Short-Course

Solar PV System Installation and Maintenance

NTQF Level II

Learning Guide -03

Unit of Competence	Apply Principles of Photovoltaic system Operation
Module Title	Apply Principles of Photovoltaic system Operation
LG Code	EIS PIM2 M04 0120 L03-LG03
TTLM Code	EIS PIM2 TTLM 0120v1

LO 3: Describe PV components

Instruction Sheet	Learning Guide 12

This learning guide is developed to provide you the necessary information regarding the following **content coverage** and topics

- PV components
- Explaining PV components
- Characteristics of PV components
- Limitations of the various PV components
- Strengths and weaknesses of different PV system components

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, **you will be able to:-**

- List PV components
- List and explain uses of PV components
- Explain characteristics of PV components
- Explain limitations of the various PV components
- Explain strengths and weaknesses of the different PV system components

1. Read the specific objectives of this Learning Guide.
2. Follow the instructions described below 3 to 6.
3. Read the information written in the information Sheet 1, Sheet 2, Sheet 3,Sheet 4& Sheet 5 in page 80, 82, 90, 96 & 98 respectively.
4. Accomplish the Self-check 1, Self-check t 2, Self-check 3, Self-check 4 & Self-check 5 in page 81, 89, 95, 97 & 99 respectively
5. If you earned a satisfactory evaluation from the Self-check proceed to Operation Sheet 1, in page 100
6. Do the LAP test in page 101

LO3: Describe PV components

Information Sheet-1	PV components

1 PV components

Photovoltaic systems consist of some or all of the following components:

- PV modules (groups of PV cells), which are commonly called PV panels;
- One or more batteries;
- A charge regulator or controller for a stand-alone system;
- An inverter when alternating current (ac) rather than direct current (dc) is required and inverter-charger for a utility-grid-connected system;
- Wiring; and
- Mounting hardware or a framework.

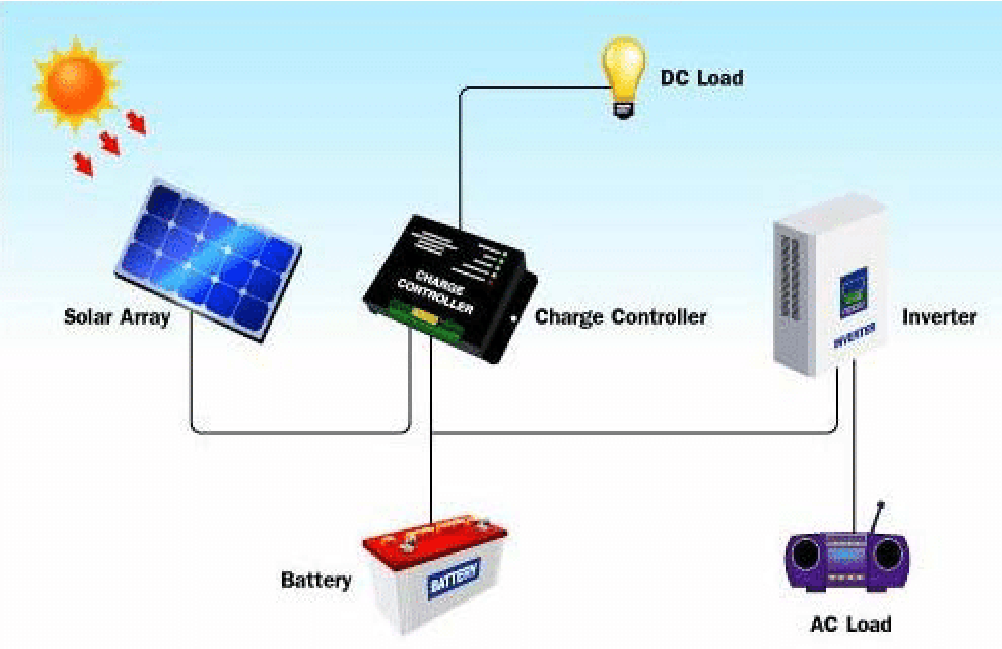


Figure 58:-Components

Self-Check -1	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next
page:

Choose the best answer from the following question below

1. All are PV components except
   - A. PV modules
   - B. Solar batteries;
   - C. A charge controller
   - D. An inverter
   - E. Wind energy

***Note:* Satisfactory rating - 1 points** **Unsatisfactory - below 1 points**

You can ask you teacher for the copy of the correct answers.

Answer Sheet

Score = ____________

Rating: _____________

Name: ___________________________ Date: ________________

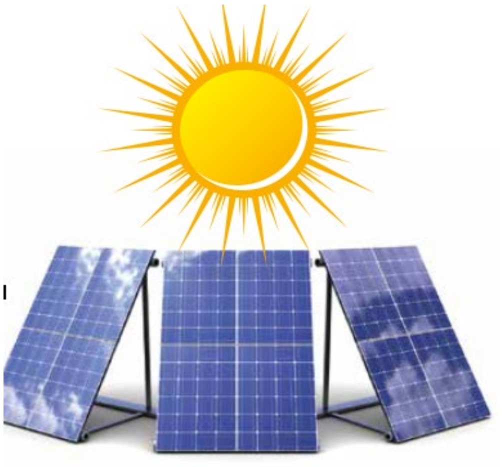
Short answer questions

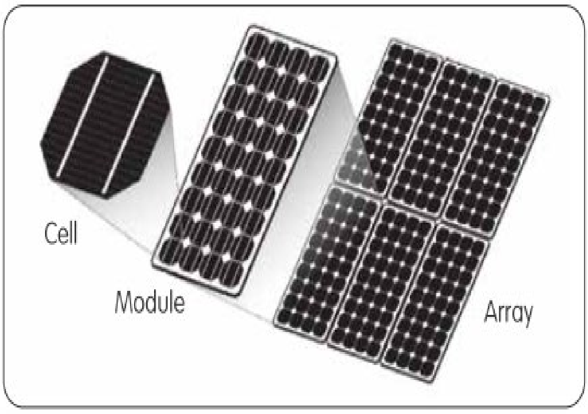
Information Sheet-2	Explaining PV components

2 Explaining PV components

2.1 Solar Modules

Solar Panel (Solar Module) The solar panel produces electricity when there is sunlight by converting it into DC (direct current) electricity.. Photovoltaic (PV) or solar cells are the building blocks of solar panels. Solar panels come in different sizes and power ratings. For off-grid applications often modules with 60 solar cells are used, in grid-connected PV systems 72 cells modules are more common. There is also a variety of smaller modules available that are made especially for solar home systems and pico solar systems. Those modules have between 5 and 150 W.





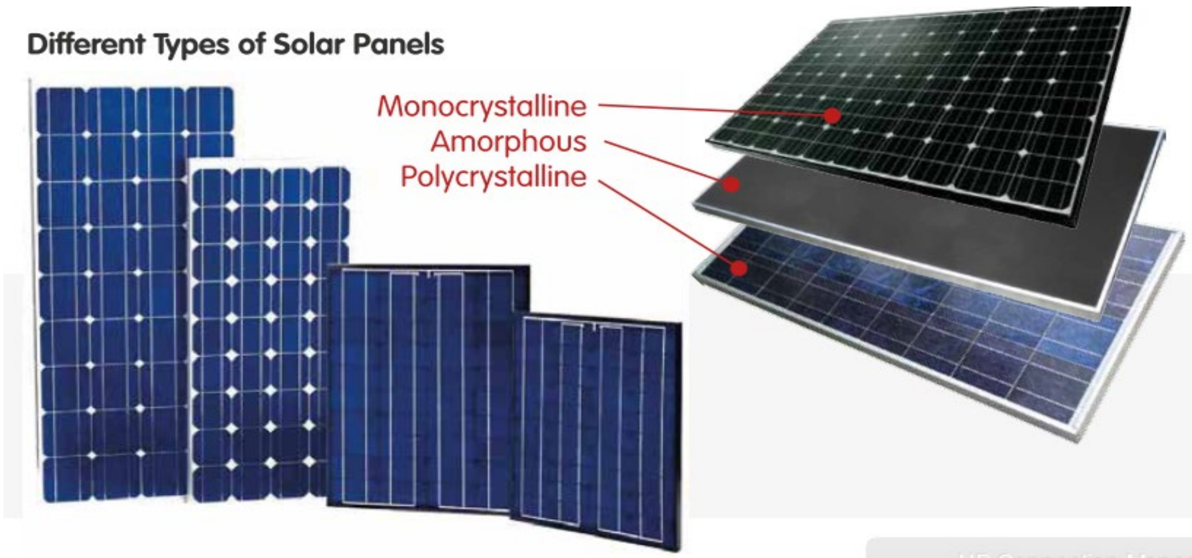


Figure 59:-Different solar panel

Every solar panel has a rated power output. The rated output of the panel is determined by the voltage and current that the solar panel can produce. The amount of current and voltage the solar panel produces determines the amount of power the solar panel produces.

The power output of solar panels is rated at "Standard test conditions", short STC. Because the power production of solar panels depends among others on temperature and irradiation, the rating of solar panels is tested under STCs to be able to compare power ratings of different modules. STC are 25°C module temperature, 1000 W/m² solar irradiation and 1 m/s wind speed. So in reality, a module rated 120W at STC can produce more electricity when e.g. the irradiation is higher than 1000W/m² or less electricity when there is less light or when it is hotter than 25°C.

2.2 Charge Controller

Manages the flow of electricity between the solar panel and the batteries. It converts the solar electricity to the right voltage level so that the battery can be charged. Its main job is to keep the batteries from overcharging and deep discharging.

When DC loads are used, they are connected to the DC output of the charge controller. The charge controller then provides the appliances with power and shuts down when the battery is almost empty.

Sometimes also inverters are connected to charge controllers but this configuration is only recommended when the charge controller has a much higher amperage than the inverter, otherwise it will damage the charge controller.

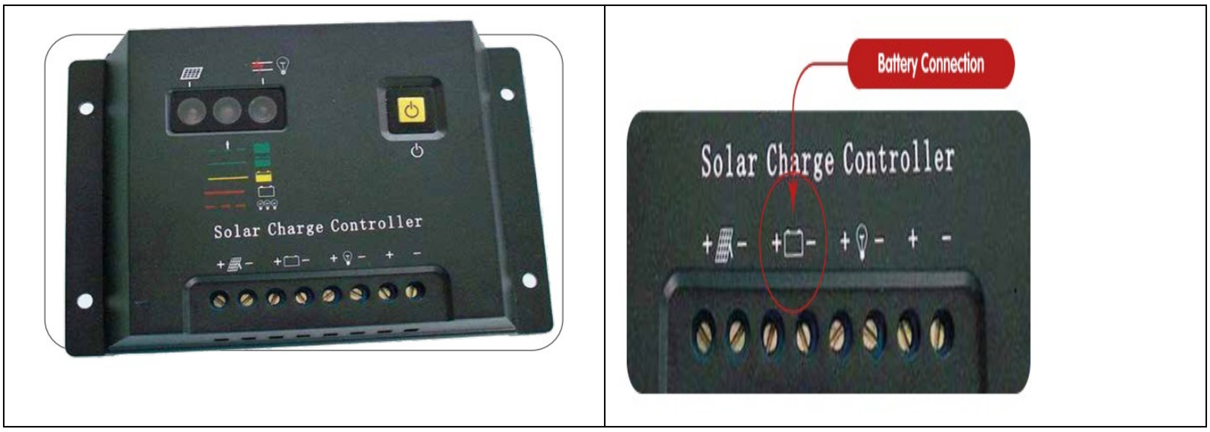


Figure 60:- Charge Controller

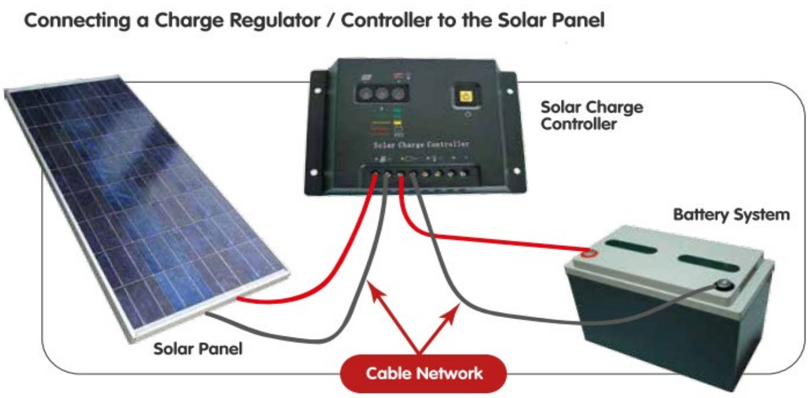


Figure 61: Charge Controller Connection

The following videos show charge controller operation

- https://www.youtube.com/watch?v=3LsLGr2qjOY

Purposes of a Charge Controller

- Protection of the battery from:
    - Overvoltage
    - deep discharge
    - Overcharging
- Increase the battery's lifetime by optimal treatment
- Increase the system efficiency by intelligent management
- Increase usability of the produced energy
- Reduce system costs by intelligent management
- Give system information
- Facilitate maintenance

2.3 Solar Batteries

The battery stores electricity produced by the solar panel for later use. It is an important part of solar systems that need to have electricity at night when the solar panel is not producing power.

The battery is one of the most expensive parts of the solar system. It also has the shortest life and is the part most easily damaged by poor maintenance or improper use. The most important thing a PV technician can learn is how to take care of batteries and how to tell if the people using a PV system are causing battery damage through improper use.

Figure 62:- Solar Battery

Connecting a Battery to a Solar System

- Before you begin the process of connecting, please ensure that the panel is shaded/covered (no sunshine reaching the collector) to avoid a sudden raise of voltage that damages the inverter.
- Always connect the battery bank first. Most charge controller automatically detect the voltage level of the system.
- To protect the battery a fuse should be put between the charge controller and battery. The fuse is mounted as close as possible to the positive battery terminal
- Fit the cable to the positive terminal of the charge controller and to the positive terminal of the battery.
- Fit the cable to the negative terminal of the charge controller and to the negative terminal of the battery characteristics.
- Insert the fuse

2.4 Inverter

Used when there are AC loads to be used in the solar system it converts DC from the batteries to AC.

Figure 63:-Inverter

Connecting the Inverter

- The inverter is connected directly to the solar battery. One should make sure that the inverter has a deep discharge protection function to avoid damaging the battery.

- Sometimes, in small applications the inverter is connected to the charge controller at the terminals indicated in the image below (+) and (-). In this case the charge controller must provide a significantly higher amperage than the inverter consumes.
- The terminals are loosened and the cable from the inverteris fitted with the same polarity:

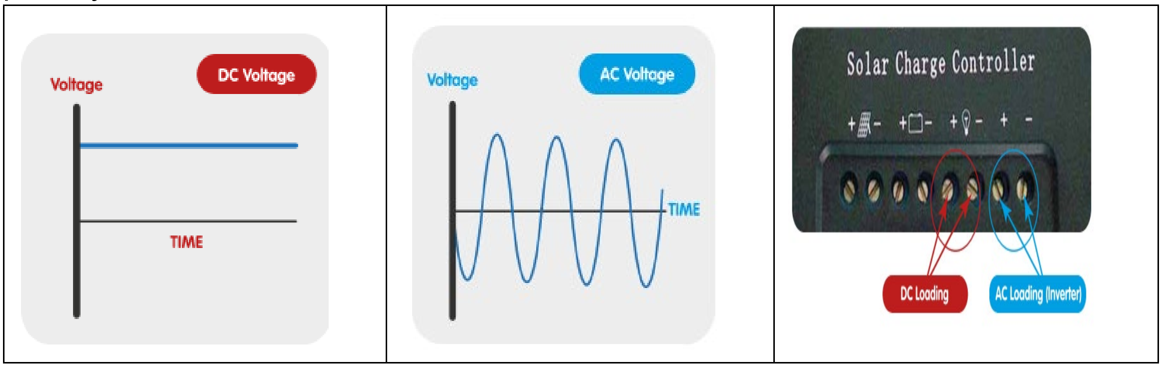


Figure 64:- Wave Form

The following videos show about the wave forms of inverter

- https://www.youtube.com/watch?v=In9VZIL8rVs

2.5 Loads

An electrical load is an electrical component or portion of a circuit that consumes (active) electric power. This is opposed to a power source, such as a battery or generator, which produces power. Typical loads are in off-grid systems are lights, computer, radio, TV

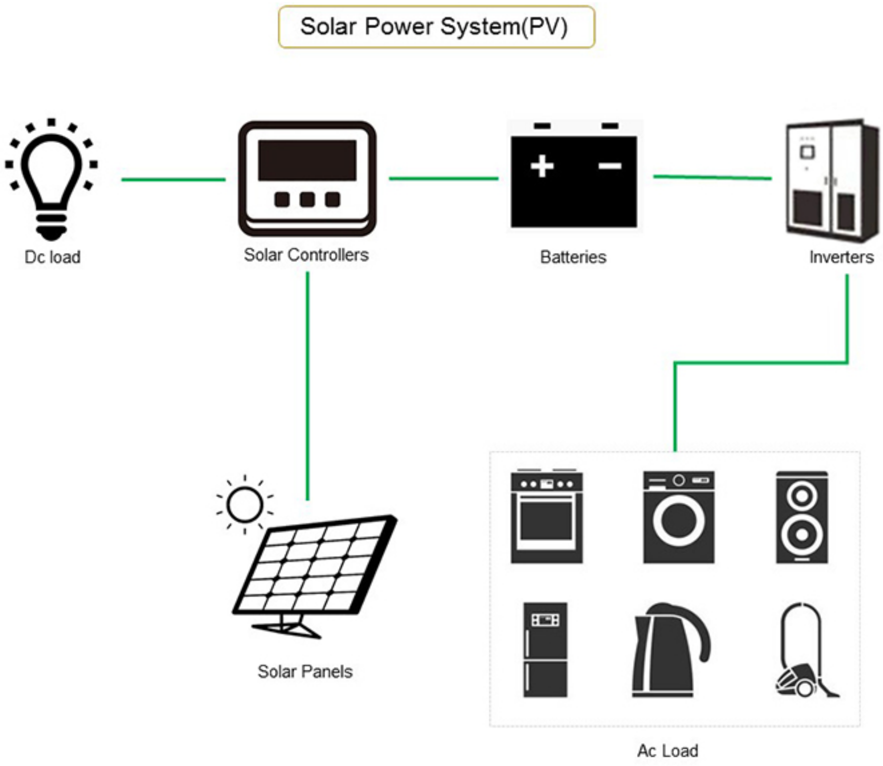


Figure 65: Output Load (source: www.1stsunflower.com/)

2.6 Wires

Connect the other various components together. Solar cables have a double insulation and better UV protection because they must resist the sunlight on the roof.

Figure 66:-Wire

2.7 General Description of PV Solar Configuration

The solar panel are connected to the Charge controller and the Controller control the power that receives from the solar panel and battery and that distributes to solar load.

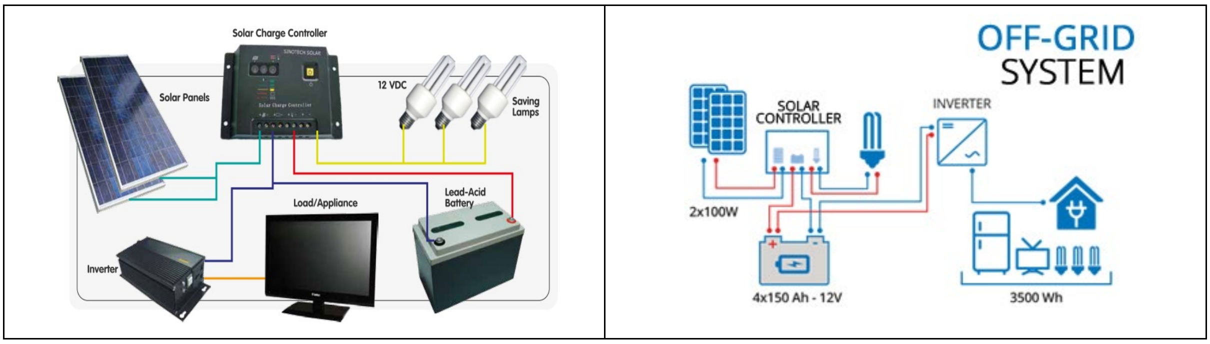


Figure 67:-General Installation

The following videos show general installations of PV solar components

https://www.youtube.com/watch?v=2I29gKFkr-M

Self-Check -2	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

I. MATCH COLUMN B TO COLUMN A

A	**B**
1. Converts sun light to electricity	A. inverter
2. Converts DC power to AC	B. battery
3. Stores electricity	C. solar panel
4. Manages the flow of electricity B/n the solar panel & load	D. charge controller
5. Produced by PV modules & Stored in batteries	E. AC
	F. DC

***Note:* Satisfactory rating - 5 points** **Unsatisfactory - below 5 points**

You can ask you teacher for the copy of the correct answers.

Answer Sheet

Score = ___________
Rating: ____________

Name: _________________________ Date: ______________

Short answer question

Information sheet -3	Characteristics of PV components

3 Characteristic PV Components

3.1 Charge Controller

There exist different types of charge controllers, the four main types are series, shunt, PWM and MPPT charge controllers. Shunt and series controllers use very simple technology which limits the functions but reduces the price. PWM charge controllers and MPPT charge controllers are electronically more sophisticated and are therefore more precise when charging and discharging the battery. For all types of charge controllers, except MPPT controllers, the voltage of the PV array must be matched to the battery voltage. MPPT controllers allow to also connect bigger modules with a higher voltage therefore MPPT charge controllers are often the preferred technology.

3.2 Solar batteries

The most common battery type is the lead-acid battery. For solar applications, special solar batteries are used which have thicker lead plates than conventional car batteries.

Of all the parts of a solar system, the battery requires the most care.

Lead acid battery

The type of battery usually used in a solar system is a Lead- Acid battery. That is its name because the main material it is made of is lead and the battery contains Sulphuric Acid.

Lead-Acid batteries are made up of cells. Each cell produces about 2 Volts. A 12 Volt battery has six 2 Volt cells connected in series (figure 68).

Figure 68: Wet Lead Acid battery

3.2.1 Wet batteries

This battery type has removable caps on top so you can test the cells and add water when it is needed. They are called ***open cell*** or***flooded cell*** or***wet batteries*** (68, a). It must be checked regularly to be sure the liquid level is correct and purified water added if the cells are low.

3.2.2 Gel battery

A more advanced version of the ordinary wet lead-acid battery with grid plates is the lead-gel battery. In these, the sulphuric acid is immobilized-that is, thickened into a gel by mean of additives.

These batteries are sealed and cannot be maintained except at the factory. They are called maintenance freeor sealed or gel batteries (figure 68, b). That type of battery has a smooth top and no filler caps.

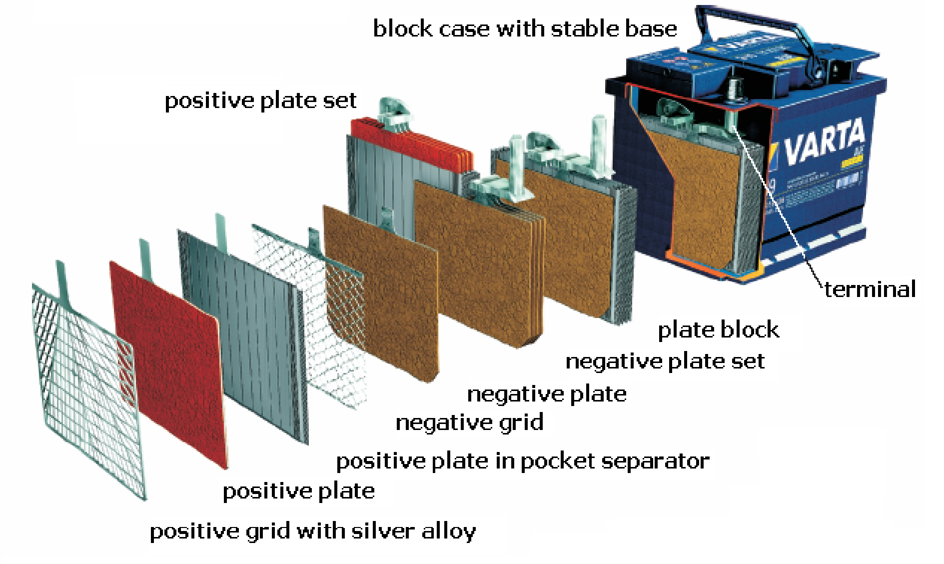


Figure 69:- Solar Battery

Although the solar battery may look like the battery used in automobiles, inside it is very different. Batteries used for vehicles are designed to provide large amounts of power for a short time while solar batteries are designed to provide a small amount of power continuously for many hours.

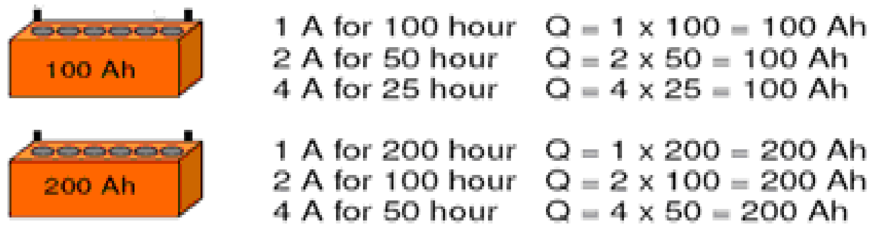
Note. If an automobile battery is used in a solar system it will not last nearly as long as the battery made especially for solar systems. You should ***never*** allow a solar system battery to be used for any other purpose.

The type battery best suited for most solar systems is called a **deep discharge battery**. It is called that because it is especially designed to deliver a high percentage of its power without any damage. You can regularly use 80% of the power stored in a deep discharge battery without damage (comparing to allowable rate 10% for a car battery). Therefore use of deep cycle battery would necessitate a correspondingly much smaller battery capacity. In order to have an optimal lifetime it is recommended to only discharge a solar battery up to 50%. So the battery should always have double the capacity you need.

If you regularly use more than 20% to 30% of the power stored in a starting battery, it will not last long. Though a starting type battery is cheaper than the same size of deep discharge battery, it will not last as long when used in a PV system and with its more frequent replacement, and therefore maybe more expensive in the long run.

Batteries are rated according to how much electricity they can store. The measure used is the Ampere-Hour (Ah). If a battery delivers one Ampere of current continuously for 100 hours it has provided 100 Ampere-hours. If a battery delivers 10 Amperes continuously for 10 hours, it is also delivering 100 Ampere hours.

Q (Battery Capacity, in Ah) = Charging/Discharging current (A) x time (h)
Example



3.3 Solar inverters

Stand-alone inverters typically operate at 12, 24, 48 volts DC input and creates 110 or 220 volts AC at 50/60 Hertz. The selection of the inverter input voltage is an important decision because it often dictates the system dc voltage; the shape of the output waveform is an important parameter. Inverters are often categorized according to the type of waveform produced;

- Square wave
- Modified sine wave
- Sine wave

The output waveform depends on the conversion method and the filtering used on the output waveform to eliminate spikes and unwanted frequencies that result when the switching occurs. Square wave inverters are relatively inexpensive, have efficiencies above 90%, high harmonic frequency content, and little output voltage regulation. They are suitable for resistive loads and incandescent lamps. Some sensitive electric devices can be damaged by square waves. Modified sine wave inverters offer improved voltage regulation by varying the duration of the pulse width in their output. Efficiencies can reach 90 %. This type of inverter can be used to operate a wider variety of loads including lights, electronic equipment, and most motors. However, these inverters will not operate a motor as efficiently as a sine wave inverter because the energy in the additional harmonics is dissipated in the motor windings. Sine wave inverters produce an ac waveform as good as that from most electric utilities.

- Power Conversion Efficiency
- Rated Power
- Duty Rating
- Input Voltage

Surge Capacity - Most inverters can exceed their rated power for limited periods of time (seconds). Surge requirements of specific loads should be determined or measured. Some transformers and ac motors require starting currents several times their operating level for several seconds.

- Standby Current
- Voltage Regulation

- Voltage Protection
- Frequency
- Modularity
- Power Factor

Electrical Characteristics	
Maximum power (Pmax)	50W
Voltage at Pmax (Vmp)	17.5V
Current at Pmax (Imp)	2.9A
Warranted minimum Pmax	45W
Short-circuit current (Isc)	3.2A
Open-circuit voltage (Voc)	21.8V

50W Module Specification

Figure 70:-Sample Electrical Characteristics of a module

Solar inverters are available in varous sizes and categories. The smallest are between 200W and 1000W. They are for simple solar home systems and often have a power outlet right at the device. They are easy to set up and have basic funtions. More complex inverters for Solar Home Systems are in the range of 1- 5 kW. These inverters can be programmed according the used battery type and enable system monitoring.

Nowadays also hybrid inverter and charge controllers are available where the inverter and charge controller is combined in one device

.ypical applications of PV

- Stand-alone power systems for cottages and remote residences,
- Remote telecommunication sites for utilities and the military,
- Water pumping for farmers,
- Emergency call boxes for highways and college campuses,
- Street Lighting
- Grid Connected supply of Electricity
- Navigational aids for the Coast Guard

3.4 Advantages and disadvantages of using photovoltaic systems

Advantages

- **Reliability-**Even in harsh climates, photovoltaic systems have proven their reliability. Often, photovoltaic systems are chosen for systems that must remain operational at all times. Photovoltaic systems may prevent costly or dangerous power failures in situation where continuous operation is critical
- **Low Maintenance Cost** on a commercial building roof or field, solar power products can be deployed in many sizes and configurations and can be installed quickly and almost anywhere in the world.
- **Universal Applications-** Solar PV is the only renewable energy technology that can be installed on a truly global scale because of its versatility and

because it generates power under virtually all conditions, i.e. even in overcast light condition

- **Peak Shaving-** The output of solar systems typically correlates with periods of high electricity demand where air conditioning systems create peak demands during hot sunny days.
- **Dual use-** Solar panels are expected to increasingly serve as both a power generator and the skin of the building.
- **Flexibility** Solar systems can be adjusted to various applications, size, costs, power complexity and yield of a system can be adjusted to the particular use (pico soalr up to utility scale)
- **Environmentally safe-** Solar power systems produce no air or water emissions or greenhouse gases and produce no noise.

Disadvantages

- **Cost-** Photovoltaic systems have a high initial cost. Each installation must be evaluated from an economic perspective and compared to existing alternatives.
- **Variability of Available Solar Radiation**- Weather can adversely affect the power output of any PV system. If there is no sunshine there is no power.
- **Energy Storage-** Some photovoltaic systems use batteries for storing energy which will be used at a later time. The battery increases the system's size and cost can make the system more complex.
- **Lack of awareness-** Photovoltaic systems use a new technology with which many people are unfamiliar. Few people understand its applicability. This lack of information slows market and technological growth.

Self-Check -3	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

I. Choose the best answer for the following questions below

1. which one of the following is a wave types of inverter
   A. Square wave
   B. Modified sine wave
   C. triangular wave
   D. A& B
   E. B& C
   F. None

2. Typical applications of PV
   A. Stand-alone power systems for cottages and remote residences,
   B. Remote telecommunication sites for utilities and the military,
   C. Water pumping for farmers,
   D. Emergency call boxes for highways and college campuses,
   E. Street Lighting
   F. all

Note:

Satisfactory rating – 1 and above points

Unsatisfactory - below 1 points

Answer Sheet

Score = ____________

Rating: _____________

Name: ____________________________ Date: _______________

Short answer question

Information Sheet-4	Limitations of the various PV components

4 Limitations of the various PV components

4.1 Limitations of PV modules

- Hot spots are places on the panels which are overloaded and therefore become warm. Hotspots on panels are mainly caused by badly-soldered connections, or are a result of a structural defect in the solar cells. Planning and construction errors can also lead to hotspot development when a cell is constantly shaded
- Delamination is the detachment of the laminated components. Delamination – but also incorrectly fitted module trim, for example – can cause moisture to penetrate or bubbles to occur. Moisture leads to corrosion
- PID stands for 'Potential Induced Degradation'. This problem can arise when a voltage difference occurs between the panel and the earthling. For safety reasons, the solar panel is earthed, which can cause a harmful potential difference between the earthing and the voltage generated by the panel.
- One phenomenon regularly encountered are 'micro-cracks' in crystalline PV panels. These are virtually imperceptible microscopic tears in the solar cells. Micro-cracks can occur during PV modules production, but also during shipping or due to careless handling practice during installation.

4.2 Limitations of Batteries

- Batteries make up the largest component cost over the lifetime of a solar system. Good batteries are expensive, but worth the investment. The right type of battery for should be chosen for the PV system.
- Batteries wear out. No matter the type, batteries eventually wear out and need to be replaced. Planning for the replacement of batteries is necessary.
- Some batteries need to be maintained. The acid/electrolyte levels have to be topped up regularly.
- Lead-acid batteries contain corrosive sulphuric acid. If spilled, sulphuric acid will burn the skin or eyes (and potentially cause blindness). It will burn holes through clothes and furniture and it will damage cement floors. Gloves an goggles needed when handling batteries!
- Batteries give off explosive hydrogen gas when they are being charged. This gas must be vented away from the battery to prevent explosions.
- Working on large battery banks and in battery rooms is extremely hazardous and should only be carried out by appropriately trained persons.

Self-Check -4	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

I. Choose the best answer for the following questions below

1. Which one of the following is not limitation of PV modules
   a. Micro cracks b. Delamination c. corrosive sulphuric acid d. Hot spots
2. Which one of the following is not limitation of batteries in solar application
   a. High cost b. Energy storage c. Potential for explosion
   d. Need for maintenance

Note:

Satisfactory rating – 1 and above points

Unsatisfactory - below 1 points

Answer Sheet

Score = ____________

Rating: _____________

Name: ____________________________ Date: _______________

Short answer Question

Information Sheet-5	Strengths and weaknesses of different PV system components

5 Strengths and weaknesses of different PV system components

5.1 Introduction

There are many different types of PV equipment available on the market. It is important to understand the various components and technology's strengths and weaknesses to make informed decisions on which equipment to procure.

In this section, we will look at the following components:

- PV Modules
- Batteries
- Charge Controllers
- Inverters

5.2 PV Modules

The following was adapted from (Mayfield, 2010)

The PV market is expanding rapidly, and manufacturers are constantly introducing new and emerging technologies. The end result of all these technologies is the same: You place the module in the sun, and it produces power. But each of the commercially available products has its own pros and cons to consider when selecting a product for a particular job.

The ones you're most likely to run into are crystalline modules and thin film modules.

Crystalline PV modules, which are made by grouping a number of individual solar cells together, are currently the most common module type for residential and commercial applications. One of the main reasons why crystalline modules are used so frequently is that they're more efficient than other PV technologies.

5.2.1 The mono-crystalline kind

Mono-crystalline modules begin as a molten vat of purified silicon that has been doped with boron to create electron holes. A starter seed, a crystal about 4 inches long and 2 inches in diameter, is introduced to the silicon-boron mixture that becomes the structure for the solar cells. During the manufacturing process, the silicon aligns itself with the starter seed and takes the exact same crystal structure of the seed.

The starter seed is then drawn out of the mixture, and a crystal grows around it, forming the beginning of the ingot, a 6- to 8-inch-diameter crystal. The ingot continues to be pulled from the molten vat until it reaches the desired length — about 6 feet. This ingot comes out as a cylinder, thereby giving mono-crystalline cells a circular shape (at least initially).

The ingot is then sliced into very thin wafers that are exposed to the diffusion process to introduce the other dopant (phosphorous). At this point, the solar cells are complete, and an electrical grid can be placed atop them (in a process that best resembles silk-screening onto a T-shirt) to effectively allow the electrons to flow.

Mono-crystalline modules are typically more efficient than their **multic-rystalline (also called poly-crystalline)** counterparts on the cell level because the molecular structure of the ingot is uniform from top to bottom. This characteristic allows the photons to move the greatest number of electrons when in sunlight because the cells are all lined up and facing the exact same direction. In a multi-crystalline cell, the crystals have various shapes and point in different directions, slightly reducing the efficiency. Mono-crystalline cells are circular when they start out their lives, but because PV modules are rectangular in shape, the cells need to be squared off in order to fit into the module.

5.2.2 The multic-rystalline kind

Multi-crystalline cells are manufactured differently than mono-crystalline ones — the ingots are essentially brick shaped or cubes rather than cylinders. The manufacturing process begins with a vat of molten silicon-boron mixture, but instead of pulling a crystal out of this mixture, the mixture is formed in a cubic crucible, which results in the silicon cooling and forming multiple crystals. After the silicon has cooled and the ingot is sliced into thin wafers, the dopant (phosphorous) and electrical grid are added to the modules.

The efficiency of multi-crystalline modules is reduced due to the many crystal structures in the cubes. When the photons strike the cells, they have a more difficult time knocking the electrons free thanks to the many different surfaces present. On the plus side, the cells can be made into squares or rectangles very easily, a fact that allows the multi-crystalline modules to have their cells packed one next to the other with very little space between them. The end result is that multi-crystalline modules have power ratings per unit area that are similar to that of their mono-crystalline counterparts even though they're less efficient on the cell level.

5.2.3 Thin film modules

The phrase thin film module is a catchall for a number of different PV technologies.

Thin film technologies vary in their raw materials and exact manufacturing processes, and I show you some of the technologies in this section. However, at the most basic level, all thin film technologies deposit a material that can produce the photovoltaic effect onto a backing material (called a substrate).

This substrate can be a sheet of glass, PVC roofing material, or even a foil sheet. The name thin film implies only that the material on the substrate is extremely thin, ranging from just nano-meters to a few micro-meters thick. As a point of reference, a human hair is approximately 100 micro-meters thick, and crystalline solar cells are approximately 250 micro-meters thick — the equivalent of two and a half human hairs.

Table 8: Comparison between Crystalline and Thin-film

Cell Technology	Crystalline Silicon	Thin Film
Types of Technology	Mono-crystalline silicon (c-Si)	Amorphous silicon (a-Si)

	Poly-crystalline silicon (pc-Si/ mc-Si)	Cadmium Telluride (CdTe) Copper Indium Gallium Selenide (CIG/ CIGS) Organic photovoltaic (OPV/ DSC/ DYSC)
Environment	Recyclable	Some Thin-film technologies very toxic to environment
Temperature Coefficients	Higher	Lower (Lower is beneficial at high ambient temperatures)
Module construction	With Anodized Aluminum	Frameless, sandwiched between glass; lower cost, lower weight
Module efficiency	13%-19% plus	4%- 12% plus
Mounting systems	Industry standard	Special clips and structures may be needed.
DC wiring	Industry standard	May require more circuit combiners and fuses
Application Type	Residential/ Commercial/ Utility	Commercial/ Utility
Required Area	Industry standard	May require up to 50% more space for a given project size
Example Brands	Canadian Solar, IBC, REC, Yingli, Trina, JA Solar, Jinko, Hanwha Q Cells, LG, Risen	First Solar, Solyndra, UniSolar, Konarka, Dye Solar, Bosch Solar, Sharp, Abound Solar, Etterbright

5.3 Batteries

The following was adapted from (wholesalesolar, 2018)

Batteries are a convenient way to store electrical energy for people to use at will. More accurately, batteries are a group of cells that store electrical energy and, through a chemical reaction, can deliver power to loads.

There are many different battery technologies available. The main groups of batteries used in solar are Lead-acid and Lithium batteries. There are many variants of both technologies.

Lead acid batteries come in two types e.g. Flooded lead-acid (FLA) and Sealed lead-acid (SLA)

The distinguishing feature of **FLA** batteries is that the plates are submerged in water. These must be checked regularly and refilled every 1-3 months to keep them working properly.

Falling behind on upkeep can shorten the life of the batteries and void the warranty. FLA batteries also need to be installed in a ventilated enclosure to allow battery gases to escape.

SLA batteries come in two types, AGM (Absorbent Glass Mat) and Gel, which have many similar properties. They require little to no maintenance and are spill-proof.

The key difference in AGM vs. gel batteries is that gel batteries tend to have lower charge rates and output. Gel batteries generally can’t handle as much charge current, which means they take longer to recharge and output less power.

There are also many variants of lithium batteries. The best lithium battery chemistry for solar applications is Lithium Iron Phosphate, shorted to LiFePO4 or LFP batteries. This new technology lasts longer and can be put through deeper cycles. They also require no maintenance or venting, unlike lead-acid batteries.

5.3.1 5 Key Differences between Lead-acid and Lithium Batteries

Cycle life

When you discharge a battery (use it to power your appliances), then charge it back up with your panels, that is referred to as one charge cycle. We measure the lifespan of batteries not in terms of years, but rather how many cycles they can handle before they expire. Think of it like putting mileage on a car. When you evaluate the condition of a used car, mileage matters a lot more than the year it was produced.

Same goes for batteries and the number of times they've been cycled. A sealed lead-acid battery at a vacation home may go through 100 cycles in 4 years, whereas the same battery might go through 300+ cycles in one year at a full-time residence. The one that has gone through 100 cycles is in much better shape.

Cycle life is also a function of depth of discharge (how much capacity you use before recharging a battery). Deeper discharges put more stress on the battery, which shortens its cycle life.

Depth of Discharge

Discharge depth refers to how much overall capacity is used before recharging the battery. For example, if you use a quarter of your battery's capacity, the depth of discharge would be 25%.

Batteries don't discharge fully when you use them. Instead, they have a recommended depth of discharge: how much can be used before they should be refilled. Lead-acid batteries should only be run to 50% depth of discharge. Beyond that point, you risk negatively affecting their lifespan.

In contrast, lithium batteries can handle deep discharges of 80% or more. This essentially means they feature a higher usable capacity.

Efficiency

Lithium batteries are more efficient. This means that more of your solar power is stored and used.

As an example, lead acid batteries are only 80-85% efficient depending on the model and condition. That means if you have 1,000 watts of solar coming into the batteries, there are only 800-850 watts available after the charging and discharging process.

Lithium batteries are more than 95% efficient. In the same example, you'd have over 950 watts of power available.

Higher efficiency means your batteries charge faster. Depending on the configuration of your system, it could also mean you buying fewer solar panels, less battery capacity and a smaller backup generator.

Charge Rate

With higher efficiency also comes a faster rate of charge for lithium batteries. They can handle higher amperage from the charger, which means they can be refilled much faster than lead-acid.

We express charge rate as a fraction, such as C/5, where C = the capacity of the battery in amp hours (Ah). So a 430 Ah battery charging at a rate of C/5 would receive 86 charging amps (430/5).

Lead-acid batteries are limited in how much charge current they can handle, mainly because they will overheat if you charge them too quickly. In addition, the charge rate gets significantly slower as you approach full capacity.

Lead acid batteries can charge around C/5 during the bulk phase (up to 85% capacity). After that, the battery charger automatically slows down to top off the batteries. This means lead acid batteries take longer to charge, in some cases more than 2x as long as a Lithium alternative.

Energy Density

The lead-acid batteries featured in the comparison above both weigh around 125 pounds. The lithium battery checks in at 192 pounds.

Most installers can handle the extra weight, but DIYers might find the lithium batteries more challenging to install. It’s wise to enlist some help lifting and moving them into place.

But that comes with a trade-off: the energy density of lithium batteries is much higher than lead-acid, meaning they fit more storage capacity into less space.

As you can see in the example, it takes two lithium batteries to power a 5.13 kW system, but you’d need 8 lead-acid batteries to do the same job. When you take the size of the entire battery bank into account, lithium weighs less than half as much.

This can be a real benefit if you need to get creative with how you mount your battery bank. If you are hanging an enclosure on the wall or hiding it in a closet, the improved energy density helps your lithium battery bank fit into tighter spaces.

5.4 Charge Controllers

The following paragraph is adapted from (Hankins, 2010) chapter 5.

The success of any off-grid PV system depends, to a large extent, on the long-term performance of the batteries. For a system to operate well and have a long lifetime, the batteries must be charged properly and kept in a high state of charge. Over several months, the energy entering the batteries during the day (i.e. the solar charge) must be roughly equivalent to the energy being discharged from the batteries at night by the load. Any off-grid PV system must be managed so that:

- Batteries are not damaged by deep discharges from over-use of the load;
- Batteries are not damaged through overcharging from the modules.

Solar electric systems use charge controllers (also called charge regulators) to manage the electrical power produced by the modules, to protect the batteries and to act as a connection point for all the system components (in systems without inverters). The charge controller has a number of primary functions.

- It provides a central point for connecting the load, the module and the battery.
- It manages the system so that the optimum charge is provided to the batteries.
- It ensures that components (especially batteries and lights) are protected from damage due to overcharge, deep discharge and changing voltage levels.
- It enables the end-user to monitor the system and identify potential system problems.

The main factors to consider when selecting the charge controller are the following:

- Charge controller PV input voltage range
- Charge controller PV input current range
- Charge controller output voltage
- Charge controller power rating
- Protective devices and other features

The following was adapted from (Solar4RVs)

There are two main types of charge controllers; PWM and MPPT.

PWM and MPPT charge controllers are both widely used to charge batteries with solar power. The PWM controller is in essence a switch that connects a solar array to the battery. The result is that the voltage of the array will be pulled down to near that of the battery. The MPPT controller is more sophisticated (and more expensive): it will adjust its input voltage to harvest the maximum power from the solar array and then transform this power to supply the varying voltage requirement of the battery plus load. Thus, it essentially decouples the array and battery voltages so that there can be, for example, a 12V battery on one side of the MPPT charge controller and panels wired in series to produce 36V on the other. It is generally accepted that MPPT will outperform PWM in a cold to temperate climate, while both controllers will show approximately the same performance in a subtropical to tropical climate.

The best panel match for a PWM controller:

- A panel with a voltage that is just sufficiently above that required for charging the battery and taking temperature into account, typically, a panel with a Vmp (maximum power voltage) of around 18V to charge a 12V battery.
- These are frequently referred to as a 12V panel even though they have a Vmp of around 18V.

The best panel match for an MPPT controller:

- The panel open circuit voltage (Voc) must be under the permitted voltage.
- The Voc must be above the “start voltage” for the controller to “kick-in”
- The maximum panel short circuit current (Isc) must be within the range specified
- The maximum array wattage must match the MPPT controller.

A PWM is a good low-cost option:

- Suitable for smaller systems
- Where the efficiency of the system is not critical, e.g trickle charging.
- For solar panels with a maximum power voltage (Vmp) of up to 18V for charging a 12V battery (36V for 24V battery, etc.)

The MPPT controller is best:

- For larger systems where the additional 20%* or more energy harvesting is worthwhile
- When the solar array voltage is substantially higher than the battery voltage e.g. using house panels, for charging 12V batteries

5.5 Inverters

The following was adapted from (Mayfield, 2010).

Inverters take direct current (DC) power produced by the PV modules and/or stored in the batteries and change it into alternating current (AC) that people can use in their homes and businesses. Inverters are also smart enough to realise when the grid is down (when connected to a grid).

There are mainly two types of inverters:

- Grid-interactive inverters
    - Grid-direct or Grid-tied (for use in grid-tied PV systems)
    - Battery-based (for use in grid-interactive, battery-based PV systems)
- Standalone inverters
    - For use in off-grid, battery bases PV systems.

5.5.1 Grid-Tied inverters

The majority of PV systems installed today feature inverters that connect directly to the PV array on one side and to the utility on the other side.

These inverters don't use any method of energy storage and are most often referred to as grid-direct inverters. They're the most widely installed inverters due to their increased efficiencies and relatively simple installation, and they're used only in grid-tied PV systems.

All grid-direct inverters are considered utility-interactive because they require the presence of the utility in order to operate; they work in parallel with the utility to supply power to common loads (including the lights in your home, your television, and anything else that uses electricity). They even have the ability to send power back into the utility's grid.

Grid-tied inverters have three main functions:

- Convert DC power from PV modules into AC power
- Synchronise with the electricity grid (voltage and frequency)
- Connect in parallel to the grid.

Grid-tied inverters don't employ any form of energy storage, so if the utility doesn't provide them with a stable, consistent power source, they can't run. In fact, grid-tied inverters are so aware of small changes in the utility's power that they shut down on occasion to meet the necessary safety standards.

This characteristic can be seen as a limitation, but it's a deliberate feature of the inverters that allows them to operate safely with the utility grid.

One of the most important safety features in all grid-tied inverters (as well as utility-interactive, battery-based inverters) is the ability to detect when the grid is suddenly disconnected. Grid-tied inverters have very sophisticated monitoring equipment that can detect the absence of the grid in fractions of a second and turn off the inverter automatically in response. The name given to this process is anti-islanding, and it's a requirement for all grid-direct inverters connected to a utility grid.

The term islanding refers to a situation in which the utility grid is out and alternate power sources from people's homes are still connected to the grid and sending power back into those "dead" lines. Islanding presents a safety issue for utility workers who may be working on those lines; they may think the lines are safe to touch when in fact electricity is present from a different source. That's why grid-direct inverters are required to recognize utility disturbances and stop producing power immediately. The inverters look at two parts of the utility power: the electrical frequency and the voltage. If either part goes out of the specified allowable range for the inverter's operation, the anti-islanding feature activates, and the inverter turns off.

All grid-direct inverters employ maximum power point tracking (**MPPT**) to produce as much power as possible from the PV array. MPPT allows the inverter to harvest the maximum amount of power and deliver it to the load, just like some charge controllers use it to deliver the maximum amount of power to a battery bank.

Because you can't simply look at a PV array and know whether it's working, inverter manufacturers have decided that some sort of display or interface is necessary to indicate how the array is functioning. Consequently, today's inverters generally include options for the user to see what his entire PV system is doing. With very few exceptions, grid-direct inverters now come standard with a display built into the unit, a feature that allows your client to obtain critical information such as voltage, power output, and total energy production from the inverter itself.

In addition, inverter manufacturers offer a wide variety of ways to collect, store, and display the data gathered by the inverter. Many have methods for connecting the inverter to the Internet and allowing the user to visit a Website and see real-time information about his system. Some even make it possible to connect the inverter directly to a computer, a feature that allows the system owner to collect and store data locally so he can review it periodically to identify potential issues if they occur.

Even though all grid-direct inverters operate on the same principles, they come in a variety of power output sizes (which are very often referred to simply as the inverters' size). Following are the three power output sizes you can expect to run into:

- Micro inverters: These are inverters that connect to a single PV module rather than a string of modules. PV folk like these inverters because their ability to turn the individual modules' power to AC reduces total system losses from factors such as shading. Micro inverters are typically less than 250 W each, which matches well with the commonly used PV modules.

- String inverters: Although the true definition of a string inverter is an inverter that's connected to a single series string the term has become synonymous with small (less than 15 kW) inverters that attach strings of PV modules for power outputs ranging from 1 kW to 15 kW or even bigger.
- Central inverters: Associated with larger commercial projects, central inverters range in size from 15 kW to 2 MW. Central inverters operate a lot like the string inverters used in residential applications, just on a much larger scale.

Grid-tied inverters can be either transformer less or with transformers. Different manufacturers may use different transformers in their inverters, and some manufacturers may not use transformers at all.

Low-frequency grid-direct inverters are currently pretty common in PV systems. They take the high DC voltage from the PV array and, through a series of switches, turn that DC into AC with the help of a transformer that keeps the AC and DC isolated by inducing the switched DC voltage across the transformer and creating the AC current on the other side of it. Low-frequency inverters get their name because the frequency at which these switches are operating is relatively low in comparison to high-frequency inverters. The advantages of low-frequency inverters include a very robust design that allows manufacturers to reduce the number of parts required to make AC from DC and keep overall costs low. However, because these inverters use a large transformer, power losses occur across that transformer. (Also, the transformer adds a lot of weight to the unit.)

High-frequency inverters use a switching technology that's similar to that of their low-frequency counterparts. The difference is that high-frequency inverters do their switching much faster, which means they can use small, lightweight transformers rather than large, heavy ones.

Some manufacturers who work with this technology are able to use the high frequency transformers to create multiple small inverters inside the same box. What's the advantage of that, you ask? Well, if the PV array is producing low levels of power, one inverter can be off, letting the second inverter operate at a higher efficiency level. After the power level gets high enough, the second inverter turns on, preventing the first inverter from being overworked.

Some inverters on the market **don't use any transformers at all**. These inverters keep the DC and AC separated electronically and prevent any DC injection into the AC line by using firmware (small electronic programs) specialized for the inverter. Transformer-less inverters are commonly referred to as ungrounded inverters because a connection to the grounding electrode system isn't required due to the lack of a transformer. However, transformer-less inverters still need to include an equipment ground in order to reduce shock hazards. Turn to Chapter 17 for information on grounding requirements in PV systems. The largest positive feature for transformer-less technology is the increase in overall inverter efficiency. Without a transformer present, the inverter has one less step to make and can turn the DC power from the array into AC power more efficiently. The major downside involves all the additional requirements you have to go through when installing a transformer-less inverter in order to be compliant with safety regulations

5.5.2 Off-grid inverters

When energy storage is a requirement for your client (calling for a utility interactive, battery-based or stand-alone, battery-based PV system), a battery based inverter is your go-to choice. Actually, battery-based inverters are better described as inverter/chargers because they have the ability (when needed) to accept an AC power source, such as the utility grid or a generator, and then turn the AC electricity into DC electricity for battery charging.

Grid-interactive, battery-based inverters operate almost identically to stand-alone, battery-based inverters, but a few major differences exist. These sections tell you all you need to know about the workings of both types of inverters and describe the features that come standard on any battery-based inverters.

A utility-interactive, battery-based inverter works in different ways depending on whether the utility is up and running or down and out.

- When the utility is working When the utility is up and running and the battery bank is full, power moves through a utility-interactive, battery-based inverter in the following route:
    - The PV array starts producing DC power in the morning and sends it to the battery bank.
    - If the battery bank is full, the charge controller "talks" to the inverter and sends the DC power toward it. The battery bank will always be full unless there has been a power outage and the client has run loads using the battery bank.
    - The inverter accepts the power from the PV array, changes it into AC power, and passes it through to the backup load. If the PV array is producing more power than the backup load is consuming, the inverter takes the excess power, turns it into AC power, and sends it to the main distribution panel (MDP).
    - The MDP then disburses power to the loads connected to it. If the PV array is producing more power than the MDP and the backup load combined, the inverter can push the AC power back into the grid.
    - As the PV array slows down and eventually stops producing power, the inverter stops sending power back toward the utility; the utility power then begins to flow into the MDP, just like it would if no PV system were present.
    - The utility power continues through the inverter into the backup load so that the loads always have power available and the batteries remain full.
- When the utility is down, No utility can stay live all the time, which is why utility-interactive, battery based inverters are ready for the occasions when one goes out. They're able to recognize the outage and automatically disconnect themselves from the utility connection, eliminating any possibility of the inverters islanding and sending power back to the utility.

    - Because utility-interactive, battery-based inverters are connected to the utility, they have to conform to the same anti-islanding standards that grid-direct inverters do, which means they have to monitor the utility and disconnect themselves when the voltage and frequency levels are out of the specified parameters.
    - At the same time that it disconnects from the utility, a utility-interactive, battery-based inverter immediately begins drawing DC power from the battery bank and sends AC power to the backup load. It then continues powering the loads from the battery bank until either the utility power returns or the batteries discharge and can't support the loads.
- If the power outage is extensive, the PV array can and will continue to charge the battery bank through the charge controller, giving the battery bank an extended run time. When the utility power returns, the inverter reconnects to it, allowing the battery bank to recharge directly from the utility. This way the battery bank can be ready to supply power if another outage occurs.

Battery-based inverters are the workhorses of the inverter world. They're capable of handling a variety of environments and delivering high-quality, reliable power. In the sections that follow, I describe some standard features found in all battery-based inverters.

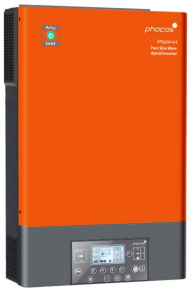
Most, but not all, of the battery-based inverters used in PV systems are actually inverter/chargers. On the other hand, some battery-based inverters are exactly that — inverters without the ability to charge a battery bank from an external AC source (such as the utility grid). With battery-based inverters, a number of features vary from manufacturer to manufacturer, so if you need a specific function, verify that the inverter can deliver what you want it to before you get too far into your design.

Battery-based inverters come in a large range of power outputs (sizes). You can buy a small 100 W inverter that connects to the DC plugs in your car all the way up to 6 kW units. The most common types used in PV systems start at 1 kW of AC output and range up to 6 kW.

For battery-based systems that require more power than a single inverter can provide, multiple units can be stacked, or connected together in such a way that they can provide more power to the loads. Of course, having multiple inverters means the inverters need to talk with each other. This communication is typically handled by connecting the inverters together via a communications cable.

Table 9 gives a summary of inverter types.

Table 9:Summary of inverter types

Grid-tied inverter	A grid-tied inverter is a device that changes the DC power from PV modules into AC power to power AC loads. It also synchronises with the electricity grid and connects in parallel to the grid.	
Inverter Charger	An inverter charger is a bi-directional device. It can charge batteries from AC power (supplied by a grid or grid-tied inverter) and it can create AC power from batteries to power loads	
Hybrid inverter	A hybrid inverter is a combination of an inverter charger and either charge controller (DC coupled) or grid-tied inverter (AC coupled) all in one box. It is generally a lower-cost device that includes PV and battery connections but often lacks the flexibility of separate inverter chargers and charge controllers or grid-tied inverters.	
Off-Grid inverter	An Off-grid inverter is not connected to the grid. These inverters take battery DC power and convert it to AC power for appliances. These inverters are one directional (i.e. it does not contain a charging function as well)	

Self-Check -5	**Written Test**

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

Say true or false for the following questions below

1. Thin film modules are the most common used modules
2. Crystalline cells are the most common used modules
3. Batteries are used to store electricity
4. Charge controller are the managers of off-grid solar systems.
5. Grid-tied inverter can be uses also in solar home systems
6. The PV array starts producing DC power in the morning and sends it to the battery bank
7. Battery-based inverters come in a large range of power outputs (sizes).

***Note:* Satisfactory rating - 5 points**
Unsatisfactory - below 5 points
You can ask you teacher for the copy of the correct answers.

Answer Sheet

Score = ___________

Rating: ____________

Name: _________________________ Date: _______________

Short answer questions

Operation Sheet 1	Identify PV Components

Operation Title: Procedure to connect PV components

Given PV system components: PV module, charge controller, battery, inverter and light bulb

Step-1.Prepare appropriate working space for the PV system components

Step-2.Use appropriate tools and measuring instruments

Step-3.Identify the capacity/ratings of each component

Step-4.Make sure the components are compatible to each other

Step-5.Connect the PV module to the charge controller appropriately. Cover the PV module with cloth or carton to avoid the danger of electric shock.

Step-6.Connect the charge controller to the battery to the correct polarity

Step-7.DC loads: check that appliance is appropriate for the DC voltage level.

Step-8. Connect the DC appliance to the charge controller on the load side terminal.

Step-9. AC loads: connect the inverter DC connection to the charge controller on the load side terminals with the correct polarities.

Step-10.Connect the AC light bulb to the inverter correctly on the AC connection

LAP Test	Practical Demonstration

Name: _______________________________ Date: _________________

Time started: __________________________ Time finished: _________________

Instructions: Given necessary components of PV system, tools and measuring instruments you are required to perform the following tasks within 1 hour.

Task-1 Connect the PV components appropriately & Measure voltage and current in the PV circuit

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