



Introduction to Renewable Energy Technologies

Lecture-17 **Solar PV Cells and Modules-1**

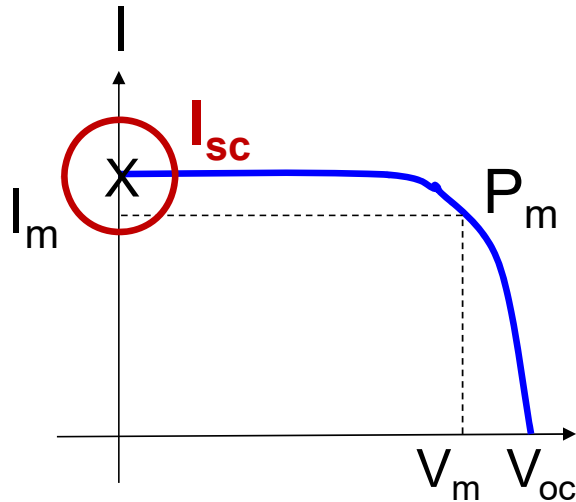
Prof. C.S. Solanki
Department of Energy Science and Engineering
chetanss@ese.iitb.ac.in



In this lecture

- ❑ Parameters of solar cells
- ❑ Series and parallel connection of solar cells
- ❑ PV module design
- ❑ Different types of modules and their ratings

Short-Circuit Current, I_{sc}

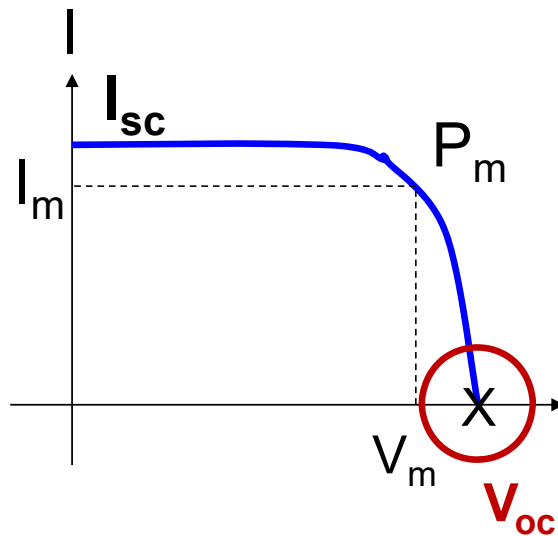


At $V=0 \rightarrow I_{total} = -I_L = I_{sc}$

$$I_{sc} = q A (W + L_p + L_n)$$

- The short-circuit current is the current through the solar cell when the voltage across the solar cell is zero (i.e., **when the solar cell is short circuited**).
- The short-circuit current is due to the generation and collection of light-generated charge carriers.
- **Short-circuit current is the largest current which may be drawn from the solar cell.**

Open Circuit Voltage: V_{oc}

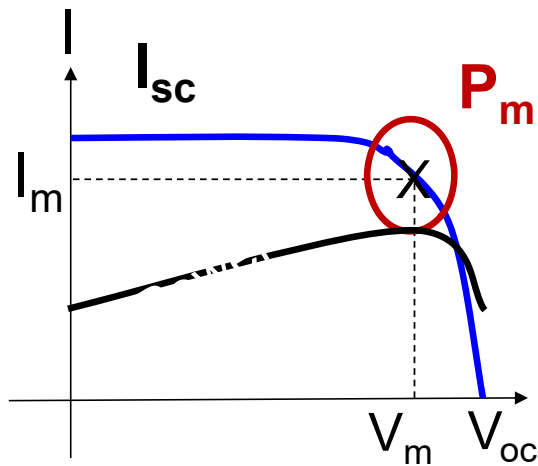


- The open-circuit voltage, V_{oc} , is the maximum voltage available from a solar cell, and this occurs at zero current.
- The open-circuit voltage corresponds to the amount of forward bias on the solar cell junction due to illumination.

by setting $I_{total} = 0$

$$V_{oc} = \frac{kT}{q} \ln\left(\frac{I_L}{I_0} + 1\right)$$

Maximum power: P_m

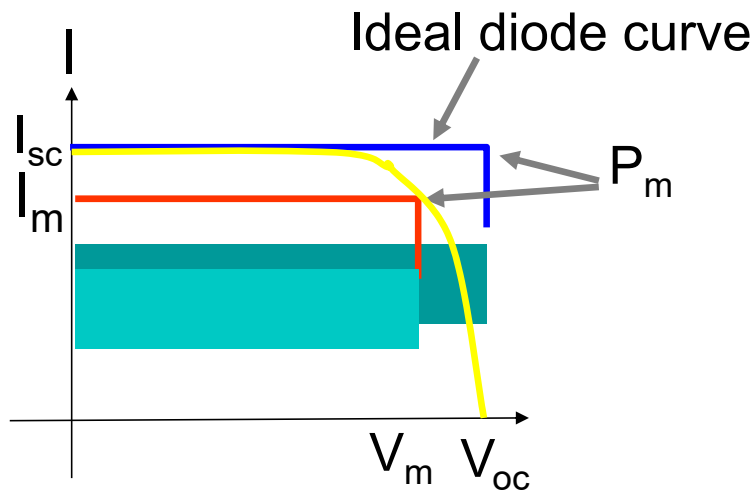


- Power out of a solar cell increases with voltage, reaches a maximum (P_m) and then decreases again.

$$P_m = I_m \times V_m$$

Remember we get DC power from a solar cell

Fill Factor: FF

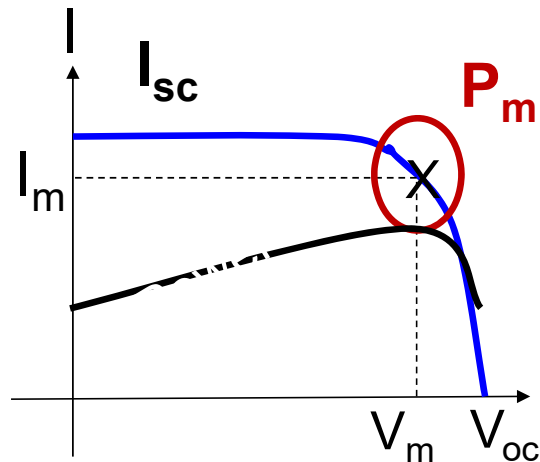


- The FF is defined as the ratio of the maximum power from the actual solar cell to the maximum power from a ideal solar cell

Graphically, the FF is a measure of the "squareness" of the solar cell

$$FF = \frac{\text{Max power from real cell}}{\text{Max power from ideal cell}} = \frac{V_m I_m}{V_{oc} I_{sc}}$$

Efficiency: η



- Efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun.

$$\eta = \frac{\text{Max. Cell Power}}{\text{Incident light Intensity}} = \frac{V_m I_m}{P_{in}}$$

$$\eta = \frac{V_{oc} I_{sc} FF}{P_{in}}$$

- The efficiency is the most commonly used parameter to compare the performance of one solar cell to another.
- Efficiency of a cell also depends on the solar spectrum, intensity of sunlight and the temperature of the solar cell.



Typical industrial Si cell parameters

$$V_{oc} = 0.55 \text{ to } 0.62V$$

$$I_{sc} = 33 \text{ to } 37 \text{ mA/cm}^2$$

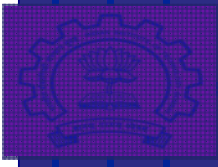
$$V_m = 0.8 \text{ to } 0.9 \text{ of } V_{oc}$$

$$I_m = 0.9 \text{ to } 0.95 \text{ of } I_{sc}$$

$$FF = 70 \text{ to } 78\%$$

Efficiency ??

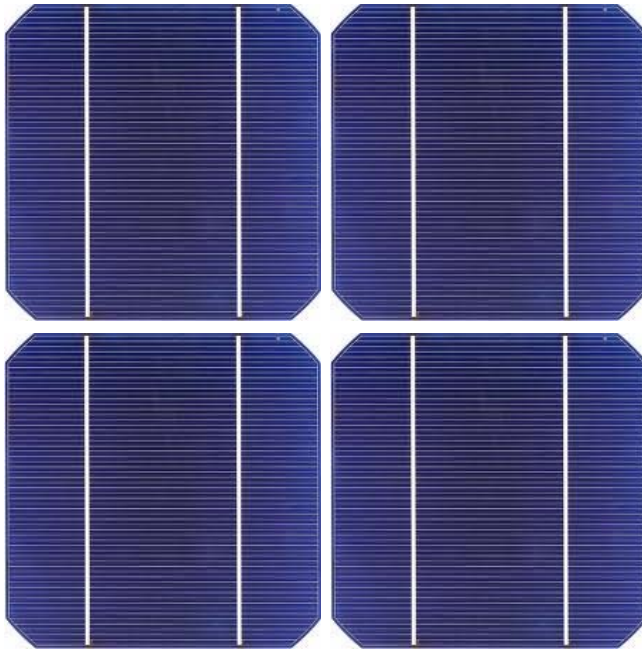
Calculate the efficiency
of a typical solar cell
with the these
parameters



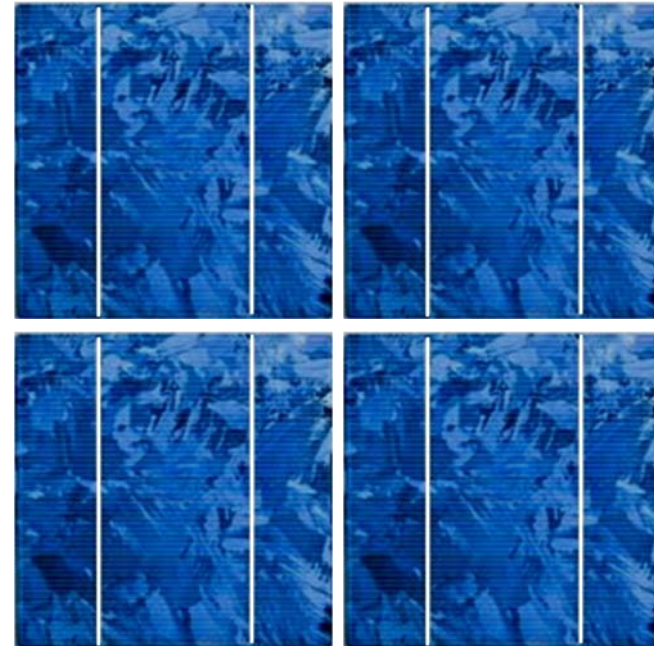
Solar PV Module

Identifying Solar PV Module

Closer look of arrangement of cells in PV modules



**Monocrystalline
PV module**



**Polycrystalline
PV module**

Solar PV module

Different type
of PV module





PV module

An array of several solar cells connected in series and parallel for getting larger power output

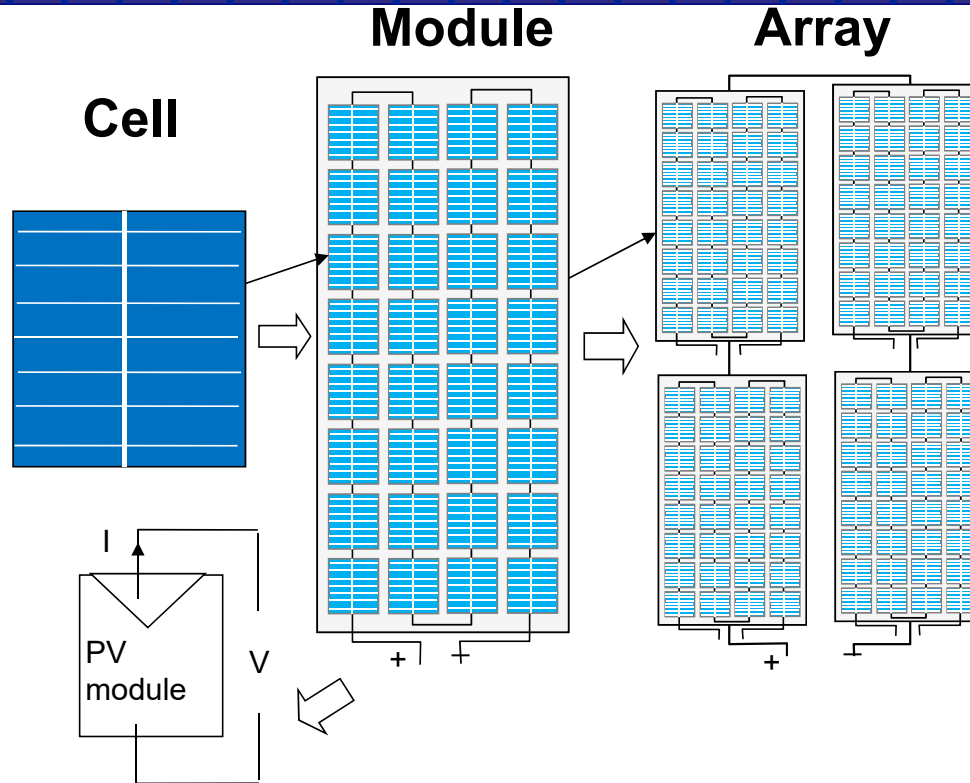
Inter connection of solar cells:

- **Thin film technology:** While process of manufacturing of solar cell
 - **Wafer based technology:** Solar cells are manufactured first and then interconnected
-

Solar PV array

Solar PV array:

- Interconnected solar PV modules.
- Provide power of 100 **W** to several **MW**.



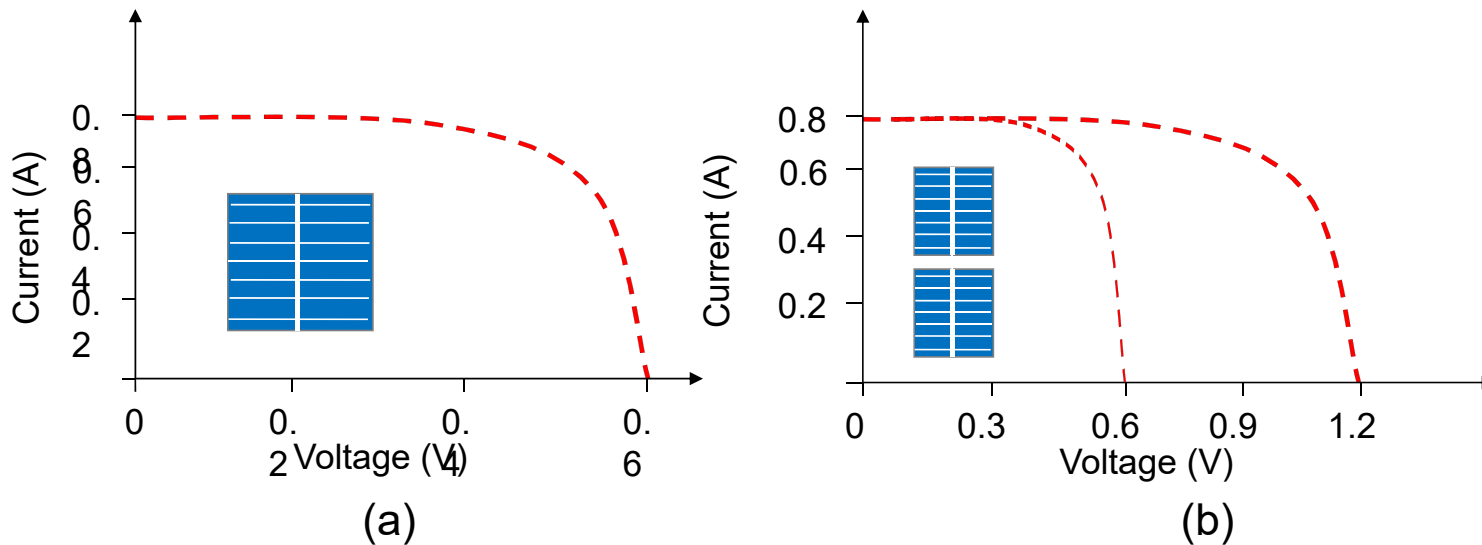
Interconnection of solar cells into solar PV modules and modules into solar PV arrays. Schematic representation of PV module is also shown.

Series and parallel connection of cells

Series connection

• Let us consider a solar cell having V_{oc} of 0.6 V and I_{sc} of 0.8 A. When two identical cells are connected in series, the V_{oc} of the two cells will be added.

The I_{sc} will be the same as that of a single cell



I-V characteristics of identical solar cells (a) single cell, (b) two cells in series

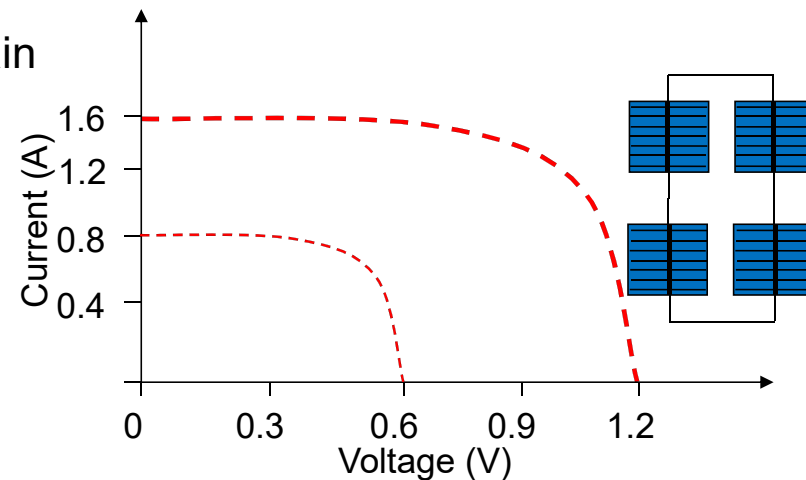
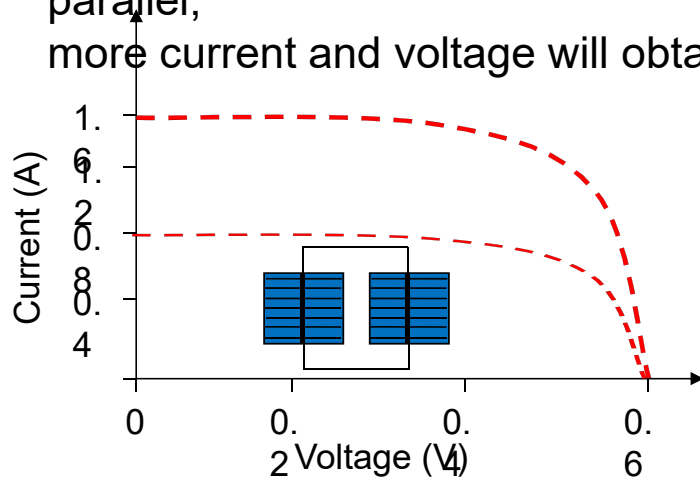
Series and parallel connection of cells

Parallel connection

- I_{sc} the two cells will be **added** .
- V_{oc} of the combination will remain **same** as that of single cell.

Series and Parallel Combination

- When more than one series connected cells are connected in parallel, more current and voltage will obtain



I-V characteristics of identical solar cells (a) two cell connected in parallel

(b) series and parallel combination of cells.

Design of Solar PV Modules

- ❑ PV module Power rating varies from $0.1 W_p$ to $400 W_p$
- ❑ One can design PV modules for different current and voltage and power ratings

Power output depends on:

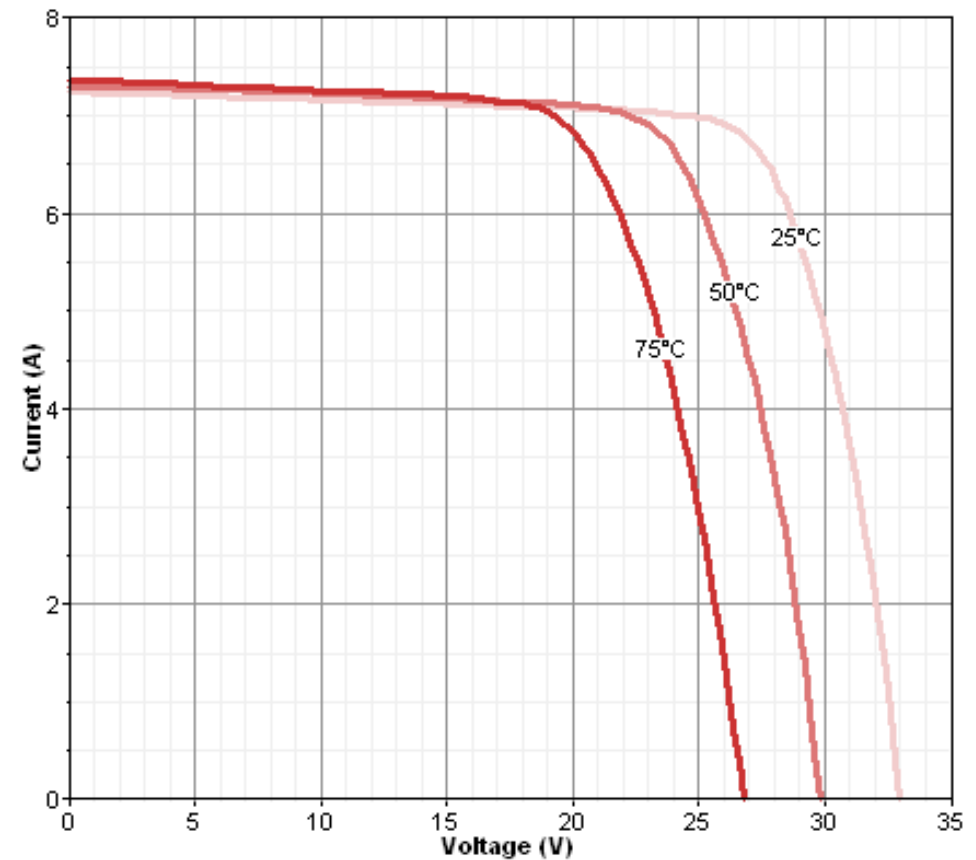
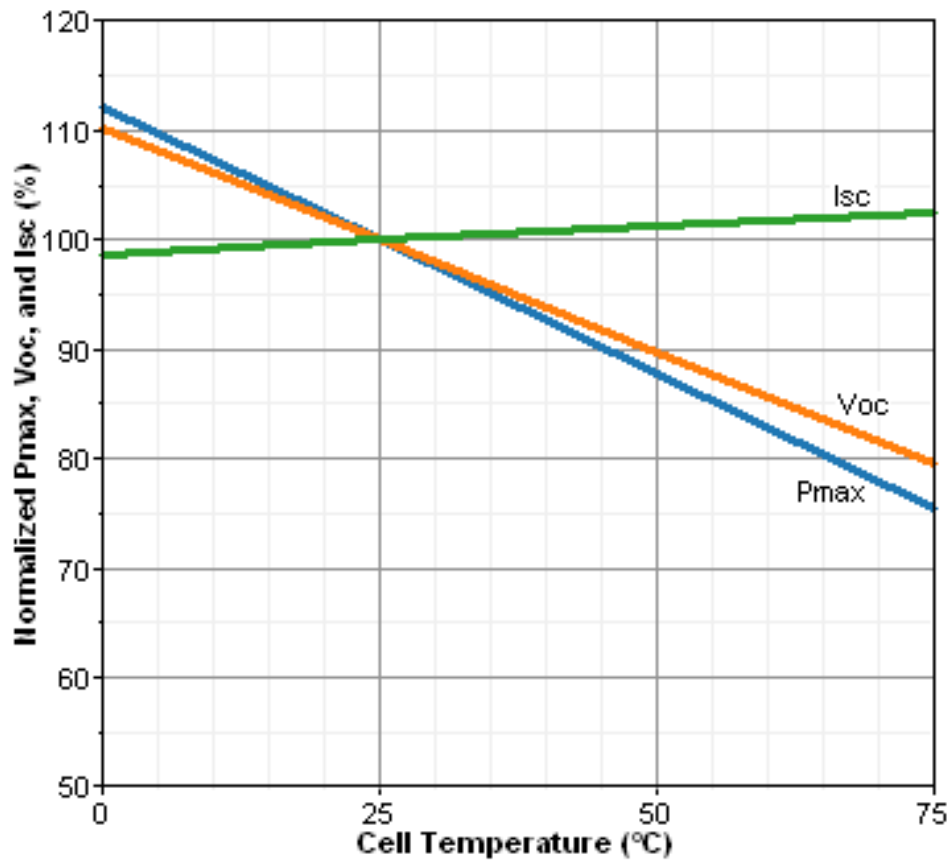
- ❑ Number of cells in series
- ❑ Number of cells in parallel
- ❑ Mismatch losses in connected cells
- ❑ Temperature of cells

Data sheet of PV modules

Parameter	Notation	Value
Voltage at maximum power point	V_{mpp} (STC) (V)	38.4
Open-circuit voltage	V_{oc} (STC) (V)	46.2
Short-circuit current	I_{sc} (STC) (A)	8.95
Current at maximum power point	I_{mpp} (STC) (A)	8.33
Power rating	P_M (STC) (W)	320
Length of module	L_{mod} (m)	0.982
Breadth of module	B_{mod} (m)	1.955
Temperature coefficient of maximum power	%/C	-0.41
Temperature coefficient of open-circuit voltage	%/C	-0.31
Temperature coefficient of short-circuit current	%/C	0.052
Number of cells		72
Number of by-pass diodes		3

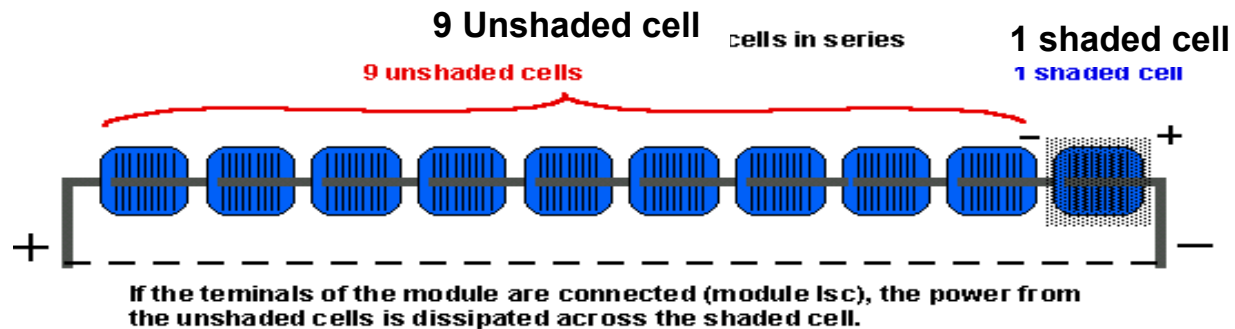
Effect of temperature on Module parameters

Overall impact of increased temperature than STC is decrease in power output



Hot-Spot Heating

Hot-spot heating occurs when there is one low current solar cell in a string of at least several high short-circuit current solar cells



One shaded cell in a string reduces the current through the good cells, causing the good cells to produce **higher voltages that can often reverse bias the bad cell**

→ Power gets dissipated in the "poor" cell

Local overheating, or "hot-spots", leads to destructive effects

→ Cell or glass cracking, melting of solder or degradation of the solar cell.



Bypass diode

Bypass diode is a diode which is used to avoid the destructive effect of hot spots

or local heating in series connected cells.

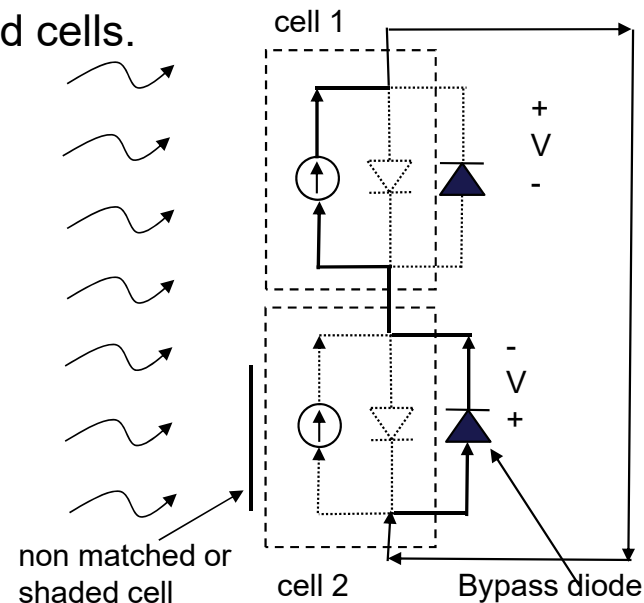
□ Bypass diode, is connected in parallel with solar cells with opposite polarity

□ In normal condition the bypass diode operates in reverse bias condition.

□ If a series connected cell is shaded, reverse bias will appear across it

□ This reverse bias will act as a forward bias for the bypass diode

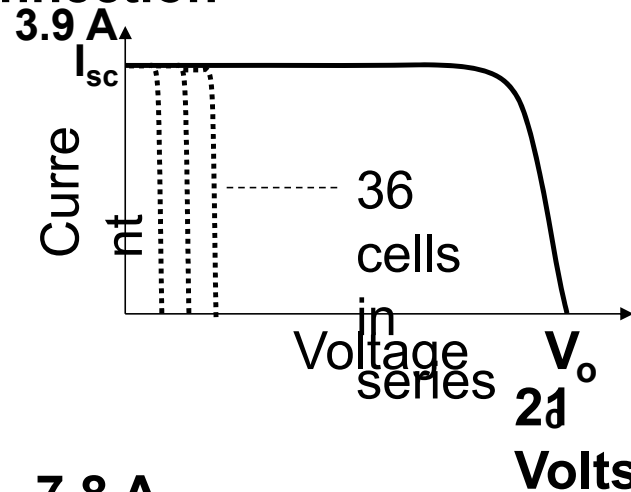
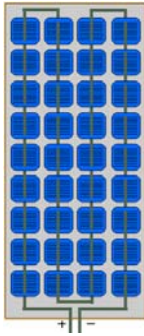
□ Extra current will be bypassed



Placing of bypass diode in parallel with cells

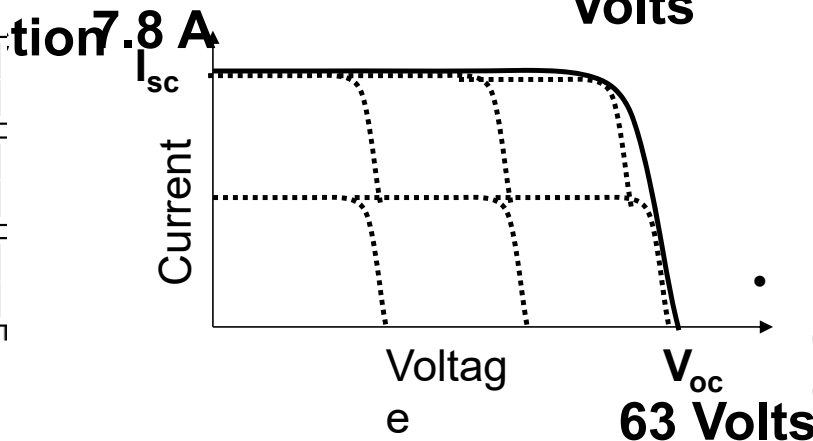
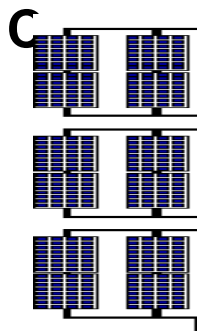
Design and Structure of PV modules

Series Connection



- Usually cell in module exhibits identical characteristics
- Shape of the I-V curve of the module is same as that of cells with change in scale of axis

Parallel Connection



- I-V relationship for N cell in series and M cell in parallel

I-V relationship of modules

$$I = I_L - [I_o e^{q(V+IR_s)/nkT} - 1]$$

$$V = -IR_s + K \ln\left(\frac{I_L - I + I_o}{I_o}\right)$$

$$V_{mo} = -I_{mo}R_{smo} + K_{mo} \ln\left(\frac{I_{Lmo} - I_{mo} + I_{omo}}{I_{omo}}\right)$$

$$V_{mo} = -I_{mo}N_sR_s + N_sK \ln\left(\frac{I_L - I_{mo} + I_o}{I_o}\right)$$

$$V_{mo} = -I_{mo} \frac{R_s}{N_p} + K \ln\left(\frac{N_{sh}I_L - I_{mo} + N_pI_o}{N_pI_o}\right)$$

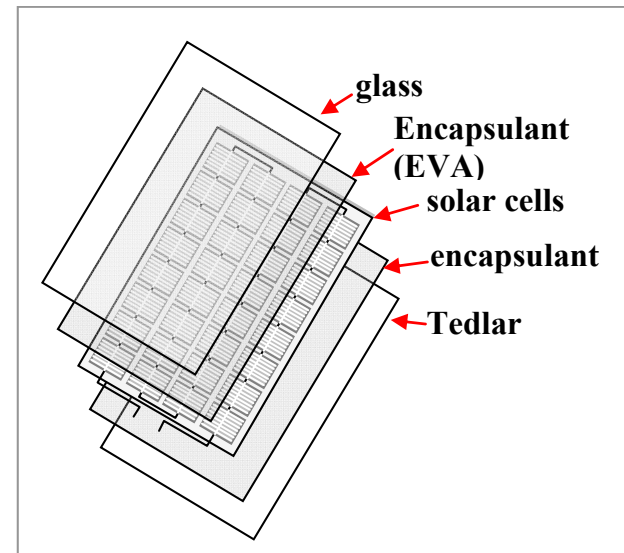
$$V_a = -I_a \frac{N_sR_s}{N_p} + N_sK \ln\left(\frac{N_{sh}I_L - I_a + N_pI_o}{N_pI_o}\right)$$

Similar to solar cell,
I-V relationship for
series connected
and parallel
connected modules
can be written

Fabrication of PV modules

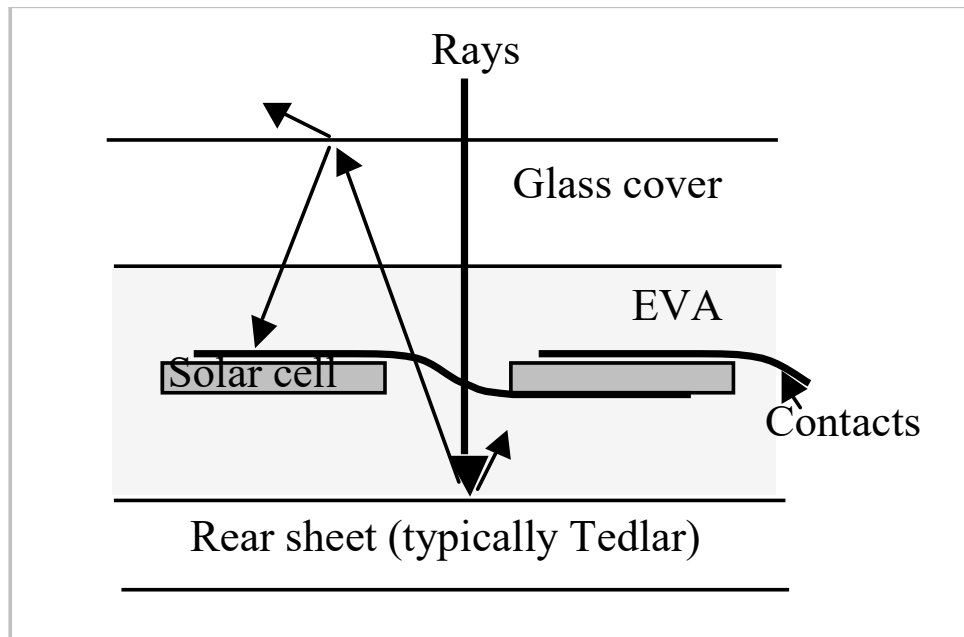
The cells should also be protected from dust, rain, mechanical shock etc. So the PV modules should package by using :

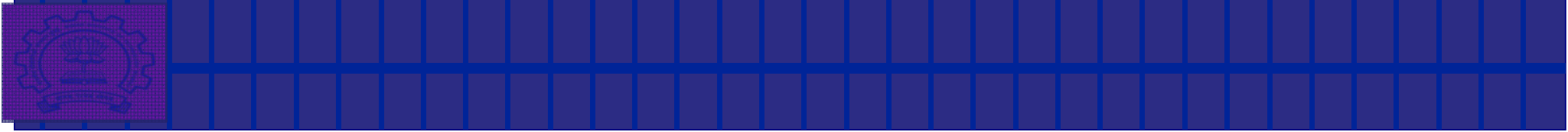
1. **Glass** at the front side
 - Low iron content, toughened and textured Glass
 - Higher transmittivity (over 90%)
2. **Ethylene vinyl acetate (EVA)** for encapsulation
 - High electrical resistivity (10^{14} Ω -cm)
 - Very low water absorption ratio
 - Good optical transmission
3. **Solar cells** (array)
4. **Rear layer** (Tedlar – white colour)
 - back reflection of light
5. **Outer frame** (Al)



Components of Si wafer based PV module.

Module Structure





Thank you