Solar Photovoltaics under Partially Shaded Conditions

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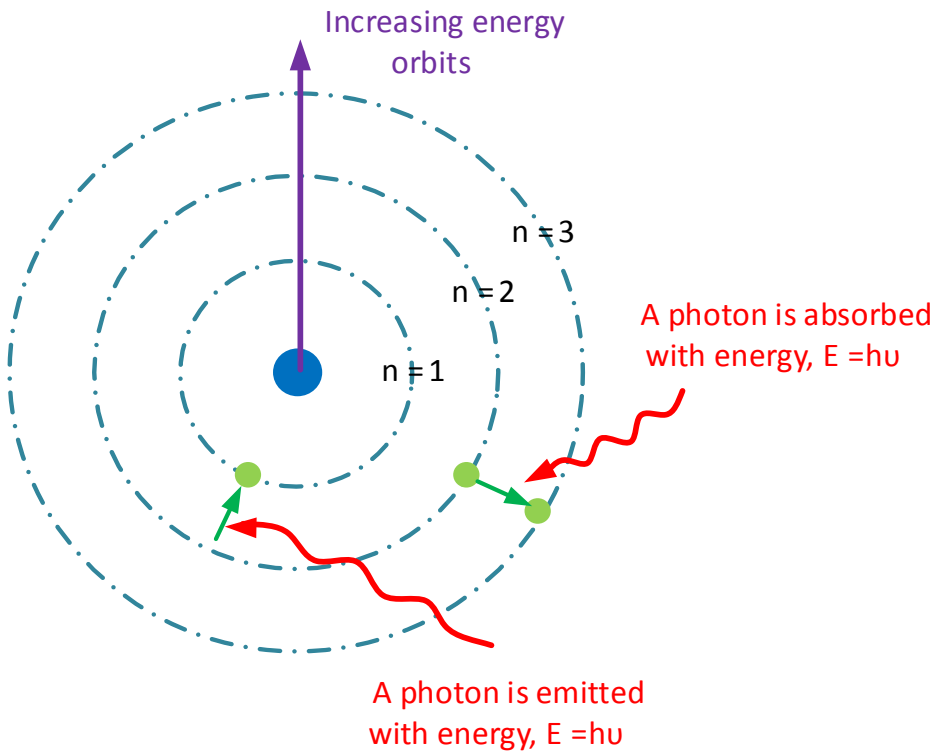
Neils Bohr's Atomic Model



- Electrons in atoms orbit the nucleus in stationary orbits where it does not radiate.
- Electrons can only gain and lose energy by jumping from one allowed orbit to another, absorbing or emitting electromagnetic radiation with a frequency ν determined by the energy difference of the levels according to the Plank's relation.

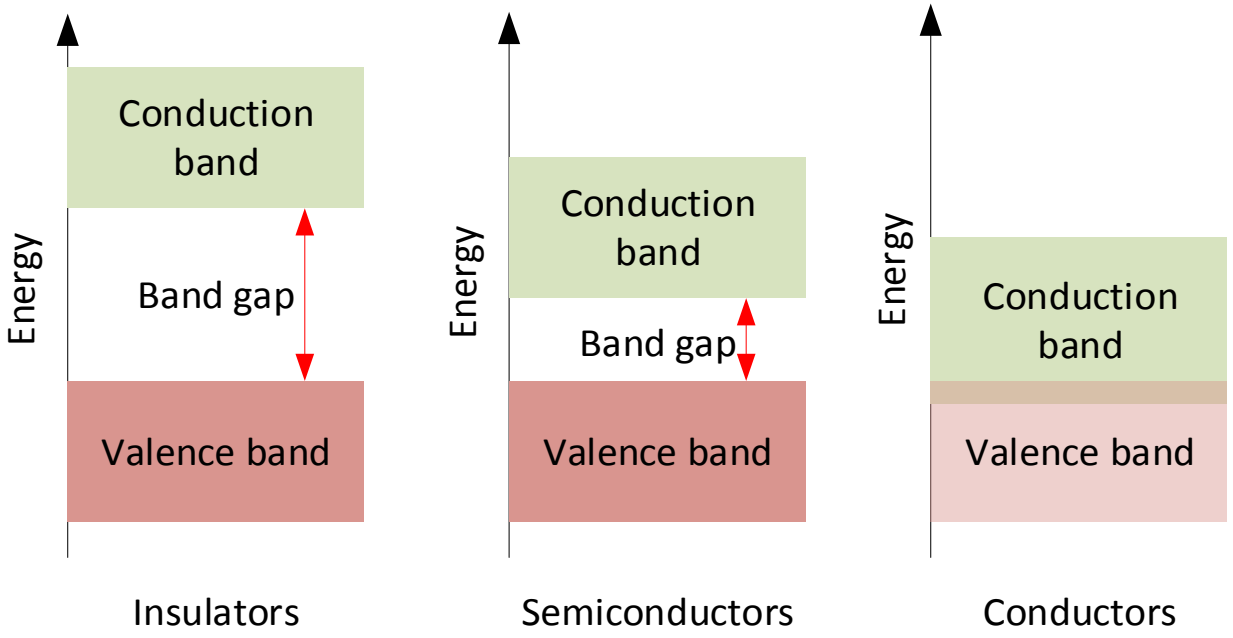
$$E = h\nu$$

(h=plank's constant and ν = frequency of the radiation.)

Different types of materials according to their conductivity

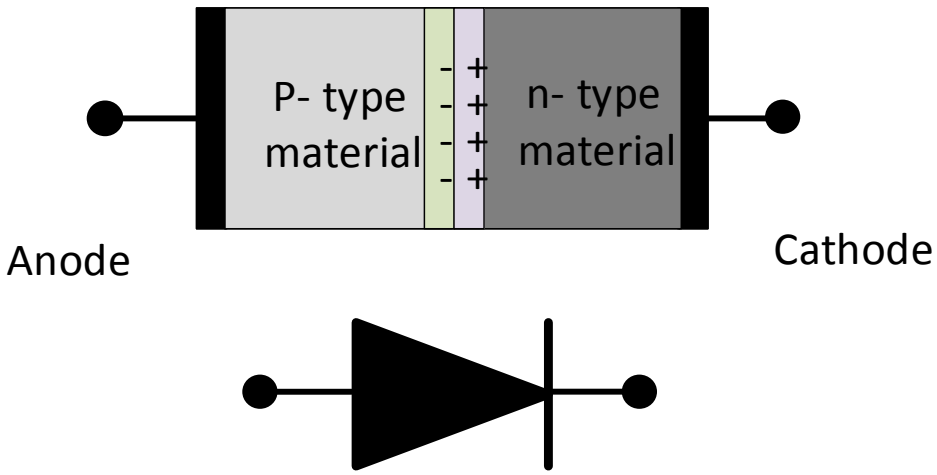
Conductors	Semiconductors	Insulators
Resistivity: 10^{-5} Ω-m	Resistivity: 10^{-5} Ω-m to 10^{5} Ω-m	Resistivity: More than 10^{5} Ω-m
Example: Copper	Example: Silicon, Ge	Example: Teflon

Energy band theory in different materials



- If energy gap is high it is difficult for electrons to jump to the conduction band.
- Then there will be less electrons in the conduction band which adversely affects the conductivity.
- However, if the band gap is small or the bands are overlapping there will be higher conductivity

P-n junction diode



- A semiconductor material is doped in such a way that a boundary interface is created between a p type and an n type material. This is called a p-n Junction diode
- They allow flow of current in only one direction
- These are widely used in signal level and power level electronics.

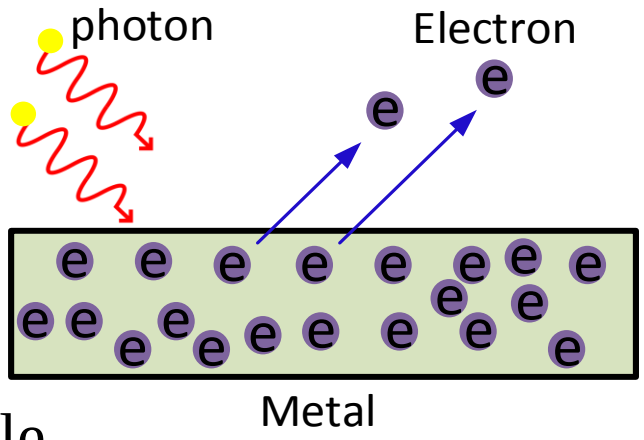
Extrinsic and Intrinsic semiconductors

- Intrinsic Semiconductors: These are the pure and un-doped semiconductors.

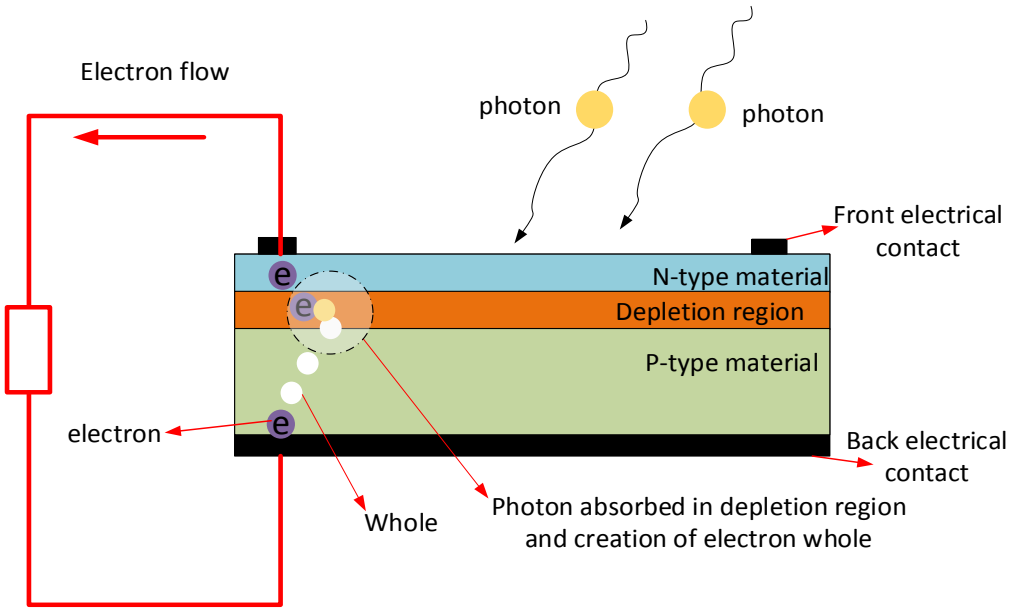
- Extrinsic semiconductors: These are the doped semiconductors with higher conductivity.

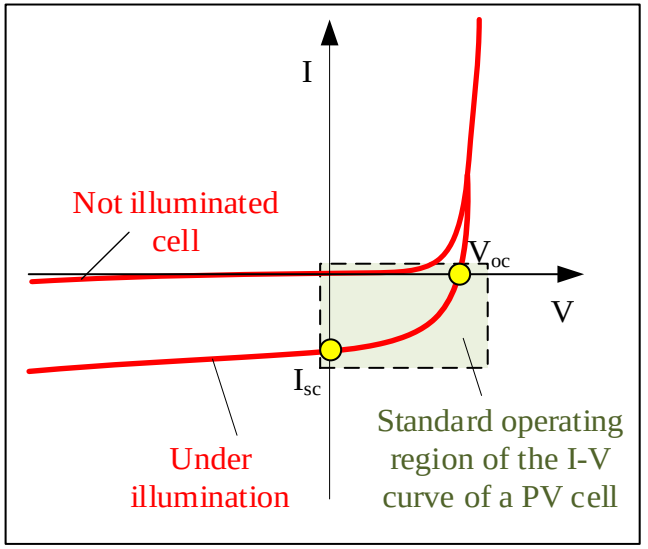
Photoelectric effect

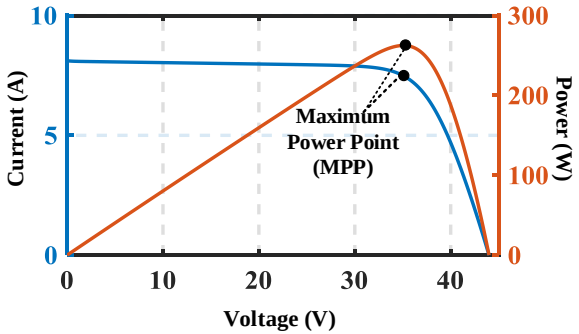
- According to photo electric effect, if a light of certain frequency, ν is incident upon a metal surface, electrons are emitted.
- The energy carried by each light particle is, E=hν, where h is plank's constant and ν is the frequency of light.
- According to Einstein, the complete energy of the photon is transferred to the electron.

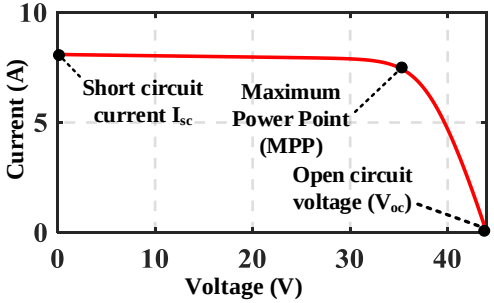


Solar Photovoltaic cell working principle and characteristics



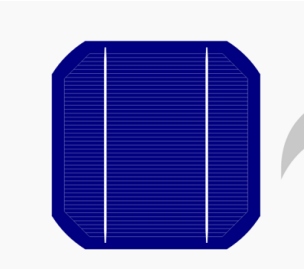






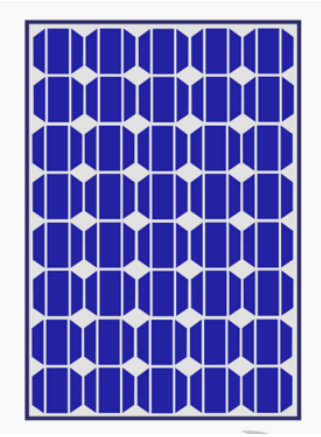
PV Cell- PV Module- PV Arrays

PV Cell



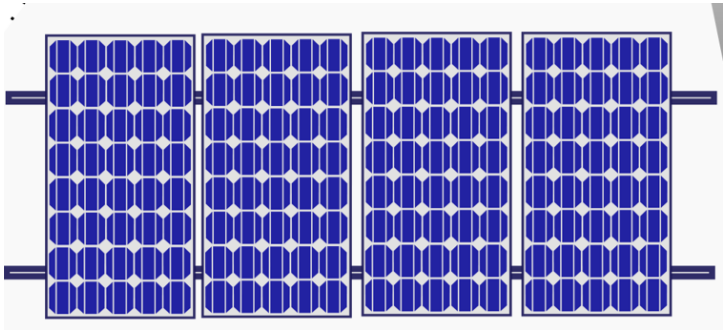
Generates electricity from solar energy using photovoltaic effect

PV Module



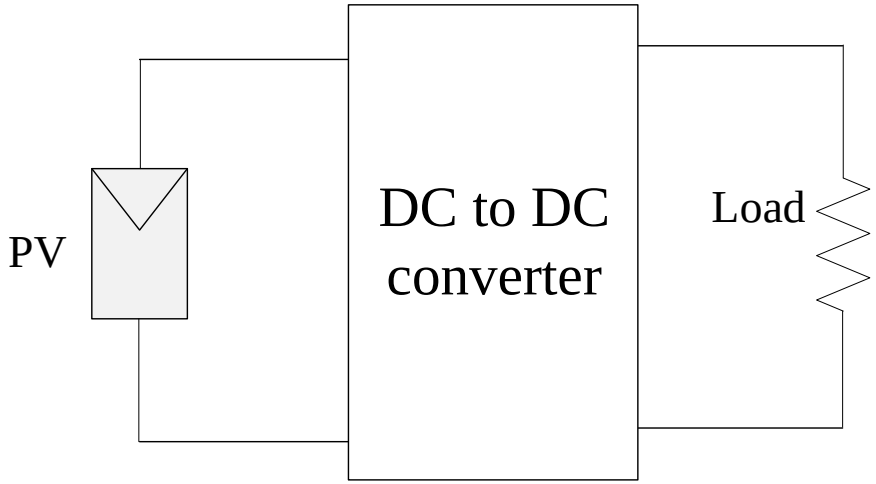
PV cells are connected and sealed to form modules

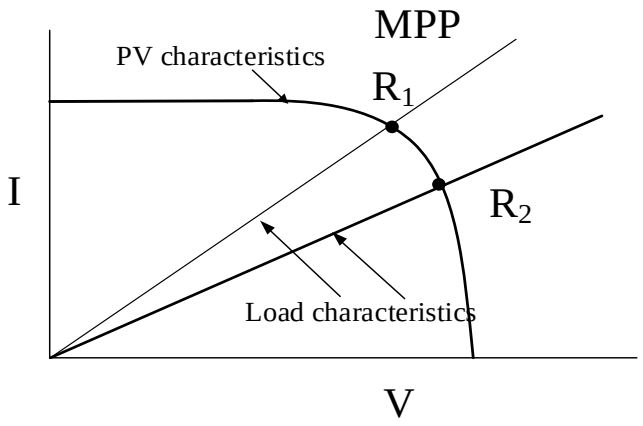
PV Array



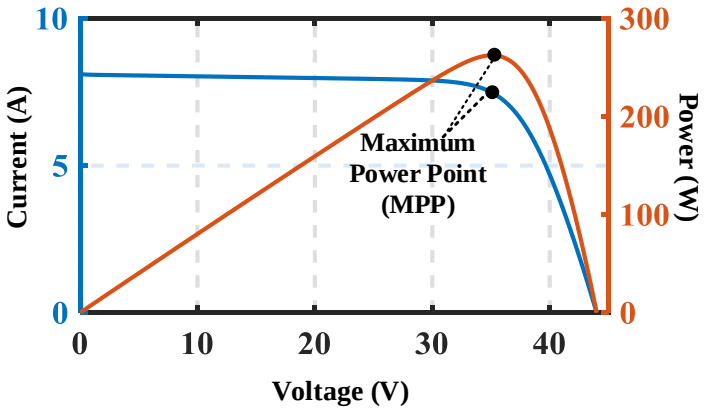
Modules are connected in series and parallel for required voltage and current rating

Maximum Power Point Tracking (MPPT)

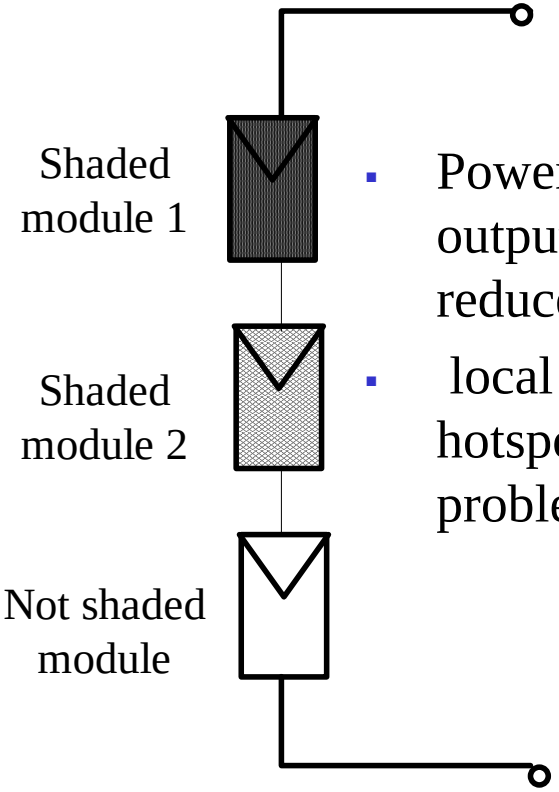




- By varying the load curve MPP is achieved
- This is done using a power converter

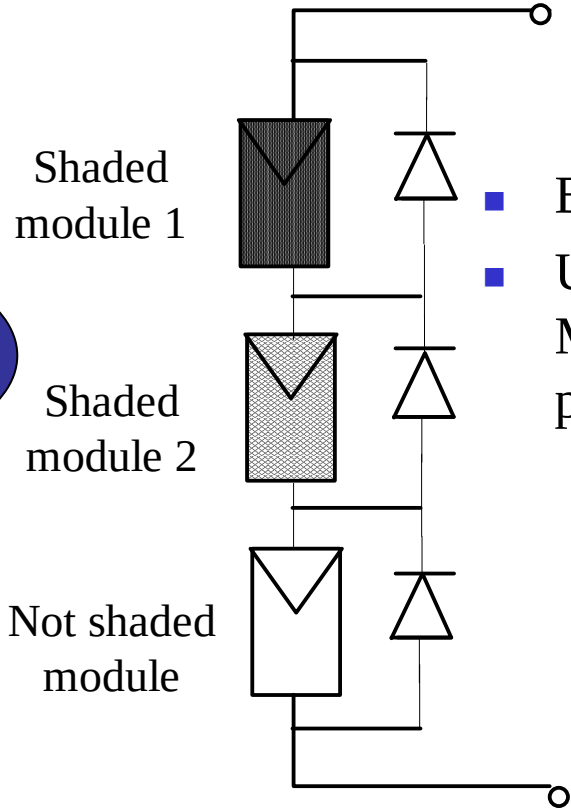


Partial Shading Condition

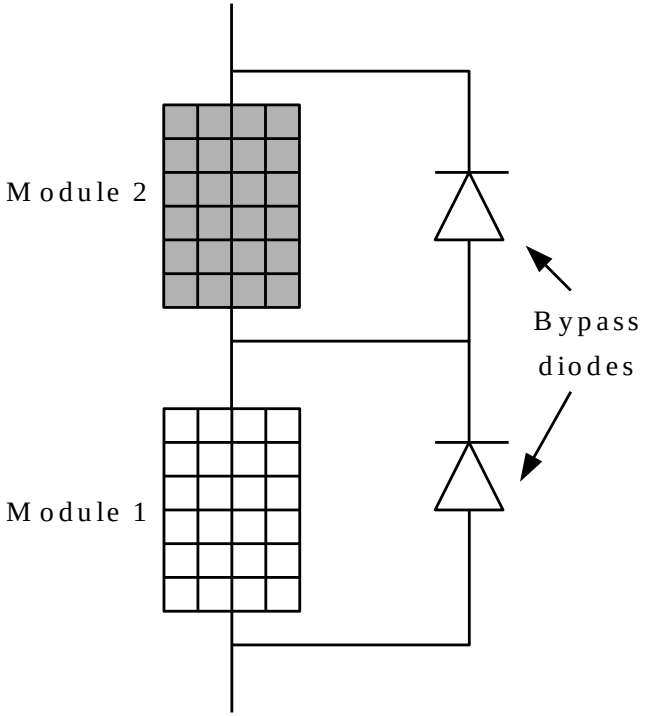


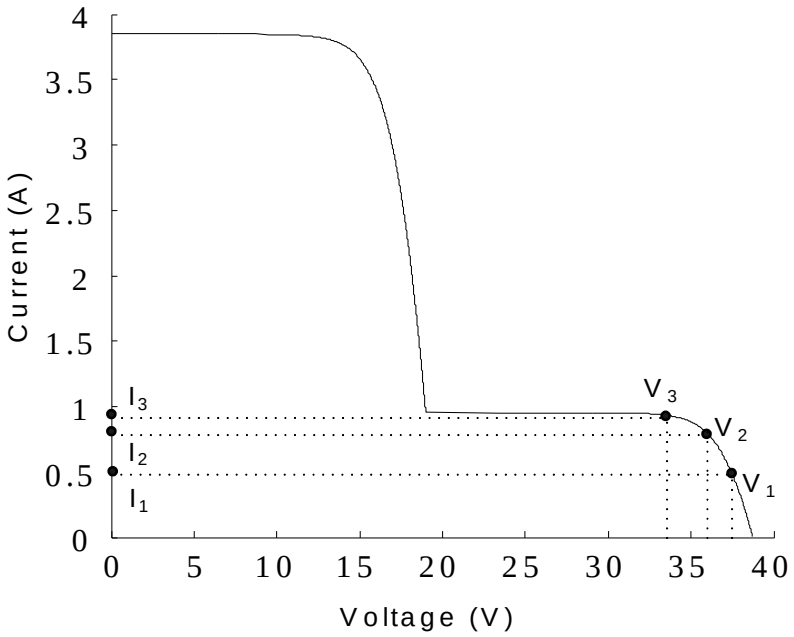
- Power output is reduced
- local hotspot problem

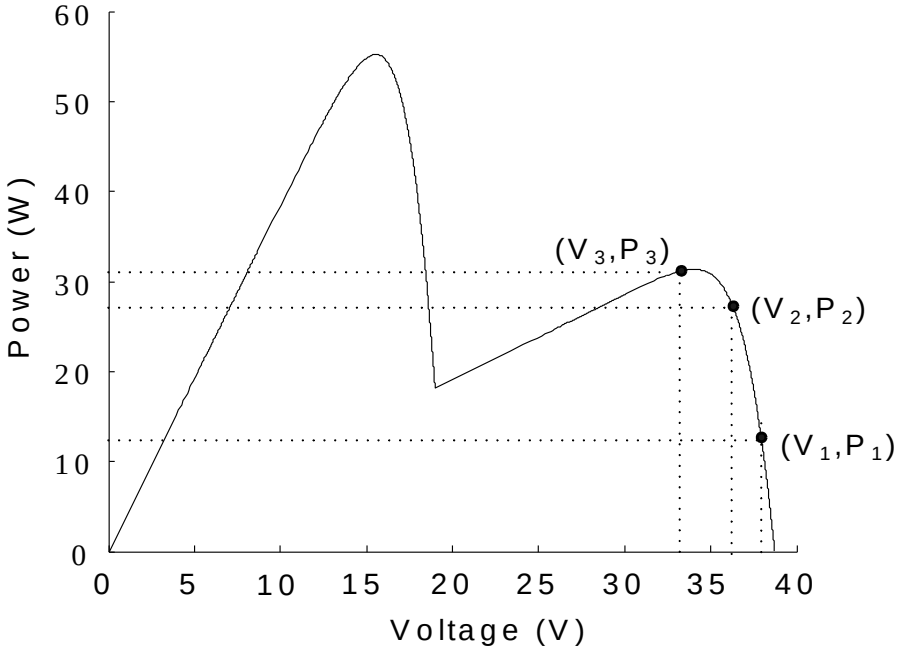
Solution ?



- Bypass Diodes
- Unshaded Module provide Power


Module 2
Module 1
Bypass
diodes

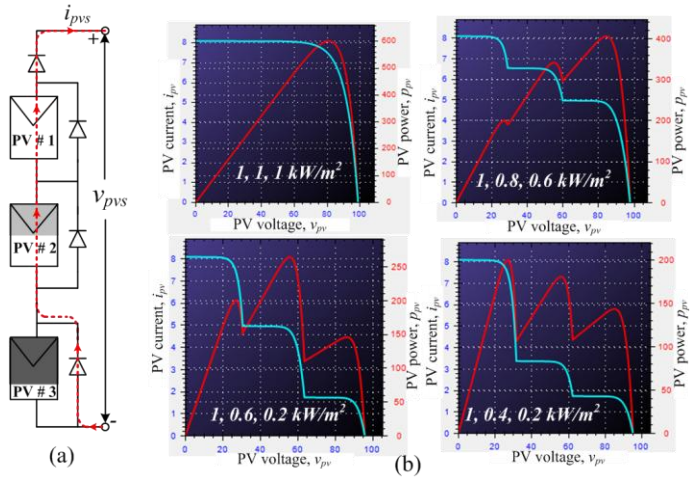


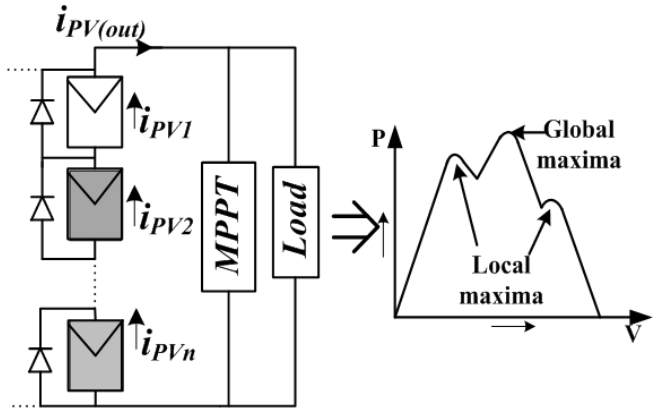


Resultant characteristics of two series connected modules. (a) *I-V* characteristics and (b) *P-V* characteristics.

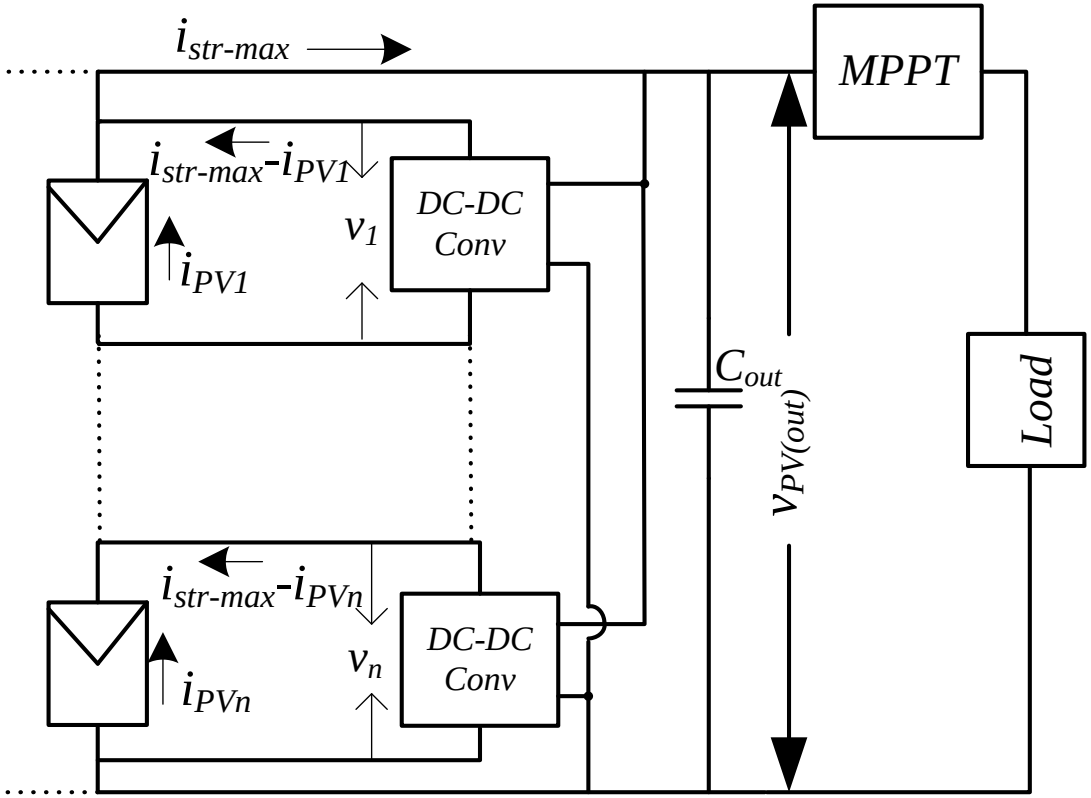
MPPT during Partial Shading

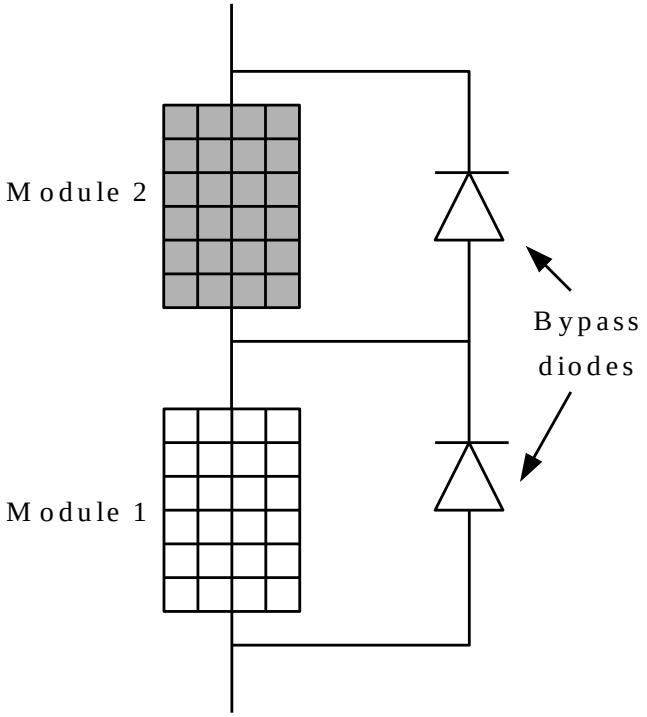
- Generation of multiple peaks in the power-voltage characteristics
- with Bypass Diode Un-shaded modules continue to provide the power
- Loss of power that a shaded module could have generated anyhow

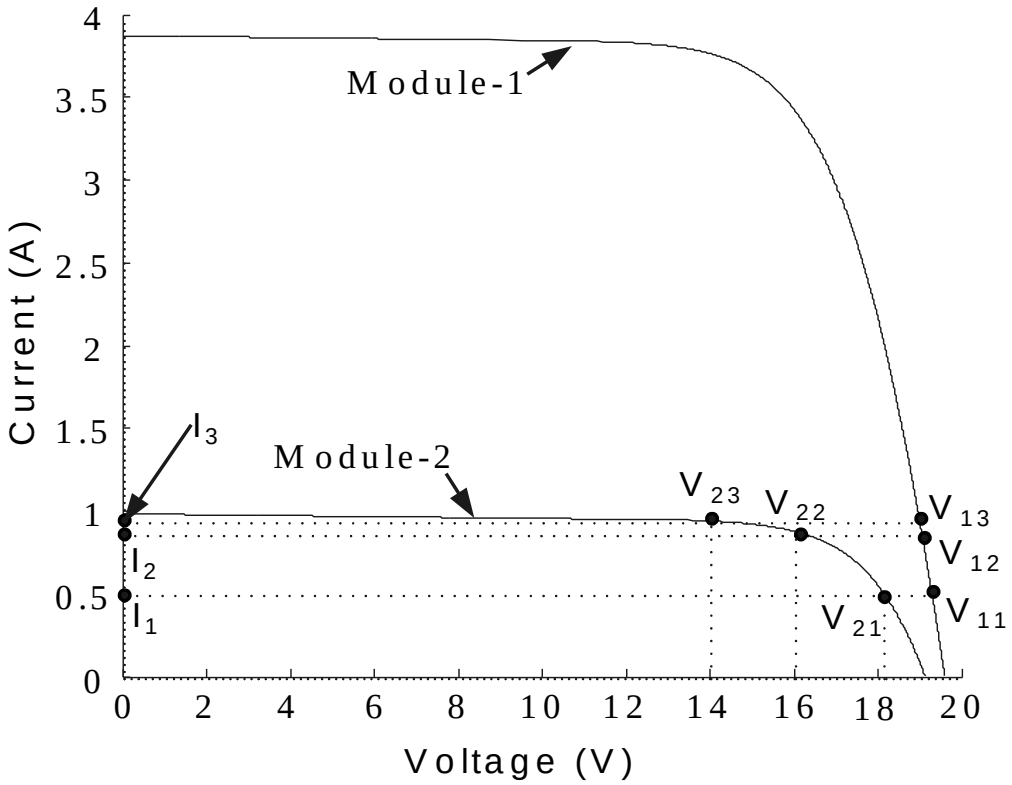




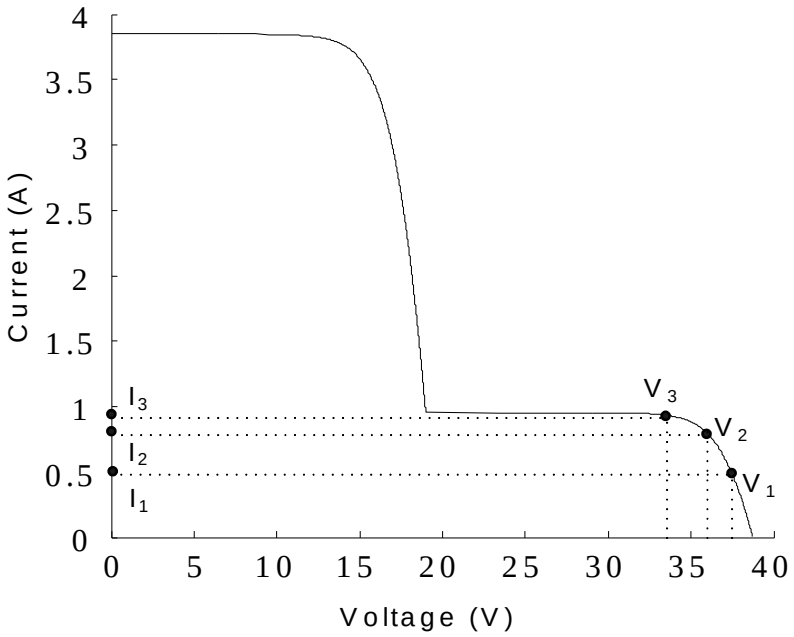
MPPT during Partial Shading

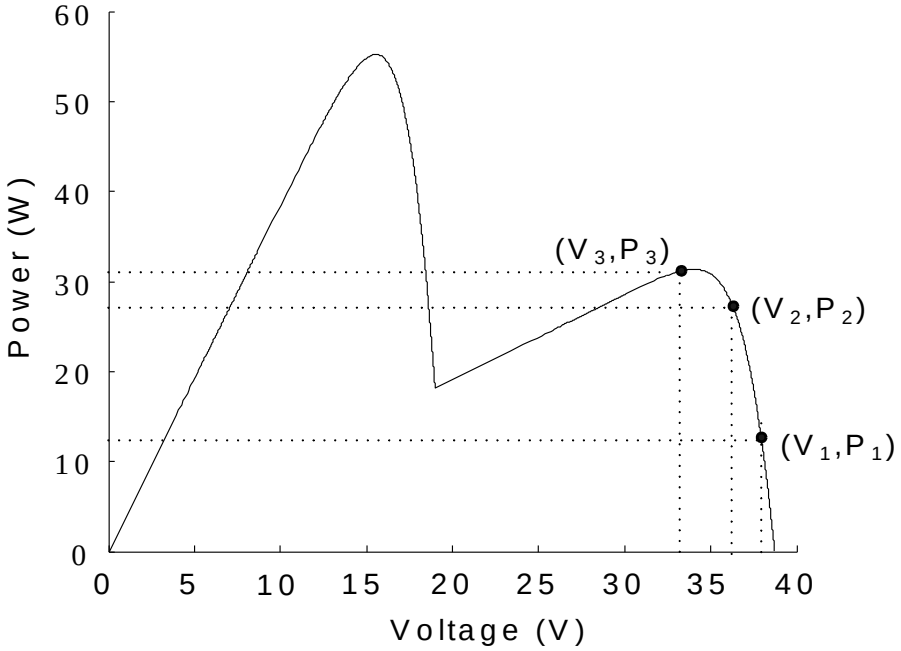






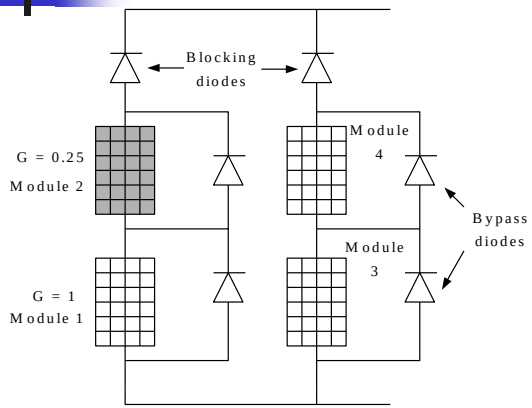
Series connected modules with bypass diodes

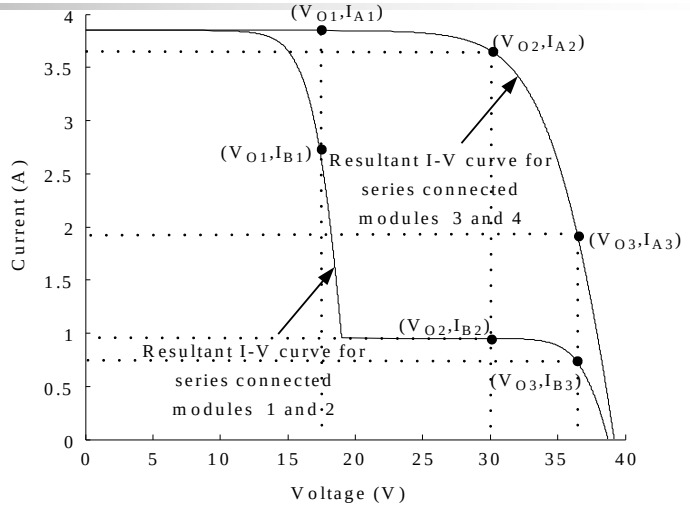


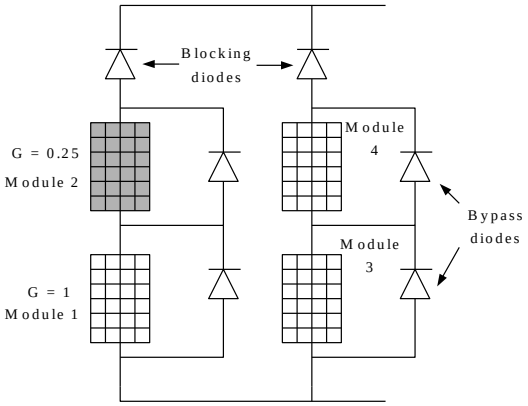


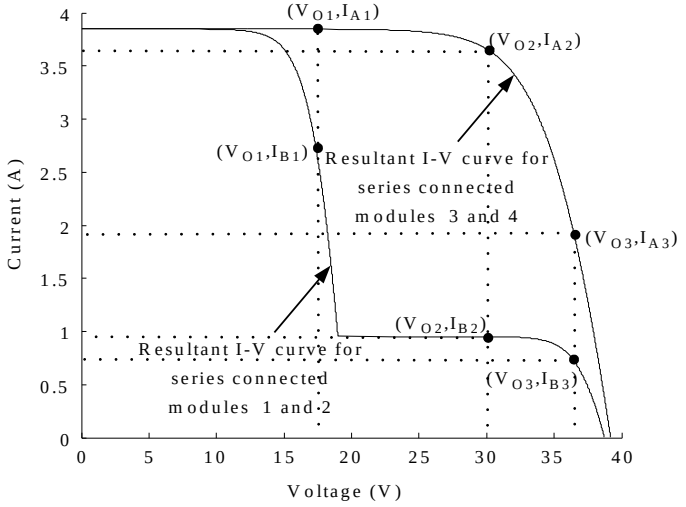
Resultant characteristics of the two series connected modules.

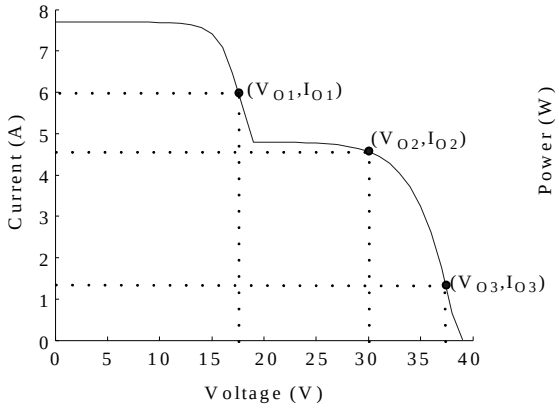
(a) *I-V* characteristics and (b) *P-V* characteristics.


Blocking
diodes
G = 0.25
Module 2
Module
4
Bypass
diodes
Module
3
G = 1
Module 1

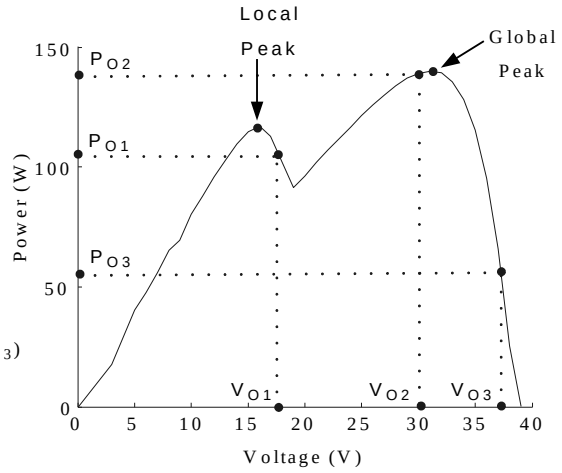

(VO1,IA1)
(VO2,IA2)
(VO1,IB1)
Resultant I-V curve for
series connected
modules 3 and 4
(VO3,IA3)
(VO2,IB2)
Resultant I-V curve for
series connected
modules 1 and 2
(VO3,IB3)
Current (A)
Voltage (V)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
5
10
15
20
25
30
35
40


Blocking
diodes
G = 0.25
Module 2
Module
4
Bypass
diodes
Module
3
G = 1
Module 1


(VO1,IA1)
(VO2,IA2)
(VO1,IB1)
Resultant I-V curve for
series connected
modules 3 and 4
(VO3,IA3)
(VO2,IB2)
Resultant I-V curve for
series connected
modules 1 and 2
(VO3,IB3)
Current (A)
Voltage (V)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
5
10
15
20
25
30
35
40


Current (A)
Voltage (V)
(V O1,I O1)
(V O2,I O2)
(V O3,I O3)

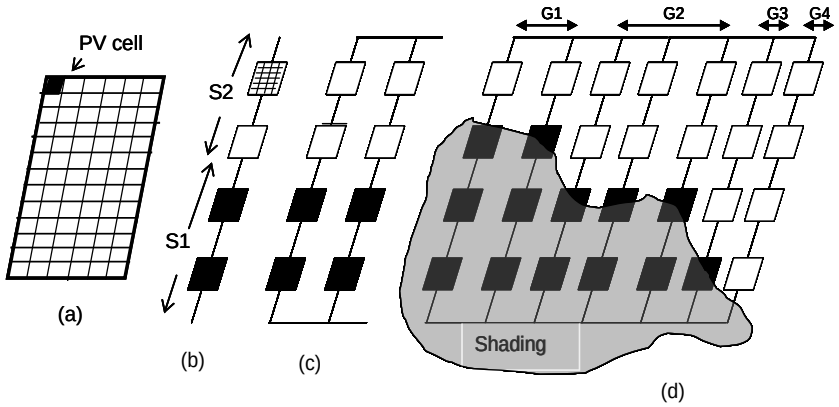
(a)


Local
Peak
Global
Peak
P O2
P O1
P O3
Power (W)
Voltage (V)
V O1
V O2
V O3

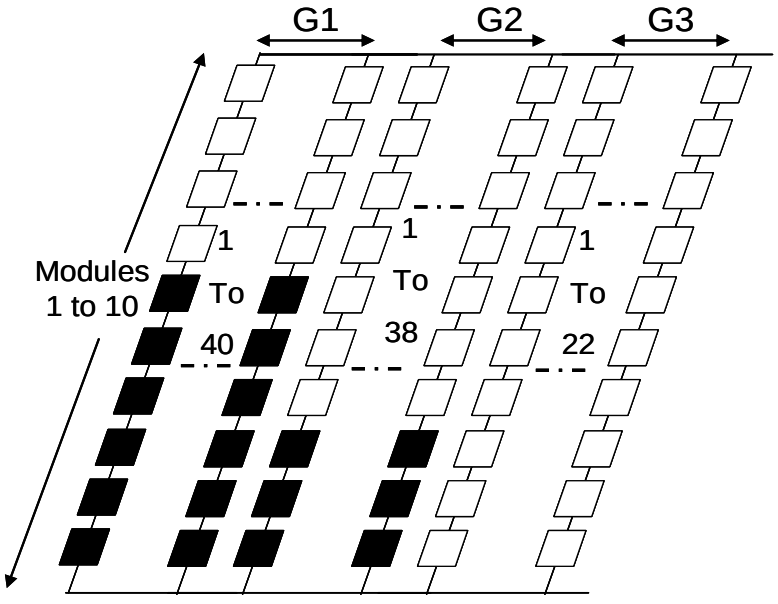
(b)

Modelling of Partial Shading

- **There is a need for a flexible, interactive, and comprehensive simulation model, which can serve as the following.**
  - A basic tool to accurately predict the PV characteristics and output power under partially shaded conditions.
  - A design aid for users who want to build actual PV systems, study the stability and interfacing aspects.
  - A tool to study the effect of array configuration on the output power for a likely/known shading pattern.
  - A planning tool that can help in the installation of efficient and optimum PV arrays in a given surrounding. And a tool to develop and validate the effectiveness of existing and new MPPT schemes.
- **Software packages like PV-Spice, PV-DesignPro, SolarPro, PVcad, and PVsyst are available, but have one or more of the following limitations:**
  - commercial, proprietary in nature and expensive;
  - too complex to model the shading effects;
  - do not support the interfacing of the PV arrays with actual power electronic systems.



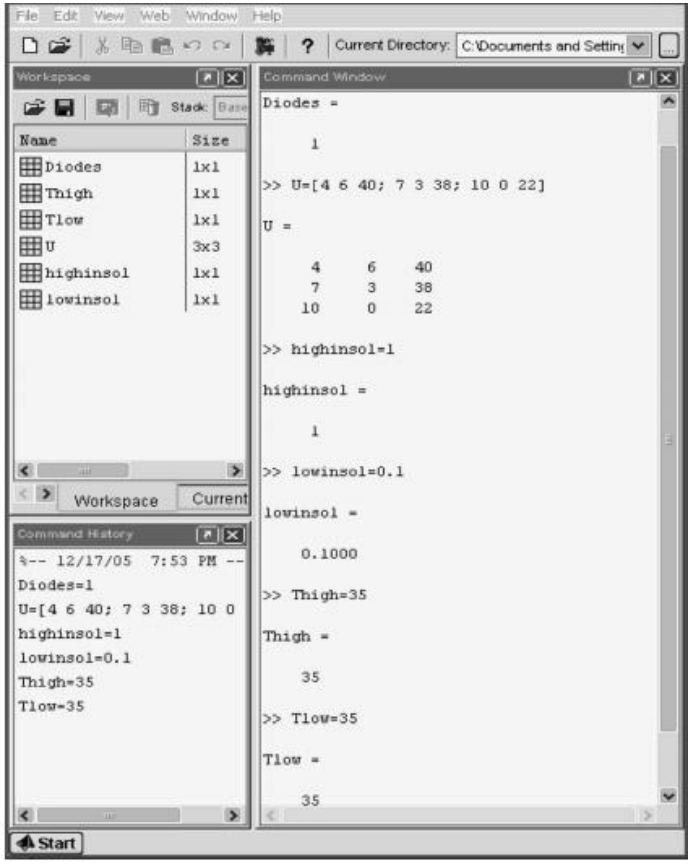
PV array terminologies (a) A PV module; (b) A series-assembly of two series connected sub-assemblies S1 and S2; (c) A group; (d) A PV array with groups G1 to G4.



Group	Number of unshaded modules in series assembly (λ=1)	Number of shaded modules in series assembly (λ=0.1)	No. of series assemblies in a group
G1	4	6	40
G2	7	3	38
G3	10	0	22

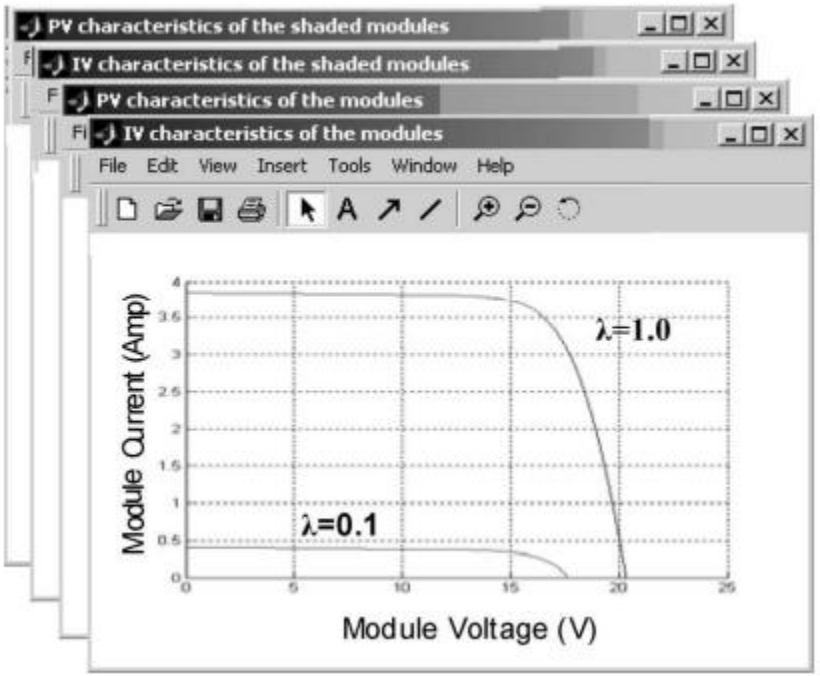
Modelling of Partial Shading: Simulation procedure

- The tool can simulate the array characteristics, for any value of temperature, insolation, and for any array configuration, with and without the bypass and blocking diodes.
- Via a MATLAB command window the given array configuration, temperature, and the insolation level(s) are described to the software.
- The matrix U of size G × 3, where G is the number of groups, represents the array configuration. Each row indicates a group with a particular shading pattern on the series assemblies within that group.
- The elements of each row represent the number of unshaded and shaded modules, respectively, in a series assembly, and the number of such series assemblies in the group.



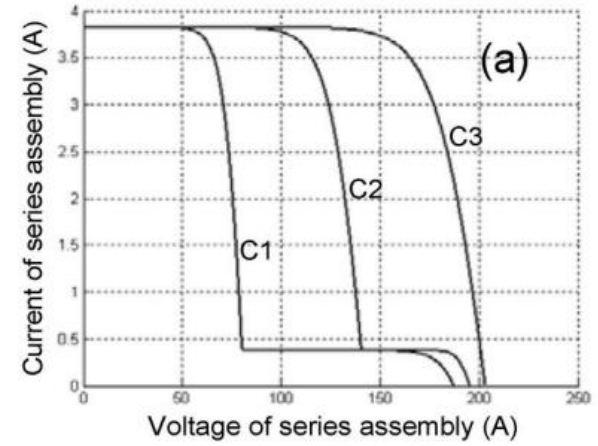
Modelling of Partial Shading: Simulation procedure

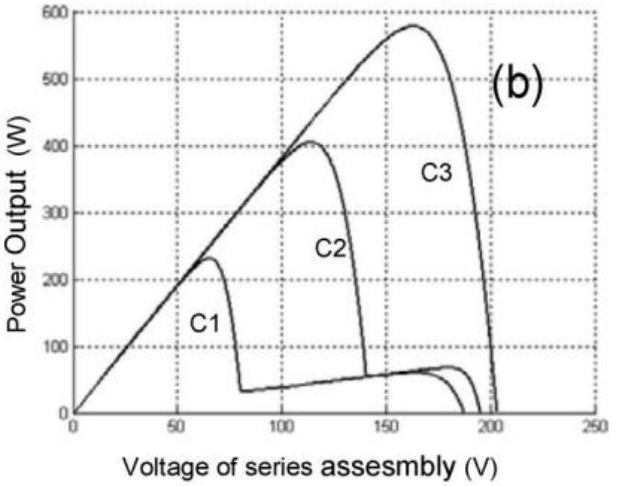
Once the information is fed into the software, various windows pop up on the monitor. These windows display the I–V and P–V characteristics of different components of the PV array.



Modelling of Partial Shading: Simulation procedure

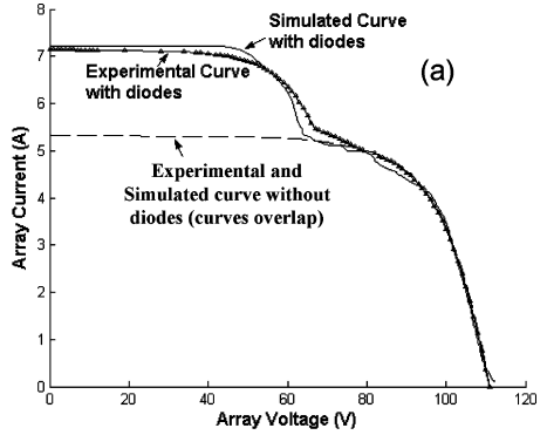
- If two PV modules are connected in series, they will conduct the same current, but the voltage across them will be different.
- In order to obtain the I–V characteristics of the series-connected modules (series assembly) conducting a current Io , the voltages across these modules, V1 and V2 , are added to determine the resultant output voltage.
- The characteristics for series assembly are, thus, obtained internally by the software by applying similar procedure at all the points on the I–V curve of the series-connected modules.

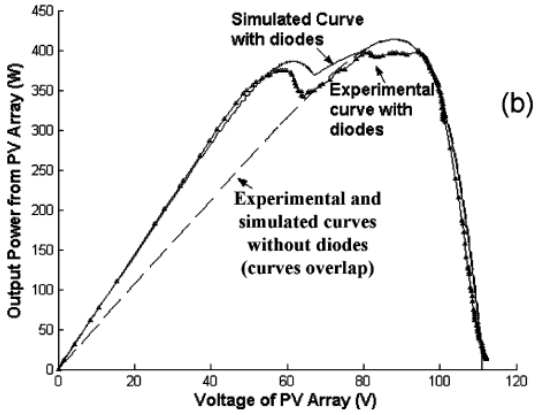




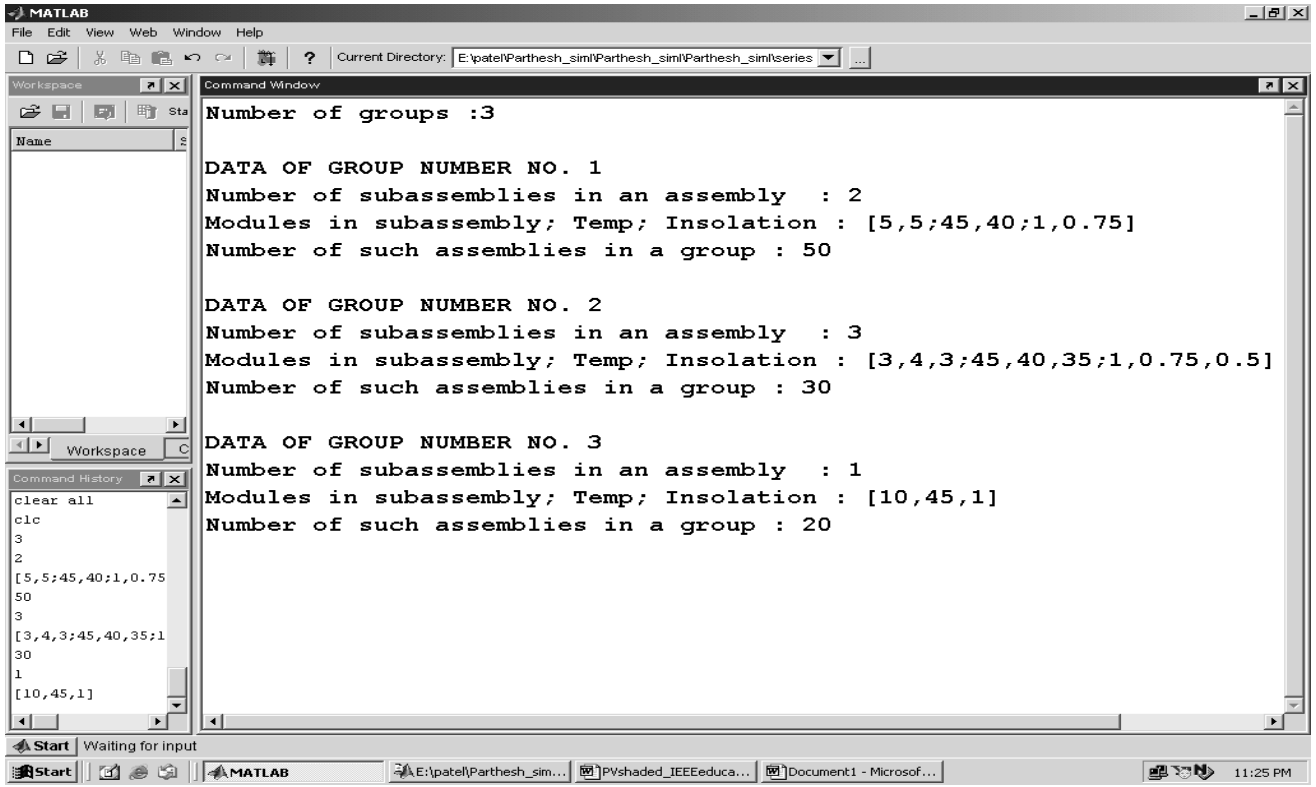
Modelling of Partial Shading

- A MATLAB-based modeling and simulation scheme suitable for studying the I–V and P–V characteristics of a PV array under a non-uniform insolation due to partial shading.
- Scope for developing and evaluating new MPPT techniques, especially for partially shaded conditions.
- The proposed models interface with the models of power electronic converters, which is a very useful feature.
- It can also be used as a tool to study the effects of shading patterns on PV panels having different configurations.





Generalized Modeling



[a] Patel, H. and Agarwal, V. (2008): MATLAB Based Modeling to Study the Effects of Partial Shading on PV Array Characteristics. IEEE Tran. on Energy Conversion 23, 302-310.