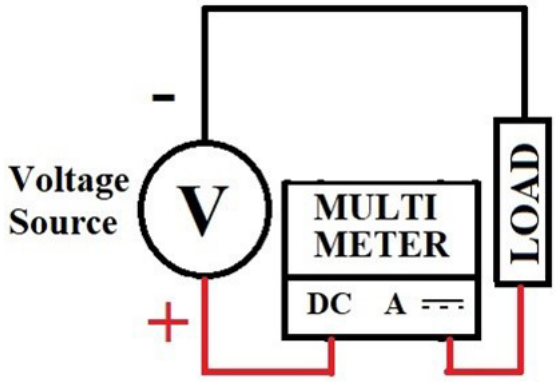

FIGURE 106: **DC current measurement on multi-meter**[102]

Steps:

1. Turn OFF the circuit.
2. Set multi-meter dial to DC current mode (DCA or A= or mA=).
3. Connect the red probe to the "A=" or "mA=" port of the multi-meter and black probe to "Com" port of the multi-meter. Ensure that the measured current does not exceed the maximum rated current of the meter. If the current is very small, then you can use the "mA=" port and "mA=" meter mode to measure smaller currents more accurately.
4. Connect the multi-meter in series to the circuit. This means that the circuit must be broken to connect the meter in series.
5. Turn ON the circuit.
6. The multi-meter screen will show the measured current in the wire.

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10.3.5 Measuring AC current using probes

FIGURE 107: AC current measurement schematic[103]

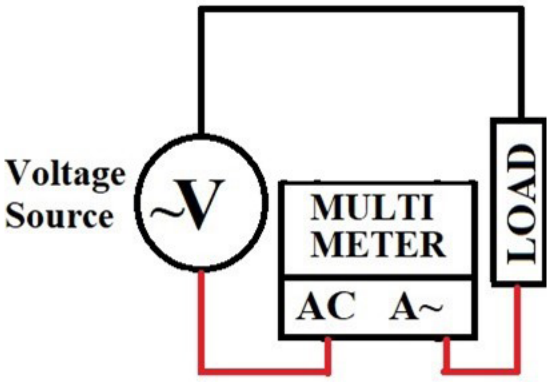

FIGURE 108: AC current measurement on multi-meter[104]

Steps:

1. Turn OFF the circuit.
2. Set multi-meter dial to AC current mode (ACA or A~ or mA~).
3. Connect the red probe to the "A~" or "mA~" port of the multi-meter and black probe to "Com" port of the multi-meter. Ensure that the measured current does not exceed the maximum rated current of the meter. If the current is very small, then you can use the "mA~" port and "mA~" meter mode to measure smaller currents more accurately.
4. Connect the multi-meter in series to the circuit. This means that the circuit must be broken to connect the meter in series.
5. Turn ON the circuit
6. The multi-meter screen will show the measured current in the wire.

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