Energy and Environment Science

Unit – 2 : Solar Energy

- ✓ Basics of Solar Energy
- ✓ Solar Thermal Energy
- ✓ Solar Photovoltaic Power:
- ✓ Advantages and Disadvantages,
- ✓ Environmental impacts and safety

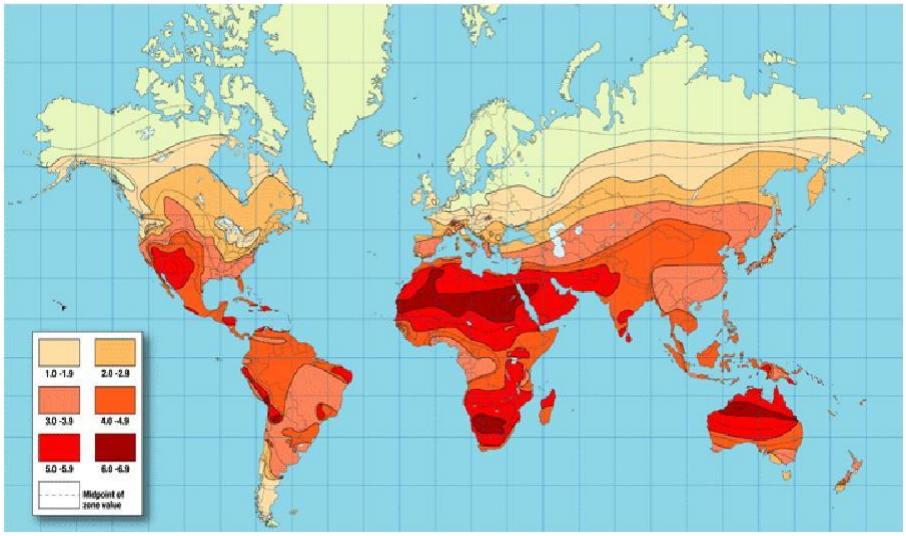
Learning Objectives

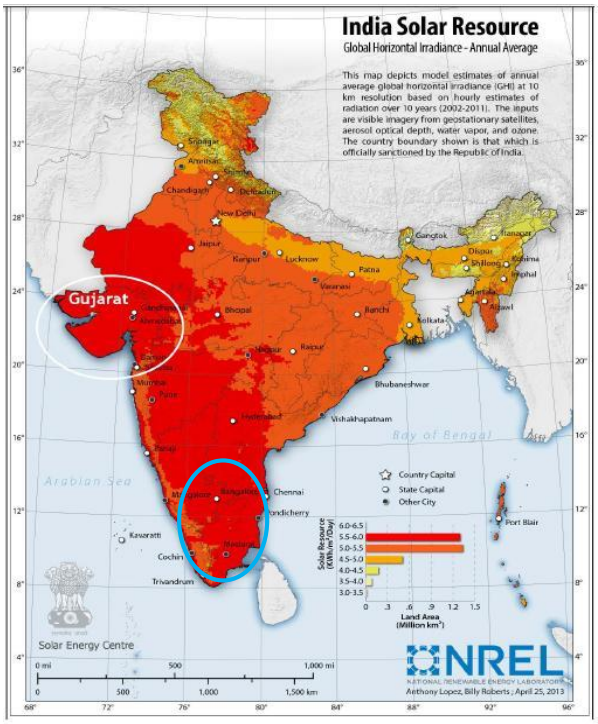
- **Basic principle involved in the operation of solar cell**
- **Environmental effects on electrical characteristics of solar cell**
- **Components of solar PV systems**
- **Design of typical solar PV systems**
- **Various applications of solar PV energy**

Major Advantages

1. It converts solar energy directly into electrical energy without going through thermal-mechanical link.
2. It has no moving parts.
3. Solar PV systems are reliable, modular, durable and generally maintenance free.
4. These systems are quiet, compatible with almost all environments, respond instantaneously to solar radiation and have an expected life span of 20 years or more.
5. It can be located at the place of use and hence no or minimum distribution network is required, as it is universally available.

Global Solar Insolation

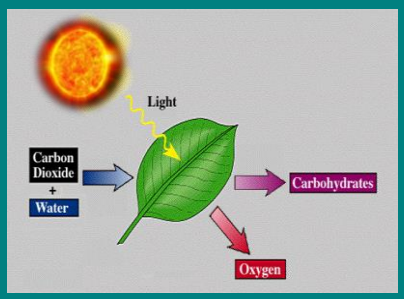




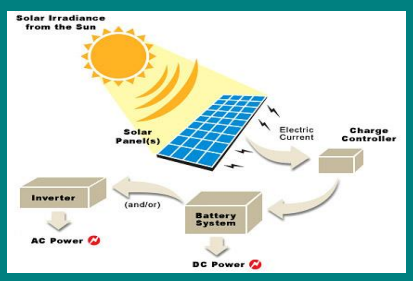
India is endowed with huge solar energy potential with most states having about 300 sunny days per year with annual solar radiation in the range of 4.5-6.5 kWhr/sq.m/day

SOLAR PV SYSTEM: FUNDAMENTAL

When photon falls on plants their energy is combination with O_2 is converted to chemical energy of plants (Photosynthesis process).



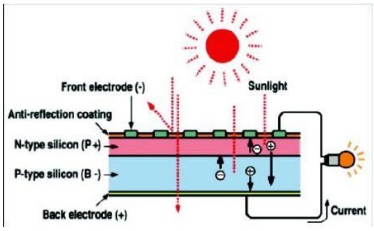
When photon falls on solar cells, their energy is converted into electrical energy.



Solar PV Power

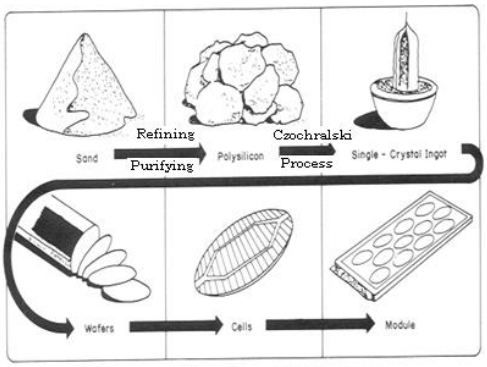
Solar Cells Background

- 1839 - French physicist A. E. Becquerel first invented the photovoltaic effect.
- **Photo+voltaic = convert light to electricity**
- 1883 - first solar cell built, by Charles Fritts, coated semiconductor selenium with an extremely thin layer of gold to form the junctions.
- **1954** - Bell Laboratories, experimenting with semiconductors, accidentally found that silicon doped with certain impurities was very sensitive to light.
- Resulted in the production of the first practical solar cells with a **sunlight energy conversion efficiency of around 6%.**
- 1958 - First spacecraft to use solar panels was US satellite



Solar Photovoltaic Effect

Solar Cell Manufacturing



Solar-cell-manufacturing process.

Semiconductors – Silicon Cells

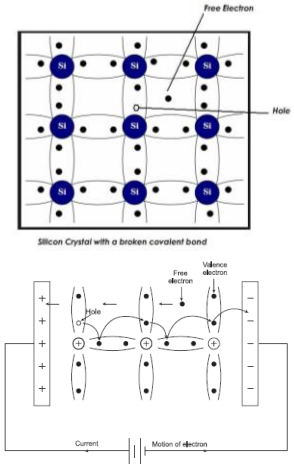
Process of Manufacture:
Sand – Poly Silicon – Single Crystal – Wafers – Cells – Modules

Wafer Based – Mono Crystalline, Poly Crystalline Cells
Thin Film Technology – Poly Silicon Sheets, Compound Semiconductors

SOLAR CELL FUNDAMENTALS

Electric Current Conduction in Semiconductors

- A silicon crystal is intrinsic if every atom in the crystal is a silicon atom. There are equal number of free electrons and holes in an intrinsic semiconductor.
- When a **potential is applied across such a crystal, free electron moves away from negatively charged plate until it reaches positively charged plate** and completes the path through external circuit.
- A hole near positively charged plate attracts a valence electron on the other side.
- This causes the valence electron to move into the hole creating new hole at this new location.
- The process continues and the **valence electron moves across the crystal from negative to positive plate** or the hole moves in a direction opposite to this.
- Thus free electrons and holes continuously move in opposite directions inside a semiconductor and **constitute electrical current.**

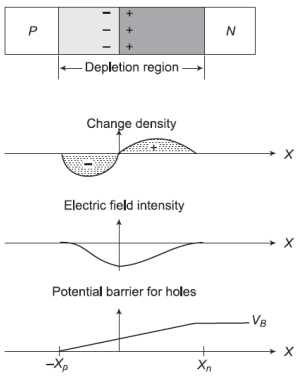


Free electron, hole flow through a semiconductor

SOLAR CELL FUNDAMENTALS

A PN Junction

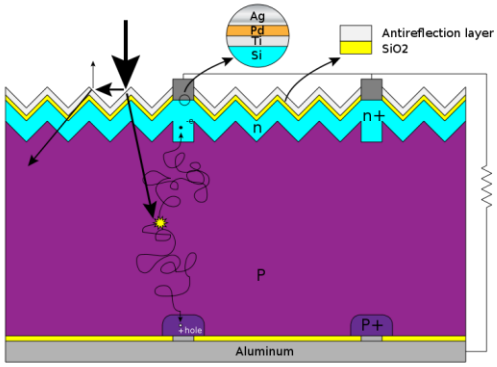
- A PN junction, where the **material changes suddenly from P to N is known as abrupt PN junction**.
- When a junction between a P-and N-type materials is formed, the carriers (free electrons and holes) diffuse from higher concentration side to lower concentration side.
- Soon after crossing the junction, these carriers recombine with the other types of carriers found in majority on the other side.
- We see that the holes, which neutralized the acceptor ions near the junction in the P-type side, disappeared as a result of recombination with free electrons, which have diffused from across the junction.
- Similarly, free electrons near the junction in the N-type side have recombined with holes, which have crossed the junction from P side.



Charge density, electric field intensity and potential barrier in a PN junction

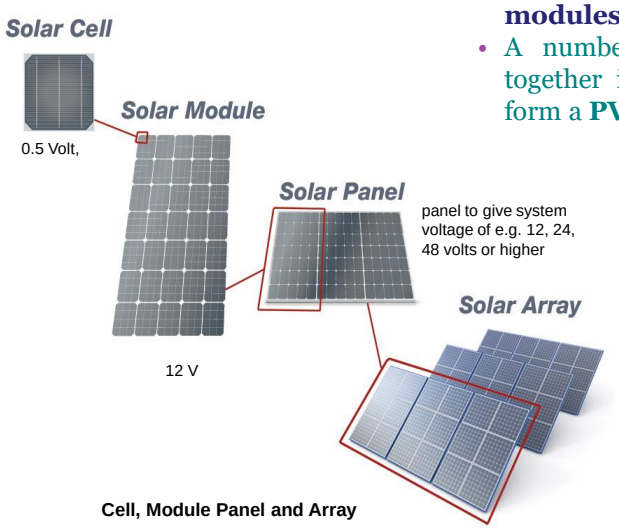
How Solar Cells Work

1. Photons in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon.
2. Electrons (negatively charged) are knocked loose from their atoms, allowing them to flow through the material to produce electricity.
3. An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.

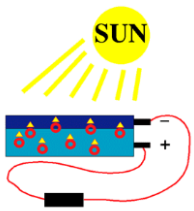


COMPONENTS OF SOLAR PV SYSTEM

- The individual units that you place in the sun to produce electricity from the sun are called **PV modules.**
- A number of modules connected together in different configurations form a **PV array.**



Cell, Module Panel and Array



Crystalline Silicon – 1.12 eV
Amorphous Silicon – 1.72eV

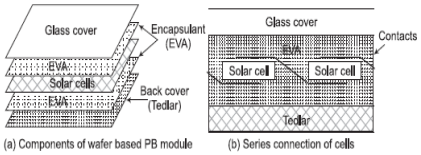
SOLAR CELL, MODULE, AND ARRAY CONSTRUCTION

Solar PV Module

- A bare single cell cannot be used for outdoor energy generation by itself.
- It is because
  (i) the output of a single cell is very small and
  (ii) it requires protection (encapsulation) against dust, moisture, mechanical shocks and outdoor harsh conditions.

- **Workable voltage and reasonable power is obtained by interconnecting an appropriate number of cells**.

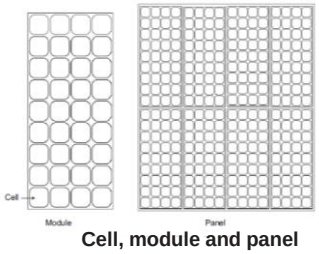
- The electrically connected cells are encapsulated, typically by using two sheets of **ethylene vinyl acetate (EVA) at either side. EVA is a good electrical insulator**, transparent material and has very low water absorption.



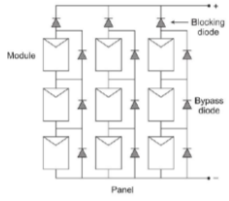
PV module details

Solar PV Panel

- Several solar modules are **connected in series/parallel to increase the voltage/current ratings.**
- When modules are connected in **series**, it is desirable to have each module's maximum power production occur **at the same current**.
- When modules are connected in **parallel**, it is desirable to have each module's maximum power production occur **at the same voltage**.
- Solar panel is a group of several modules connected in series-parallel combination in a frame that can be mounted on a structure. Fig.shows the construction of module and panel.



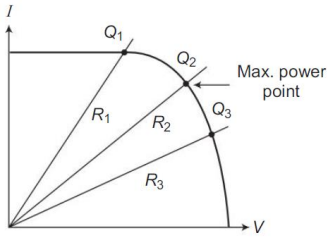
Cell, module and panel



A typical panel: Series-parallel connection of modules

MAXIMISING THE SOLAR PV OUTPUT AND LOAD MATCHING

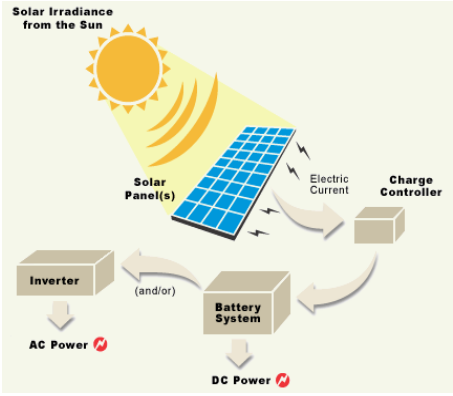
- To make best use of solar PV system, the output is maximized in two ways.
- The first is **mechanically tracking the sun and always orienting the panel in such a direction as to receive maximum solar radiation under changing positions of the sun**. That means adjusting the panel such that the sun rays always fall normal to its surface.
- The second is electrically tracking the operating point by manipulating the load to maximize the power output under changing conditions of insolation and temperature.



Load matching with resistive load

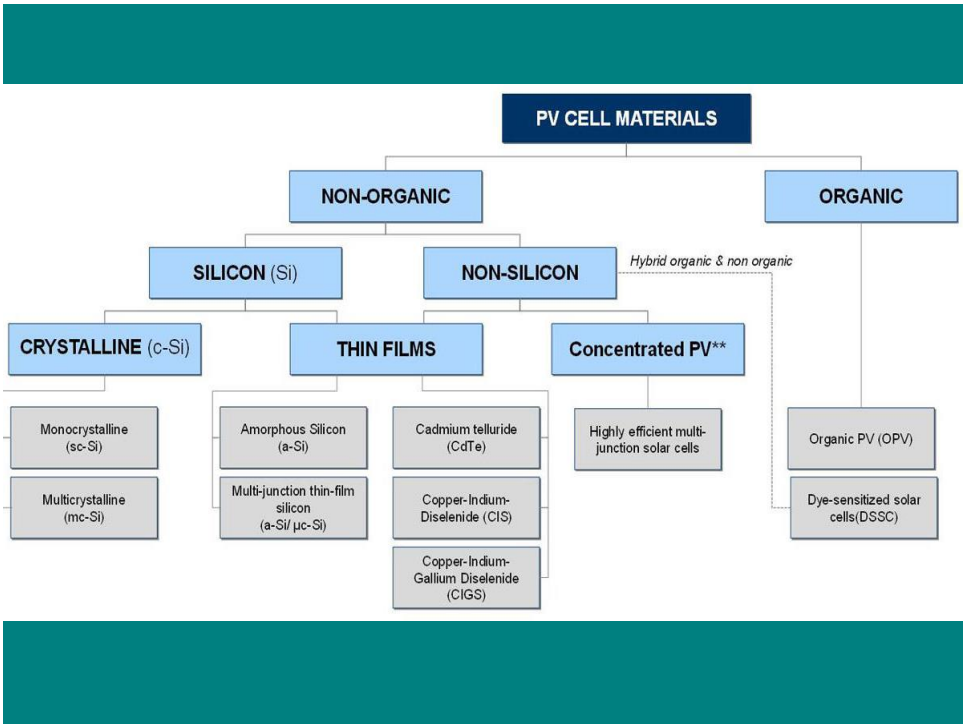
Solar Photovoltaic Technology

PV System



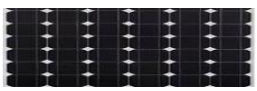
- A Photovoltaic (PV) module comprise of PV panels (known as **solar panels**), battery system, charge controller, inverter.
- PV panels comprise of PV cells

- PV module can be maOne silicon **cell** produces 0.5 Volts. 36 such cells connected together are called a **PV module** and it has enough voltage to charge 12 V battery and run pump and motor.
- Manufactured with capacity ranging from **5 Wp to 120 Wp. (250/300Wp)**



Difference Between Monocrystalline, Polycrystalline and Thin film Module

Mono-Si Panels	Poly-Si Panels	Thin Film Panels
1. Most efficient with max. efficiency of 21%.	1. Less efficient with efficiency of 16% (max.)	1. Least efficient with max. efficiency of 12%.
2. Manufactured from single Si crystal.	2. Manufactured by fusing different crystals of Si.	2. Manufactured by depositing 1 or more layers of PV material on substrate.
3. Performance best at standard temperature.	3. Performance best at moderately high temperature.	3. Performance best at high temperatures.
4. Requires least area for a given power.	4. Requires less area for a given power.	4. Requires large area for a given power.
5. Large amount of Si hence, high embodied energy.	5. Large amount of Si hence, high Embodied energy.	4. Low amount of Si used hence, low embodied energy.
6. Performance degrades in low-sunlight conditions.	6. Performance degrades in low-sunlight conditions.	5. Performance less affected by low-sunlight conditions.



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Classification

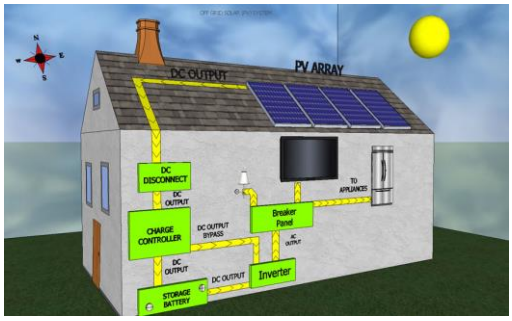
Solar Photovoltaic Technology

Solar Photovoltaic Technology — Classification

There are two types of PV system, namely:

a) Off-grid (Stand-alone) system

b) Grid-tied system



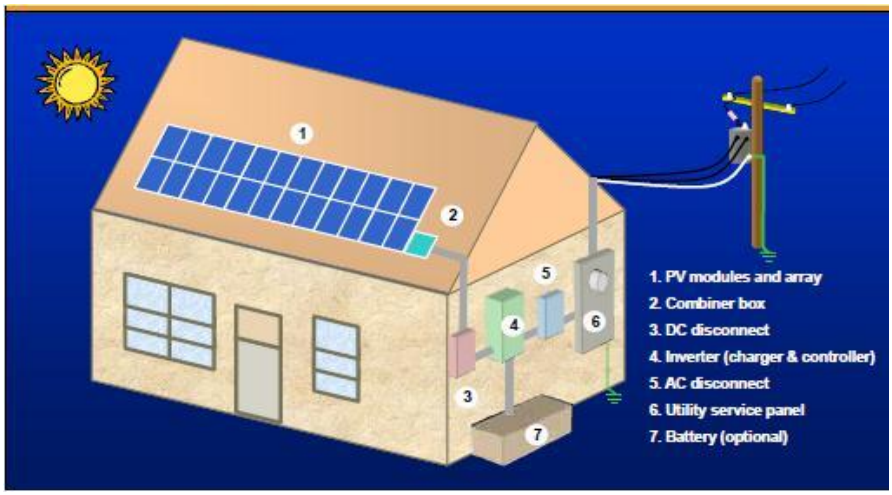
Stand-alone System (AC-Off Grid)

Stand-alone SPV Power Plant*:* In an SPV power plant, electricity is generated and made available to users through a local grid in a 'stand-alone mode.

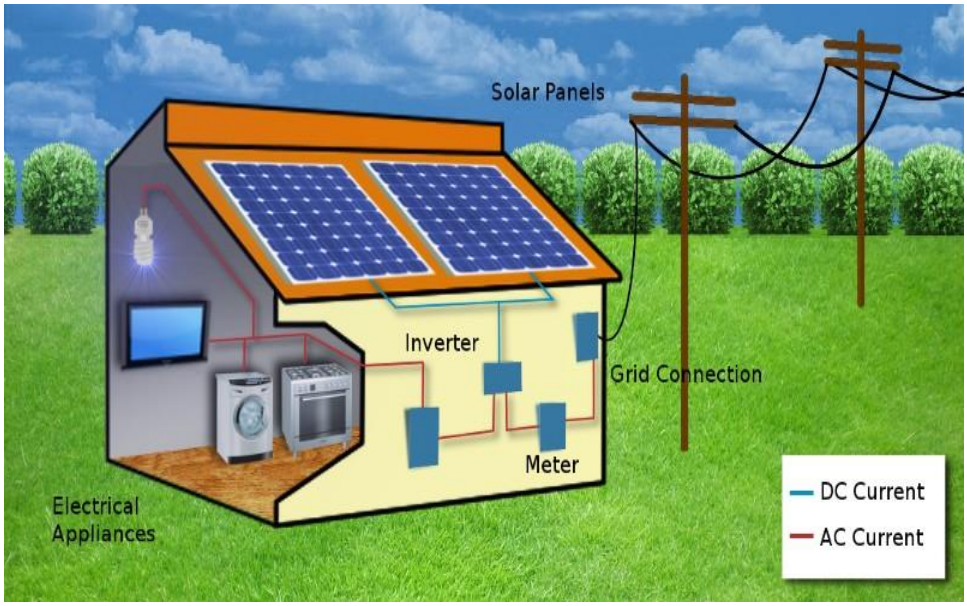
- Used for electrification of remote villages, power for **hospitals, hotels, communication equipment, railway stations, border outposts** etc

Solar Photovoltaic Power Systems

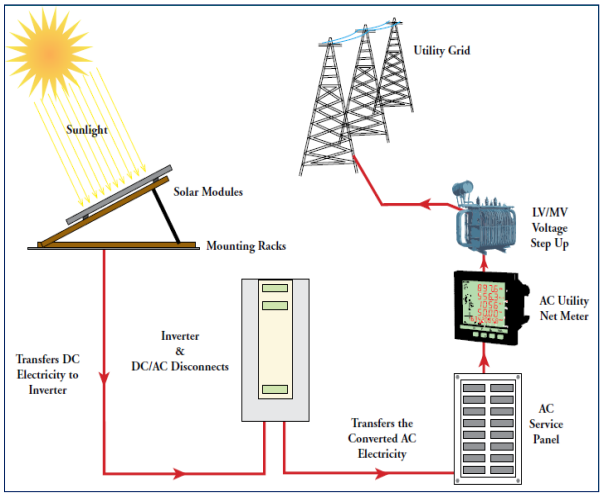
PV System Components



Type of Solar PV Systems – Grid Connected

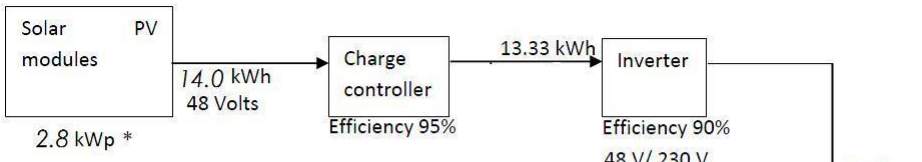


SOLAR PV TECHNOLOGY

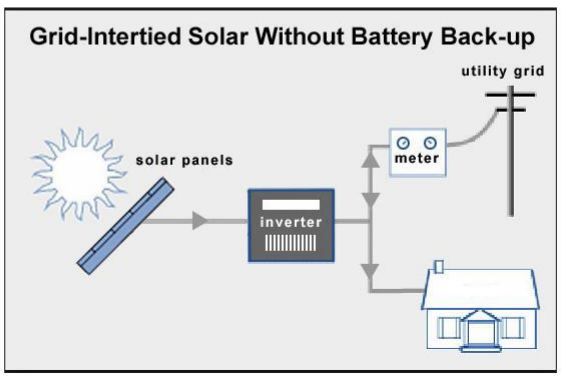


Grid connected Solar System: used as an inverter that synchronizes with the utility power. These systems **do not generally require batteries,** although batteries can be used to provide backup power if the utility power goes out.

Overall System Design



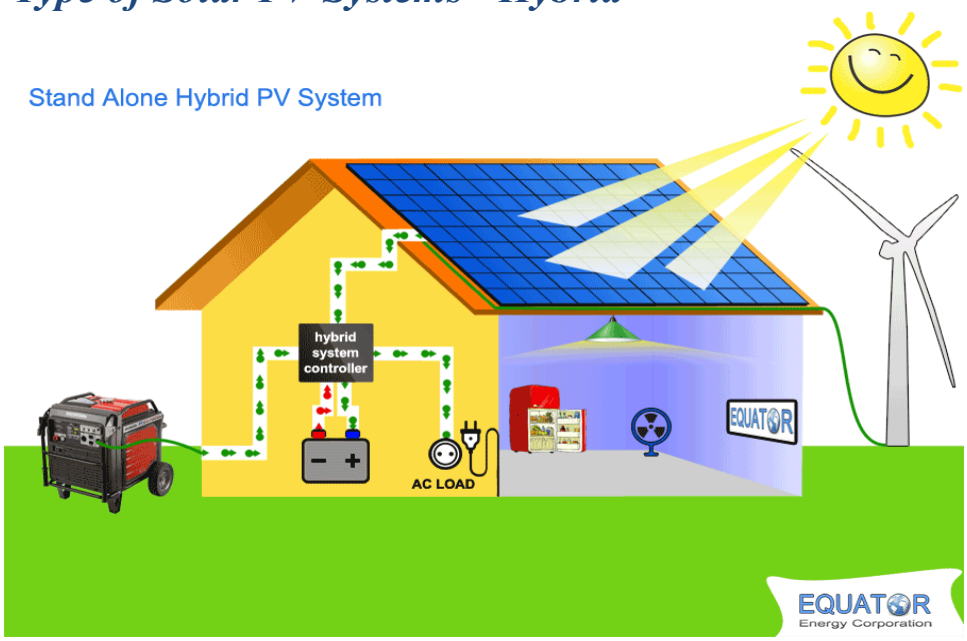
* *PV Module capacity required = Total kWh required /Peak sunshine hrs = 14/5 = 2.8 kWp*



➢Advantages of grid connected system

- Reduce the power bill as it is possible to sell surplus electricity produced to the local electricity supplier.
- Easier to install as they do not require a battery system.
- Effective utilization of generated power because there are no storage losses involved.
- A photovoltaic power system is carbon negative over its lifespan, as any energy produced over and above that to build the panel initially offsets the need for burning fossil fuels.
- Even though the sun doesn't always shine, any installation gives a reasonably predictable average reduction in carbon consumption.

Type of Solar PV Systems - Hybrid



Off-grid or grid-tied PV?

Parameters	Off-grid	Grid-tied
Grid connection	Operates independent of the utility power grid	Connected to the utility power grid
Suitability	Suitable when utility power is not easily accessible or cannot be installed	Used when selling power to utility or the system smaller than the minimum power load.
Storage required	Yes	No
Cost	Costlier– due to battery bank	Less expensive
Installation	Easy to commission	Complex – restricted by the utility grid
Monitoring	Important, but not critical	Requires grid related monitoring, feedback and safety features

How much of Solar Energy is converted into Electrical Energy in Photovoltaic Cells?

Numerical problem

The energy conversion efficiency is a measure of how much of the solar energy is converted into electrical energy. The calculation for the energy conversion factor is,

$\eta = (Pm / (E * A)) * 100$

Where,

η = Energy conversion factor, percent.

Pm = Maximum power output, watts.

E = Solar energy, insolation, watts per square meter.

A = Area of the solar cell, square meters.

Example:

For example, what is the energy conversion efficiency of a 175-watt solar panel that measures 0.75 x 1.50 meters, if the solar insolation is 1,000 W/m^2?

Ans

Since the area of the solar cell is 0.75 * 1.50 = 1.125 m^2, the efficiency is,

$\eta = (175 / (1.125 * 1,000)) * 100$

$\eta = 15.6\%$.

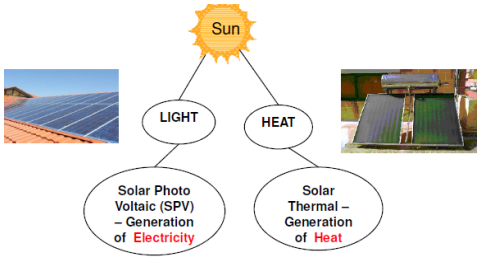
This particular unit converts **15.6% of** the available solar energy into electrical energy.

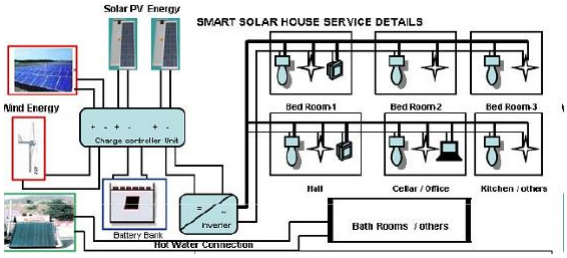
Solar PV System Design considerations

- Energy required = **Load x No. of Hrs** (say Load 2.5 Kw and 4 Hrs) = 2.5 x 4 = 10Kwh
- Battery Energy = Kwh/Inv.Eff = 10/0.9 = 11Kwh
- Battery Voltage Assumed 48V
- Battery Storage (say for 2 days) = 11000 x 2/48v
- With DoD factor of 80%, AH = 460/0.8= 515AH
- Battery Spc. 48V, 600AH (Battery 24 x 2V)
- Inverter Rating = Max. Load = 2.5Kw

PV APPLICATION

Solar and Smart Homes





SM - RE Solar Energy 33

Electrical Power (PV)

- Solar Lamp
- Home Lighting System
- Garden Lighting System
- Street/Yard/Forest Lighting
- Solar Signalling (Rail / Roadways)
- Remote Village Electrification
- Solar Pumps
- Solar Mini Refrigerator


Solar Signalling


Street Light

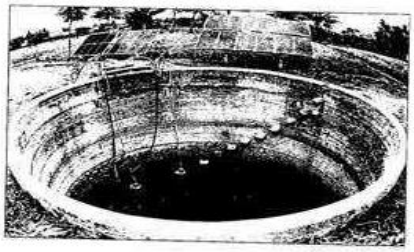

Home Lighting System


Solar Pumps


Garden Lighting System


Innovative Solar Cooler

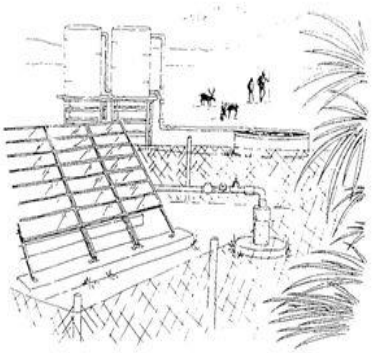
Solar Power for Farmers



HYDRASOL Floating Pump System with Solar Photovoltaic Power

Maximum Head 13 Mts.(42Feet)-Discharge per sunny day1,20,000 Litres with 900Watts Solar Panel

Solar Operated Pump System for Borewells



At 30 Mts.(100Feet) can pump Appx. 22,000 Litres per sunny day with 900Watts Solar Panel.

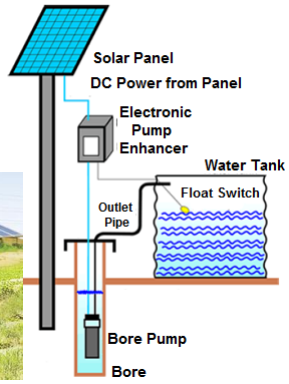
(Maximum Head can go upto 60 Mts., but Discharge will be less per sunny day)

Solar PV Power and Irrigation

Solar Panel and Sub. Pump

SPV water pumping system

Capacity of motor pump set is from 0.5 HP to 2 HP
Deliver a 65,000 liters per day with a 900 watts panel
watts panel from a depth of 7 meters on a clear sunny day
deep well submersible pumps, the water output will be 45000 liters from a 1200 watts panel.



Solar Photovoltaic Power Systems

- Charge Controllers
- Limits the voltage and or current delivered to a battery from a charging source to regulate state-of-charge (prevent damage to batteries or hazardous conditions resulting from overcharging)
- Overdischarge protection for the battery by disconnecting dc loads at low state-of-charge.
- Controls load
- Provides monitoring and indicators of battery voltage and other system parameters

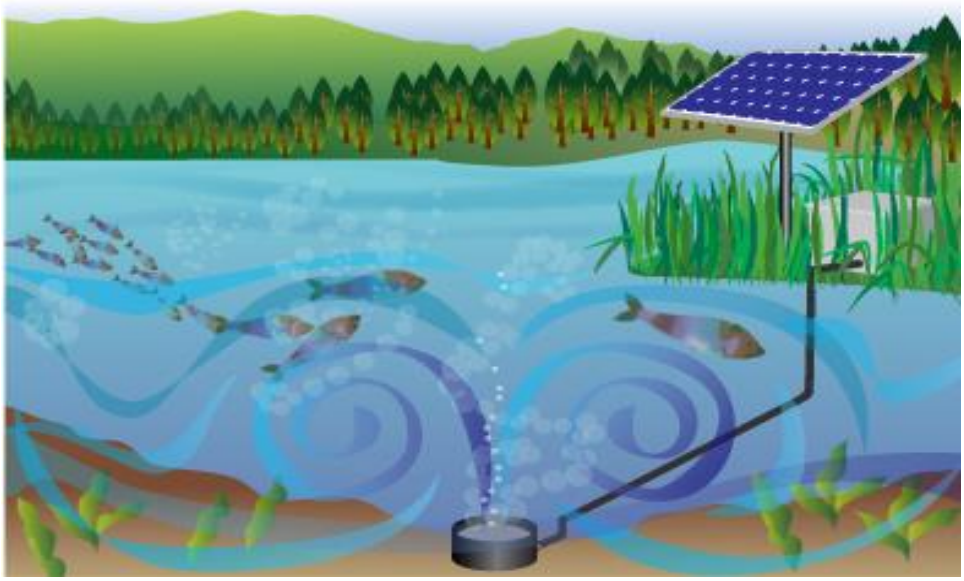
Building-integrated PV Systems: PV panels are integrated into the roof or façade of a building as shown in Figure 11.10. BIPV provides photovoltaic power as well as weather proofing and glazing of buildings

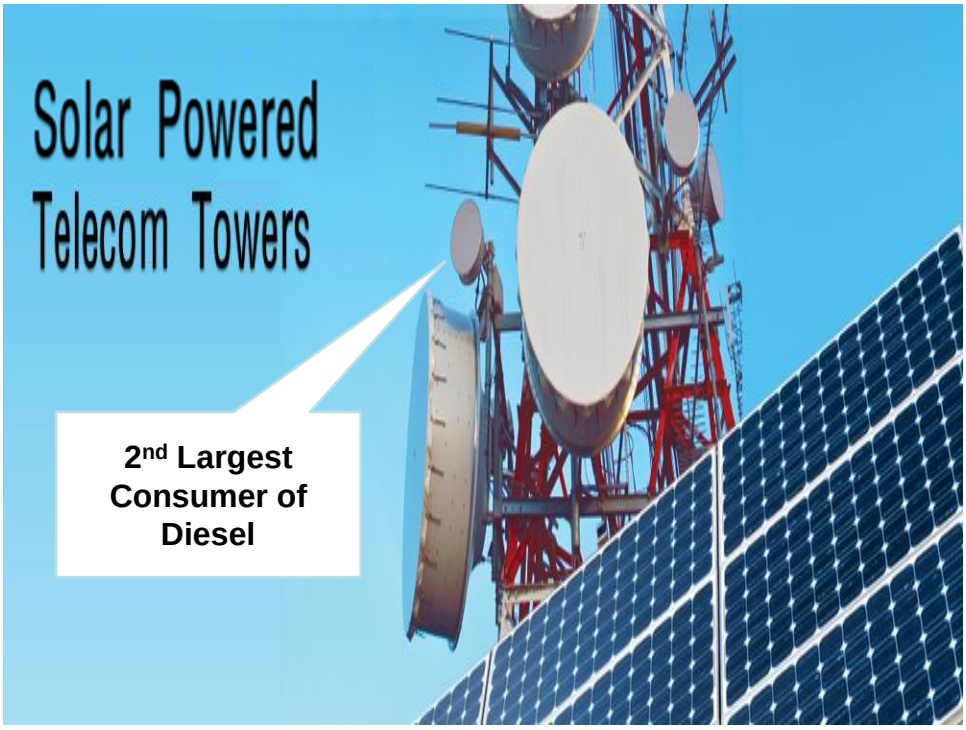
.Since PV cells are integrated into the buildings, no separate costly mountings are required

BIPV

Solar Street Lights

Solar Aerator





Solar Micro / Mini Grid

Solar Desalination Plant

Solar Car Charging Station

Solar Boats

Solar Fountain

Solar Greenhouse

Case Study

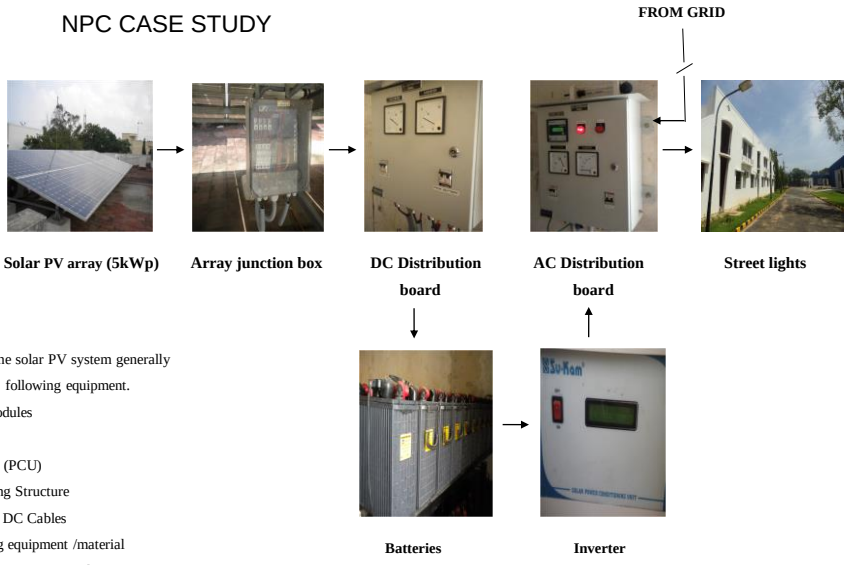
SOLAR PHOTO VOLTAIC STAND ALONE

ENERGY EFFICIENT STREET LIGHTING

Institute street lighting is 100% powered by solar power

SOLAR PHOTO VOLTAIC GRID connected

NPC CASE STUDY



The stand alone solar PV system generally comprises the following equipment.

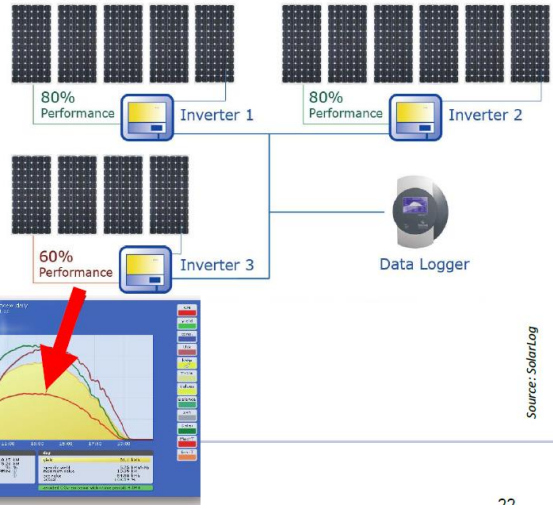
- SPV modules
- Battery
- Inverter (PCU)
- Mounting Structure
- AC and DC Cables
- Earthing equipment /material
- Junction Boxes or combiners
- Instruments and protection equipments

Plate 2.3. Components of the Standalone Photovoltaic System installed at NPC

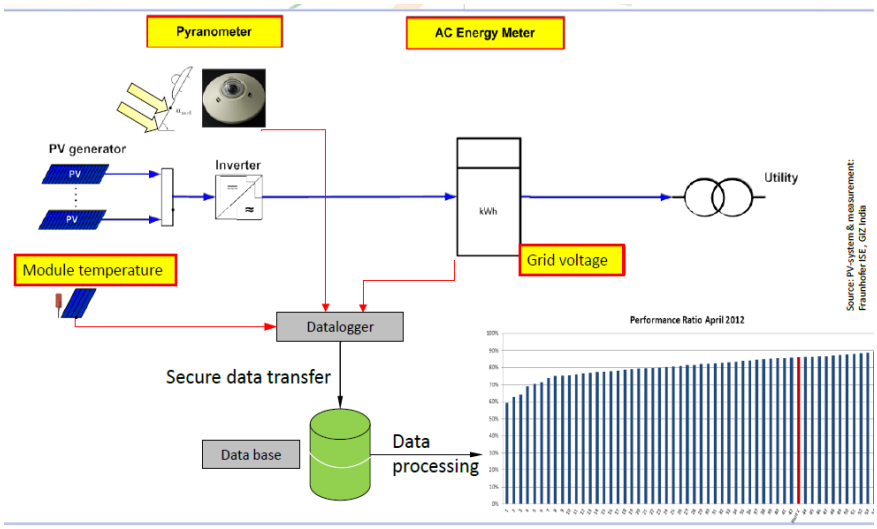
PV Performance Monitoring

PV Performance Monitoring

Many malfunctions can be detected with detailed plant monitoring units used by skilled operators .

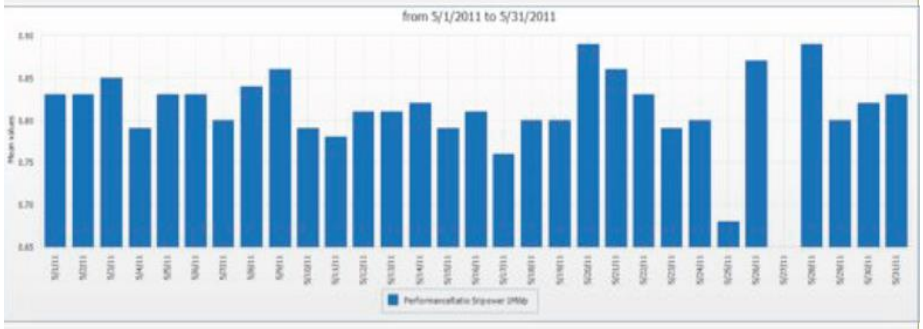


PV Performance Monitoring



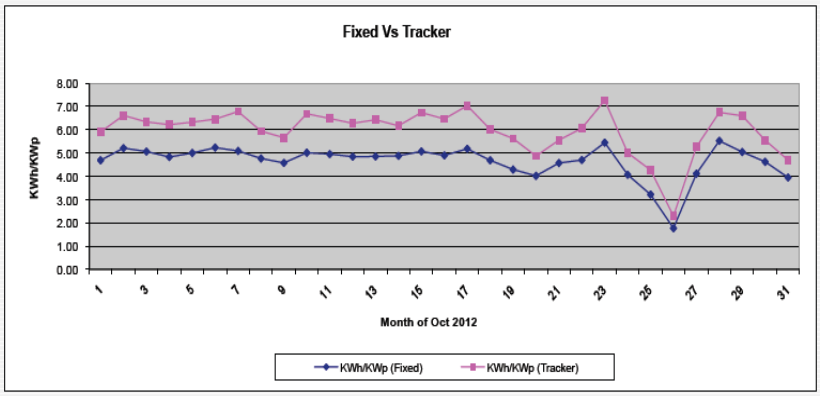
Performance Evaluation

$$\text{Performance Ratio} = \frac{\text{Actual Reading of Plant Output in KWh}}{\text{Calculated, Nominal Plant Output in KWh}}$$



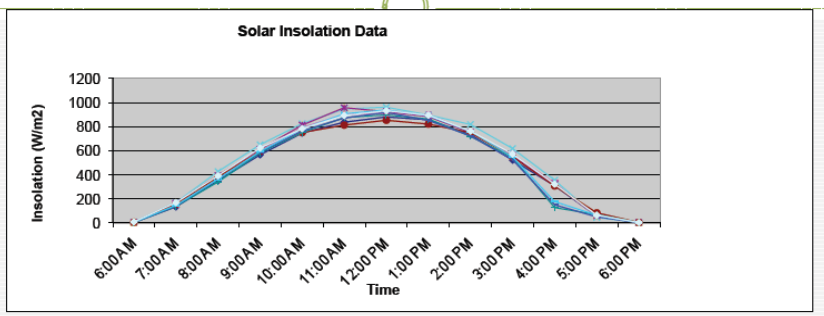
Average Performance Ratio = 82.6%

Tracking Vs Fixed Performance



Single Axis Tracking: On Average is 23% better than Fixed Tracking

PV Central Inverters



- Loads on the Inverters are not the same through-out the day, as the solar insolation is not constant.
- Inverter Efficiency is not flat for all loads from 0-100%
- At lesser input loads, the efficiency is less than the peak efficiency.

MCQ

1. Plants convert solar energy into _____ energy

(a) Chemical energy,
(b) Light energy
(c) Heat energy
(d) None of the above

2. Which of the following statement is not true about solar cell?

(a) It has no moving part
(b) It is reliable and almost maintenance free
(c) It is modular in design
(d) It is cheap and efficient,

3. The charge carrier available in a semiconductor material:

(a) free electrons and holes,
(b) only electrons
(c) only holes
(d) Positively charged ions

4. If no load is connected to solar PV system:

(a) it will stop absorbing light,
(b) it will dissipate energy in the panel and increase its temperature
(c) its voltage will go on increasing till its breakdown
(d) it will start reflecting the light

5. At a temperature of 0 K, silicon behaves as a (an):

(a) superconductor,
(b) normal conductor
(c) insulator
(d) semiconductor

6. The energy associated with a photon is:
(a) directly proportional to wavelength
(b) inversely proportional to frequency
(c) directly proportional to intensity of radiation
(d) inversely proportional to wavelength,

7. The single solar cell voltage is about _____
(a) 0.2 V
(b) 0.5 V ,
(c) 1.0 V
(d) 2.0 V

8. The solar energy directly used for _____
(a) Drying
(b) Water heating
(c) Distillation
(d) **All of the above,**

9. The efficiency of a solar cell may be in the range_____
(a) 2 to 7%
(b) 10 to 20%,
(c) 30 to 40%
(d) 50 to 60%

10. A module in a solar panel refers to_____.
(a) series arrangement of solar cells
(b) parallel arrangement of solar cells
(c) **series and parallel arrangement of solar cells,**
(d) None of the above

Thank You

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