Components of Solar Photovoltaic Systems

- A solar system consists of the following components, which perform various functions in the system. These components are
  - **Solar panels**
  - **Charge controllers**
  - **Batteries**
  - **Inverters**
  - **Cables and protective devices**.

Semiconductors

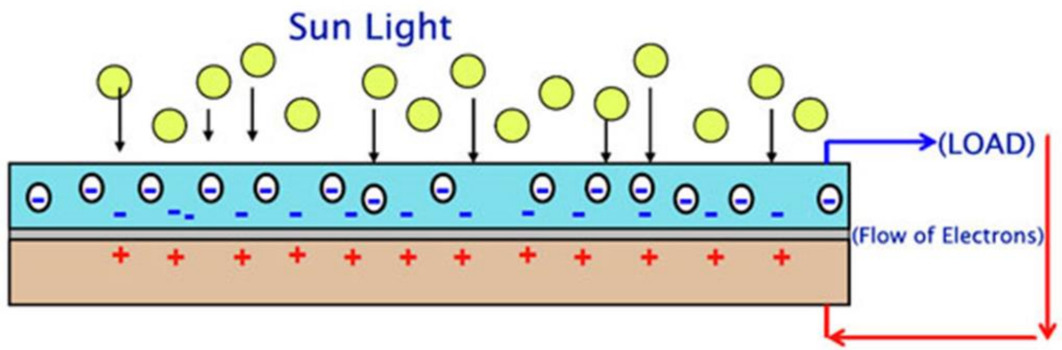
- A semiconductor is a material or substance that is capable of transmitting electricity (conductor) under certain conditions. It also possesses the ability to restrict the flow of electricity under other conditions (insulator).

- The semiconductor provides the basis for the design and manufacture of solar panels.

- The most frequently used semiconductor material used to manufacture solar cells is silicon, which is found abundantly in the form of quartz sand.

Photovoltaic Principle

- The photovoltaic principle refers to how light is converted into electricity. In certain types of semiconductors, electrons start to flow when exposed to light. The flow of electrons creates an electric current.

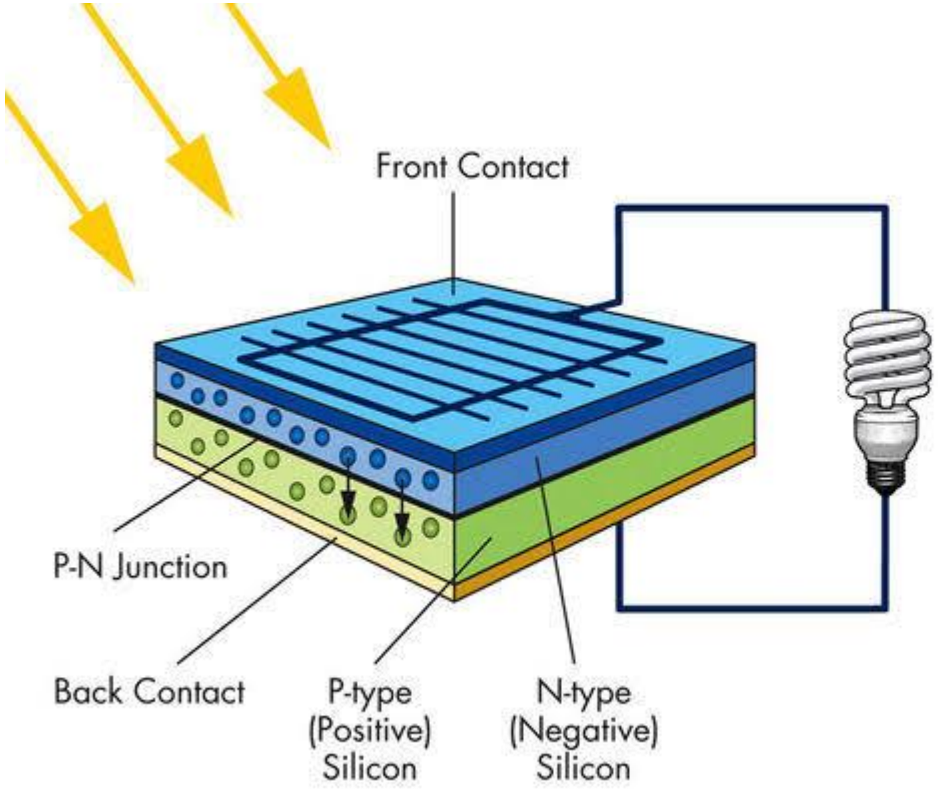


Solar Cell

- A solar cell (also known as a photovoltaic cell) is an electronic device that converts light to electricity.
- Solar cells can be made from a variety of semiconductor materials. However, for commercial use, silicon-based solar cells are commonly employed.
- Solar cells are used in a variety of applications such as calculators, wristwatches and in larger applications, e.g. for pumping water or generating domestic electricity.

How do Solar Cells Work?

- When light strikes a solar cell, direct current (DC) is generated.
- When the solar cell is connected to an electrical load via cables, this direct current can be used to power devices.
- Current cannot flow without sunlight.

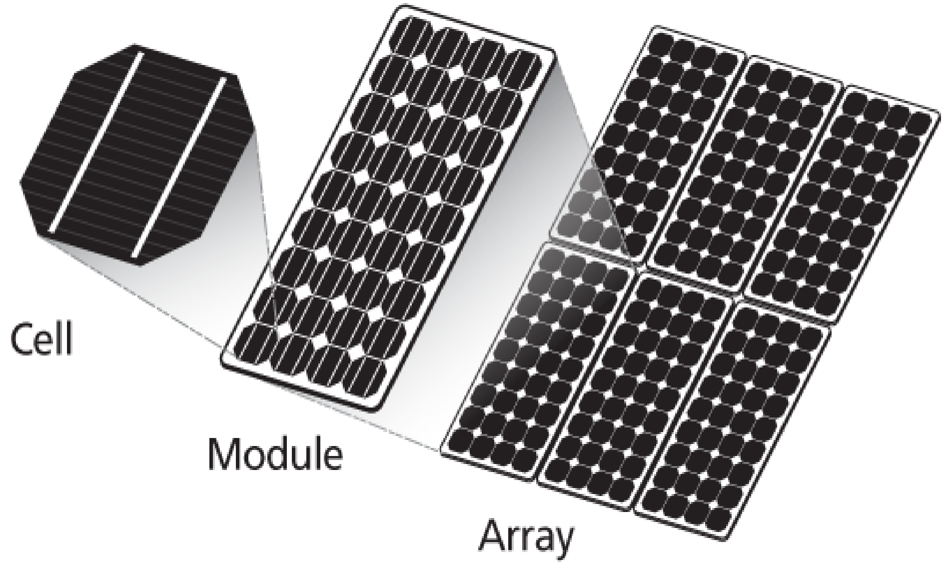


Solar Panels

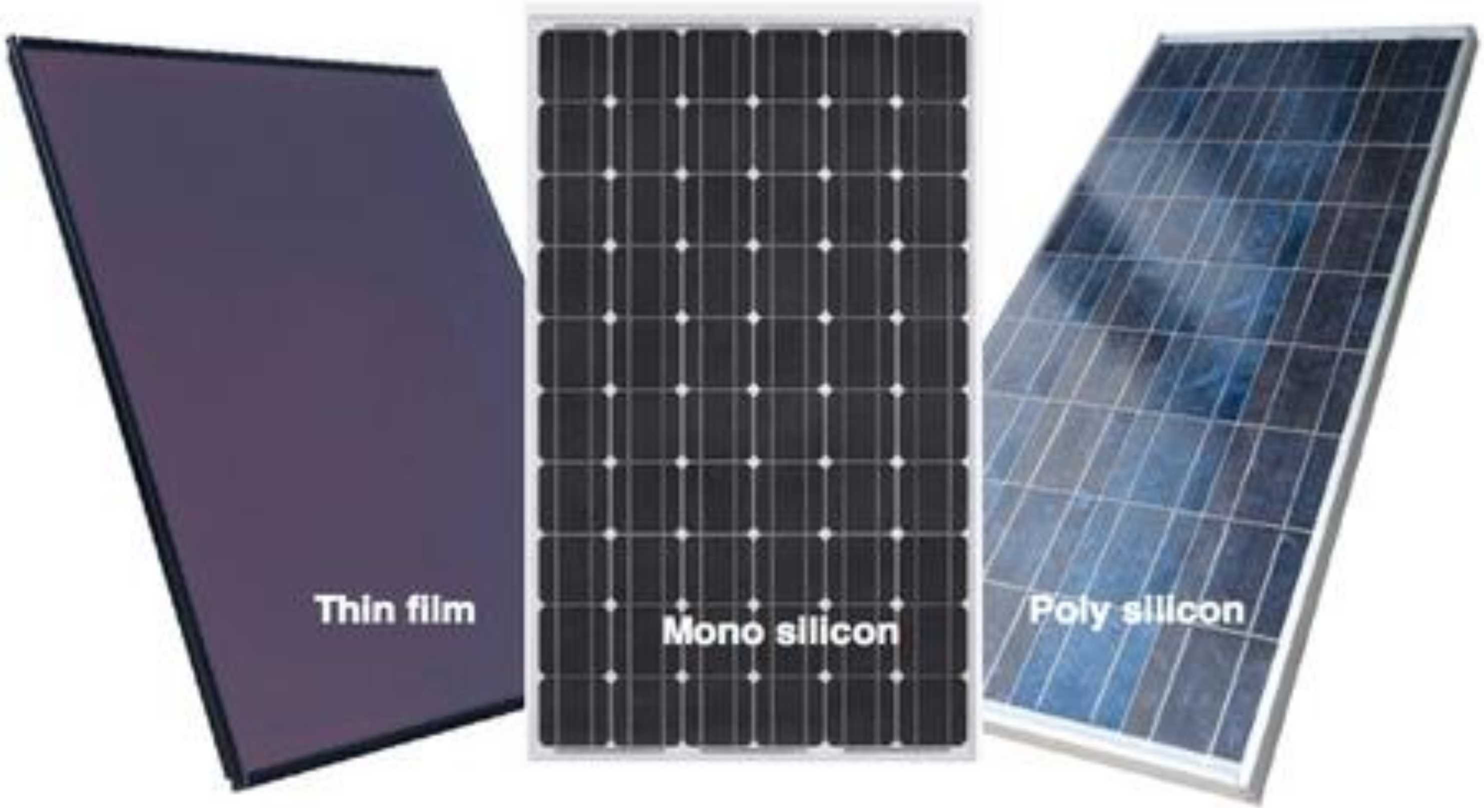
- Solar panels come in various sizes which are rated based on their output power in watts.
- A label on the back of a solar panel indicates the output power.
- The usable voltage from solar cells depends on the semiconductor material. In silicon it amounts to approximately 0.5 V or 0.6V.

Solar Cell, Module and Array

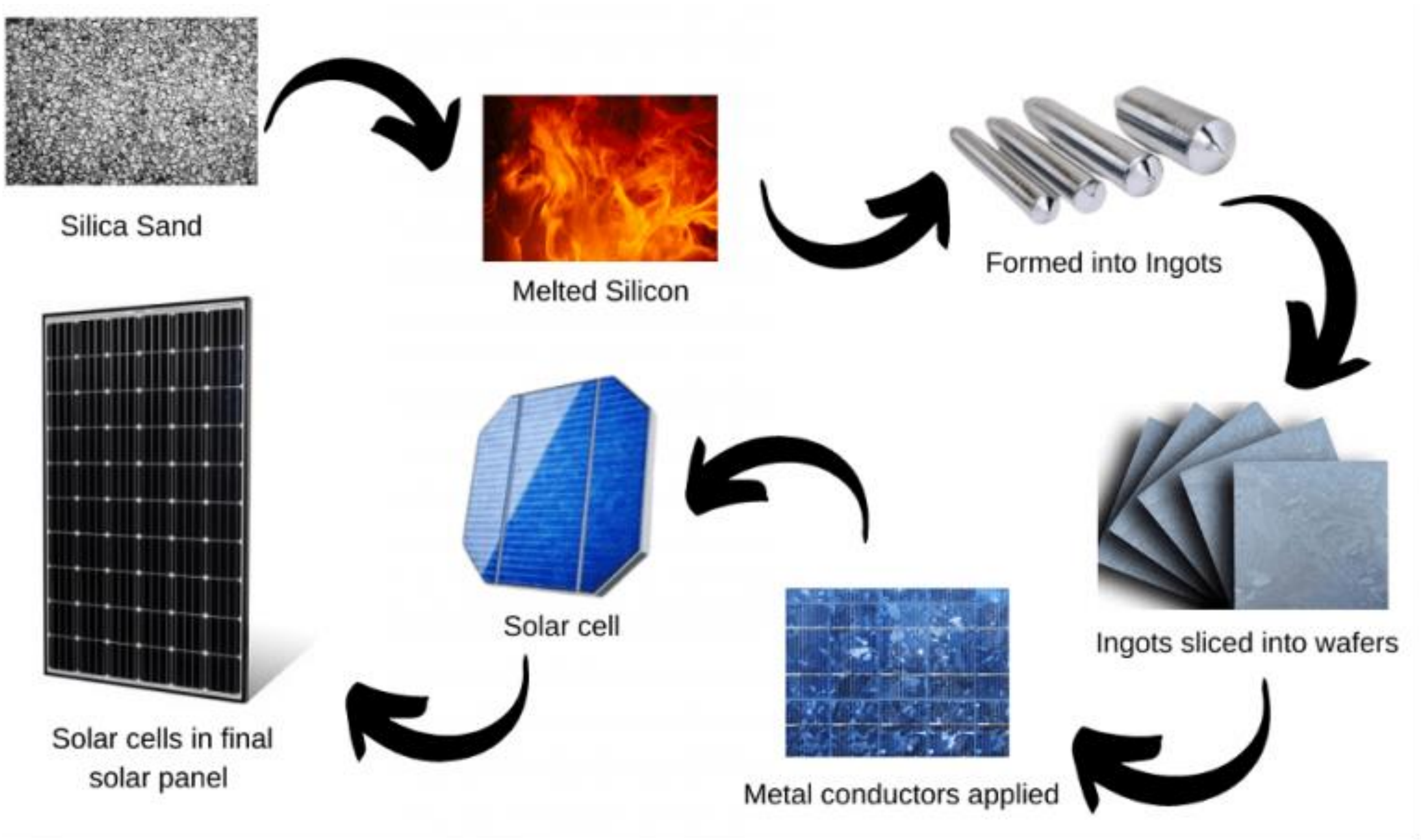
- Silicon is used to make the solar cells that go into solar panels.
- Multiple solar panels are connected to form an array.
- Larger systems need an array to supply the required electrical power. In some instances, more than one array is required.



Types of Solar Panels

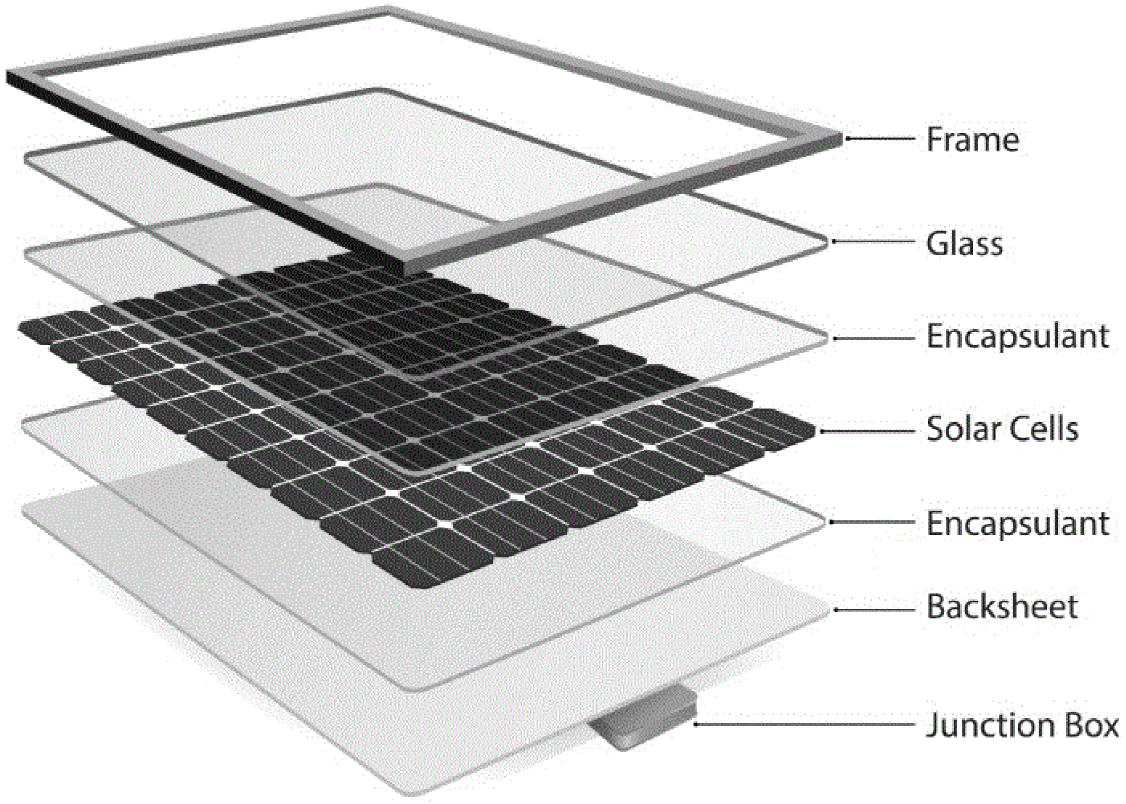


Steps of producing a crystalline solar panel



Production of Crystalline Solar Panels

- A solar PV panel consists of solar cells, glass, EVA(Ethylene vinyl acetate),back sheet and frame
- There are three types of solar panels available in the market:
  - Monocrystalline solar panels
  - Polycrystalline solar panels
  - Thin film solar panels cell
- Monocrystalline and polycrystalline solar panels have a some what similar manufacturing process



Testing the Modules

- There are hundreds of solar panel manufacturers available in the market.
- Therefore, the solar industry needs a way to categorize and compare modules.
- This is done through a lab test under which all solar panels must be submitted to test their performance under the same conditions.
- **The process by which PV modules are tested is called flash testing**
- These are known as the Standard Test Conditions (STC). The STC reference parameters used in lab tests are:
  - Irradiance: 1kW/m^2
  - Temperature: 25°C (77°F)
  - Air Mass: 1.5

Testing the Modules

- Once the module is ready, testing is carried out to ensure the cells perform as expected. STC (Standard Test Conditions) are used as a reference point.
- The panel is put in a **flash tester** at the manufacturing facility.
- The tester will deliver the equivalent of 1000W/m^2 irradiance, 25°C cell temperature and an air mass of 1.5g

NOCT

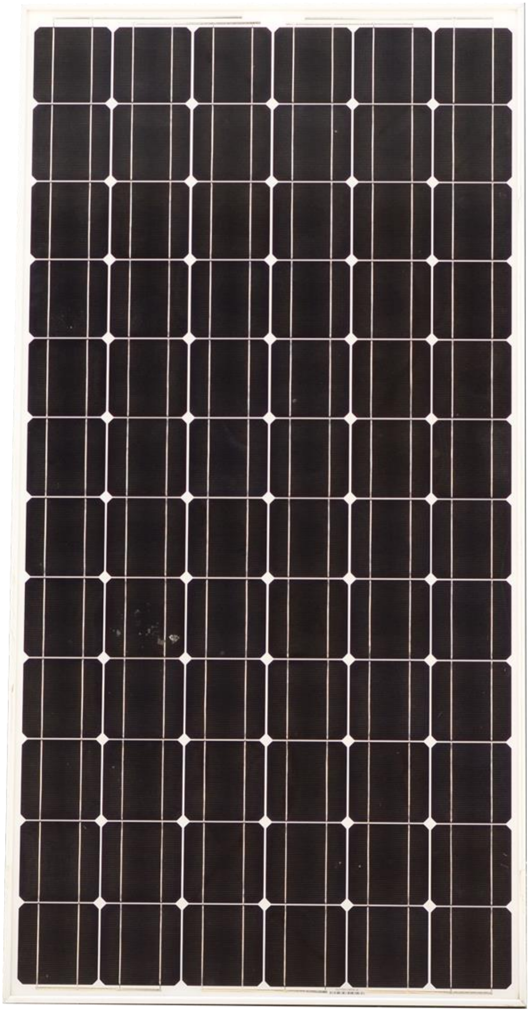
- Another typical reference value is the NOCT, acronym for Nominal Operating Cell Temperature.
- This standard uses parameters closer to the typical operation of the solar panel since STC conditions are many times, unreal.
- The temperature value that is stated in NOCT represents the temperature of the cell under the open-circuit condition and under the following circumstances:
  - Irradiance: 800W/m^2
  - Wind Speed: 1 m/s
  - Ambient Temperature: 20°C (68°F)
  - The temperature in the surface of the panel: 45°C (113°F)
  - Mounting system: Open rack

Monocrystalline Silicon Cell

- Mono crystalline cells are manufactured from a single crystal of silicon.

Characteristics

  - Have higher efficiencies (14%-20%)
  - They make use of single-crystal silicon
  - Approximate area required for 1kWp: $10m^2$
  - Generally have a black-ish hue
  - More expensive
  - They last for over 20 years
  - Examples include: Canadian Solar, Sunpower etc.



Polycrystalline Silicon cell

- Polycrystalline Solar cells are made from melting several silicon crystals together.

Characteristics

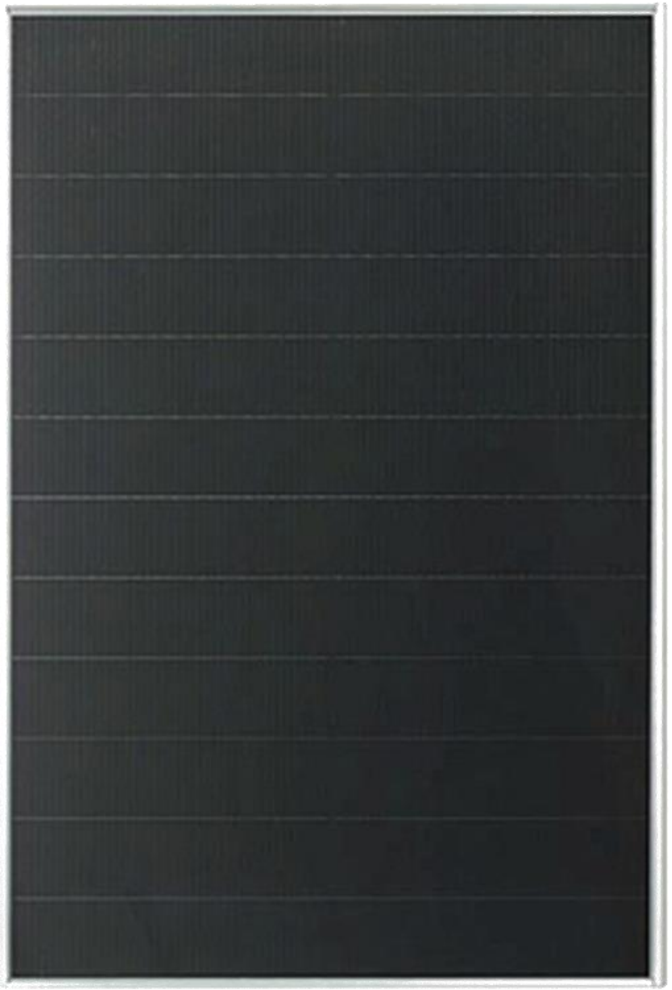
- – Have lower efficiencies than monocrystalline modules (13%-16%)
- – They make use of multiple crystal silicon
- – Approximate area required for 1kWp: $11m^2$
- – Generally have a blue-ish hue
- – They are cheaper than monocrystalline modules
- – They last for over 20 years
- – Examples include: Trina Solar, Hanwha etc.

Amorphous Silicon cell (Thin Film cell)

- This type of cell is made from non-crystalline or *amorphous* silicon and is one type of **thin film cell.** The film of amorphous silicon is sprayed as a gas onto some surface, such as glass or flexible rubber material. After this a conducting grid and electrical contacts are attached

Characteristics:

  - Lower Temperature Coefficient than crystalline modules
  - Lower efficiency (6%-9%)
  - Frameless
  - Lower cost and lower weight
  - Approximate area required for 1kWp: $15m^2$
  - Examples include: First Solar, Solyndra, Unisolar etc



Characteristics of different solar panel types

	Monocrystalline	**Polycrystalline**	**Amorphous**
Cell Efficiency	14 – 20%	13 – 16%	6 – 8%
Required area for 1kWp	$10m^2$	$11m^2$	$15m^2$

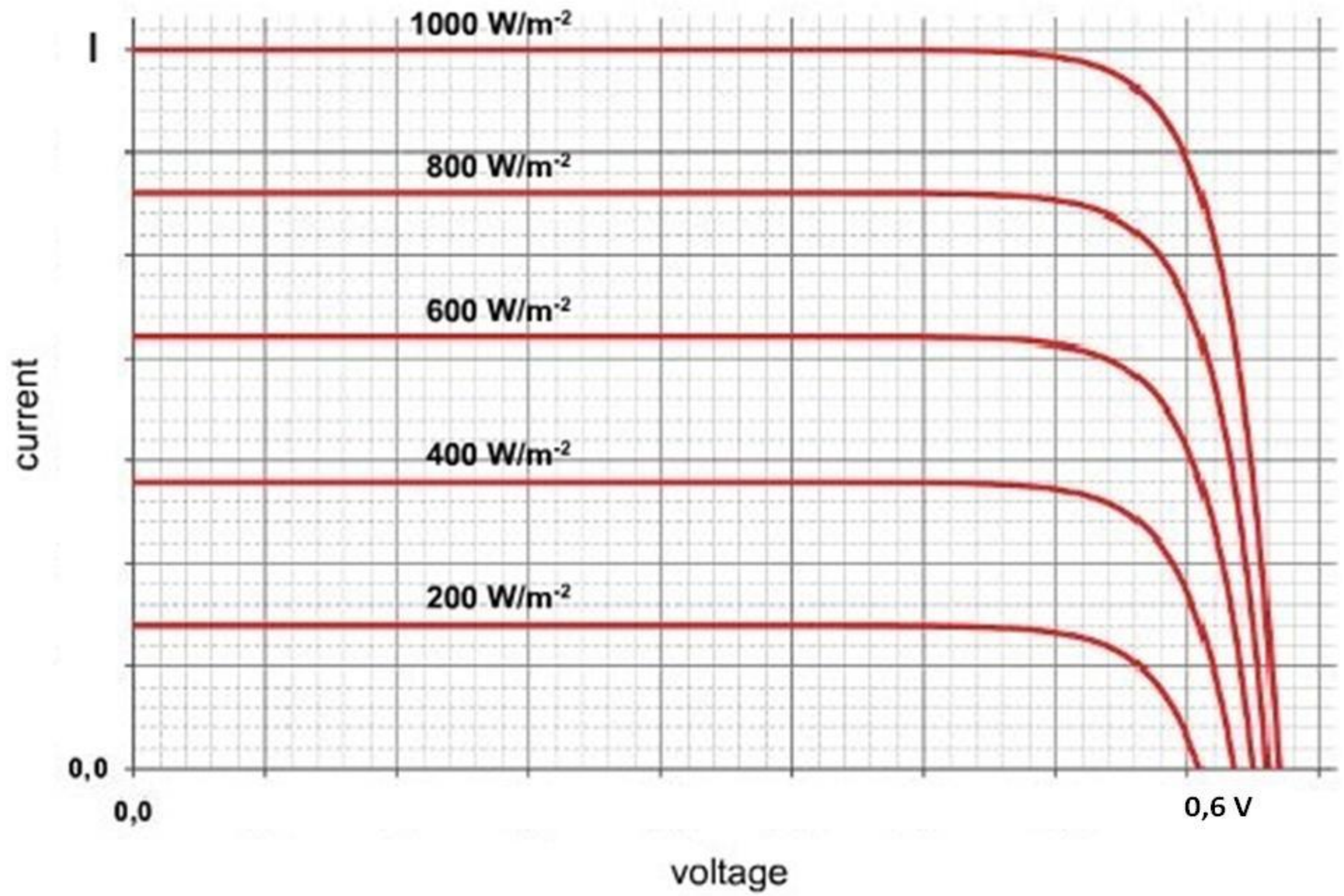
Solar Panel Lifespan

- Solar panels last about 25-30years or sometimes more. However this doesn’t mean the panels on your roof will stop producing electricity after a couple of decades.
- It means their production will decrease by what manufacturers consider as optimal to meet your energy needs.

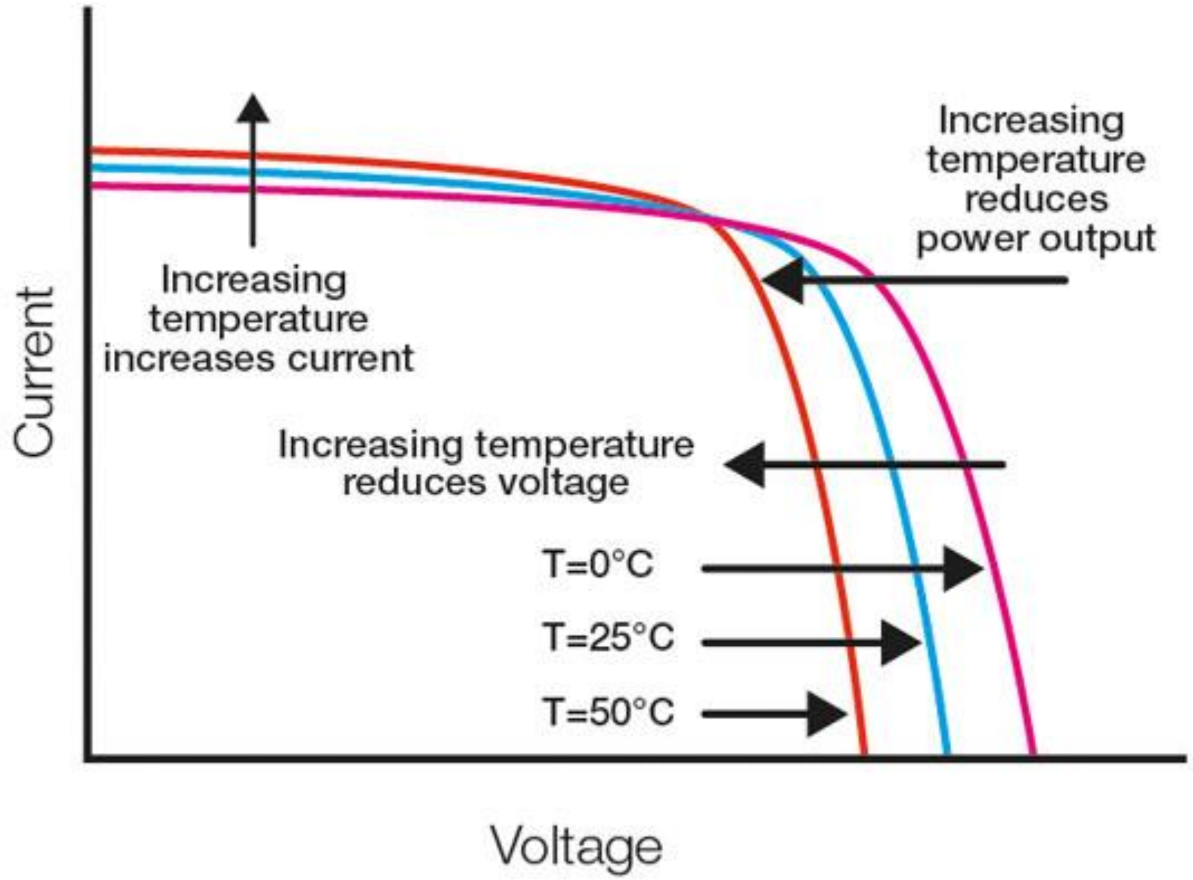
PV module output

- PV module output depends on two major factors:
  - Irradiance or light intensity
  - Temperature
- The higher the solar radiation it receives, the higher is the current a module will produce. The voltage will remain the same.
- As the temperature of a solar cell increases, the open circuit voltage Voc decreases but the short circuit current Isc increases marginally.

IV Curve and irradiance

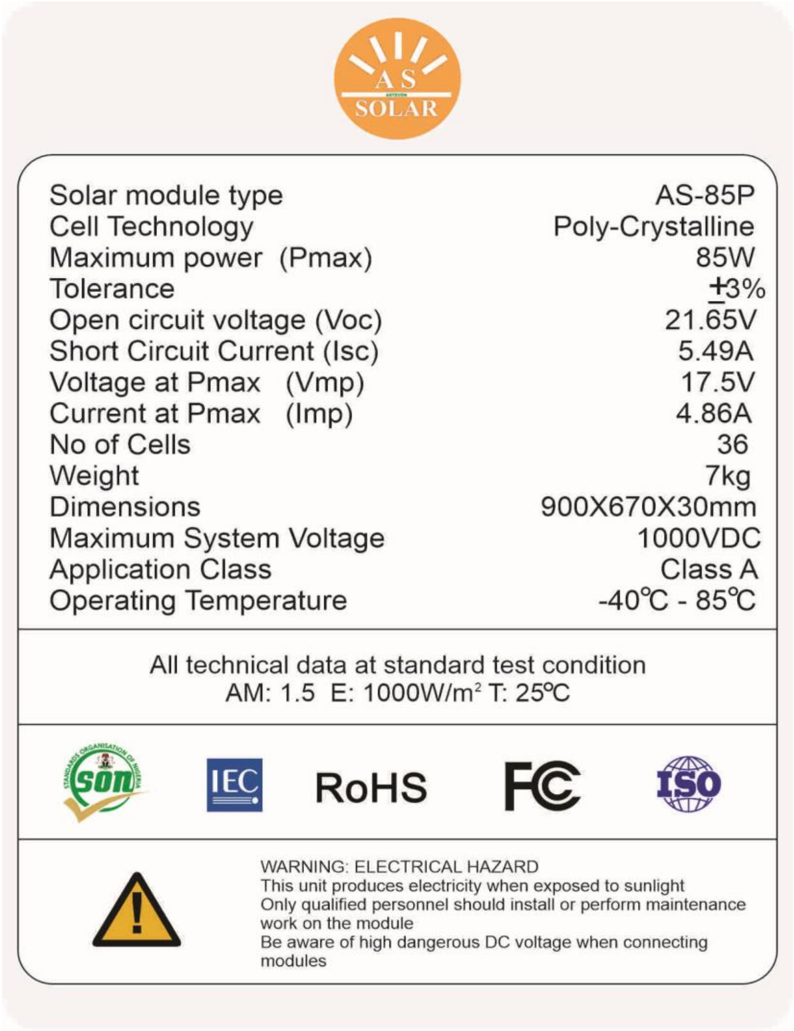


IV Curve and temperature



Interpreting the nameplate

- Every PV module comes with an adhesive nameplate attached to the back of the panel that contains vital details for optimum system performance.
- The nameplate specifies the module's electrical and mechanical characteristics under STC.



AS SOLAR

Solar module type	AS-85P
Cell Technology	Poly-Crystalline
Maximum power (Pmax)	85W
Tolerance	±3%
Open circuit voltage (Voc)	21.65V
Short Circuit Current (Isc)	5.49A
Voltage at Pmax (Vmp)	17.5V
Current at Pmax (Imp)	4.86A
No of Cells	36
Weight	7kg
Dimensions	900X670X30mm
Maximum System Voltage	1000VDC
Application Class	Class A
Operating Temperature	-40℃ - 85℃

All technical data at standard test condition
AM: 1.5 E: 1000W/m² T: 25℃

son IEC RoHS FC ISO

WARNING: ELECTRICAL HAZARD
This unit produces electricity when exposed to sunlight
Only qualified personnel should install or perform maintenance work on the module
Be aware of high dangerous DC voltage when connecting modules

Interpreting the nameplate

Parameter	Explanation
Cell technology	Technology used to manufacture the PV module
Maximum power(Pmax)	Power generated by solar panel under STC
Tolerance	Output of the PV module under STC may vary between 82W and 88W
Open circuit voltage(Voc)	No load voltage across the PV module
Short circuit current(Isc)	No load current flowing through the PV module under STC. This is the current when the voltage across the PV is zero
Voltage at Pmax	Maximum voltage across the terminal of the PV module

Interpreting the nameplate

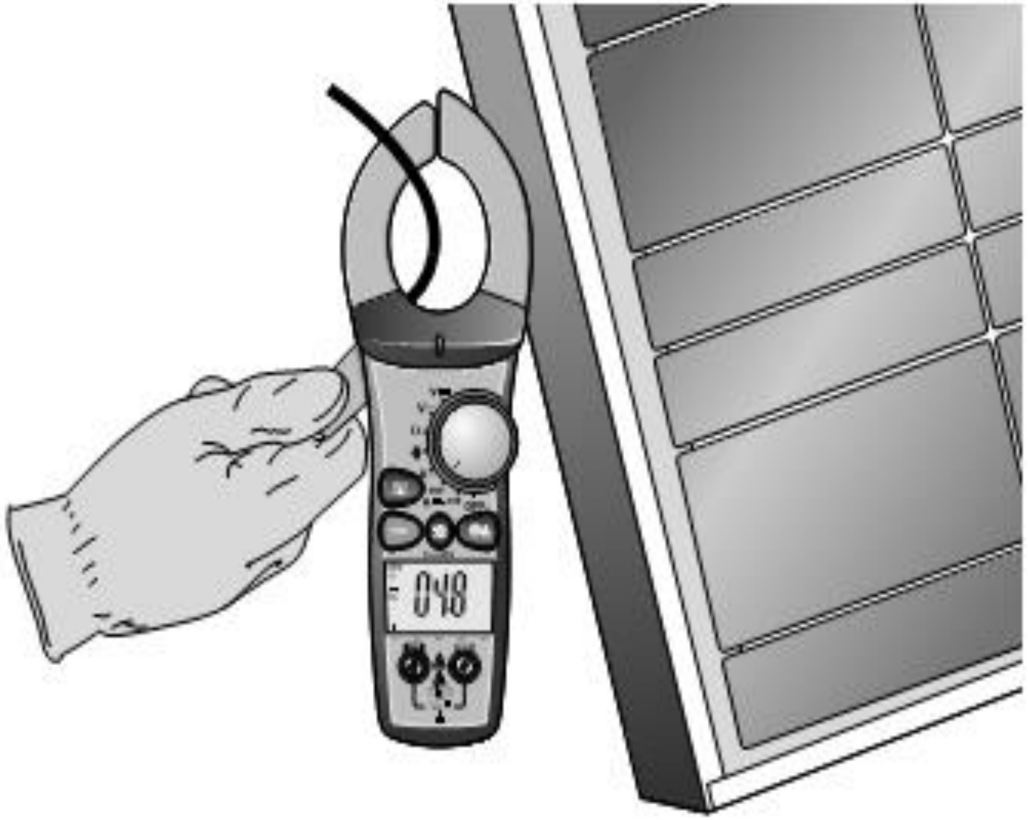
Parameter	Explanation
Current at Pmax	Maximum current generated at STC
No of cells	Number of module cell
Weight	Weight of the PV module
Dimension	Length, breadth and width of PV module
Maximum system voltage	Maximum array voltage possible for this type of module
Operating temperature	Cell temperature which is reached through real life operation of the PV module

Interpreting the nameplate

- Label on solar panel, indicating:
  - Power Pmax 85 Wp
  - Operating current Imp 4.86 A
  - Operating voltage Vmp 17.5 V
  - Voltage without load Voc 21.65 V
  - Short-circuit current Isc 5.49A
- The electric power voltage and current which are labeled on a solar panel can only be achieved at $1kW/m^2$ and at a cell temperature of 25°C

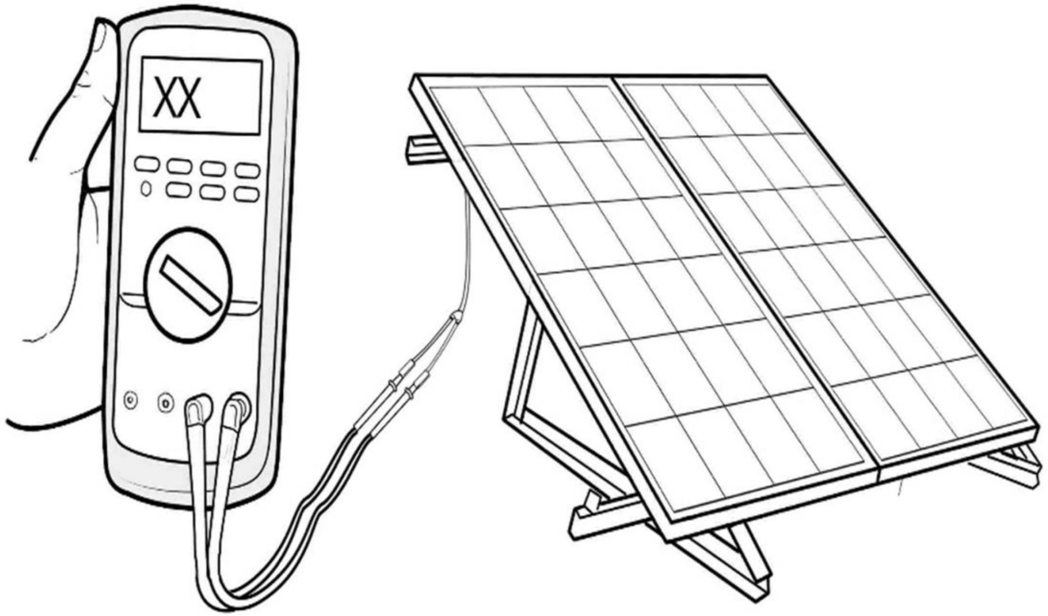
How to measure Solar panel parameters

- When a solar panel is manufactured, it is tested to ensure it meets the required standards. There are two important parameters to be considered during testing;
  - The **short-circuit current (ISC) is** the current measured when the solar panel terminals (positive and negative) are connected together and there is no load



How to measure Solar panel parameters

– The **open-circuit voltage (VOC)** is the voltage across the negative and positive terminals of the solar panel when it is not connected to any load.



Nominal Voltage of Solar Panels

- **Nominal voltage** is a way to categorize battery-based solar equipment. Because a higher voltage is required to charge a battery, nominal voltages are used to help see what equipment goes with what.
- A nominal 12V panel actually has a Voc voltage of around 22V, plus or minus a volt or two, and a Vmp of around 17V. This difference often confuses people when they try to measure the voltage of a solar panel when it’s not connected to anything but a voltmeter.
- If you count the number of cells, it will likely have 36 cells wired in series.

Nominal Voltage of Solar Panels

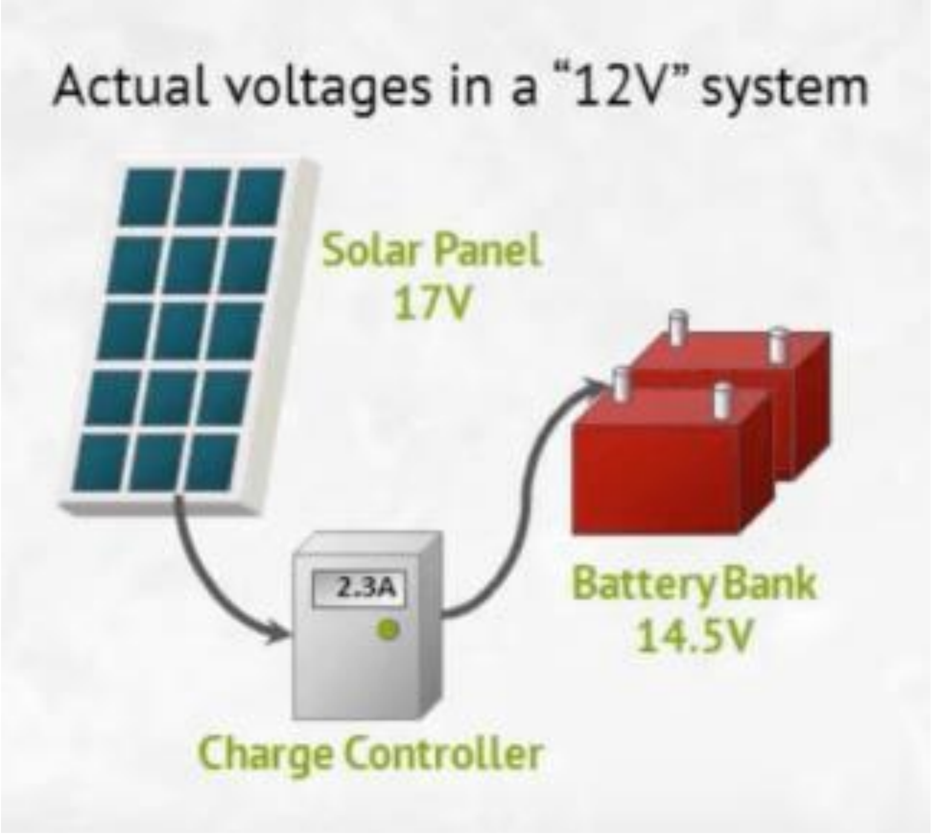
- Nominal Voltage is grouping for battery charging
- A SOLAR panel that was designed to charge a 24V battery bank will have a Voc of around 44V and a Vmp of around 36V.
- Counting the cells will come up with 72, twice as many as a 12V panel. If you wire two 24V panels in series, or four 12V panels in series, you can charge a 48V battery bank.

Vmp and Voc of Solar panels

Nominal Voltage	Voc	Vmp	Number of Cells in series
12	22	17	36
24	44	36	72

Nominal Voltages in a 12V system

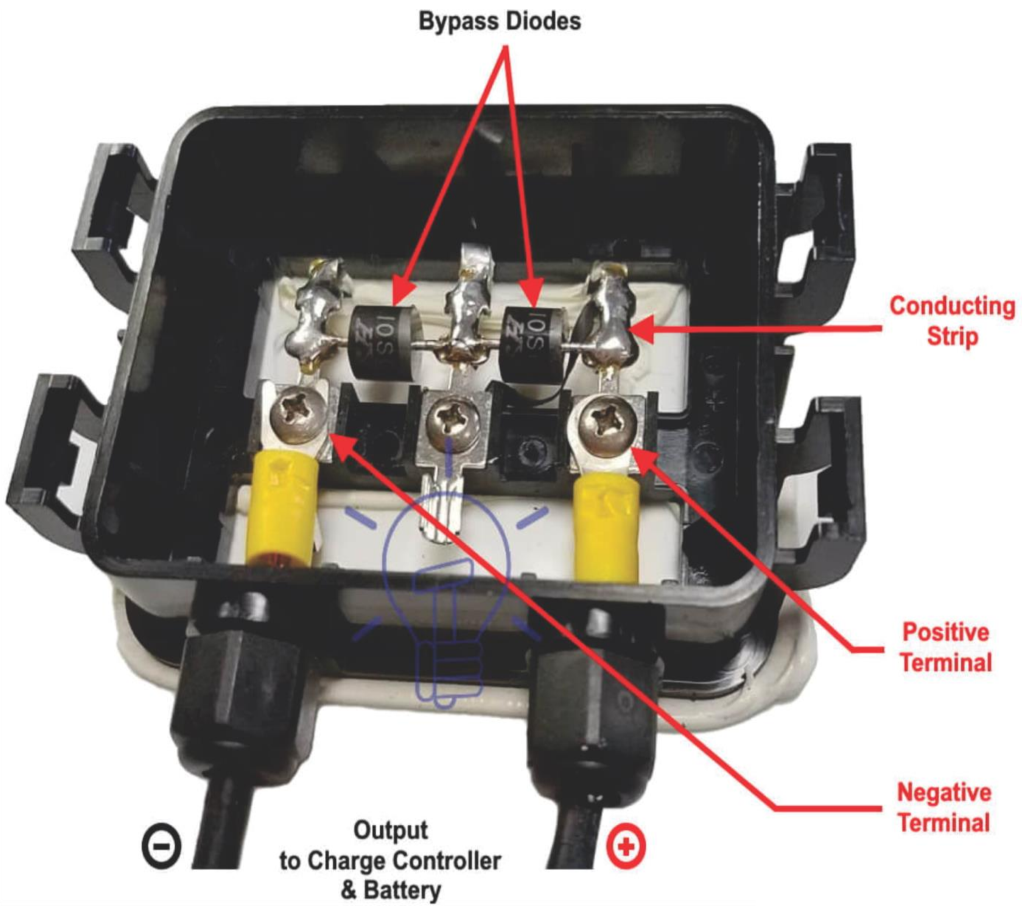
- **Example:** PV voltage is higher than battery bank voltage in order to charge it. The system below is 12 nominal voltage system.



PV Junction box

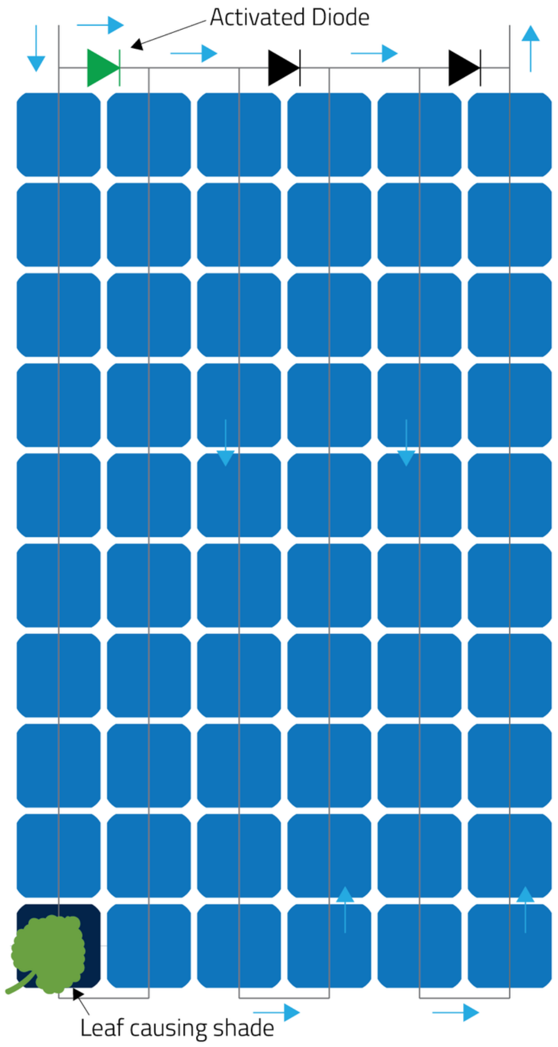
Diodes

- A diode is designed to let current flow in one direction.
- There are two purposes of diodes in a solar power system - bypass diodes and blocking diodes.
- The same type of diode is generally used for both, but how they are wired and what they do is what makes them different.



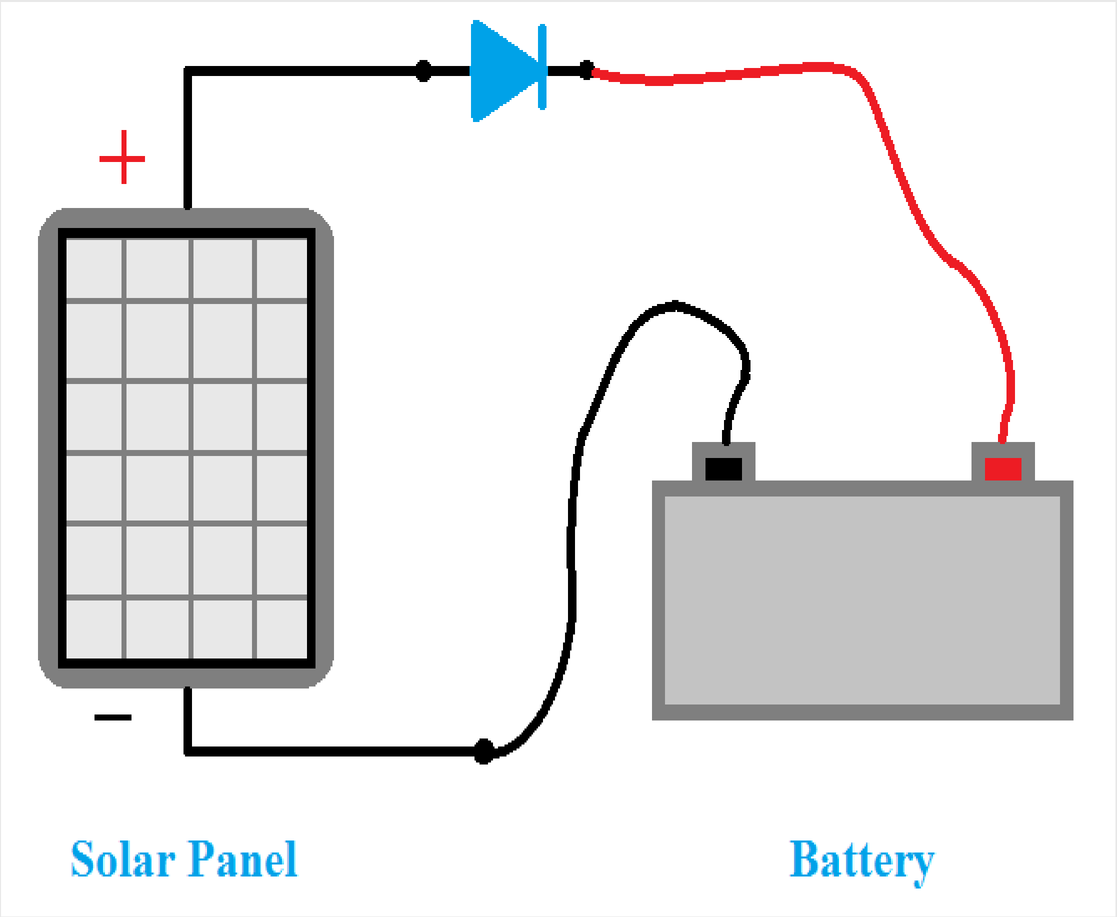
Bypass Diodes

- This type of a diode is wired within a module to divert current around a few cells in the event of shading.
- Typically several bypass diodes are pre-wired in a module, each in parallel with a set of cells.



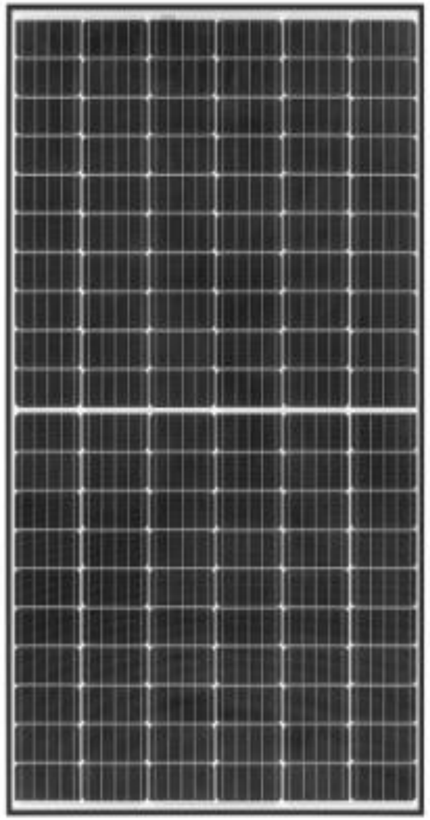
Blocking Diodes

- Blocking diodes are used to prevent your batteries from discharging backwards through your solar panels at night.
- If the solar panel is connected directly to a battery, at night the voltage of the solar panel is going to be lower than the voltage of the battery, so there is a possibility of some backwards flow, pulling power out of the battery.
- Nowadays, solar power systems have a charge controller which prevents this backflow of electricity, eliminating the need for a blocking diode.

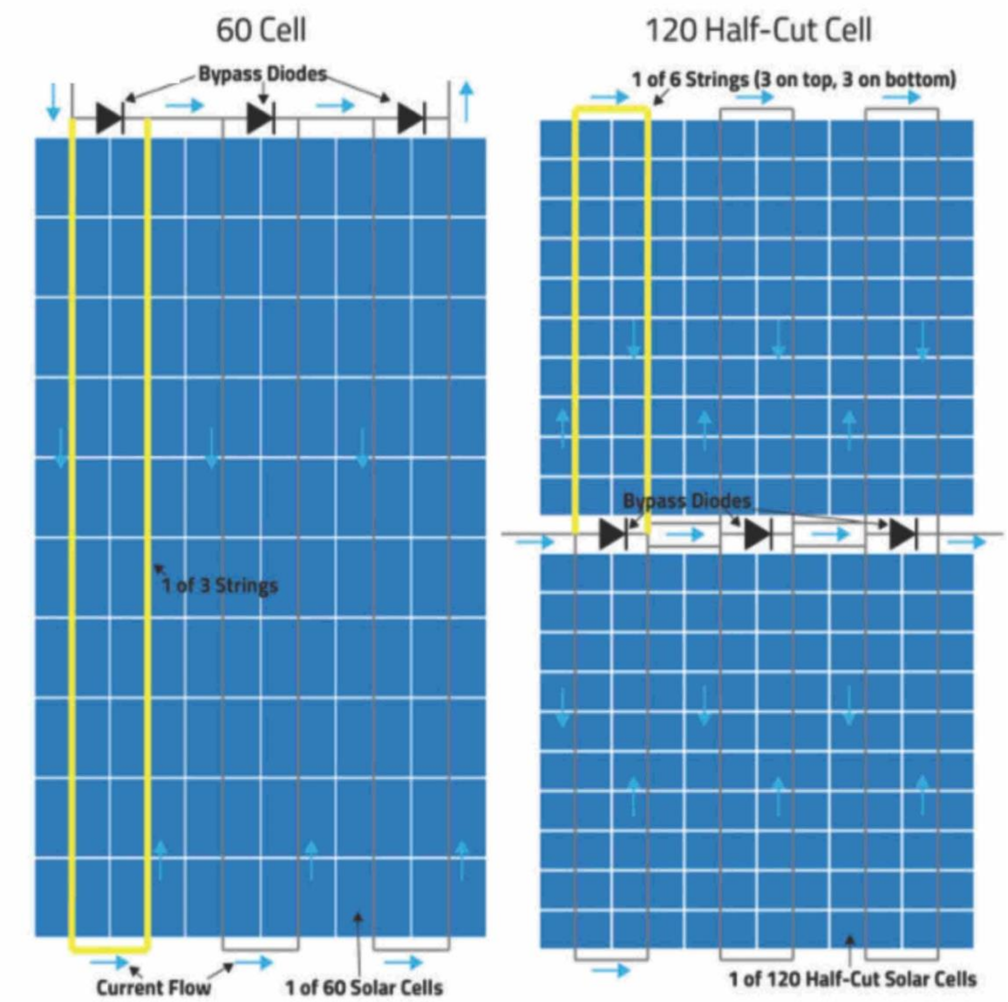


Half-Cut Solar Modules

- When solar cells are halved their current is also halved, so resistive losses are lowered and the cell can produce little more power.
- Smaller cells experience reduce mechanical stresses, so a decreased opportunity for cracking.
- Half cell modules have higher output ratings and are more reliable than traditional panels.
- Half cut cells also have relatively higher shade tolerance



Traditional Vs Half Cut Solar Panel

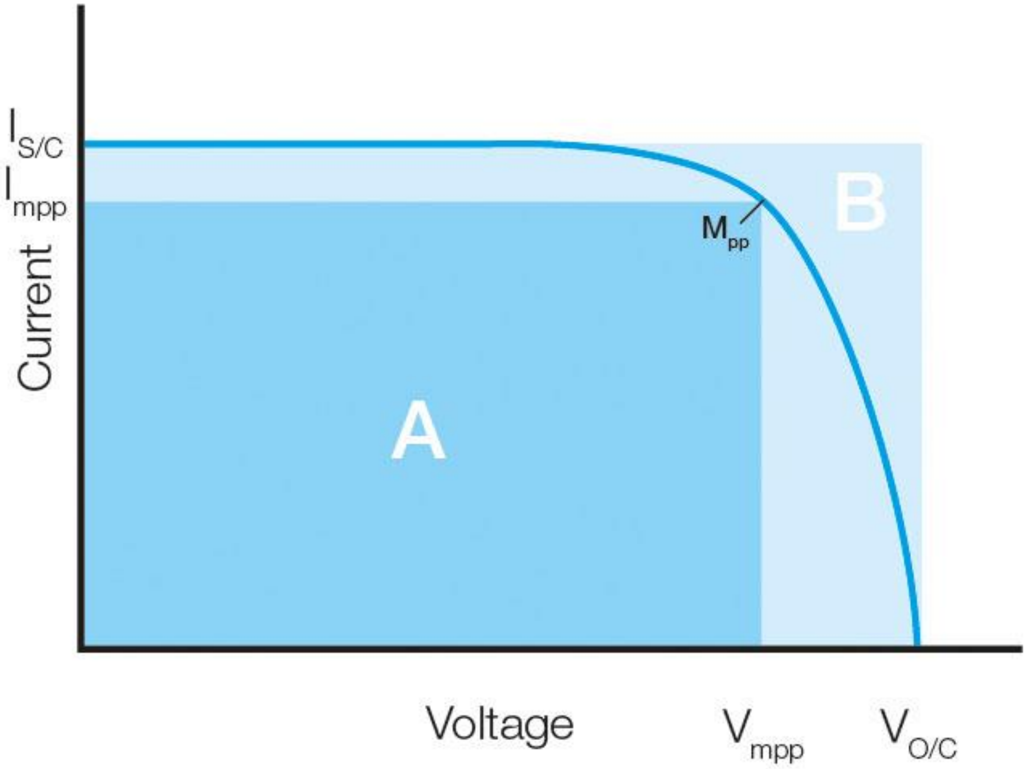


Bifacial solar modules

- Bifacial solar modules produce solar power from both sides of the panel.
- Some manufacturers claim up to 30% increase in production just from extra power generated from the rear.

Solar Cell Fill Factor(%)

- The fill factor (FF) is essentially a measure of quality of the solar cell.
- It is the ratio of actual rated maximum power P_{max} to the theoretical(not actually obtainable) maximum power(Isc x Voc)
- Fill factor(FF) = $\frac{Imp \times Vmp}{Isc \times Voc}$
- The FF of a silicon PV cell is about 75% - 80%
- A higher fill factor solar panel has less losses due to the series and parallel resistances within the cells themselves.



Solar Panel Discoloration

- Solar discoloration is a chemical reaction between the cell surface and chemicals used in back sheet and glass treatment.
- This causes power loss from the panel.

Solar panel defects losses

- Scratches on the glass or frame
- Excessive or uneven glue marks on glass
- Gap between frame and glass due to sealing
- Always lower output than stated on datasheet
- Inconsistent cell colour
- Inconsistent cell alignment
- Fading labels

Class Work

- Suppose a certain model of the solar PV module has the following parameters:
  - Peak Power (Wp)- 35 Watts
  - Open Circuit Voltage (Voc)- 20.8 V
  - Maximum Power Voltage (Vmp)- 16.4 V
  - Short Circuit Current (Isc)- 2.3 A
  - Maximum Power Current (Imp)- 2.14A

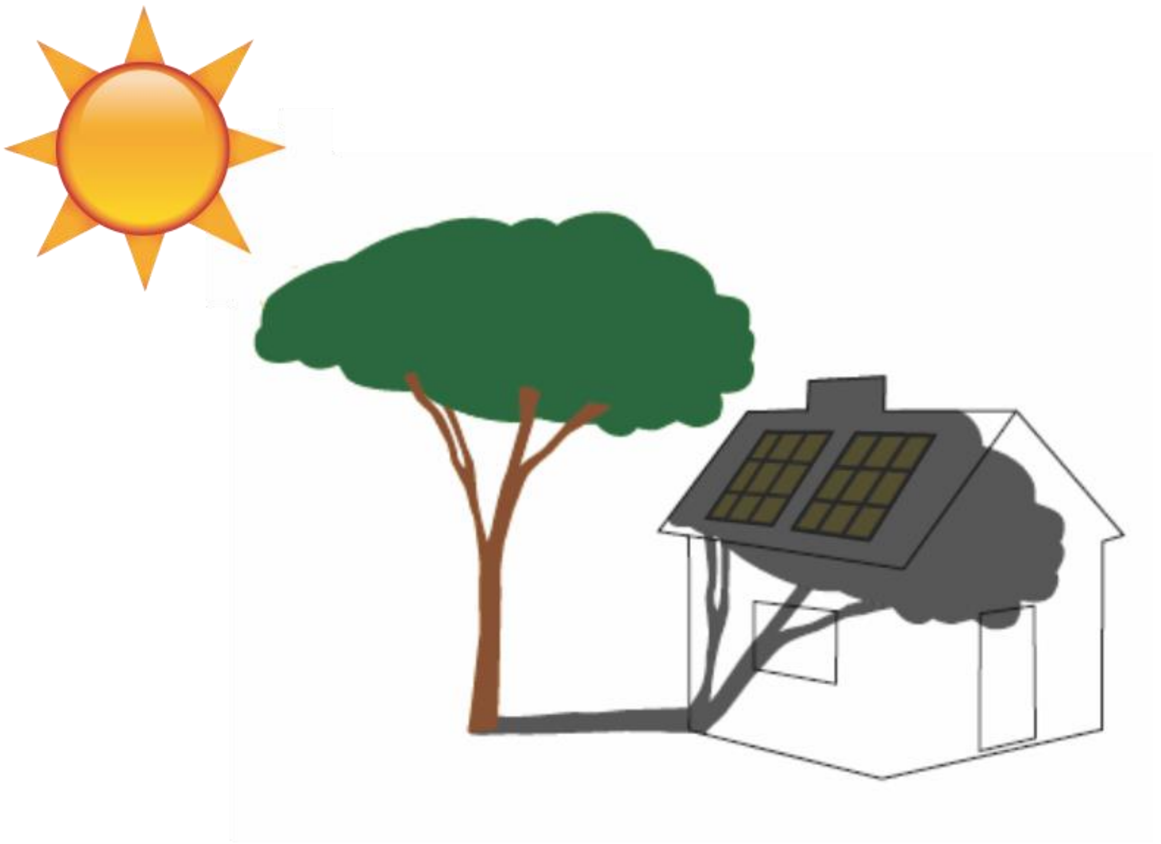
Calculate the fill factor of the module

PV Array Installation

- Firstly, the position of the array needs to be determined. Solar panels produce the most electricity when they are perpendicular to the sun.
- Since the sun moves all day, it is not practical to keep moving the panel all day to keep it perpendicular to the sun (unless a tracking system is used but it is expensive).
- Three factors that will influence the performance of the array are:
  - Shading
  - Orientation
  - Tilt

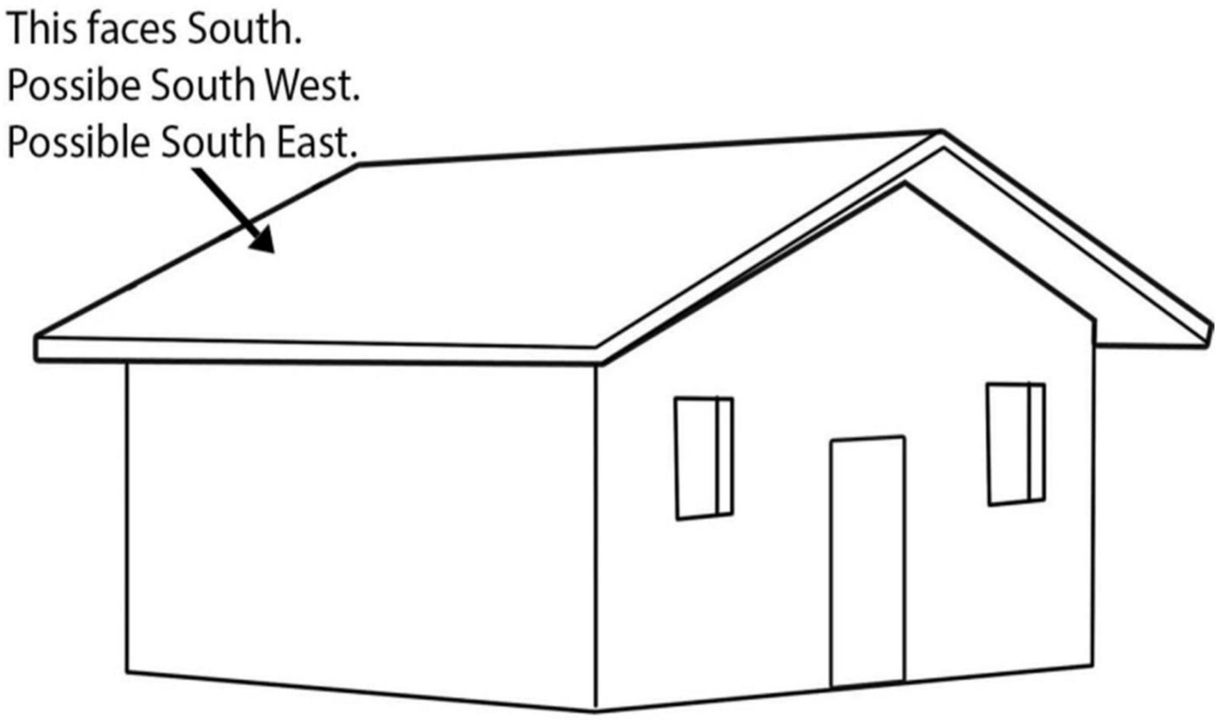
Shading

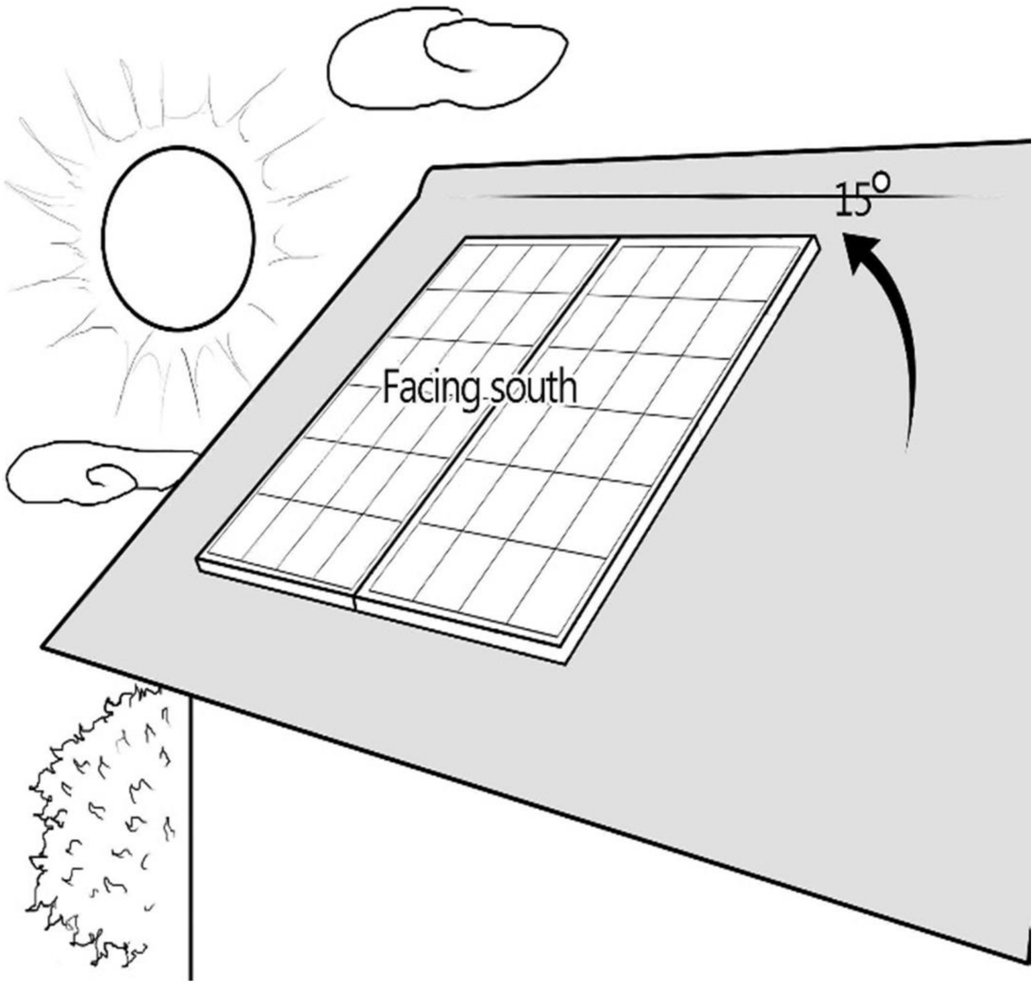
- When a solar panel is shaded in whole or part, for example, by tree branches and or a building, it captures less energy from the sun thus its performance is reduced.
- Less voltage and current will be produced. This is because most solar cells are connected in series such that if one of the cells is not producing some energy the output will be reduced.

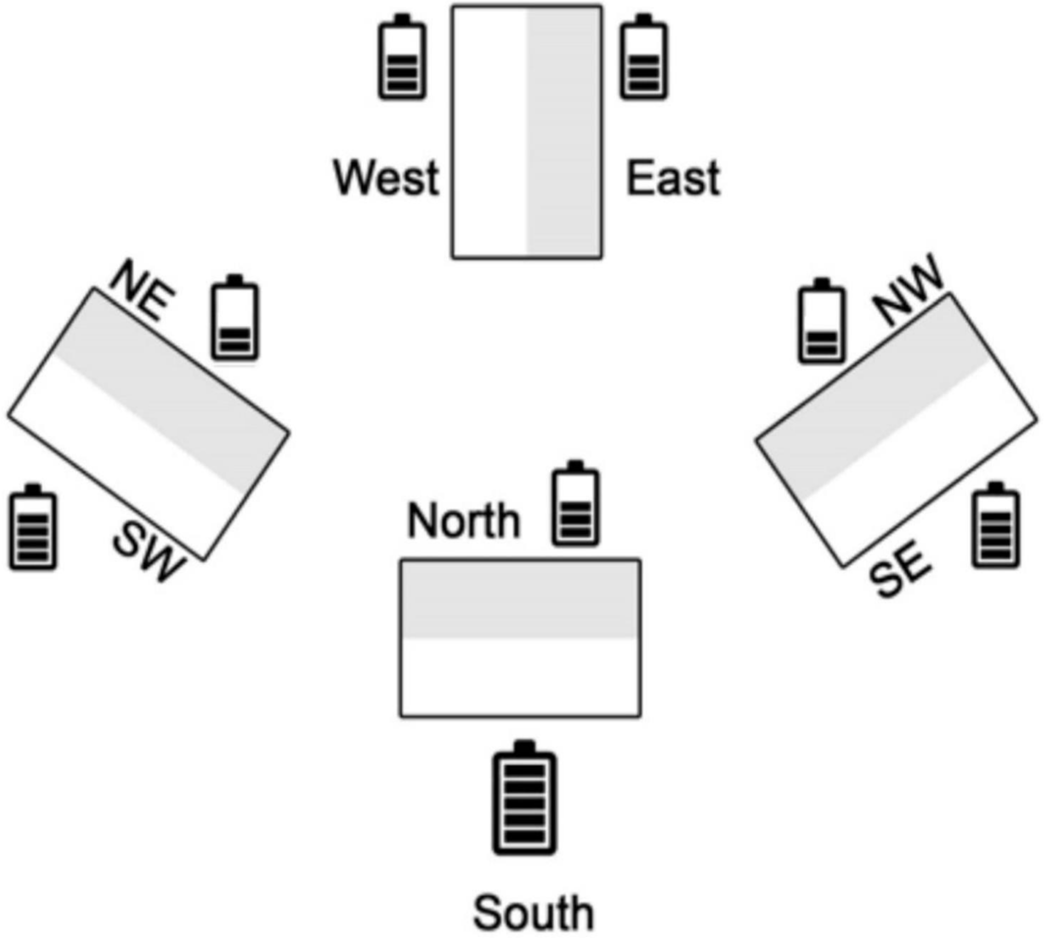


Orientation and inclination of PV modules

- To maximize the performance of a solar PV module, it must be installed at the optimum orientation (angle of inclination and azimuth).
- **Angle of inclination: This is the angle that the solar PV array makes with the horizontal** plane to the ground. For Nigeria, you should always use 15º.
- In Nigeria the solar PV array should always face South because Nigeria is in the Northern hemisphere.
- A non-ideal orientation (north, east west) could reduce the performance of the solar panels by up to 35%.




15°
Facing south


West
East
NE
SW
NW
SE
North
South

Solar Panel Performance Ratio(PPR)

- PV modules are rated in terms of their power output under standard test conditions (STC). However, The actual output would be a lot lower because of inefficiencies and losses in the PV system.
- Losses in a solar PV system arise from weather factors, site constraints and voltage drop.
- Under actual conditions, solar panels generate only about 65% of the rated output power

Energy Yield = Peak Sun Hour X Module Rated Power X Panel Performance ratio

Taking measurements

- As with any installation job, you need to understand, which measurements are important.
- As the supervisor in charge of installation, you must be familiar with how to take measurements and interpret the results.
- For photovoltaic installations, the most important measurements are: Solar irradiance, Length, angles, Current, voltage and power

Solar irradiance

- This is the quantity of solar resource available at the installation site. For large multimegawatt systems, this measurement is taken using a pyranometer or a pyrheliometer.
- Prior to installation, solar irradiance is usually measured for multi-megawatt projects over longer periods of time (i.e. as longitudinal data over 6 to 12 months).
- For smaller domestic or commercial systems, solar irradiance is mostly measured for system evaluation purposes

Lengths

- Knowing how to measure linear distances and lengths is critical for planning the installation of a solar PV system. Some of the linear measurements that you shall be required to take include:
  - Length of each cable type to be installed
  - Position of the solar PV modules
  - Length of shadow cast by modules, trees or other objects

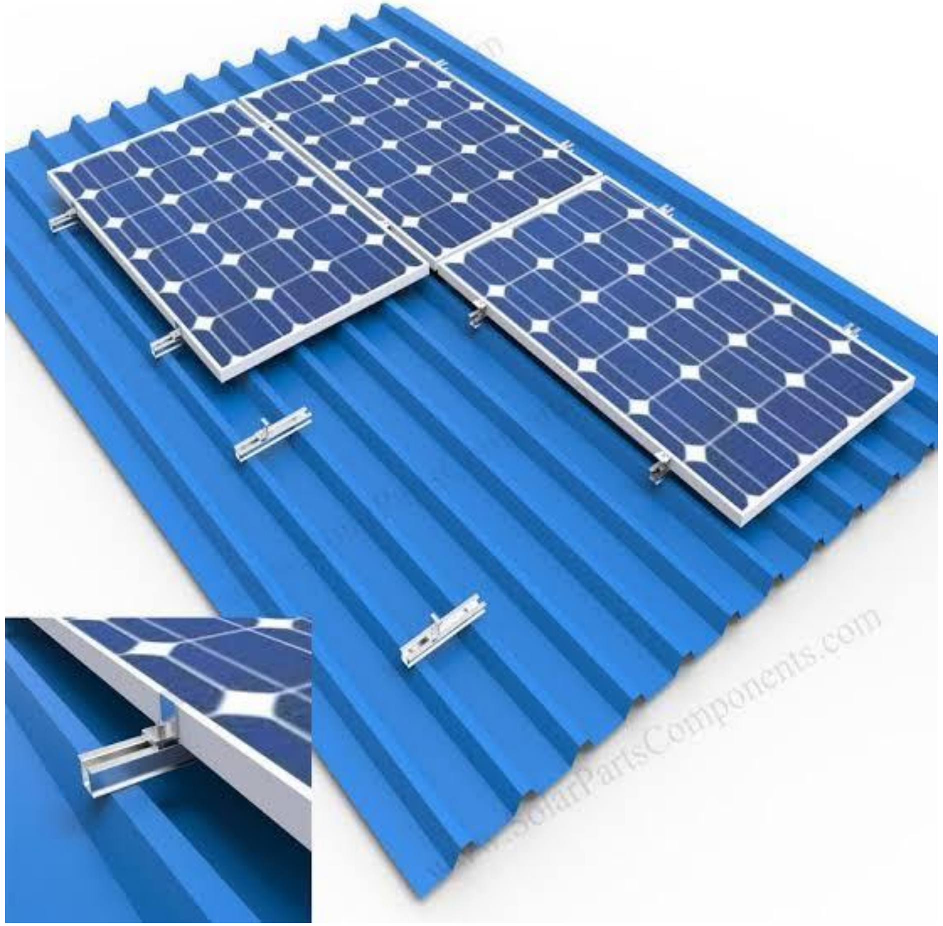
Lengths are measured using a tape measure.

Angles

- To properly install a solar PV system, you need to be conversant with angles and trigonometry.
- This is critical when determining parameters such as the angle of inclination and the minimum distance to mitigate shading. Angle measurements can be taken using instruments such as an inclinometer.

Temperature And Wind Consideration

- Because the efficiency of solar panels decreases as temperature increases, solar panels mounting system should allow for spacing around the individual solar panels for air circulation.
- The idea is to allow air cooling in the hot sun to reduce the temperature of the solar panels.



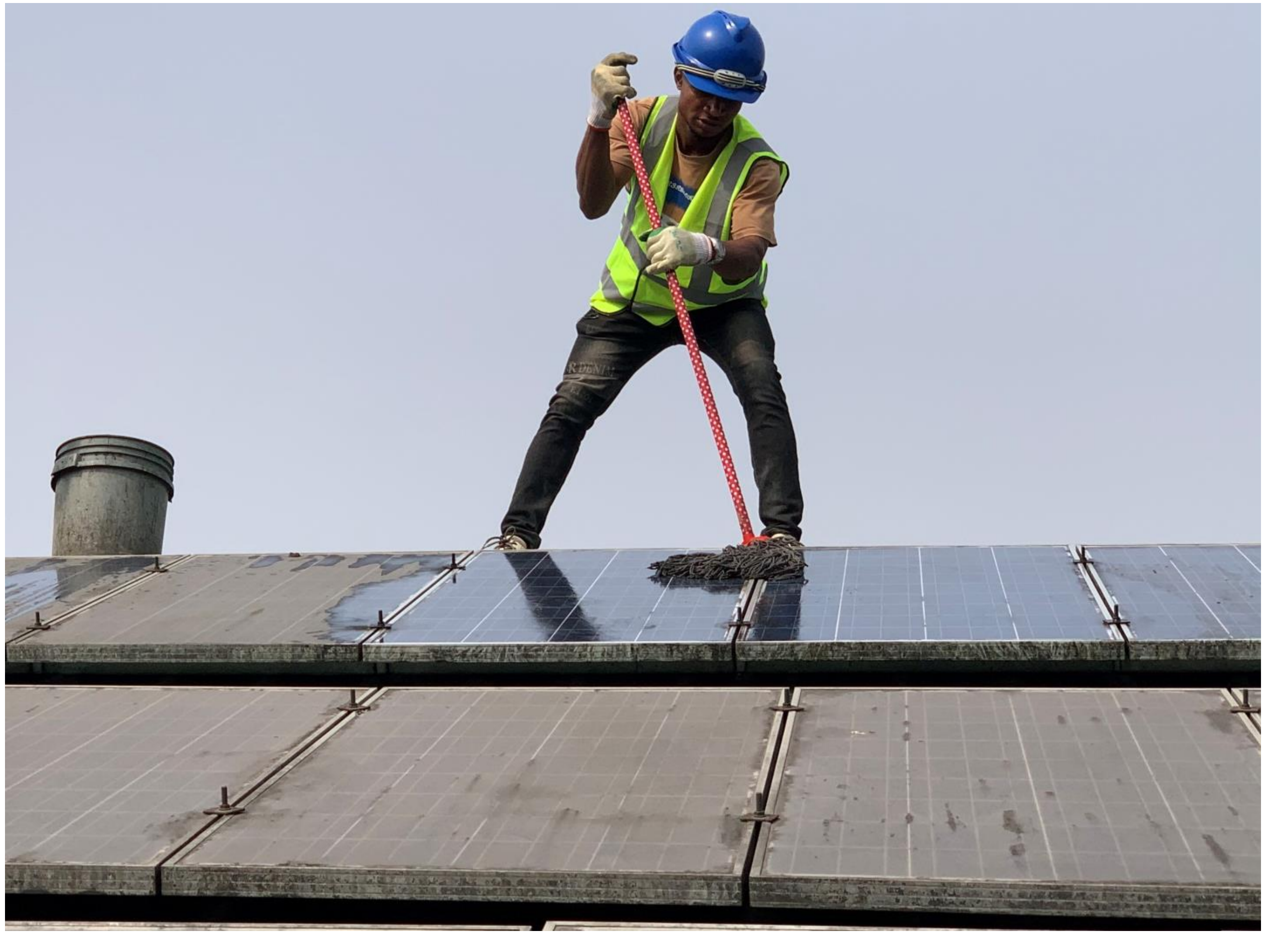
Current, voltage and power

- The solar PV system is an electrical power supply system.

- Your ability to use a multimeter (Clamp) to measure electrical parameters such as current and voltage is critical for your success as a solar installer.

Maintenance of solar panel

- The solar system is characterized with low maintenance mainly due to the absence of moving parts.
- Regular maintenance involves inspection for damage and simple cleaning if necessary.



Buying Used Solar Panels

- Purchasing used solar panels for residential or commercial installations presents multiple problems that far outweigh the possible economic benefits.
- Used solar panels can be on sale for different purposes, but mainly there are two reasons:
  - First, the homeowner no longer wants to use all the panels for his/her PV system and wants to get some money back.
  - Second, the solar panels suffered some sort of damage, or their performance is not what was expected from them.
- Solar panels also degrade over time, and it is hard to specifically estimate the number of years that the solar panel has been working.
- Used solar panels have another problem that is related to technology. The solar panel industry has quickly evolved in the last decade.

Solar Panels in the Market

- 12V 5W
- 12V 10W
- 12V 20W
- 12V 30W
- 12V 40W
- 12V 50W
- 12V 60W
- 12V 80W
- 12V 85W
- 12V 100W
- 12V 130W
- 12V 140W
- 12V 150W
- 12V 170W
- 12V 180W

- 12V 190W
- 24V 190W
- 24V 200W
- 24V 230W
- 24V 250W
- 24V 280W
- 24V 300W
- 24V 320W
- 24V 320(Half cut)
- 24V 375W
- 24V 380(Half cut)
- 24V 400(Half cut)
- 24V 440(Half cut)

Solar panel brands

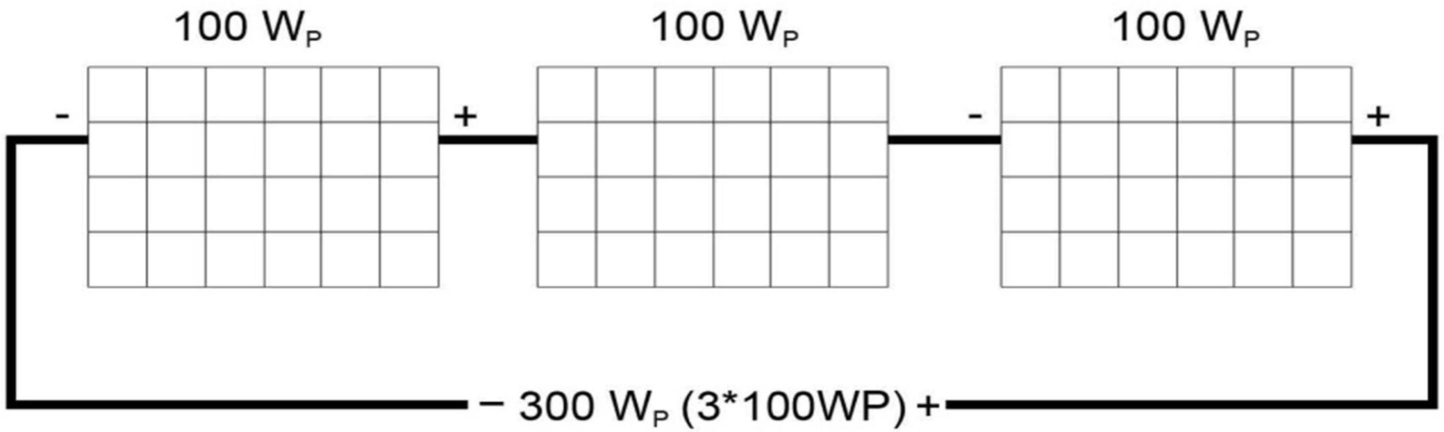
- Jinko
- LG
- LONGi
- Yingli
- Trina
- JA Solar
- Auxano Solar
- Hanwha Q CELLS
- ERA Solar
- Canadian Solar
- First Solar
- ReneSolar
- Kyocera
- SunPower Corp
- First Solar
- Solyndra
- Unisolar

PV array connection

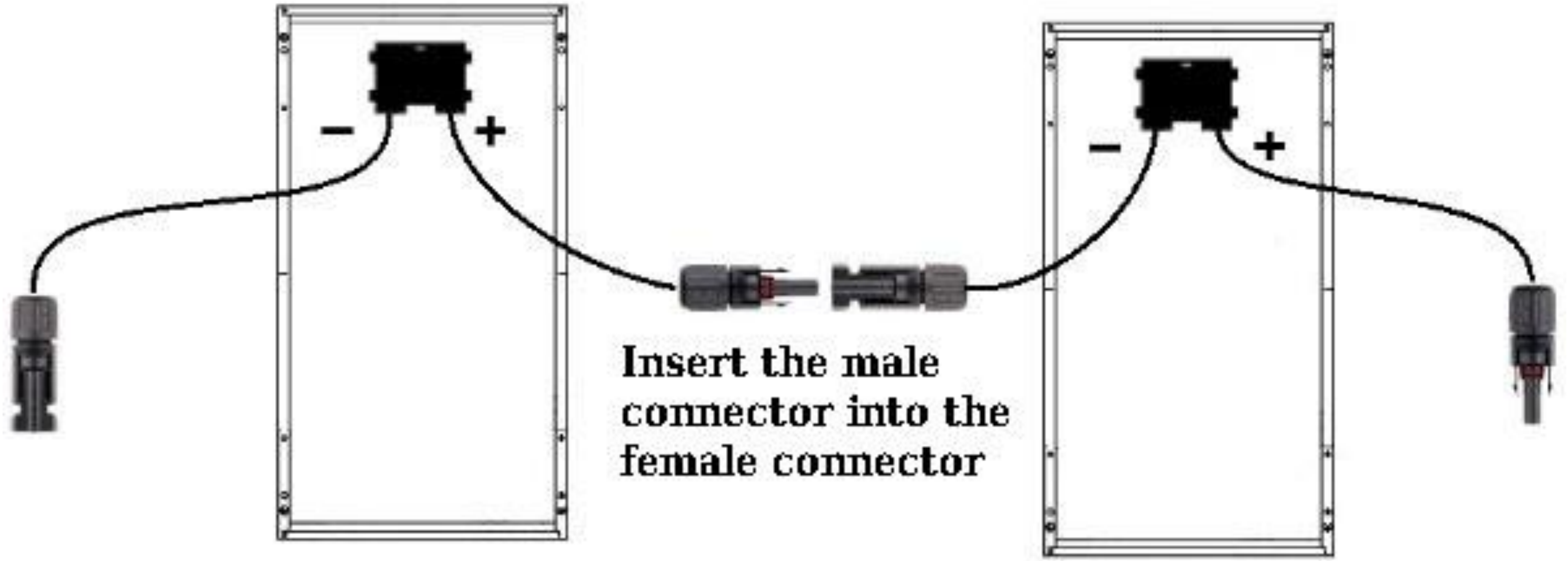
- Solar panels are connected to form arrays. When solar panels are connected to form an array, the total power from that array is the sum of the power rating of each individual solar panel.
- Interconnecting solar panels to form an array can be done in three different ways.
  - Series connections to increase the output voltage of the solar panel array.
  - Parallel connections to increase the output current of the solar panel array.
  - Series-parallel connections to increase both the output voltage and the current of a solar panel array.
- A series connected set of solar cells or modules is called a **string**

Connecting identical solar panels in an array

- For example, if you have three solar panels that are rated at 100 WP and they are to be connected either in series or parallel combinations, the total output power from the array will be 300 WP.

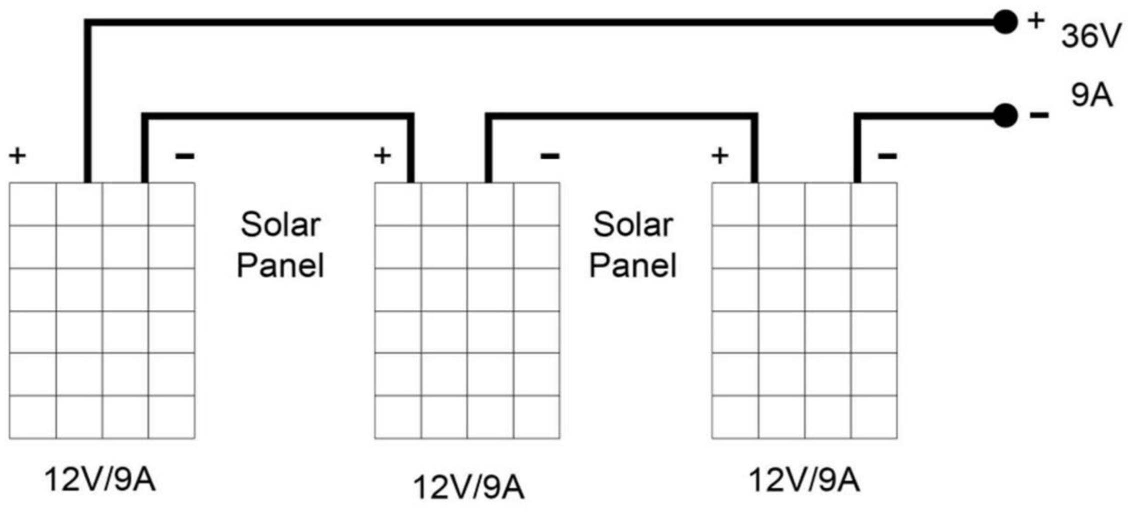


Connecting solar panels in Series using MC4 Connectors



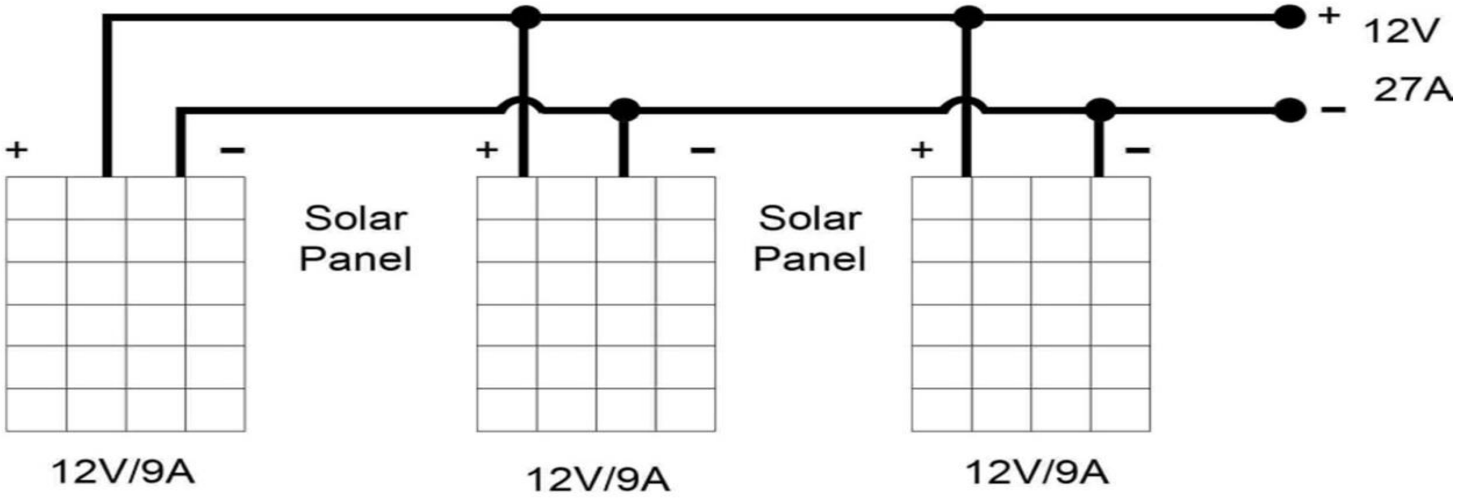
Solar panels in series

- To connect solar panels in series, the positive (+) terminal of a solar panel is connected to the negative (−) terminal of the next solar panel in the array.

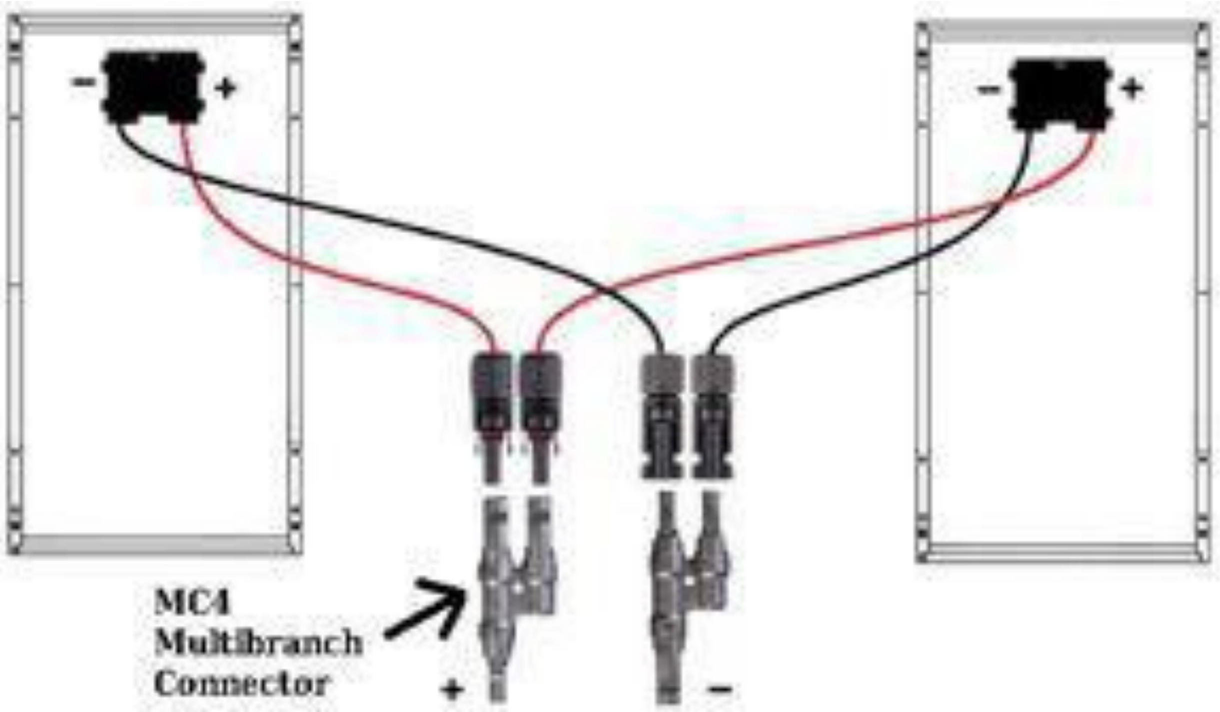


Solar panels in parallel

- To connect solar panels in parallel, the positive (+) terminal of a solar panel is connected to the positive (+) terminal of the next solar panel in the array.

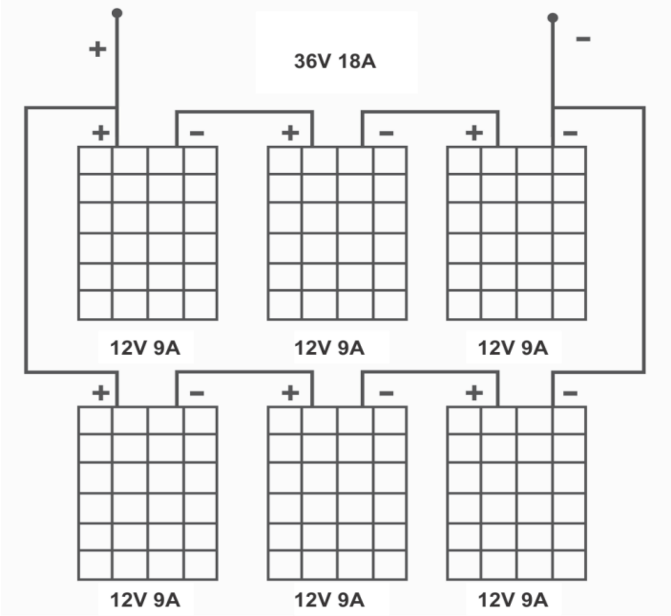


Connecting solar panels in Parallel using MC4 Connectors

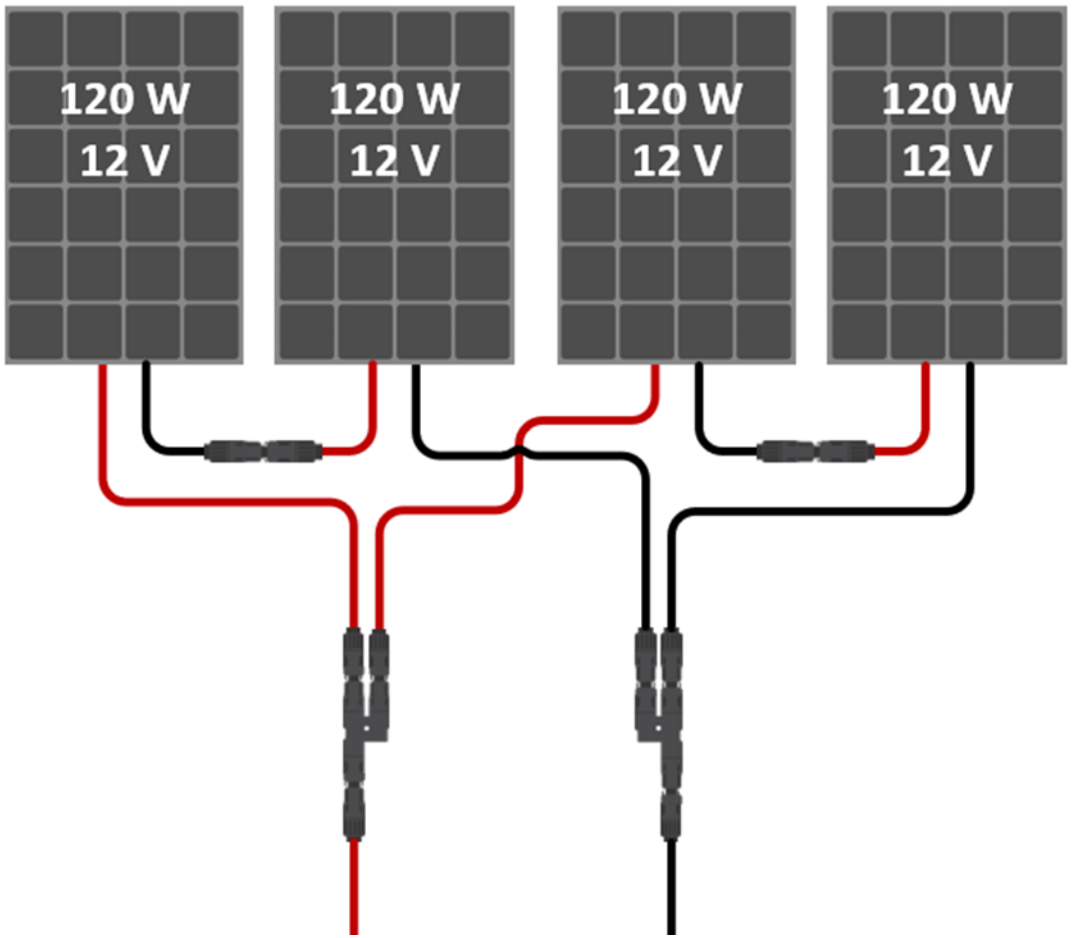


Solar panels in series-parallel

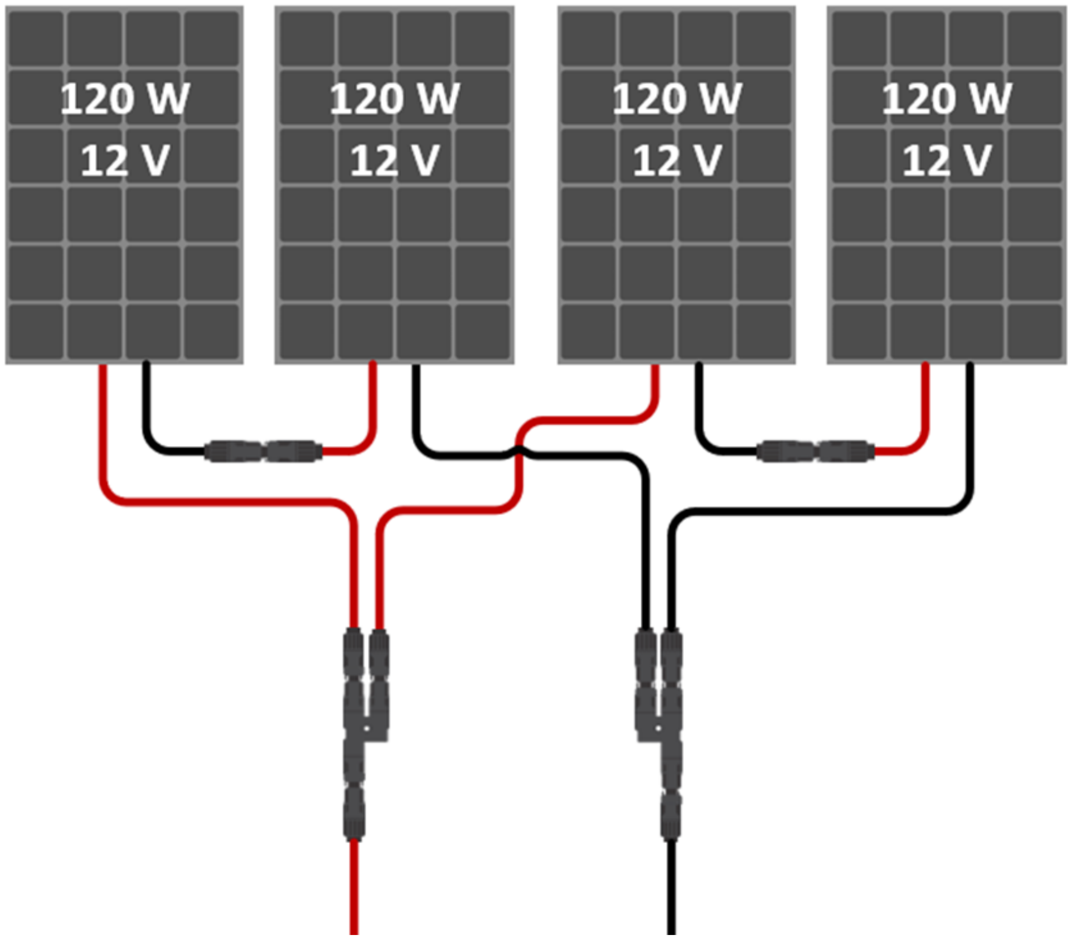
- When wiring solar Panels in Series-parallel, both the amperage and voltage are addictive. When connecting panels in series parallel, we connect three panels in series twice then, we connect the loosed end of each string. The positive wires connect to the main positive wire, and the negative wires connect to the main negative wire.



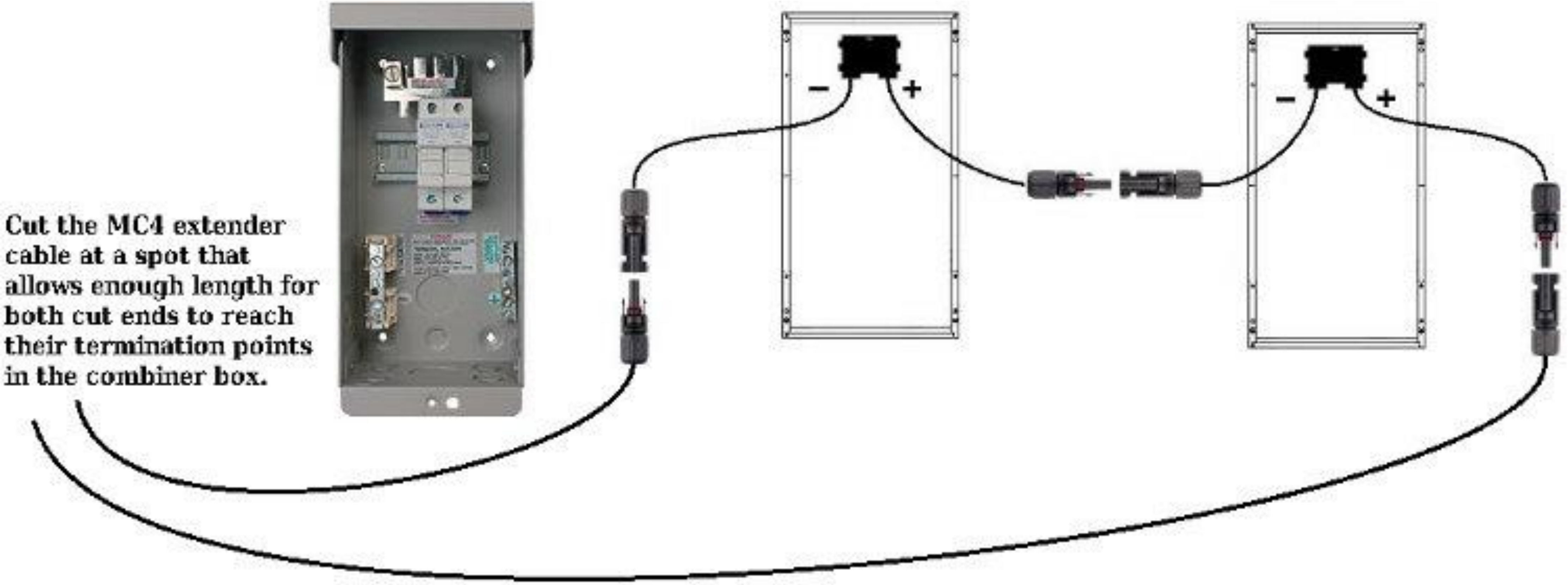
Connecting solar panels in Series-parallel using MC4 Connectors



Connecting solar panels in Series-parallel using MC4 Connectors



MC4 extension cable



Tools and connectors required for PV module wiring