Solar Power System
An Introductory Guidebook

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Ministry of Industries & Production
Government of Pakistan
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1.1 Introduction to SMEDA

The Small and Medium Enterprises Development Authority (SMEDA) was established in October 1998 with an objective to provide fresh impetus to the economy through development of Small and Medium Enterprises (SMEs).

With a mission "to assist in Employment Generation and Value Addition to the national income, through development of SME sectors, by helping increase the number, scale and competitiveness of SMEs", SMEDA has carried out 'sectoral research' to identify Policy, Access to Finance, Business Development Services, strategic initiatives and institutional collaboration & networking initiatives.

Preparation and dissemination of prefeasibility studies in key areas of investment has been a successful hallmark of SME facilitation by SMEDA.

Concurrent to the prefeasibility studies, a broad spectrum of Business Development Services is also offered to the SMEs by SMEDA. These services include identification of experts and consultants and delivery of need-based capacity building programs of different types in addition to business guidance through help desk services.

For more information on services offered by SMEDA, please contact our website: www.smeda.org

1.2 Industry Support Program

In order to enhance competitiveness of SMEs and achieve operational excellence, SMEDA established an Industry Support Cell (ISC) for provision of foreign technical support and knowledge transfer in collaboration with International Development Organizations. SMEDA's Industry Support Program (ISP) initially launched with Japan International Cooperation Agency (JICA) and actively engaged in reducing energy inefficiencies and improving production and quality of products with the support of Japanese Experts. Later on, similar activities with other international partner organizations like German Corporation for International Cooperation (GIZ), Training and Development Centers of the Bavarian Employers' Association (bfz), Germany, and United Nations Industrial Development Organization (UNIDO) were also successfully implemented.

Pakistan has a huge solar potential considering the irradiation across the country which is around 4.5-7.0 kWh/m²/day. The total estimated potential of solar power in Pakistan is around 2900GW and its effective use will help in achieving industrial growth and becoming global competitive by reducing the energy cost.

2. Introduction of Solar Cells

Solar Cells are semiconductor devices that convert sunlight into direct current (DC) electricity. Sunlight contains photons or "packets" of energy sufficient to create electron-hole pairs in the n and p regions. Electrons accumulate in the n-region and holes accumulate in the p region, producing a potential difference (voltage) across the cell. When an external load is connected, the electrons flow through the semiconductor material and provide current to the external load. The electricity generated can be either stored or used directly, fed back into grid line.

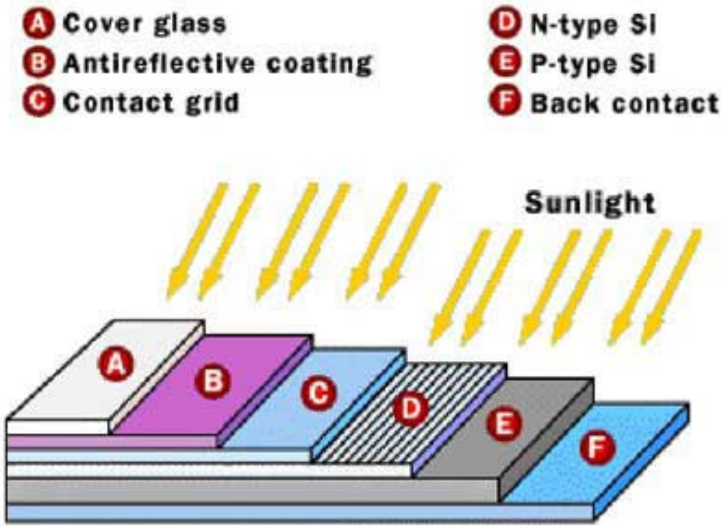


Fig 1. Structure of solar cell

2.1 Difference between Solar Cell, Panel, and Array

Solar cells are connected electrically in series and/or parallel circuits to produce higher voltages, currents and power levels.

Solar panel consist of solar cells circuits sealed in an environmentally protective laminate, and are the fundamental building blocks of solar systems.

A solar array is the complete power-generating unit, consisting of any number of solar panels.

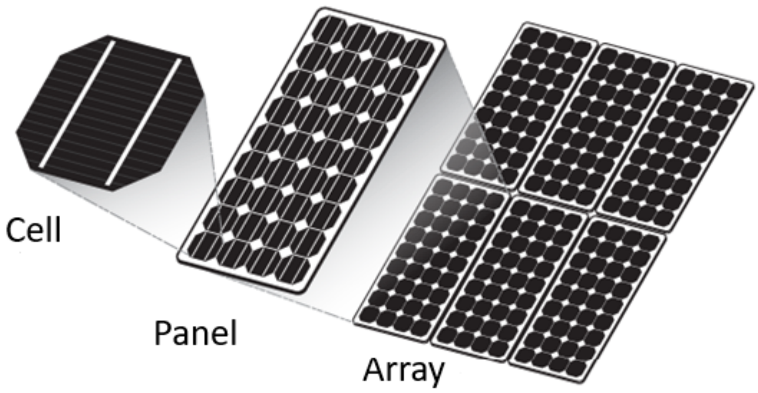


Fig.2 Cell, Panel and Array

2.1.1 Solar Cell

Solar cells are typically 100 cm^2 to 225 cm^2 in size. The usable voltage from silicon solar cells is approximately 0.5 V to 0.6 V. Terminal voltage is only slightly dependent on the intensity of light radiation but the current increases with light intensity. For example, a 100 cm^2 silicon cell reaches a maximum current of approximately 2 A when radiated by 1000 W/m^2 of light.

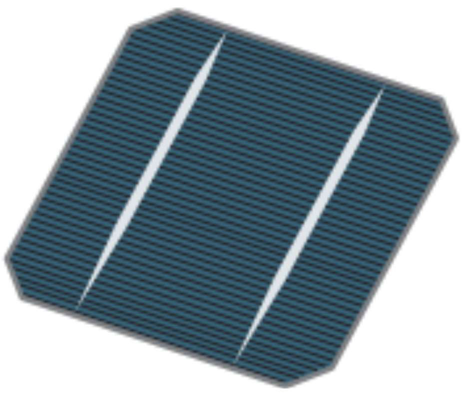


Fig 3. Solar Cell

Individual solar cells are typically only a few inches in diameter, but multiple cells can be connected to one another in panel, panels can be connected in arrays, and arrays can be connected in very large systems. This enables solar cells to be combined in scale to produce large, multi-MW central station power generation facilities.

2.1.2 Solar Panel

To produce a larger voltage, a number of pre-wired cells in series, all encased in tough, weather-resistant package, to form a panel. A typical solar panel may have 36, 54, 72, or 96 cells in series. Multiple panels can be wired in series to increase voltage and in parallel to increase current.

Fig. 4 Solar panel

2.1.3 Solar Array

A solar array consists of a number of panels that have been wired together in a series and/ or parallel to deliver the voltage and amperage a particular system requires. An array can be as small as a single pair of panel, or large enough to cover acres. A solar array is the complete power-generating unit, consisting of any number of solar panels. When installed at a site, solar panels are wired together in series to form strings.

Fig.5 Solar Array

3 What is Solar Power System?

Solar power system is one of renewable energy system which uses solar panels to convert sunlight into electricity. Solar power system is very reliable and clean source of electricity that can suit a wide range of applications such as residence, industry, agriculture, livestock, etc.

The solar panel collects energy from the sun and converts it to electrical energy through the photovoltaic process. Of course, the solar panel will not produce the specified power output all of the time. For example, if there is 4 hours of peak sun during a given day, a 100 W panel will produce 4 x 100 W = 400 Wh of energy excluding efficiency of panel. For the hours that the sun is not peak, the output will depend on the percentage of peak sun and is less than the specified output. A system is typically designed considering the annual of average peak sun per day for a given geographical area.

3.1 Types of Solar Energy Systems

Solar Energy Systems can be classified based on the end-use application of the technology. Depending on the system configuration, we can distinguish following three main types of solar systems:

- OFF Grid System
- ON Grid System
- Hybrid system

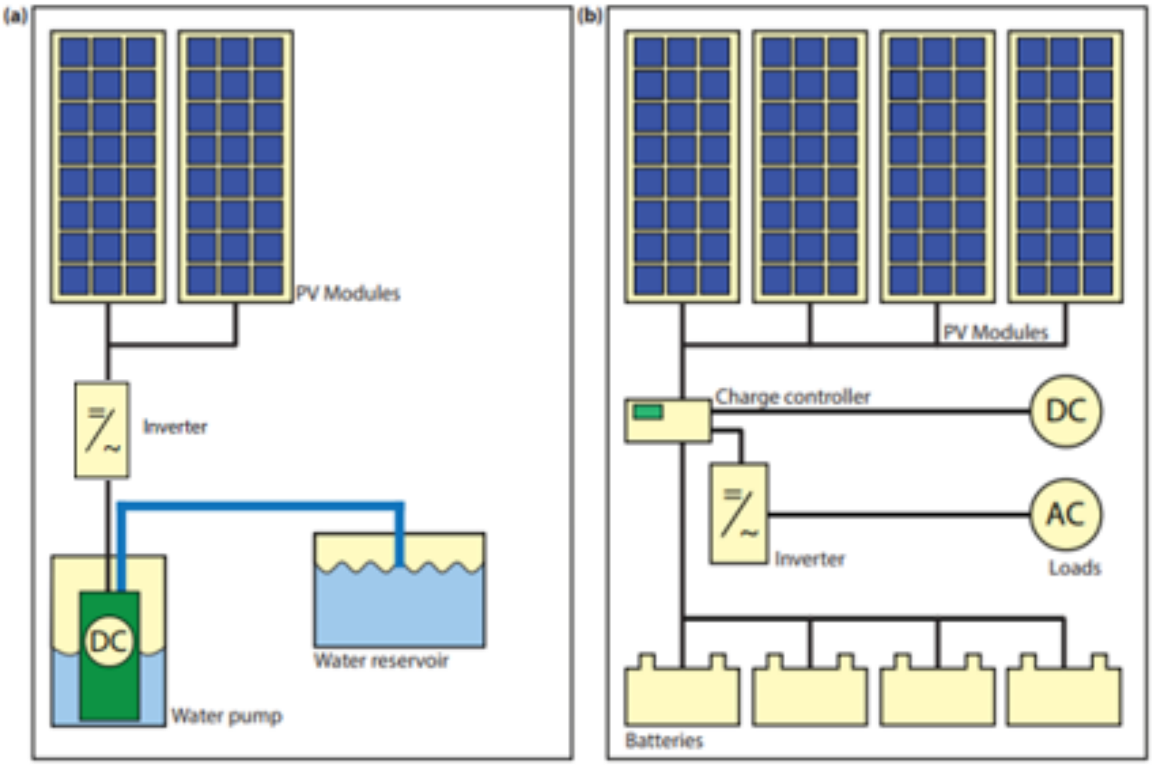
The basic solar system principles and elements remain the same. Systems are adapted to meet particular requirements by varying the type and quantity of the basic elements.

3.1.1 OFF Grid System

Off-grid system can generate the power and run the appliances by itself. Off-grid systems are suitable for the electrification of small community and is viable for the remote areas in the countries where they do have little or no access to the electricity because of the distinct living and spread population in the vast area.

This kind of system uses batteries to store electricity produced by panels. There is no connection to the utility power grid so a building is completely dependent on Solar System. This type of system is more complicated and expensive.

The Off Grid system consists of solar panels, which are connected with charge controller to control the panel’s current and voltage.



Off Grid System Without Batteries	Off Grid System With Batteries

Fig.6 Schematic Representation of OFF Grid System

3.1.2 ON Grid System

On Grid systems have become increasingly popular for building integrated applications. As illustrated in Fig. 7, the system consists of solar panels directly feed to an inverter and the inverter is connected to an Electricity Transmission and Distribution System (referred to as the Electricity Grid) such that the system can draw on the grid's reserve capacity in times of need, and feed electricity back into the Grid during times of excess production.

Solar energy system owners get paid for the electricity they add to the grid through net metering. For example, a solar system on a residential customer's roof may create more electricity than the home consumes during daylight hours. If the home is net-metered, the electric meter will run backwards to provide a bill against the amount of electricity used at night or during other times when the home's electricity consumption exceeds the system's output. Only 20-40% of a solar energy system's output ever makes it into the grid, and this solar electricity is used to power local customers' loads.

For more details and requirements of Net metering, visit National Electric Power Regulatory Authority (nepra) website: nepra.org.pk

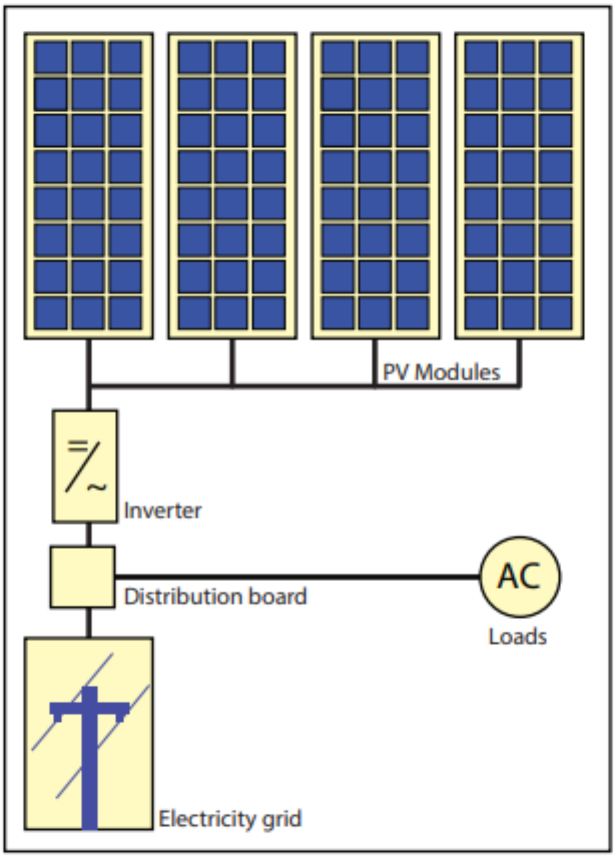


Fig.7 Schematic representation of an On Grid System

3.1.3 Hybrid System

Solar energy systems generate power in the same manner that on-grid solar systems do, but also store energy in specific hybrid inverters and batteries for later use.

Hybrid solar system generate power in the same way that ON Grid system do, but it also store energy in specific hybrid inverters and batteries for later use. This ability to store energy enables most hybrid systems to also operate as a backup power supply during a blackout, similar to a UPS system. Traditionally the term hybrid referred to two generation sources such as wind and solar, but in the solar world, the term 'hybrid' refers to a system which uses a combination of solar and batteries that can interact with the electricity grid.

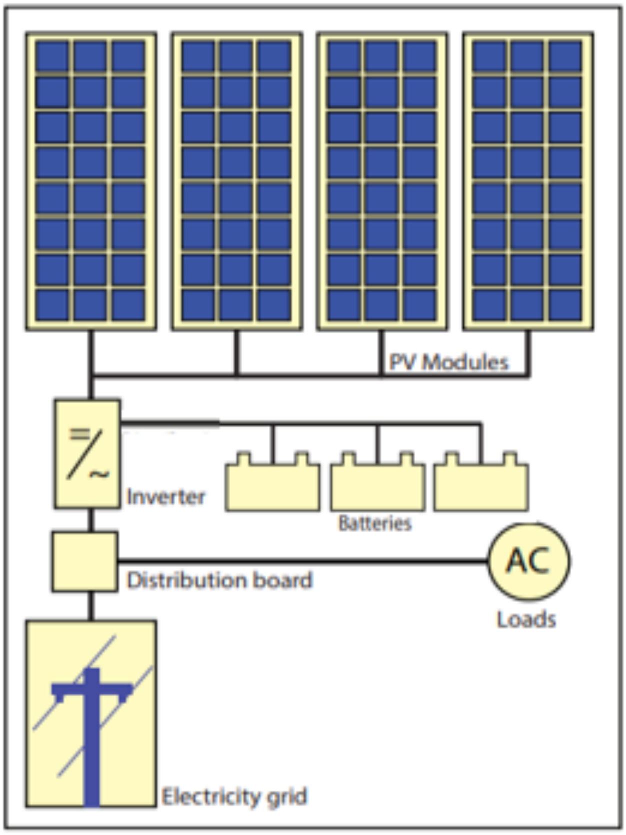


Fig.8 Schematic representation of a hybrid solar system

The Charge Controller conditions the DC electrical voltage and current produced by the Solar Panel to charge a battery. The battery stores the DC electrical energy so that it can be used when there is no solar energy available (night time, cloudy days etc). DC loads can be powered directly from the Solar Panel / Battery. The inverter converts the DC power produced by the Solar Panel stored in the battery into AC power to enable powering of AC loads. Currently most inverters have built in charge controller so there is no need to install separate charge controller in system.

4. Solar System Components

1- Solar Panels
2- Array mounting racks
3- Combiner box
4- Surge protection (often part of the combiner box)
5- Inverter
6- Batteries (optional)
7- Bidirectional Meter (In case of net metering)

4.1 Types of Solar panels

Solar Panels can be classified into first, second and third generation.

The first generation solar panels also called conventional, traditional or wafer-based cells—are made of crystalline silicon, the commercially predominant solar cell technology that includes materials such as poly silicon and mono crystalline silicon.

Second generation solar panels are thin film solar panels that include amorphous silicon, Cadmium Telluride (CdTe) and Copper Indium Galium Selenide (CIGS) panels and are commercially significant in utility-scale solar power stations, building integrated with solar system or in small standalone power system.

The third generation of solar panels includes a number of thin-film technologies often described as emerging photovoltaic—most of them have not yet been commercially applied and are still in the research or development phase. 3rd Generation solar panels are Bio-hybrid solar cells, Nano crystal based solar cells, Polymer based solar cells, Dye sensitized solar cells, concentrated solar cells.

4.1.1 1st Generation Solar Panels

1st generation solar panels are made of mono crystalline silicon or polycrystalline silicon and are most commonly used in conventional surroundings.

4.1.1.1 Mono crystalline Solar Panels

This type of solar panels (made of mono crystalline silicon) are the purest one. They are easily recognized from the uniform dark look and the rounded edges.

Due to the purity of the silicon, this type of solar panel has one of the greatest efficiency rates, with the newest ones reaching above 20%. Mono crystalline panels have a high power output, occupy less space, and last the longest.

Another advantage to consider is that they tend to be slightly less affected by high temperatures compared to polycrystalline panels.

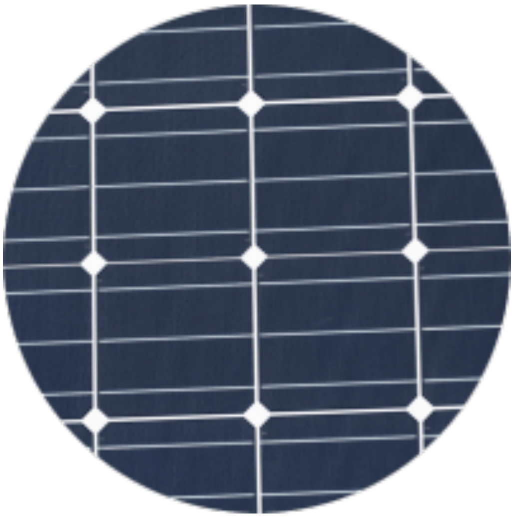


Fig.9 Monocrystalline solar panel

4.1.1.2 Polycrystalline Solar Panels

They are easily recognizable, square-shaped, its angles aren't trimmed, and it has a blue, speckled appearance. They are made by melting raw silicon, which is a faster and cheaper process than that used for mono crystalline panels.

Because of the cheaper process final price is lower but also have the lower efficiency (around 15%) and space efficiency, and a shorter lifespan since they are affected by hot temperatures to a greater degree.

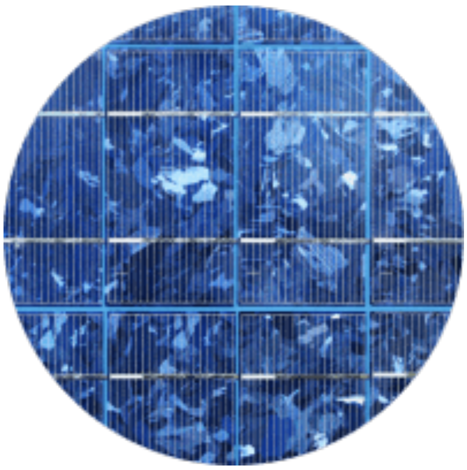


Fig.10 Polycrystalline solar panel

4.1.2 2nd Generation Solar panel

These panels consist different types of thin film solar cells and are mainly used for solar power stations, integrated in buildings or smaller solar systems.

4.1.2.1 Amorphous Silicon Solar panel (A-Si)

This type of solar panel uses a triple layered technology and are manufactured by placing one or more films of photovoltaic material (such as silicon, cadmium or copper) onto a substrate. These types of solar panels are the easiest to produce and economies of scale make them cheaper than the alternatives due to less material being needed for its production. They are also flexible—which opens a lot of opportunities for alternative applications—and is less affected by high temperatures.

The main issue is that they take up a lot of space which makes them unsuitable for residential installations. Moreover, they carry the shortest warranties because their lifespan is shorter than the monocrystalline and polycrystalline types of solar panels.

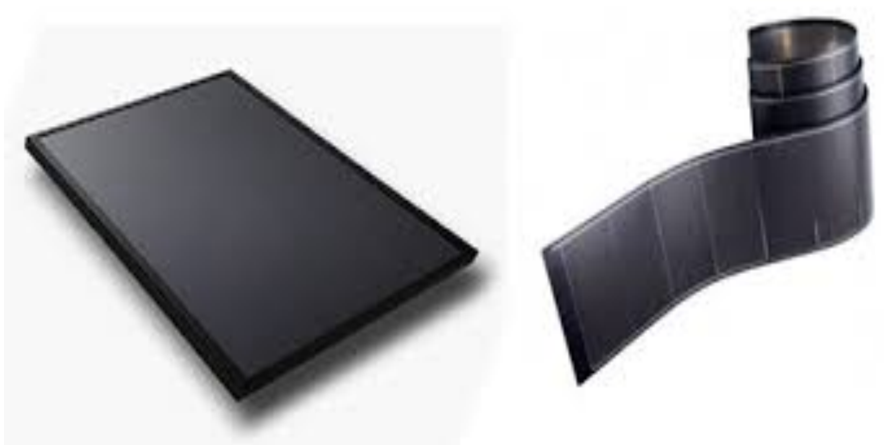


Fig.11 Amorphous solar panel

4.1.3 3rd Generation Solar Panels

3rd generation solar panels include a variety of thin film technologies and multi junction cells but most of them are still in the research or development phase. Some of them generate electricity by using organic materials, others use inorganic substances (Cadmium Telluride for instance).

4.1.3.1 Bio hybrid Solar panel

These panels are in research phase and the idea behind the new technology is to take advantage of the photosystem and thus emulate the natural process of photosynthesis. The greatest advantage the bio hybrid solar cell has is the way it converts solar energy to electricity with almost 100% percent efficiency. Cost is also a lot less for producing bio hybrids because extracting the protein from spinach and other plants is cheaper compared to the cost of metals needed to produce other solar cells. While the efficiency of the biohybrid cells are much greater they also have many disadvantages. For instance, traditional solar cells produce more power than those currently being achieved by biohybrid cells. The lifespan of biohybrid solar cells is also really short, lasting from a few weeks to nine months. The durability of the cells proves to be an issue, compared to current solar cells can work for many years.

4.1.3.2 Concentrated Solar panels

Concentrated solar panels generate electrical energy just as conventional solar systems do. Those multi-junction types of solar panels have an efficiency rate up to 41%, which, is the highest among other solar systems.

Fig.12 Concentrated Solar panel

4.1.4 Latest types of solar panels commercially available

1- Half Cut Mono PERC (Passivated Emitter and Rear Contact)
2- Half Cut Poly PERC (Passivated Emitter and Rear Contact)
3- Bi facial solar panel

4.1.4.1 Half Cut Mono PERC

Half-cut cell mono PERC solar panel have solar cells that are cut in half, which improves the solar panel's performance and durability. PERC stands for "Passivated emitter and rear contact" or "rear cell". Solar panels built with PERC cells have an additional layer on the back of the traditional solar cells. This additional layer allows more sunlight to be captured and turned into electricity, making PERC cells more efficient than traditional cells. Conventional mono crystalline solar panels generally have 60 to 72 solar cells, so when those cells are cut in half, the quantity of cells increases. Half-cut solar panels have 120 to 144 cells and are generally made with PERC technology, which offers higher panel effectiveness.

Smaller cells experience reduced mechanical stresses, reaching a decreased opportunity for cracking.

Fig.13 Half Cut Mono PERC

4.1.4.2 Half Cut Poly PERC

Half-cut poly PERC solar panels have higher output ratings and are more reliable than conventional polycrystalline solar panel.

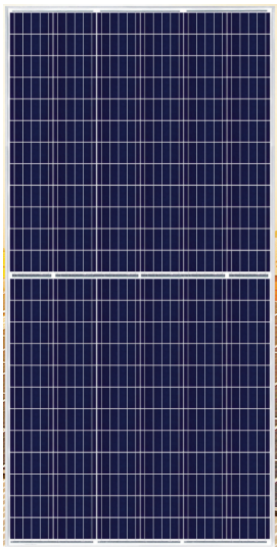


Fig.14 Half Cut Poly PERC

4.1.4.3 Bi Facial Solar panel

Bifacial solar panels produce solar power from both sides of the panel. Bifacial panel come in many designs. Some are framed while others are frameless. Some are dual-glass, and others use clear black sheets. Mostly use mono crystalline cells, but there are polycrystalline designs as well.

These solar panels are more productive than other solar panels but use the same PERC technology.

Fig.15 Bi Facial Solar panel

4.2 Types of Mounting for solar system

Proper choice of the mounting racks (also called: mounting structures) for solar system project is very essential in terms of the overall efficiency and lifetime of solar panels. Solar panels need to be secured, mounted and tightened on a very stable and durable structure, protecting the array against impacts from wind, hail, rain and even minor earthquakes. Arrays are most commonly mounted on roofs or on steel poles set in concrete. In certain applications, they may be mounted at ground level or on building walls. Solar panels can also be mounted to serve as part or all of a shade structure such as a patio cover.

There are five basic types of mounting structures of which four are fixed-angle types and one variable-angle type.

- Roof Mounted Racks
- Ground Mounted Racks
- Top-of-pole Mounted Racks
- Side-of-pole Mounted Racks
- Tracking System Mounted Racks

There are many types of mounts available in Pakistan, but the most common are ground mounted racks and top of the pole mounted racks.

Ground mounted racks further categorized into three types:

1- Fixed Mount
2- Tilt Legs Mount
3- Ballasted Mounts

4.2.1 Fixed Mount

These are simple fixed metal frames that are embedded in concrete or held in place by bolts drilled in the roof.

Fig.16 Fixed Mounting

4.2.1.1 Advantages of Fixed mount

1- Sturdy under extreme weather conditions
2- Suitable for most flat roofs

4.2.1.2 Disadvantages of Fixed mount

1- Offers no tilt adjustment
2- Requires drilling on roof-top
3- May cause roof seepage and leakage problems in long run

4.2.2 Tilt Legs Mount

This is the most common type of mounting structure in Pakistan. Usually made from Anodized Aluminum Alloy or Galvanized Iron, it offers optimal tilt positioning for increased efficiency.

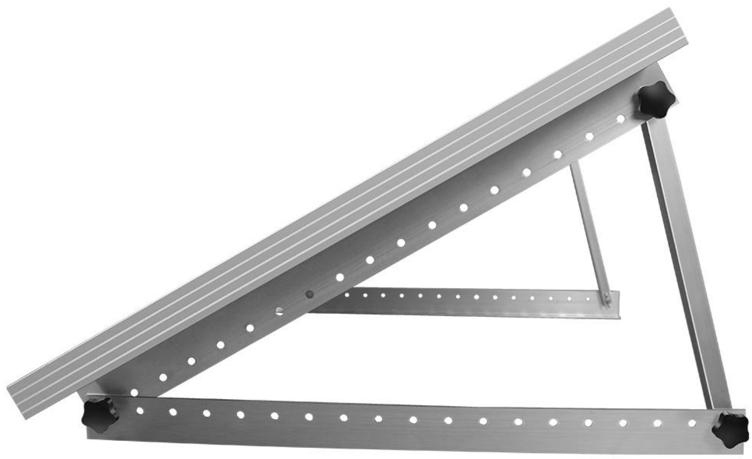


Fig.17 Tilt leg mount

4.2.2.1 Advantages of Tilt legs mount

1- Offers tilt adjustment
2- Suitable for most flat roofs
3- Sturdy and provides good wind loading

4.2.2.2 Disadvantages of Tilt legs mount

1- Requires drilling on roof-top
2- May cause roof seepage and leakage problems in long run

4.2.3 Ballasted Mounts

These are metal frames usually made from Galvanized Iron that are placed on the roof and held in place with weights made from concrete blocks. Ballasted mounts do not require roof penetrations, are faster and cheaper to install and allow for a panel tilt of up to 20 degrees for optimal solar exposure. However, this mount increases the load on your roof, has lower power density, and is less suitable for high-wind areas.

Fig. 18 Ballasted Mount

4.2.3.1 Advantages of Ballasted mounts

1- No drilling required
2- No chance of seepage, or leakage in the long run
3- Easier to replace, upgrade or remove

4.2.3.2 Disadvantages of Ballasted mounts

1- Can't be placed on slopes
2- Expensive due to pre-fabricated concrete blocks
3- Inadequate weight may cause damage in extreme weather conditions

4.2.4 Top of Pole mounted racks

Pole-mounted solar arrays can incorporate tracking devices that allow the array to automatically follow the sun. Tracked Solar arrays can increase the system's daily energy output by 25 percent to 40 percent. Despite the increased power output, tracking systems usually are not justified by the increased cost and complexity of the system. The advantage of pole mounting is that there is no need for creating a complicated foundation or level the land (necessary step for ballasted mounts). Instead just a simple steel pole with a concrete anchor is placed on the ground. This simple structure provides in general sufficient support to solar panels. In some cases, due to the unsuitable soil type or extreme weather conditions, special adjustments are required.

Fig.19 Top of Pole Mount

4.3 Combiner Box

A combiner box typically includes a safety fuse or breaker for wires and may include a surge protector. Wires from solar panels are run to the combiner box, typically located on the roof.

4.4 Lightning and Surge Protection

Surge protectors help to protect solar system from power surges that may occur if the solar system or nearby power lines are struck by lightning. A power surge is an increase in voltage significantly above the design voltage. Lightning (surge) arrestors are designed to absorb voltage spikes caused by electrical storms and effectively allow the surge to bypass power wiring.

4.5 Inverters

A solar inverter is one of the most important elements of the solar electric power system. It converts the direct current (DC) output of a solar panel into alternating current (AC). The inverter's DC voltage input window must match the nominal voltage of the solar array, usually 235V to 600V for systems without batteries and 12, 24 or 48 volts for battery-based systems.

Criteria for selecting an Inverter for solar system:

1- Identify the type of inverter according to solar system. It could be (OFF-Grid Inverter, ON Grid inverter, Hybrid inverter)
2- Rated output power
3- DC Voltage input
4- AC Power output
5- Surge capacity
6- Efficiency
7- Frequency and voltage regulations
8- Additional inverter features such as meters, indicator lights, and integral safety
9- Isolator
10- Warranty

4.6 Batteries

Batteries store direct current electrical energy for later use. Batteries also increase the complexity and cost of the system. Types of batteries commonly used in solar systems are:

- Lead-acid batteries
    - Flooded (Liquid vented)
    - Sealed (Valve-Regulated Lead Acid)
        - Absorbent glass mat
        - Gel cell
- Alkaline Batteries

    - Nickel-cadmium (Ni-Cd)

    - Nickel-iron

4.6.1 Lead-Acid Batteries

Lead-acid batteries are most common in solar systems in general and sealed lead acid batteries are most commonly used in grid-connected systems. Sealed batteries are spill-proof and do not require periodic maintenance. Flooded lead acid batteries are usually the least expensive but require adding distilled water at least monthly to replenish water lost during the normal charging process. There are two types of sealed lead acid batteries: sealed absorbent glass mat (AGM) and gel cell. AGM lead-acid batteries have become the industry standard, as they are maintenance free and particularly suited for grid-tied systems where batteries are typically kept at a full state of charge.

Fig. 20 Flooded lead acid battery

Fig. 21 Sealed lead acid battery

4.6.2 Alkaline Batteries

Because of their relatively high cost, alkaline batteries are only recommended where extremely cold temperatures (-50^{o}F or less) are anticipated or for certain commercial or industrial applications requiring their advantages over lead-acid batteries. Advantages of alkaline batteries are tolerance of freezing or high temperatures, low maintenance requirements, and the ability to be fully discharged or over-charged without harm.

Fig. 22 Alkaline battery (Ni-Cd)

4.7 Bidirectional Meter

A bi-directional meter works by measuring energy in two directions; how much energy you consume from the grid, and how much excess energy you export back to the grid.

5 Critical Factors To Be Considered

The first step in the design of a solar system is determining if the site you are considering has good solar potential. Following are the parameters that need to be considered:

- Mounting location
- Shading effect
- Orientation and tilt angle
- Precautions

5.1 Mounting Location

Solar panels are usually mounted on roofs. If roof area is not available, panels can be pole-mounted, ground-mounted, and wall-mounted or installed as part of a shade structure in some cases. A 10 m^2 area is required for the installation of a 1 kW solar system. If a house has a small roof area, solar panels with higher efficiency will be chosen.

5.2 Shading Effect

Solar arrays are adversely affected by shading. A well-designed solar system needs clear and unobstructed access to the sun's rays throughout the year. Even small shadows, such as the shadow of a single branch of a leafless tree can significantly reduce the power output of a solar panel. Several factors contribute to this issue, the most common cause of shade on a solar panel are:

1) Shade from neighboring trees and buildings in vicinity
2) Typical cloudy weather

3) Shade from adjacent solar panels. Keep in mind that an area may be unshaded during one part of the day but shaded at another part of the day.

5.3 Orientation and Tilt Angle

Solar panel placement and orientation are just as critical as the type of solar panel utilized in a particular location. In the northern hemisphere, the general rule for solar panel placement is, solar panels should face true south (and in the southern, true north). Usually this is the best direction because solar panels will receive direct light throughout the day. Solar panels face the correct direction and have an appropriate tilt will help ensure that they produce maximum energy as they are exposed to the highest intensity of sunlight for the greatest period of time. Tilt angle is the setting of the panels one needs to have to get the maximum radiance. Ideally the tilt angle is the latitude of the geographic location.

Generally, in Pakistan the yearly optimum tilt angle is found as 23°.

5.4 Precautions

Installation of the solar system requires some additional checks and precautions, which are listed below:

1- Solar panel mountings arrangement should be sturdy, long lasting, galvanized steel or aluminum channels.
2- Ensure work surfaces are free from oil, water, and other substances.
3- Solar panel cables should not be cut and twisted together for any kind of inter-connection.
4- Seal any holes on the rooftop, skylight, or ground level worksite. Prior assessment of the roof and the areas helps identify problematic areas.
5- Do not use panels with different ratings for a system in order to minimize power losses.
6- Gloves are a requirement for workers handling the panels. Wearing hats and keeping arms and legs covered while working should be mandatory.
7- Be cautious when wiring solar cells, the same way they handle main power lines. Circuit test device or meter can be used to ascertain all the circuits are de-energized before tapping them.
8- When Solar panel connectors or any wiring linked to the system are under load, you should never disconnect them.
9- All cables should be properly secured using properly sized ties, not tied with metal wire or ordinary string.
10- Current carrying cable from solar panels to inverter should be DC cable of proper rating, should have separate colors to identify positive/ negative, and should be in separate conduit.
11- The AC input /output of inverters should be properly protected by proper amperage circuit breakers.
12- If an inverter is mounted outdoors it has to be protected against rain and insulation. Avoid keeping the inverter under direct sunlight.