SRI CHANDRASEKHARENDRA SARASWATHI VISWA MAHAVIDYALAYA

Deemed to be University U/S3 of the UGC Act, 1956

Accredited with ‘A’Grade by NAAC

Enathur, Kanchipuram -631 561.

Department of Electrical & Electronics Engineering

Solar PV Systems Design Simulation and Monitoring Control and Maintenance

(As per NSDC Surya Mitra Course)

Course Material

Dr.D.Vanitha

JUNE 2023

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Prepared By

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Open Elective Course

B.E Regular – VII Sem & BE PT – VI Sem

Solar PV systems Design Simulation and Monitoring Control and Maintenance

(As per NSDC Surya Mitra Course)

Unit- 1 Introduction to solar PV installation

Basics of solar energy systems and power generation, DNI, GHI and diffused irradiance and radiation, solar energy compound such as panels, batteries, charge controllers, Inverters – Series and parallel connection of solar batteries – Handling procedure for solar panels – Energy storage control and conversion – Panel mounting and inclination and angle of tilt – Placement of solar panel mounting – sunlight and direction assessment – Tools involved in installation of system. Types of solar photo voltaic system – ON grid and OFF grid connected solar systems – Stand-alone systems

Unit –II Commissioning of solar systems

Charge controller – Inverters – ON grid and OFF grid system components – Testing equipments – Application equipments – Clamping accessories for installation – Identification of load to be connected – Reading and interpreting the single line diagrams –Site survey before installation – Testing of solar system components including fault finding and analysis including continuity testing and polarity checking – Fundamentals of earthing for solar systems.

Unit – III Testing import and export of Solar systems

Regulations and standards for solar interconnection of solar cells – Testing for import and export of solar energy – Testing and verify inverter operation and including anti- islanding functioning, over loading testing for power quality of a roof top solar systems – Testing for phase imbalance.

Reference/ Text Books

1. "Solar Photo Voltaic- Fundamentals, Technologies and Applications", Chetan Singh Solanki, PHI Learning Pvt. Ltd, 2012.

2. "Terrestrial Solar Photovoltaics" , Tapan K. Bhattacharya, London Narosa Publishing House,1998.

3. NPTEL Course Videos: "Design of photovoltaic systems", Prof. Dr. L. Umanand, Department of Electronics System Engineering (DESE) of Indian Institute of Science, Bangalore.

Unit - 1

Solar Measurements

Energy from solar can be utilised by two forms. One way of utilisation is heat energy from solar. Another way of utilisation is light energy from solar is converted into electrical energy. We are going to discuss about how the solar energy will be concerted in to light energy, measuring instrument in solar radiation, solar panels types, classification of PV systems, types of batteries used in solar PV systems, components and tools used in solar PV systems in detail.

Energy can be classified

1. Primary and Secondary energy
2. Commercial and Non-commercial energy
3. Renewable and Non-Renewable energy
4. Conventional and Non-conventional energy

Commercial Energy : The energy sources that are available in the market for a definite price are known as commercial energy. Most important forms of commercial energy are electricity, coal and refined petroleum products. Commercial energy forms the basis of industrial, agricultural, transport and commercial development in the modern world.

Example: Electricity, lignite, coal, oil, natural gas etc.

Conventional Energy

Conventional energy resources which are being traditionally used for many decades and were in common use around oil crisis of 1973 are called conventional energy resources, e.g., fossil fuel, nuclear and hydro resources.

Non-conventional energy (NCE)

Non-conventional energy resources which are considered for large - scale use after oil crisis of 1973, are called non-conventional energy sources, e.g., solar, wind, biomass, etc.

Merits:

1. NCES are available in nature, free of cost.

2. They cause no or very little pollution. Thus, by and large, they are environmental friendly.

3. They are inexhaustible.

4. They have low gestation period.

Demerits:

1. Though available freely in nature, the cost of harnessing energy from NCES is high, as in general, these are available in dilute forms of energy.

2. Uncertainty of availability: the energy flow depends on various natural phenomena beyond human control.

3. Difficulty in transporting this form of energy.

PHOTOVOLTAIC (PV) - The process of converting light energy into electric energy.

Any physical activity in this world, whether carried out by human beings or by nature, is cause due to flow of energy in one form or the other The work output depends on the energy input.

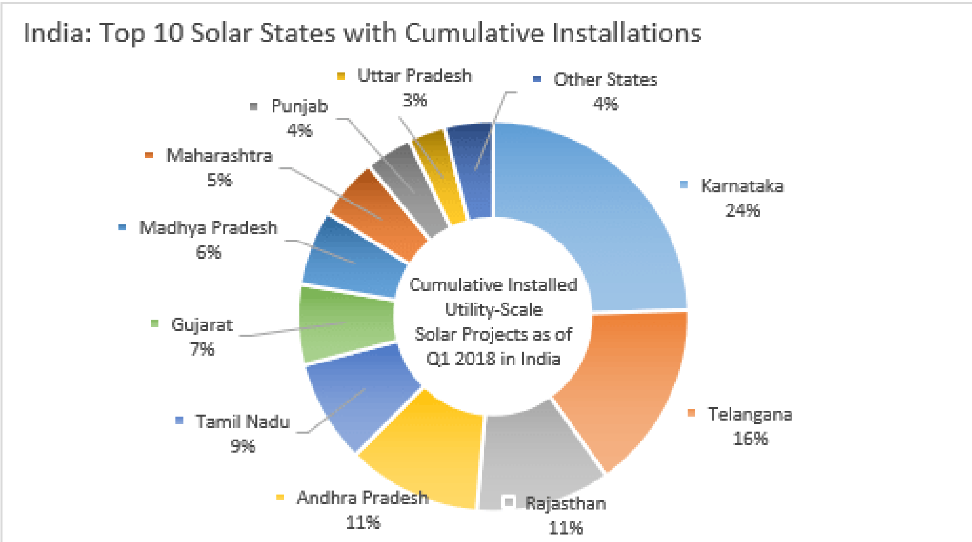
Energy is one of the major inputs for the economic development of any country. In the case of the developing countries, the energy sector assumes a critical importance in view of the ever increasing energy needs requiring huge investments to meet them

PV INDUSTRY INDIA

Solar power in India is a fast developing industry. The country's solar installed capacityreached 37.627 GW as of 31 March 2020. India has the lowest capital cost per MW globally toinstall solar power plants.

Installed solar PV on 31 March

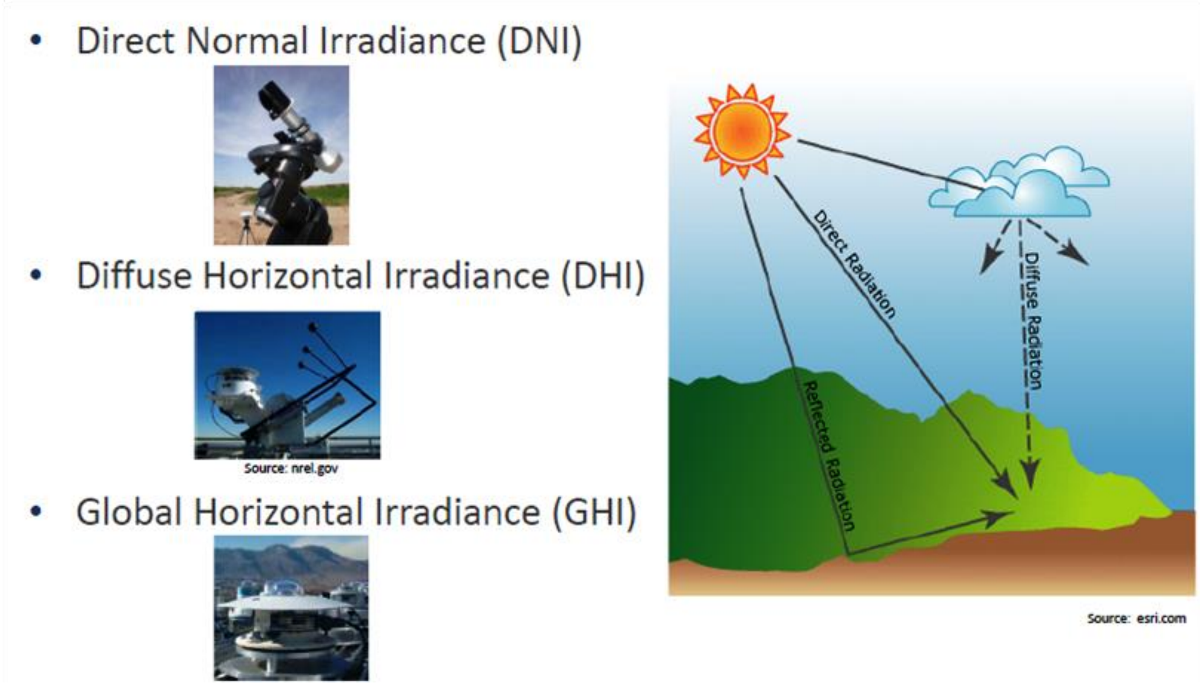
Year	Cumulative Capacity (in MW)
2010	161
2011	461
2012	1,205
2013	2,319
2014	2,632
2015	3,744
2016	6,763
2017	12,289
2018	21,651
2019	28,181
2020	37,627



Basic Definition in Solar PV

Direct Normal Irradiance (DNI) is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky.

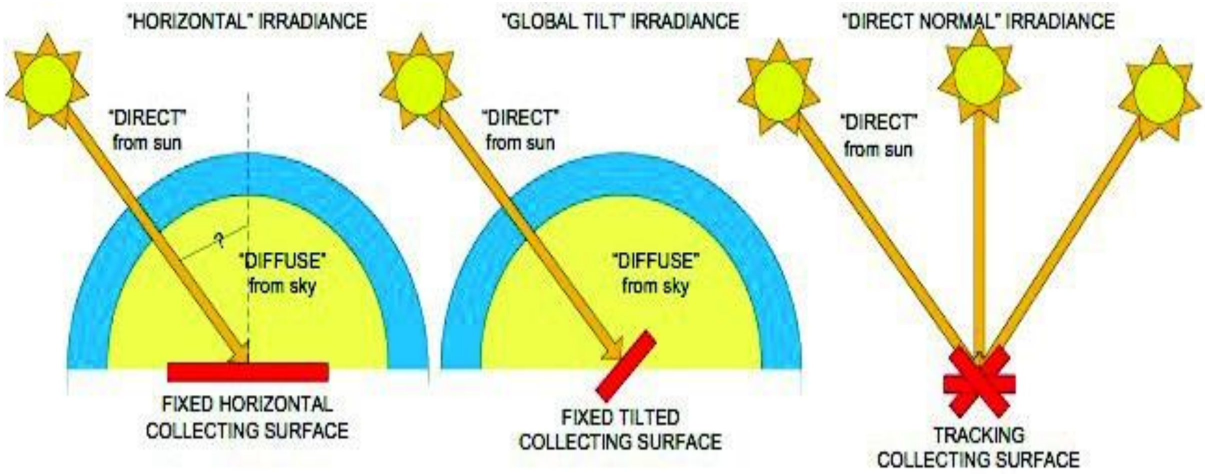
Typically, you can maximize the amount of irradiance annually received by a surface by keeping it normal to incoming radiation. This quantity is of particular interest to concentrating solar thermal installations and installations that track the position of the sun.



Diffuse Horizontal Irradiance (DHI) is the amount of radiation received per unit area by a surface (not subject to any shade or shadow) that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and comes equally from all directions

Global Horizontal Irradiance (GHI) is the total amount of shortwave radiation received from above by a surface horizontal to the ground. This value is of particular interest to photovoltaic installations and includes both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI).

Global Horizontal (GHI) = Direct Normal (DNI) X cos(θ) + Diffuse Horizontal (DHI)



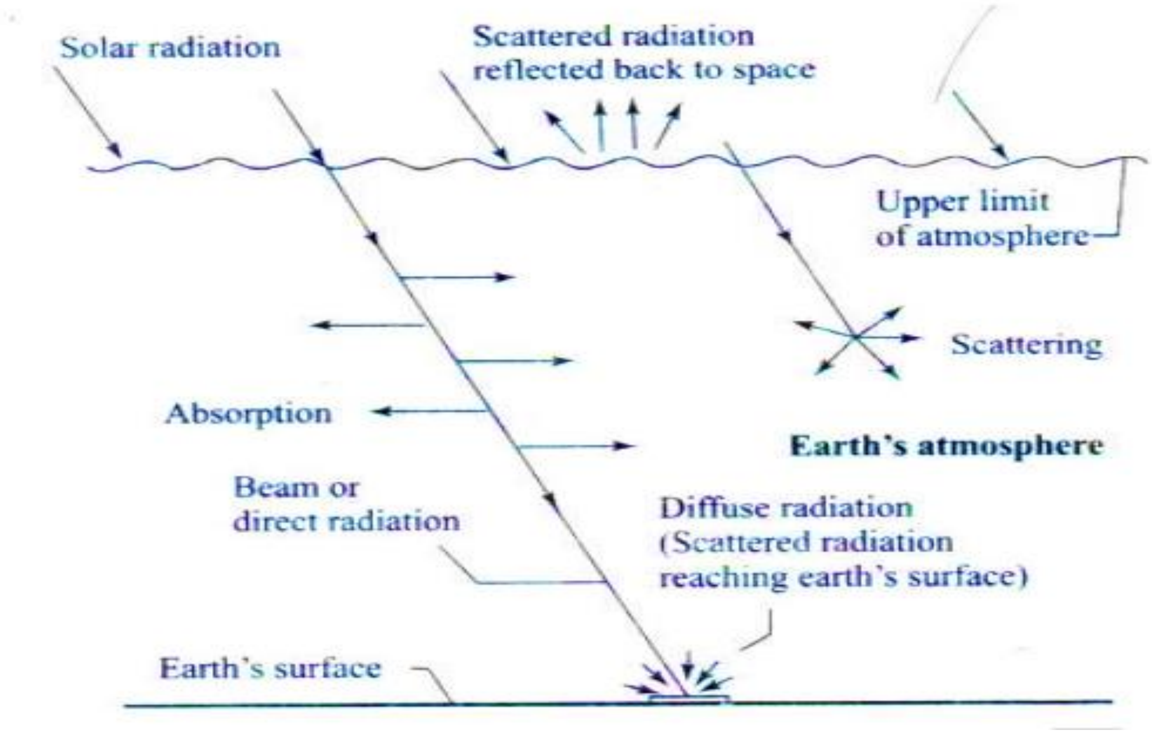
1.**Solar Radiation Outside The Earth's Surface:**

Sun is a large sphere of very hot gases, the heat being generated by various kinds of fusion reactions.

It's diameter is $1.39X10^6$km, while that of the earth is $1.27X10^4$ km.

It subtends an angle of 32minutes at the earth's surface. This is because it is also at large distance.

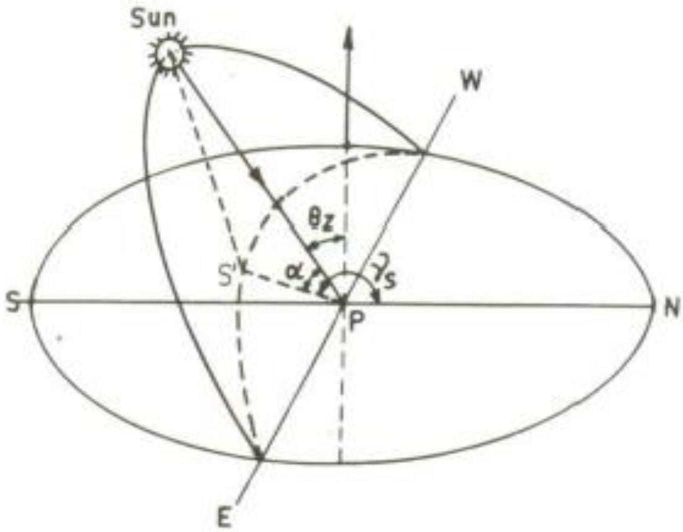
The brightness of the sun varies from it's centre to it's edge.



(b) Zenith angle(θz):

It is Complementary angle of Sun's Altitude angle

It is a vertical angle between Sun's rays and line perpendicular to the horizontal plane through the point i.e. angle between the
Beam & the vertical.



(c) Solar Azimuth Angle(γs):

It is the solar angle in degrees along the horizon east or west of north or

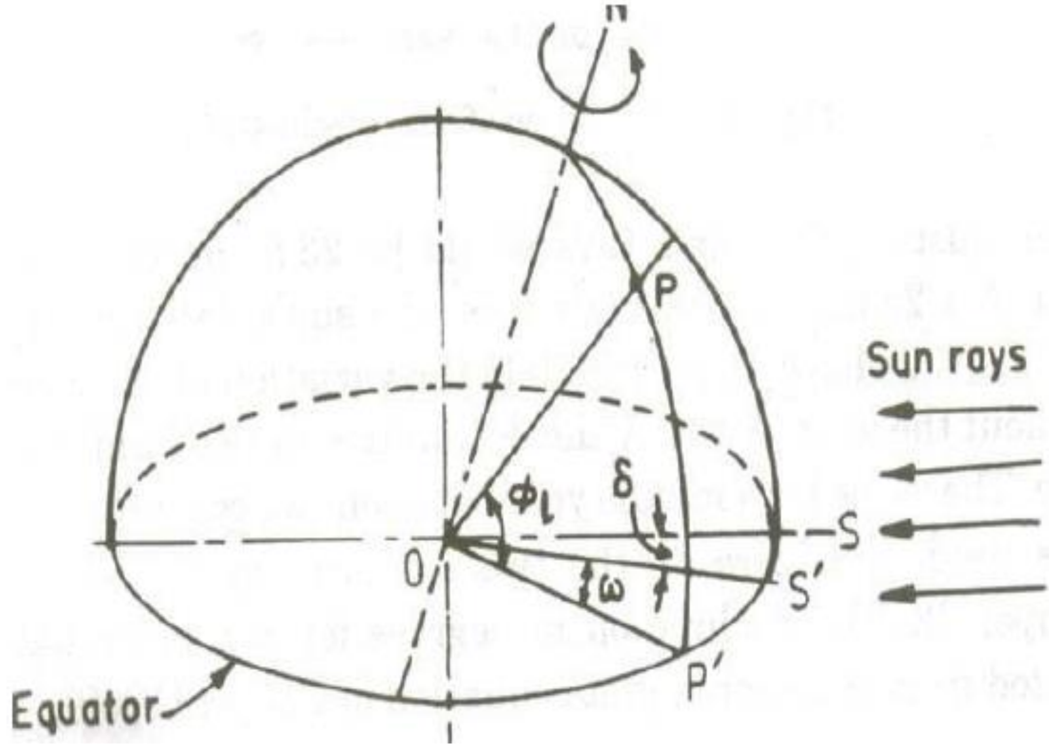
It is the horizontal angle measured from north to the horizontal projection of sun's rays.

(d) Declination(δ):

It is the angle between a line extending from the centre of the Sun and center of the earth and projection of this on earth's equatorial planeThe declination formula is given by

$$\delta = 23.45\ Sin\left\{\frac{360}{365}(284 + n)\right\}$$

Where n is the day of the year



(e) Meridian:

Meridian is the imaginary line passing through a point or place on earth and north and south poles of the earth.

(f) Hour angle(ω):

Hour angle is the angle through which the earth must turn to bring meridian of the point directly in line with the sun's rays. Hour angle is equal to 15° per hour.

(g) slope(β):

Angle between the collector surface with the horizontal plane is called slope(β).

(h) surface azimuth angle(γ):

Angle between the normal to the collector and south direction is called surface azimuth angle(γ)

(i) Solar Incident angle(θ):

It is the angle between an incident beam radiation falling on the collector and normal to the plane surface

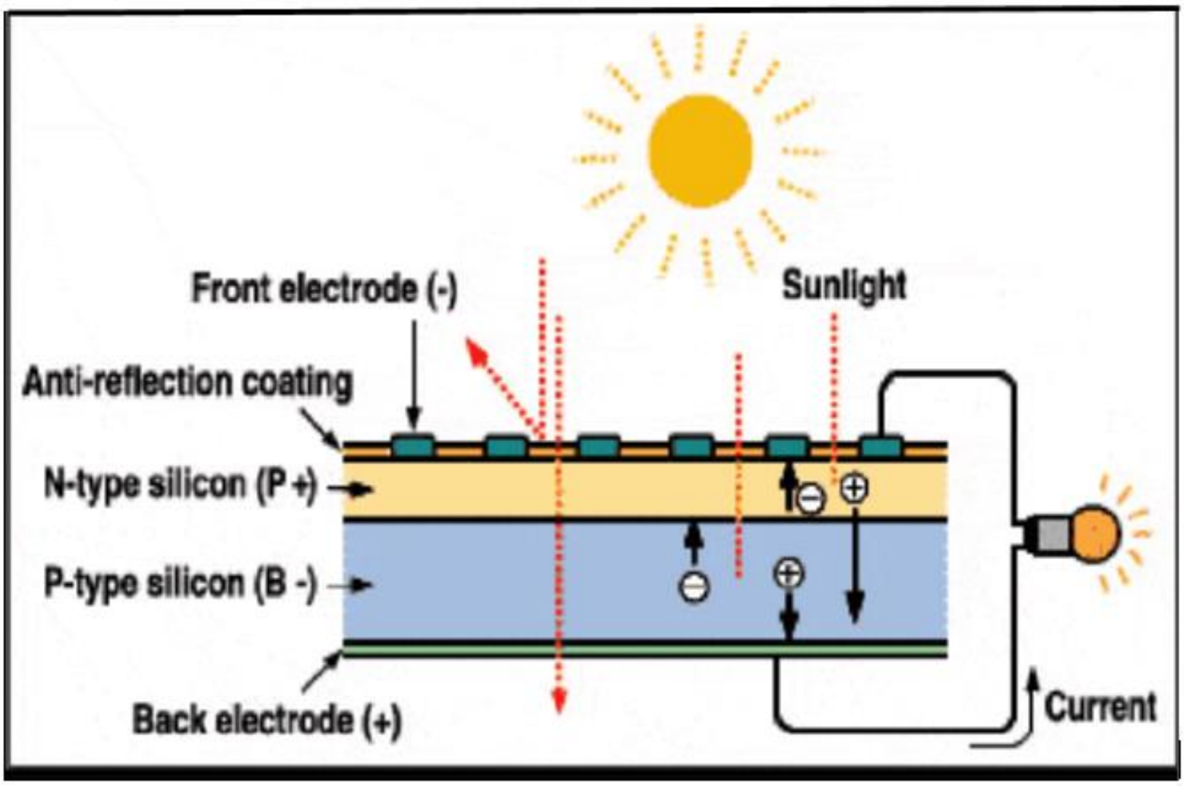
Photovoltaic Phenomena

Solar Cell : Solid state device that converts incident solar energy directly into electrical energy

The junction of dissimilar materials (n and p type silicon) creates a voltage

Energy from sunlight knocks out electrons, creating a electron and a hole in the junction

Connecting both sides to an external circuit causes current to flow



In essence, sunlight on a solar cell creates a small battery with voltages typically 0.5 v. DC

It consists of a 0.2–0.3mm thick mono crystalline or polycrystalline silicon wafer having two layers with different electrical properties formed by ''doping'' it with other impurities (e.g., boron and phosphorus).

An electric field is established at the junction between the negatively doped (using phosphorus atoms) and the positively doped (using boron atoms) silicon layers.

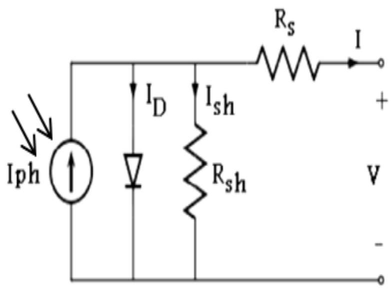
If light is incident on the solar cell, the energy from the light (photons) creates free charge carriers, which are separated by the electrical field. An electrical voltage is generated at the external contacts, so that current can flow when a load is connected.

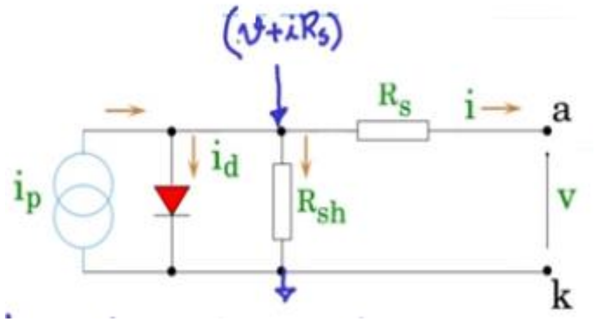
The photocurrent **(Iph),** which is internally generated in the solar cell, is proportional to the radiation intensity.

A simplified equivalent circuit of a solar cell consists of a current source in parallel with a diode as shown in Fig.

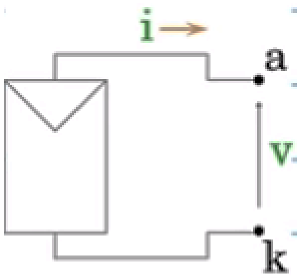
'The solar-cell-model with serial and parallel-resistance' is depicted in Fig & consists of diode & current-source connected-parallel. Voltage-source& the parallel-resistance $\mathbf{R_{pv}}$ constitute the current-source.

Current source current is directly proportional to the solar radiation.





Equivalent model of PV cell   Equivalent circuit of PV cell



Symbol of PV cell

From the above equivalent circuit

$i_p = i_d + i_{sh} + i$

Where

i_p – Photo current

i_d – Diode current

i_{sh} – Current in the shunt path

i – Output current

From this terminal current " i " is

$$i = i_p - i_d - i_{sh}$$

$$i_{sh} = \frac{(V + iR_s)}{R_{sh}}$$

According to PN junction theory

$$i_d = I_s \left(e^{V + iR_s / nV_T} - 1 \right)$$

$$i = i_p - i_s \left(e^{V + iR_s / nV_T} - 1 \right) - \frac{(V + iR_s)}{R_{sh}}$$

Performance of the PV cell can be analysed based on the above equation.

Where,

i_d	-	Diode-current (A),
i_{sh}	-	Current in the shunt resistance in (A)
V	-	Terminal voltage
i_s	-	Diode-reverse saturation-current (A)
	≈	range 10^{-8} A/m^2
V	-	Diode-voltage (V)
V_T	-	Thermal-voltage (see-equation-below')
	=	V_T = 25.7 mV-at 25°C
n	-	Diode ideality factor = 1...2 (-n = 1-for-ideal-diode)

V_T - Thermal-voltage (V) can be estimated with-the subsequent-equation:

$$V_T = \frac{K.T}{q}$$

'k' - Boltzmann-constant = $1.38 \cdot 10^{-23}$ J/K,

'T' - Temperature (_K)

'q' - Charge-of-electron = $1.6 \cdot 10^{-19}$ As

I – V Characteristics of PV cell

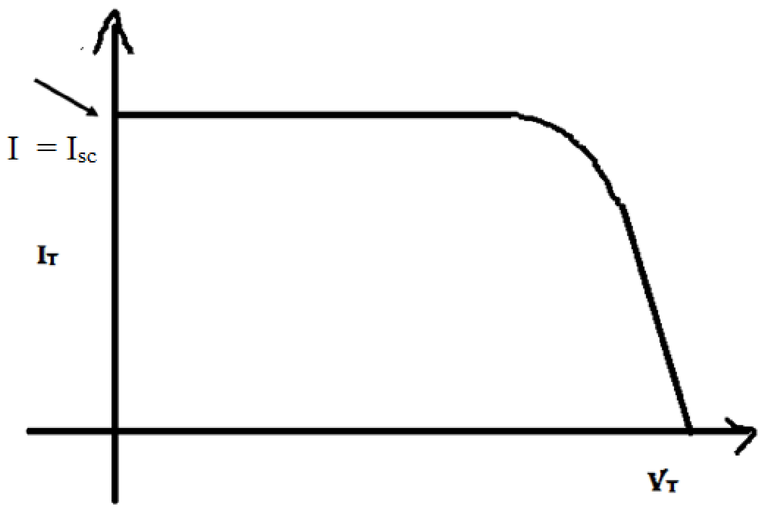
In that exceeding solar model equivalent circuit, we can relate Kirchhoff current Law, current from the solar-cell is

$$i = i_p - i_s\left(e^{V+iR_S/nV_T} - 1\right) - \frac{(V+iR_S)}{R_{sh}}$$

This is I - V characteristic curve of a PV diode

If 'R_S>> R_{SH}', than

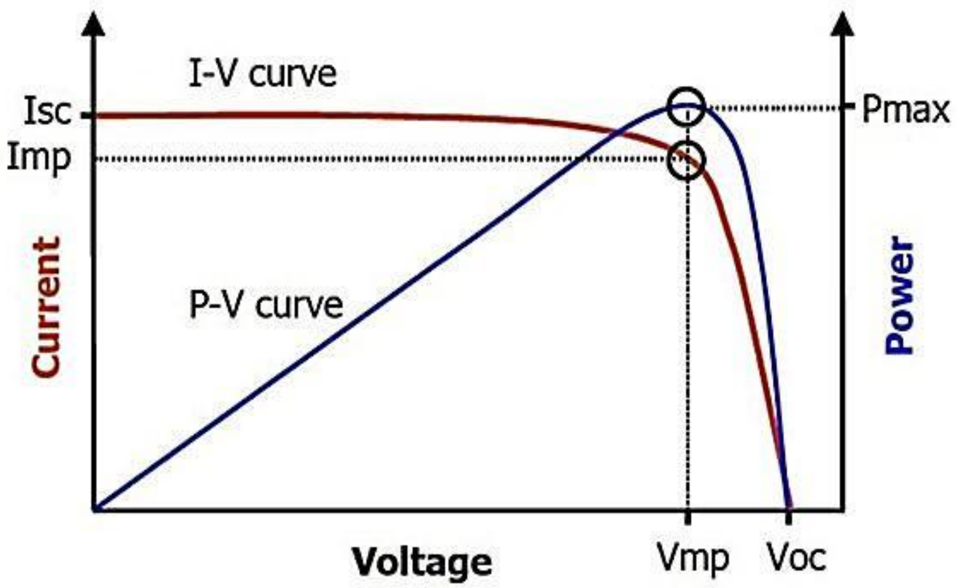
$$I = I_{PH} - I_S\left(e^{\left(\frac{V+IR_S}{V_T}\right)} - 1\right)$$



Following **four parameters** are regarded while obtained the 'I-V and P-V' characteristics-curves

'Short circuit current (I_{SC})' is the maximum current in flows in the PV-cell, when P and N are short circuited. At that time PV-cell voltage (V=0) is 0. It will be in terms of milliamps per centimetre square.

Open circuit voltage (V_{OC}) is the maximum voltage across the PV-cell (panel), when they kept open i.e., I=0. It will be in terms of milli-volts to few volts.



Maximum Power Point (P_m or P_{max}): It is the maximum power a solar cell produces underSTC. The higher the P_m, the better is the cell. It is given in terms of Watt (W). Since it is the maximum power or the peak power, it is sometimes referred as W_{peak} or W_p. It islocated at the knee of the IV Curve.

$$P_m \text{ or } P_{max} = I_m \times V_m$$

Current at Maximum Power Point (I_m): This is the current which solar cell will produce when operating at maximum power point. The I_m will always be less than I_{sc}. It is givenin terms of Ampere (A) or milli-ampere (mA).

Voltage at Maximum Power Point (V_m): This is the voltage which solar cell will produce when operating at maximum power point. The V_m will always be less than V_{oc}. It is givenin terms of volts (V) or milli-ampere (mV).

Fill-factor (FF) is the ratio of maximum-power (P_{Max}) obtained from the PV-cell to ideal power (P_o). It will be represented in terms of percentage.

$$\boldsymbol{Fill\ Factor\ (FF) = \frac{P_{MP}}{P_O} = \frac{(V_{MP} I_{MP})}{(V_{OC} I_{OC})}}$$

$$\mathbf{FF = I_m \times V_m / I_{sc} V_{oc}}$$

$$\mathbf{FF = P_m / I_{sc} \times V_{oc}}$$

$$\mathbf{P_m = I_{sc} \times V_{oc} \times FF}$$

Efficiency (η) is the ratio of output power (P_{Max}) to input power (P_{Rad}). As per the International-standards of PV cell P_{Rad} is $1000W/m^2$

$$\boldsymbol{Efficiency\ (\eta) = \frac{P_{Max}}{P_{Rad}}}$$

However, because solar energy generation is so variable, based on temperature, weather conditions, the time of day and so on, a new **watt-peak (Wp)** rating is now used specifically for solar systems.

A watt-peak rating shows how much power can be generated by asolar panel at its peak rating. It has been introduced tohighlight the fact that the amount of energy a solar panel can generate is variable and to remind consumers that a solar panel rated at 50 watts is not going to be producing 50 watt-hours of energy every single hour of every single day.

V X A = W (Volts X Amps = Watts)

24 V	x	100 A	=	2,400 W
48 V	x	50 A	=	2,400 W
120 V	x	20 A	=	2,400 W

240 V	x	10 A	=	2,400 W
480 V	x	5 A	=	2,400 W

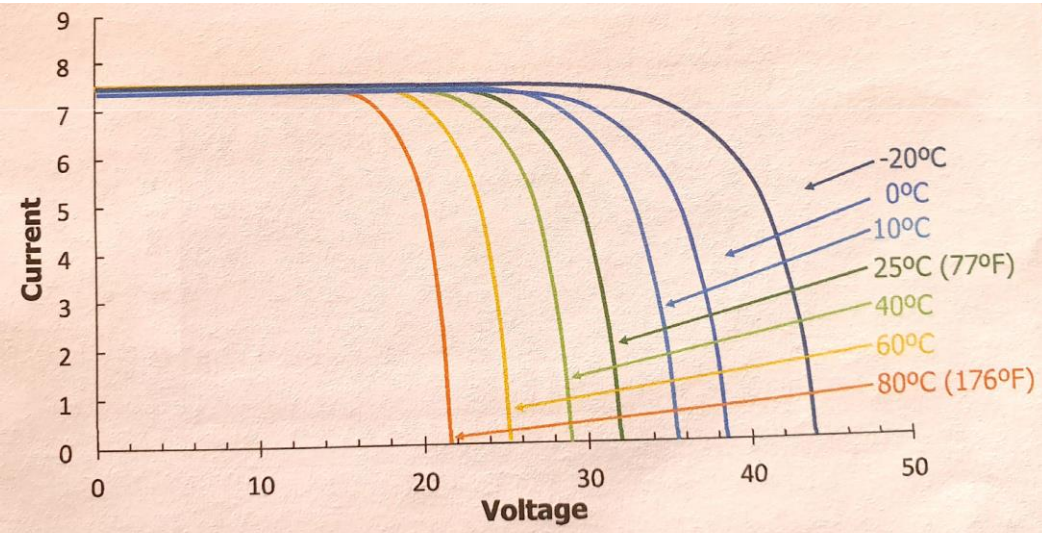
When voltage rating of the panel increases corresponding its current is decreased.

Voltage and current are inversely proportional.

Effect of Cell Temperature on Module Performance

$$i = i_p - i_s\left(e^{V+iR_s/nV_T} - 1\right) - \frac{(V+iR_s)}{R_{sh}}$$

If temperature varies V_T is varies. Even though V_T varies is not varies drastically. So V_{oc} is almost constant



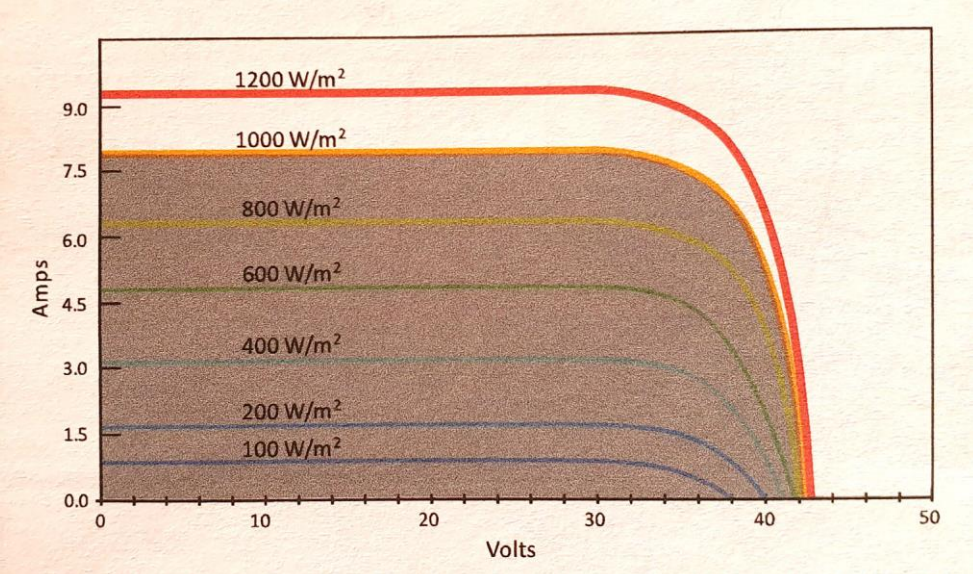
Effect of Irradiance on Module Performance

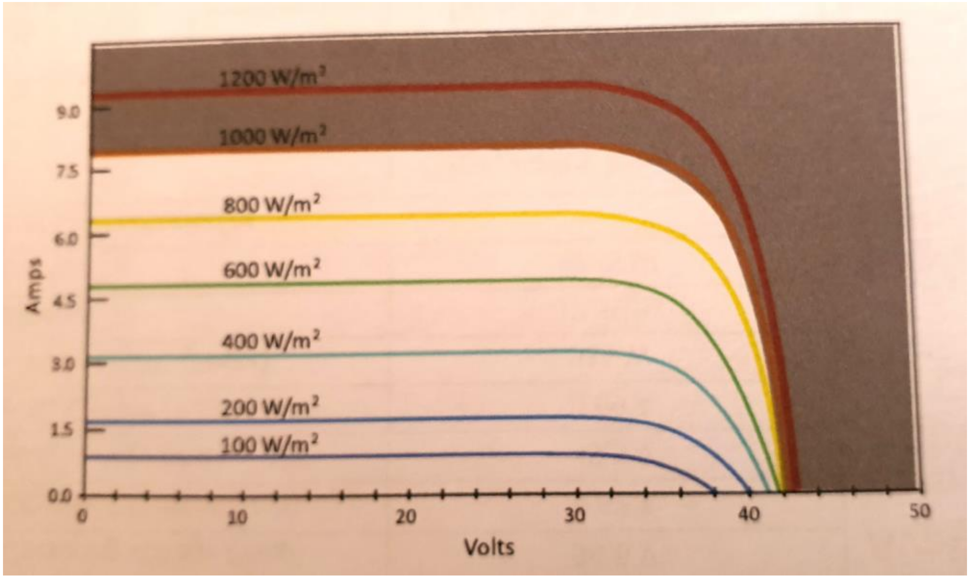
$$i = i_p - i_s\left(e^{V+iR_s/nV_T} - 1\right) - \frac{(V+iR_s)}{R_{sh}}$$

Irradiation affects the photo current. Under short circuit in the above equation Subsitute, V=0,

$$i = i_{SC} = i_p$$

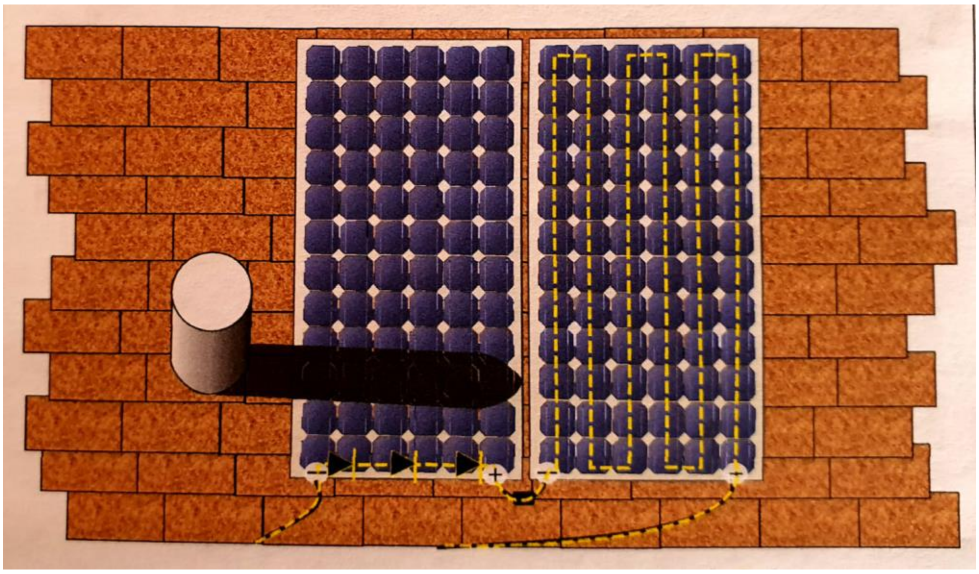
Based on the radiation fall on the surface of the PV cell photo current generated. The graph will explain the same for the different irradiations the value of $\mathbf{I_{sc}}$



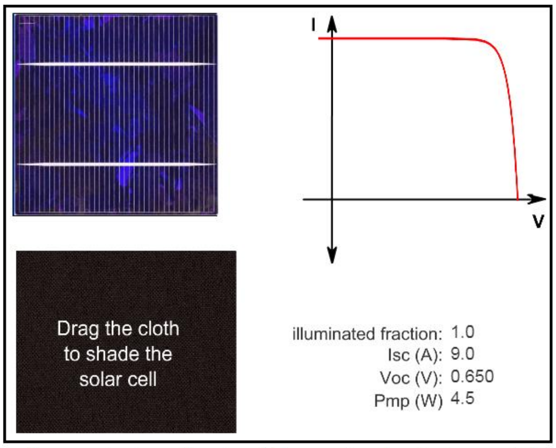


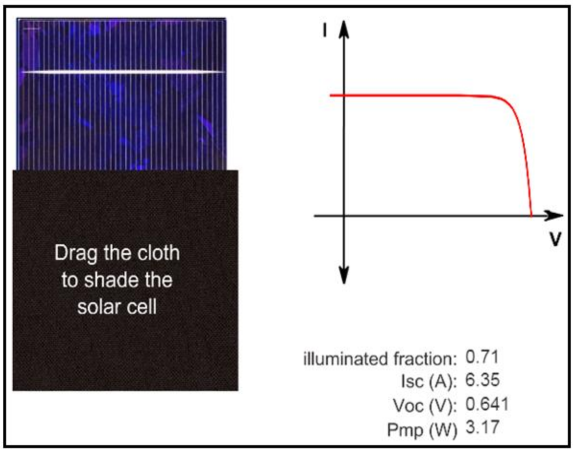
1000 W/m^2 is standard irradiation value & consider as base for all standard test condition of PV module manufacturers.

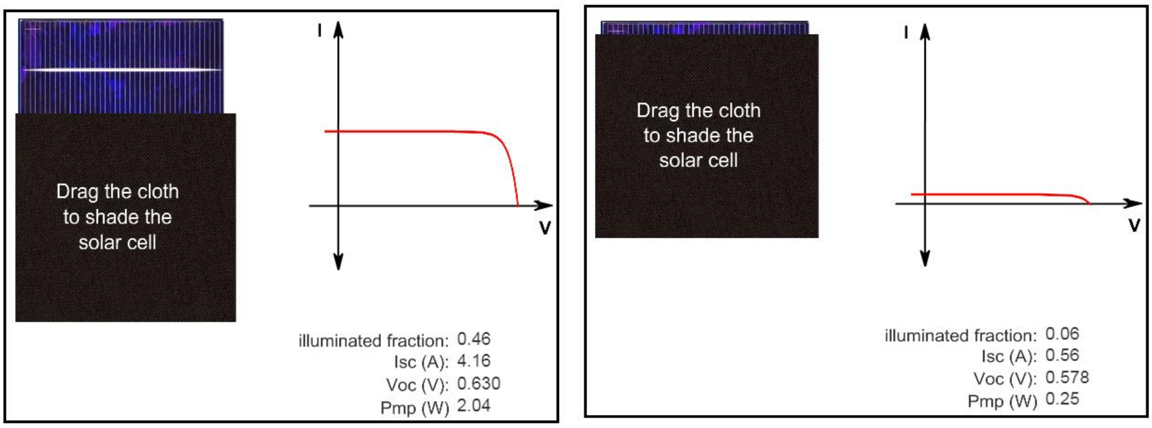
Effect of Shadow on Module Performance



An individual solar cell has an output of 0.5 V. Cells are connected in series in a module to increase the voltage. Since the cells are in series, the current has to be the same in each cell and shading one cell causes the current in the string of cells to fall to the level of the shaded cell. Typically, the module I_{SC} is reduced to the **lowest** I_{SC} of all the cells in a string. Shading just one cell in a module to half causes the output power of the whole module to fall to half. No matter how many cells there are in the string, completely shading one cell causes the output power of the module to fall to zero. The lost output power of all the unshaded cells is dissipated in the shaded cell. It is even worse at the system level, where multiple modules are in series to increase the system voltage to 600 or 1000 V and shading one cell would affect the entire module string.







Measurement of Solar Radiations:

Solar radiation can be measured by using the following instruments

1. Pyrano Meter
2. Pyrheliometer

Pyranometer:

Sun generates radiation over the range of wavelengths from 0.15 to 4.0 μm which is known as the solar spectrum. The amount of this radiation is called as global solar radiation or sometimes known as short-wave radiation. The global solar radiation can occur when both the solar radiations like direct & diffuse receives from the hemisphere on the plane of the pyranometer. It is hard to find out an environmental development on the earth which is driven directly otherwise indirectly through the energy of the sun. The measurements of global solar radiation are used in various applications for various purposes. Solar energy determines the efficiency of the panel because these panels will change the energy from the sun's energy to electrical.

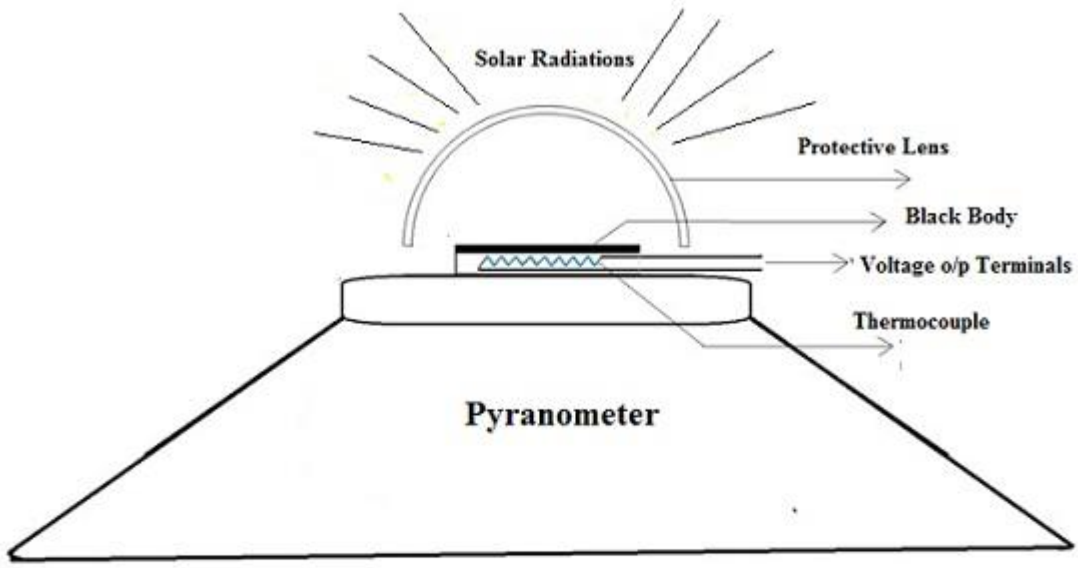
The amount of electromagnetic radiation on a solar panel can be measured to know how much power a solar panel can use from the sun. To overcome this, a pyranometer is used to measure solar radiation from all directions.

Definition: A type of actinometer used to measure irradiance of solar energy within the preferred location as well as flux density of solar radiation. The range of solar radiation extends between 300 & 2800 nm.

The SI units of irradiance are W/m^2 (watts /square meter). Usually, these are used in the fields of researches like climatological & weather monitoring, but current attention is showing interest in pyranometers for solar energy worldwide.

Pyranometer Construction

The pyrometer design or construction can be done using the following three components.



Thermopile

As the name implies, it uses a thermocouple used to notice dissimilarity in temperature between two surfaces. These are hot (labelled active) and cold (reference) accordingly. The labelled active surface is a black surface in flat shape and it is exposed to the atmosphere. The reference surface depends on the difficulty of the pyranometer because it changes from a second control thermopile to the covering of the pyranometer itself.

Glass Dome

Glass dome in the pyrometer limits the response of spectral from 300 nm to 2800 nm from 180 degrees of view. It also protects the thermopile sensor from rain, wind, etc. This construction of the second dome gives extra radiation protection among the inner dome & sensor compared to a single dome because a second dome will reduce the instrument offset.

Pyranometer Working Principle

The working principle of the pyranometer mainly depends on the difference in temperature measurement between two surfaces like dark and clear. The solar radiation can be absorbed by the black surface on the thermopile whereas the clear surface reproduces it, so less heat can be absorbed.

The thermopile plays a key role in measuring the difference in temperature. The potential difference formed within the thermopile is due to the gradient of temperature between the two surfaces. These are used to measure the sum of solar radiation.

But, the voltage which is generated from the thermopile is calculated with the help of a potentiometer. The information of radiation needs to be included through planimetry or an electronic integrator.

Types of Pyranometer

Pyrometers are classified into two types like thermopile pyranometer, photodiode-based pyranometer.

1. Thermopile Pyranometer

This type of pyranometer is used to measure the flux density of the solar radiation from a 180° angle. Usually, it measures 300nm to 2800 nm with a largely level spectral sensitivity. The first generation of this pyranometer includes the sensor that works as an active part by dividing black & white sectors equally. Irradiation was measured from the two sectors like white & black within the temperature. Here, the black sector is exposed to the sun whereas the white sector doesn't expose to the sun.

These pyranometers are normally used in climatology, meteorology, building engineering physics, photovoltaic systems & climate change research.

Photodiode-based Pyranometer

Photodiode based pyrometer is also known as a silicon pyrometer. This is used to detect the segment of the solar spectrum between 400 nm & 900 nm. This photodiode changes the frequencies of the solar spectrum to current at high speed. This change will be influenced through the temperature with the raise in current, generated by the temperature rise.
These types of pyranometers are executed wherever the amount of irradiation of the noticeable solar spectrum needs to be

measured and it can be done by using diodes with exact spectral responses.

These are used in cinema, lighting technique & photography; sometimes these are connected closely to photovoltaic system modules.

Advantages and Disadvantages

The **pyranometer advantages** are

- The temperature coefficient is extremely small
- Standardized to ISO standards
- Measurements of performance ration & performance index are accurate.
- Response time is longer compare to PV cell

The **disadvantage** of the pyranometer is, its spectral sensitivity is imperfect, so it does not observe the complete spectrum of the sun. So errors in measurements can occur.

Pyranometer Applications

The applications are

- The solar intensity data can be measured.
- Climatological & Meteorological studies
- PV systems design
- Locations of the greenhouse can be established.
- Expecting the requirements of insulation for building structures

Pyranometer is used to measure diffused sun energy whereas Pyrheliometer is used to measure the sun's energy directly.

Pyrheliometer

Definition: The Pyrheliometer is one type of instrument, used to measure the direct beam of solar radiation at the regular occurrence. This instrument is used with a tracking mechanism to follow the sun continuously. It is responsive to wavelengths bands that range from 280 nm to 3000 nm. The units of irradiance are W/m². These instruments are specially used for weather monitoring & climatological research purposes.

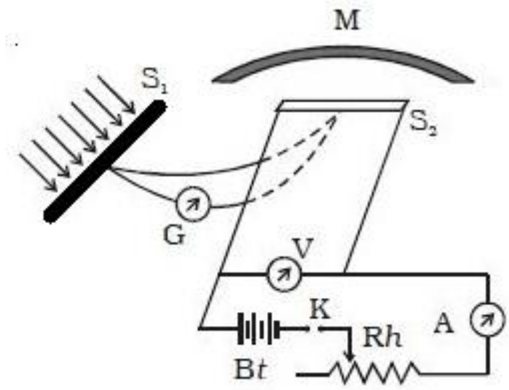
Pyrheliometer Construction & Working Principle

The external structure of the Pyrheliometer instrument looks like a telescope because it is a lengthy tube. By using this tube, we can spot the lens toward the sun to calculate the radiance. The Pyrheliometer basic structure is shown below. Here the lens can be pointed in the direction of the sun & the solar radiation will flow throughout the lens, after that tube & finally at the last part where the last apart includes a black object at the bottom.

The irradiance of solar enters into this device through a crystal quartz window and directly reaches onto a thermopile. So this energy can be changed from heat to an electrical signal that can be recorded.
A calibration factor can be applied once changing the mV signal to a corresponding radiant energy flux, and it is calculated in W/m² (watts per square meter). This kind of information can be used to increase Insolation maps. It a solar energy measurement, that is received on a specified surface region in a specified time to change around the Globe. The isolation factor for a specific area is very useful once setting up solar panels.

Pyrheliometer Circuit Diagram

The circuit diagram of the Pyrheliometer is shown below. It includes two equal strips specified with two strips S1 & S2 with area 'A'. Here, a thermocouple is used where its one junction can be connected to S1 whereas the other is connected to S2. A responsive galvanometer can be connected to the thermocouple. The S2 Strip is connected to an exterior electrical circuit.



Once both the strips are protected from the radiation of solar, then the galvanometer illustrates there is no deflection because both the junctions are at equal temperature. Now 'S1' strip is exposed to the solar radiation & S2 is protected with a cover like M. When S1 strip gets heat radiations from the sun, then strip temperature will be increased, thus the galvanometer illustrates deflection.

When current is supplied throughout the S2 strip, then it is adjusted and the galvanometer illustrates there is no deflection. Now, again both the strips are at equal temperature.

If the heat radiation amount occurred over the unit area within the unit time on S1 strip is 'Q' & its absorption co-efficient, so the heat radiation amount which is absorbed through the S1 strip S1 within unit time is 'QAa'. In addition, the heat generated in unit time within the S2 strip can be given through VI. Here, 'V' is the potential difference & 'I' is the flow of current through it.

When heat absorbed is equivalent to the heat generated, so

QAa = VI

Q=VI/Aa

By substituting the values of V, I, A and a, the value of 'Q' can be calculated.

Different Types

There are two **types of Pyrheliometers** like SHP1 and CHP1

SHP1

The SHP1 type is a better version compare with CHP1 type, as it is designed with an interface including both improved analog o/p & digital RS-485 Modbus. The response time of this kind of meter has below 2 seconds & independently calculated temperature correction will range from -40°C to +70°C.

CHP1

The CHP1 type is the most frequently used radiometer used to measure solar radiation directly. This meter includes one thermopile detector as well as two temperature sensors. It generates an utmost o/p like 25mV beneath usual atmospheric situations. This type of device totally obeys the most recent standards which are set by ISO and WMO about the criteria of the Pyrheliometer.

Advantages

The **advantages of the Pyrheliometer** include the following.

- Very low power consumption
- Operates from a wide range of voltage supplies
- Ruggedness
- Stability

Pyrheliometer Applications

The applications of this instrument include the following.

- Scientific meteorological

- Observations of Climate
- Testing research of Material
- Estimation of the solar collector's efficiency
- PV devices

Pyranometer	Pyrheliometer
It is one kind of acidometer mainly used to measure the solar irradiance over a planar surface.	This instrument is used to measure direct ray solar irradiance.
It uses thermoelectric detection principle	In this, the thermoelectric detection principle is used
In this, the measurement of increasing temperature can be done through thermocouples which are linked in series otherwise series-parallel to build a thermopile.	In this, the increasing temperature can be calculated through thermocouples that are allied in series/series-parallel to create a thermopile.
This is frequently used in meteorological research stations	This is also used in meteorological research stations
This instrument calculates global solar radiation.	This instrument calculates direct solar radiation.

Difference between Pyrheliometer and Pyranometer

Both the instruments like Pyrheliometer & Pyranometer are used to calculate solar irradiance. These are related in their intention but there are some dissimilarities in their construction & working principle.

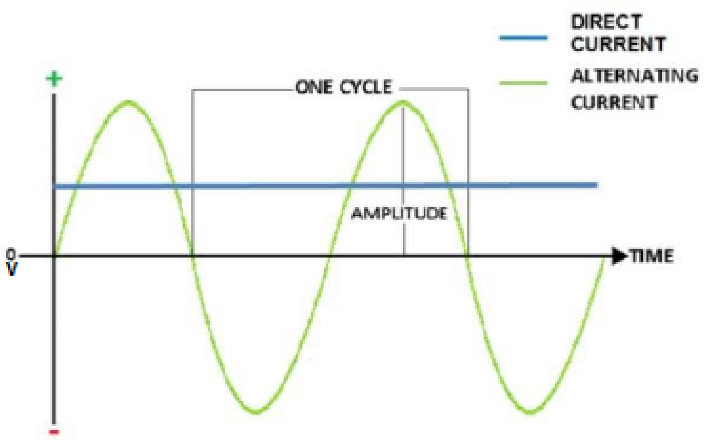
Solar PV Components & systems configuration

Fundamentals of Electricity

Electric Potential

Types of Electricity

Voltage x Time
1/50 of a Second



50 Hertz in India
(50 cycles in a second)

DC = Direct current
One-way charge movement
- PV cells
- Batteries

AC = Alternating current
Two-way charge movement
- Utility power
- Generators
- Wind and hydro turbines

Electro Magnetism:

Relationship between electricity & magnetism, which enables electrical energy to be generated from mechanical energy (such as generator) and enables mechanical energy to be generated from electrical energy (such as in electric motor).

Electric Potential :

Potential difference in the electrical energy between two points, such as between two positive tip and the negative tip of the battery. It is measured in Volts. The greater the electric potential (volts), the greater capacity for the work electricity has.

Relationship between : Volts, Amps, Ohms, Watt & Watt-Hour

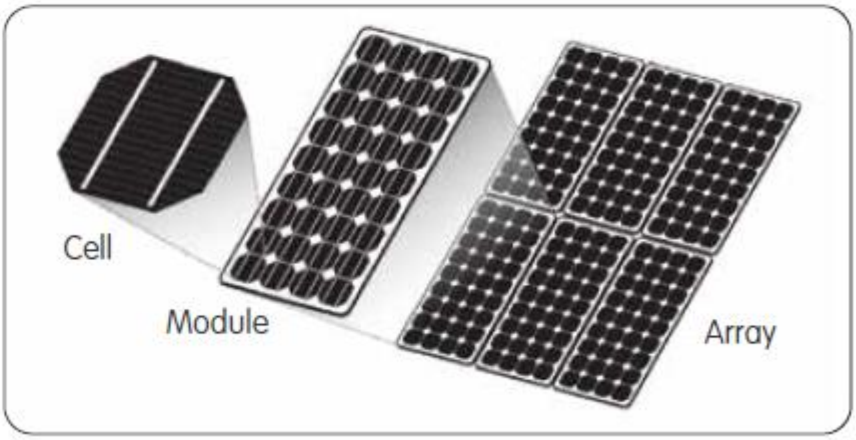
Volts = Current X Resistance

(V) = I X R

Current = Volts / Resistance

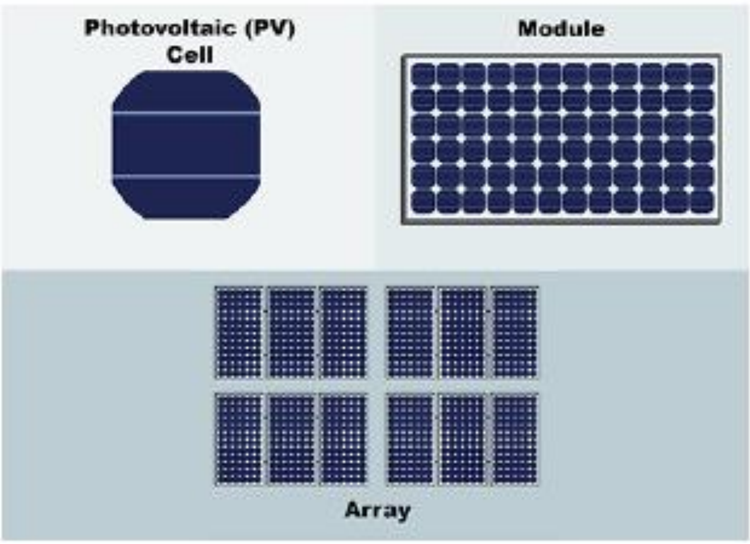
PV Module:

A group of PV cells connected together to generate more power than a single PV cell



PV Array:

Combination of PV modules connected in series and parallel



Types of Solar Panels

If you're thinking of taking the solar route to generate electricity, one of the key items on your list would be deciding between different kinds of solar panels available in the market.
A solar energy system's core lies in photovoltaic panels or modules, which are responsible for absorbing sunlight and converting it into a source of energy to generate electricity. Continuous research in the field of solar energy has brought forth a variety of solar panels, and choosing between them can be a challenge.

Ideally, these solar panels can be classified into the following three generations:

- **First generation**: These are the traditional solar panels made of silicon. Currently, these are the most efficient panels available for residential purposes. However, these panels have a higher risk of losing their efficiency at higher temperatures (scorching and sunny days).

- **Second generation:** Second generation solar panels are also known as thin-film modules because when compared to the first generation panels, these are made of layers of semiconductor materials only a few micrometers thick. These are cheaper because they use lesser materials than the first generation panels.

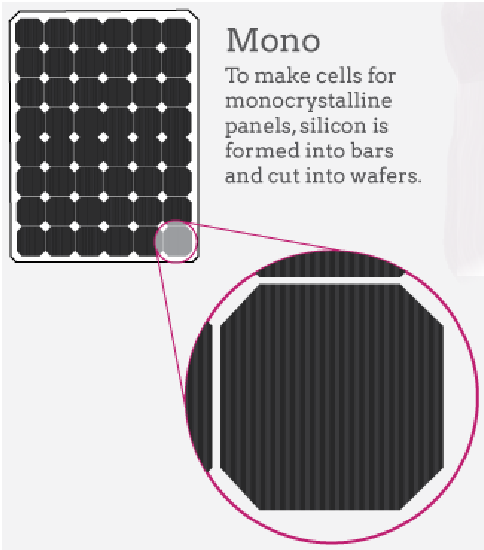
- **Third generation:** Third generation solar modules are still under a lot of research. They're made of a variety of materials besides silicon – including nanotubes, solar inks, silicon wires, organic dyes, and conductive plastics. These solar panels are expected to overhaul the efficiency and reducing the price of commercially available solar panels.

Let's look at some of the commercially available solar panels – including their advantages and disadvantages:

1) Mono crystalline Solar Panels:

This is the oldest solar technology and is still widely used. These solar panels belong to the first generation and are therefore made of extremely thin wafers of silicon. They're referred to as mono crystalline because the constituent cells are sliced from large single

crystals that have been grown under carefully controlled conditions.
Compared to the other types, these are up to 20% more efficient. What this means is that you'll generate 20% more electricity from a mono crystalline solar panel than other solar panels of the same area. This is extremely useful if you wish to mount these panels in a limited space or for aesthetic reasons. However, growing large crystals of silicon is an extremely energy-intensive process, hence the production costs for this type of panels are the highest of all the solar panel types.
The cost of mono crystalline solar panels in India is around Rs. 60 per watt. Now, let's look at some advantages of disadvantages of the same.



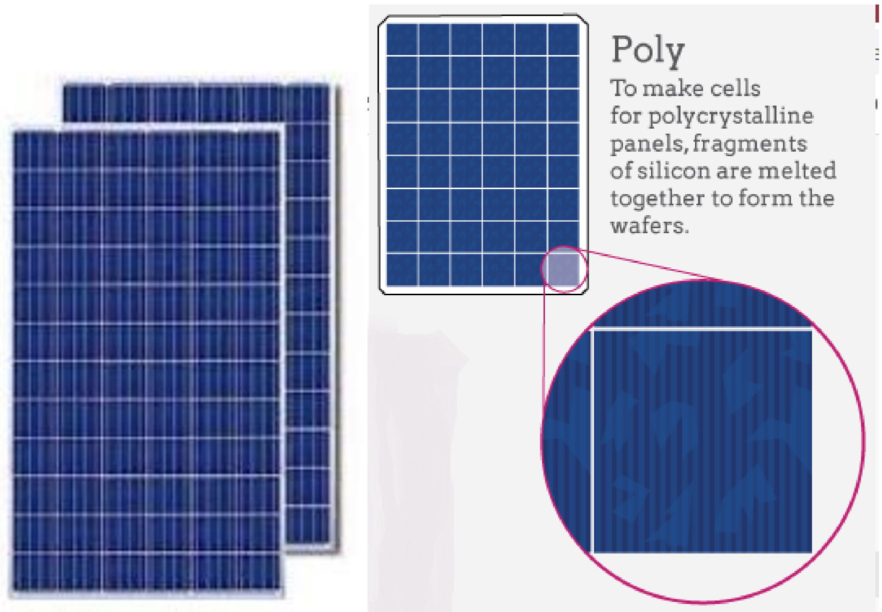
Advantages:
1. Highly energy and space-efficient.
2. Live the longest and come with an extended warranty of 25 years.
3. Tend to perform better than similarly rated polycrystalline panels even at low-light conditions.

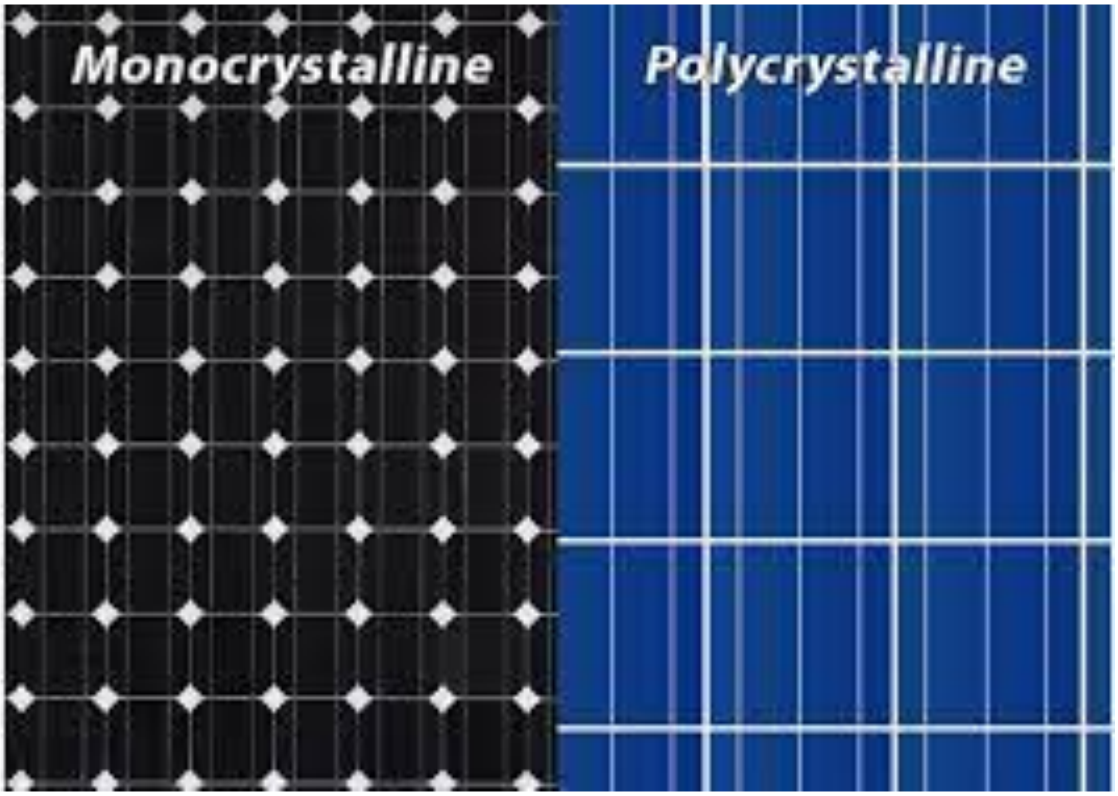
2) Polycrystalline Solar Panels:
Polycrystalline solar panels are made by pouring molten silicon into a cast. This is a cheaper process as it is relatively cost-efficient to produce silicon wafers in molds from various crystals rather than from a single crystal. These solar panels, too, belong to the first generation.

Raw silicon is melted and poured into a square mold, which is cooled and cut into perfectly square wafers. Hence, these panels are cheaper but relatively less efficient. These solar panels cost around Rs. 45 per watt. These are ideal for small rooftop like installations spanning 100-1000 Watts.
Let's look at some advantages and disadvantages.

Advantages:

1. Simpler manufacturing process.
2. Cost-effective.





3) Thin-film Solar Panels:

Thin-film solar panels are made of TFSC (thin-film solar cells). These belong to the second generation and are manufactured by depositing one or a few thin layers of photovoltaic material onto a substrate.

These solar panels can be categorized as follows depending on the photovoltaic material is deposited onto the substrate:

1. Amorphous silicon (a-Si)
2. Cadmium telluride (CdTe)
3. Copper indium gallium selenide (CIS/CIGS)
4. Organic photovoltaic cells (OPC)

Out of these, only amorphous silicon, cadmium telluride, and copper indium gallium selenide are commercially available in the market.

These are easier to produce and hence have seen an increase in their usage. To add to that, they're also cheaper than both the first generation panels. However, these are less efficient than the other modules we discussed.

Advantages:

1. Mass production is extremely simple.
2. Homogeneous in nature, hence they're aesthetically pleasing.
3. Can be made flexible, thus opening the gates for numerous potential applications.

Nominal Operating Cell Temperature

A PV module will be typically rated at 25 °C under 1 kW/m^2. However, when operating in the field, they typically operate at higher temperatures and at somewhat lower insolation conditions. In order to determine the power output of the solar cell, it is important to determine the expected operating temperature of the PV module. The Nominal Operating Cell Temperature (NOCT) is defined as the temperature reached by open circuited cells in a module under the conditions as listed below:

1. Irradiance on cell surface = 800 W/m^2
2. Air Temperature = 20°C
3. Wind Velocity = 1 m/s
4. Mounting = open back side.

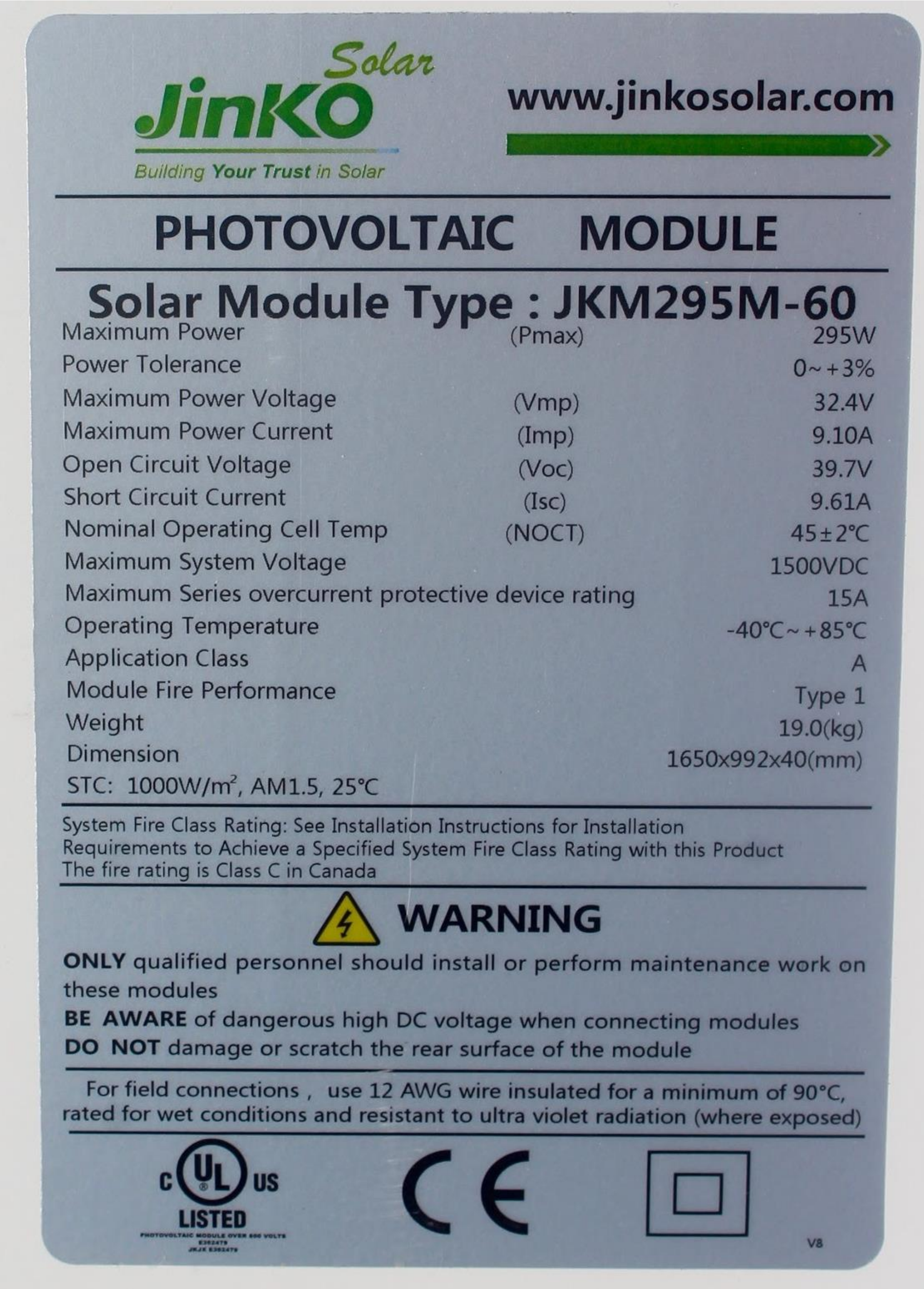
Module Measurement

Safety First

- Do not measure a module when it is installed in an array. The voltage is up to 1000 V and deadly.
- Only measure one module at a time. Do not measure modules connected together.
- Check that the module voltage is below 50 V by consulting the label.
- Modules get hot in sunlight. Be careful about hot surfaces and/or wear gloves.

The accurate measurement of a module is quite challenging. Special testers give the standard test conditions: 1000 W/m2 of sunlight, 25 °C and spectrum of Air mass 1.5 (AM 1.5). The guides on the following pages are to give an indication that the module is functional. Further tests would be needed to ensure that the module is performing to specification.

Interpretation of a module label



A module label shows the specifications of a module under standard test conditions. It is usually on the back of the module. Standards vary slightly throughout the world but most labels will follow this format.

Modules from major manufacturers are measured according to standards. A typical module label is shown above. Measurements are at STC unless otherwise stated.

Solar Module Type

Usually looking up the module type will give a more detailed data sheet on the module. In this case, we can tell its a 295 W module and there are 60 cells in the module. As there are 60 cells it is more likely to be used in residential applications than a large centralized power station.

Maximum Power (Pmax)

295 watts is the power of the module under STC at the maximum power point. In the field, the module will likely be at a higher temperature so the actual power will be lower.

Power Tolerance

Under STC the module might have a power up to 3% higher. A higher power is not always a good thing as it could overload the power electronics.

Maximum Power Voltage (V_{MP})

When operating at Pmax the voltage is 32.4 volts.

Maximum Power Current (I_{SC})

When operating at Pmax the current is 9.1 amps. Note that 32.4 V × 9.1 A = 295 W.

Open Circuit Voltage (V_{OC})

At STC the no-load voltage is 39.7 volts. This is the voltage that would be measured on a sunny day when the light intensity is close to 1000 W/m2 and the temperature is 25 °C.

Maximum Power Current (I_{SC})

When the leads of the panel are shorted the current is 9.61 amps.

Nominal Operating Cell Temperature (NOCT)

In the field the module will operate at 45°C under the specific conditions of NOCT, which is different from STC. NOCT has Irradiance 800 W/m^{2,} air temperature or 20°C, wind velocity of 1 m/s and an open back.

The rest of the details cover how the module is installed and that it passes safety standards.

STC

STC – Standard test conditions. The label finally notes that the standard test conditions are 1000 W/m2 of sunlight, 25 °C and spectrum of Airmass 1.5 (AM 1.5). All modern modules are tested using these conditions.

The label usually does not give the fill factor but we can calculate it. In this case it is (32.4 × 9.1)/(39.7 × 9.61) = 0.772. Most modules will have a fill factor from 0.7 to 0.8.

PV Systems Mounting Types

We talked briefly about tracking systems and some design considerations for **the tilt angles** in Lesson 2. However, we didn't elaborate on the **mounting types available for PV systems**. Each **PV system is different from the rest in terms of racking structure and mounting types.** This is due to the fact that **PV systems are space constrained and the installation requirements vary from one place to another**. For that reason, **many structural holding** solutions have been developed to accommodate different needs such as **ground mount, pole mount, and roof mount**. Each type comes with **advantages and disadvantages** that allow a good designer to make the optimal decision for each specific PV system.

1.Ground Mount

This type of mounting structure allows multiple rows of modules to be installed on the ground, as shown in Figure 5.1.

Advantages

- Cooler module temperature
  - PV modules can get extremely hot during daytime due to **the excessive heat generated** from the modules and the ambient temperature. The best way to cool down the modules **is natural convection using air**, which is easily done when modules are elevated from the ground or roof so that air can carry out the heat and cool down the modules.
- Safe installation (no climbing required)
- Easy access for maintenance/troubleshooting
- No roof penetration/liability
- Flexible positioning for max production (potential use for single axis tracking). Ground mount is usually not restricted to be positioned at a certain tilt angle. That said, it is easier to choose the optimum tilt for maximum production.

Disadvantages

- Easy access (theft, vandalism, damage)
- Requires earth construction work (concrete, foundation, trenching)
- Space requirement

- Inter-row shading considerations
    - PV modules can shade one another when installed in rows. For example, the first row can shade the second row located behind it. For more information, please refer to the video (6:08) explanation below from EME 810(link is external)

2.Pole Mount

This structure is common in public areas where the system is space constrained, as seen in Figure 5.2.

Advantages

- Cooler module temperature
    - PV modules can get extremely hot during daytime due to the excessive heat generated from the modules and the ambient temperature. The best way to cool down the modules is the natural convection using air, which is easily done when modules are elevated from the ground or roof so that air can carry out the heat and cool down the modules.
- Easy access for maintenance/troubleshooting
- No roof penetration/liability

- Flexible positioning for max production
- Easy to adjust the tilt angle (potential use for dual axis tracking)

- Small footprint (one pole)

Disadvantages

- Easy access (theft, vandalism, damage)
- Requires construction (concrete, steel, foundation, trenching)

3.a.Roof Mount (without roof penetration)

There are various **types of roof mounts that don't require roof penetration especially** when the roof is flat, as illustrated in Figure 5.3. Of these types, ballasted roof mount is one of the most used racking structure for PV systems installed on flat roofs. It utilizes the weight of concrete or sand to ensure the system stays still to stand all kinds of external forces such as pullout wind forces.

Advantages

- Low material cost
- **Utilizes unused spaces**
- Provides **secure access for authorized individuals only**
- Flexible positioning for ideal production
- No roof penetration needed

Disadvantage

- May require structural engineering and/or roof **reinforcement due to added**

3.b.Roof mount (with roof penetration) weight

These mounting structures allow the system to be installed parallel to the roof for the best esthetic solution for pitched roofs, as seen in Figure 5.4.

Advantages

- Lower material cost
- Utilizes unused spaces
  - In most buildings, the roof is considered unused space. PV array can occupy these spaces and transfer them to useful spaces that can generate electricity for the building.
- Provides secure access for authorized individuals only

Disadvantages

- Requires roof penetration (roof leak liability or roof damage)
- Requires professional installers
- Higher module temperature (poor ventilation)
  - PV modules can get extremely hot during daytime due to the excessive heat generated from the modules and the ambient temperature. Since PV modules cannot be elevated from the roof for more than a couple of inches, air movement is restricted from carrying out the heat to cool down the modules.
- Difficult conduit runs
  - Most roofs have different gable shapes and sizes. In addition, the main electrical panel is usually located at the bottom of the building. That said, the PV array conduits have to run through the roof to the main panel and that route can be wiggly and require more attention to the details when installing the system.
- Fixed title and orientation
  - Most roofs come with single pitch that cannot be changed. When a PV array is installed on the roof, the orientation and tilt are restricted by the roof pitch and orientation, and that might affect the production of the PV system.
- Pullout forces
  - Wind speed flowing against the PV modules on the roof can cause forces that act similarly to pullout forces that try to remove the modules from the roof. That said, PV designers should ensure that the PV array is securely fastened to the roof using the right attachment mechanisms, such as screws and hooks.

Considerations

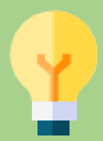
- Roof age
  - **Roof age** is a critical factor to installing a PV array. A weak and old roof may not be able to withstand the added weight from the PV array.
- Snow and wind loading

- Snow and wind can add weight to the roof. If the roof is not designed to carry that additional weight, the roof might collapse.

- Fire issues
  - When PV arrays are installed on roofs, installers should work with the local fire department to ensure that there are no fire hazards or accessibility issues if fire occurs.

Electrical Terms, Definitions & Symbols

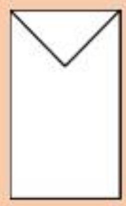
Electric Load
Any equipment that uses electricity to function.


Graphical Symbol

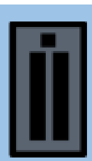

Electrical Symbol

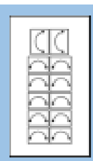
Photovoltaic (PV) Modules generate DC electricity from sunlight.


Graphical Symbol

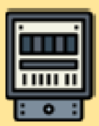

Electrical Symbol

An **Electrical Service Panel** allows for the distribution of power through branch circuits protected by circuit breakers.


Graphical Symbol

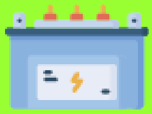

Electrical Symbol

An **Electrical Meter** counts the amount of electricity (in KWh) flowing to or from a building.

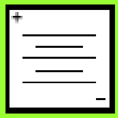

Graphical Symbol

Electrical Symbol

A **Battery** is a device that stores electrical energy.

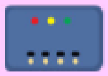


Graphical Symbol

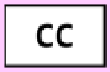


Electrical Symbol

A **Charge Controller** regulates battery charging and discharging.



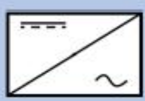
Graphical Symbol



Electrical Symbol (may vary)

Inverter converts direct current (DC) to alternating current (AC).

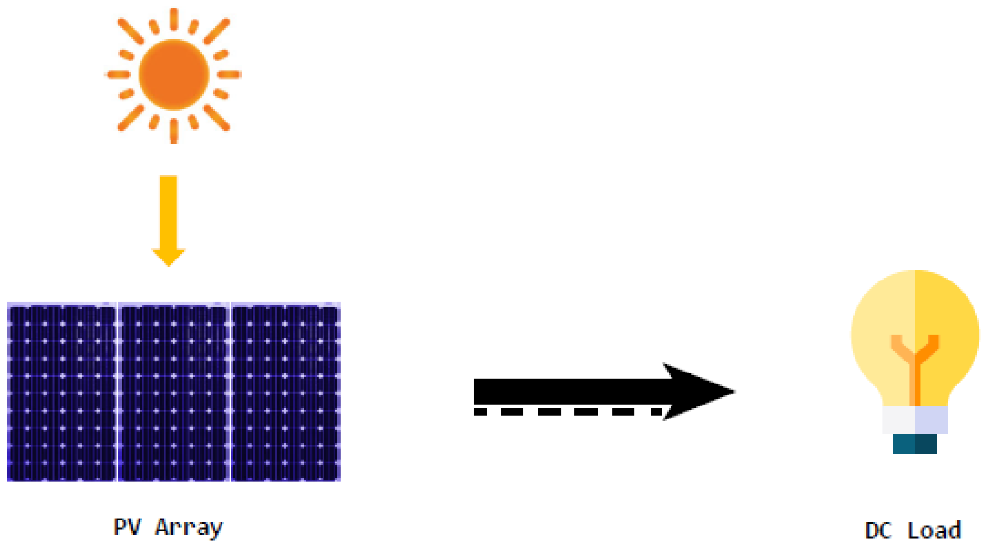
Graphical Symbol



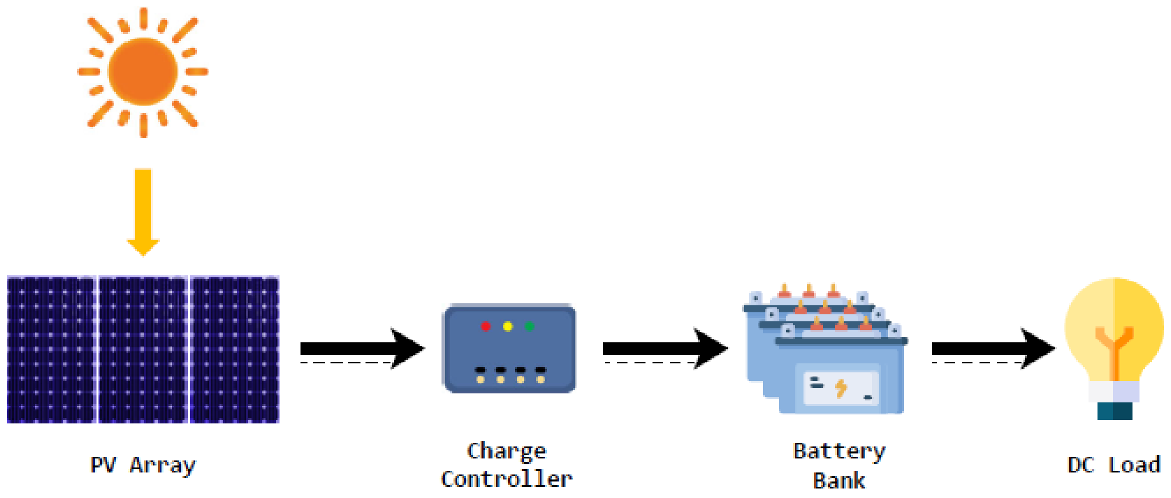
Electrical Symbol

Types of PV Systems

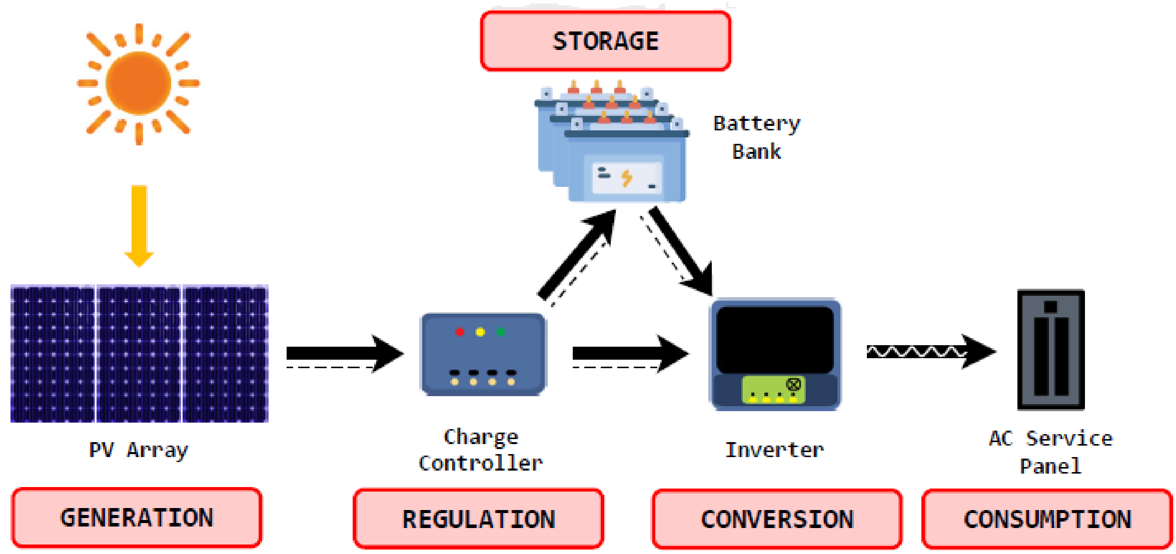
1. PV – Direct Systems



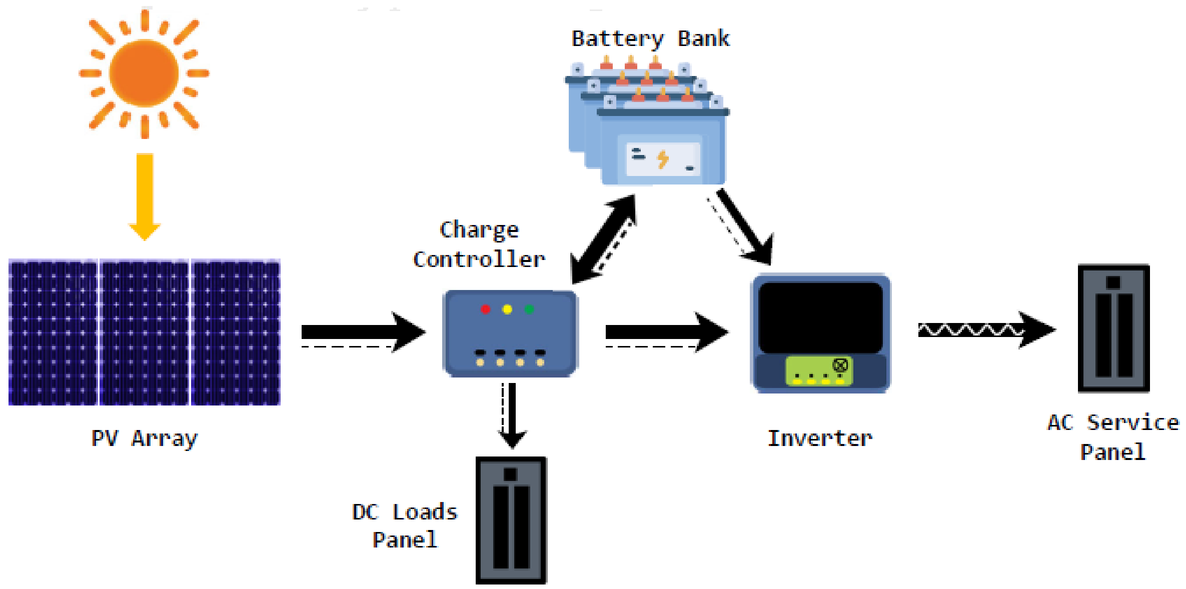
2. Stand – Alone PV Systems – DC Loads only



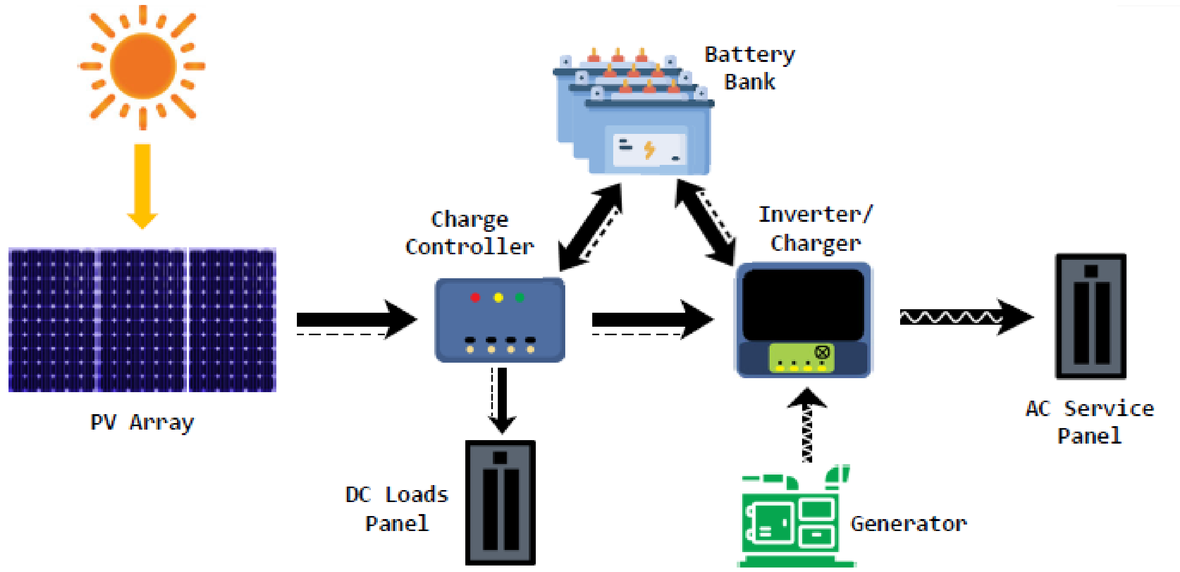
3. Stand – Alone PV Systems – AC Loads only



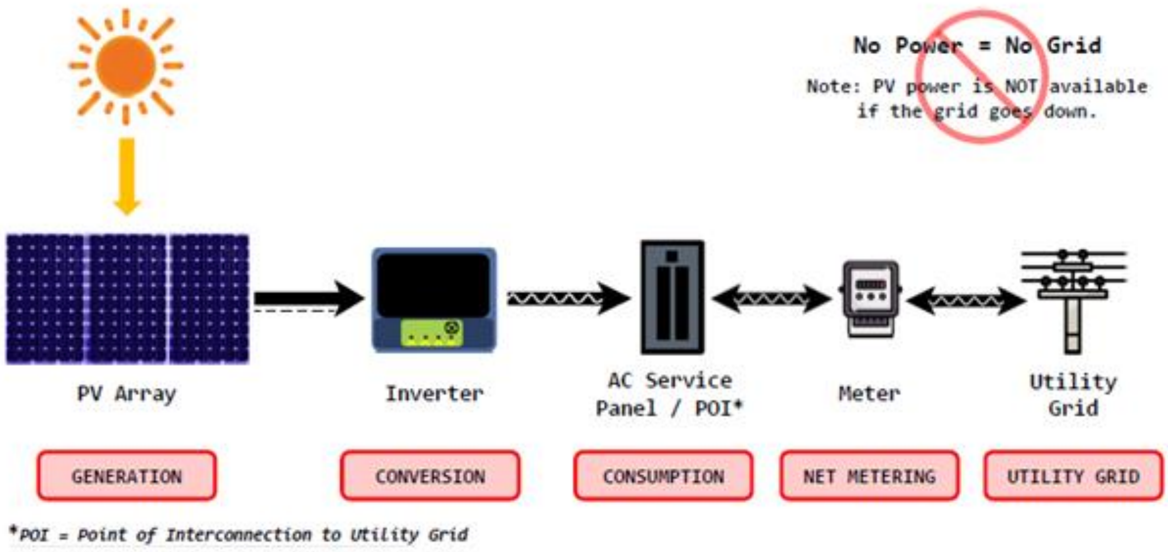
4. Stand – Alone PV Systems – DC & AC Loads



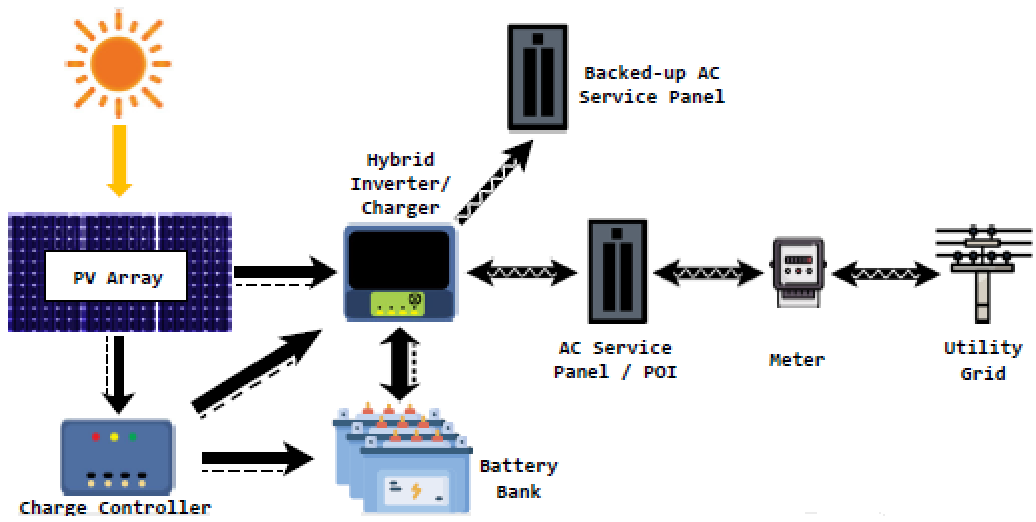
5. Stand – Alone PV Systems – DC & AC Loads with Backup Generator



6. Grid Direct Systems



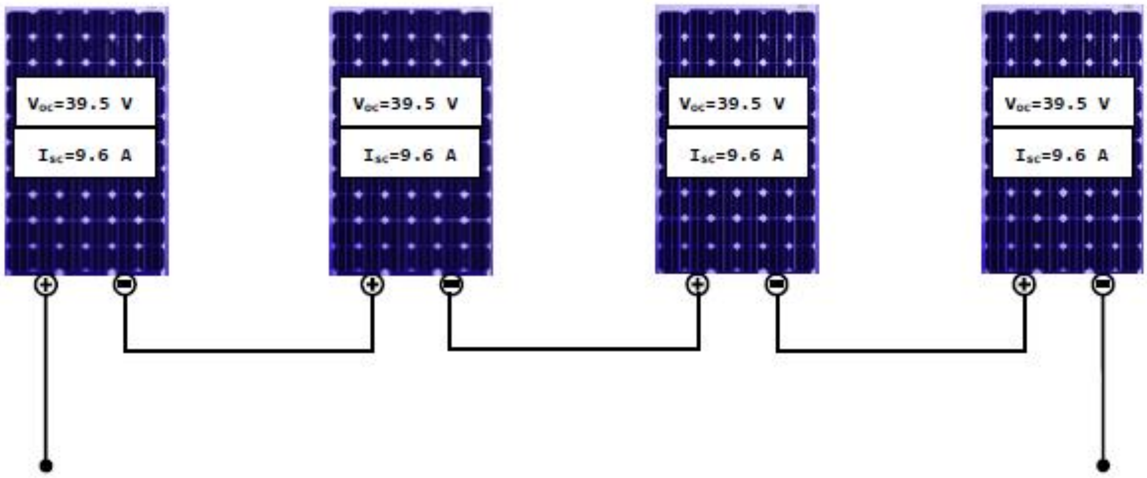
7. Hybrid / Multi mode Systems



Panels in series connections

Series Connections:

- Negative from one module connects with positive from another.
- Voltage is additive
- Current remains the same through all parts of the circuit.
- Modules in series form a "series-string" or PV source circuit.
- Unused/ open leads become the positive and negative homeruns for the PV source circuit



In series connection **voltage is additive** & entire current remains same

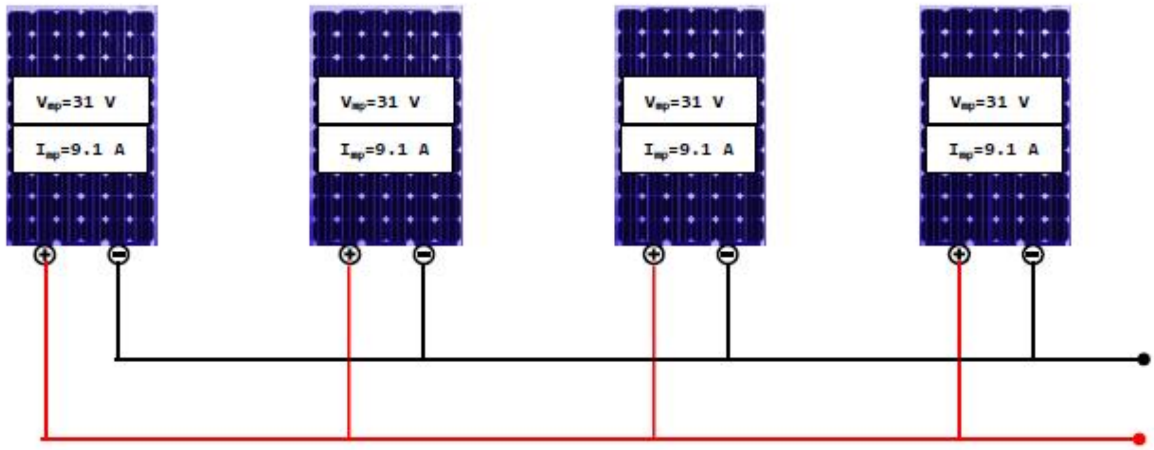
In each panel V_{OC} = 39.5 v
4 units connected in series
Total Voltage = 39.5 + 39.5 + 39.5 + 39.5 = **158 V**
In each panel I_{SC} = 9.6 A
4 units connected in series, Total Current = **9.6 A**

For the series string panel connections

Voltage = 158 V **Current =** 9.6 A

Parallel Connections:

- Positive to positive & negative to negative.
- Current is additive.
- Voltage remains same through all parts of the circuit.
- PV source circuit is parallel from a PV output circuit.
- Positive & negative wire exit from the point of the parallel connection and are routed to the next system component.



In parallel connection **current is additive** & entire circuit voltage remains same

In each panel I_{SC} = 9.1 A
4 units connected in parallel
Total Current = 9.1 + 9.1 + 9.1 + 9.1 = **36.4 A**
In each panel V_{OC} = 31 v
4 units connected in series, Total Voltage = voltage across in each panel
= **31V**

Voltage & current of the above array connected in parallel

Voltage = 31 V **Current =** 36.4 A

Solar Power Batteries

Batteries are often used in PV systems for the purpose of storing energy produced by the PV array during the day, and to supply it to electrical loads as needed (during the night and periods of cloudy weather).

Other reasons because batteries are used in PV systems are to operate the PV array near its maximum power point, to power electrical loads at stable voltages, and to supply surge currents to electrical loads and inverters. In most cases, a battery charge controller is used in these systems to protect the battery from overcharge and over discharge.

In stand-alone systems, the power generated by the solar panels is usually used to charge a lead-acid battery. Other types of battery such as nickel-cadmium batteries may be used, but the advantages of the lead-acid battery ensure that it is still the most popular choice.

A battery is composed of individual cells; each cell in a lead-acid battery produces a voltage of about 2 Volts DC, so a 12 Volt battery needs 6 cells. The capacity of a battery is measured in ***Ampere-hours or Amp-hours (Ah).***

To properly select batteries for use in stand-alone PV systems, it is important that system designers have a good understanding of their design features, performance characteristics and operational requirements. The information in the following sections is intended as a review of basic battery characteristics and terminology as is commonly used in the design and application of batteries in PV systems.

Manufacturers have variations in the details of their battery construction, but some common construction features can be described for most all batteries. Some important components of battery construction are described below.

Cell: The cell is the basic electrochemical unit in a battery, consisting of a set of positive and negative plates divided by separators, immersed in an electrolyte solution and enclosed in a case.

Active Material: The active materials in a battery are the raw composition materials that form the positive and negative plates, and are reactants in the electrochemical cell. The amount of active material in a battery is proportional to the capacity a battery can deliver. *In lead-acid batteries*, the *active materials* are ***lead dioxide (*** PbO_2 ***) in the positive plates and metallic sponge lead (Pb) in the negative plates, which react with a sulphuric acid (*** H_2SO_4 ***)*** solution during battery operation.

Electrolyte: The electrolyte is a conducting medium which allows the flow of current through ionic transfer, or the transfer of electrons between the plates in a battery.

In a lead-acid battery, the electrolyte is a diluted sulphuric acid solution, either in liquid (flooded) form, gelled or absorbed in glass mats. In flooded nickel- cadmium cells, the electrolyte is an alkaline solution of potassium hydroxide and water. In most flooded battery types, periodic water additions are required to replenish the electrolyte lost through gassing. When adding water to batteries, it is very important to use distilled or de-mineralized water, as even the impurities in normal tap water can poison the battery and result in premature failure.

Grid: In a lead-acid battery, the grid is typically a lead alloy framework that supports the active material on a battery plate, and which also conducts current.

Alloying elements such as antimony and calcium are often used to strengthen the lead grids, and have characteristic effects on battery performance such as cycle performance and gassing. Some grids are made by expanding a thin lead alloy sheet into a flat plate web, while others are made of long spines of lead with the active material plated around them forming tubes, or what are referred to as tubular plates.

Plate: A plate is a basic battery component, consisting of a grid and active material, sometimes called an electrode. There are generally a number of positive and negative plates in each battery cell, typically connected in parallel at a bus bar or inter-cell connector at the top of the plates.

A pasted plate is manufactured by applying a mixture of lead oxide, sulphuric acid, fibres and water on to the grid. The thickness of the grid and plate affect the deep cycle performance of a battery. In automotive starting or SLI type batteries, many thin plates are used per cell.

This results in maximum surface area for delivering high currents, but not much thickness and mechanical durability for deep and prolonged discharges. Thick plates are used for deep cycling applications such as for forklifts, golf carts and other electric vehicles. The thick plates permit deep discharges over long periods, while maintaining good adhesion of the active material to the grid, resulting in longer life.

Separator: A separator is a porous, insulating divider between the positive and negative plates in a battery, used to keep the plates from coming into electrical contact and short-circuiting, and which also allows the flow of electrolyte and ions between the positive and negative plates.

Separators are made from micro-porous rubber, plastic or glass-wool mats. In some cases, the separators may be like an envelope, enclosing the entire plate and preventing shed materials from creating short circuits at the bottom of the plates.

Element: An element is defined as a stack of positive and negative plate groups and separators, assembled together with plate straps interconnecting the positive and negative plates.

Terminal Posts: Terminal posts are the external positive and negative electrical connections to a battery. A battery is connected in a PV system and to electrical loads at the terminal posts. In a lead-acid battery the posts are generally lead or a lead alloy, or possibly stainless steel or copper-plated steel for greater corrosion resistance. Battery terminals may require periodic cleaning, particularly for flooded designs. It is also recommended that the clamps or connections to battery terminals be secured occasionally as they may loosen over time.

Cell Vents: During battery charging, gasses are produced within a battery that may be vented to the atmosphere. In flooded designs, the loss of electrolyte through gas escape from the cell vents it a normal occurrence, and requires the periodic addition of water to maintain proper electrolyte levels.

In sealed, or valve-regulated batteries, the vents are designed with a pressure relief mechanism, remaining closed under normal conditions, but opening during higher than normal battery pressures, often the result of overcharging or high temperature operation. Each cell of a complete battery unit has some type of cell vent.

Case: Commonly made from a hard rubber or plastic, the case contains the plates, separators and electrolyte in a battery. The case is typically enclosed, with the exception of inter-cell connectors which attach the plate assembly from one cell to the next, terminal posts, and vents or caps which allow gassing products to escape and to permit water additions if required.

Clear battery cases or containers allow for easy monitoring of electrolyte levels and battery plate condition. For very large or tall batteries, plastic cases are often supported with an external metal or rigid plastic casing.

Battery Types and Classifications

Many types and classifications of batteries are manufactured today, each with specific design and performance characteristics suited for particular applications. Each battery type or design has its individual strengths and weaknesses.

In PV systems, lead-acid batteries are most common as we said before, due to their wide availability in many sizes, low cost and well understood performance characteristics. In a few critical, low temperature applications nickel-cadmium cells are used, but their high initial cost limits their use in most PV systems. There is no "perfect battery" and it is the task of the PV system designer to decide which battery type is most appropriate for each application.

In general, electrical storage batteries can be divided into to major categories, ***primary and secondary batteries***.

1. Primary Batteries

Primary batteries can store and deliver electrical energy, but cannot be recharged. *Typical carbon-zinc and lithium batteries commonly used in consumer electronic devices* are primary batteries. Primary batteries are not used in PV systems because they cannot be recharged.

2. Secondary Batteries

A secondary battery can store and deliver electrical energy, and can be recharged by passing a current through it in an opposite direction to the discharge current. Common *lead-acid batteries* used in automobiles and PV systems are secondary batteries.

The following common secondary battery types and their characteristics which are of importance to PV system designers. A detailed discussion of each battery type follows.

Lead-Acid Battery Classifications

Many types of lead-acid batteries are used in PV systems, each having specific design and performance characteristics.

While there are many variations in the design and performance of lead-acid cells, they are often classified in terms of one of the following three categories:

a)SLI Batteries

Starting, lighting and ignition (SLI) batteries are a type of lead-acid battery designed primarily for shallow cycle service, most often used to power automobile starters. These batteries have a number of thin positive and negative plates per cell, designed to increase the total plate active surface area. The large number of plates per cell allows the battery to deliver high discharge currents for short periods.

While they are not designed for long life under deep cycle service, SLI batteries are sometimes used for PV systems in developing i.e,s where they are the only type of battery locally manufactured. Although not recommended for most PV applications, SLI batteries may provide up to two years of useful service in small stand-alone PV systems where the average daily depth of discharge is limited to 10-20%, and the maximum allowable depth of discharge is limited to 40-60%.

b).Motive Power or Traction Batteries

Motive power or traction batteries are a type of lead acid battery designed for deep discharge cycle service, typically used in electrically operated vehicles and equipment such as golf carts, fork lifts and floor sweepers. These batteries have a fewer number of plates per cell than SLI batteries, however the plates are much thicker and constructed more durably. High content lead-antimony grids are primarily used in motive power batteries to enhance deep cycle performance. Traction or motive power batteries are very popular for use in PV systems due to their deep cycle capability, long life and durability of design.

c) Stationary Batteries

Stationary batteries are commonly used in un-interruptible power supplies (UPS) to provide backup power to computers, telephone equipment and other critical loads or devices. Stationary batteries may have characteristics similar to both SLI and motive power batteries, but are generally designed for occasional deep discharge, limited cycle service.

Battery type (Standard application area)	**SLI** (Cars)	**SLI** (Trucks)	**Lighting/Leisure** (caravans boats cottages)	**Solar** (modified for PV use)	**Semi Traction** (golf carts, lawn mowers etc.)	**Traction** (fork lift trucks i.e.)	**Stationary** (telecom i.e.)
Positive plate design	Pasted	Pasted	Pasted	Pasted	Pasted/ Rod	Tubular	Tubular/ Rod
Advantages	High power	High power			Fairly high power	Accepts deep discharge	Rugged
	Rapid recharge possible	Rapid recharge possible			Acceptable cycle life	Accepts overcharge	Reliable
		Longer PV- life than car battery	Longer PV- life than car battery	Longer PV- life than car battery		Good for cycling application	
Disadvant-ages	Sensitive to deep discharge	Sensitive to deep discharge	Limited cycle life	Limited cycle life	Limited cycle life	Require high overcharge	Sensitive to high overcharge and deep discharge
Relative invest-ment cost (Ref. 2)	1.0-1.3	1.3-1.5	1.5-2	1.4-1.6	1.5-2.0	4-8	4-7
Comments	**Very short life in most PV systems. Not recommended for PV systems**	**Can achieve acceptable lifetime in low cost PV system with shallow cycling**	**Can achieve accept-able lifetime in low cost PV system with shallow cycling**	**Best lifetime in low cost PV systems**	May give favourable life cycle cost in professional PV system with shallow cycles	May give favourable life cycle cost in professional PV system with deep cycles	Plante type is not recommended for PV systems.

There are several types of lead-acid batteries manufactured. The following sections describe the types of lead-acid batteries commonly used in PV systems.

1.Lead-Antimony Batteries

Lead-antimony batteries are a type of lead-acid battery which use antimony (Sb) as the primary alloying element with lead in the plate grids. The use of lead-antimony alloys in the grids has both advantages and disadvantages.

Advantages include providing greater mechanical strength than pure lead grids, and excellent deep discharge and high discharge rate performance. Lead-antimony grids also limit the shedding of active material and have better lifetime than lead-calcium batteries when operated at higher temperatures.

Disadvantages of lead-antimony batteries are a high self-discharge rate, and as the result of necessary overcharge, require frequent water additions depending on the temperature and amount of overcharge.

Most lead-antimony batteries are flooded, open vent types with removable caps to permit water additions.

They are well suited to application in PV systems due to their deep cycle capability and ability to take abuse, however they do require periodic water additions. The frequency of water additions can be minimized by the use of catalytic recombination caps or battery designs with excess electrolyte reservoirs. The health of flooded, open vent lead-antimony batteries can be easily checked by measuring the specific gravity of the electrolyte with a hydrometer.

Lead-antimony batteries with thick plates and robust design are generally classified as motive power or traction type batteries, are widely available and are typically used in electrically operated vehicles where deep cycle long-life performance is required.

2. Lead-Calcium Batteries

Lead-calcium batteries are a type of lead-acid battery which use calcium (Ca) as the primary alloying element with lead in the plate grids.

Like lead-antimony, the use of lead-calcium alloys in the grids has both advantages and disadvantages. ***Advantages*** include providing greater mechanical strength than pure lead grids, a low self-discharge rate, and reduced gassing resulting in lower water loss and lower maintenance requirements than for lead-antimony batteries.

Disadvantages of lead-calcium batteries include poor charge acceptance after deep discharges and shortened battery life at higher operating temperatures and if discharged to greater than 25% depth of discharge repeatedly.

2.1. Flooded Lead-Calcium, Open Vent

Often classified as stationary batteries, these batteries are typically supplied as individual 2 volt cells in capacity ranges up to and over 1000 ampere-hours. Flooded lead-calcium batteries have the advantages of low self-discharge and low water loss, and may last as long as 20 years in stand-by or float service. In PV applications, these batteries usually experience short lifetimes due to sulfation and stratification of the electrolyte unless they are charged properly.

2.2. Flooded Lead-Calcium, Sealed Vent

Primarily developed as 'maintenance free' automotive starting batteries, the capacity for these batteries is typically in the range of 50 to 120 ampere-hours, in a nominal 12 volt unit. Like all lead-calcium designs, they are intolerant of overcharging, high operating temperatures and deep discharge cycles.

They are “maintenance free” in the sense that you do not add water, but they are also limited by the fact that you cannot add water which generally limits their useful life. This battery design incorporates sufficient reserve electrolyte to operate over its typical service life without water additions. These batteries are often employed in small stand-alone PV systems such as in rural homes and lighting systems, but must be carefully charged to achieve maximum performance and life.

While they are low cost, they are really designed for shallow cycling, and will generally have a short life in most PV applications An example of this type of battery that is widely produced throughout the world is the Delco 2000.

It is relatively low cost and suitable for unsophisticated users that might not properly maintain their battery water level. However, it is really a modified SLI battery, with many thin plates, and will only provide a couple years of useful service in most PV systems.

3.Lead-Antimony/Lead-Calcium Hybrid

These are typically flooded batteries, with capacity ratings of over 200 ampere-hours. A common design for this battery type uses lead-calcium tubular positive electrodes and pasted lead-antimony negative plates.

This design combines the advantages of both lead-calcium and lead-antimony design, including good deep cycle performance, low water loss and long life. Stratification and sulfation can also be a problem with these batteries, and must be treated accordingly. These batteries are sometimes used in PV systems with larger capacity and deep cycle requirements. A common hybrid battery using tubular plates is the Exide Solar battery line manufactured in the United States.

4. Captive Electrolyte Lead-Acid Batteries

Captive electrolyte batteries are another type of lead-acid battery, and as the name implies, the electrolyte is immobilized in some manner and the battery is sealed under normal operating conditions. Under excessive overcharge, the normally sealed vents open under gas pressure. Often captive electrolyte batteries are referred to as valve regulated lead acid (VRLA) batteries, noting the pressure regulating mechanisms on the cell vents. Electrolyte cannot be replenished in these battery designs, therefore they are intolerant of excessive overcharge.

Captive electrolyte lead-acid batteries are popular for PV applications because they are spill proof and easily transported, and they require no water additions making them ideal for remote applications were maintenance is infrequent or unavailable. However, a common failure mode for these batteries in PV systems is excessive overcharge and loss of electrolyte, which is accelerated in warm climates. For this reason, it is essential that the battery charge controller regulation set points are adjusted properly to prevent overcharging.

This battery technology is very sensitive to charging methods, regulation voltage and temperature extremes. Optimal charge regulation voltages for captive electrolyte batteries varies between designs, so it is necessary to follow manufacturers recommendations when available. When no information is available, the charge regulation voltage should be limited to no more than 14.2 volts at 25 C for nominal 12 volt batteries.

A benefit of captive or immobilized electrolyte designs is that they are less susceptible to freezing compared to flooded batteries. Typically, lead-calcium grids are used in captive electrolyte batteries to minimize gassing, however some designs use lead-antimony/calcium hybrid grids to gain some of the favourable advantages of lead-antimony batteries.

In the United States, about one half of the small remote PV systems being installed use captive electrolyte, or sealed batteries. The two most common captive electrolyte batteries are the gelled electrolyte and absorbed glass mat designs.

4.1. Gelled Batteries

Initially designed for electronic instruments and consumer devices, gelled lead-acid batteries typically use lead-calcium grids. The electrolyte is 'gelled' by the addition of silicon dioxide to the electrolyte, which is then added to the battery in a warm liquid form and gels as it cools. Gelled batteries use an internal recombinant process to limit gas escape from the battery, reducing water loss. Cracks and voids develop within the gelled electrolyte during the first few cycles, providing paths for gas transport between the positive and negative plates, facilitating the recombinant process.

Some gelled batteries have a small amount of phosphoric acid added to the electrolyte to improve the deep discharge cycle performance of the battery. The phosphoric acid is similar to the common commercial corrosion inhibitors and metal preservers, and minimizes grid oxidation at low states of charge.

4.2. Absorbed Glass Mat (AGM) Batteries

Another sealed, or valve regulated lead-acid battery, the electrolyte in an AGM battery is absorbed in glass mats which are sandwiched in layers between the plates. However, the electrolyte is not gelled. Similar in other respects to gelled batteries, AGM batteries are also intolerant to overcharge and high operating temperatures. Recommended charge regulation methods stated above for gelled batteries also apply to AGMs.

A key feature of AGM batteries is the phenomenon of internal gas recombination. As a charging lead-acid battery nears full state of charge, hydrogen and oxygen gasses are produced by the reactions at the negative and positive plates, respectively. In a flooded battery, these gasses escape from the battery through the vents, thus requiring periodic water additions.

In an AGM battery the excellent ion transport properties of the liquid electrolyte held suspended in the glass mats, the oxygen molecules can migrate from the positive plate and recombine with the slowly evolving hydrogen at the negative plate and form water again. Under conditions of controlled charging, the pressure relief vents in AGM batteries are designed to remain closed, preventing the release of any gasses and water loss.

5. Calcium-Calcium

The next stage has dominated on a wide front in recent years and is called Calcium-Calcium. This involves the antimony on both the negative and positive plates being replaced by calcium alloy. The benefits are obvious. The fluid loss of the battery is about 80 % lower than that of antimony batteries and the self-discharge is lower, i.e. they can remain unused for longer periods without losing a lot of their charge.

The ***disadvantage*** is that they are more demanding when charging if they have been over-discharged. Efforts made in avoiding the gassing had a positive affect, namely that the bubbles moved about in the acid causing it to be thoroughly mixed when charging. Without these bubbles the acid can stratify at different densities, acid weights, and is quite a common phenomenon. An acid weight of 1.35 or more at the bottom and maybe 1.17 at the top when you are looking for an even weight of 1.28 may cause the battery to be affected by sulphating and increased grid corrosion despite the battery being apparently fully charged.

Lead-Acid Battery Chemistry

Now that the basic components of a battery have been described, the overall electrochemical operation of a battery can be discussed. The basic lead-acid battery cell consists of sets positive and negative plates, divided by separators, and immersed in a case with an electrolyte solution.

In a ***fully charged lead-acid cell,*** the positive plates are lead dioxide (PbO_2), the negative plates are sponge lead (Pb), and the electrolyte is a diluted sulphuric acid solution. When a battery is connected to an electrical load, current flows from the battery as the active materials are converted to lead sulphate ($PbSO_4$).

Lead-Acid Cell Reaction

The following equations show the electrochemical reactions for the lead-acid cell.

During battery discharge, the directions of the reactions listed goes from left to right.

During battery charging, the direction of the reactions are reversed, and the reactions go from right to left. Note that the elements as well as charge are balanced on both sides of each equation.

(i) DISCHARGING (Fig. a)

When the cell is fully charge, its positive plate or anode is PbO_2 (dark chocolate brown) and the negative plate or cathode is Pb (slate grey). When the cell discharges i.e. it sends current through the external load, then H_2SO_4 is dissociated into positive H_2 and negative SO_4 ions. As the current within the cell is flowing from cathode to anode, H_2 ions move to anode and SO_4 ions move to the cathode.

At anode (PbO_2), H_2 combines with the oxygen of PbO_2 and H_2SO_4 attacks lead to form $PbSO_4$.

$$PbO_2 + H_2 + H2_{S}O_4 \longrightarrow PbSO_4 + 2H_2O$$

At the cathode (Pb), SO_4 combines with it to form $PbSO_4$

$$Pb + SO_4 \longrightarrow PbSO_4$$

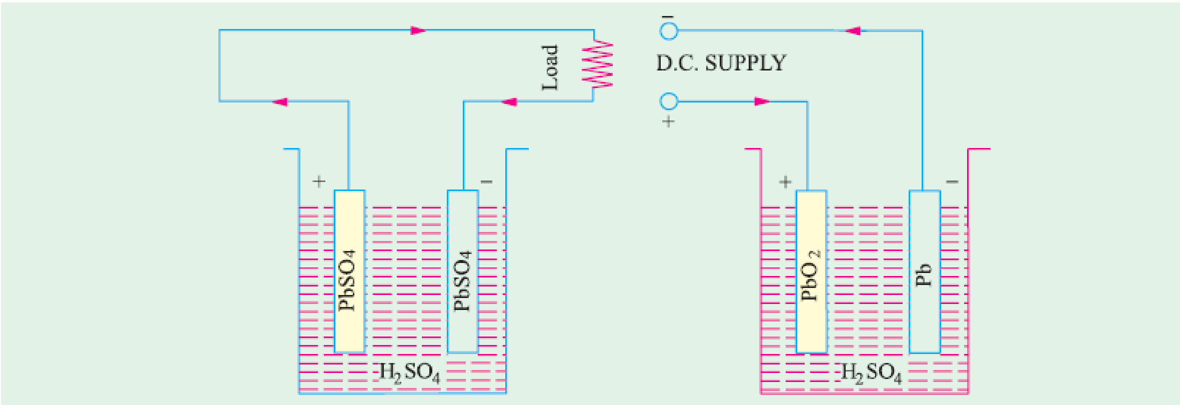


Fig. a   Fig. b

It will be noted that *during discharging :*

(i) Both anode and cathode become PbSO4 which is somewhat whitish in colour.

(ii) Due to formation of water, specific gravity of the acid decreases.

(iii) Voltage of the cell decreases.

(iv) The cell gives out energy.

(ii) CHARGING (Fig.b)

When the cell is recharged, the H2 ions move to cathode and SO4 ions go to anode and the following changes take place :

At Cathode $PbSO_4 + H_2 \longrightarrow Pb + H_2SO_4$

At Anode $PbSO_4 + 2H_2O \longrightarrow PbO_2 + 2H_2SO_4$

Hence, the anode and cathode again become PbO_2 and Pb respectively.

It will be noted that *during charging :*

(i) The anode becomes dark chocolate brown in colour (PbO2) and cathode becomes grey metallic lead (Pb).

(ii) Due to consumption of water, specific gravity of H2SO4 is increased.

(iii) There is arise in voltage.

(iv) Energy is absorbed by the cell.

The charging and discharging of the cell can be represented by a single reversible equation given below :

Pos. Plate		Neg. Plate	Discharge / Charge	Pos. Plate		Neg. Plate
$PbO_2 + 2H_2SO_4$	+	Pb	$\leftrightharpoons$	$PbSO_4 + 2H_2O$	+	$PbSO_4$

For discharge, the equation should be read from left to right and for charge from right to left

Nickel-Cadmium Batteries

Nickel-cadmium (Ni-Cad) batteries are secondary, or rechargeable batteries, and have several advantages over lead-acid batteries that make them attractive for use in stand-alone PV systems.

These advantages include long life, low maintenance, survivability from excessive discharges, excellent low temperature capacity retention, and non-critical voltage regulation requirements. The main disadvantages of nickel- cadmium batteries are their high cost and limited availability compared to lead-acid designs.

Ni-Cd Types:

1.Sintered Plate Ni-Cads

Sintered plate nickel cadmium batteries are commonly used in electrical test equipment and consumer electronic devices. The batteries are designed by heat processing the active materials and rolling them into metallic case. The electrolyte in sintered plate nickel-cadmium batteries is immobilized, preventing leakage, allowing any orientation for installation. The

main disadvantage of sintered plate designs is the so called 'memory effect', in which a battery that is repeatedly discharged to only a percentage of its rated capacity will eventually 'memorize' this cycle pattern, and will limit further discharge resulting in loss of capacity. In some cases, the 'memory effect' can be erased by conducting special charge and discharge cycles, regaining some of its initial rated capacity.

2.Pocket Plate Ni-Cads

Advantages: These batteries can withstand deep discharges and temperature extremes much better than lead-acid batteries, and they do not experience the 'memory effect' associated with sintered plate Ni-Cads.

The main disadvantage of pocket plate nickel cadmium batteries is their high initial cost, however their long lifetimes can result in the lowest life cycle cost battery for some PV applications.

Unit –II

Commissioning of solar systems

Charge controller – Inverters – ON grid and OFF grid system components – Testing equipments – Application equipments – Clamping accessories for installation – Identification of load to be connected – Reading and interpreting the single line diagrams – Site survey before installation – Testing of solar system components including fault finding and analysis including continuity testing and polarity checking – Fundamentals of earthing for solar systems.

Basic Meters Used with PV Systems

PV installation work is for qualified personnel only. All workers must be competent and understand the hazards involved with electrical work.

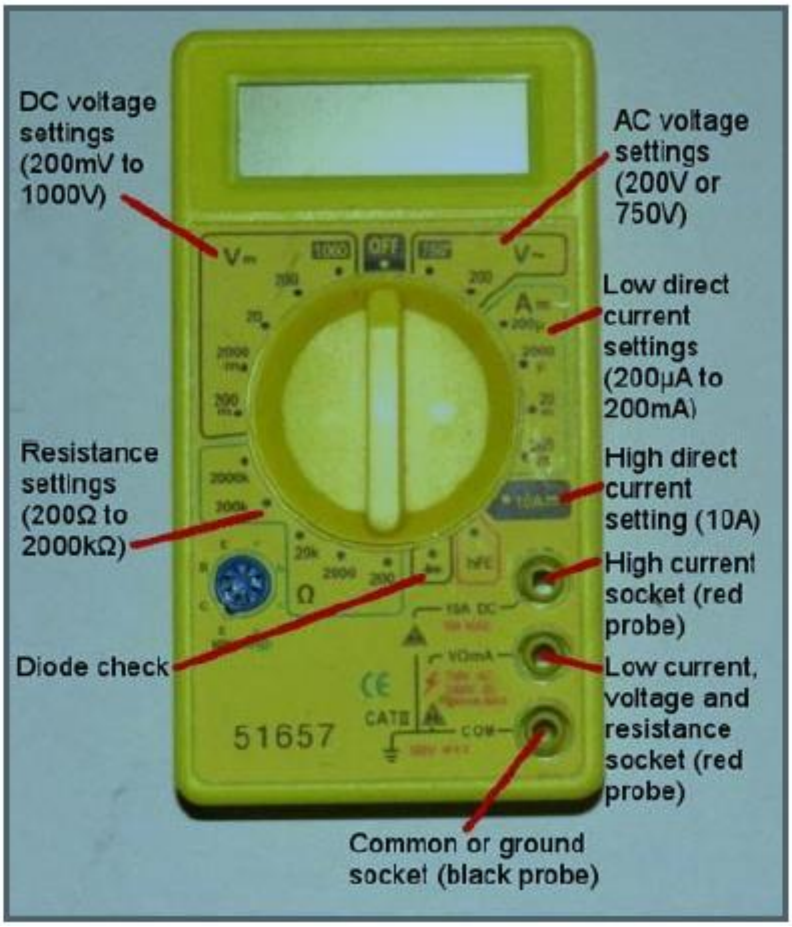
1 Digital Pyranometer

- Pyranometer is used to measure the sunlight intensity.
- It measures irradiance in Watts/m2
- Gives data in digital format.
- Instantaneous or data-logged / saved measurements.

2. Digital Multimeter

- Used in DC & AC voltage testing.
- Continuous testing.

- Current testing.
- Avoid testing current of a PV with meter probes – you will pull an arc



3. Clamp – On Ammeter

- Non-Contact current testing measures using induction
- Only method for measuring high current levels (>10 – 20 Amps)
- Typically has all basic features of Digital Multi Meter.
- Confirm Accuracy.
- Use this meter to ensure no current flow before opening non – loaded break rated devices.

4. Infra-Red Temperature Gun

- IR temperature gun is used to measure the cell temperature of the PV module.
- It measures temperature in Celsius and Fahrenheit.
- Gives data in digital format.

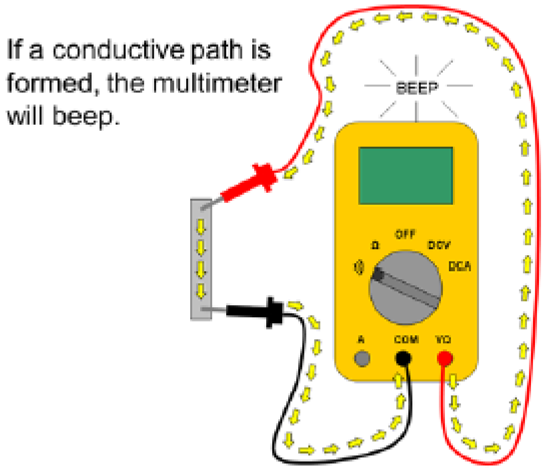
Meter Testing Procedure:

- Testing an energised PV system is the most dangerous electrical activity for technician.
- Proper **PPE (Personal Protective Equipment)** must be worn testing energised circuits.

- Check for current in all circuits before operating non – load break rated devices, such as fuse holder
- Calculate the expected value – before you test.
- Test voltage and polarity in each piece of the equipment before installing fuse or closing disconnect.

Continuity Check / Test

- Test used to determine whether an electrical path exists.
- Commonly used to verify if a fuse is good or bad, or determine if equipment is bonded together
- Most meters have audible indication of continuity as well.



Transformer - Based

- Uses transformer to change voltage.
- Heavier than Transformer Less.
- Less efficient than Transformer Less.
- Also called " Isolated Inverters"

Transformer Less

- Uses electronic circuitry to change voltage
- Lighter
- May be less expensive
- Produce less heat
- Higher efficiency
- Safer
- Also called "Non-Isolated"

ON GRID Components of PV systems

- It means grid tied PV
- It consists of
  - PV panel
  - Inverter

- Grid connections

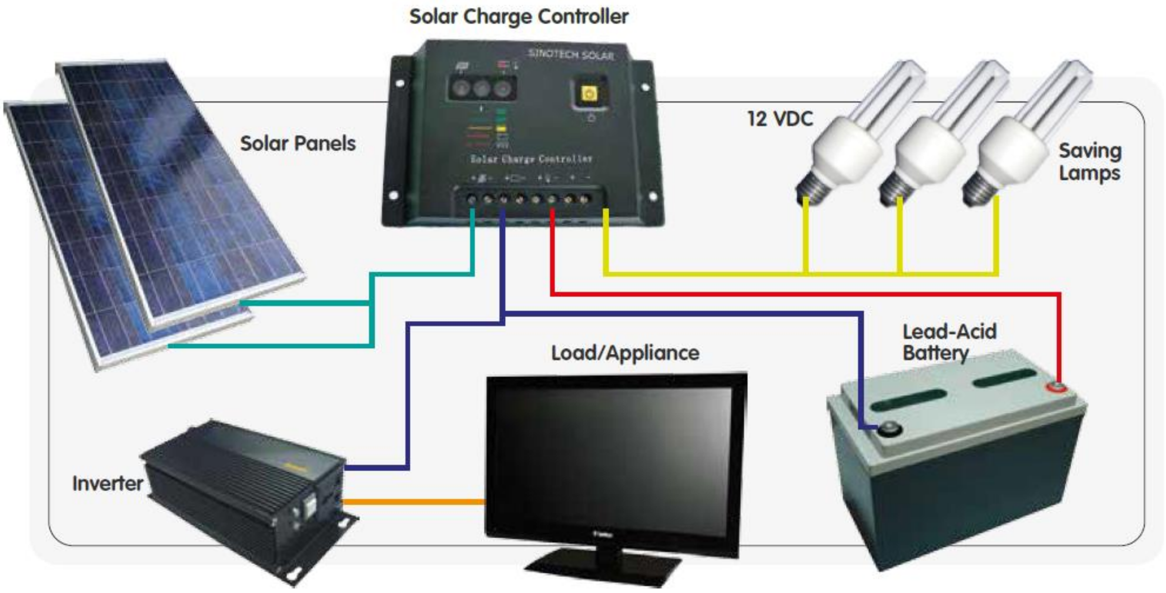
- No battery & charge controllers are required.

OFF GRID Components of PV systems

- It means stand-alone system which can run an individual applications

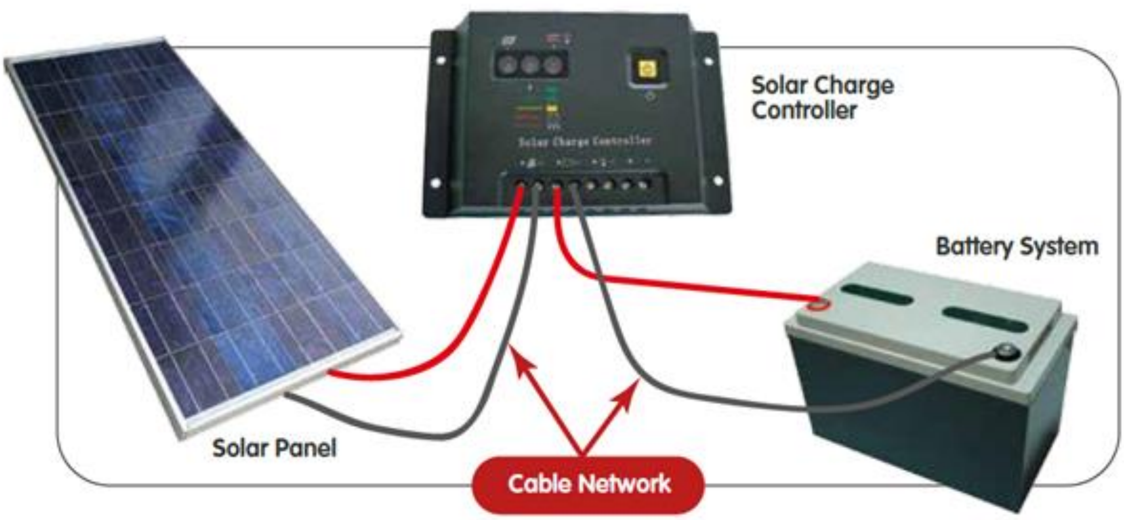
- It Consists of
    - PV panel
    - Charge Controller
    - An Inverter

Solar Charge Regulator/ Charge Controller



The solar charge regulator/ charge controller is a voltage and/or current regulator which is connected between the solar panel, the battery and the load.

Its main job is to keep the batteries from over charging and over discharging.



Connecting a Charge Regulator / Controller to the Solar Panel

● Ensure that the collector (the solar panel) is shaded to avoid the danger of electric shock.
● Using the right tools, loosen the screws at the correct terminals, below the solar panel picture, as shown in the image below:

Fit the positive electrical cable from the solar panel to the positive terminal of the charge controller.

FEATURES OF CHARGE CONTROLLES

- PV charge controllers are sometimes called **solar charge regulators**
- The controllers are used in both wind energy and PV systems
- They protect the battery from overcharging or over discharging
- Over charging or discharging can damage a battery
- Small power systems that have wind and solar energy use hybrid controllers
- Larger systems have their own controllers
- The controller is one of the most important parts of any energy system
- The latest technologies have effective battery charging routines
- Advanced controllers use maximum power point tracking charging
- Controllers provide vital charging information to users

Do & Don't Do – Charge controllers

Do's

● Ensure connections are firm. In case of a problem, consult your solar installer or supplier.

Don't Do's

- Tamper with the charge controller.
- Place it where water can penetrate.

- **Some have colour coding:**
- **RED is postive (+)**
    - Connect the **Positive** (Solar Panel) to the **Positive** (Charge Controller)
- **BLACK is negative (-)**
    - Connect the **Negative** (Solar Panel) to **Negative** (Charge Controller)

Importance or Use of a Charge Controller

● It monitors the battery voltage

● It stops charging when the battery is fully charged

● It extends battery life

● It regulates power from the solar panels, protecting the battery from overcharging. Overcharging damages batteries and reduces battery life

● It prevents overly deep discharge which damages the batteries

● It protects your appliances and gadgets

Dangers of Bypassing a Charge Controller

Bypassing the charger controller will cause:

● Damage of batteries because there is no regulation of power

● Damage of electrical appliances

Care for the Cable Network

- **Do's**
- Inspect the cable network every 3 to 5 years to ensure they are no exposed wires.
- Protect your solar wiring from damage as this can result in the failure of your system.
- Avoid short-circuiting your cables as this can lead to system damage.

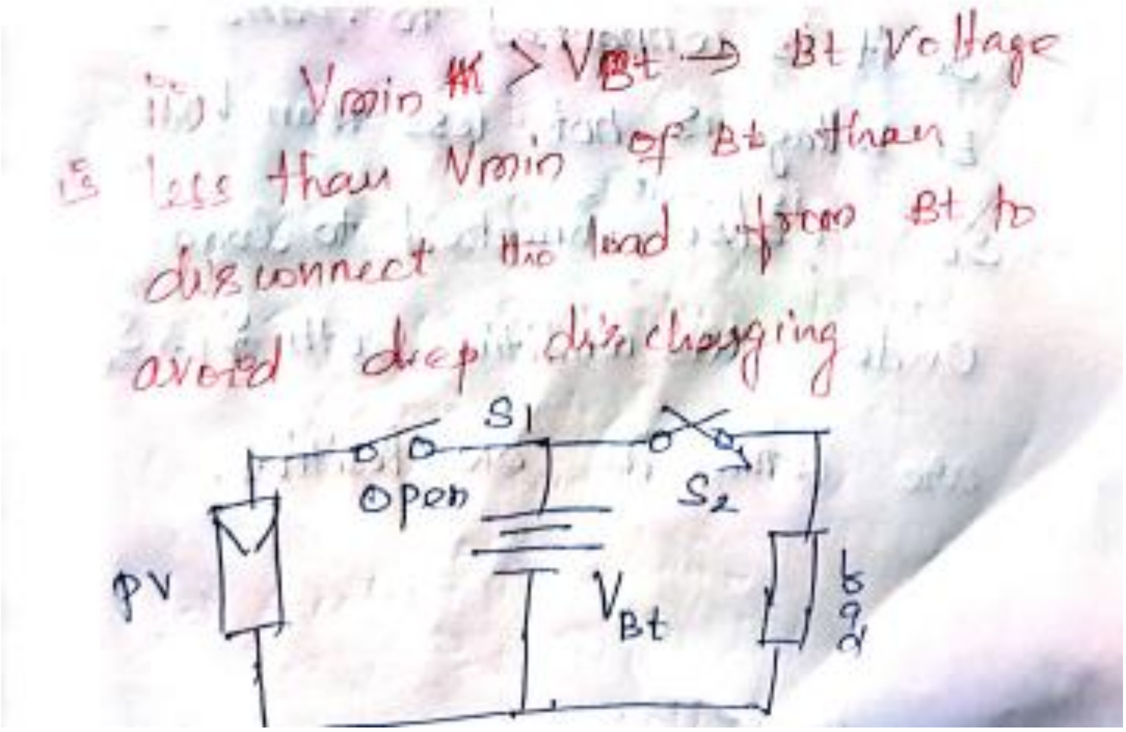
Don't Do's

- Try to make connections when you are not sure. Seek expert advice and help.

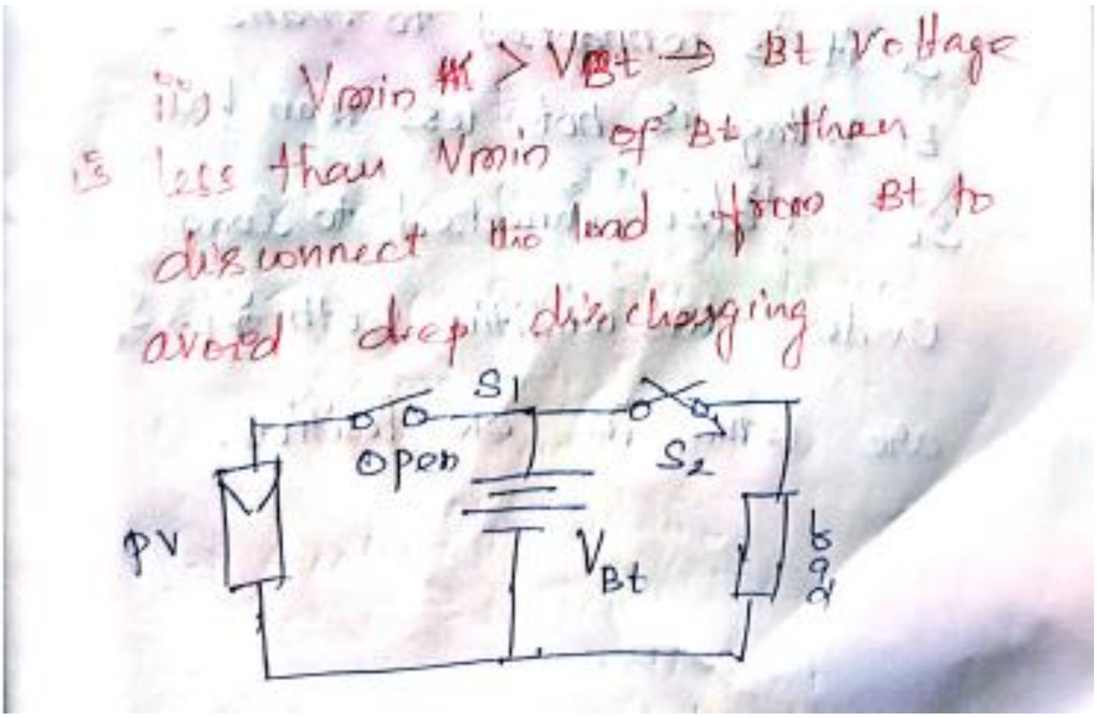
Main function of a charge controller is 3

- **Case – 1** $V_{Bt} > V_{max}$
- **Case – 2** $V_{min} > V_{Bt}$
- **Case – 3** $V_{min} \leq V_{Bt} \geq V_{max}$

Case – 1 $V_{Bt} > V_{max}$



Case – 2 $V_{min} > V_{Bt}$



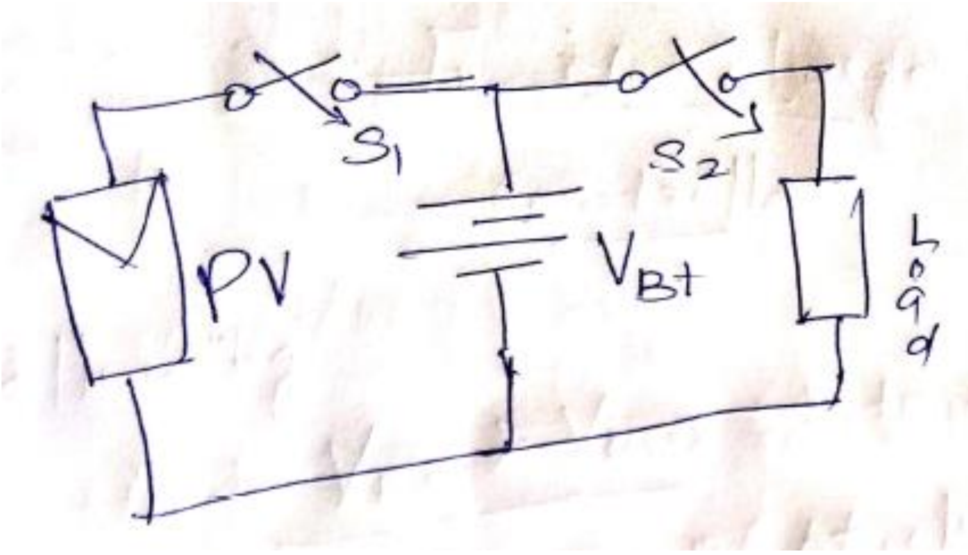
Under this condition Bt is connected to load, it starts discharging to load. Bt voltage starts ↓, if it is less than V_{min} of Bt we are going / ckt going to disconnect the Bt from load. By means of opening the S_2 switch.

Case – 3 $V_{min} \leq V_{Bt} \geq V_{max}$

iii). If $V_{min} \leq V_{Bt} \leq V_{max}$

Bt voltage not more that V_{max} so it is connected to panel & Bt voltage is not less than V_{min} so it is also connected to load.

Under this condition, both S_1 & S_2 are connec in ON Position.



Practical Circuit of Charge Controller

Charge controller circuit

D – free wheel – not BJT blow

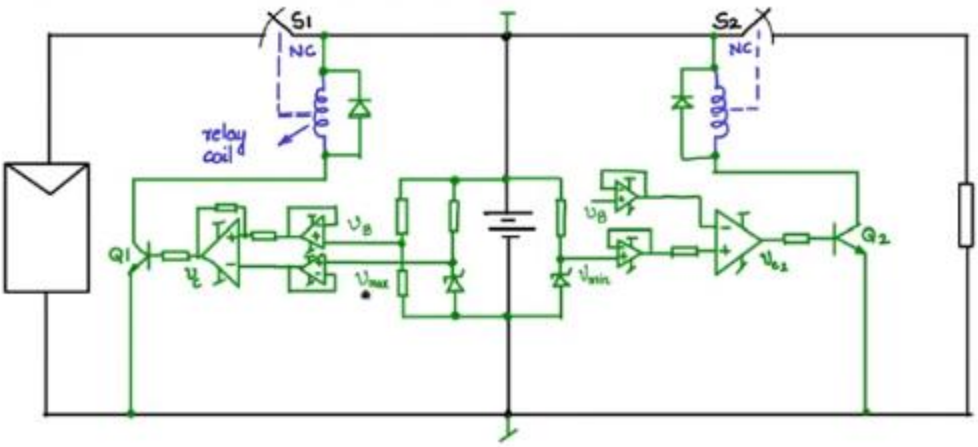
Vb- bt voltage

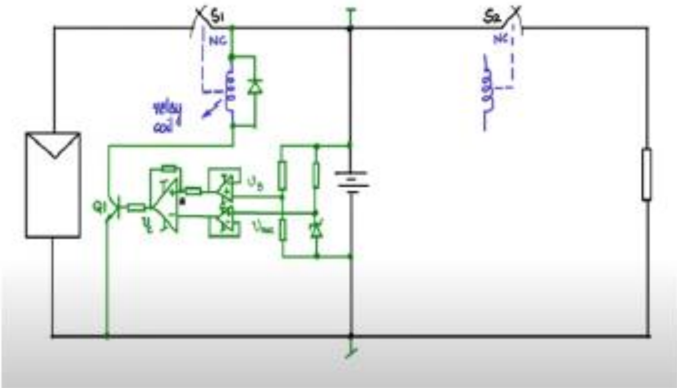
Vb>Vmax = comparator goes high

Q1 – ON

Relay energised

S1 is open





Vb<Vmin

Com o/p high

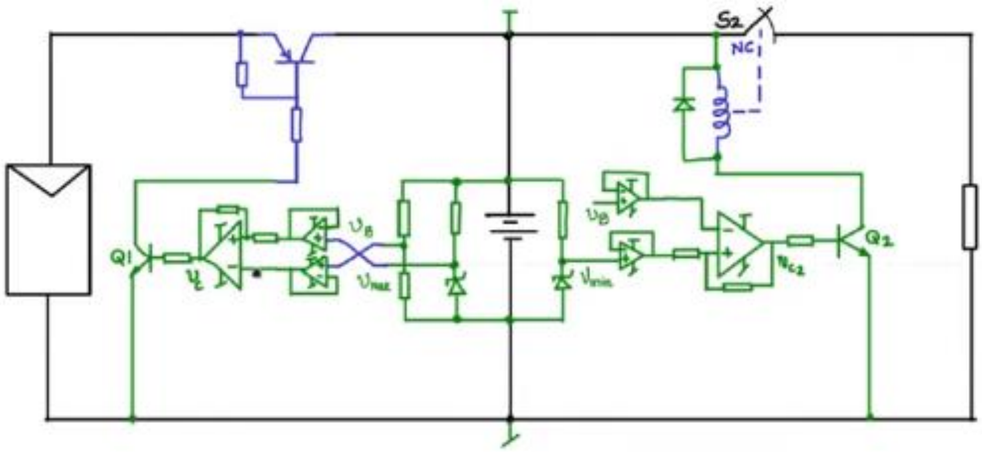
Q2 on

Relay -2 energised

S2 Open

& S1 closed & Bt is charged

S1 & S2 –MOSFET /BJT



Battery based inverter/chargers

With the growth of solar + storage, battery-based inverter/chargers are becoming increasingly important. Battery based inverter/chargers are bi-directional in nature, including both a battery charger and an inverter. They require a battery to operate. Battery-based inverter/chargers may be grid-interactive, standalone grid-tied or off-grid, depending on their UL rating and design.

The primary benefit of inverter/chargers is that they provide for continuous operation of critical loads irrespective of the presence or condition of the grid. UL1741 requires the grid-tied generation source to stop generating power in the event of a grid outage. This de-powering is known as anti-islanding, as opposed to 'islanding' which is defined as generating power to power a location in the event of a grid outage. Therefore, UL1741 grid-tie inverters will not generate power in the event of a grid outage, so a user will experience an outage irrespective of the availability solar harvest.

Battery-based inverter/chargers will power the critical loads in the event of a grid outage, but will do so in a manner to not create the islanding condition. Further, UL1741 inverter/chargers may be rated as either interactive or standalone. The former export excess power to the grid, while the latter do not–by rating and by definition. In all instances, the battery based inverter/charger manages energy between the array and the grid while keeping the batteries charged. They monitor battery status and regulate how the batteries are charged.

PV charge controllers

A PV controller can also prevent overcharge. Once a battery is fully charged, it can't **store** incoming solar energy. If that energy continues to be applied, the battery voltage becomes too high.

A PV charge controller prevents overcharge by reducing the flow of energy to your battery once it reaches a certain voltage. Once the voltage drops when the sun intensity is lower or there is an increase in electrical usage, the controller will allow for the maximum charge possible. This is known as voltage regulation and is a vital function of the controller. Essentially, the controller looks at the voltage and then regulates the battery charging. Certain controllers will regulate the flow of energy to the **solar generator** battery by switching the current either fully off or on. This is known as the on/off control. Other controllers will gradually reduce the current.

STAND-ALONE PHOTOVOLTAIC SYSTEMS - Battery charge control

Small stand-alone PV systems generally use battery backup, and the roles of the system electronics are to control the charging of the battery and if necessary to change the voltage or to convert the DC to AC for the load. The most widely used batteries are lead acid batteries in one of their various forms. This is because they are relatively cheap, have relatively good energy storage density, and can be robust and reliable. Their disadvantage is that they do need some care in controlling the charging and discharging if good life and a large number of charge/discharge cycles are to be obtained.

A typical, simple, ideal, charging cycle for a lead acid battery is as illustrated in Fig. 12. Initially the battery is charged at constant current (the bulk charge phase) until the voltage reaches some predefined value then the voltage is held constant while the charging current decays

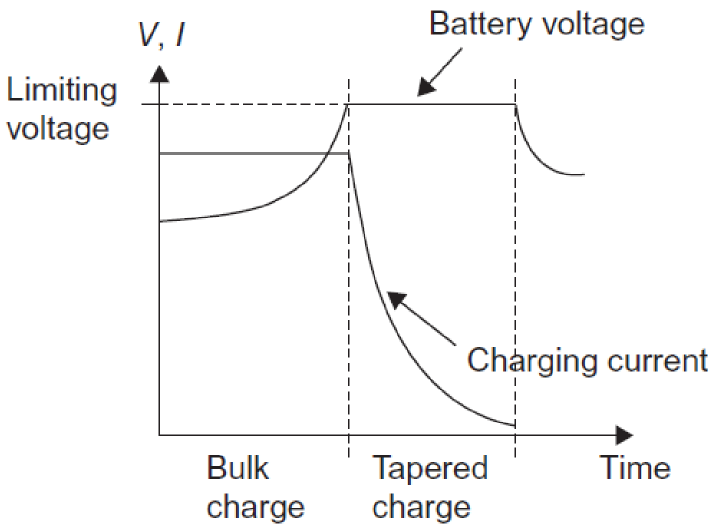


Figure 12 The typical ideal charging cycle for a lead–acid battery.

(tapered charge phase). After a suitable time, the charging voltage is reduced, or removed completely to avoid excessive gassing and loss of electrolyte. This ideal charging sequence can never be achieved with a PV system where the available power is constantly changing. The best the controller can do is to limit the peak charging current if necessary during the bulk charge phase, limit the voltage during the tapered charge phase and cut off the charge if the battery is deemed fully charged. Some charging schemes, rather than cutting off the charge altogether reduce the charging voltage by 5%_10% to provide a trickle charge with a voltage low enough to avoid significant gassing. With some types of lead acid cell it is also desirable to overcharge the battery occasionally to promote gassing and stir up the electrolyte.

With a PV array there are two basic methods by which the voltage or current may be controlled. A series regulator introduces resistance in series with the array (Fig. 13A), reducing the load current but allowing the array voltage to rise toward its open-circuit value, and a shunt regulator which dumps current from the array pulling down both load and array voltage (Fig. 13B). The diodes are necessary to avoid the battery being discharged either through the array or through the shunt regulator. Such regulators may be implemented using transistors as variable resistance elements. This approach requires the transistors to dissipate a large amount of power and is not generally used. The much more popular approach is to use the transistors as switches which turn on and off in

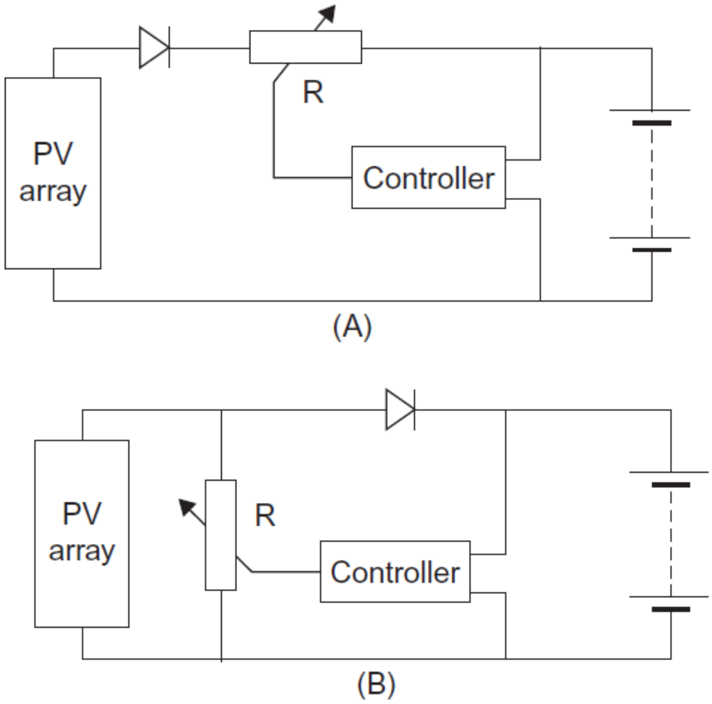


Figure 13 (A) Series regulation of battery charge current; (B) Shunt regulation.

such a way as to reduce the mean current flowing to the battery (Fig. 14). Again either a series (a) or a shunt connection is possible (b). In the series-switching regulator the switch makes and breaks the current to the battery. The mean switch current depends on the fraction of the time for which the switch is on. If the switching is rapid the voltage across the battery will be almost constant as the battery voltage responds quite slowly to changes in current. The excess power from the PV array is dissipated in the cells of the array. The shunt switching regulator operates in a similar manner. The diode prevents the battery from discharging through the switch and effectively acts as a series switch, which is off when the controlled switch is on. Again excess power is dissipated within the PV array.

Provision should also be made for cutting off the supply to the load if the state of charge of the battery falls below an acceptable level otherwise permanent damage to the battery may result. This requires some method of measuring or estimating the state of charge of the battery. This information
is important to know when to shed load, it is also needed to establish when to discontinue charge. The state of charge is

frequently deduced from the terminal voltage, either off load or with a known load.
However, this method is not very reliable as the voltage depends on many factors such as temperature and the recent charge/discharge history of the battery. For flooded lead acid cells the electrolyte specific gravity may be used, but this is not easy to measure using electronic techniques and may

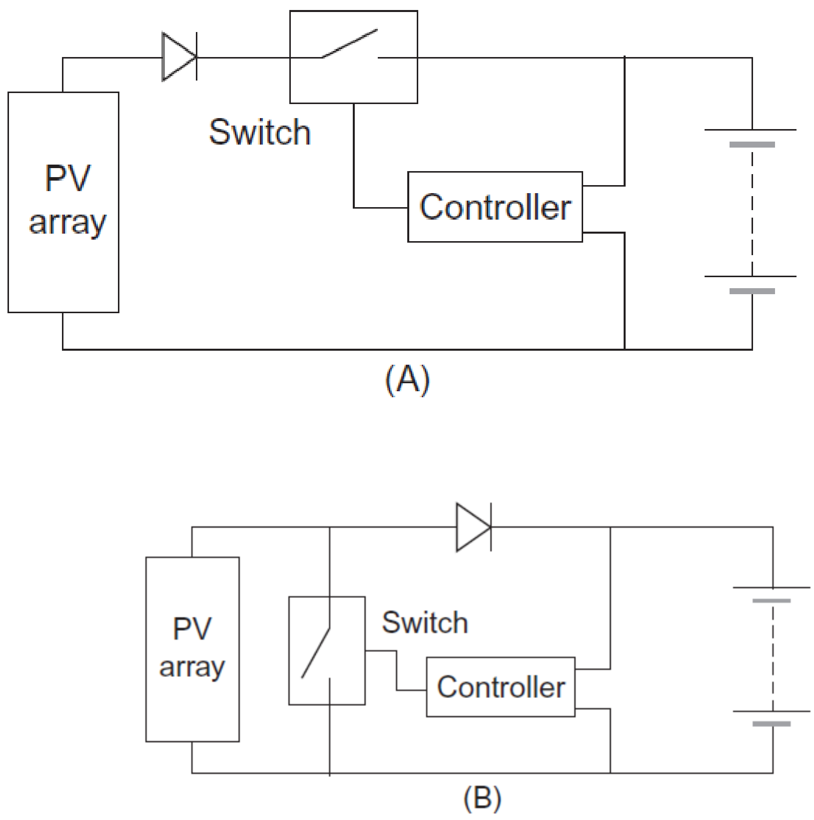


Figure 14 (A) Series-switching regulator; (B) Shunt switching regulator.

be modified by stratification of the electrolyte or loss of water due to excessive gassing. To try to overcome this ampere hour counting may be used to establish how much charge has been removed or added to the battery and hence deduce the state of charge. This method will drift, but may be recalibrated if there are times when the battery is known to be fully charged.

PRACTICAL CONSIDERATIONS - Charge controllers

The role of the charge controller is to ensure that the battery is not overcharged. There is a bewildering array of commercial devices from a large number of manufacturers, with current ratings from a few amps up to hundreds of amps, and operating voltages generally in multiples of 12 V
up to 48 V (nominal battery voltage).

Most commercially available charge controllers for PV applications use a switched series regulator to control the charging current Fig. 14A. The most common control scheme is PWM. The power to the battery is switched on and off at a constant frequency, with the duty ratio varied, to
control either the mean current to the battery or the charging voltage of the battery. This scheme is similar to a buck converter, but with a PV power source the current is limited, so a series inductor to limit the peak current is unnecessary, and the load voltage is smoothed by the battery.

The control algorithm depends on the type of battery and most charge controllers provide a number of settings to accommodate different voltages and types of lead_acid battery. A typical control scheme would allow continuous current until the battery reaches a predetermined voltage and then the duty ratio of the PWM is reduced to limit the battery voltage. Some controllers use a three-stage charging algorithm with a bulk charge phase, where the charging current is the maximum available, a taper phase where the voltage is held constant, and a float phase where the battery voltage is held constant at a reduced value. Many controllers will have control algorithms that will allow different control regimes and/or settings to accommodate different battery types.

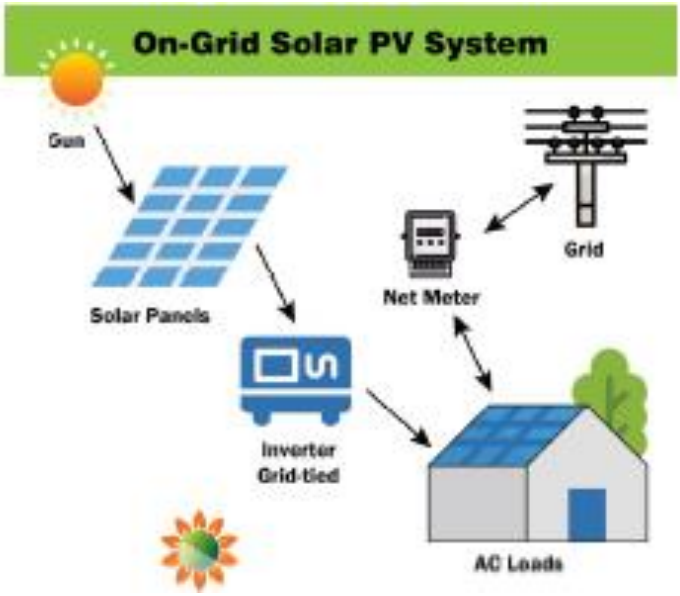
A few controllers use switched shunt regulation. In this case a transistor switch bypasses the current from the PV array (Fig. 14B). Again PWM may be used to control the mean load current. A variant on the shunt controller uses switches to divert power from charging the battery to a diversion load, again using PWM. The diversion load might be a water heater or similar. This enables the energy not used for charging the battery to be used usefully, rather than dissipated as heat in the PV panel. It is not clear that either series or shunt regulation is to be preferred. Both can achieve high overall efficiency.

In both series and shunt controllers the switches used are field effect transistors (FETs) with an ON state resistance of only a few mΩ. Thus the voltage drop across the switch when it is on is usually small, avoiding unnecessary power dissipation, and in the case of a series regulator ensuring that overall efficiency is high. Control schemes other than PWM are possible and are used by some suppliers. One proprietary scheme, Flex charge, uses the way in which the battery voltage rises and falls as the current is switched ON and OFF to control the switching. The switch supplies current to charge the battery until the battery voltage reaches a desired upper limit. The current is then switched off until the voltage has fallen to a lower limit. This procedure charges the battery with pulses of current, which become shorter and less frequent as the battery approaches full charge.

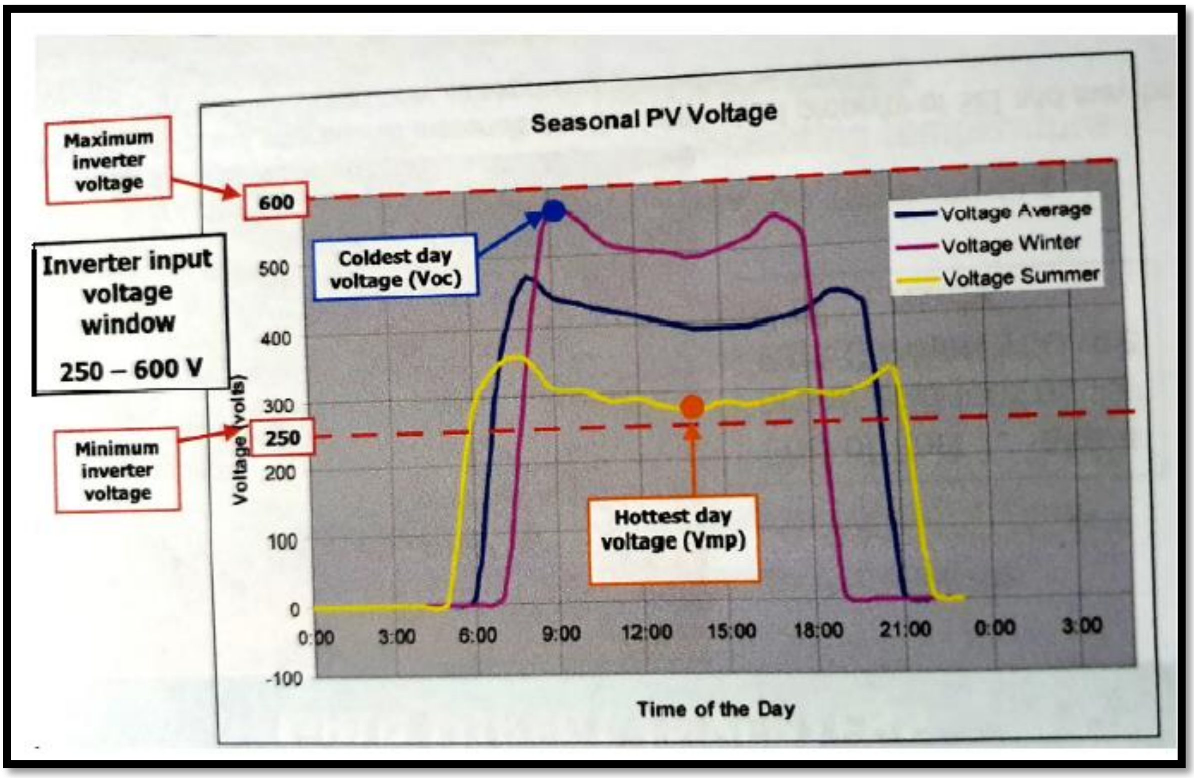
Charge controllers incorporating MPP tracking are available, but much less common than simple charge controllers. To be useful a MPP tracker must have an efficiency of greater than 90%. This calls for careful design and the cost of such systems is significantly greater than for a basic charge controller. The gain in system efficiency, however, may be significant; gains of up to 30% are claimed. Such large gains will only be achieved when the battery is in a low state of charge (low voltage) and the PV array is cold (high voltage). Average efficiency gains are, however, likely to be significantly less (of the order of 10%). The cost of the MPP tracker must be weighed against the cost of extra array area.

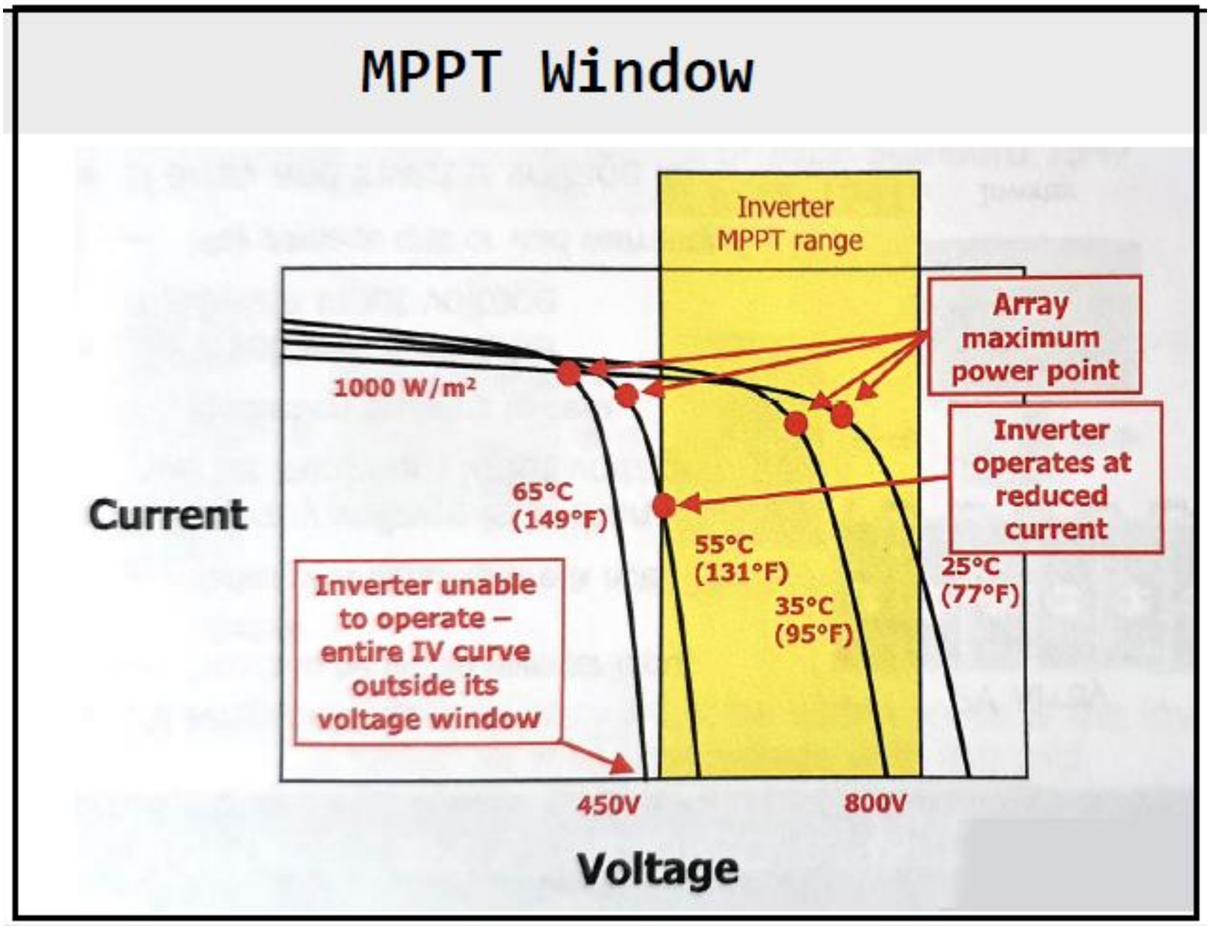
Solar inverters

It's an electric device used to convert direct current (DC) electricity to alternating current (AC) electricity.



Selection of voltage for the Inverters





Based on generated electricity by the PV will decide the value of the inverter required for the particular place.

Specifying a Grid – Direct Inverter

- Watts output AC – total connected watts of PV
    - STC rating of the PV array
    - DC voltage window – array voltage within inverter range
    - Single module – module level power electronics
    - 100-600 volts DC (in the some cases up to 1500 V)
    - 250-550 volts is typical for residential – scale inverters
- Output voltage (AC)
    - 230 volts Residential
    - Various other voltages
- Frequency
    - 50Hz

Features of Grid - Direct Inverters

- High Efficiency

- Reliability
- Weather – Proof enclosure
- Long warranty period
- Maximum Power Point Tracking (MPPT)
    - Standard feature
- Ground fault protection
    - Standard feature
- Integrated AC/DC disconnects and series fusing
- Metering, remote metering, wireless metering
- DC arc – fault protection
- Transformer based or Transformer less

Types of Solar Inverters

Inverters are an important part of any solar installation; they are the brains of the system. Although the inverter's main job is to convert DC power produced by the solar array into usable AC power, its role is only expanding. Inverters enable monitoring so installers and owners can see how a system is performing. Inverters can also provide diagnostic information to help O&M crews identify and fix system issues. These important components are increasingly taking on decision-making and control functions to help improve grid stability and efficiency. With the growth of solar + storage, inverters are also taking on responsibility for battery management. Here is a look at some different types of solar inverters.

1. String inverters

Solar panels are installed in rows, each on a "string." For example if you have 25 panels you may have 5 rows of 5 panels. Multiple strings are connected to one string inverter. Each string carries the DC power the solar panels produce to the string inverter where it's converted into usable AC power consumed as electricity. Depending on the size of the installation, you may have several string inverters each receiving DC power from a few strings.

String inverters have been around for a long time and are good for installations without shading issues and in which panels are positioned on a single plane so do not face different directions. If an installation uses string inverters and even one panel is shaded for a portion of the day reducing its performance, the output of every panel on the string is reduced to the struggling panels' level. Though string inverters aren't able to deal with shading issues, the technology is trusted and proven and they are less expensive than systems with microinverters. String inverters are commonly used in residential and commercial applications. Also, as technology improves allowing string inverters to have greater power density in smaller sizes, string inverters are becoming a popular alternative over central inverters in small utility installations smaller than 1 MW.

String inverters can also be paired with power optimizers, an option that is gaining popularity. Power optimizers are module-level power electronics meaning they are installed at the module level, so each solar panel has one. Some panel manufacturers integrate their products with power optimizers and sell them as one solution known as a Smart Module. This can make installation easier. Power optimizers are able to mitigate effects of shading that string inverters alone cannot. They condition the DC electricity before sending it to the inverter, which results in a higher overall efficiency than using a string inverter alone. Power optimizers offer similar benefits as microinverters, but tend to be less expensive and so can be a good option between using strictly string inverters or microinverters.

Advantages of String Inverters

- Doesn't have to be on the roof – allows easy access for service.
- Cost per watt is typically less than MLPE(micro inverter)
- Many models have multiple MPPT channels.
- DC array voltage higher which reduces voltage drop.

Limitations

- Single Inverter – if fails then the entire system is down.
- Must protect DC wire in metallic conduit inside house.
- Shading can have greater effect.
- It can be hard to expand the system using the existing inverter.

2. Central inverters

Central inverters are similar to string inverters but they are much larger and can support more strings of panels. Instead of strings running directly to the inverter, as with string models, the strings are connected together in a common combiner box that runs the DC power to the central inverter where it is converted to AC power. Central inverters require fewer component connections, but require a pad and combiner box. They are best suited for large installations with consistent production across the array.

High Lights

- Essentially a large string inverter.
- Connects to string of modules in series, with many strings connected in parallel.
- Used for large commercial or utility scale systems
- Typically 100 KW and larger up to 2MW +

Advantages of Central Inverters

- Often rated for 1000 volts DC which reduces balance of system (BOS)costs

- Cost per watt is typically less than the string inverters.

- Many larger models come in pre-configured units that include BOS equipments.

Limitations

- Single / large inverter – if it fails entire system is down or a large amount of power is offline.

- Few MPPT channels relative to array size.

- Big, heavy and harder to work with.

- Additional cost / labour involved

    - Trenching

    - Concrete Pad

    - Placement

3. Microinverters

Microinverters are also becoming a popular choice for residential and commercial installations. Like power optimizers, microinverters are module-level electronics so one is installed on each panel. However, unlike power optimizers which do no conversion, microinverters convert DC power to AC right at the panel and so don't require a string inverter. Also, because of the panel-level conversion, if one or more panels are shaded or are performing on a lower level than the others, the performance of the remaining panels won't be jeopardized.

Microinverters also monitor the performance of each individual panel, while string inverters show the performance of each string. This makes microinverters good for installations with shading issues or with panels on multiple planes facing various directions. Systems with Microinverters can be more efficient, but these often cost more than string inverters.

Microinverters can also be sold through panel manufacturers already integrated into the panel, similar to Smart Modules but instead known as an AC Module. This makes installation easier and cheaper.

Micro Grid Inverters Advantages:

- Module – level MPPT
- Minimise shading effects
- Maximise space
- Utilise different orientations
- Failure limited to one module

- Module level monitoring
- Module level emergency shutdown
- Rapid shunt down

Limitations:

- High operating temperature

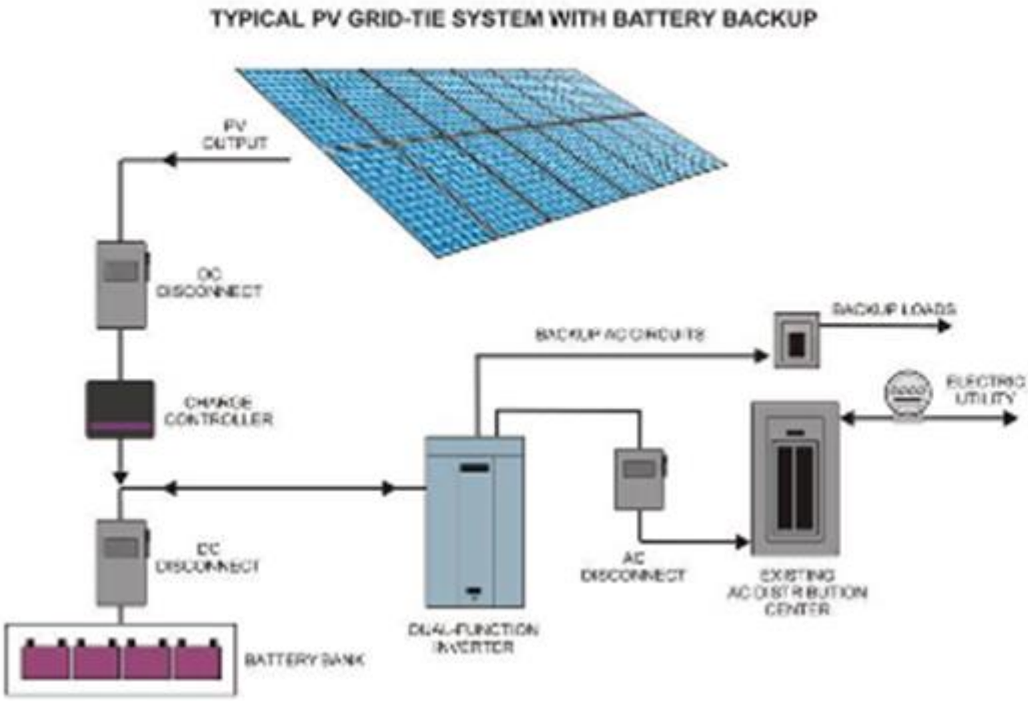
Single line diagrams of PV system

- A 1-line diagram or a single-line diagram (SLD) is a diagram to show information about the circuit system but the details of the connections and the operations of the system are not required.

Normally used to communicate how a system works in general and which components are connected to another.

- It uses single lines to connect graphic symbols representing the different components to indicate the path and components of an electrical circuit.
- Not all of the components may be shown in a 1-line diagram, but only the relevant components.
- Electrical systems should be drawn separate from other drawings such as architectural, structural, and mechanical.
- Electricalsymbolsshouldbedrawndarkerthanthebackgrounddrawingshowingothersystemsand/orbuildingstructure
- It is preferable that the solar PV electrical system drawing is done separately from other electrical systems but referencing them if it help switch clarity
- Electrical plans are generally drawn to scale, but graphic symbols only indicate the approximate locations of electrical equipment
- The symbols on the diagram do not represent the size or location of the electrical equipment. But the diagram should be organized based on some kind of logic. In most cases it makes sense to organize the diagram based on the general locations of the components (ie indoor/outdoor).
- The diagram should provide a fast, easy understanding of the connections and use of components

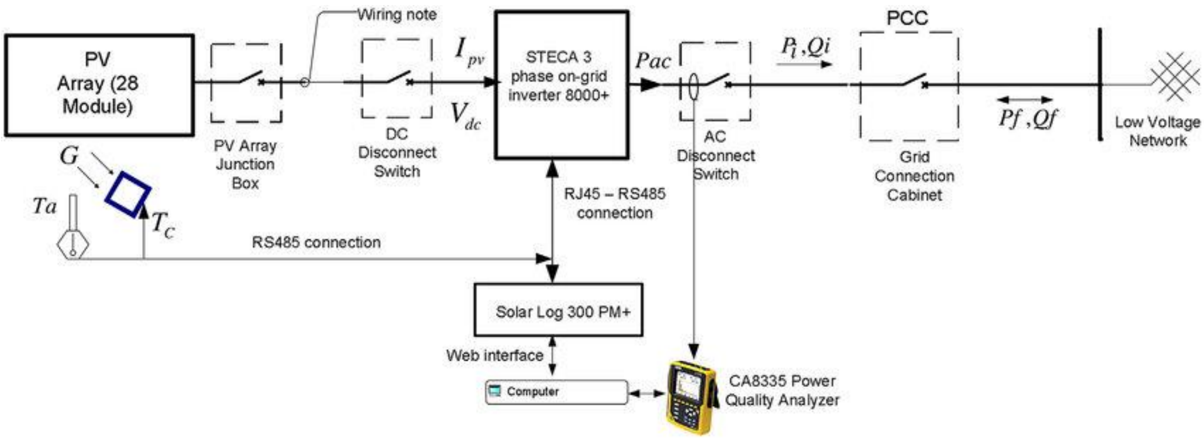
- In some cases it may make more sense to organize the diagram based on the circuit flow from component to component rather than locations.
- The design engineer should consider the stakeholders who need to read the information and draw them accordingly



Case study

The 8 kW PV array is divided into two strings with an average PV output voltage 500 V. the outputs of the two strings are pooled in the array junction box through DC breakers.
A surge protector is incorporated in the system for transient protection and as DC disconnect switch. The output of the array is brought to control room, where the DC power is fed to the power conditioning unit. The 8 kW Grid inverter, that includes filters, maximum power point tracking and control unit, is used to convert the DC PV power into AC power (three phase-four wire), 380 V, 50 Hz and to synchronize it with the grid. The output voltage and frequency of the inverter can follow the grid voltage and frequency during its normal operation.

A single line diagram of the set-up grid-connected system is shown in Fig. As shown in this figure, the PV power quality monitoring system is set around the power quality analyser CA8335. This analyser is designed as a universal meter for the entire field of power electronics and network analysis. It can be used practically in all power electronics applications, systems testing, and quality assurance. It can be used for measurements in motors, transformers, conventional and switched power supply units. The monitored results are collected using 1 s step. The recorded data are exported and averaged every 5 min and stored in hard disk for analysis and evaluation.



Site survey for solar installation

Site survey is necessary to design a correct and profitable solar energy generation system for the owner of the system.

The location of solar panels, their direction, orientation and the potential of sunlight play an important role in determining the amount of energy you can generate from the sun.

A Site survey is a mandatory step in the overall solar process. Our sales manager will visit your site to conduct a site survey after which our Engineering and Design team creates a customised solution from the detailed data gathered.

An ideal site survey should contain the following parameters:

1. **Climate condition of site:** The solar irradiation level, temperature and variation in wind speed at the site provides

an estimate of the potential for the solar PV installation and the specific components required. For instance, at low solar irradiation level sites an efficient solar panel is required as compared to high solar irradiation sites. Similarly solar panels work more efficiently in colder regions as compared to hotter regions. Also installation design of solar system should consider the worst wind load on the panels and the structure they are placed on.

2. **Type of property and its roof:** Defining the type of property as residential, commercial, industrial or institutional is essential as the structure of the property and its roof type determines the design of solar system. The type of roof is also important as there can be various types such as RCC, Metal sheet, Aluminum sheet and Asbestos.. A roof can be flat or sloping with a specific potential to carry weight of panels so this helps determine many other factors dependent on this information.
3. **Location of solar PV array:** It is important to determine the ideal solar PV array during the site survey. South, south-east and south-west are three directions of the property where solar PV array can be installed.
4. **Shade analysis:** Ideally, the location where solar PV array is to be installed should be shadow free. During site survey, any obstructions such as adjacent buildings, trees, water tanks, dish antennas, parapet walls, etc should be noted as any obstacles can cause shade which can impact electricity generation. Shadow analysis is done to ensure maximum sunlight is captured throughout the year during the time frame of 9:00am to 3:00pm.
5. **Space availability:** The space needed for a 1kW solar system is 80sqft. So for a 10kW system the space needed is 800sqft. During site survey, the potential area is measured on the roof or the ground and on this basis the solar PV system is designed. The structure and type of roof (flat or slope), its direction, nearby obstructions and its accessibility impact the location where solar PV array is to be installed.
6. **Size and location of existing electrical connection:** To get the correct information on the size and location of the connection it is necessary to answer a few questions. Is it a single phase or a three phase electrical connection? At what voltage and frequency electricity is supplied to the property? Where is the

main connection of the property to the electricity grid? These questions will help analyse the site survey better.

7. **Location for mounting solar system components:** Once the ideal location of the PV installation is decided, , the location and diagram of mounting other components is to be specified in site survey. Factors such as distribution box, the inverter and the wiring route of the whole system should be determined as well. If the installation is off-grid, the placement of the battery is also necessary.

8.Solar PV System Usability

The site analysis helps to have the solar pv system installed with user convenience in mind. From a usability point of view consider:

- The location of items like inverter, battery backup, distribution box etc
- The way Solar PV system is connected with the existing electrical system.

Steps to commissioning a photovoltaic system for maximum performance

Despite great engineering, no system is fail proof. That's where commissioning comes in, establishing a baseline of performance for customer acceptance and follow-on maintenance. Commissioning is important not only for photovoltaic (PV) system performance, but also for longevity of equipment, safety, ROI, and warranties.

Step 1: Photovoltaic system design and production

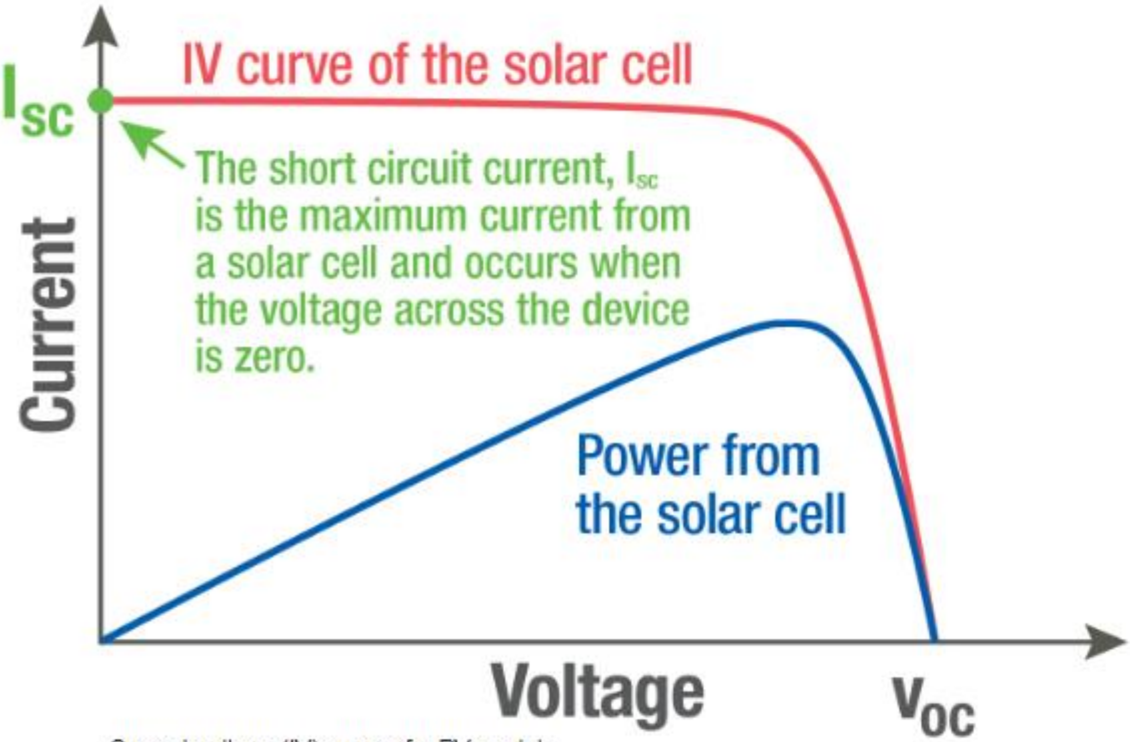
To find the expected production at your site, determine your solar resource and take into account any shading that may occur on the panels. The solar resource is measured in peak sun hours, which is the number of hours your installation achieves 1,000 watts per square meter per day. For instance, in many parts of California the solar resource is great: 6,000 watts per square meter, or 6 peak sun hours. Use the Fluke IRR-1 Solar Irradiance Meter to determine the actual solar irradiance (watts/m2) and shading at your site to develop a baseline.

Let's say you have a 10 kW PV array. You can calculate expected annual production by multiplying the 10-kW array x 6 peak sun hours x 365 days per year x 0.85 (15% derating due to power losses in wiring and inverter). This array should produce 18,615 kWh of energy for us per year, or 51 kWh per day.

Step 2: Measuring PV performance

Once your system is installed, make sure it's operating as designed by measuring its electrical characteristics and the actual power output of the array.

The performance of a PV array is based on its current-voltage (IV) curve. Not only does an inverter convert DC to AC, it maximizes its power output by capturing the current and voltage — since power is voltage x current — at which the string is producing the most power. The short circuit current (Isc) is the maximum current from a cell and no power will be produced because there is no voltage difference: the positive and negative wires are touching. The open circuit voltage (Voc) is the maximum voltage from a cell: no power will be produced because the circuit is open. The point at which the module produces the most power is called the maximum power point (mpp).



Current-voltage (IV) curve of a PV module

To know if an array is working as designed, you need to know the Voc and Isc, which are listed on the module datasheet. Measure the Voc and Isc before and after installation.

Voc is measured by using the Fluke 393 FC CAT III Solar Clamp Meter to determine the voltage between the positive and negative terminals. The 393 FC is CAT III 1500 V / CAT IV 600V rated, making it safe and reliable for making measurements in CAT III environments like solar installations. Use the Fluke 64 MAX IR Thermometer to determine the temperature of the module to account for the effect of temperature on Voc (the lower the temperature, the higher the voltage and vice versa). The 393 FC provides audio polarity warning while testing Voc. If it’s reversed, the combiner box or other circuits may be unintentionally connected in series, resulting in voltages over the maximum inverter input voltage.

To test Isc disconnect all parallel circuits and safely short the circuit. Measure the current between the positive and negative terminals through a multimeter. Set the dial to a current greater than expected. Record the values of Isc and Voc on the Fluke Connect™ app and save them for trending and reporting

Check the insulation resistance of your conductors, the connections between modules and between modules and racking, and your resistance to ground. Use the Fluke 1630-2 FC Earth Ground Clamp to measure earth ground resistance to ensure a resistance of less than 25 ohms.

Step 3: Diagnosing variances

Even when installed correctly, a PV system may not meet the expected electrical production. It's very important for a module to have the electrical characteristics specified, because an inverter has a minimum and maximum input current, below and above which it will have no power output.

Scenario 1: Open circuit voltage or short circuit current is higher or lower than on the datasheet

In this case, your string has one or more modules whose characteristics don't meet specification. Open circuit voltage out of range means your inverter may not output power. Short circuit current out of range indicates you may have module mismatch, which can severely degrade your array's performance because the current of a string is limited by the module with the lowest current. Identify and replace the modules.

Scenario 2: Power output is low

If you see that power output is lower than expected, you may have a problem. While some fluctuation in output is expected, consistently less than predicted output could be a sign of a faulty string, a ground fault, or shading.

One reason could be hot spots, the accumulation of current and heat on a short-circuited cell, leading to reduced performance and possible fire. Thermal imagers like the Fluke Ti480 PRO Infrared Camera or the TiS75+ Thermal Camera can quickly identify hot spots.

Ground faults are another, but they're harder to diagnose and require testing the voltage and current of each conductor and the equipment grounding conductor (EGC), which carries stray current to ground. Voltage and current on the EGC indicate a ground fault. Ground faults can occur due to damaged conductor insulation, improper installation, pinched wires, and water, which can create an electrical connection between a conductor and the EGC. Find the source of the problem and replace the damaged wires or improve the conditions.

Other reasons for low power output could be shading and poor tilt and compass direction (azimuth angle) for your location. Use a solar pathfinder to find any new sources of shading and remove them, if possible. While it may not be feasible to change the tilt and compass direction of the array to point the panels more directly toward the sun, you should know the tilt and azimuth angles to establish a baseline for future reference.

In large-scale PV systems, the power from a solar system goes through transformers after being inverted to step up the voltage, then to switchgear and medium voltage cables where decreased insulation resistance is a common issue. For medium and high voltage cables, use the Fluke 1555 FC 10 kV Insulation Tester, which can test up to 10,000 volts

Troubleshooting common PV system problems

The number of solar installations around the country is growing faster each year, creating an ever-increasing demand for technicians who know how to troubleshoot photovoltaic (PV) systems efficiently and effectively.

Troubleshooting a PV system will typically focus on four parts of the system: the PV panels, load, inverter, and combiner boxes.

The all-around best tool to use for working in most areas of a solar installation is the Fluke 393 FC CAT III 1500 V Solar Clamp Meter. This is the world's only CAT III 1500V rated, IP 54 ac/dc clamp meter with features — such as dc power, audio polarity, and visual continuity — that are tailor-made for test and measurement in solar PV applications.

1. Troubleshooting PV panels

First check the output of the entire system at the metering system or inverter. Before you begin troubleshooting, check and record the inverter's input voltage and current level from the array. You will likely encounter one of two scenarios:

The entire PV system, or a portion of it, is down or not producing power; this may be related to a problem with the inverter. Or the PV system output is less than expected; this may be related to a problem with one of the arrays or modules.

Trace out the individual branch wiring backward from the concentrator. Check the entire system visually for any obvious damage or accidental disconnections. Once you find the failed module or array, check all wires, switches, fuses, and circuit breakers. Replace blown fuses; reset the breakers and switches. Check for broken wires and loose or dirty connections; replace and clean as needed. Be on the lookout for loose connections between the modules. They may have worked loose and caused lack of contact.

The combiner box can be a great place to troubleshoot the system because the individual wires from the modules are brought back to it. Each module may have a fuse that you should check with your Fluke 393 FC.

Wiring problems and loose connections may also cause a module to produce too low a voltage. Check all wiring connections. If a module output is low, it may mean that an individual section of cells is bad. These can be traced out using the 393 FC at the junction boxes until the culprit is found.

The Fluke 393 FC provides an audio polarity warning when you’re testing Voc. If you find that polarity is reversed, it may mean that other circuits in the combiner box are unintentionally connected in series, resulting in voltages over the maximum inverter input voltage.

Any dirt or shade on the modules themselves can cause reduced output. Although the modules are usually designed to be maintenance free for years, they may need to be cleaned. Pollen and dust can be a significant problem in some areas of the country.

2. Troubleshooting PV loads

The PV system is used to operate building electrical loads; any problems with the loads will affect the system as well. The first step is to check the load switches, fuses and breakers with the Fluke 393 FC to see if the proper voltage is present at the load's connection. Next, use the 393 FC to check the fuses and circuit breakers. If you find blown fuses or tripped breakers, locate the cause and fix or replace the faulty component. If the load is a motor, an internal thermal breaker might be tripped or there might be an open winding in the motor. For testing purposes, plug in another load and see if it operates properly.

As with any electrical system, check for broken wires and any loose connections. Clean all dirty connections and replace all bad wiring. With the power off, check for and repair any ground faults. If any fuses or breakers blow or trip again, there's a short that you need to locate and repair.

If the load still does not operate properly, use the Fluke 393 FC to check the system's voltage at the load's connection. The wire size may be too small and need to be increased. It may also be possible that that the wires running to the loads are too long. This will show up as a low voltage at the load. In this case you can reduce the load on the circuit or run a larger wire

3. Troubleshooting PV inverters

You likely work with variable speed drives every day, so are used to checking ac and dc power. The inverter in a PV system can also fail and cause problems. The inverter converts dc from the PV system into ac power for building use.

If the inverter isn't producing the correct output, first use check and record the inverter's operating dc input voltage and current level. On the ac side, use the Fluke 393 FC to check the inverter's output voltage and current levels. Many of these systems have a display that indicates current inverter and system performance. Because the 393 FC produces a true-rms reading, you can use the voltage and current to measure and record the kilowatt (kW) output. If possible, use the inverter display to show the current total kilowatt hours (kWh). You can then write down this value and compare it to the one recorded during the last inspection. On the dc side, you can use the 393 FC to check the dc power and save the reading to the Fluke Connect™ app on your phone.

If the inverter does not produce the right amount of power, there may be several problems — all of which you can easily check with the Fluke 393 FC:

- Blown fuse
- Tripped breaker
- Broken wires

Use the 393 FC to measure the output ac side of the inverter; the load on the inverter might have a current demand that's too high. With the dual display showing ac voltage and frequency, you can determine whether the inverter ac output is operating correctly.

The inverter may be tied into the local utility. The ac current output from the inverter fluctuates with the level of solar input on the array. The inverter maintains the correct output voltage and phase to the utility. Any voltage problems from the utility may cause the inverter to shut down. In that event, contact the utility for repairs.

Fluke 393 FC CAT III 1500 V True-rms Clamp Meter with iFlex™ flexible current probe

4. Troubleshooting Combiner Boxes

When you're troubleshooting combiner boxes, amperage measurements and calculations are crucial to establishing whether the PV arrays are operating correctly. Measuring current on individual arrays or combining current measurements will help you determine if a cell has malfunctioned.

The thinner jaw design of the Fluke 393 FC clamp meter lets you get several conductors in the jaw for combined current measurements, even in tight or crowded spaces like inverter or combiner boxes.

Solar PV safety hazards and how to avoid them

Although much of the public may think radiation from the sun is magically transformed into electricity that powers all types of equipment and devices, solar technicians know there is much more to it.

In PV, current is "wild" and not limited by electronics, which has implications for hidden ground faults, wire sizing, and is the impetus for rapid shutdown. The control measures and best practices to mitigate risks will differ when working with PV versus any other kind of energy generating resource.

1. Shock or electrocution from energized conductors

Just as with other electric power generation, PV systems present the risk of shock and electrocution when current takes an unintended path through a human body. Current as low as 75 milliamps (mA) across the heart is lethal. The human body has a resistance of about 600 ohms. Per Ohm's law, voltage (V) equals current (I) times resistance (R), so V = IR.

To calculate the amount of current that would course through a person's body if exposed to 120 V, simply divide 120 V by 600 ohms (I = V/R), which totals 0.2 amps or 200 mA. That's more than 2.5 times the lethal limit of 75 mA, so protecting yourself and your workers against such an event is critical.

Electrical shocks are typically caused by a short circuit resulting from corroded cables and connections, loose wiring, and improper grounding. Key places to look for these conditions in a PV system include the combiner box, PV source and output circuit conductors, and the equipment grounding conductor. The grounding conductor bonds all metallic components together—and eventually to ground—through the grounding electrode conductor and grounding electrode.

Control measures: Rapid shutdown systems

Energy produced from PV string systems varies directly with the sun. To reduce shock hazard for technicians and first responders, we need a way to shut those strings off during a short circuit or power outage. The 2017 National Electrical Code (NEC), Section 690.12 requires the "rapid shutdown" of PV systems both inside and outside the PV array boundary. According to section 690.2 of that code, PV array boundary is a mechanically integrated assembly of modules or panels with a support structure and foundation, tracker, and other components, that form a DC or AC producing unit. This includes controlled conductors located inside the boundary or up to three feet from the point where they penetrate the surface of the building.

As of 2019, the NEC made these requirements more stringent by requiring:

Modules and exposed conductive parts within the PV array boundary to be reduced to 80 V within 30 seconds.

Conductors located outside the array boundary to be limited to 30 V within 30 seconds.

Rapid shutdown devices must be located either at the service disconnect or there must be a special rapid shutdown switch. There is an exception for systems that are controlled by module-level power electronics—such as micro-inverters and power optimizers—that reduce voltage. Arrays with no exposed conductive parts and located more than eight feet from exposed grounded conductive parts, are not required to comply.

In addition, many jurisdictions in the U.S. require that rooftop PV arrays have setbacks that allow fire fighters to access the system. For instance, the California Residential Fire Code requires PV modules be at least three feet from the ridge of the roof.

2. Arc faults that spark fires

As with any electrical system, fire is always a potential hazard. Perhaps one of the most common causes is electrical arc faults, which are high power discharges of electricity between two or more conductors. The heat caused by this discharge can cause the wire insulation to deteriorate and thus cause a spark or "arc" that causes a fire.

PV systems are subject to both series arc faults caused by a disruption in continuity of a conductor, or parallel arc faults caused by unintended current between two conductors, often due to a ground fault.

Control measures: Arc-fault circuit interrupters

An arc fault may lead to a short circuit or ground-fault, but it may not be strong enough to trigger a circuit breaker or a ground fault circuit interrupter (GFCI). To protect against arc faults, you need to install an arc-fault circuit interrupter (AFCI) outlet or an AFCI circuit breaker. AFCIs detect low level hazardous arcing currents and shut off the circuit or outlet to reduce the chances of such an arc fault sparking an electrical fire.

The NEC Section 690.11 mandates that PV systems operating at 80 V DC or greater between any two conductors be protected by a listed PV AFCI or equivalent system component. The protection system needs to be able to detect arc faults resulting from a failure in the intended continuity of a conductor, connection module, or other component in the PV system DC circuits.

3. Arc flash leading to explosions

Large-scale PV arrays with medium and high levels of voltage are susceptible to arc flash. This is especially true when a technician is checking for faults in energized combiner boxes where PV source circuits are combined in parallel to increase current, and when checking medium-to-high voltage switchgear and transformers. An arc flash releases hot gases and concentrated radiant energy up to four times the temperature of the sun's surface—as high as 35,000° F (~19,500° C). It occurs when a large amount of energy is available to an arc fault, in both DC and AC conductors.

Arc flash is an issue for systems over 400 V so both residential inverters that typically have a maximum input voltage of 500 V and large-scale inverters that have a maximum of 1,500 V are at risk. Before the advent of large-scale solar energy systems, arc flash was solely considered an AC issue since DC voltage was limited to off-grid applications where batteries of less than 100 V were used. The National Fire Protection Association (NFPA) Standard 70E requires an arc flash hazard risk analysis be conducted and Personal Protective Equipment (PPE) used for DC systems over 100 V.

Control measures: AC and DC side mitigation

Arc flash mitigation in PV systems is divided by DC (before the inverter) and AC (after the inverter). DC-side mitigation for large solar arrays (100 kW +), is especially important at the combiner box where multiple strings of solar panels are combined in parallel to increase the current. To reduce the potential for arc flash, large-scale systems can use multiple string inverters that themselves can connect multiple strings in parallel, instead of using one or two large central inverters that require combiner boxes. AC-side mitigation includes arc resistant switchgear, which redirects arc flash energy through the top of the enclosure, away from personnel and equipment.

Basic PPE for electricians and solar PV technicians—includes the Fluke 87-V Industrial Multimeter

Basic PPE for electricians and solar PV technicians—includes the Fluke 87-V Industrial Multimeter

Choose the correct solar testing equipment

Protecting your workers and PV system from electrical hazards requires adherence to safe work practices and ensuring that your equipment is rated to withstand these potential hazards. That means multimeters, test leads, and fuses must all be rated for the application you are working on. Here are some basic guidelines:

CAT-appropriate equipment: Choose a meter rated for the appropriate measurement category (CAT rating) and the voltage level of your application. Your multimeter must be able to withstand average voltage levels and high voltage spikes and transients that can deliver a shock or produce an arc flash. Overvoltage category III 1500 V systems are becoming the new normal in solar. The Fluke 393 FC True-RMS Solar Clamp Meter is the only CAT III 1500 V/CAT IV 600 V TRMS clamp meter that meets the insulation requirements for CAT III environments like solar installations. It also has Fluke Connect™ wireless capabilities, so you can monitor measurements from a safe distance on your smart phone.

High-altitude considerations: CAT III and IV equipment must be used for PV systems at high altitudes because air becomes less insulating and less dense as you go up, which decreases its cooling ability. This means the breakdown voltage—the minimum voltage causing an insulator to become electrically conductive—decreases with altitude. For instance, for a 1-centimeter gap between conductors, the breakdown voltage would be 30kV at sea level, 1.2 kV at 50,000 feet, and 300 V at 150,000 feet.

High-quality test leads: Select test leads that are CAT rated to match or exceed the CAT rating of the digital multimeter.

High-energy fuse replacements: Always replace high-energy fuses with the same quality part and amperage rating. These fuses are designed to keep energy generated by an electrical short contained within the fuse enclosure. They are life savers and should never be replaced with cheaper generic fuses.

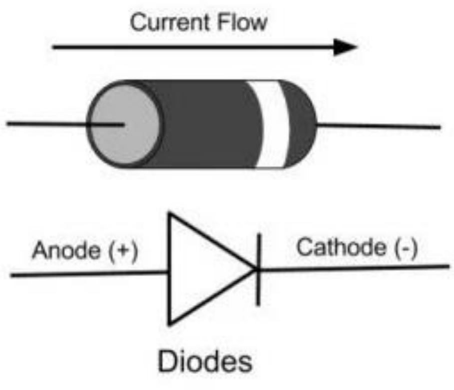
Probes and probe accessories: Use retractable probes, probe tip covers, or probes with shorter tips to avoid accidentally touching metal to metal and causing a short circuit

Personal protective equipment: Wear appropriate PPE, including arc-rated clothing, gloves, safety glasses or goggles, hearing protection, and leather footwear as required for the voltage you are working on. The 2018 NFPA Standard 70E Table 130.7(C)(15)(c) identifies a complete list of PPE categories and the appropriate arc rated clothing for each rating.

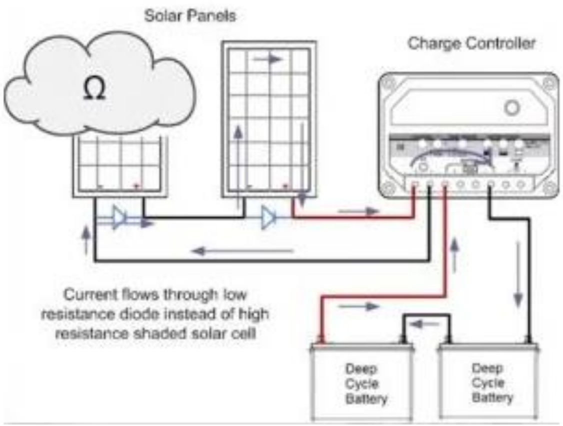
These are just the highlights of how to work safer when maintaining PV systems. Be sure to follow all relevant safety standards and regulations, manufacturers' instructions and your company's safety procedures when testing or servicing electrical equipment.

Figure Out the Plus and Minus Terminals of a Solar Panel

So, you just got a solar panel that has no polarity labels. How can you figure out the proper polarity, which terminal or wire is plus and which is minus? Here’s a couple of easy tips than can even be done inside, away from the sun.



The negative of the bypass diode (i.e. the cathode) in a bypass diode is located with the positive of the solar panel.



If you can open up the junction box, you will likely see at least one bypass diode inside. This is to help prevent power loss due to shading of a solar panel. It provides an alternative path for the current when the panel is shaded, and therefore at a higher resistance. There may only be one diode, which bypasses the whole panel in a solar array, as seen in the diagram, or multiple diodes, bypassing cells within the solar panel itself, as seen in the picture.

The striped cathode of the diode will be pointing towards the positive side of the solar panel. The other side is the negative.

For more information on diodes in a solar system, watch our video Blocking and Bypass Diodes in a Solar Panel Systems.

Diode stripe (cathode) pointing to positive

MEASURE WITH VOLT METER

Another way to find the polarity of the solar panel is to check with a volt meter. A simple voltage reading will show you the polarity of a solar panel, even when inside.

To measure across the solar panel terminals or wires, put the red positive meter lead on one side, and the black negative on the other. Set the volt meter to read DC Volts. If the volt meter shows a negative number, indicated by a minus symbol, the leads are the wrong direction. Switching them over shows a positive number, with no negative symbol, so the red meter lead is on the positive, and the black meter lead is on the negative.

Note in the pictures you can also see the bypass diode in the junction box. You can see the stripe of the diode is on the side with the red positive lead, proving the previous method correct.

The solar panel is only putting out 3 volts, because it is upside down inside the building, and just getting a little light hitting it. But it is enough to get a correct polarity reading. If you were to try to measure current, there likely would be none with such little light, as voltage is less affected by the intensity of light than current is.

Reverse Polarity

Correct Polarity

Grounding Strategies for Solar PV Panels

In a solar photovoltaic (PV) farm, solar PV panels are fixed on a grounded structure with bolts and nuts. The structure, the frame of the PV panels, and the bolts and nuts are metallic (together called the assembly) and the layout of all assemblies of the entire solar farm depends on the terrain where they are installed.

Lightning protection systems which are installed on a solar PV farm are mostly based on a Franklin rod (connected to a down-conductor) as the preferred point of attachment. Consequently, it utilises the concept of protective angle or rolling sphere method to determine the protective zone to the solar panel assemblies. Hence, many such rods would be installed in a solar farm. These lightning rods can be installed either as isolated systems or as non-isolated systems from the solar panel assemblies. Each isolated system consists of a free-standing mast (connected to a Franklin rod at the top) that is erected some distance away from the solar PV assembly Fig a. The non-isolated system is installed as an integral part of the structure of the assembly itself Fig b. For the latter, the structure forms part of the lightning down conductor system.

Despite the installation of the lightning protection system (LPS), direct lightning strikes to the solar PV panel frame/structure might still happen. Hence, lightning current will flow through the PV frame/structure to the ground. Therefore, the project investigates the effects of direct lightning strikes onto a solar PV assembly by considering the overvoltage resulting on the system due to various grounding arrangements.

Two strategies are considered for the case of protection which is:

- Individual and
- Group groundings.

These are illustrated in Fig. (a), Fig. (b) and Fig. (c). For each strategy, an impulse current will be injected at point A in these figures.

The lightning current considered in this investigation is defined by the double exponential expression as in (1). The corresponding lightning protection level (LPL) 1 is used in this investigation where the subsequent stroke of 0.25μs front time and 100μs tail time current waveform is considered and its parameters are tabulated in Table 1. In general, subsequent strokes have a higher rate of rise of current in comparison to the first strokes although they have lower peak currents. The resulting voltage drops are then assessed for each strategy with different soil resistivity of 10 ohm-m and 100 ohm-m respectively. Furthermore, aluminium is used as the material for the solar panel structure and for the down conductor between PV assembly and earth.

$$i = \frac{I}{k} \times \frac{(t/\tau_1)^{10}}{1+(t/\tau_1)^{10}} \times e^{(-t/\tau_2)} \qquad (1)$$

Where

- I is the peak current,
- K is the correction factor for the peak current,
- t is the time,
- ζ_1 is the front time constant, and
- ζ_2 is the tail time constant.

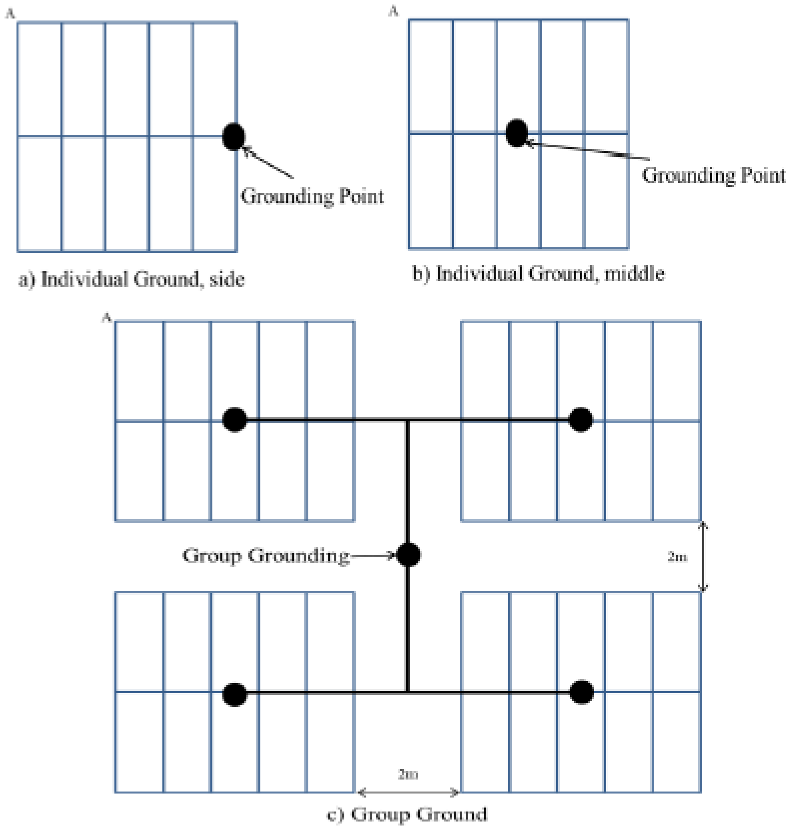


Fig. Location of grounding arrangement points; Individual Grounding, a) side – top left, b) middle – top right and c) Group Ground – bottom. All illustrations are based from top view.

A study of grounding strategies for solar PV panels has been presented by considering 2 different positions of the PV assembly for grounding and also for 2 different soil resistivity of 10 ohm-m and 100 ohm-m.

The results for side grounding with different soil resistivities were compared and it is found that voltage drops at the grounded point of an assembly varied significantly.

On the other hand, the results obtained for mid-section grounding arrangement with different soil resistivities have apparently shown that mid-section grounding may not be advisable because it does not offer any obvious advantage.

Therefore, for a single assembly, side grounding may be the best grounding strategy to be adopted.

Further work will be conducted on different points of lightning attachment for a single solar PV assembly, and for groups of solar PV assembly.

Unit – III

Testing import and export of Solar systems

Regulations and standards for solar interconnection of solar cells – Testing for import and export of solar energy – Testing and verify inverter operation and including anti- islanding functioning, over loading testing for power quality of a roof top solar systems – Testing for phase imbalance.

Interconnection Standards

Interconnection standards dictate how renewable energy systems can be legally connected to the electricity grid. They are a set of requirements and procedures for both utilities and customers.

Typically, interconnection standards outline a multi-step process. In some jurisdictions, simple systems (typically smaller and inverter-based) can be eligible for simplified, or fast-tracked, interconnection approval processes. For more complex systems, or in jurisdictions where simplified interconnection is not available, interconnection is generally a two-stage process.

While interconnection standards are usually implemented at the state regulatory level and mandate how utilities must connect renewable energy systems to the electric grid, there is often a parallel permitting process required by a local jurisdiction (e.g., municipal building permit department) to ensure that residents' systems are installed safely by installers, contractors, or the residents themselves.

Background

In the United States, state-level public utility commissions (PUCs) establish interconnection standards that customers and utilities must follow. Standards vary by state. Additionally, in May 2005, the Federal Energy Regulatory Commission (FERC) enacted interconnection standards for projects up to 20 megawatts (MW) for projects subject to FERC's jurisdiction. These are called the Small Generator Interconnection Procedures (SGIP).

Benefits

Interconnection standards establish transparent processes for multiple stakeholders to follow ensuring safe deployment of renewable energy systems. Transparency also provides more certainty and less risk for renewable energy system investors and developers.

Implementation Issues

Unclear, lengthy, and complicated interconnection standards may increase distributed generation "soft costs" (i.e., non-hardware costs), thereby delaying the deployment of renewable energy systems. Agreement on which types of systems can qualify for certain types of screening can also be difficult to reach.

Design Best Practices to Support Solar Distributed Generation

Although interconnection standards are not consistent across states and utilities, many states adopt engineering and safety requirements based on IEEE 1547 and UL 1741 standards. Additionally, state interconnection standards are increasingly modeled after FERC's SGIP (see Background section above). Interconnection standards can also vary by:

- Net metered vs. non-net metered systems
- System capacity requirements
- Eligible technologies
- Eligible sectors (e.g., commercial, residential)
- Fees
- Insurance requirements

Solar Islanding

Solar islanding is when a home solar power system continues to generate electricity even though the grid is down. Many people would consider this a good thing, as your home still has power from your solar panels while everyone else has no power.

However, things become dangerous when your solar panel system produces electricity, and it goes into the grid. This situation poses serious safety concerns to utility workers who are trying to fix the grid, as they could be injured if the grid is still "live".

Here's what could happen if solar islanding wasn't prevented:

- The local grid goes down.
- Your grid-tied home solar power system still produces electricity.
- Once the panels have supplied electricity to your home, any excess energy flows back into the grid.
- Meanwhile, utility workers are repairing damaged power lines on the "should-be-dead" grid.
- With energy still in the grid, these workers might come into contact with a live wire.
- Any contact with a live wire can be catastrophic, leading to severe burns, shocks, or even death.

Luckily, if you still want to use your solar power during a power outage, you can set up your home for safe islanding. We'll explain how, in more depth, later in this article.

Grid-Tied Solar Vs. Off-the-Grid

The vast majority of homes with solar panels remain tied to the grid, which means you'll have access to electricity from the grid if your home is using more than your panels are creating. If the grid goes down for any reason, your solar panel system is designed to turn off automatically to ensure the safety of utility workers who might be fixing any damaged power lines.

On the other hand, if you're completely off the grid, you're already on your own power island. Your islanding solar inverter works independently from the power grid. If there's a storm or other event that knocks out the main power grid, your solar power system will continue running and providing power to your home.

We mention this because many people mistake going solar with going off-grid, but that's typically not the case. To be truly off-the-grid, you must generate 100% of your electricity without depending on the distribution system operated by the local utility company. As you'd imagine, that isn't easy to achieve because your home still needs electricity when the sun isn't shining, so you typically need a large battery backup system to store extra electricity.

(To learn more about going off-the-grid, check out: What "Off The Grid" Means – Does Solar Mean Going Off-Grid)

Islanding

Islanding is the condition in which a distributed generator (DG) continues to power a location even though external electrical grid power is no longer present. Islanding can be dangerous to utility workers, who may not realize that a circuit is still powered, and it may prevent automatic re-connection of devices. Additionally, without strict frequency control, the balance between load and generation in the islanded circuit can be violated, thereby leading to abnormal frequencies and voltages. For those reasons, distributed generators must detect islanding and immediately disconnect from the circuit; this is referred to as anti-islanding.

A common example of islanding is a distribution feeder that has solar panels attached to it. In the case of a power outage, the solar panels will continue to deliver power as long as irradiance is sufficient. In this case, the circuit detached by the outage becomes an "island". For this reason, solar inverters that are designed to supply power to the grid are generally required to have some sort of automatic anti-islanding circuitry.

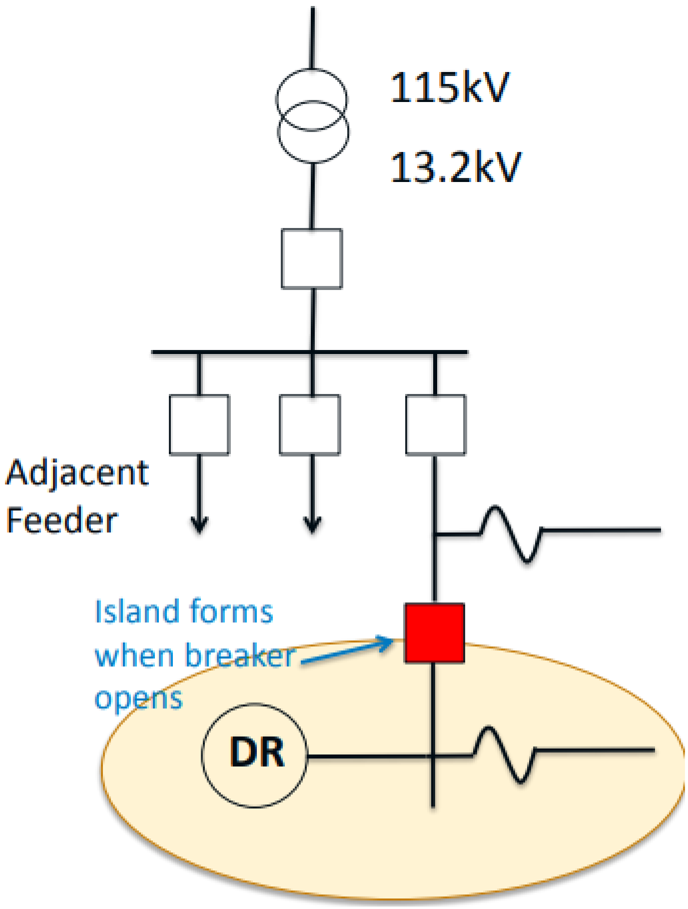
Some designs, commonly known as a microgrid, allow for intentional islanding. In case of an outage, a microgrid controller disconnects the local circuit from the grid on a dedicated switch and forces the distributed generator(s) to power the entire local load

In nuclear power plants, islanding is an exceptional mode of operation of a nuclear reactor. In this mode, the power plant is disconnected from the grid, and power for cooling systems comes from the reactor itself. For some reactor types, islanding is part of the normal procedure when the power plant disconnects from the grid, in order to quickly recover electricity production. When islanding fails, emergency systems (such as diesel generators) take over. For instance, French nuclear power plants conduct islanding tests every four years. The Chernobyl disaster was a failed islanding test.

- Area EPS – Area Electric Power System
- Local EPS – Local Electric Power System
- PCC – Point of Common Coupling
- DR – Distributed Resource (e.g. distributed generation (DG), distributed energy resource (DER))
- DER – Distributed Energy Resource (The IEEE 1547 Working
- Group voted and decided to change DR to DER in the next version. DER will NOT include Demand Response as it does in some countries)
- Anti-islanding (non-islanding protection) – The use of relays or controls to prevent the continued existence of an unintentional island

Island: A condition in which a portion of an Area EPS is energized solely by one or more Local EPSs through the associated PCCs while that portion of the Area EPS is electrically separated from the rest of the Area EPS.

- Intentional (Planned)
- Unintentional



Intentional (Planned) Islanding

IEEE 1547.4 is a guide for Design, Operation, and Integration of Intentional Islands (e.g. Microgrids)

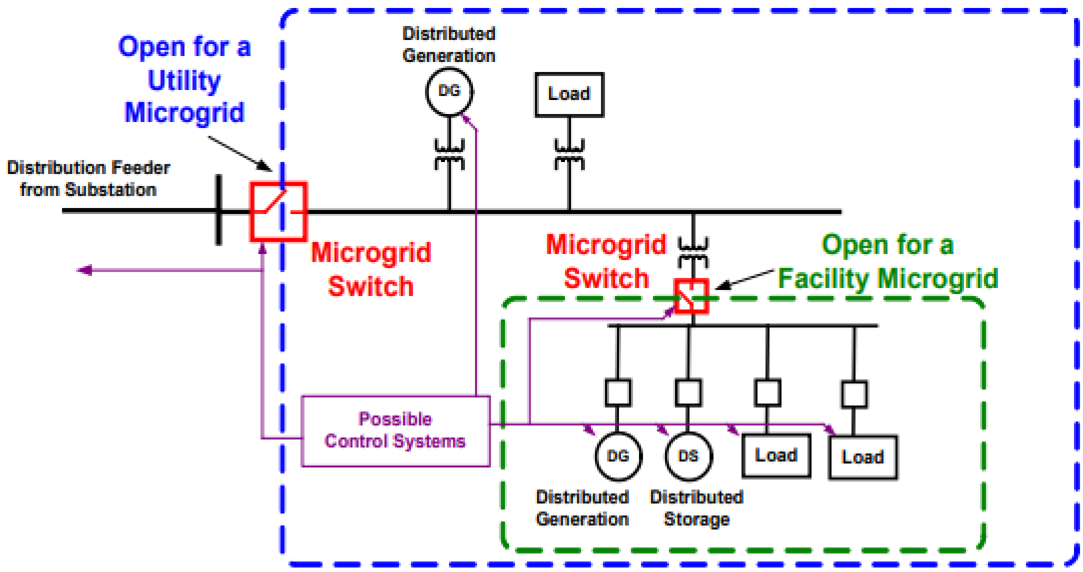
(1) have DR and load

(2) have the ability to disconnect from and parallel with the area EPS

(3) include the local EPS and may include portions of the area EPS, and

(4) are intentionally planned.

IEEE 2030.7 and 2030.8 – In development and cover microgrid control design and testing



Source: *Making microgrids work* [2]

Issues with Unintentional Islands

- Personnel Safety – Unintentional islands can cause hazards for utility workers if they assume downed lines are not energized during restoration

- Overvoltages – Transient overvoltages due to rapid loss of load are possible. If an adequate ground source is not present in the island, a ground fault can result in voltages that exceed 173% on the unfaulted phases.

- Reconnection out of phase - This can result in large transient torques applied to motors connected to the islanded area EPS and their mechanical systems (e.g., shafts, blowers, and pumps), which could result in damage or failure.

- Power Quality – Unplanned island area EPS may not have suitable power quality for loads

- Protection – Unintentional islands may not provide sufficient fault current to operate fuses or overcurrent relay protection devices inside island

IEEE 1547-2003: 4.4.1 Unintentional Islanding Requirement

For an unintentional island in which the DR energizes a portion of the Area EPS through the PCC, the DR interconnection system shall detect the island and cease to energize the Area EPS within two seconds of the formation of an island.

Methods of protecting against unintentional islands

- Reverse/Minimum Import/Export Relays
- Passive Anti-islanding
- Active Anti-islanding

  e.g. instability induced voltage or frequency drift and/or system impedance measurement coupled with relay functions
- Communication-Based Anti-Islanding
  - Direct transfer trip (DTT)
  - Power line carrier (PLC)
  - Impedance Insertion
- Methods Under Development
  - Phasor-based anti-islanding

Passive Anti-islanding

- Over/under voltage and frequency trip settings
- Voltage and frequency relay functions (81o, 81u, 27, 59)
- Set a V/F window – if conditions are outside window, then DR trips
- Non-detect zone (NDZ) exists between trip points
- Amendment 1 (IEEE 1547a) allows for adjustable clearing times

New Voltage and Frequency Trips Settings from Amendment 1 of IEEE 1547-2003 [38]

Table 1—Interconnection system default response to abnormal voltages

Default settings[a]		
Voltage range (% of base voltage[b])	Clearing time (s)	Clearing time: adjustable up to and including (s)
V < 45	0.16	0.16
45 ≤ V < 60	1	11
60 ≤ V < 88	2	21
110 < V < 120	1	13
V ≥ 120	0.16	0.16

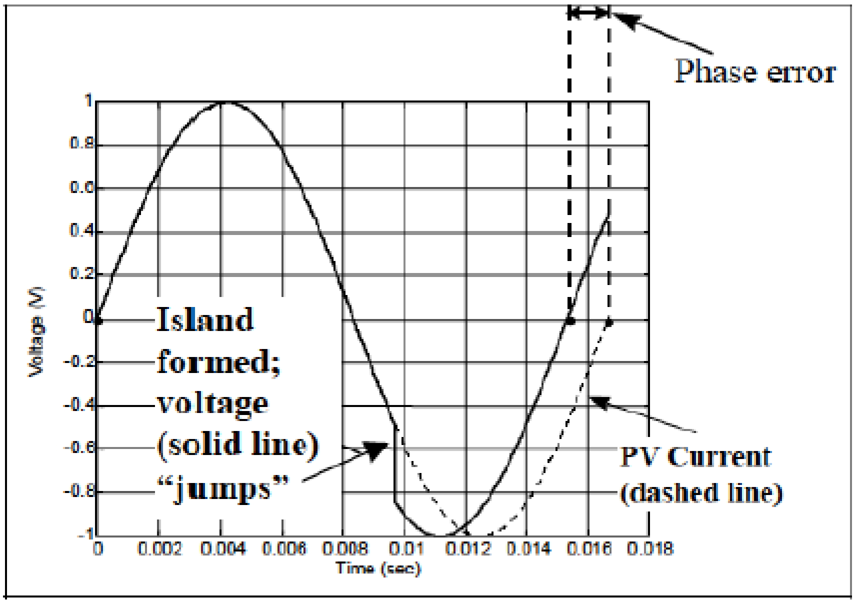
[a] Under mutual agreement between the EPS and DR operators, other static or dynamic voltage and clearing time trip settings shall be permitted
[b] Base voltages are the nominal system voltages stated in ANSI C84.1-2011, Table 1.

Table 2—Interconnection system default response to abnormal frequencies

	Default settings		Ranges of adjustability	
Function	Frequency (Hz)	Clearing time (s)	Frequency (Hz)	Clearing time (s) adjustable up to and including
UF1	< 57	0.16	56 – 60	10
UF2	< 59.5	2	56 – 60	300
OF1	> 60.5	2	60 – 64	300
OF2	> 62	0.16	60 – 64	10

Other Passive Anti-islanding

- Rate-of-change-of-frequency (ROCOF)
- Voltage or Current Harmonic Monitoring – monitor voltage harmonic distortion
- Voltage Phase jump - detect a sudden “jump” in phase displacement between inverter voltage and output current



Voltage Phase Jump

Active Anti-islanding

- Impedance Measurement
- Detection of Impedance at a Specific Frequency
- Slip-mode Frequency Shift
- Frequency Bias
- Sandia Frequency Shift
- Sandia Voltage Shift
- Frequency Jump
- ENS or MSD (a device using multiple methods)

***Active methods** generally attempt to detect a loss in grid by actively trying to changing the voltage and/or frequency of the grid, and then detecting whether or not the grid changed.*

Communications-based Methods

- power Line Carrier – Provide a permissive run signal, when signal goes away, the DR ceases to energize circuit

- Impedance Insertion – Remotely add capacitors that cause a large enough voltage change to trip O/U voltage protection

- Direct Transfer Trip (DTT)

Solar Anti-Islanding

Solar anti-islanding is a safety feature built into grid connected solar power systems that can shut them off and disconnect them from the grid during a power outage.

If you hear someone say that their inverter is fitted with anti-islanding protection, it simply means that it has islanding detection (often based on voltage and frequency detection) and can sense when the grid is down. That way, it can stop feeding power back to the grid and protect the utility workers.

An anti-islanding solar inverter might seem like a small detail, but it's important because:

1. Solar anti-islanding ensures the safety of workers fixing the grid during an outage
Like we mentioned earlier, islanding in photovoltaic (PV) systems can pose grave safety concerns to utility workers who might be fixing a "should-be-dead" grid. Solar anti-islanding ensures that these workers are safe from burns, shock, and even death.

2. Solar anti-islanding keeps the grid equipment safe
The grid infrastructure is set up in such a way that it will shut down when it detects a severe problem. Without solar anti-islanding protection, your solar panels will continue to send voltage back to the grid, which could damage the grid hardware and lead to other costly losses.

3. Solar anti-islanding prevents inverter damage

Solar islanding could cause damage to inverters, rendering them non-functional. Anti-islanding exists to protect your inverters from overload and save you from costly damages.

Is it possible to find a modern grid-tied solar system that lacks anti-islanding protection? The short answer is no. UL Standard 1741 requires every grid-tied PV system to have a built-in anti-islanding solar inverter, and the solar industry follows that standard. While these laws were initially meant to protect utility workers, they've since been amended to include protection for your solar panel system and electricity grid at large.

Anti-islanding (non-islanding protection) – The use of relays or controls to prevent the continued existence of an unintentional island

Import and export of solar energy – Regulations

TAMIL NADU ELECTRICITY REGULATORY COMMISSION
The following draft of the Regulations which it is proposed to make in exercise of the powers conferred by section 181 read with Sections 61, 86(1) (e) of the Electricity Act, 2003 (Central Act 36 of 2003) and all other powers enabling it in this behalf, is hereby published for information of all persons likely to be affected thereby, as required by sub section (3) of section 181 of the said Act.

2. Notice is hereby given that the draft Regulations will be taken into consideration after expiry of fifteen days from the date of publication of this Notification in the TNERC website and that any objection or suggestion, which may be received from any person before the expiry of the aforesaid period will be considered by the Commission.

3. Objection or suggestion, if any, should be addressed in duplicate along with soft copy to the Secretary, Tamil Nadu Electricity Regulatory Commission, 4th Floor, SIDCO Corporate Office Building, Thiru Vi Ka Industrial Estate, Guindy, Chennai – 600 032.

REGULATIONS

1. Short title, and commencement

1.1 These Regulations may be called the Tamil Nadu Electricity Regulatory Commission (Grid Interactive Solar PV Energy Generating Systems) Regulations, 2021.
1.2 These Regulations shall extend to the whole of the State of Tamil Nadu.
1.3 These Regulations shall come into force from the date of their publication in the Tamil Nadu Government Gazette.

2. Definitions

2.1. In these Regulations, unless the context otherwise requires,
a) "Act" means the Electricity Act, 2003 (36 of 2003) as amended from time to time ;
b) "Agreement" means a connection agreement entered into between the Distribution Licensee and the consumer;
c) "Area of supply" means the geographic area within which the licensee, for the time being, is authorized by its License to supply electricity.
d) "Billing Cycle" or "Billing Period" means the period for which the electricity bill is raised by the concerned Distribution Licensee;
e) "Check Meter" means a meter, used for accounting and billing of electricity in case of failure of Net Meter or Solar Generation Meter;
f) "Commission" means the Tamil Nadu Electricity Regulatory Commission constituted under the Act;
g) "Contracted Load or "Sanctioned Load" means the load specified in the agreement between the consumer and the Licensee engaged in the business of supplying electricity to him.
h) "Distribution licensee" or "licensee" means a person granted a licence under Section 14 of the Act authorizing him to operate and maintain a distribution system for supplying electricity to the consumers in his area of supply;
i) "Electricity Supply Code" means the Tamil Nadu Electricity Supply Code, 2004 and subsequent amendments thereof;

j) “Eligible Consumer” means a consumer of electricity in the area of supply of the Distribution Licensee who uses or intends to use a Grid Interactive

Solar PV System having a capacity less than 1 MW, subject to conditions in capacity / category / voltage level specified in the regulations.

k) "Generic Tariff” means the Generic Tariff approved or adopted by the Commission for generation from different Renewable Energy sources in accordance with the Tamil Nadu Electricity Regulatory Commission (Power Procurement from New and Renewable Sources) Regulations 2008 as amended from time to time.

l) “Financial Year” or “Year” means the period beginning from first (1st) of April in an English calendar year and ending on thirty first (31st) of March of the next year;

Grid Interactive Solar Photovoltaic Power Plant / System” (GISS) means the solar photo voltaic power system installed on the rooftops or land of consumer premises that uses sunlight for direct conversion into electricity through photo voltaic technology.

m) “gross-metering” means a mechanism whereby the total solar energy generated from Grid Interactive rooftop Solar Photovoltaic system of a Prosumer and the total energy consumed by the Prosumer are accounted separately through appropriate metering arrangements and for the billing purpose, the total energy consumed by the Prosumer is accounted at the applicable retail tariff and total solar power generated is accounted for at feed-in tariff determined by the Commission;”

n) “Inter-connection Point” means the interface of the Rooftop Solar System with the outgoing terminals of the meter / Distribution Licensee‟s cut- outs/ switchgear fixed in the premises of the Eligible Consumer:

Provided that, in the case of an Eligible Consumer connected at the High Tension („HT‟) level, the „Inter-connection Point‟ shall mean the interface of the GISS with the outgoing terminals of the Distribution Licensee‟s metering cubicle placed before such Consumer‟s apparatus;

o) kWp means kilo Watt peak ; MWp means Mega Watt peak

p) “Net meter” or “bidirectional meter” means an energy meter which is capable of recording both import and export of electricity.

“Net-metering” means a mechanism whereby solar energy exported to the Grid from Grid Interactive rooftop Solar Photovoltaic system of a Prosumer is deducted from energy imported from the Grid in units (kWh) to arrive at the net imported or exported energy and the net energy import or export is billed or credited or carried-over by the distribution licensee on the basis of the applicable retail tariff by using a single bidirectional energy meter for net-metering at the point of supply;”

“net-billing or net feed-in” means a single bidirectional energy meter used for net-billing or net feeding at the point of supply wherein the energy imported from the Grid and energy exported from Grid Interactive rooftop Solar photovoltaic system of a Prosumer are valued at two different tariffs, where-

(i) the monetary value of the imported energy is based on the applicable retail tariff;

(ii) the monetary value of the exported solar energy is based on feed-in tariff determined by the Commission;

(iii) the monetary value of the exported energy is deducted from the monetary value of the imported energy to arrive at the net amount to be billed (or credited / carried-over);

q) “Net work charges” means the charges determined under regulation 70 of TNERC‟s Tariff Regulation 2005 to recover the cost incurred towards Distribution wire business.

r) “Obligated Entity” means an entity required to fulfill a Renewable Purchase Obligation („RPO‟) as specified by the Commission in Regulations governing such Obligation („the RPO Regulations‟);

s) “Prosumer” means a person who consumes electricity from the grid and can also inject electricity into the grid for distribution licensee, using same point of supply.

t) “Premises” means and includes roof-tops or any areas on the land, building or infrastructure or part or combination thereof in respect of which a separate meter has been provided by the Distribution Licensee for the supply of electricity;

u) “Renewable Energy Generation Meter” means a unidirectional energy meter installed at the point at which the electricity generated by solar energy system of the eligible consumer is delivered to the grid of the distribution
licensee;

Provided that a separate Renewable Energy Generation Meter shall be installed for each source of Renewable Energy in case of hybrid or combination of such sources;

V) “Renewable Energy certificate ’’ shall be as defined in Tamil Nadu Electricity Regulatory Commission (Renewable Purchase Obligation) Regulations 2010.

w) “Settlement Period” means the period beginning from the first day of April of a calendar year and ending with the thirty-first day of March of the following calendar year.

Provided for a newly commissioned solar power system, the first settlement period shall be from the date of commissioning to March of next year.

Words and expressions used in these Regulations which are not specifically defined herein but are defined in the Act shall have the meaning assigned to them in the Act; and, if not defined in the Act, shall have the meaning assigned to them in any Act of Parliament or the State Legislature applicable to the electricity industry.

x) “Supply Licensee” means a person / company who has been granted licence under section 14 and authorized to supply electricity in a particular area .

3 Scope and Applicability

3.1 These Regulations shall apply to the distribution licensee and consumers of electricity of the distribution licensee availing supply from it in its area of supply in the State of Tamil Nadu.

3.2 These Regulations shall be applicable to all Grid Interactive Solar PV energy Generating Systems for which Applications are preferred after notification of this regulation

3.3 The Eligible Consumer may install Grid interactive Solar PV System under net -metering or net-billing or gross - metering arrangement which,

a) shall be within the permissible rated capacity as defined under these Regulations.

b) shall interconnect and operate safely in parallel with the distribution licensee network in accordance with all relevant Codes and Regulations issued under the Electricity Act from time to time.

4 Eligible consumers and individual project capacity

4.1 Net-metering : All domestic consumers are eligible for Net metering mechanism up to the level of sanctioned load/ contracted demand of their service connection irrespective of voltage level.

a. The existing consumers under the net metering scheme shall continue to be governed by the provisions in the Order No.3 of 2013 dt 13.11.2013.

b. Domestic consumers who have been provided with the solar net-feed-in facility as per Order No.3 of 2019 of the Commission shall have option to migrate to the solar energy net metering mechanism as provided for in this order to avoid discrimination within the same category of consumers.

4.2 Net billing or net feed-in : All categories of consumers irrespective of load, tariff and voltage level are eligible for net-billing or net feed-in mechanism up to the level of sanctioned load/ contracted demand of their service connection.

4.3 Gross Metering : The existing consumers of all category and tariff of all voltage level as well as new applicants are eligible for gross metering mechanism. The minimum size of the Solar System that can be set up under Gross Metering mechanism shall be 1 kW up to a maximum capacity of 999 KW.

Provided that the installation of gross-metered rooftop solar systems on the eligible consumer premises intending to inject its total generated power into the grid shall use separate service line. Such service line up to the nearest service pole/ distribution transformer, as the case may be, shall be laid and maintained by the eligible consumer at his own cost.

4.4. The applicant shall be a consumer of the local

distribution licensee and own or in legal possession of the premises including the rooftop or terrace or building or infrastructure or open areas of the land or part or combination thereof on which the Solar PV System is proposed to be installed;

4.5 Consumers with pending arrears / outstanding dues with the Distribution Licensee shall not be eligible for provisions under this regulation.

5 Metering arrangement

5.1 Net-metering mechanism and Net billing or feed-in mechanism: An eligible consumer under the net metering or Net billing / feed-in mechanism shall be entitled to use the power generated from the GISS at his premises and the inject the surplus to the distribution system of the Licensee at the interconnection point.

At service connection point, a single bidirectional energy meter to record the energy import from the TANGEDCO grid and energy export to the TANGEDCO grid shall be provided. This shall be a digital four quadrant vector summation energy meter configured for bidirectional energy measurement whereby both imported and exported active energy readings and allied parameter are programmed to be displayed. If the eligible consumer is within the ambit of Time-of-Day (ToD) Tariff, the bidirectional energy meter to be provided shall have programmable ToD (time-of-the-day) registers with a minimum of four energy import ToD registers and four energy export ToD registers.

5.2 Gross-metering mechanism: A renewable energy generation meter to record the gross solar energy generation shall be provided. This meter is to be installed immediately after the solar grid inverter. If the eligible consumer is within the ambit of Time-of-Day (ToD) Tariff, the energy meter shall have programmable ToD (time- of-the-day) registers with a minimum of four energy export ToD registers. The total solar power generated is accounted for feed-in tariff determined by the Commission from time to time. The energy consumed, if any, by the prosumer shall be metered and accounted separately.

5.3 HT (11 kV and above) Consumers may install and connect Renewable Energy Generating System at their LT Bus Bar System: Provided that, in such cases, the Net Meter shall be installed on the HT side of the Consumer‟s Transformer.

5.4 Energy meters shall be of class 1.0 accuracy and shall comply with applicable CEA (Central Electricity Authority) and BIS (Bureau of Indian Standards) standards.

6 Billing and accounting process

6.1 Net metering :

6.2 The solar energy exported to the Grid from grid connected solar photovoltaic system is deducted from energy imported from the grid in units to arrive at the net imported or exported energy. The net imported or exported energy is billed or credited or carried over to the next billing period. This process shall continue until the end of the settlement period. At the end of the settlement period, credit i.e the net units of surplus generation available if any shall get lapsed.

6.3 In case the Eligible Consumer is within the ambit of Time of Day (ToD) tariff, the electricity consumption in any time block, i.e. peak hours, off-peak hours, etc., shall be first compensated with the quantum of electricity injected in the same time block; any excess injection over and above the consumption in any other time block in a Billing Cycle shall be accounted as if the excess injection had occurred during off- peak hours;

6.4 Net billing or Net feed-in:

6.4.1 The monetary value of the imported energy is debited based on the applicable retail tariff determined by the Commission from time to time. The monitory value of the exported energy is credited based on the feed-in tariff determined by the Commission from time to time. The monetary value of the exported energy is deducted from the monetary value of imported energy to arrive at the net amount to be billed. If the cumulative credit amount exceeds the debit amount during any billing cycle, the net credit amount is carried over to the next billing cycle. At the end of a 12-month settlement period ie 31st March, the net credit balance (if any) shall be carried-over to the next settlement period.

6.5 Gross -metering :
Gross metering is permitted for prosumers who opts to sell all generated solar energy to the distribution licensee instead of availing the net-metering or net feed-in facility. An eligible consumer under the gross metering scheme shall inject the entire power generated from the Solar PV installation to the distribution system of the distribution licensee at the interconnection point. The exported solar energy is credited at the feed in tariff determined by the Commission. The amount is credited in the operators/consumers electricity bill for every billing cycle.

7 Technical Requirements

7.1 The Distribution Licensee shall permit Net Metering or net billing or gross metering arrangement, as the case may be, on a non-discriminatory and Distribution Transformer wise „first come, first serve" basis to Eligible Consumers who have installed or intend to install Grid Interactive Solar energy Generating System (GISS) connected to the Network of such Distribution Licensee provided that

The solar PV system and the interconnection with the Licensee grid shall comply with all applicable regulations and standards of the Central Electricity Authority (CEA), Grid Codes and the Tamil Nadu Electricity Distribution Code with latest amendments.

7.2 The distribution licensee will enhance and update its metering and billing system in line with the requirement of this regulation such that relevant parameters pertaining to billing and payment under all metering mechanisms are properly assessed and clearly furnished in the electricity consumers" bills. Distribution licensees will make available online all of the above billing data for each consumer, along with a sample bill explaining the various billing components.

7.3 The solar plant capacity under both metering mechanisms of net metering and net billing or net feed-in, shall not exceed the sanctioned load/contracted demand of the service connection.

7.4 The cumulative capacity of solar PV systems under net metering and net billing put together connected to a distribution transformer, shall not exceed 100% of the distribution transformer capacity.

7.5 The cumulative capacity of all Solar generating systems under Gross Metering mechanism in case of HT connected to a Power transformer shall not exceed 50% of the Power Transformer capacity.

7.6 Distribution licensees shall update the status of the cumulative solar energy system capacity connected and solar energy generated by each system at each distribution transformers on their website every month.

7.7 Where ever separate meter measuring the gross solar generation is not available in existing grid connected solar system, Licensee shall take prompt action to install it as mandated.

7.8 For all grid connected solar energy systems , the distribution licensee shall make use of the existing distribution network to the maximum extent possible so that utilisation of such infrastructure is optimized.

8 Inter-Connection with the Grid, Standards and safety.

8.1 In case of net metering or net billing , the interface point shall be the net meter at consumer‟s premises i.e., prosumer side of the meter. In case of gross metering, the interface point shall be the gross solar power generation meter installed on the licensee side. In case of net metering or net billing mechanism, the installation solar systems on eligible consumer premises will utilize the same service line and installation for injection of excess power into the grid, which is currently being used by the consumer for drawal of power from the distribution licensee. In case of gross metering mechanism, the installation of gross-metered solar systems on the eligible consumer premises intending to inject its total generated power into the grid shall use separate service line. Such service line up to the nearest service pole/ distribution transformer, as the case may be, shall be laid and maintained by the eligible consumer at his own cost. Required diagram to show the scheme of such connection shall be submitted along with the application.

8.2 The Distribution Licensee shall ensure that the inter-connection of the Renewable Energy Generating System with its Network conforms to the specifications, standards and other provisions specified in the CEA (Technical Standard for Connectivity of the Distributed Generation Resources) Regulations, 2013, the CEA (Measures relating to Safety and Electric Supply), Regulations, 2010, and the Tamil Nadu Electricity Grid Code 2005, as amended from time to time.

8.3 The Eligible Consumer/Prosumer may install a Renewable Energy Generating System with or without storage:
Provided that, if an Eligible Consumer opts for connectivity with storage, the inverter shall have appropriate arrangement to prevent the power from flowing into the grid during the absence of grid supply to prevent electrical accidents, and that an automatic as well as manual isolation switch shall also be provided.

8.4 The Eligible Consumer shall be responsible for the safe operation, maintenance and rectification of any defect in the Renewable Energy Generating System up to the point of Net Meter or Renewable Energy Generation Meter, beyond which point such responsibility, including in respect of the Net Meter, shall be that of the Distribution Licensee:
Provided further that the Renewable Energy Generation Meter shall be maintained by the Distribution Licensee.

8.5 The Distribution Licensee shall have the right to disconnect the Renewable Energy Generating System from its network at any time in the event of any threat of accident or damage from such System to its distribution system so as to avoid any accident or damage to it:
Provided that the Distribution Licensee, considering the criticality, may call upon the Consumer to rectify the defect within a reasonable time

8.6 The solar power generator and equipments shall meet the requirement specified in the CEA‟s (Technical Standards for connectivity of the Distributed Generation Resources) Regulations 2013 and as amended from time to time. The responsibility of operation and maintenance of the solar power generator including all accessories and apparatus lies with the solar power generators. The design and installation of the roof top Solar Photo Voltaic (SPV) should be equipped with appropriately rated protective devices to sense any abnormality in the system and carryout automatic isolation of the SPV from the grid. The inverters used should meet the necessary quality requirements. The protection logics should be tested before commissioning of the plant. Safety certificates for the installation should be obtained from the appropriate authorities.

8.7 The automatic isolation of the SPV should be ensured for no grid supply and low or over voltage conditions and within the required response time. Adequate rated fuses and fast acting circuit breakers on input and output side of the inverters and disconnect/Isolating switches to isolate DC and AC system for maintenance shall be provided. The consumer should provide for all internal safety and protective mechanism for earthing, surge, DC ground fault, and transients etc. as per the CEA regulation/standards.

8.8 The inverter should be a sine wave inverter suitable for synchronizing with the distribution licensee‟s grid. The inverter shall have features of filtering out harmonics and other distortions before injecting the energy into the system of the Distribution Licensee.

8.9 Any battery backup shall be restricted to the consumer‟s network and the consumer shall be responsible to take adequate safety measures to prevent battery power/Diesel Generator (DG) power/backup power extending to distribution licensee‟s LT grid on failure of distribution licensee‟s grid supply.

8.10 To prevent back feeding and possible accidents when maintenance works are carried out by distribution licensee‟s personnel in his network, suitable isolator/ isolating disconnect switches which can be locked by distribution licensee personnel should be provided. This is in addition to automatic sensing and isolating on grid supply failure etc and in addition to internal disconnect switches. In the event of distribution licensee LT supply failure, the SPG has to ensure that there will not be any solar power being fed to the LT grid of distribution licensee. The consumer is solely responsible for any accident to human being/animals whatsoever (fatal/non-fatal/departmental/non departmental) that may occur due to back feeding from the SPG plant when the grid supply is off. The distribution licensee reserves the right to disconnect the consumer installation at any time in the event of such exigencies to prevent accident or damage to men and material.

8.11 All eligible consumers/ prosumers shall abide by all the codes and regulations issued by the CEA/Commission to the extent applicable and in force from time to time. The eligible consumer/ prosumer shall comply with CEA/TNERC/CEIG/ distribution licensee‟s requirements to the extent they are applicable with respect to safe, secure and reliable function of the SPG plant and the grid. The power injected into the grid shall be of the required quality in respect of wave shape, frequency, absence of DC components etc.

8.12 The SPG shall restrict the harmonic generation, flicker within the limit specified in the Indian Electricity Grid Code and relevant regulations issued by the Central Electricity Authority.

8.13 Grid Connected Renewable Energy Generating Systems connected behind the Consumer‟s meter, and not opting for either Net Metering Arrangement or Net Billing Arrangement, shall be allowed only after prior intimation to the respective Distribution Licensee: Provided that the Consumer shall be responsible for ensuring that all necessary safeguarding measures as specified by Central Electricity Authority (CEA) are taken: Provided further that the Commission may determine additional Fixed Charges or Demand Charges and any other Charges for such Grid Connected systems excluding Non-fossil fuel-based Cogeneration Plants, in the retail Tariff Order, if the Distribution Licensee proposes such additional Fixed Charges or Demand Charges and any other Charges for such systems, in its retail supply Tariff Petition, supported by adequate justification:
Provided also that in case the Consumer installs Renewable Energy Generating Systems behind the Consumer‟s meter without prior intimation to the respective Distribution Licensee, then the total additional liabilities in terms of additional Fixed Charges or Demand Charges and any other Charges for such systems, shall be levied at twice the determined rate for such period of default.

8.14 The Licensee shall not be responsible for any accident resulting in injury to human beings or animals or damage to property that may occur due to back-feeding from the Renewable Energy Generating System when the grid supply is off. The Licensee may disconnect the installation at any time in the event of such exigencies to prevent such accident.

9 Metering Infrastructure

9.1 All meters installed at the Renewable Energy Generating System shall comply with the CEA (Installation and Operation of Meters) Regulations, 2006 and subsequent amendments thereof.

9.2 All meters shall have Advanced Metering Infrastructure (AMI) facility with RS 485 (or higher) communication port.

9.3 The Net Metering Arrangement shall include a single-phase or a three-phase Net Meter, as may be required, located at the point of inter-connection as ascertained by the Distribution Licensee.

9.4 Existing Meter in the premises of the Eligible Consumer shall be replaced by the Net Meter at the cost of the Consumer, in accordance with the provisions of the Electricity Supply Code.

9.5 If the Eligible Consumer is within the ambit of Time-of-Day („ToD") Tariff, the Net Meter installed shall be capable of recording ToD consumption and generation.

9.6 The Distribution Licensee shall be responsible for the testing, installation, and maintenance of the metering equipment, and its adherence to the applicable standards and specifications.

9.7 The Eligible Consumer shall procure, at his own cost from the authorized suppliers by the Licensee, a Renewable Energy Generation Meter conforming to the applicable CEA Regulations to be installed at appropriate location to measure the energy generated from the Renewable Energy Generating System. If the meter is not available with the authorized suppliers, consumers can buy from open market and get them calibrated by the Licensee.

9.8 The Renewable Energy Generation Meter shall be maintained by the Distribution Licensee.

9.9 All the meters under all mechanisms of this regulation such as Net Meter , Renewable Energy Generation Meter etc., shall be installed at such locations in the premises of the Eligible Consumer that would enable easy and safe access to the Distribution Licensee for inspection and meter reading at any time.

9.10 In case of Renewable Energy Generating System with capacity above 20 kW set up under Net Metering Arrangement, a Check Meter of appropriate class may be installed by the Distribution Licensee for the Renewable Energy Generation Meter:
Provided that installation of Check Meter shall be optional for Renewable Energy Generating System with capacity up to and including 20 kW.

9.11 In case of Renewable Energy Generating System set up under Net metering or net billing arrangement, an additional Check Meter for the Renewable Energy Generation Meter of appropriate class shall be installed by the Distribution Licensee at their option.

10 Net work charges:

10.1 Net work charges shall be applicable to the prosumers categorised under net metering or net billing or net feed in mechanism , as determined by the commission under regulation 70 of TNERC (Terms and conditions for determination of Tariff) Regulations 2005, from time to time.
10.2 The extent of concession if any, to any category of consumers under proper justification shall be determined by the commission from time to time

10.3 The total units generated by the solar plant shall be reckoned for calculation of network charges.

10.4 The net work charges determined by the Commission for respective HT/LT category shall be payable by all existing and new consumers/ prosumers

11 General Conditions

11.1 The seniority of applications under all categories of this regulation shall be considered on first come, first serve basis.

11.2 At the end of one-year period, the Distribution Licensee shall furnish the capacity of Solar PV system installed under net metering, Net billing and gross metering mechanism , the impact of such solar systems on the grid and on the other factors of the distribution licensee to the Commission . Any amendment , if required, may be considered after due consideration of comments/ objections/ recommendations of the various stakeholders.

11.3 The Distribution Licensee shall update the Distribution Transformer-wise,Power Transformer wise capacity available and the cumulative capacity of the Renewable Energy Generating Systems installed under Net Metering/Gross Metering arrangements quarterly, and provide the information on its website every quarter .

11.4 The Distribution Licensee shall make available the Agreement formats on its website, along with the applicable procedure and Application and other relevant forms, within two months of notification of these Regulations.

11.5 In case the Eligible Consumer / Prosumer leaves the system or changes the Supply Licensee, the excess electricity shall be considered in the following manner:

a) The unadjusted Units as on date of leaving the system or changing the Supply Licensee shall be compensated at the Generic Tariff, and adjusted along with the final bill settlement with the existing Supply Licensee;

b) Any injection of electricity without entering into a new Net Metering Agreement with the new Supply Licensee shall be considered as inadvertent injection and shall not be paid for by the new Supply Licensee.

12 Energy accounting during meter defect / failure / burnt

12.1 In case of defective/failure/burnt condition of any meter, the Distribution Licensee shall replace the meter as specified in the Electricity Supply Code.

12.2 The electricity generated by the Renewable Energy Generating System during the period in which the meter is defective shall be determined based on the readings of the Check Meter or the reading / consumption recorded in the inverter. Provided that if the Check Meter is not installed or the energy is not recorded in the inverter or the energy recorded in the inverter is erratic , then the electricity generated shall be considered equal to the average monthly generation in the last one year or such shorter period as available.

12.3 The consumption of the Consumer during the period in which the Consumer meter or Net Meter is defective shall be determined as specified in the Electricity Supply Code.

13 Renewable Purchase Obligation

13.1 The quantum of electricity consumed by the Eligible Consumer from the Renewable Energy Generating System under the Net Metering Arrangement shall qualify towards his compliance of RPO, if such Consumer is an Obligated Entity.

13.2 The quantum of electricity consumed by the Eligible Consumer from the Renewable Energy Generating System under the Net Metering arrangement shall, if such Consumer is not an Obligated Entity, qualify towards meeting the RPO of the Distribution Licensee.

13.3 All units of Renewable Energy purchased by the Distribution Licensee shall qualify towards meeting its RPO.

13.4 Under the Net Billing Arrangement and Gross metering arrangement , the entire quantum of electricity recorded by the Generation Meter shall qualify towards meeting the RPO of the Distribution Licensee.

14 Eligibility under Renewable Energy Certificate mechanism
The Renewable Energy generated by an Eligible Consumer under the Net Metering Arrangement or the Net Billing Arrangement under these Regulations shall not be eligible for issuance of Renewable Energy Certificate.

15 Procedure for Application and Registration

15.1 The Eligible Consumer shall apply to the concerned Distribution Licensee for connectivity of the Grid Interactive Solar System with the Licensee"s Network along with following registration fee either through online or submit the application in the prescribed form (Annexed) at the section office.

Sl.No.	Description	Registration fee
1	LT – up to 20 KW	Rs.500
2	LT – above 20 KW and up to 150 KW	Rs.500 up to 20KW and Rs.100 therafter for every 20KW or part there of.
3	HT- above 150KW and up to 500KW	Rs.5000
4	HT- above 500 KW to less than 1 MW	Rs.10000

15.2. In case the application form submitted in hard copy form, the same shall be scanned and uploaded on the website as soon as it is received.

15.3. Acknowledgement with the registration number for that application shall be generated and intimated to the applicant within three working days of receipt of application. In case of applications being received online, the acknowledgement

15.4. In case of any deficiencies in the application form, the same shall be intimated within 3 working days from the date of receipt of application . The consumer shall rectify the defects and resubmit within 7 days to retain the registration number. If the application form is not submitted with rectification within 7 days the application shall stand cancelled and the registration fee shall be forfeited.

15.5. The application shall be deemed to be received on the date of generation of acknowledgement with registration number.

15.6. The distribution licensee shall evolve technical feasibility within 15 working days from the date of registration of application.
15.7. The technical feasibility shall be conducted on the following aspects and any other which the licensee considers appropriate :
i AC Voltage level at which connectivity is sought;
ii Sanctioned Load / Contract Demand of the Applicant;
iii Rated Output AC Voltage of the proposed Renewable Energy Generating
System;
iv Available cumulative capacity of relevant Distribution Transformer/ power Transformer.

15.8 If found technically feasible, the Distribution Licensee shall, within 7 working days of the completion of the feasibility study, convey its approval for installing the Renewable Energy Generating System. The approval shall indicate the maximum permissible capacity of the System, and shall be valid for a period of 6 months from the date of approval, or such extended period as may be agreed to by the Distribution Licensee

15.9. The Applicant shall, within the period of validity of such approval, submit the work completion report, along with relevant details (such as technical specifications,
test reports received from manufacturer / system provider, safety certificate from CEIG as may be applicable etc.), with a request to the Distribution Licensee for the testing and commissioning of the Renewable Energy Generating System..

15.10 . The Distribution Licensee shall complete the testing and commissioning of the System within 10 working days from receipt of

such request and shall install the bidirectional meter and synchronise the Renewable Energy Generating System within 10 days thereafter.
15.11 The applicant and Licensee shall enter in to agreement in the prescribed format after the solar system is installed but before it is synchronized with the network.

15.12. The commissioning test of the Solar PV System shall be carried out in the presence of representatives of consumer/owner of Rooftop Solar PV System, and concerned officer of the distribution licensee. The commissioning certificate shall be signed by all the above named parties.

15.13. The Commissioning certificate must contain of the following details:
i. Details of Solar PV panels including name of the manufacturer, type, size/capacity of the panels, etc.;
ii. Details regarding inverter, types of inverters and size;
iii. Total capacity of the Solar PV Plant;
iv. Details of meter installed along with the types of meter accuracy, serial
number, etc.
15.14 The formats of contract agreement and installation certificate shall be placed in the web portal of the Dist licensee.
15.15 The application tracking mechanism based on the unique registration number shall be provided by the distribution licensee through web-based module or any other mode to monitor the status of processing of the application like receipt of application, site inspection, meter installation, commissioning, etc

15.16 Consumer shall have the option of purchasing the bidirectional meter from the authorized suppliers which shall be tested and installed by the Licensee.

15.17 The timelines as specified in these regulations shall be adhered to by the Licensee.

15.18 The Distribution licensee shall take necessary action to comply with provisions prescribed in adhere to Rule 11(4) of Electricity (Consumer) Rules 2020.

16 Access and Disconnection

16.1 The Eligible Consumer shall provide access to the Licensee to the metering equipment and disconnecting devices of Renewable Energy Generating System, both automatic and manual.

16.2 If, in an emergent or outage situation, the Licensee cannot access the disconnecting devices of the Renewable Energy Generating System, both automatic and manual, it may disconnect power supply to the premises.

16.3 Upon termination of this Agreement under Clause 5, the Eligible Consumer shall disconnect the Renewable Energy Generating System forthwith from the Network of the Licensee.

17 . Connection Agreement

17.1. The Distribution Licensee and Eligible Consumer shall enter into a Connection Agreement after approval of connectivity of the Renewable Energy Generating System with the distribution Network but before the start of actual generation from the System.

17.2 A model Grid connected SPG plant agreement is provided at Annexure , which the Distribution Licensee may modify suitably, subject to consistency with these Regulations with the approval of the Commission..

17.3 The Connection Agreement shall remain in force for twenty five years:
Provided that the Eligible Consumer may terminate the Agreement at any time by giving 90 days" notice to the Distribution Licensee:

17.4 Any eligible consumer/Prosumer, who intends to discontinue net metering arrangement with the distribution licensee shall be allowed, subject to a written notice to the distribution licensee made at least one month in advance. Any excess energy generation remaining unadjusted as on the date of termination of the agreement shall not be adjusted by the distribution licensee.
Provided further that the Distribution Licensee may terminate the Agreement by giving 30 days‟ notice, if the Eligible Consumer breaches any term of the Agreement and does not remedy such breach within 30 days, or such other longer period as may be provided, of receiving notice from the Licensee of such breach, or for any other valid reason to be communicated in writing:
Provided also that the Distribution Licensee may terminate the Agreement by giving 15 days‟ notice in case the consumer fails to pay his dues in a timely manner or indulges in any malpractices: Provided also that the Agreement may be terminated at any time by mutual consent.

17.5 Any unbilled energy generation as on the date of termination of the agreement shall be paid within one month from the date of termination of agreement by the distribution licensee.

17.6 The Eligible Consumer shall, upon termination of the Agreement, disconnect forthwith its Renewable Energy Generating System from the Distribution Licensee‟s Network.

18. Power to give directions

Subject to provisions of the Act, the Commission may from time to time issue such directions and orders as considered appropriate for implementation of these Regulations.

19. Power to relax

The Commission may by general or special order, for reasons to be recorded in writing, and after giving an opportunity of hearing to the parties likely to be affected, may relax any of the provisions of these

Regulations on its own motion or on an application made before it by an interested person.

20. Power to amend

The Commission may from time to time add, vary, alter, suspend, modify, amend or repeal any provisions of these Regulations for reasons to be recorded.
These regulations supersede the earlier regulations and statutory orders issued by the Commission so far and for all practical and resolutions of disputes, only these regulations shall prevail without prejudice to all actions taken and orders issued under the earlier orders and regulations.

21 . Power to remove difficulties

If any difficulty arises in giving effect to the provisions of these Regulations, the Commission may, by an order, make such provisions, not inconsistent to the provision of the Act and these Regulations, as may appear to be necessary for
removing such difficulty.

(By order of the Tamil Nadu Electricity Regulatory Commission)

Solar Inverter Testing Procedure for Stand-Alone PV Systems

Currently the use of inverters in stand-alone PV systems has become widespread for rural electrification purposes. This allows the use of PV systems to power conventional AC appliances, which represent advantages in terms of user convenience and satisfaction. However, the standard AC appliances are normally designed to operate under certain conditions of the conventional grid. Therefore, some possibility of the occurrence of malfunction, even damage, on the electrical equipment, should be considered in the design of PV systems. This paper is intended to validate performance testing procedure of inverter for stand-alone PV systems

Currently the use of inverters in stand-alone PV systems has become widespread for rural electrification purposes. This allows the use of PV systems to power conventional AC appliances, which represent advantages in terms of user convenience and satisfaction. The inverters used to convert dc power (typically low voltage) produced from PV array and/or stored in battery into ac (at 230V, 50Hz) as required for conventional/ac appliances. Therefore, the inverter is now becoming the most important part of conventional and renewable power systems, such as solar, fuel cell, electrical energy storage systems, wind power plants and gas turbine power systems [2]. As competition in the renewable energy industry grows, companies strive to ensure their photovoltaic inverters and converters are safe, functional and compliant with relevant standards.

A number of inverter products are now available in the market for various applications with different sizes, qualities, and performances. To make sure their qualities and performances comply with the standards, testing facility and procedure have to be developed according to national or international standards.

Among the principal characteristics of power inverter, efficiency is considered as an important factor in solar PV applications. Several tender documents for development of SAPV systems in Indonesia require inverter efficiency of more than 93%. The IEC 61683 is a standardized procedure for measuring the efficiency of power conditioners which is necessary for their widespread use in PV systems by increasing the reliability of their claimed efficiency. Generally speaking, inverter efficiency is affected by the following parameters, such as: power level, input voltage, output voltage, power factor, harmonic content, load nonlinearity, temperature.

Solar PV inverter

Solar PV inverter is a power electronic device, which convert dc (typically low voltage) from a SAPV system into ac power (at 230V, 50Hz) as required for conventional appliances. In general, there are two types of solar PV inverter available, i.e. stand-alone and grid-tie inverters. Stand-alone or battery supplied inverters are demand driven. They provide any power or current up to the rating of the inverter and assuming that there is enough energy in the battery. The storage batteries are also the heart of all SAPV systems. By storing excess energy when the sun is strong, they offer a reliable source of electricity, which can be used when solar power is not available. Their function is therefore to balance the outgoing electrical requirements with the incoming energy supply. The batteries are also able to provide short term power output, many times higher than the charging source output.

(i) Test Procedure and Efficiency Calculation

The test procedure of solar PV inverters developed in the study uses standard of the IEC 61683, called "photovoltaic systems – power conditioners – procedure for measuring efficiency". The purpose of this standard is to provide the means to evaluate the intrinsic efficiency of power conditioners by a direct measurement of input and output power in the factory. This standard describes guidelines for measuring the efficiency of inverters used in stand-alone and utility-interactive photovoltaic systems, where the output of the inverter is a stable a.c. voltage of constant frequency. The efficiency is calculated from a direct measurement of input and output power in the factory. An isolation transformer is included where it is applicable.

The purpose of the inverter test is to check the conformity of the technical specifications provided by the manufacturer and to provide a technical representation of the inverter performance described by rated capacity or other parameters, such as efficiency, current and voltage output waveform, stability, and Total Harmonic Distortion (THD). The measurement results do not specify the test passing criteria, but the inverter performance test results will be useful for the consumer to know the extent of the suitability of the inverter power capacity to the specifications listed by the manufacturer.

The inverter testing procedures can be described are as follow:

1. Preliminary test is a visual inspection which includes examination of completeness of accessories (LED indicator, Alarm, as well as technical document of inverter operation manual, and also to check the function of inverter operation.

2. Self consumption test is to check the inverter performance with no load. This test is intended to know the power consumption of the inverter components when operating without load.

3. Load test is the inverter performance test with using a resistive load (PF = 1.0) and inductive (PF = 0.5 and 0.8), with a gradual load variation of 0% to 120% of inverter power capacity. In addition, the procedure also includes with performance test with a sudden load change of 0-50%, 50-100%, and 100-50% of the nominal capacity of the inverter.

4. Under and over voltage test is the performance test of the load of the inverter with the voltage input under the working voltage and above the working voltage. This test is intended to verify the inverter behaviour under battery under and over voltage conditions.

5. Under and over load test is the performance test of inverter with load variation, lower and higher load than nominal capacity of inverter.

6. Continuous load test is the inverter performance test with full load (100%) continuously.

7. Protection test is to check the protection function of the inverters. Rated output efficiency of the inverter can be calculated from measured data , with the following equation:

$$\eta R = (Po / Pi) \times 100 \qquad \text{------- (1)}$$

Where

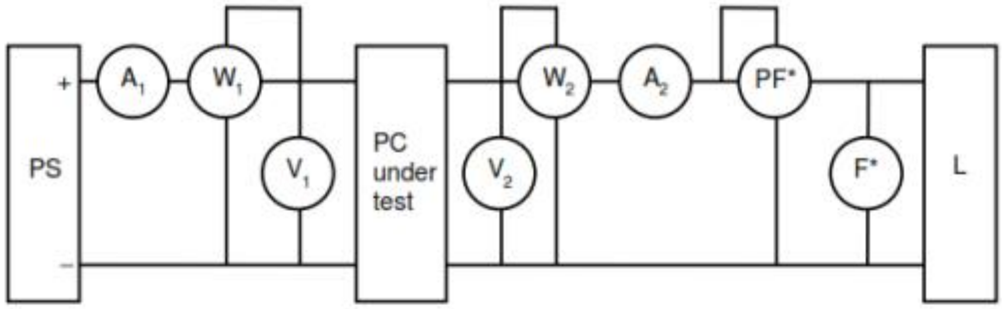
– ηR is the rated output efficiency (%);

– Po is the rated output power from power conditioner (kW);

– Pi is the input power to power conditioner at rated output (kW).

(ii) . Test Circuits

Fig. 1 shows the recommended test circuits for the inverter which have a single-phase a.c. output and d.c.output.



PC power conditioner
PS variable voltage-current d.c. power supply
A_1 DC ammeter
A_2 AC or d.c. ammeter
W_1 DC wattmeter
W_2 AC or d.c. wattmeter
L load
F frequency meter
V_1 DC voltmeter
V_2 AC or d.c. voltmeter
PF power factor meter

Fig. 1. Test circuit for inverter test

For power conditioners or inverters operating with fixed input voltage, the d.c. power source shall be a storage battery or constant voltage power source to maintain the input voltage. At unity power factor, or at the intrinsic power factor of stand-alone inverters without power factor adjustment, measure the efficiency for power levels of 10 %, 25 %, 50 %, 75 %, 100 % and 120 % of the inverter's rating. Stand-alone inverters shall also be measured at a power level of 5 % of rated. The inverter test should be conducted with a specified resistive and reactive grid impedance. For stand-alone inverters, measure the efficiency with a load which provides a power factor equal to the manufacturer's specified minimum level (or 0,25, whichever is greater) and at power levels of 25 %, 50 % and 100 % of rated VA. Repeat for power factors of 0,5 and 0,75 (do not go below the manufacturer's specified minimum PF) and power levels of 25 %, 50 %, and 100 % of rated VA.

Power Quality Issues of Roof top Solar PV Energy Systems Integrated into the Grid

The renewable energy sources have increased significantly due to environmental issues and fossil fuels elevated cost. Integrated power grid is an electric power system formed as a result of the integration of several individual power grids. The individual member systems retain their separate functions, but their operations are supervised by a single control centre. Some of the challenges and issues associated with the grid integration of various renewable energy sources particularly solar photovoltaic and wind energy conversion systems are discussed. Due to the wind speed's uncertain behaviour it is difficult to obtain good quality power, since wind speed fluctuations reflect on the voltage and active power output of the electric machine connected to the wind turbine. Solar penetration also changes the voltage profile and frequency response of the system and affects the transmission and distribution systems of utility grid. The increasing number of renewable energy sources and distributed generators requires new strategies for the operation and management of the electricity grid in order to maintain or even to improve the power-supply reliability and quality. The technical issues for small scale generation and large scale generation; some of the non-technical issues has been discussed.

The grid must have standard conditions of supply to ensure that end-use equipment and infrastructure can operate safely and effectively. These conditions are commonly referred to as power quality requirements .They most commonly relate to voltage and frequency regulation, power factor correction and harmonics. In all distribution networks, challenges to maintaining these power quality requirements arise from the technical characteristics and end-user operation of electrical loads. Some loads have significant power demands that increase network current flows pulling down line voltage (such as electric hot water heaters and large air-conditioners). Some have very major power draws on start-up (such as standard induction motors) driving voltage fluctuations.

Power quality is defined as ―the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment, or a household appliance. All of these devices and others react adversely to power quality issues, depending on the severity of problems. A simpler and more concise definition might state: ―Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy.‖ This definition embraces two things that we demand from an electrical device: performance and life expectancy. In light of this definition of power quality, this chapter provides an introduction to the more common power quality terms along with descriptions, causes and consequences of the terms.

A. VOLTAGE SAG (OR DIP)

Description: A decrease of the normal voltage level between 10 and 90% of the nominal rms voltage at the power frequency, for durations of 0, 5 cycle to 1 minute.

Causes: Faults on the transmission or distribution network (most of the times on parallel feeders).Faults in consumer's installation. Connection of heavy loads and start-up of large motors. Consequences: Malfunction of information technology equipment, namely microprocessor-based control systems (PCs, PLCs, ASDs, etc) that may lead to a process stoppage. Tripping of contactors and electromechanical relays. Disconnection and loss of efficiency in electric rotating machines

B. VERY SHORT INTERRUPTIONS

Description: Total interruption of electrical supply for duration from few milliseconds to one or two seconds.

Causes: Mainly due to the opening and automatic reclosure of protection devices to decommission a faulty section of the network. The main fault causes are insulation failure, lightning and insulator flashover. Consequences: Tripping of protection devices, loss of information and malfunction of data processing equipment. Stoppage of sensitive equipment, such as ASDs, PCs, PLCs, if they're not prepared to deal with this situation.

C. LONG INTERRUPTIONS

Description: Total interruption of electrical supply for duration greater than 1 to 2 seconds. Causes: Equipment failure in the power system network, storms and objects (trees, cars, etc) striking lines or poles, fire, human error, bad coordination or failure of protection devices. Consequences: Stoppage of all equipment

D. VOLTAGE SPIKE

Description: Very fast variation of the voltage value for durations from a several microseconds to few milliseconds. These variations may reach thousands of volts, even in low voltage.

Causes: Lightning, switching of lines or power factor correction capacitors, disconnection of heavy loads. Consequences: Destruction of components (particularly electronic components) and of insulation materials, data processing errors or data loss, electromagnetic interference.

E. VOLTAGE SWELL

Consequences: Data loss, flickering of lighting and screens, stoppage or damage of sensitive

Description: Momentary increase of the voltage, at the power frequency, outside the normal tolerances, with duration of more than one cycle and typically less than a few seconds. Causes: Start/stop of heavy loads, badly dimensioned power sources, badly regulated transformers (mainly during off-peak hours) equipment, if the voltage values are too high.

F. HARMONIC DISTORTION

Description: Voltage or current waveforms assume non-sinusoidal shape. The waveform corresponds to the sum of different sine-waves with different magnitude and phase, having frequencies that are multiples of power-system frequency.

Causes: Classic sources: electric machines working above the knee of the magnetization curve (magnetic saturation), arc furnaces, welding machines, rectifiers, and DC brush motors. Modern sources: all non-linear loads, such as power electronics equipment including ASDs, switched mode power supplies, data processing equipment, high efficiency lighting. Consequences: Increased probability in occurrence of resonance, neutral overload in 3-phase systems, overheating of all cables and equipment, loss of efficiency in electric machines, electromagnetic interference with communication systems, errors in measures when using average reading meters, nuisance tripping of thermal protections.

G. **VOLTAGE FLUCTUATION**

Description: Oscillation of voltage value, amplitude modulated by a signal with frequency of 0 to 30 Hz.

Causes: Arc furnaces, frequent start/stop of electric motors (for instance elevators), oscillating loads. Consequences: Most consequences are common to under-voltages. The most perceptible consequence is the flickering of lighting and screens, giving the impression of unsteadiness of visual perception.

H. **VOLTAGE UNBALANCE**

Description: A voltage variation in a three-phase system in which the three voltage magnitudes or the phase-angle differences between them are not equal.

Causes: Large single-phase loads (induction furnaces, traction loads), incorrect distribution of all single-phase loads by the three phases of the system (this may be also due to a fault). Consequences: Unbalanced systems imply the existence of a negative sequence that is harmful to all three phase loads. The most affected loads are three-phase induction machines.

(i) . POWER QUALITY ISSUES OF WIND AND SOLAR ENERGY SYSTEM INTEGRATED INTO THE GRID

A grid-connected PV (photovoltaic) power system is electricity generating solar PV power system that is connected to the utility grid. A grid-connected PV system consists of solar panels, one or several inverters, a power conditioning unit and grid connection equipment. They range from small residential and commercial rooftop systems to large utility-scale solar power stations. Unlike stand-alone power systems, a grid-connected system rarely includes an integrated battery solution, as they are very expensive. When conditions are right, the grid-connected PV system supplies the excess power, beyond consumption by the connected load, to the utility grid.

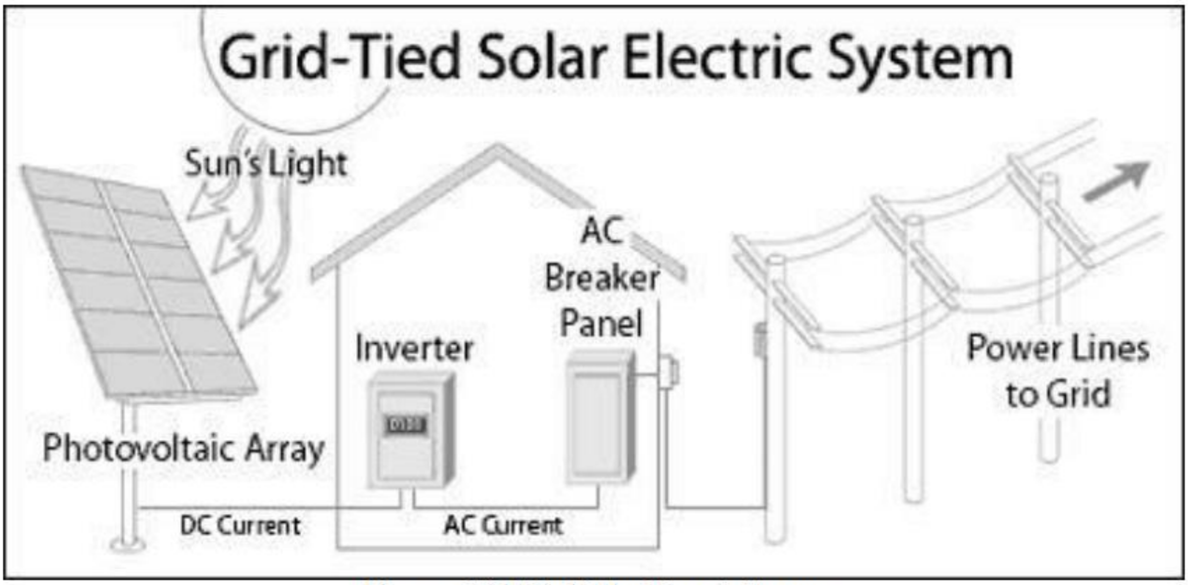


Fig 2 Grid- Tied Solar Electric System

Solar energy gathered by photovoltaic solar panels, intended for delivery to a power grid, must be conditioned, or processed for use, by a grid-connected inverter. An inverter changes the DC input voltage from the PV to AC voltage for the grid. This inverter sits between the solar array and the grid, draws energy from each, and may be a large stand-alone unit or may be a collection of small inverters, each physically attached to individual solar panels. The inverter must monitor grid voltage, waveform, and frequency. One reason for monitoring is if the grid is dead or strays too far out of its nominal specifications, the inverter must not pass along any solar energy.

An inverter connected to a malfunctioning power line will automatically disconnect in accordance with safety rules. Another reason for the inverter monitoring the grid is because for normal operation the inverter must synchronize with the grid waveform, and produce a voltage slightly higher than the grid itself, in order for energy to smoothly flow outward from the solar array. In general, grid-connected PV systems are installed to enhance the performance of the electric network; PV arrays (as well as other distributed generation (DG) units) provide energy at the load side of the distribution network, reducing the feeder active power loading and hence improving the voltage profile. As a result, PV systems can delay the operation time of shunt capacitors and series voltage regulators, thus increasing their lifetime. PV systems can also reduce the losses in distribution feeders if optimally sized and allocated. PV systems can increase the load carrying capability (LCC), which is the amount of load a power system can handle while satisfying certain reliability criteria, of existing networks. To meet increased demand while satisfying the same reliability criteria, utilities have to increase their generation capacity However, PV systems can also impose several negative impacts on power networks, especially if their penetration level is high. These impacts are dependent on the size as well as the location of the PV system.

PV systems are classified based on their ratings into three distinct categories:

(1) Small systems rated at 10 kW or less,
(2) Intermediate systems rated between 10 kW and 500 kW, and
(3) Large systems rated above 500 kW.

The first two categories are usually installed at the distribution level, as opposed to the last category which is usually installed at the transmission/sub-transmission levels.

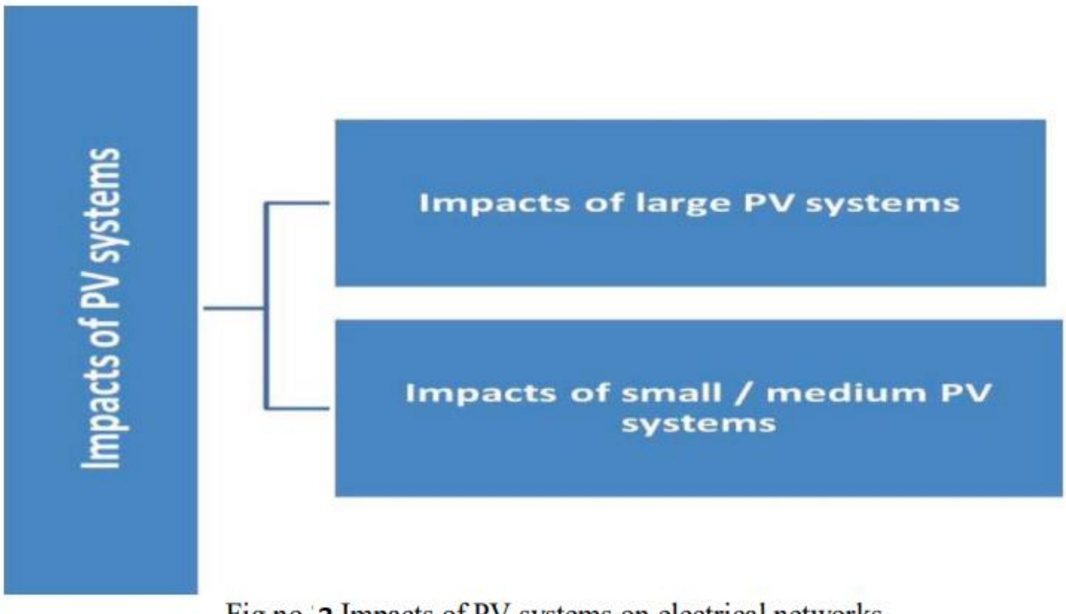


Fig no.:3 Impacts of PV systems on electrical networks

(i. a) Large-scale PV systems

The anticipated impacts of large-scale PV systems (above 500 kW) on transmission/sub-transmission networks are as follows

1. **Severe power, frequency, and voltage fluctuations**
   PV arrays' output is unpredictable and is highly dependent on environmental conditions such as temperature and insolation levels as depicted in Fig.no.4 and 5, respectively. Partial shading due to passing clouds, temperature, and insolation random variations are all factors that will affect PV system production, resulting in rapid fluctuations in its output power. In a practical study on a 2 MW solar plant on a distribution feeder, the power output was measured and recorded every 5 min. The measurements showed sudden and severe power fluctuations caused by passing clouds and morning fog. Active power fluctuations result in severe frequency variations in the electrical network, whereas reactive power fluctuations result in substantial voltage fluctuations. These voltage fluctuations may cause nuisance switching of capacitor banks.

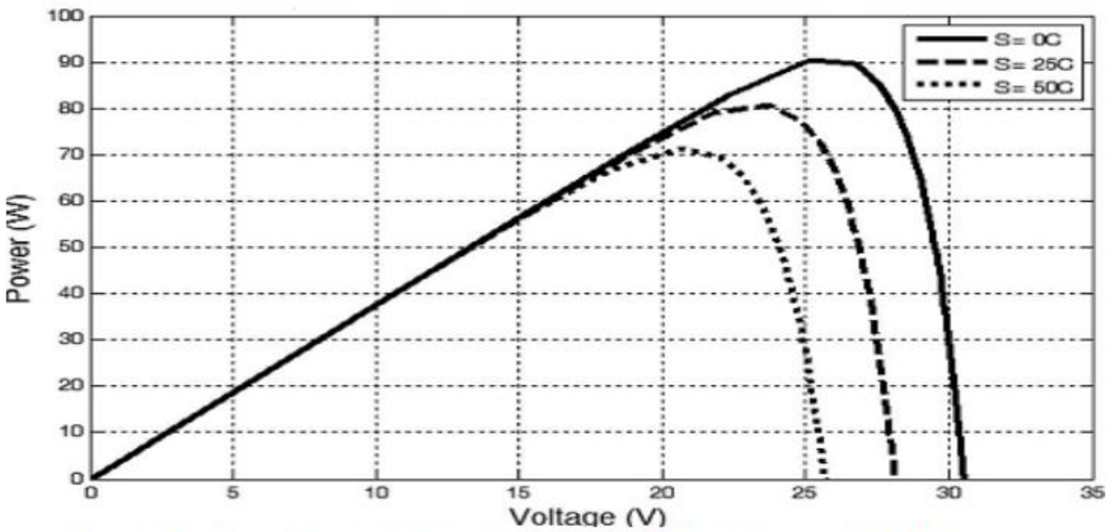


Fig.no.4 Effect of temperature variation on the DC power output of a PV array

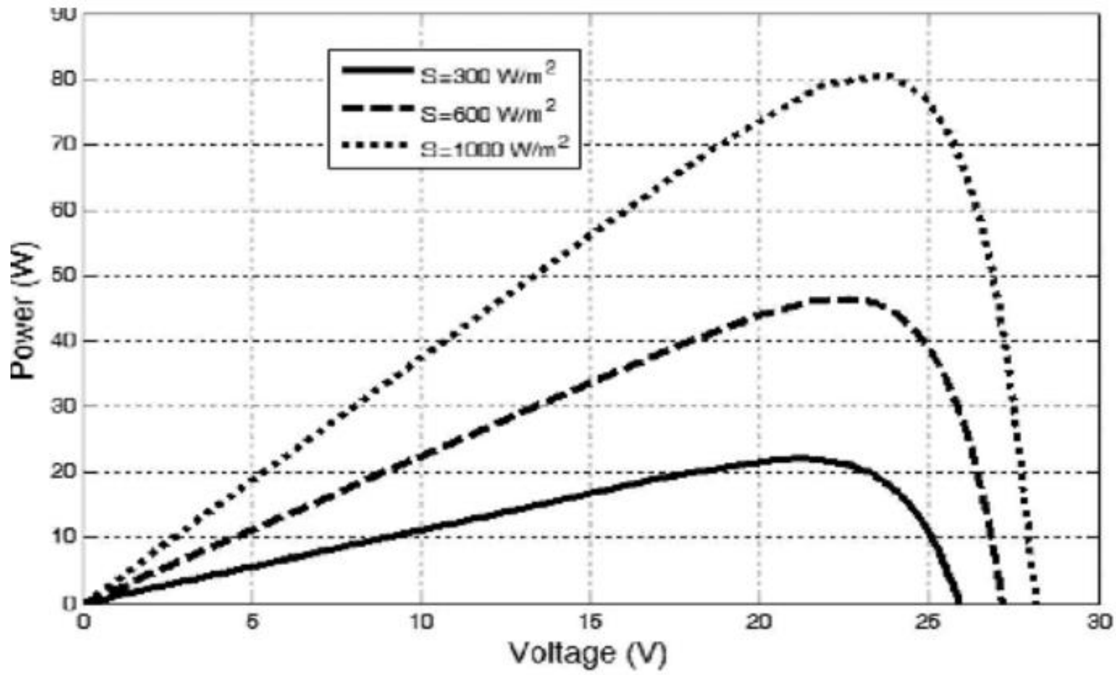


Fig.no.5 Effect of insolation variation on the DC power output of a PV array

2. Increased ancillary services requirements

Since the grid acts as an energy buffer to compensate for any power fluctuations and firm up the output power of PV sources, thus, generating stations' outputs need to be adjusted frequently to cope with the PV power fluctuations, i.e., to dance with the sun. For example, if a cloud blanked out a PV system supplying 1 MW of electricity in 10 s, then the electric grid should be able to inject extra power at a rate of 1 MW/10 s or else voltage and frequency disturbances will occur in the power system.

As a result, utilities need to incorporate fast ramping power generation to compensate for these power fluctuations from PV arrays before voltage and frequency variations exceed the allowable limits. The previous situation also necessitates a significant increase in the frequency regulation requirements at higher penetration levels of PV systems. The frequency regulation should increase by 10%. Geographical distribution of PV arrays in a certain region plays an important role in deter-mining the maximum allowable PV penetration in that region; the closer those PV arrays are, the more power fluctuations are expected due to clouds, and the more frequency regulation service is needed to balance out those power fluctuations.

1.3% if the PV system is located at a central station.
6.3% if the PV system is located in 10 km2 area.
18.1% if the PV system is located in 100 km2 area.
35.8% if the PV system is located in 1000 km2 area.

These results indicate that, due to their dispersed nature, small-scale PV systems are not likely to impact frequency regulation requirements and so, these requirements should be deter-mined based on the penetration level of large, centralized PV stations only.

3. Stability problems

PV arrays' output is unpredictable and is highly dependent on environmental conditions. This unpredictability greatly impacts the power system operation as they cannot provide a dispatch able supply that is adjustable to the varying demand, and thus the power system has to deal with not only uncontrollable demand but also uncontrollable generation. As a result, greater load stability problems may occur.

PV arrays do not have any rotating masses; thus, they do not have inertia and their dynamic behaviour is completely controlled by the characteristics of the interfacing inverter. As the penetration level of PV increases, more conventional generators are being replaced by PV arrays; thus, the damping ratio of the system increases. As a result, the oscillation in the system decreases. The presence of solar PV generation also can change the mode shape of the inter-area mode for the synchronous generators those are not replaced by PV systems. Some critical synchronous generators should be kept online (even if they are operating beyond their economic operating range) to maintain sufficient damping of the system. During fault conditions in a system with high PV penetration, rotors of some of the conventional generators swing at higher magnitudes.

The study on the impacts of large-scale PVs on voltage stability of sub-transmission systems concluded that PV sizes, locations, and modes of operation have strong impacts on static voltage stability; voltage stability deteriorates due to PV inverters operating in constant power factor mode of operation, whereas PV inverters operating in the voltage regulation mode may improve the system voltage stability

(i. b) Small/Medium PV systems (below 500 kW)

The anticipated impacts of small/medium PV systems (below 500 kW) on distribution networks are as follows

1. **Excessive reverse power flow**
   In a normal distribution system, the power flow is usually unidirectional from the Medium Voltage (MV) system to the Low Voltage (LV) system. However, at a high penetration level of PV systems, there are instants when the net production is more than the net demand (especially at noon), and as a result, the direction of power flow is reversed, and power flows from the LV side to the MV side. This reverse flow of power results in overloading of the distribution feeders and excessive power losses. Reverse power flow has also been reported to affect the operation of automatic voltage regulators installed along distribution feeders as the settings of such devices need to be changed to accommodate the shift in load centre. Reverse power flow may have adverse effects on online tap changers in distribution transformers especially if they are from the single bridging resistor type.
2. **Over voltages along distribution feeders**
   Reverse power flow leads to over voltages along distribution feeders. Capacitor banks and voltage regulators used to boost voltage slightly can now push the voltage further; above the ac-acceptable limits. Voltage rise on MV networks is often a constraining factor for the widespread adoption of wind turbines. Voltage rise in LV networks may impose a similar constraint on the installation of PV systems. This problem is more likely to occur in electrical networks with high penetration of dispersed PV power generation.
3. **Increased difficulty of voltage control**
   In a power system with embedded generation, voltage control becomes a difficult task due to the existence of more than one supply point. All the voltage regulating devices, i.e., capacitor banks and voltage regulators, are designed to operate in a system with unidirectional power flow.

4. **Increased power losses**

   DG systems reduce system losses as they bring generation closer to the load. This assumption is true until reverse power flow starts to occur. Distribution system losses reach a minimum value at a penetration level of approximately 5%, but as the penetration level increases, the losses also increase and may exceed the no-DG case.

5. **Severe phase unbalance**

   Inverters used in small residential PV installations are mostly single phase inverters. If these inverters are not distributed evenly among different phases, phase unbalance may take place shifting the neutral voltage to unsafe values and increasing the voltage unbalance.

6. **Power quality problems**

   Power quality issues are one of the major impacts of high PV penetration on distribution net-works; power inverters used to interface PV arrays to power grids are producing harmonic currents; thus, they may increase the total harmonic distortion (THD) of both voltage and currents at the point of common coupling (PCC).Voltage harmonics are within limits if the net-work is stiff enough with low equivalent series impedance. Current harmonics, on the other hand, are produced by high pulse power electronic inverters and usually appear at high orders with small magnitudes. An issue with higher-order current harmonics is that they may trigger resonance in the system at high frequencies. Diversity effect between different current harmonics can also reduce the overall magnitude of those current harmonics. Another power quality concern is the inter-harmonics that appear at low harmonic range (below the 13th harmonic). These inter-harmonics may interact with loads in the vicinity of the inverter. Even harmonics (especially the second harmonics) can possibly add to the unwanted negative sequence currents affecting three phase loads. DC injections as well may accumulate and flow through distribution transformer, leading to a possible damage.

7. **Increased reactive power requirements**

PV inverters normally operate at unity power factor for two reasons. The first reason is that current standards (IEEE 929-2000) do not allow PV inverters to operate in the voltage regulation mode. The second reason is that owners of small residential PV systems in the incentive-programs are revenued only for their kilowatt-hour yield, not for their kilovolt-ampere hour production. Thus, they prefer to operate their inverters at unity power factor to maximize the active power generated and accordingly, their return. As a result, the active power requirements of existing loads are partially met by PV systems, reducing the active power supply from the utility. However, reactive power requirements are still the same and have to be supplied completely by the utility. A high rate of reactive power supply is not preferred by the utilities because in this case distribution trans-formers will operate at very low power factor (in some cases it can reach 0.6). Transformers' efficiency decreases as their operating power factor decreases, as a result, the overall losses in distribution transformers will increase reducing the overall system efficiency.

8. **Electromagnetic interference issues**

   The high switching frequency of PV inverters may result in electromagnetic interference with neighbouring circuits such as capacitor banks, protection devices, converters, and DC links leading to mal-function of these devices.

9. **Difficulty of islanding detection**

   Islanding detection techniques are characterized by the presence of non-detection zones defined as the loading conditions for which an islanding detection method would fail to operate in a timely manner, and are thus prone to failure. Moreover, the inclusion of islanding detection devices increases the overall cost of integrating PV systems in electrical networks.

Maximum Allowable Penetration Levels For PV Systems

Penetration limit	Limiting factor
5%	Ramping rates of generators during cloud transients (central station PV)
15%	Ramping rates of generators during cloud transients (distributed PV)
1.3%	Power fluctuations due to clouds transients for central station PV
6.3%	Power fluctuations due to clouds transients if the PV system is distributed in 10 km^2 area
18.1%	Power fluctuations due to clouds transients if the PV system is located in 100 km^2 area
35.8%	Power fluctuations due to clouds transients if the PV system is distributed in 1000 km^2 area
10%	Frequency regulation expansions vs. break-even costs
Minimum feeder loading	Over voltages assuming no load tap changers (LTCs) exist in the MV/LV transformer
40%	Voltage regulation
5%	Minimum distribution system losses
33%	Overvoltages

Table no.1Summary of Allowable PV Penetration Limits

From the above results, it can be concluded that there is no agreed-upon maximum allowable penetration limit for PV electricity. It can vary from 1.3% up to 40% depending on the limiting factor as well as the size, location, and geographic distribution of PV arrays. A comprehensive techno-economic assessment should be performed for each individual network to determine the maximum allowable PV penetration in such a network. For example, Hydro One—the largest distribution utility in Ontario— requires that distributed generation —to be interconnected to a distribution system circuit line section, including the proposed generator, not to exceed 7% of the annual line section peak load.

Photovoltaic System – Unbalanced (Imbalanced) Voltage

(i) Introduction

Photovoltaic solar energy is a kind of renewable and clean energy which is highly reliable and sustainable. Solar energy through photovoltaic systems is directly converted into electric power and there is no need of using interface procedures. Photo cell and module production have had considerable proliferation in recent years, totally reaching to 2500 MW in the year peak. Also there are some problems in power distribution. The existing problems in distribution networks in power quality point of view could be discussed from two perspectives; network and consumer. In network view, the consumer is causing turbulence in the network and creates phenomena like flicker, imbalance load in which unbalanced current takes happen, and non-linear loads which receives harmonic currents from the network. These turbulences have adverse effects on consumers and network equipment. In the other hand, consumers believe the turbulence is imposed by the network and it creates other phenomena such as voltage imbalance, voltage harmonic turbulence, voltage sag, disruption, frequency deviation etc. Meanwhile, voltage and current imbalance are one of the most important issues of power quality in low voltage distribution networks.

Voltage imbalance can have adverse consequences on electrical equipment and power systems. In case of voltage imbalance, the power network sustains more losses and also less stability. Given that in reality, the utilization of distribution network results in voltage imbalance, IEC the standard, 2% voltage imbalance has been proposed for electrical systems. In study, some methods include positive/negative phase shift sequences, voltage drop curves, distance effect, unbalanced voltage drop sensitivity and combinations of different line configurations supported by these methods of analysis, general guidelines and recommendations for phase load arrangement are found to reduce voltage imbalance and excessive voltage drop for a certain phase. This provides a direction for network adjustment rather than guessing the way of modification by checking numerous load flow results. In Some studies new algorithms for maximum power point tracking has been presented. In study, two large Photo Voltaic (PV) systems has been use to demonstrate effectiveness of Load Power Controller (LPC) for the enhancement of loading balance in a Taipower distribution system. Results show that the loading balance of distribution systems with intermittent PV power generation can be obtained effectively by the implementation of LPC to achieve adaptive control of load transfer between distribution feeders. The power loss reduction of test feeders after loading balance by LPC has also been derived in this paper.

(ii) Voltage Imbalance

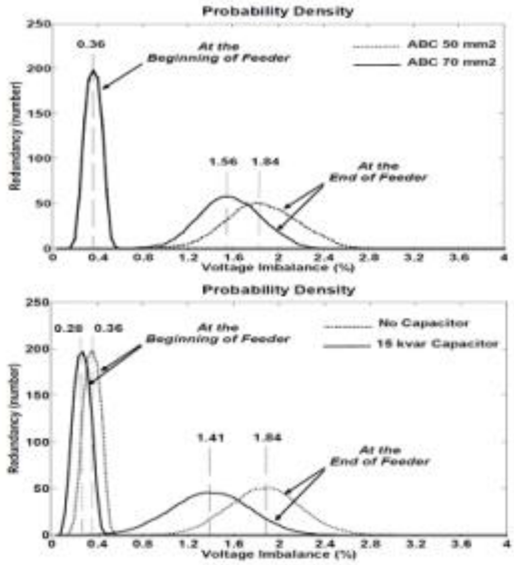
Electrical energy losses due to remarkable damages which it imposes to power industry are considered by power industry experts and its harmful effect in network requires to be analyzed to determine the practical procedures of its reduction. One factor of energy loss which occurs usually in network distribution is voltage imbalance which it is possible to take positive steps of losses reduction with adjusting it1 . Electrical power losses appear from load imbalance in distribution networks. These networks have various loads; industrial, domestic, commercial and the biggest portion of them one-phase loads12. Increasing in loss, energizing of neutral point of network, warming electrical motors and transformers and saturation of magnetic cores are some examples of load imbalance adverse results13. European standards, define the voltage unbalanced factor Voltage Unbalance Factor (VUF) as the ratio of negative voltage sequence (V–) to positive voltage sequence (V+) as shown in relation 5. Positive, zero and negative sequence of voltage are converted to Va , Vb and Vc which are three-phase line voltages as shown in relation 6 and V+, V0 and V- are the voltage elements of positive, zero and negative sequences.

$$VUF(\%) = \frac{V^-}{V^+} \qquad (1)$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} V^0 \\ V^+ \\ V^- \end{bmatrix} \qquad (2)$$

(iii) The Usual Methods of Modifying Voltage Imbalance in Distribution Systems Containing a Photovoltaic System

Problems casing voltage imbalance are divided in two categories; structural and operational factors. Three methods will be discussed in this section to improve current. The first of all is increasing of feeder cross section. This leads voltage sag reduction in feeder, so causes a low difference in three-phase voltage amplitude at the end of a feeder. Results of statistical studies are shown in Figure 6 for two different cross sections, 70 and 95 mm. As can be seen, Voltage Unbalance (VU) is decreased from 1.84 to 1.56% in the feeder terminal. The second effective method is to install switched capacitors in low pressure feeders. Based on IEEE guideline for using parallel power capacitors, in distributed uniform loads, the capacitor must be installed at 2/3rd distance to the distribution transformer. It is essential to note that if a three-phase capacitor is installed on a low pressure feeder, voltage imbalance will remain the same. But if three one-phase



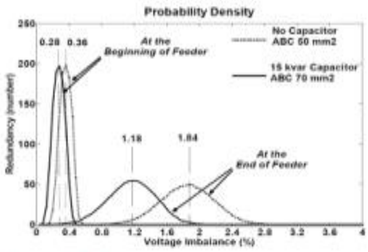


Figure 6 Probability density function of the feeder end a) the increase of cross-section, b) capacitor installation, c) the both combination a&b.

switching capacitors are used while only an one-phase capacitor is connected to the phase in which voltage amplitude is lower than 0.95 pu, if correct instruction is used to adjust the capacitor, voltage profile on that phase can be reduced and reached to an amplitude near to voltage amplitude of other phases. In this case, the voltage imbalance can be improved as well. Monte Carlo results for these materials are shown in Figure 3 in part b and it shows while a capacitor 15 KVAR with the described features is installed at 2/3 of feeder length from its beginning, VU decreases from 0.36% to 0.28% in the beginning of the line and from 1.84% to 1.41% in the end of the line. The same methods could be used to find the best place for capacitor installation. The last method to improve current is a combination of the two previous ways, the capacitor installation and the increase of feeder cross-section. VU improvement in this method has remarkable results compared to using these methods separately. In the examined case, VU has been decreased from 1.84% to 1.18% at the end of the feeder which is shown in Figure 3 in part c.

(iv) PV-DVR Structure to Decrease Voltage Imbalance Factor

It is expected that in unbalanced network, consumers would not suffer by using this structure. According to the above explanation, the bus bar number 8 in Figure 7 is considered as the feeding location of PV-DVR system. Now for comparison, at first an infinite bus bar that has a voltage imbalance and is representative of an unbalanced distribution network is connected to a set of photovoltaic system and DVR. It appears that the balanced load which is located after this structure doesn't recognize the source to have any imbalance. However, two phases of three phase source three phases have about 10% voltage imbalances. As it could be seen in Figures 8 and 9, voltage wave form in bus number 13 has the voltage imbalance of 8% and after using the PV-DVR system, the voltage imbalance level decreases to zero. It is noteworthy that the above system has an ability to modify voltage imbalance up to 10%

For proposed network, Fast Fourier Transform (FFT) analysis is done. Therefore harmonic load flow illustrates. The suggested photovoltaic system using PV-DVR is acceptable from harmonic distortion point of view.

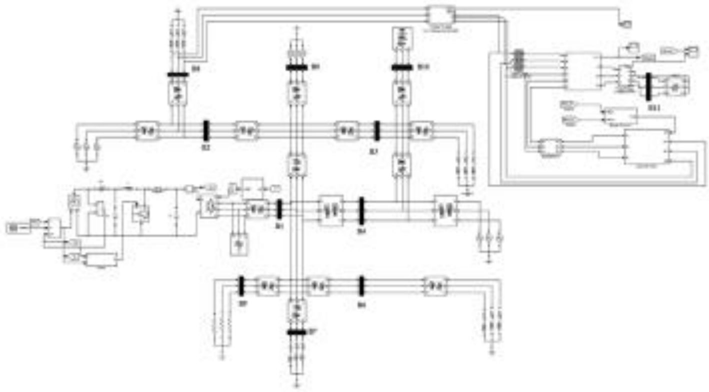


Figure 7. The connection of PV-DVR system to a typical distribution network.

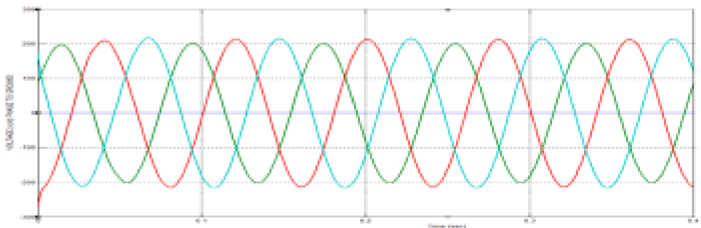


Figure 8. Unbalanced supply voltage waveform before the connection of PV-DVR system to the typical distribution network.

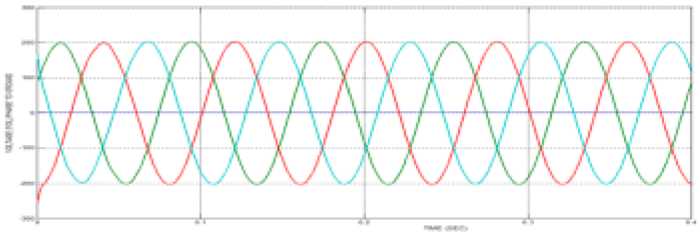


Figure 9 Balanced load voltage waveform after the connection of PV-DVR system to the typical distribution network.

For this aim, Total Harmonic Distortion (THD) formula is used according to relation (3):

$$THD_F = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots}}{V_1} \quad (3)$$

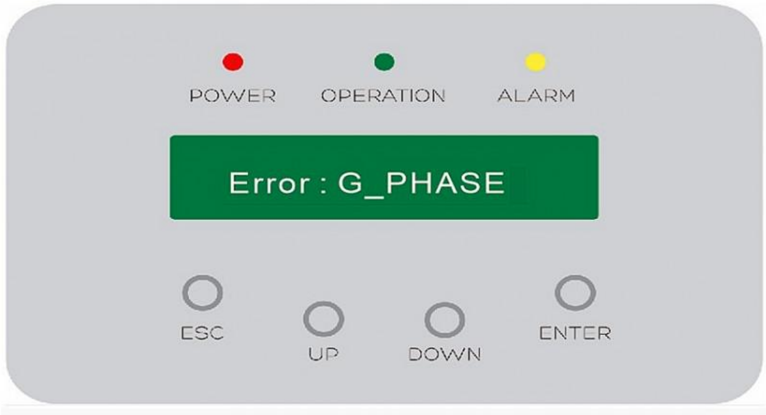
In relation (3), V_n , n = 1,2,3,… is the RMS voltage of n^{th} harmonic and n = 1 is fundamental frequency 15. THD is obtained around 2.27% that is good value for PV-DVR system in comparison with 5% allowable standard value.

Phase Voltage Imbalance at in PV

In PV systems, there can be errors caused by problems on the grid side. As an important operating function of a solar PV system and the grid, inverters are very sensitive to grid problems and will respond quickly. Among them, grid imbalance faults, although rare, can easily affect inverters, PV systems and sometimes even loads. In this Solis seminar, we will share information on "grid unbalanced" or G-PHASE errors that appear in PV systems and their solutions.

Fault Description

On start-up, Soils inverter will detect the status of the grid. If the grid phase is unbalanced, the inverter will disconnect itself from the grid and display the "G_PHASE" error.



Causes of "G-PHASE" Errors

1. Voltage imbalance on the grid side

Grid unbalanced is an important issue that causes this alarm for the inverter because the inverter will monitor the grid voltage in real time figure 1. When the three-phase waveform of the grid is abnormal, the inverter will immediately give feedback and disconnect from the grid.

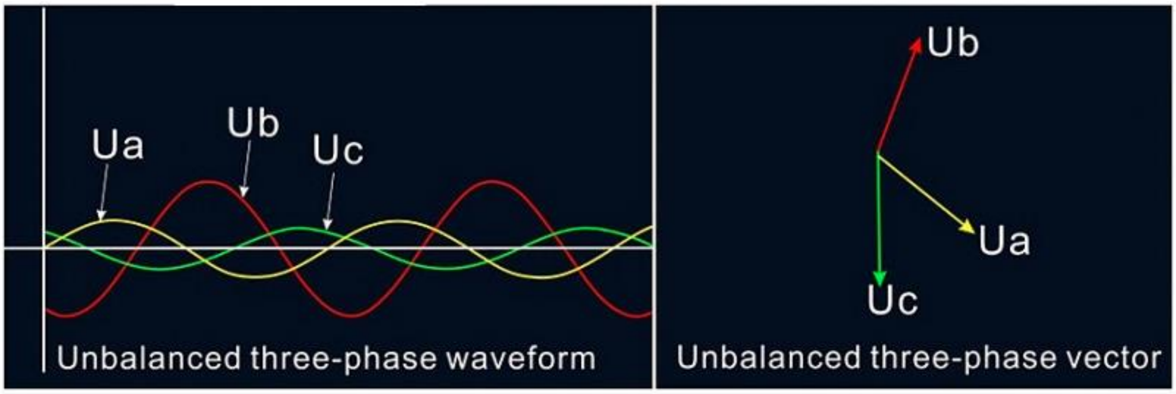


Figure 1 Waveform diagram when the power grid is unbalanced

2. Large-scale equipment is in use, which has an impact on the grid and causes the grid to be unstable

For PV systems installed in industrial areas, inverters are more prone to alarms from the grid, such as grid overvoltage, grid unbalanced, and grid imbalance. These are all because the operation of large current equipment will affect the operation of the inverter through the grid.

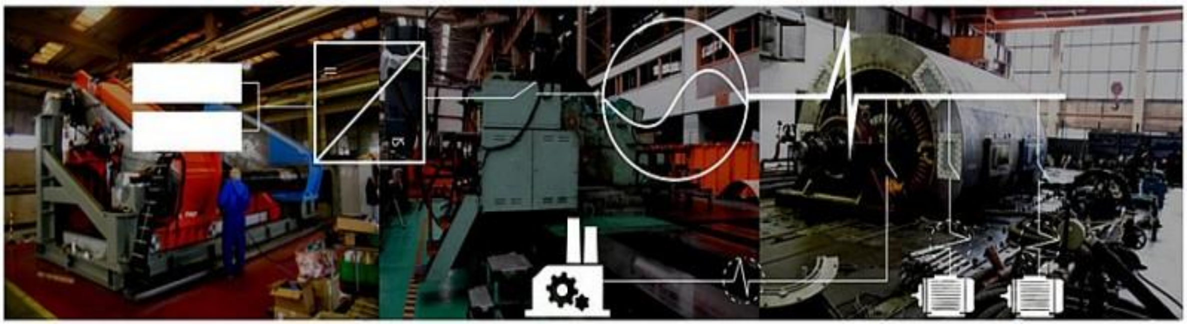


Figure 2. The grid problems caused by various load shocks

Solution：
Use an oscilloscope to check whether the three-phase voltage and waveform of the grid are normal. If not, record the waveform and report it to your local Solis technical team for technical support.

Possible Inverter Related Causes

1. The AC cable is incorrectly connected
During the installation process, errors can be caused by cables being incorrectly connected which causes phase unbalanced in the power injection process.

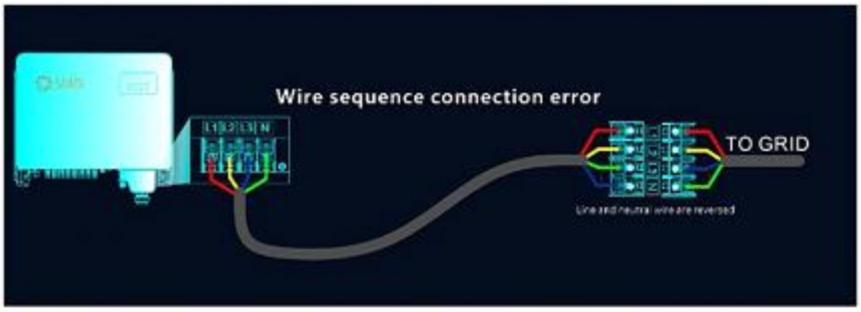


Figure 3. Wire sequence connection error

Solution：
Reconnect the AC cable and make sure that the wiring sequence is correct.

1. ***The AC wire used in the PV system is unsuitable***

If an unsuitable cable is selected during the design process, such as inferior AC cable made from low grade material or with a small diameter this can cause problems. The system will be in contact with the metal of the cable due to the current heating effect during long-term operation of the system. The film is deformed and blackened, and the impedance is significantly different, which will cause the three-phase voltage to appear unbalanced and cause the inverter to alarm.

Solution：
For correct selection of cables and specifications, please refer to the manual provided with your Solis inverter, which contains detailed cable recommendations.

2. ***The AC terminal of the inverter is in poor contact***

If there is a problem with the AC terminal of the inverter, such as loose lead wire, poor lead contact, etc., this alarm will also appear. Our suggestion is to replace the AC terminal of the inverter. Your local Solis service team can provide support and advice on this.

Summary

G_PHSAE error is an uncommon type of problem, but it will still cause system shutdown and affect power generation. So, when this fault occurs in a solar PV system, it needs to be rectified in time to minimize system downtime.