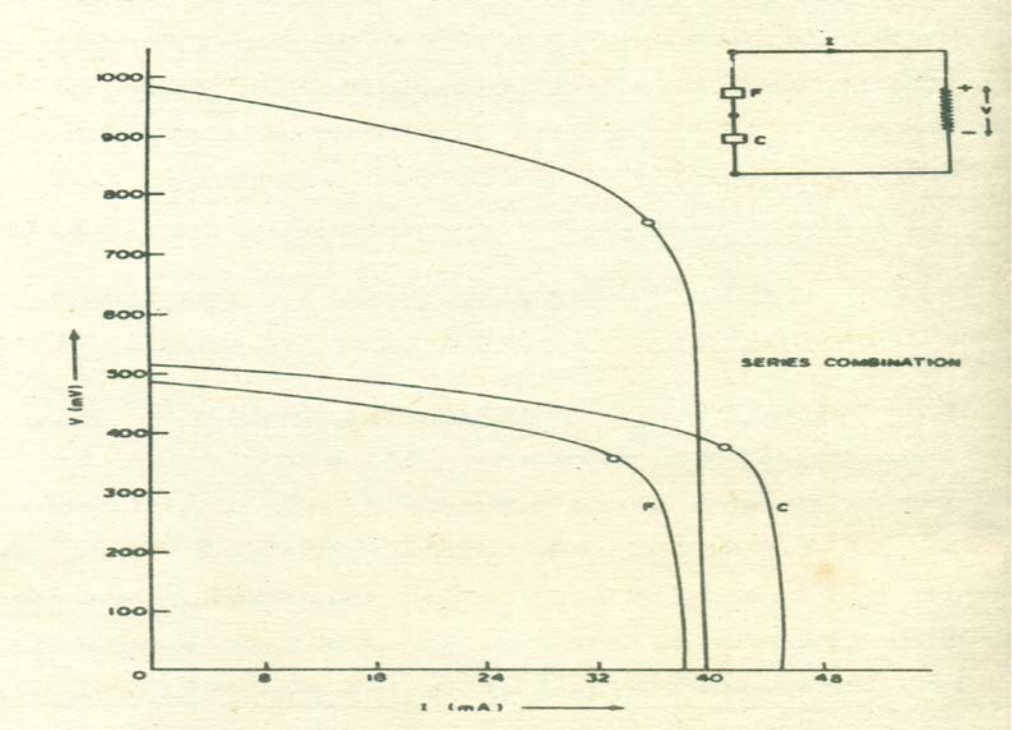
Series and Parallel connection of solar cells

A. Series connection of cells:

N identical cells can be connected in series. If each cell is biased at its maximum power point corresponding to a voltage $V_{mp}$and a current I_{mp}, the total voltage obtained from the string of N cells in series in NV_{mp}. The current, however, remains I_{mp}. The load resistance, which for a single cells is $V_{mp}/ I_{mp}= R_{mp}$ now becomes NR_{mp} for series string of N cells. If the N cells are not identical, the composite I-V characteristic can be obtained by adding the voltage across each cell for the value of the current flowing though the string

$$V_N.I = \sum_{I=1}^{N} V_i \text{ x } \mathbf{I} \text{ , where}$$

V_i is the voltage across the i^{th} cell at current **I**. Knowing the composite I-V characteristic, the load resistance for maximum power available can be determined from the maximum power point in the composite I-V characteristic. Fig.1 shown the individual and composite I-V characteristics of two unidentical individual and composite I-V characteristics of two unidentical solar cells connected in series. Following figure shows the individual and composite I – V characteristics of two non identical solar cell in series.



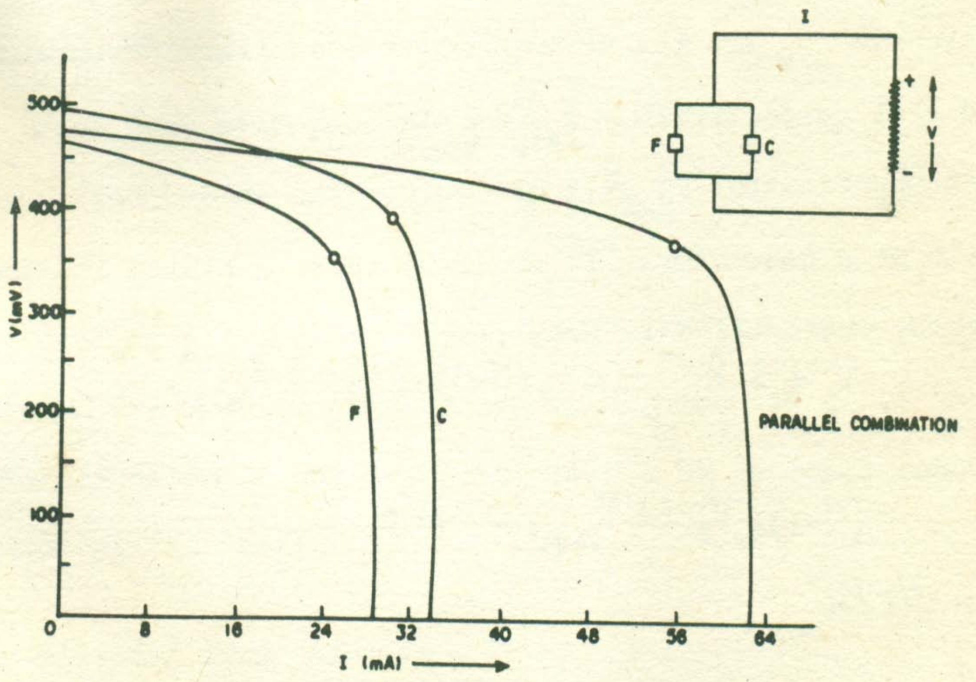
V-I characteristics of cells in series.

B. Parallel connection of cells

M identical cells biased for maximum power can be connected in parallel. Now the load current would be (M. I_{mp}) and the voltage is that of the individual cell V_{mp}. The load resistance becomes [$V_{m.p.}/I_{m.p.} \cdot M$]= R_{mp}/M and the maximum available power is M.$P_{mp.}$If M cells are not identical the composite I-V characteristic can be obtained by adding the current of each cell for each voltage value.

$$I_M.V = \sum_{I=1}^{N} I_i \text{ x } \mathbf{V} \text{ , where}$$

I_i is current from the i th cell. The maximum power point of the parallel connection of the cells can be obtained from the composite curve. Following figure shows the individual and composite I – V characteristics of two non identical solar cells connected in parallel.



V-I Characteristics of cells in parallel.

Output for Parallel and Series

The power out put of a single cell is not sufficient for any practical use. So to get the useful and required power the relatively small power output from an individual cell is multiplied by the number of solar cells in an array. The cell's output current is multiplied by the number of cells connected in parallel, and its voltage output by the number of cells

Following figure shows the concepts of series and parallel connection.
Let us define the following quantities:
Ns = number of cells connected in series
Np = number of cells connected in parallel
Nt = total number of cells on the array
Ve = cell output voltage
Va= array output voltage
Ic =cell output capability
Ia = array output current capability
Pc = cell output power capability
Pa = array output power capability
Than we have the following relationships:
Va =NsVc, Ia = NpIc and Pa = NtPc

And of course Pa = VaIa, Pc = VcIc and Nt = NsNp

Example.1

Let a certain solar cell type have an output capability of 0.5 A at 0.4 V. Assume that we build an array of such cells with 100 cells connected in parallel by 300 cells in series. Find the out put power.

Given: Va = 0.4 V, Ic = 0.5 A
Ns = 300, Np = 100

Find: Va, Ia, andPa.

Solution: Va= Ns Vc = 300 x 0.4 = 120V.
Ia=NpIc = 100 x 0.5 = 50V
Pa =Nt Pc = Ns NpVcIc
= 300 x 100 x 0.4 x 0.5
= 6000W or Pa = VaIa = 120 x 50 = 6000W.

Example 2

A solar cell array is required to deliver 100 W peak output at 120 V.dc bus voltages. The solar cells to be used are rated for 0.1 W assuming no assembly losses, define the array.

Solution.

Each cell produces $P_c = 0.1$ W,
Therefore, $N_t P_c = N_t \times 0.1 = 100$,
or$N_t = 100/0.1 = 1000$ cells.
Also, $0.4\ N_s = 120$, or $N_s = 120 / 0.4 = 300$ cells in series.

Since $N_t = N_p\ N_s$, so, $N_p = N_t / Ns = 1000 / 300 = 3.3$

Therefore a decision must be made to use either three or four cells in parallel, resulting in either one of these arrays:

For $N_p = 3$:
$N_t = N_p N_s = 3 \times 300 = 900$
Array power $= P_c N_t = 0.1 \times 900 = 90$W;

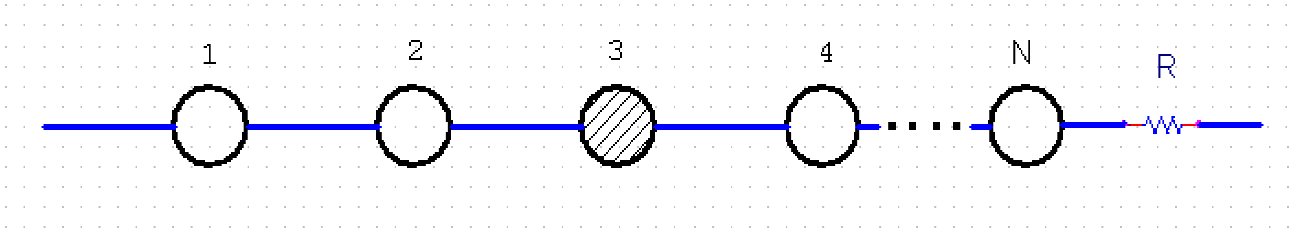
For $N_p = 4$:
$N_t = N_p N_s = 4 \times 300 = 1200$
Array power $= P_t N_t = 0.1 \times 1200 = 120$W.

Effect of shading in PV system

It can be shown that the effect of shading on one or more cells in an array depends upon whether the cells are connected in series or in parallel.

A) Series configuration

Consider N identical cells connected in series and one cell completely shaded as shown in the fig.1,



From Kirchoff's voltage law

$$(N-1). (V_I - IR_{m.p.}) + (V_S - IR_{m.p.}) = 0$$

Where V_I and V_S are voltages across an illuminated and a shaded cell respectively. R_{mp} is the resistive load for maximum power out put of a single cell. The shaded cell would cease to be a generator. So it would be reverse biased and would dissipate power. If N is very large, then

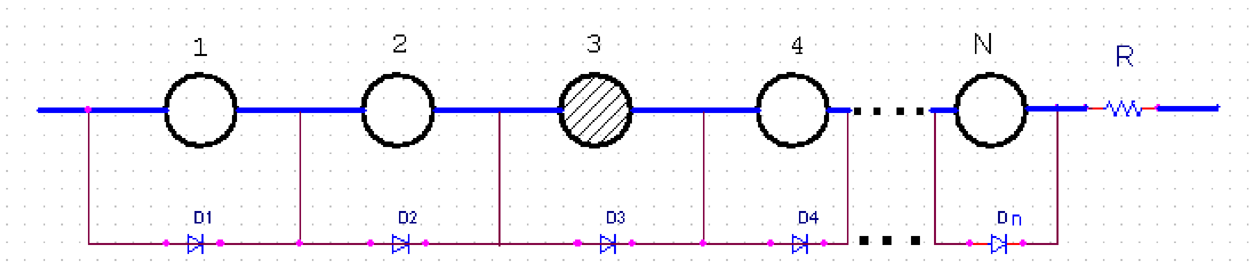
$$V_S - IR_{m.p} << (N-1) . (V_I - IR_{m.p.})$$

and hence

$$(N-1) . (V_I - IR_{m.p.}) \rightarrow 0$$

or $$I = V_I / R_{m.p}$$

At this value of current, the reverse voltage would be high and so also the power. This power dissipation heats the shaded cells and produces hot spot. The shape of the reverse characteristic strongly affects this power loss. Cells with lower reverse currents result in greater power loss for a given value of current. The reverse voltage and power absorption can be eliminated if an ideal diode is placed in parallel with each series cell as shown in the fig.2.



Shunt diodes short out any reverse voltage and they shunt currents around shaded cells. The positive voltage of illuminated cells would reverse bias the diodes across them so that un-shaded cells are unaffected.

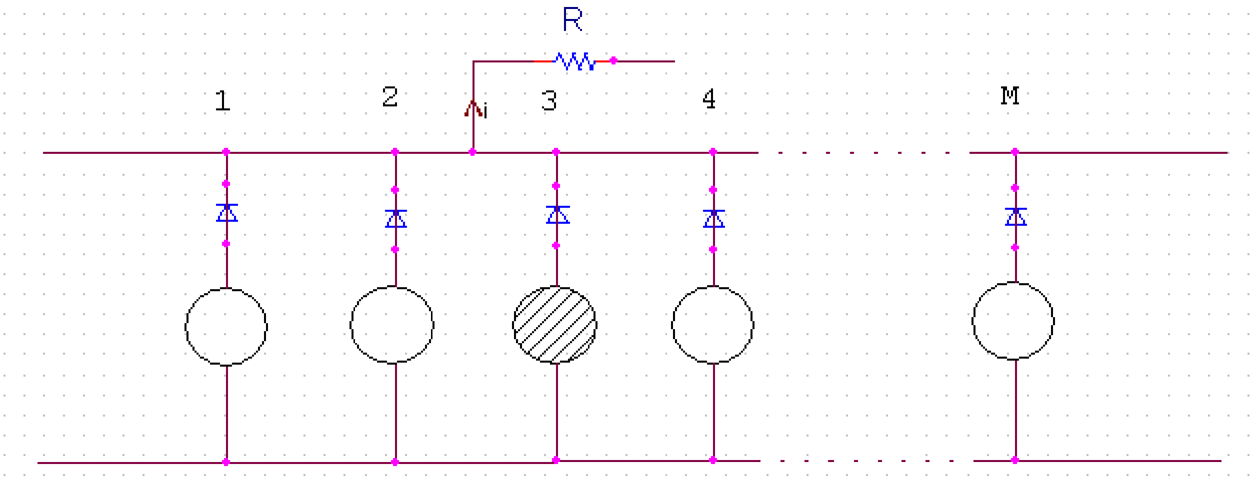
$(N-1). [V_I-IR_{m.p.}N/N-1] \rightarrow 0$

$$V_I/_I = N.R/N-1m.p.$$

Shunt diodes drastically reduce power loss and prevent hot spots. For a single cell shaded, the un-shaded cells should be operated at their maximum power points reducing load resistance to (N-1) $R_{mp,.}$

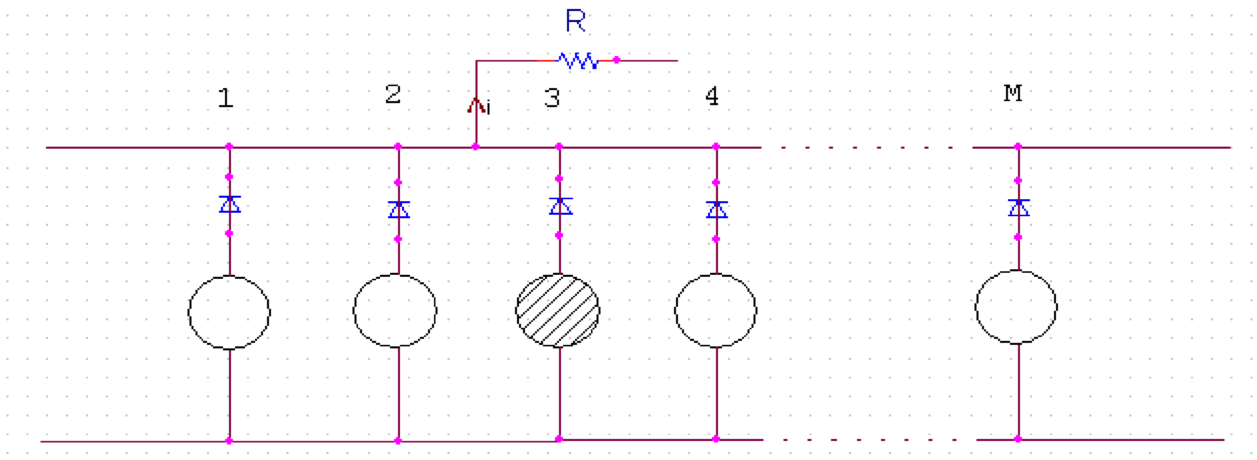
B) Parallel configuration

Let us consider M identical cells all connected in parallelas shown in fig.3. It can be shown that with one cell shaded, Kirchoff’s law requires that



$(N-1). [I_I-V/R_{m.p}] + [I_S-V/R_{m.p}] =0,$

Where I_I and I_S are the currents in illuminated and shaded cells respectively. There is a finite voltage across the shaded cell, which results in a flow of current in the shaded cell and biases it in the power absorbing mode. This partially shorts out the photocurrent generated in the illuminated cells. In contrast to series, both the voltage and current across the shaded cell are low and power loss is low. This small loss can be eliminated by the addition of ideal diode in series with each cell and oriented so that only forward current can flow, fig 4.



Therefore in equation for this configuration, $I_S = 0$ and

$$V - I_I.R_{m.p.} M-1 / M = 0$$

or $$V / I_I = R_{m.p}. M-1 / M$$

The theoretical minimum power loss for M cells in parallel would be obtained with ideal diode in series with each cell and a variable load that would change from $R_{m.p}/M$ to $R_{m.p}/M-1$ when one cell is shaded.

C) Combination of series and parallel arrays

The parallel configuration is more attractive than series configuration in view of the lower loss with shading.
The voltage of a single cell is too low for practical application e.g. for is solar it is around 0.5V. Series connection must be used to obtain required voltage level. If enough cells are available it is necessary to find the best way to connect the cells. Fig.5 shows the P and S arrangements. In both the configuration the required voltage is achieved by series connection of cells of group of cells. The load resistance for normal operation = $N.R._{m.p}/M$ and the total un-shaded power is $N.M.R_{m.p}$: It can be shown that as far as power loss with shading is concerned, the P array is superior to the S array under all circumstances.

As regards hot spots small percentage shading does not produce localized heating with the P array but does given it with S array. With larger shading values, the situation is different but then array placement with large shading is an inherently bad design. With diode protection, there is little chance of hot spot development. Significantly fewer diodes are required for P array. Hence P arrays should perform better than S arrays in all cases.