

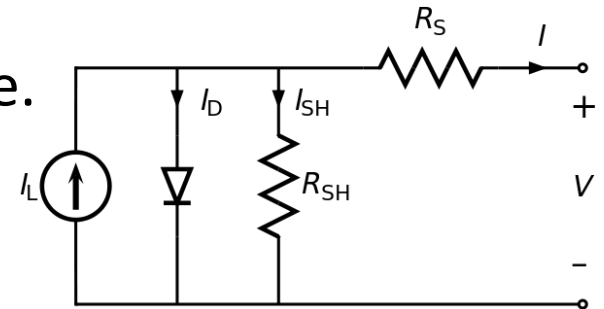
# PV Cells Interconnection: Effects of Shading & Bypass Diodes

34553: Applied Photovoltaics

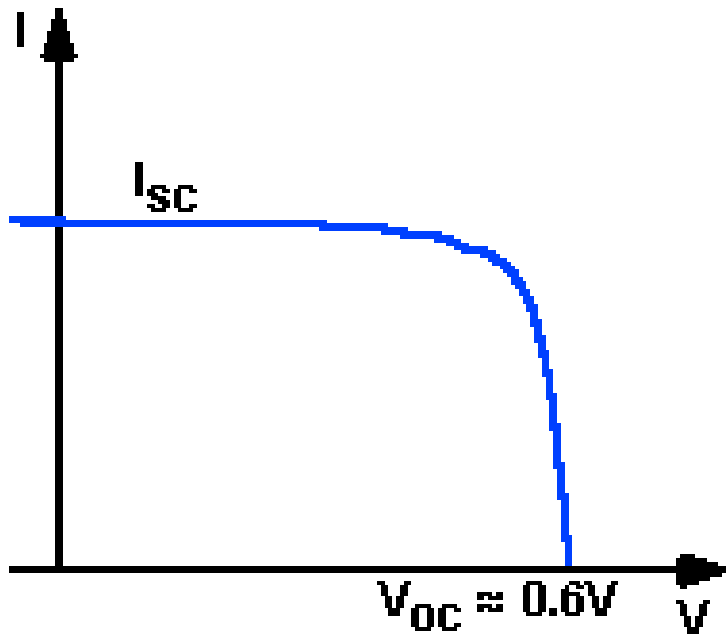
Adrián A. Santamaría Lancia, Nicholas  
Riedel, Sune Thorsteinsson

# Solar Cells IV Curve

- A solar cell can be modelled as a diode.

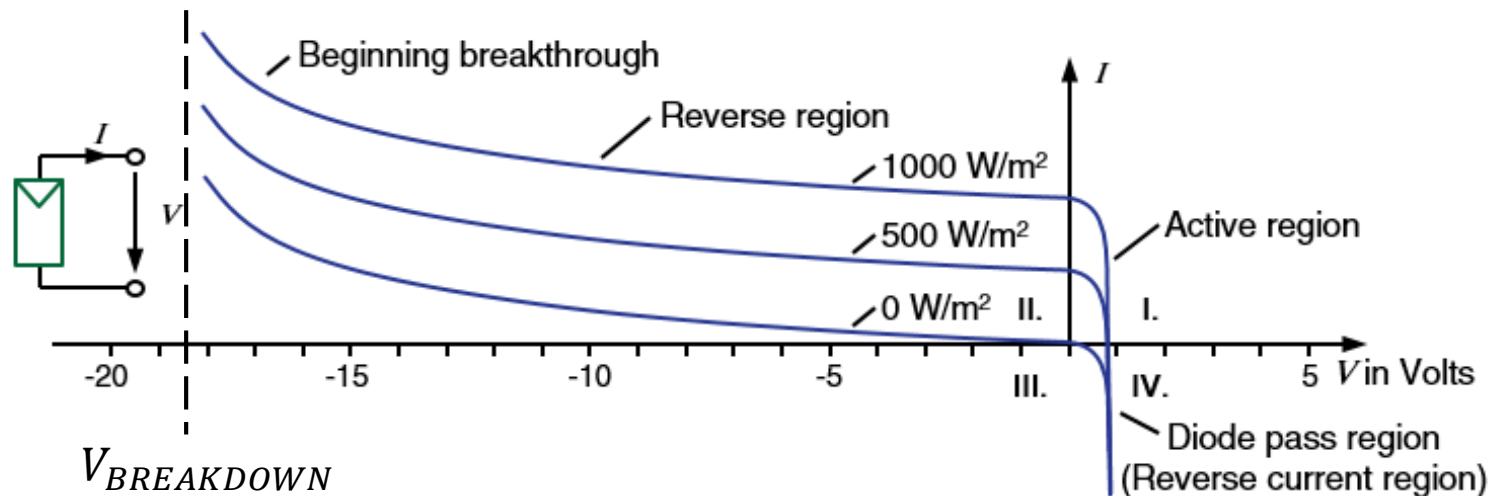


- We use the IV curve to characterize its electrical performance.



# Solar Cells IV Curve

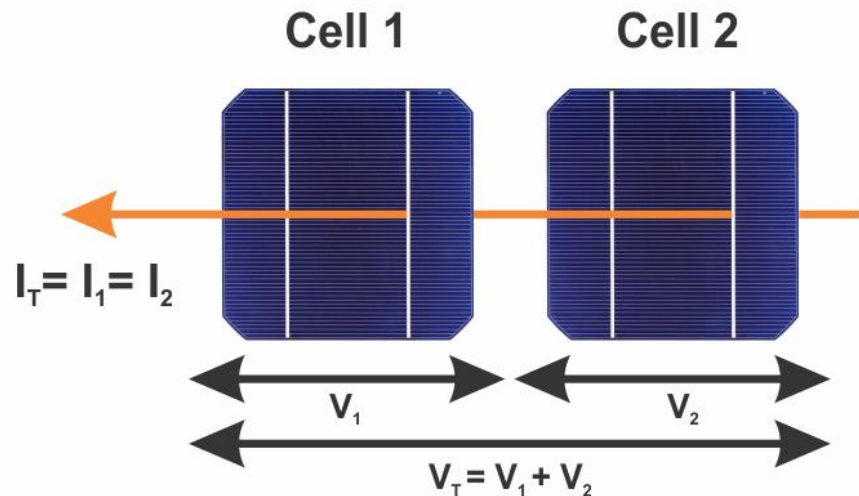
- To supply power to the load, the PV device should operate on the active region.
- The Active region is the typical IV curve shown in all documentation.
- However, the cell can be exposed to reverse voltage conditions.
- If the reverse voltage reaches the Breakdown Voltage value, the cell will irreversible damaged and current would flow in the opposite direction, as in a short-circuit.



Source: K. Mertens: textbook-pv.org

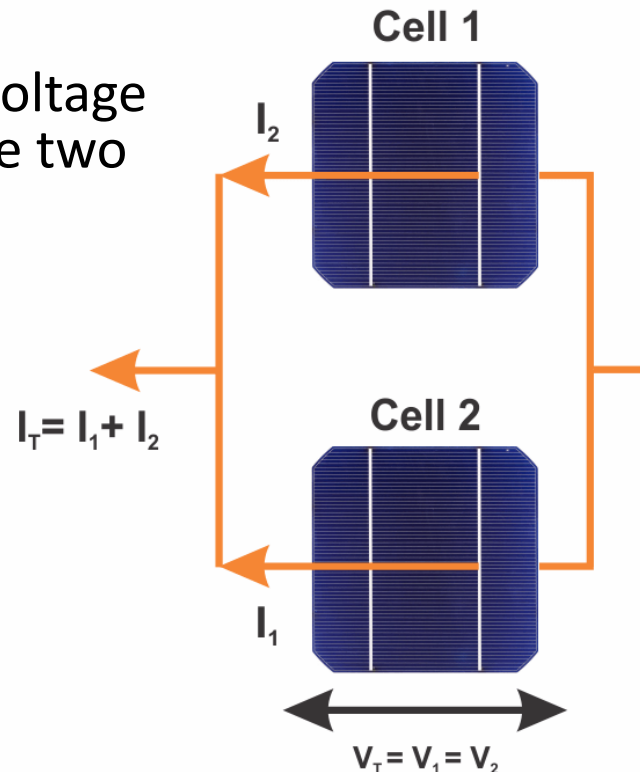
# Solar Cells Interconnection

- Solar Cells in Series
  - The total current of the string is the current passing through both cells.  
(fixed, lowest of the two  $I$  values)
  - The voltage of the string is the addition of each cell voltage.



# Solar Cells Interconnection

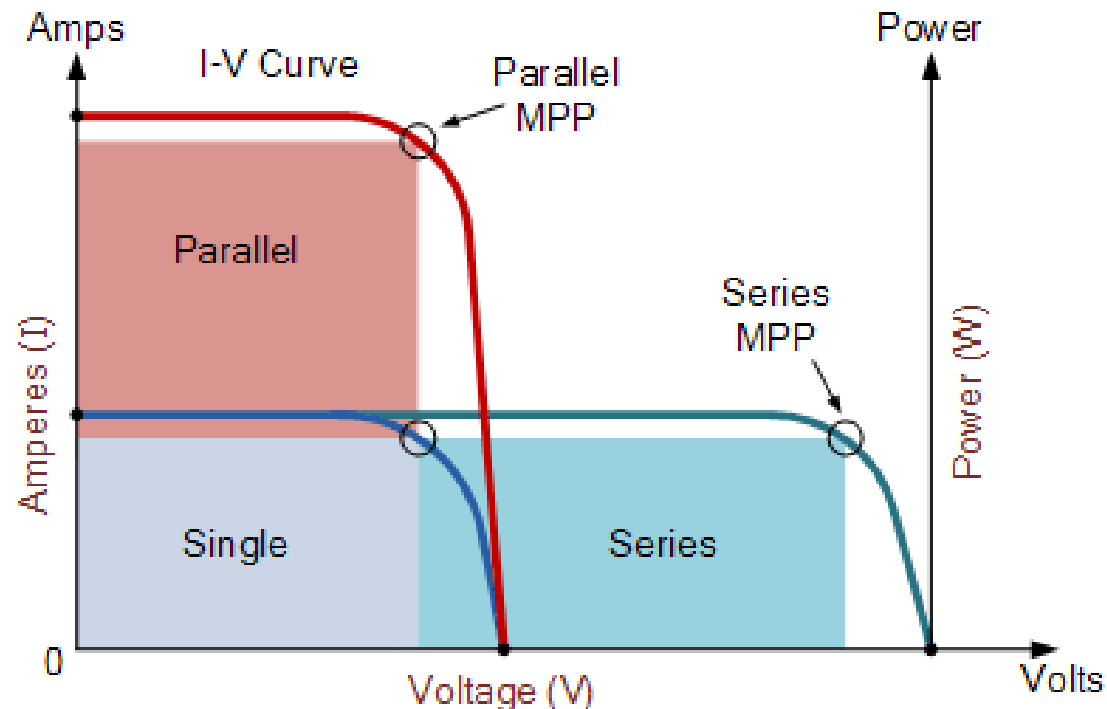
- Solar Cells in Parallel
  - The total current of the string is the addition of the currents of each cell.
  - The voltage of the string is the voltage of both cells. (fixed, between the two V values)



# Solar Cells Interconnection

## IV Curve:

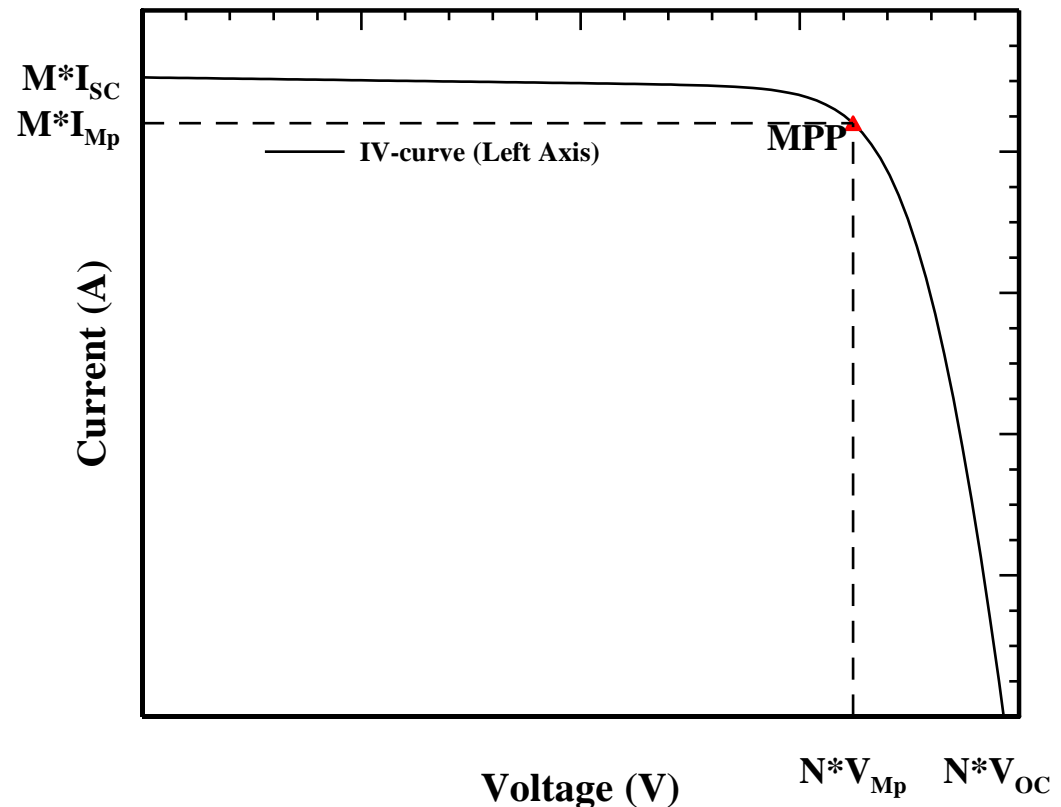
- Cells in parallel add up in current.
- Cells in series add up in voltage



# Solar Cells Interconnection

IV Curve for a PV Module composed of a total number of (M x N) Cells:

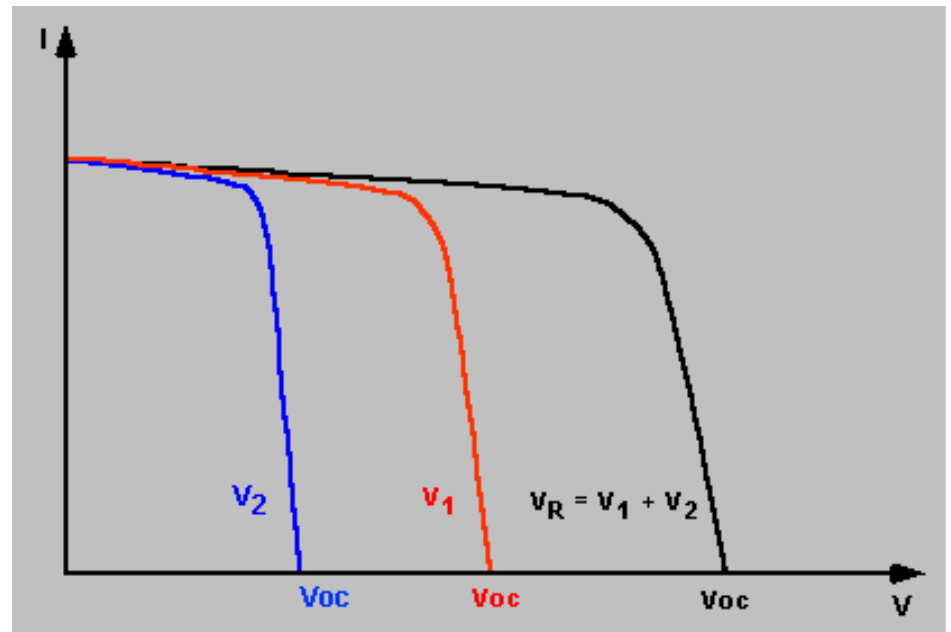
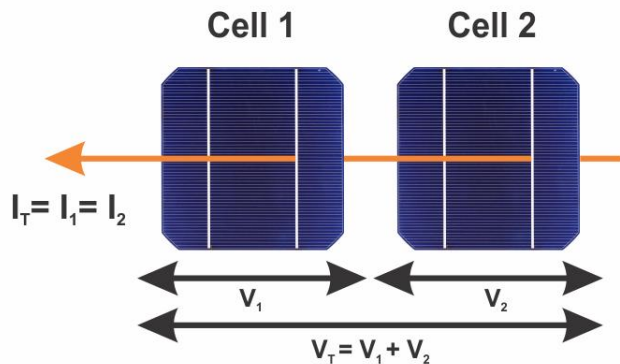
- M strings in parallel.
- Each string is made by N cells in series.



# Mismatch Effects: Cells Connected in Series

## Mismatch in Voltage:

The voltage of the string in series is the summation of the individual voltages.



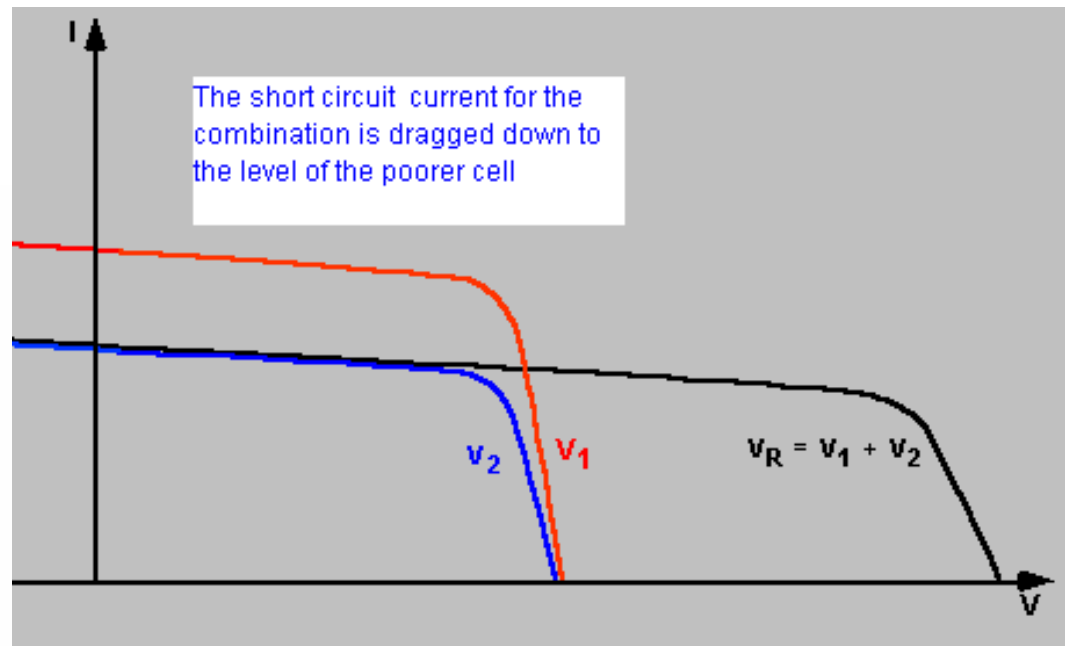
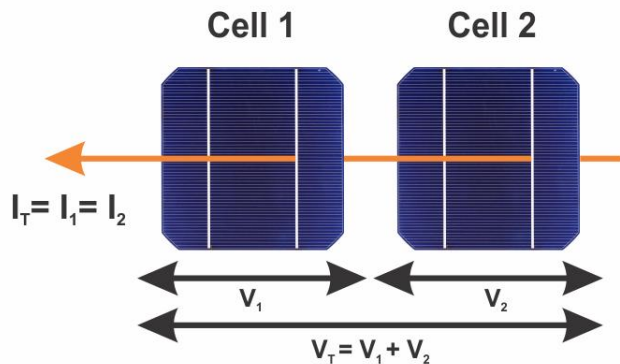
[www.pveducation.org](http://www.pveducation.org)



# Mismatch Effects: Cells Connected in Series

## Mismatch in Current:

The resulting current of the string is limited by the poorest performing cell.

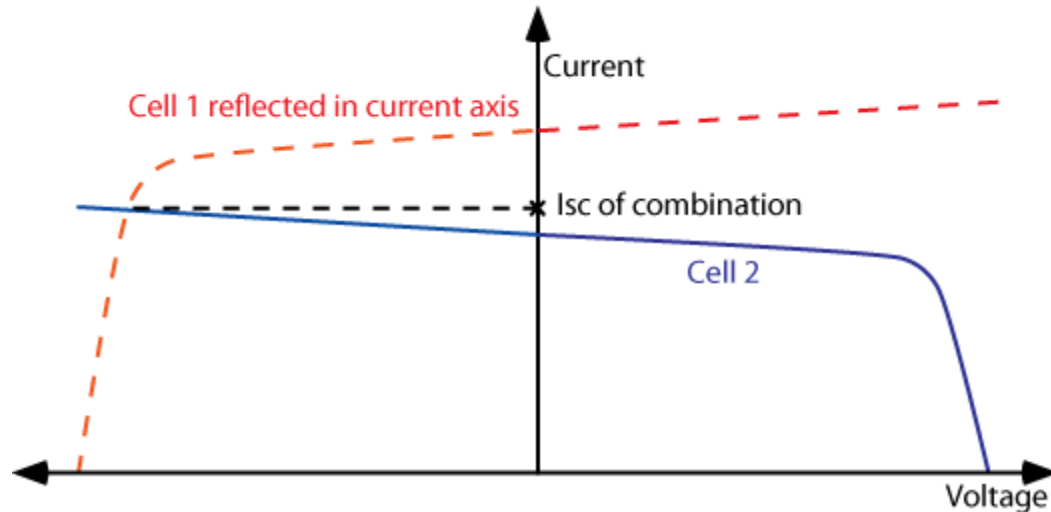


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# Mismatch Effects: Cells Connected in Series

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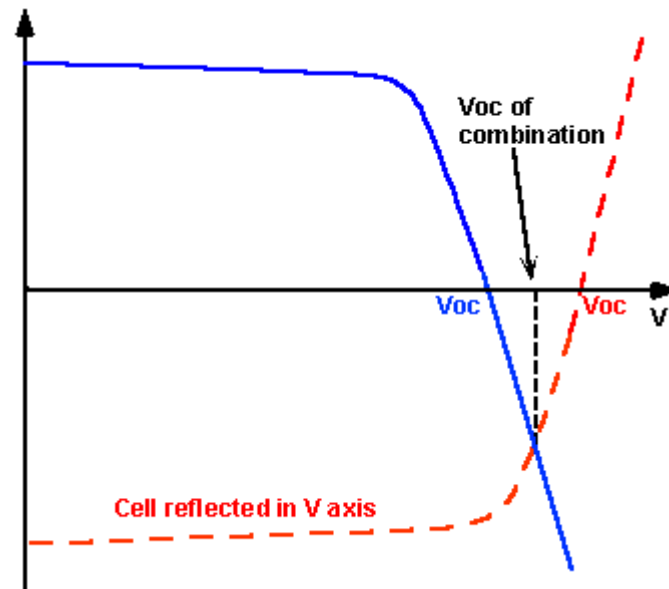
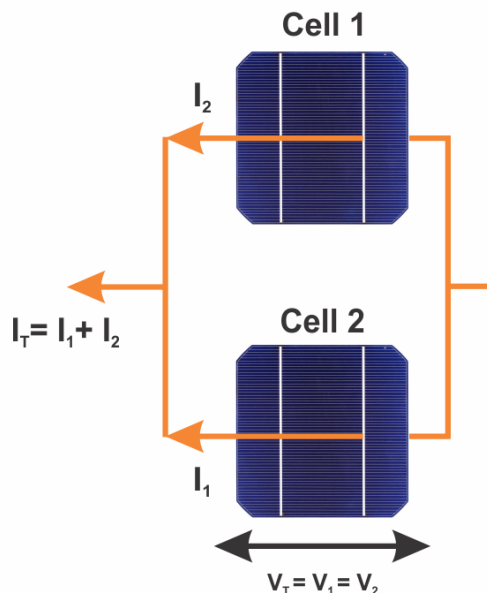
# Mismatch Effects: Cells Connected in Parallel

## Mismatch in Current:

The total current is the summation of the individual currents.

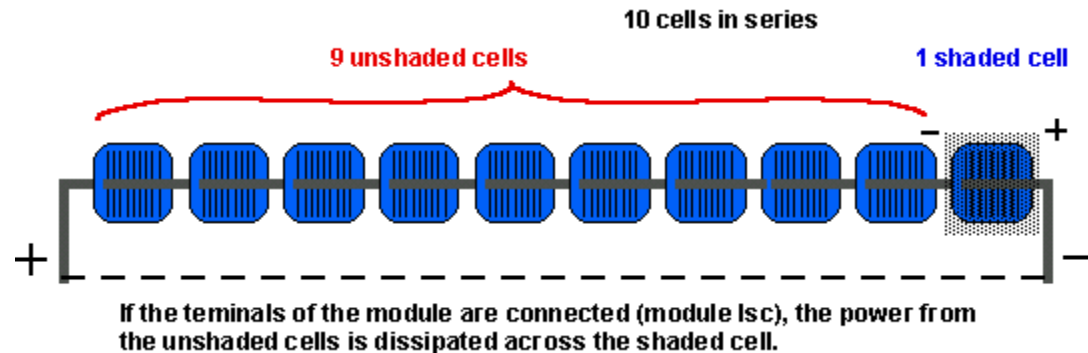
## Mismatch in Voltage:

The resulting Voc of the string is a combination of the cell's individual Voc values.



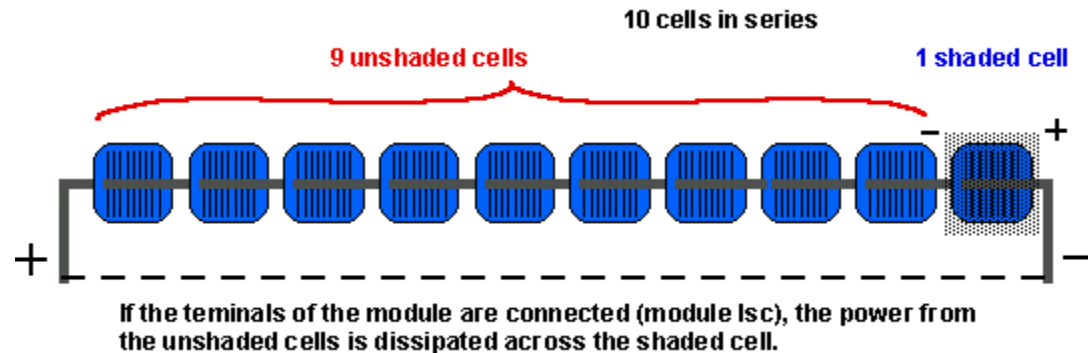
[www.pveducation.org](http://www.pveducation.org)

# Effects of Shading in Strings of Solar Cells



- A partially shaded cell produces lower current than the rest of the cells in the string.
- The current of the shaded cell limits the total current of the string.
- The illuminated cells are forward biased by their generated current.
- If the string is, for example, short circuited, the summation of their voltages in series are the reverse voltage on the shaded cell.
- The shaded cell becomes a load and dissipates power, which raises its temperature and can cause damage to the cell and module. **(Hot Spot Effect)**

# Effects of Shading in Strings of Solar Cells



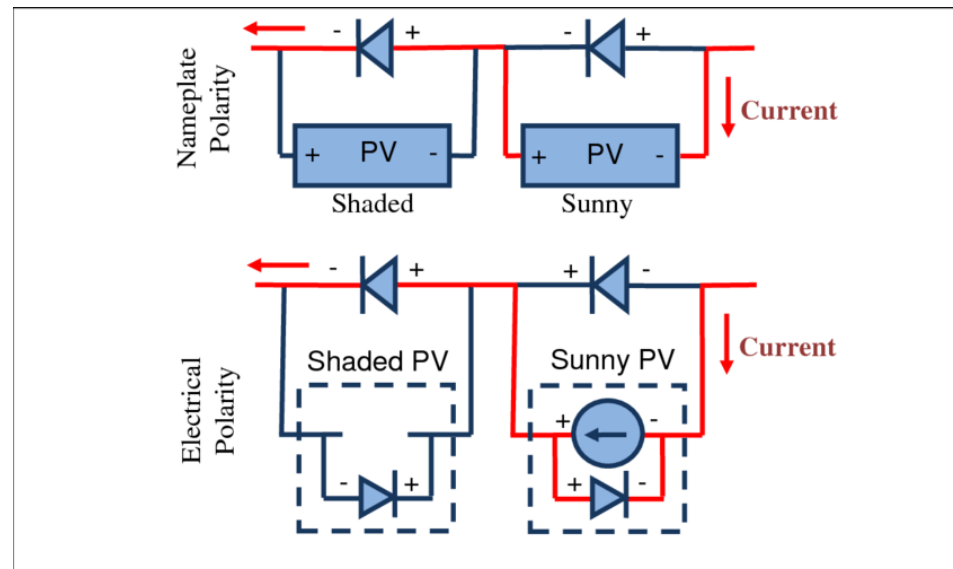
- The total reverse voltage on the shaded cell depends on the number of cells connected in series in the string.
- The shaded cell can be destroyed by reverse breakdown voltage if the number of cells in the string is high enough.

$$|V_{BRK}| > |V_{OC} \times (n - 1)|$$

- Thermal damage by hot spot effect depends on the duration and intensity of the conditions the cell is subjected to, but electronic damage by reverse breakdown voltage is immediate.

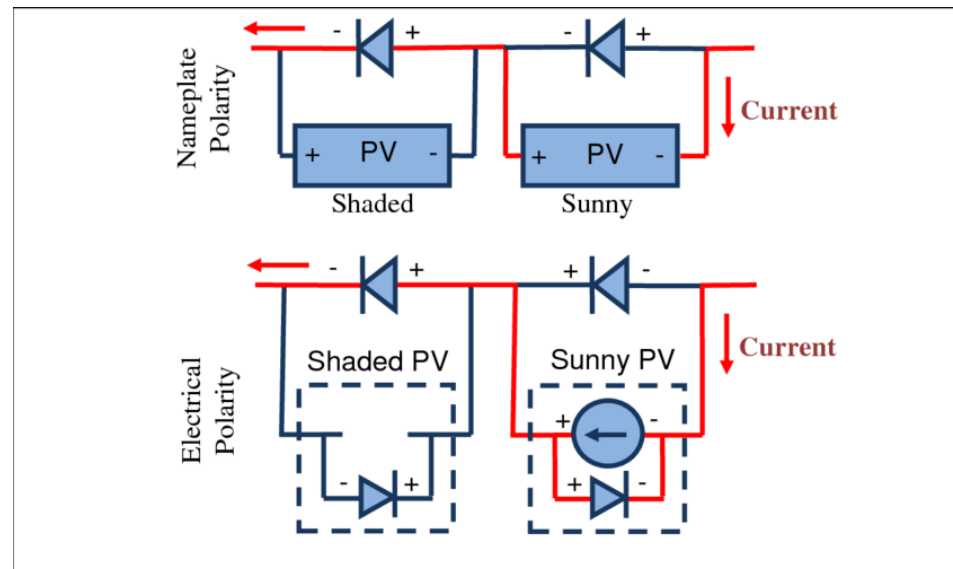
# Bypass Diodes

- Bypass diodes are connected in parallel to a string of pv cells that allow an alternative path for the current through the module to flow to the load.
- This avoids cell damages by hot spot effect, by excessive reverse voltage, and contributes to minimize power performance loss of the module.



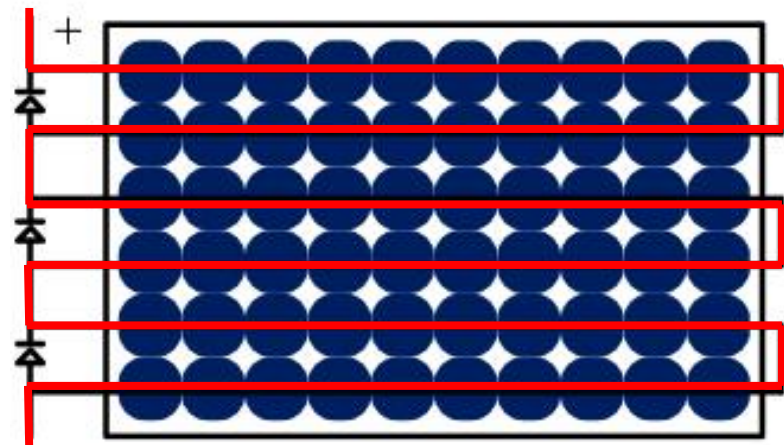
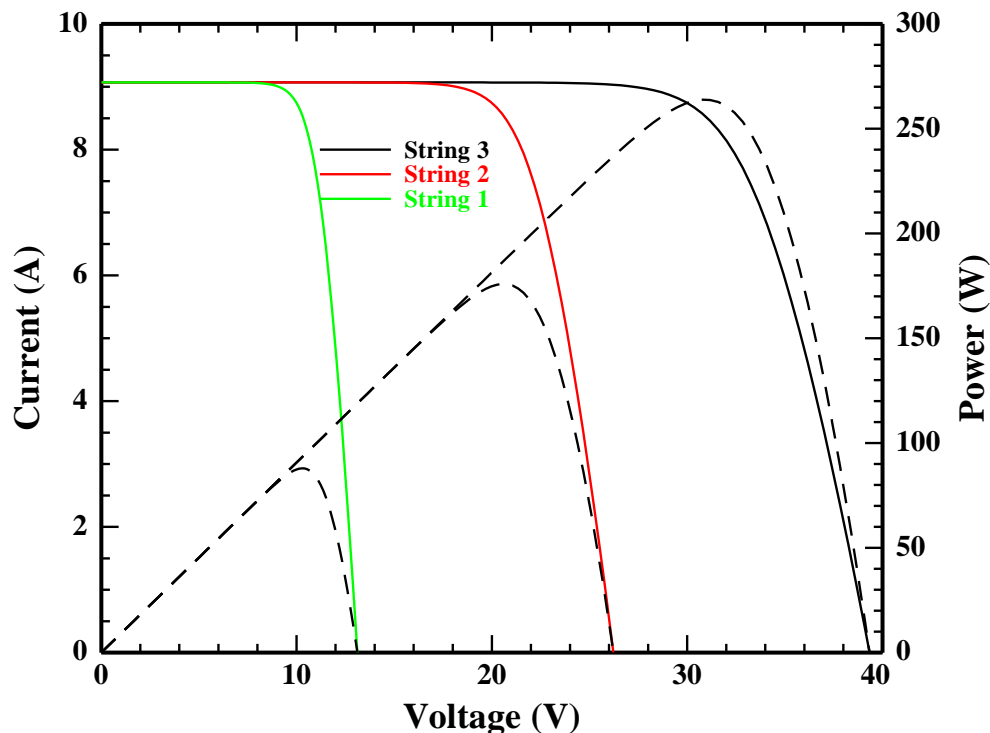
# Bypass Diodes

- The bypass diodes remain in reverse bias during normal operation of the module and do not conduct current.
- When a cell becomes shaded, the bypass diode becomes forward biased and conducts current of the illuminated cells without loss, plus the current of the shaded cell.



# Effects of Shading in a PV Module with 3 Bypass Diodes

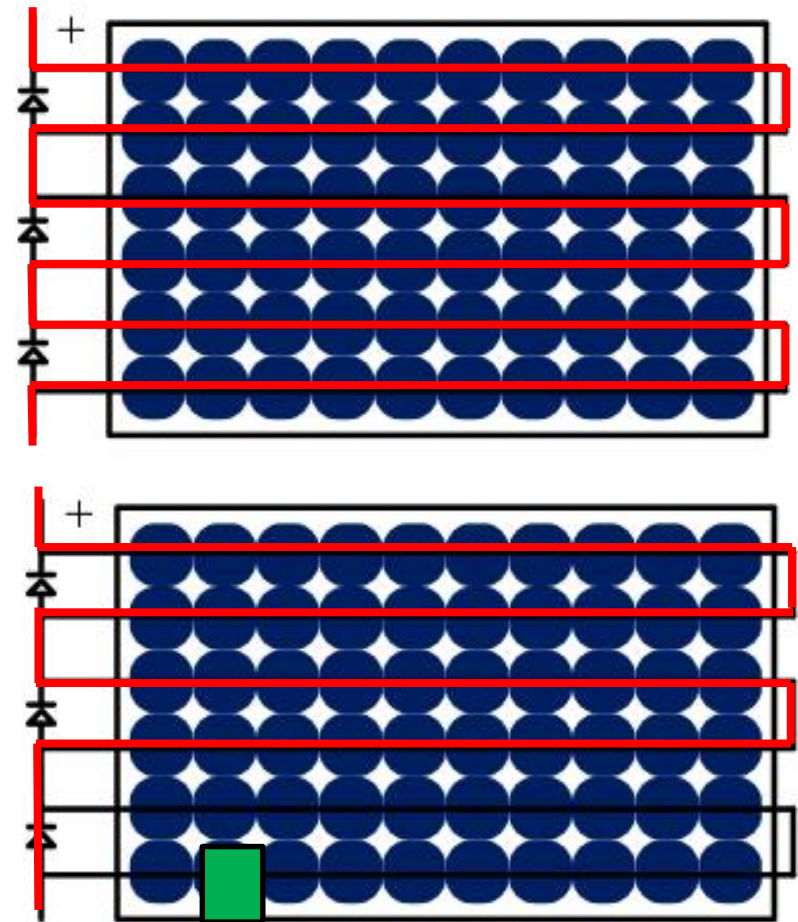
- PV module of 60 cells in series, each bypass diode is connected to 20 cells in series.
- The IV curve of the module is the summation of the IV curves of the 3 strings.



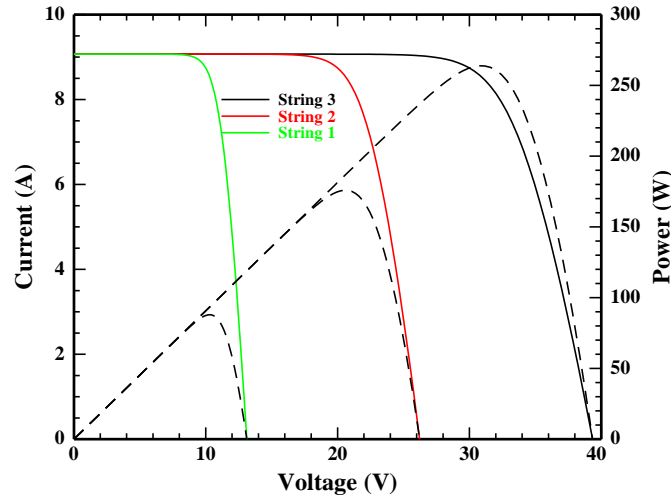


# Effects of Shading in a PV Module with 3 Bypass Diodes

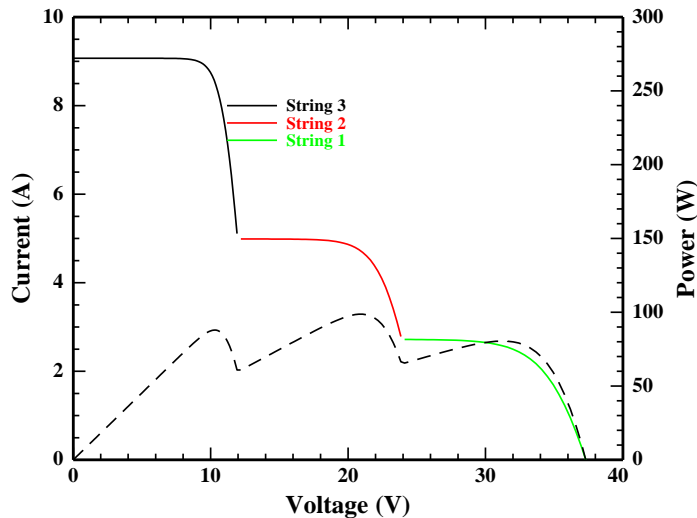
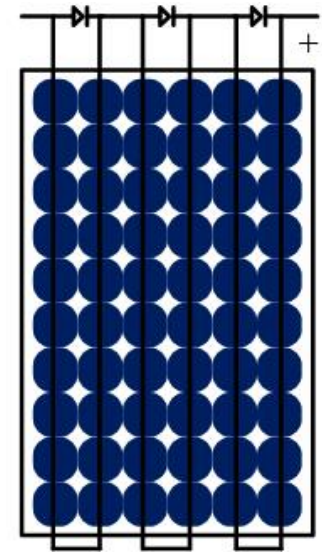
- Bypass diodes limit the reverse voltage of the shaded cell to the number of cells inside its string. This voltage is designed to be lower than the breakdown voltage.
- The drop in current value occurs only in the affected string instead of the whole module.



# Effects of Shading in a PV Module with 3 Bypass Diodes



**Unshaded Module:**



**Shaded Module:**

Diffuse light: 30%

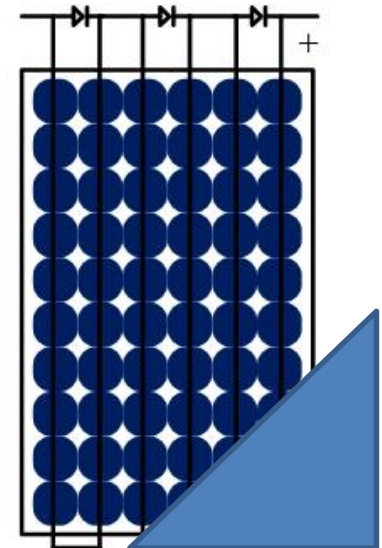
String 3: 100%

String 2: 65%

String 1: 30%

**Powerloss = 35%**

**Shaded area = 7.5%**



Voltage drop of BP-diodes neglected

Thank you for your attention!