RENEWABLE ENERGY TECHNOLOGIES

Unit 2 : **SOLAR RADIATION**

Module : 3

Solar thermal energy storage, Fundamentals of solar photovoltaic conversion, solar cells, Solar PV systems, solar PV applications.

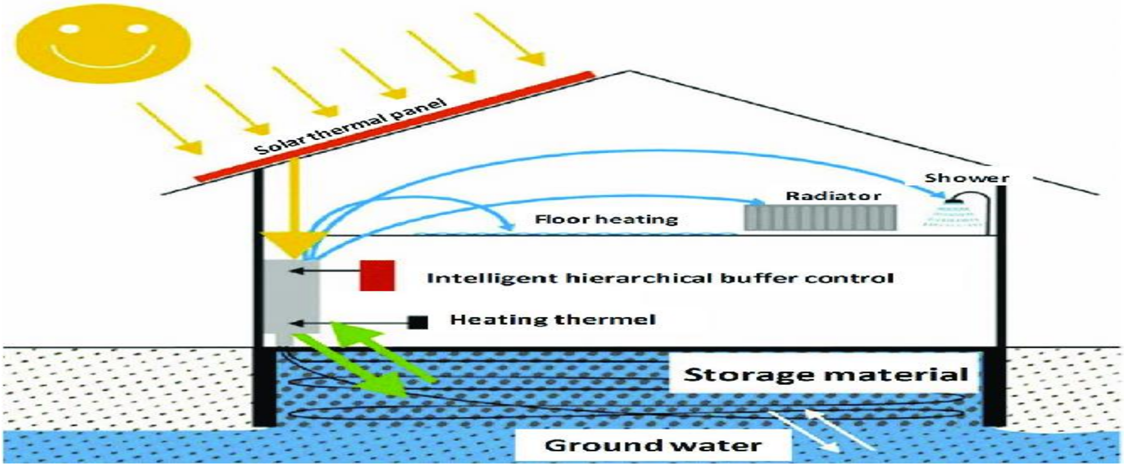
Solar thermal energy storage:

Thermal energy can be stored as a change in internal energy of a material as sensible heat, latent heat or thermochemical or combination of these. Sensible heat storage is due to temperature change of material while latent heat storage is due to the phase transformation which may be solid-liquid, liquid-gas or solid-solid. Different types of thermal energy storage of solar energy are given below,

Sensible heat storage

In sensible heat storage (SHS), thermal energy is stored by raising the temperature of a solid or liquid. SHS system utilizes the heat capacity and the change in temperature of the material during the process of charging and discharging. The amount of heat stored depends on the specific heat of the medium, the temperature change and the amount of storage material.

Water appears to be the best SHS liquid available because it is inexpensive and has a high specific heat. However, above 100oC, oils, molten salts and liquid metals, etc. are used. For air heating applications rock bed type storage materials are used.

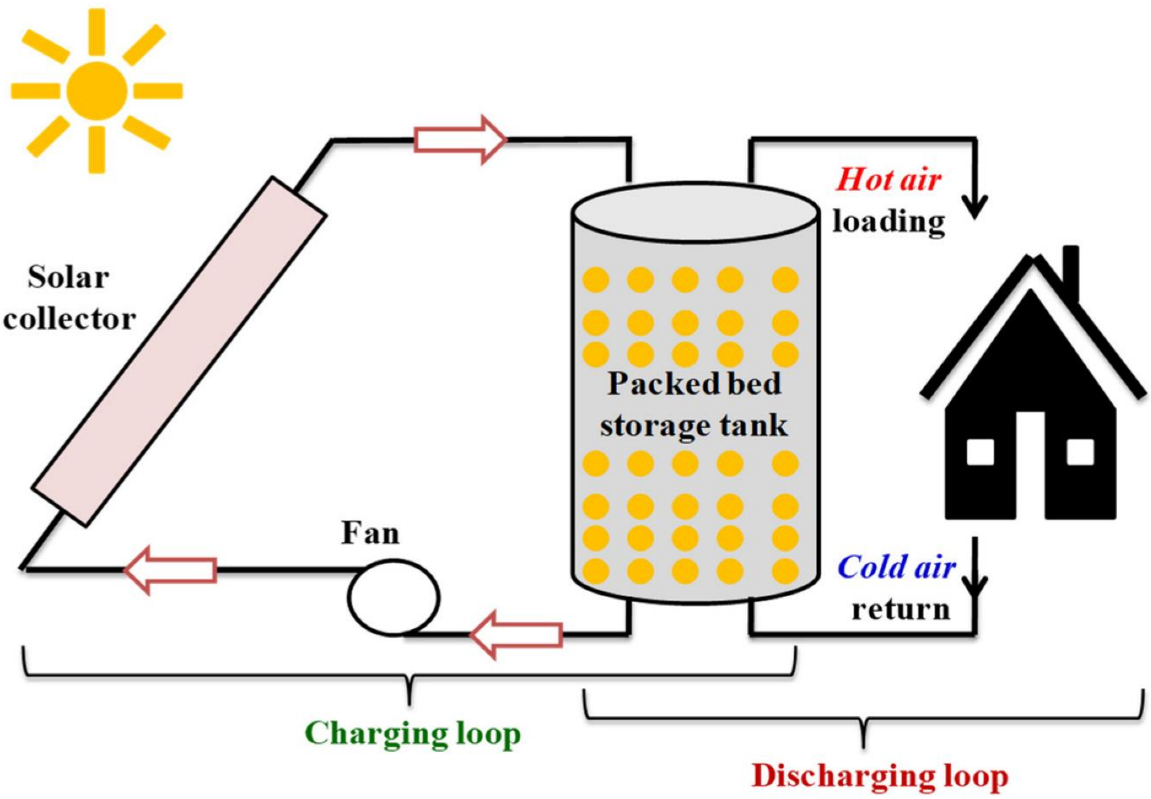


Latent heat storage

In the latent heat storage system, charging and discharging phenomenon occurs when the storage material undergoes phase change either from solid to liquid, liquid to gaseous or solid to solid. The storage capacity of latent heat storage system with a PCM medium is given by the following equations,

$$Q = \int_{T_i}^{T_m} m\, C_p\, dT + m a_m \Delta h_m + \int_{T_m}^{T_f} m C_p\, dT$$

$$Q = m[C_{sp}(T_m - T_i) + a_m \Delta h_m + C_{lp}(T_f - T_m)]$$



Thermo chemical energy storage

Charging and discharging phenomenon takes place during the breaking and reforming of molecular bonds in a complete reversible chemical reaction. In this case, the stored heat depends upon the amount of storage material, the endothermic heat of reaction, and the extent of conversion.

Above mentioned thermal energy storage technique, which is known as the latent heat storage technique is one of the best energy storage techniques because of its high energy storage density and its characteristics to store heat at constant temperature called phase transition temperature of PCM. Phase change can be in the following form: solid-solid, solid-liquid, solid-gas, and liquid- gas and vice versa.

Solid -Solid transition

- Change in crystalline structure
- Small change in volume
- Smaller storage capacity than solid liquid transition
- Less containment required and greater design flexibility

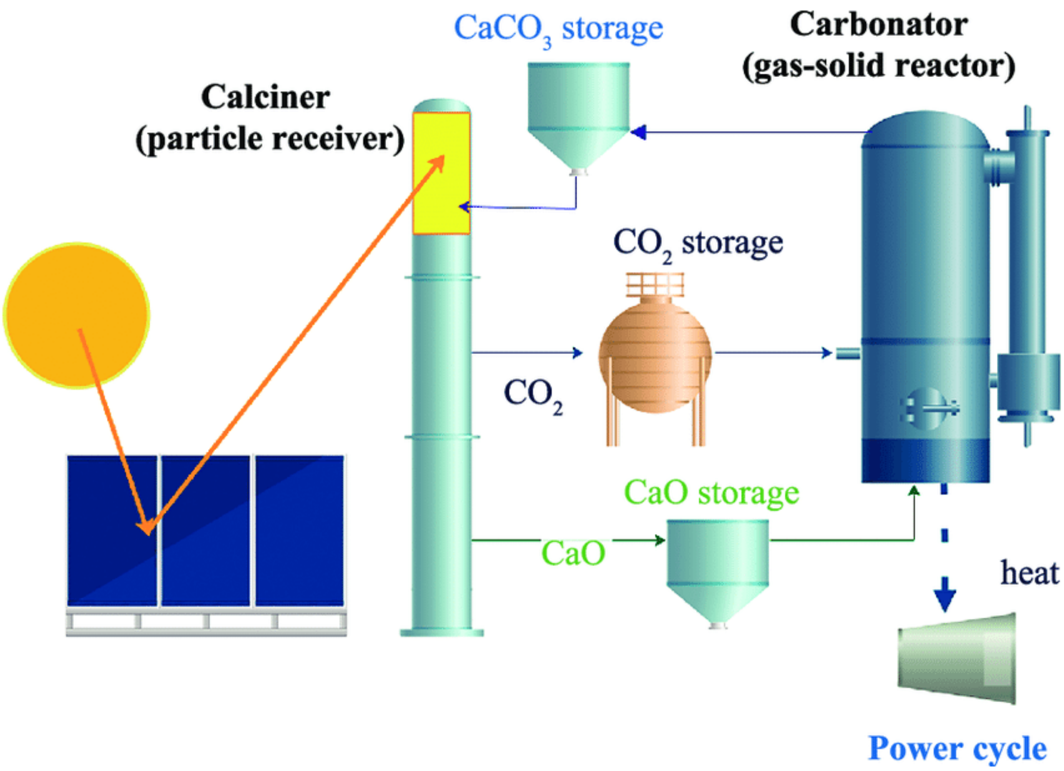
Most preferable materials for solid-solid phase transition are the organic solid solutions whose characteristics, melting points and latent heats of fusion are tabulated below.

Solid–gas or liquid gas transition

- Higher latent heat of phase transition
- Larger volume changes on phase transition
- Larger containment required
- Impractical and complex system

Solid-liquid transition

- Intermediate latent heat of phase transition, volume change
- Most practical and economical system



Fundamentals of solar photovoltaic conversion:

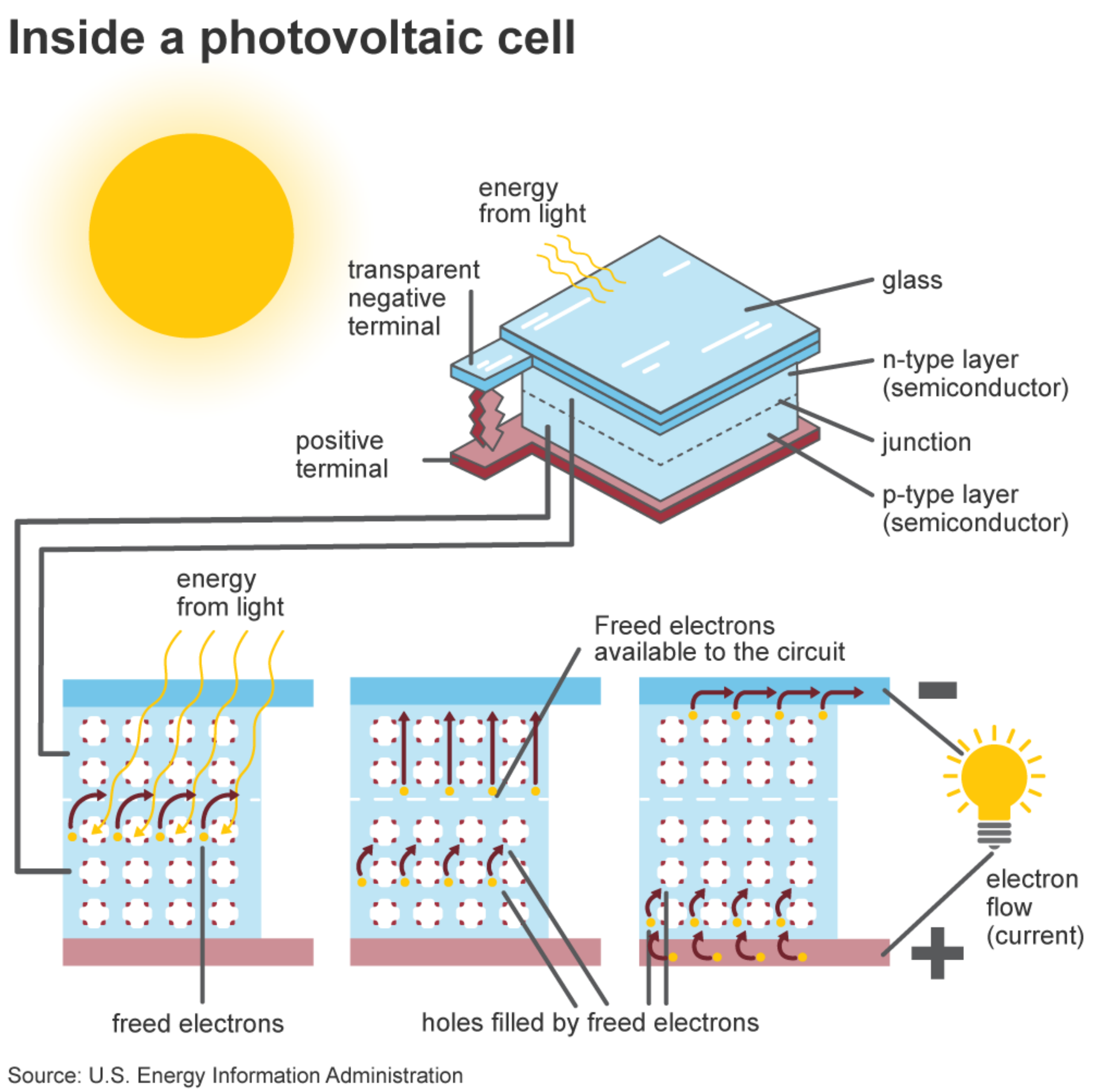
A photovoltaic (PV) cell, commonly called a solar cell, is a non mechanical device that converts sunlight directly into electricity. Some PV cells can convert artificial light into electricity.

Sunlight is composed of photons, or particles of solar energy. These photons contain varying amounts of energy that correspond to the different wavelengths of the solar spectrum.

A PV cell is made of semiconductor material. When photons strike a PV cell, they may reflect off the cell, pass through the cell, or be absorbed by the semiconductor material. Only the absorbed photons provide energy to generate electricity. When the semiconductor material absorbs enough sunlight (solar energy), electrons are dislodged from the material's atoms. Special treatment of the material surface during manufacturing makes the front surface of the cell more receptive to the dislodged, or free, electrons so that the electrons naturally migrate to the surface of the cell.

The flow of electricity in a solar cell

The movement of electrons, each carrying a negative charge, toward the front surface of the solar photovoltaic cell creates an imbalance of electrical charge between the cell's front and back surfaces. This imbalance, in turn, creates a voltage potential like the negative and positive terminals of a battery. Electrical conductors on the cell absorb the electrons. When the conductors are connected in an electrical circuit to an external load, such as a battery, electricity flows through the circuit.



Solar cells:

Solar cells can convert the energy of sunlight directly into electricity. Consumer appliances used to provide services such as lighting, water pumping, refrigeration, telecommunications, and television can be run from photovoltaic electricity.

Solar cells rely on a quantum-mechanical process known as the ‘‘photovoltaic effect’’ to produce electricity. A typical solar cell consists of a p n junction formed in a semiconductor material similar to a diode. Figure 1 shows a schematic diagram of the cross section through a crystalline solar cell. 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.

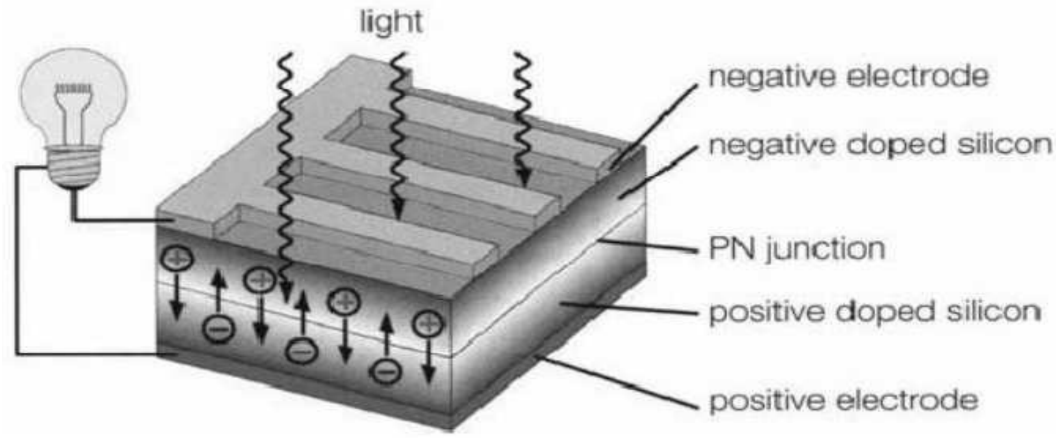


Figure 1: Solar Cell

A simplified equivalent circuit of a solar cell consists of a current source in parallel with a diode as shown in Fig. A variable resistor is connected to the solar cell generator as a load. When the terminals are short-circuited, the output voltage and also the voltage across the diode are both zero. The entire photocurrent (Iph) generated by the solar radiation then flows to the output. The solar cell current has its maximum (Isc). If the load resistance is increased, which results in an increasing voltage across the p n junction of the diode, a portion of the current flows through the diode and the output current decreases by the same amount. When the load resistor is open circuited, the output current is zero and the entire photocurrent flows through the diode.

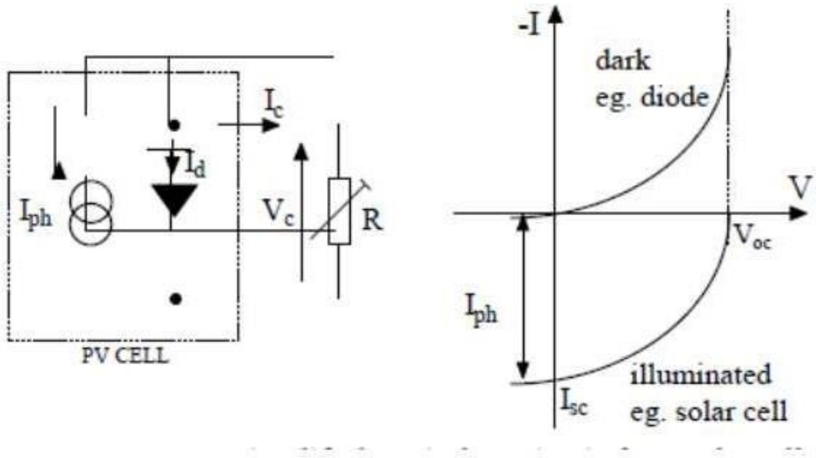


Figure 2: Equivalent circuit of a solar cell

Solar PV systems:

SPV system configurations can be of three types for different applications as described below:

- Stand-alone SPV systems without storage battery and storage battery
- Grid interactive SPV system.
- Hybrid systems
- Building Integrated SPV systems.

Stand- Alone SPV Systems without Storage Battery:

As the name indicates, these are used for stand- alone applications, which are least expensive and simpler like the water pumps and water sprinkler systems. These do not require any battery storage as it is meant for specific purpose for an abbreviated period of time and hence can be achieved when sun is at its peak with maximum intensity.

Since there is no battery associated with these systems, it eliminates the cost related to it and the charge controller. These are lighter and easily installed and maintained.

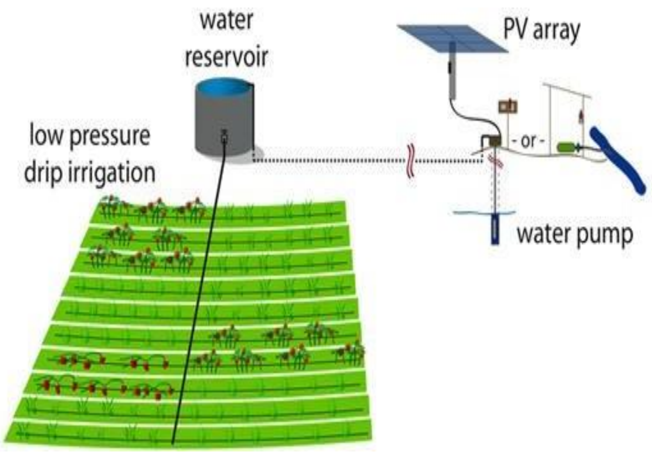


Fig-6: Solar water sprinkler- drip irrigation

Stand- Alone SPV Systems with Battery Storage:

A simple stand-alone PV system harness the solar energy and store it in battery banks that could be used even at night times when there is no sunlight. A stand-alone small-scale PV system employs rechargeable [10] batteries.

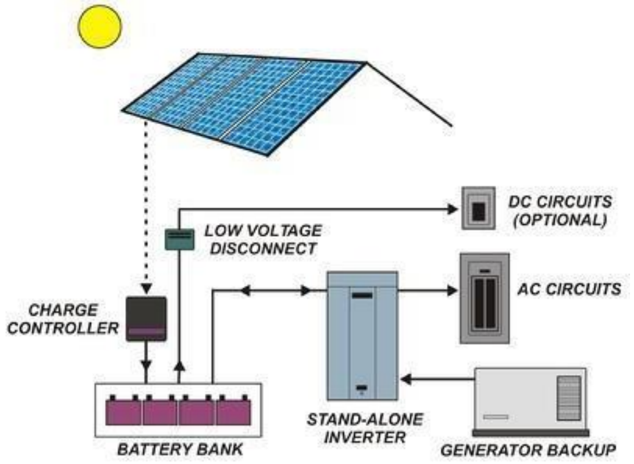


Fig- : Stand-alone roof top system with battery storage

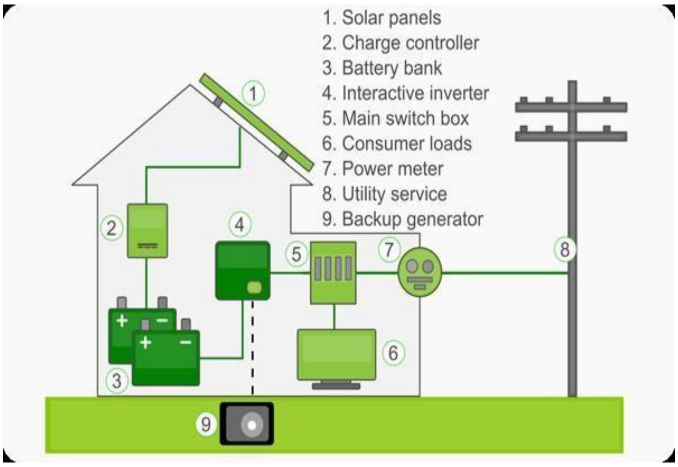
Roof top systems are best suitedexample for these systems. In the roof top system as shown in fig-4 it consists of solar modules which produces electricity are connected to the battery via charge controller. Further it is connected to the stand-alone inverter to convert direct current (DC) to alternating current (AC), making it available to connect to AC loads. Deep cycle lead acid batteries are generally used to store the solar power generated by the PV panels, and then discharge the power when energy is required. Deep cycle batteries are not only rechargeable, but they are designed to be repeatedly discharged almost all the way down to a very low charge.

Grid interactive SPV system

A grid-connected photovoltaic power system, is an electricity generating system that is connected to the utility grid. A grid-connected PV system consists of solar panels, one or more inverters, a power conditioning unit (PCU) and grid connection equipment. When conditions are right, the grid-connected PV system supplies the excess power, beyond consumption by the connected load, to the utility grid.

A grid connected system is connected to a large public electrical grid (owned by utility company) and feeds power into the grid. Grid connected systems vary in size from residential (2-10kW) to solar power stations (1- 10MW). In the case of residential or building mounted grid connected PV systems, the electricity demand of the building is met by the PV system. Only the excess is fed into the grid when there is an excess.

The feeding of PV generated electricity into the grid requires the transformation of DC into AC by a grid- controlled inverter. On the AC side, the function of grid-connected inverter is to supply electricity in sinusoidal form, synchronized to the grid frequency, limit feed in voltage to no higher than the grid voltage including disconnecting from the grid if the grid voltage is turned off. On the DC side, because the power output of a module varies as a function of the voltage that power generation can only be optimized by varying the system voltage to find the 'maximum power point'. Most inverters therefore incorporate 'maximum power point tracking' (MPPT).

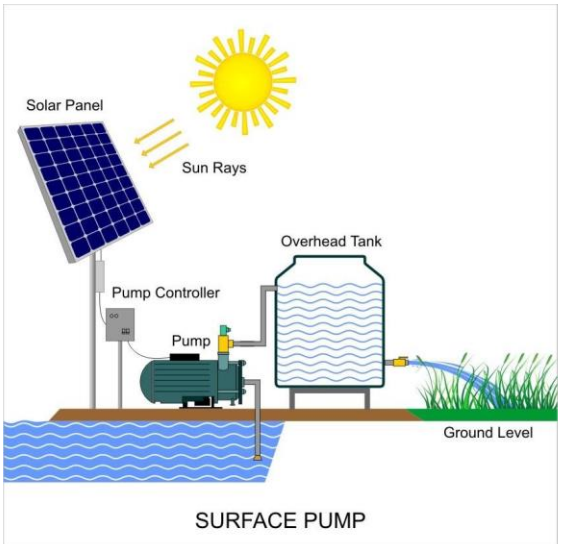


Solar grid connected system

Solar PV Applications:

Water Pumping:

Solar power is commonly used for water pumping facility which has been proved more effective in villages for agricultural purposes. The energy from the solar panel is used to operate the pump that is used lift the water from lower level to higher level. Following figure shows the diagrammatic representation of it.



Solar Water Pumping System

- ## Cooking:

solar cookers are the most happening in the present market. Solar cookers are commercially available and are easy to operate and maintain. The world's largest solar kitchen has been set up in India at Taleti, near Mount Abu, situated at a height of 1219 m above sea level in Rajasthan. It boasts of a six-module solar steam cooking system and a total of 84 parabolic dish concentrators shell type receivers.

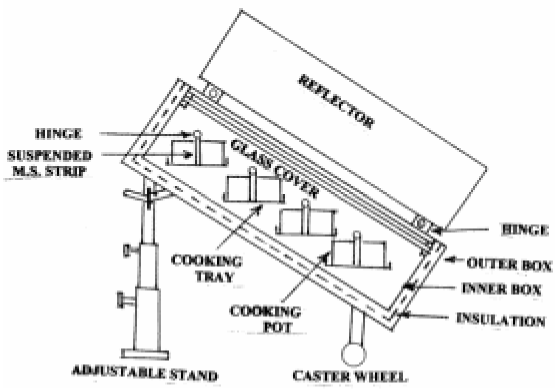


Fig-: Schematic Representation of Solar Cooker

- ## Heating:

solar water heaters and air heaters have been very common since decades even before PV cells could exist. Solar water heaters alone help reduce the consumption of energy to a major extent. These trap the heat energy from the sun, and store hot water in the containers.

- **Lighting:**

solar photovoltaic lighting system can be used for street lights, and rural areas. Small sized panels can easily harness enough energy to glow a street light and LEDs.

Fig-4: Solar Lighting

- **Traffic Signals:**

Traffic signals at all areas can easily be operated using solar panels. Shadow free area is the only concern for this.

- **Cold Storage:**

Solar energy can be used for cold storage as well as air conditioning application. Vapor compressor system using solar photovoltaic panels and vapor absorption system using thermal collectors can be used for these purposes.

- **Solar PV System in Space:**

The solar arrays arranged in space station produce more than required power for the space station. When the station is in sunlight, about 60 percent of the electricity that the solar arrays generate is used to charge the station's batteries.

Fig-: The solar panels in space