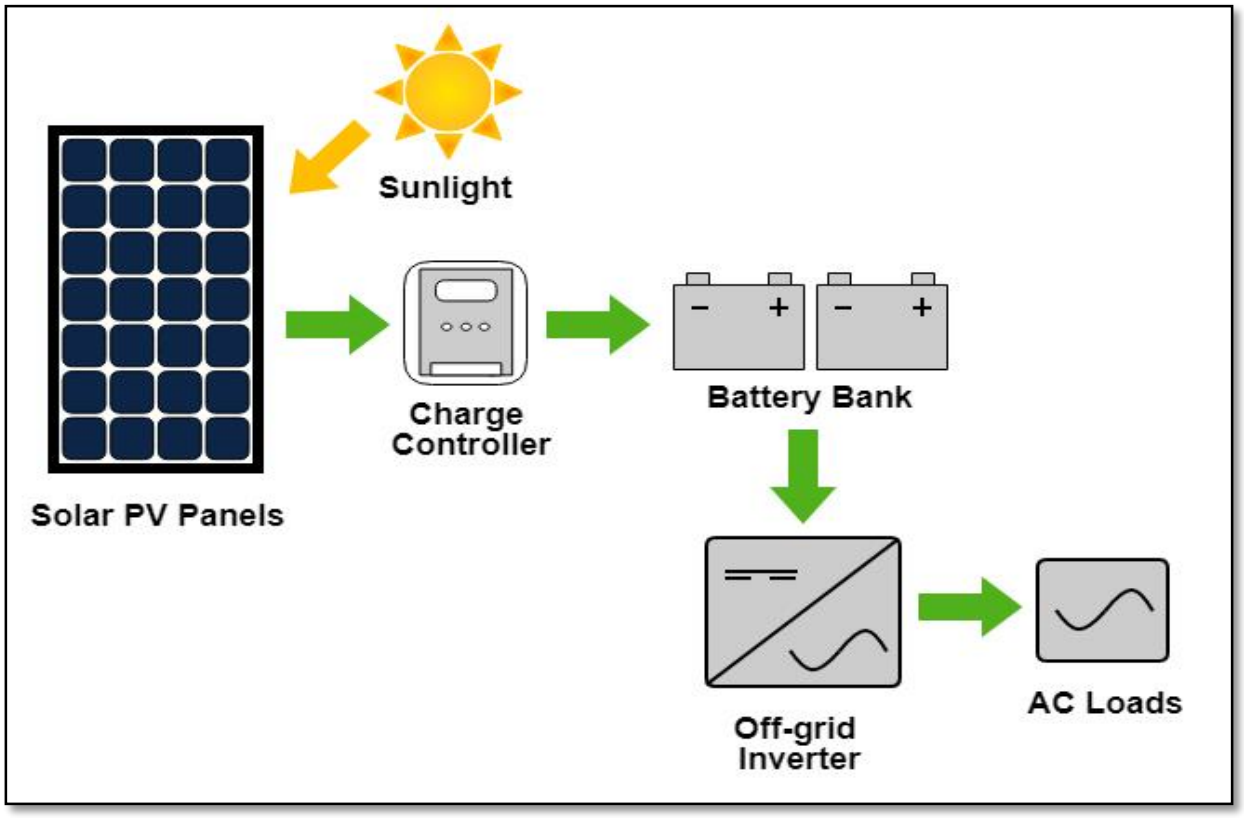
02.SOLAR PHOTOVOLTAIC SYSTEMS

❖ Solar Photovoltaic Systems :

Solar cells, also called photovoltaic (PV) cells, convert sunlight directly into electricity. PV gets its name from the process of converting light (photons) to electricity (voltage), which is called the PV effect.

The main components of a solar photovoltaic system are:

- PHOTOVOLTAIC ARRAY.
- BATTERY BANK.
- POWER CONDITIONING UNIT.
- DC AND AC DISCONNECT.
- MAIN PANEL (AC)
- ELECTRIC METER.



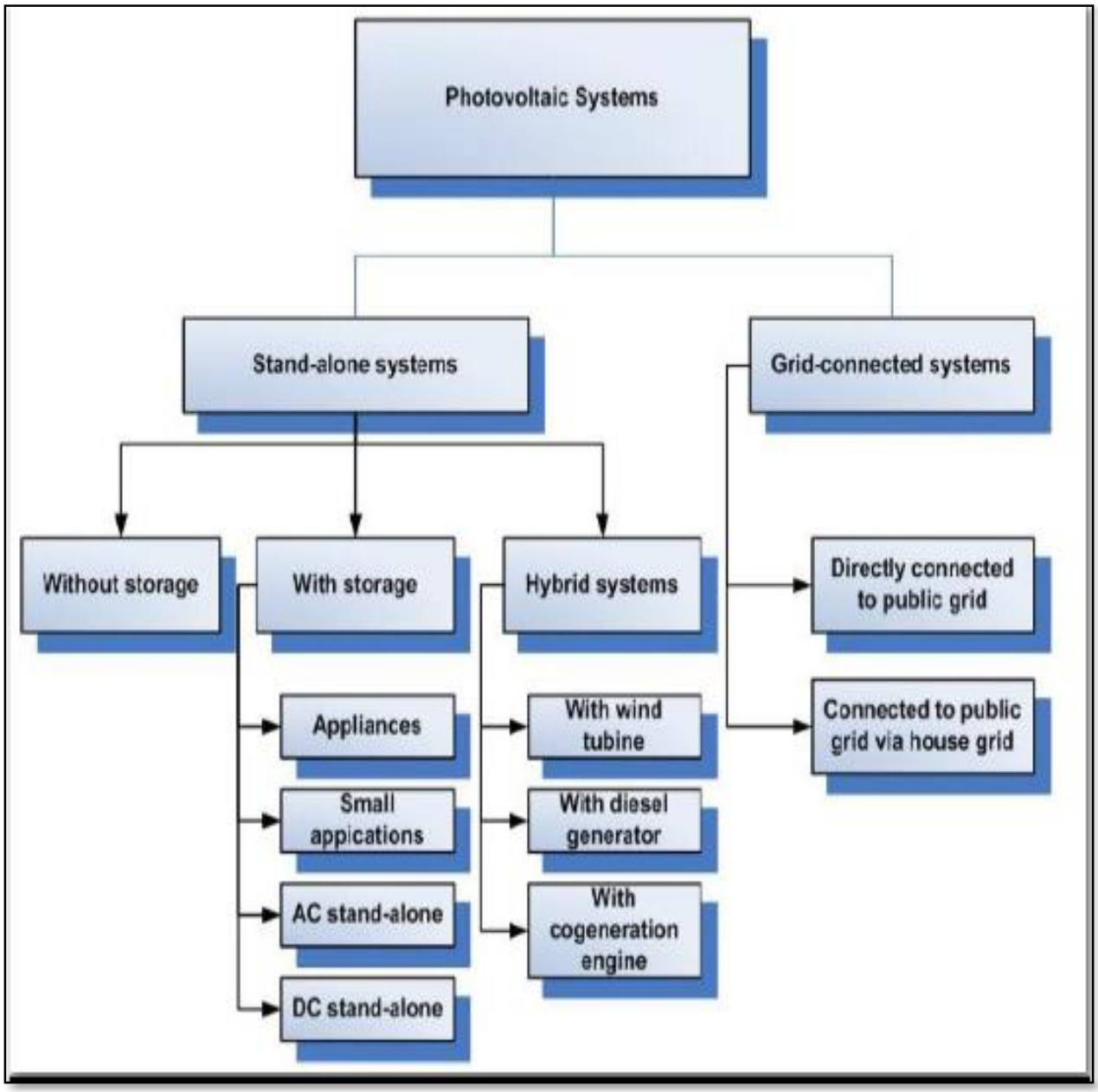
❖ Advantages:

- PV panels provide clean – green energy. During electricity generation with PV panels there is no harmful greenhouse gas emissions thus solar PV is environmentally friendly.
- Solar energy is energy supplied by nature – it is thus free and abundant!
- Solar energy can be made available almost anywhere there is sunlight
- Photovoltaic panels, through photoelectric phenomenon, produce electricity in a direct electricity generation way.
- Operating and maintenance costs for PV panels are considered to be low, almost negligible, compared to costs of other renewable energy systems.
- PV panels have no mechanically moving parts, except in cases of sun-tracking mechanical bases; consequently they have far less breakages or require less maintenance than other renewable energy systems (e.g. wind turbines)
- PV panels are totally silent, producing no noise at all; consequently, they are a perfect solution for urban areas and for residential applications.
- Because solar energy coincides with energy needs for cooling, PV panels can provide an effective solution to energy demand peaks – especially in hot summer months where energy demand is high.
- Residential solar panels are easy to install on rooftops or on the ground without any interference to residential lifestyle.

❖ Disdvantages:

- As in all renewable energy sources, solar energy has intermittency issues; not shining at night but also during daytime there may be cloudy or rainy weather.
- Consequently, intermittency and unpredictability of solar energy makes solar energy panels less reliable a solution.
- Solar energy panels require additional equipment (inverters) to convert direct electricity (DC) to alternating electricity (AC) in order to be used on the power network.
- For a continuous supply of electric power, especially for on-grid connections, Photovoltaic panels require not only Inverters but also storage batteries; thus increasing the investment cost for PV panels considerably.
- In case of land-mounted PV panel installations, they require relatively large areas for deployment; usually the land space is committed for this purpose for a period of 15-20 years – or even longer.
- Solar panels efficiency levels are relatively low (between 14%-25%) compared to the efficiency levels of other renewable energy systems.
- Though PV panels have no considerable maintenance or operating costs, they are fragile and can be damaged relatively easily; additional insurance costs are therefore of ultimate importance to safeguard a PV investment.

❖ Classification of Solar Photovoltaic systems:



❖ PV Cells:

- A photovoltaic cell (PV cell) is a specialized semiconductor diode that converts visible light into direct current (DC). Some PV cells can also convert infrared (IR) or ultraviolet (UV) radiation into DC electricity.
- Photovoltaic cells are an integral part of solar-electric energy systems, which are becoming increasingly important as alternative sources of utility power.
- The first PV cells were made of silicon combined, or doped, with other elements to affect the behavior of electrons or holes (electron absences within atoms).
- There are two basic types of semiconductor material, called positive (or P type) and negative (or N type). In a PV cell, flat pieces of these materials are placed together, and the physical boundary between them is called the P-N junction.
- The device is constructed in such a way that the junction can be exposed to visible light, IR, or UV. When such radiation strikes the P-N junction, a voltage difference is produced between the P type and N type materials. Electrodes connected to the semiconductor layers allow current to be drawn from the device.

❖ Types of PV Systems:

- Photovoltaic power systems are generally classified according to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads.
- The two principal classifications are grid-connected or utility-interactive systems and stand-alone systems. Photovoltaic systems can be designed to provide DC and/or AC power service, can operate interconnected with or independent of the utility grid, and can be connected with other energy sources and energy storage systems.

Stand-Alone Photovoltaic Systems

- Stand-alone PV systems are designed to operate independent of the electric utility grid, and are generally designed and sized to supply certain DC and/or AC electrical loads. These types of systems may be powered by a PV array only, or may use wind, an engine-generator or utility power as an auxiliary power source in what is called a PV-hybrid system. The simplest type of stand-alone PV system is a direct-coupled system, where the DC output of a PV module or array is directly connected to a DC load (Figure 3). Since there is no electrical energy storage (batteries) in direct-coupled systems, the load only operates during sunlight hours, making these designs suitable for common applications such as ventilation fans, water pumps, and small circulation pumps for solar thermal water heating systems. Matching the impedance of the electrical load to the maximum power output of the PV array is a critical part of designing well-performing direct-coupled system. For certain loads such as positive-displacement water pumps, a type of electronic DC-DC converter, called a maximum power point tracker (MPPT), is used between the array and load to help better utilize the available array maximum power output.

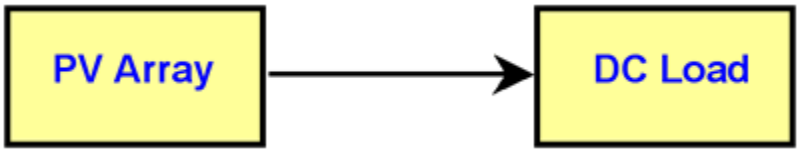


Figure 2. Direct-coupled PV system.

- In many stand-alone PV systems, batteries are used for energy storage. Figure 3 shows a diagram of a typical stand-alone PV system powering DC and AC loads. Figure 4 shows how a typical PV hybrid system might be configured.

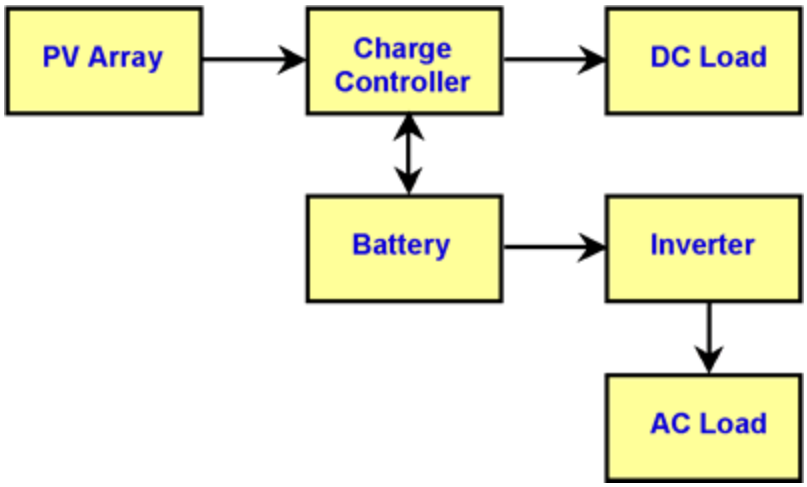


Figure 3. Diagram of stand-alone PV system with battery storage powering DC and AC loads.

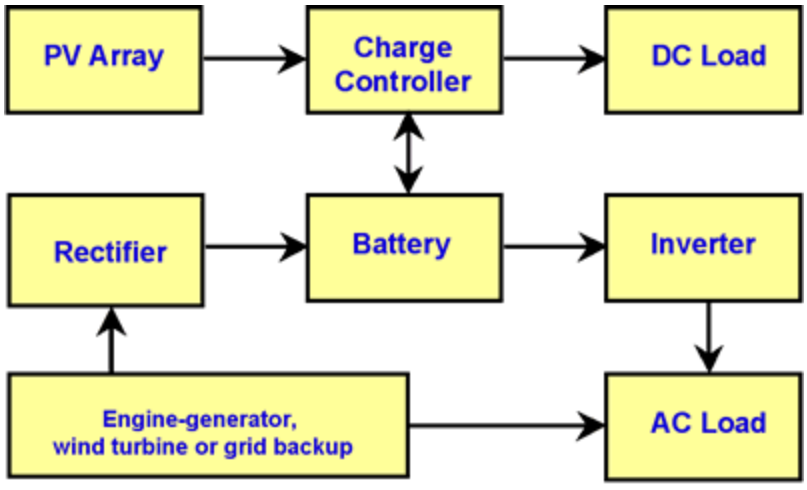
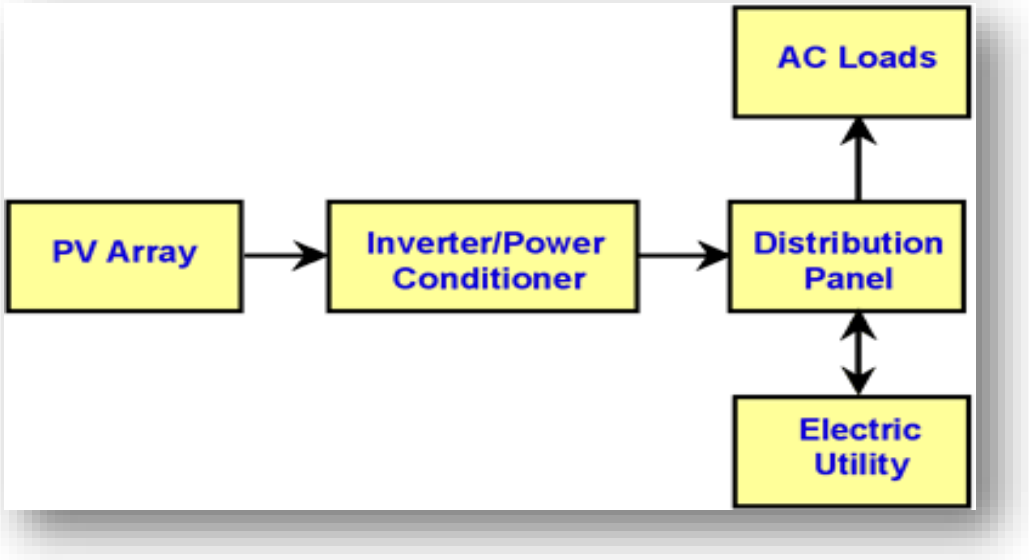


Figure 4. Diagram of photovoltaic hybrid system.

❖Grid-Connected System:

- Grid-connected or utility-interactive PV systems are designed to operate in parallel with and interconnected with the electric utility grid. The primary component in grid-connected PV systems is the inverter, or power conditioning unit (PCU).
- The PCU converts the DC power produced by the PV array into AC power consistent with the voltage and power quality requirements of the utility grid, and automatically stops supplying power to the grid when the utility grid is not energized.
- A bi-directional interface is made between the PV system AC output circuits and the electric utility network, typically at an on-site distribution panel or service entrance. This allows the AC power produced by the PV system to either supply on-site electrical loads, or to back-feed the grid when the PV system output is greater than the on-site load demand.
- At night and during other periods when the electrical loads are greater than the PV system output, the balance of power required by the loads is received from the electric utility This safety feature is required in all grid-connected PV systems, and ensures that the PV system will not continue to operate and feed back into the utility grid when the grid is down for service or repair.



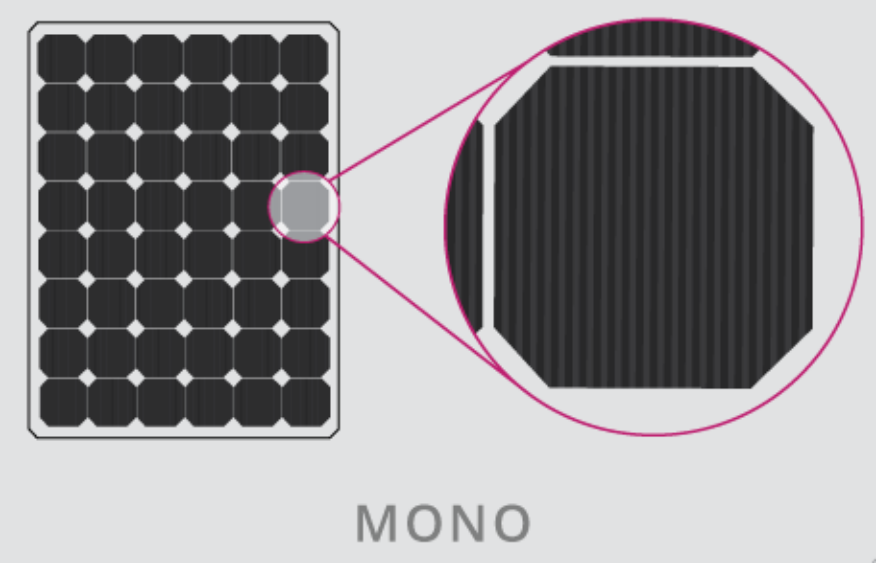
❖ SOLAR PANELS:

- Solar Panels are panels that are typically placed on a household's roof to absorb energy from the sun. The panels convert this energy (sunlight) into Direct Current electricity (DC electricity). This DC energy is then fed into the inverter.
- A number of solar panels working together is referred to as a Solar Array.

❖ Types of Solar Panels:

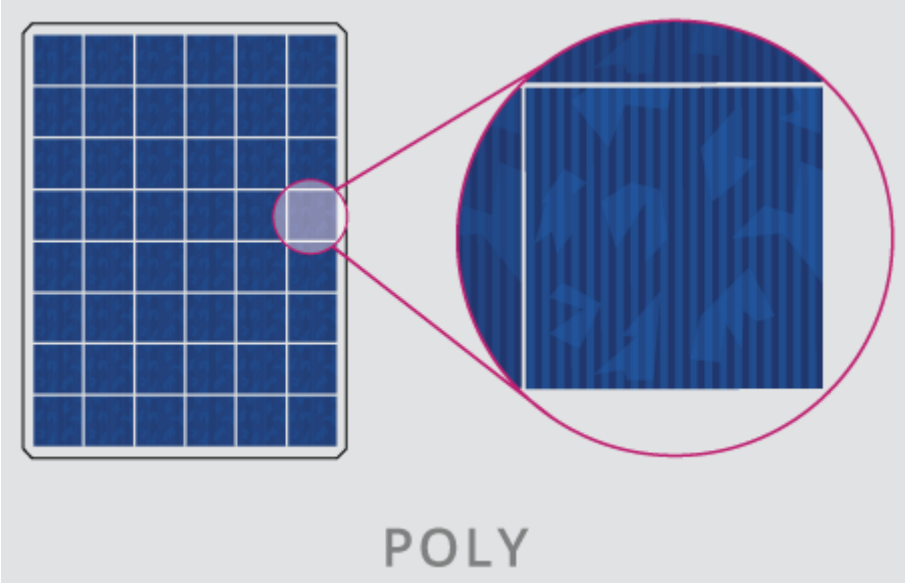
Most of the solar panel options currently available fit in one of three types: **Monocrystalline**, **Polycrystalline** and **Thin-film**. These solar panels vary in how they're made, appearance, performance, costs, and the installations each are best suited for.

1. Monocrystalline Solar Panels:



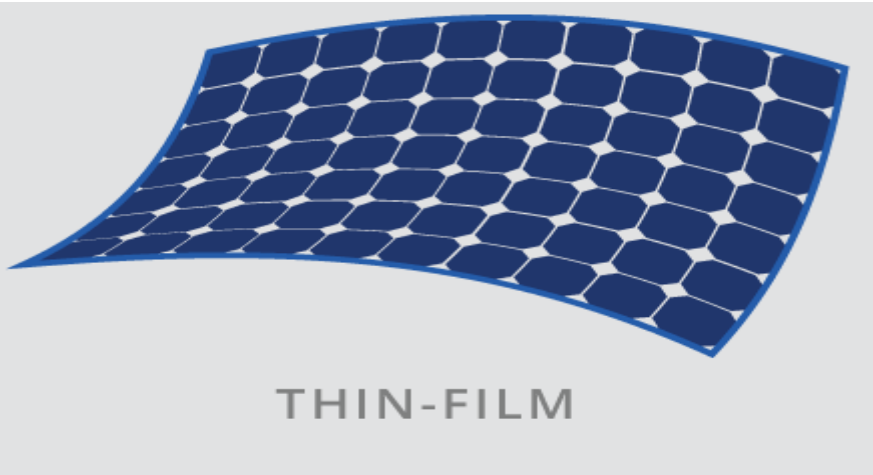
- If you see a solar panel with black cells, it's most likely a monocrystalline panel. These cells appear black because of how light interacts with the pure silicon crystal.
- While the solar cells themselves are black, monocrystalline solar panels have a variety of colors for their back sheets and frames. The back sheet of the solar panel will most often be black, silver or white, while the metal frames are typically black or silver.

2. Polycrystalline solar panels



- Unlike monocrystalline solar cells, polycrystalline solar cells tend to have a bluish pattern to them due to the light reflecting off the silicon fragments in the cell in a different way than it reflects off a pure monocrystalline silicon wafer.
- Similarly to monocrystalline, polycrystalline panels have different colors for back sheets and frames. Most often, the frames of polycrystalline panels are silver, and the back sheets are either silver or white.

3. Thin-film solar panels



- The biggest differentiating aesthetic factor when it comes to thin-film solar panels is how thin and low-profile the technology is. As their name suggests, thin-film panels are often slimmer than other panel

ty[es. This is because the cells within the panels are roughly 350 times thinner than the crystalline wafers used in monocrystalline and polycrystalline solar panels.

- It's important to keep in mind that while the thin-film cells themselves may be much thinner than traditional solar cells, an entire thin-film panel may be similar in thickness to a monocrystalline or polycrystalline solar panel if it includes a thick frame. There are adhesive thin-film solar panels that lie as-close-as-possible to the surface of a roof, but there are more durable thin-film panels that have frames up to 50 millimeters thick.

❖ Electrical Energy Storage:

Electrical energy storage can be achieved by following methods:

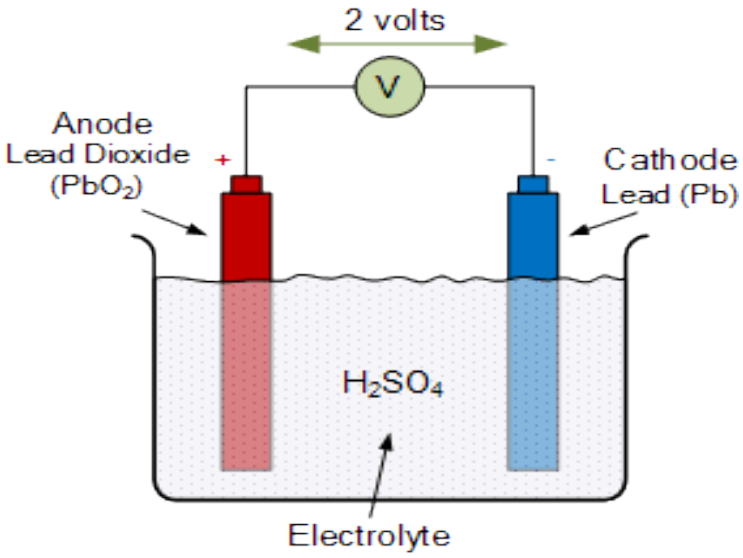
01.Batteries

02.Superconductivity

03.Fuel Cell

01.Batteries:

- Usually lead acid batteries called storage batteries are used for storage of electrical energy using electrochemical reaction.
- In the fully charged state, the negative plate consists of lead, and the positive plate lead dioxide. The electrolyte is concentrated sulfuric acid, which stores most of the chemical energy. Overcharging with high charging voltages generates oxygen and hydrogen gas by electrolysis of water, which is lost to the cell.
- At the positive battery terminal, the electrons rush back in and are accepted by the positive plates. The oxygen in the active material (lead dioxide) reacts with the hydrogen ions to form water, and the lead reacts with the sulfuric acid to form lead sulfate.



- In the discharged state both the positive and negative plates become lead sulfate ($PbSO_4$), and the electrolyte loses much of its dissolved sulfuric acid and becomes primarily water.
- Negative plate reaction

  $Pb(s) + HSO^{-}4(aq) \rightarrow PbSO4(s) + H^{+}(aq) + 2e^{-}$

  The release of two conducting electrons gives the lead electrode a negative charge.

  As electrons accumulate they create an electric field which attracts hydrogen ions and repels sulfate ions, leading to a double-layer near the surface. The hydrogen ions screen the charged electrode from the solution which limits further reaction unless charge is allowed to flow out of electrode.
- Positive plate reaction

  $PbO2(s) + HSO^{-}4(aq) + 3H^{+}(aq) + 2e^{-} \rightarrow PbSO4(s) + 2H2O(l)$

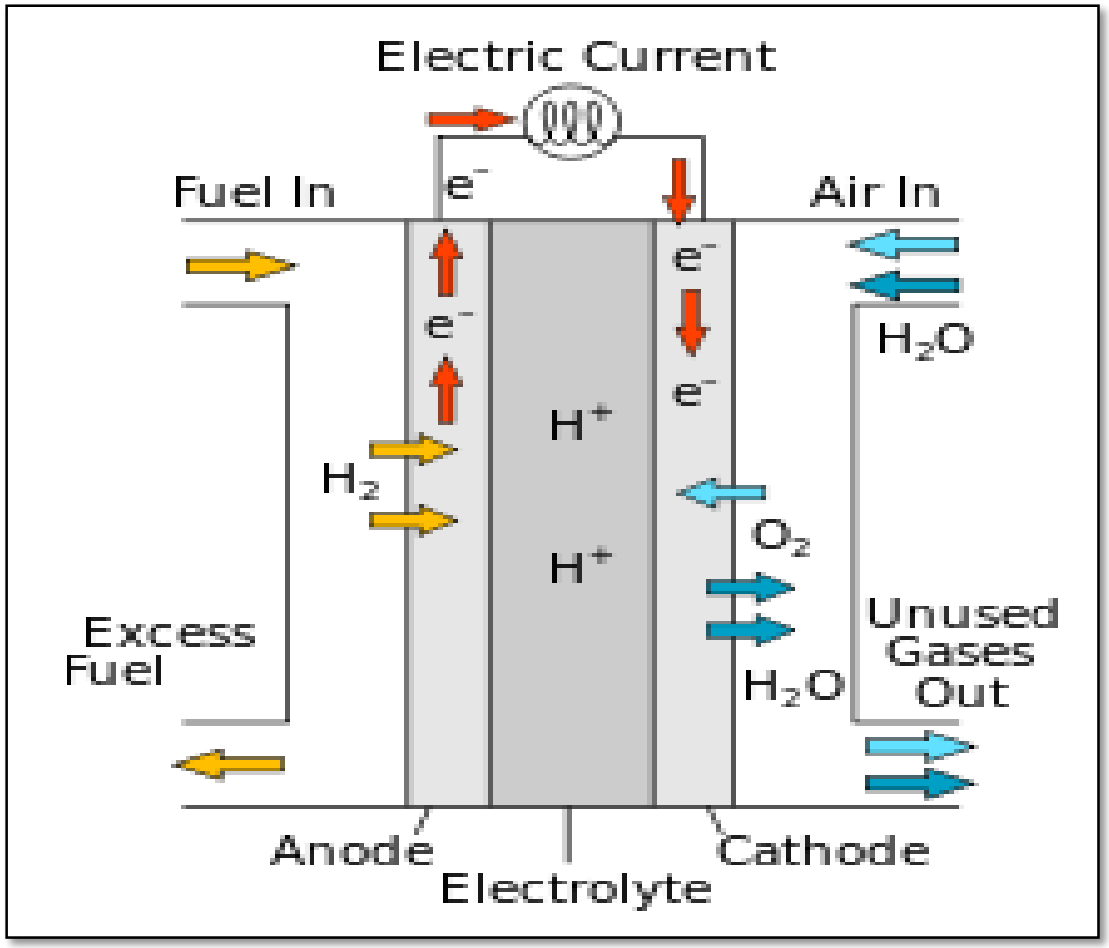
02.Super Capacitor:

- There are certain materials which are at extremely low temperatures in the range of 10K to 20K (-263^0c to (-253^0c), their resistance falls to zero and they can conduct very amount of current without overheating.
- Power transmitted is V.I and heat generated is I^2R , these material are called as Superconductor.
- Therefore these superconductors can store extremely large amount of electrical energy since current I can have very values at extremely low temperatures having negligible resistance. These low temperatures are achieved by magnetic cooling.
- These materials which can store large electric energy at very low temperatures are called Super Capacitors.

03.FUEL CELLS:

"A fuel cell may be defined as a device that converts chemical energy from a fuel into electricity through a chemical reaction. The chemical reaction occurs in the presence of oxygen or an oxidizing agent."

- Hydrogen fuel cells are cells that contain hydrogen as the fuel. Hydrogen fuel is a zero emission fuel that releases energy during combustion or through electrochemical reactions.
- Fuel cells and batteries produce an electric current through a chemical reaction, but a fuel cell will produce energy as long as there is fuel, thus never losing its charge.



Operation of a Hydrogen Fuel Cell

The basic construction of a hydrogen fuel cell consists of two electrodes, an electrolyte, a fuel (hydrogen) and a power supply. An electrolyte that separates the two electrodes is an ion conducting material which facilitates the free passage of ions.

In a fuel cell, an oxidizing agent (or oxygen) is made to flow through a fuel (hydrogen). Hydrogen and oxygen combine to form water and generate heat. At the anode, hydrogen is stripped of its electron and its proton is made to pass through the electrolyte.

The electron is made to pass through an external DC (direct current) circuit to power devices.

- # Advantages and Disadvantages of Hydrogen Fuel Cells

The advantages of using hydrogen fuel cells are listed below:

- Hydrogen is an abundant resource
- Fuel cells do not emit harmful emissions
- Hydrogen gas is non-toxic and does not produce any harmful byproducts
- High efficiency and powerful energy production
- Hydrogen fuel cells are highly fuel efficient
- Hydrogen is a renewable source of energy

Disadvantages of using hydrogen fuel cells, as mentioned below:

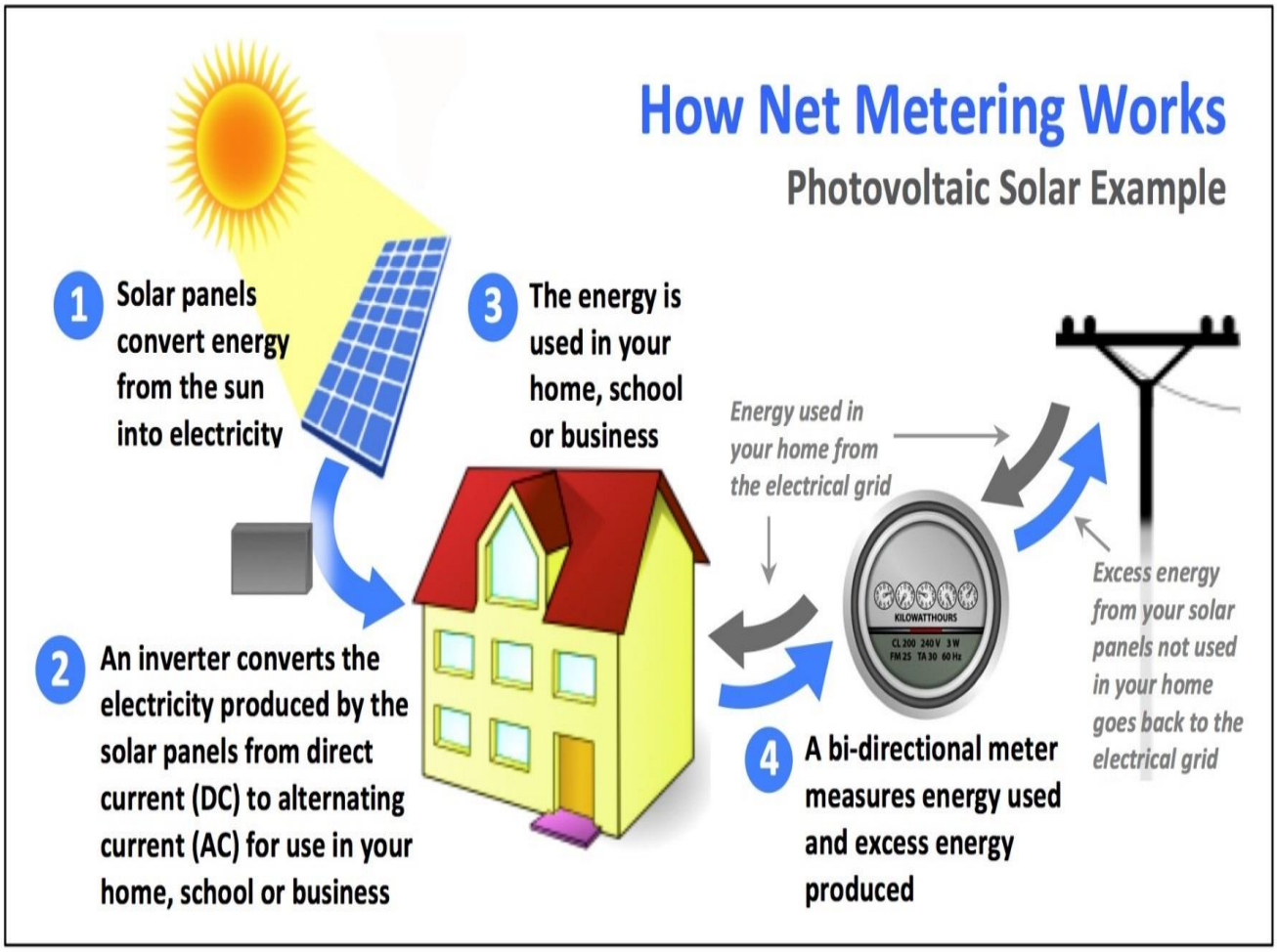
- Expensive to construct and maintain
- Storage of hydrogen gas is difficult
- Compressed hydrogen gas is highly flammable.

❖ NET METERING:

Solar PV (Photo Voltaic) cells convert sun energy into electrical energy, thus using cleaner way to generate power. Net Metering systems work in perfect sync with Grid power to support the load connected.

These systems do not have Battery back-up and consume solar energy generated on-line & excess generated electricity units will get banked in to the grid.

Net metering is a billing mechanism that credits solar energy system owners for the electricity they add to the grid.



❖ INSTALLATION PROCEDURE OF SOLAR ROOF TOP SYSTEMS:

Let us talk about how to install solar panels.

- Step – 1: Solar Panel Installation Made Easy
- Step – 2: Assembly of Solar Panels
- Step – 3: Electrical Wiring
- Step – 4: Connection between Solar Panel and Solar Inverter
- Step – 5: Connection between Solar Inverter and Solar Battery
- Step – 6: Connection between Solar Inverter and Grid
- Step – 7: Start Solar Inverter through Solar Panel & Grid

Step – 1: Solar Panel Installation Made Easy:

The mounting structure provides the base for the entire solar system so make sure it is sturdy and properly fastened to the rooftops of your house or commercial establishment. A typical mounting structure is made up of aluminum. The performance of the solar panels depends upon the direction in which these panels are placed.

Step – 2: Assemble Solar Panels:

Once the solar structure is fixed accurately, we will connect it with solar modules. We should ensure that all nuts and bolts of solar modules are fixed with solar structure so that it is properly secured and lasts long.

Step-3: Electrical Wiring:

MC4 connectors are used to connect solar panels. These are universal connectors and can be connected with any type of solar panels. The solar array wiring becomes simpler and faster using MC4 connectors.

Step-4: Connection between Solar Panel and Solar Inverter:

In the picture given below, the backside of an inverter is shown where solar panel wire is connected. Connect the positive wire from the solar panel with the positive inverter terminal and the negative wire with negative terminal of the inverter.

There are other connections too like battery wire connection and output wire connection with the inverter. In all, Solar panel, Solar Battery and Grid input are connected with the solar inverter to produce electricity. The output of a series string of solar modules is connected to the input of the inverter. Make sure the inverter is turned off while the connections are being done.

Step-5: Connection between Solar Inverter and Solar Battery:

In an off grid solar system, Battery is mandatory where it is used to store power backup. This battery is connected with solar inverter to recharge it with solar panel and grid. The positive terminal of the battery is connected with the positive of the inverter and vice versa.

Step-6: Connection between Solar Inverter and Grid:

In order to connect the inverter to the grid simply plug it in in the main power switch board, so that it gets power from the grid. The output wire is also connected with board that is supplying electricity in home.

In order to calculate the excess energy generated from the solar system we need to install a metering device. We need to connect the positive wire from the metering device with the line terminal and the negative wire to the neutral terminal of the inverter.

Step-7: Start Solar Inverter through Solar Panel & Grid:

After all the connections are done, we switch on the mains. There is a digital display which shows the total solar unit generated during the day, what is supply volt and current (amp) from solar panel etc. In the picture below is shown the front side of Microtek solar inverter.

- ## Commissioning Procedure:

  - After the installation of any PV system is completed and the inspection is done, the system will be ready to be plugged to the grid to transfer energy. That process is referred to as Commissioning the system.
  - Commissioning Procedure:
    When intending to start the PV system the first time, the procedure starts at the array and ends at the point of connection. This will reduce hazards and make the diagnostic and testing of subsystems easier in case there is a problem in the installation.

1: Connect power sources to systems (this includes connecting PV module wire runs)

- Considerations
  - AC and DC disconnects need to remain in “OFF” position
  - Fuses are not connected

2: Test DC voltage and polarity

- Make sure to use proper meter settings for DC
- Test after connecting PV modules in series and measure
- Expected voltage (from calculation of modules)
- Voltage polarity
- Considerations:
  - AC and DC disconnects need to remain in “OFF” position
  - Fuses not connected as well
  - Watch for negative sign on meter that means lead positions of meter is not correct or circuit is not wired properly.

3: Test AC voltage at inverter output

- Make sure to use proper meter settings for AC
- Test Line to Line and Line to Neutral
- Compare with inverter AC voltage (specs sheet)
- If inverter has settings for more than one connection, match your service setting for voltage
- After this step, return fuses if applicable

4: Start-up procedure

- Lift AC disconnect lever (inverter to grid)
- Lift DC disconnect lever (PV to inverter)
  Considerations
  - Check with manufacturer’s manual for specific startup procedure
  - Most inverters have Delay to check on grid and synchronize before connecting.

- **Maintenance Of Solar Roof Top System**:

Solar Operation & Maintenance services will encompass performing preventative maintenance on the main components of a solar PV system:

• Solar Panels
• Battery
• Charge Controller
• Inverter
• Wiring and connections

01.Solar Panel Maintenance:

For a general cleaning, you can just use an ordinary garden hose to wash the face of the panels. You should do this in the morning or evening.
• Also, avoid spraying them with cold water while they are hot because that might damage them.
• If the panels need some more cleaning that the hose cannot provide, you can use a sponge to scrub them.
• Solar panel owners can also get the services of O&M personnel. This is advisable if the panels are too high or need more thorough cleaning.
• AVOID using a metal brush to clean solar panel surface, neither the detergents.
• A visual inspection of the modules can then be done to check for defects in the modules such as cracks, chips, de-lamination, fogged glazing, water leaks and discoloration.

02.Battery Maintenance:

- Batteries should be regularly and carefully maintained to extend their useful life. It is advisable for the users to conduct inspections and cleaning of batteries at regular intervals.
- A visual inspection is recommended to assess the general condition of the system's battery. Make sure to check for any electrolyte leak, cracks in the batteries, or corrosion at the terminals and connectors.
- The batteries should be kept clean, dry and free of electrolyte and corrosion residue. Cleaning should be done once in a month. Also, it should be borne in mind that before performing maintenance work, each component of the system should be isolated.

03. Charge Controller/Regulators

- Most of the renewable energy sources require Charge Controller/Regulators. It should be kept in mind that any controller or regulator needs to be installed in a dry, clean and ventilated space.
- The Charge Controller/Regulators is an electronic device that facilitates in controlling the voltage of the charging sources energy output to the installed battery bank.

04. Inverter Maintenance

The inverter should be installed in a clean, dry, and ventilated area which is separated from, and not directly above, the battery bank. While the system is operating the following operational checks can be made:

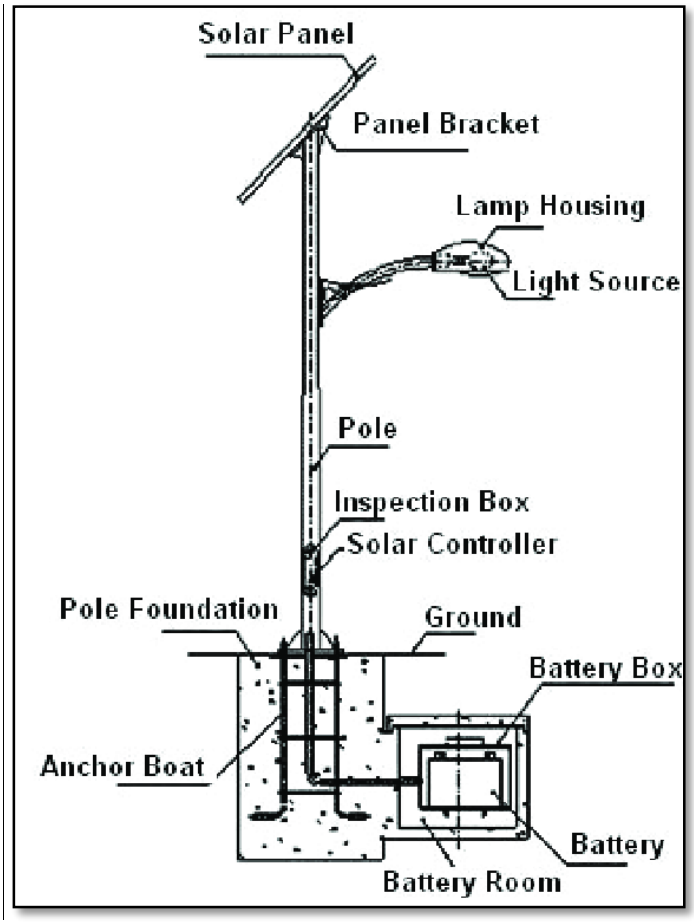
• Visually inspect inverters for any damage.
• Check connections for resistive joints.
• Check the DC voltage applied to inverter input.
• Ensure that there is free space around the units for cooling purposes.
• Check for all the indicators such as LED lights are working and that the wires leading to and from this device are not loose.
• This component can be maintained by minimizing dust accumulation. A dry cloth should be used to wipe away any accumulated dirt/dust.
• Review the inverter display panel for any recorded faults (refer to the manufacturer's instructions for advice).

05.Wiring and Connections

It is advisable to check the Wiring installations for any cracks, breaks or deterioration in the insulation/conduits. Make sure to inspect the panel boxes to check for unwanted rodents and insects. Also, examine the connections for any corrosion or burning. Switches should not spark when turned on or off. The following sections of conduit and wiring should be checked for any signs of damage:

• Solar panels to the charge controller
• Charge controller to the battery bank
• Inverter/charger to the battery bank
• Generator to Inverter/Charger
• Inverter/charger and Generator to the AC outlets
• Battery back to the DC outlets/load

❖ STAND ALONE STREET LIGHT SYSTEM:



The solar street lights work on the principle of the photovoltaic cell or solar cell. The solar cell converts solar energy to the electrical energy which is stored in the battery. The solar lamp draws the current from this battery and it requires no other wiring.

Working of Solar Street Lights

The solar street lights use solar energy, a form of the renewable energy. These days it is common to see the solar street lamps along the sides of roads. The solar street lights comprise of, which absorb the solar energy during daytime. The photovoltaic cells convert solar energy into electrical energy, which is stored in the battery. At the nighttime the lamp starts automatically and it consumes the electricity already stored in the battery. During the day time the battery gets recharged and the process keeps on repeating every day.

Solar LED lights: LED stands for light emitting diode. LED comprises of the chemical compound that gives of the light when direct current (DC) from the battery passes through it. Solar LEDs are available from number of companies in different sizes, shapes and styles. The life of LED is usually very high extending up to 50,000 hours. The LEDs require very little current hence the solar panels of smaller sizes are required for the solar lights with LED lamps.

Advantages:

1. There are lower chances of the automatic street light system overheating & risk of accidents is also minimized.
2. Cost of operating automatic solar street lights is far less when compared to the conventional street lights.
3. The automatic street light system is eco-friendly & hence helps in reducing the carbon footprint.