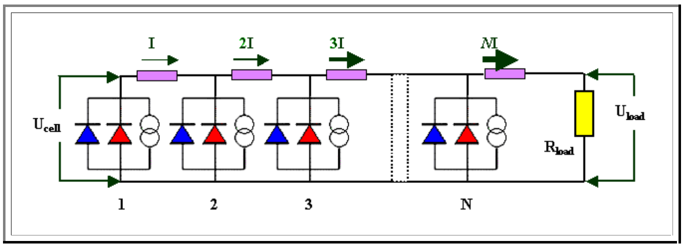
Series and Parallel Connection

Advanced

First Basic Question

- We take a number ***N*** of solar cells; assuminng that all oft them are perfectly identical, to keep things simple at first. We also assume that there are no shunts in those solar cells, but that they have some series resistance R_{SE}.
  - The first basic question now is : How can you deliver maximum power into some load resistor R_{load} - by switching the ***N*** solar cells in series or parallel?
- Let's look at switching in parallel first.



  - Every individual solar cell delivers a current I, theses currents add up, and the current flowing through the load resistor R_{load} of the solar cell No. k under short circuit conditions is $I_{load}(k) = k \cdot I$
  - The corresponding total voltage drop in all ***N*** series resistor each with resistivity R_{SE} is U_{SE} given by

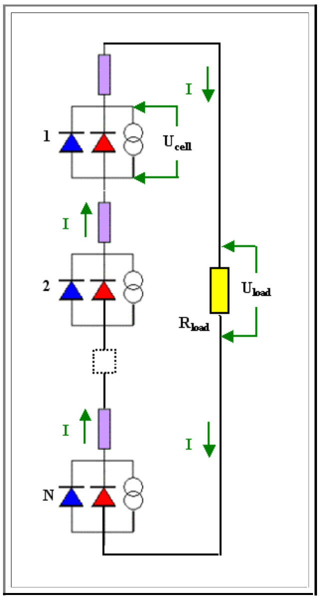
$$
\begin{aligned}
U_{SE} &= I \cdot (R_{SE} + 2R_{SE} + 3R_{SE} + ... + NR_{SE}) \\
&= I \cdot R_{SE} \cdot ½N \cdot N \qquad \text{(remember young Gauss?)} \\
&= \frac{I \cdot R_{SE} \cdot N^2}{2}
\end{aligned}
$$

- The product of maximum output voltage times current give some fictive power $P_{parallel}$ akin to just multiplying I_{SC} and U_{OC} of the "ideal" solar cell. The actual power $P_{load,\ p}$deposited into the load resistor depends, of course, on the value R_{load}; it will be maximal for some specific value of R_{load} but always smaller than $P_{parallel}$.

$$
\begin{aligned}
P_{parallel} &= N \cdot I \cdot (U_{cell} - ½\, N^2 \cdot I \cdot R_{SE}) \\
&= N \cdot I \cdot U_{cell} - ½N^3 \cdot I^2 \cdot R_{SE}
\end{aligned}
$$

- The total losses due to series resistors thus are at least $P_{loss,\ p} = ½N^3 \cdot I^2 \cdot R_{SE}$

- Now let's look at a series connection.
  - The current flowing through the load resistor is I
  - The voltage U_{load} is ***N*** times the cell voltage minus the voltage drop in the internal resistance, i.e. minus $N \cdot R_{SE} \cdot \mathbf{I}$; we have $U_{load} = N \cdot (U_{cell} - I \cdot R_{Se})$
  - The power P_{series} deposited in the load resistor is such



$$
\begin{aligned}
P_{series} &= I \cdot N\, (U_{cell} - I \cdot R_{SE}) \\
&= I \cdot N \cdot U_{cell} - I^2 \cdot N \cdot R_{SE}
\end{aligned}
$$

  - Your total losses due to series resistors thus are $P_{loss,\ s} = N \cdot I^2 \cdot R_{SE}$

- The relation between the losses of a solar cell array in in parallel or in series thus are

$$\frac{P_{\text{loss, p}}}{P_{\text{loss, s}}} = \frac{N^3 \cdot I^2 \cdot R_{SE}}{2 \cdot N \cdot I^2 \cdot R_{SE}} = \frac{N^2}{2}$$

  - In words: You *must* switch your solar cells in series! You loose far too much power if you have them in parallel

Second Basic Question

- We take a number ***N*** of solar cells; assuminng that all oft them *except for one* are perfectly identical, to keep things not too simple anymore.
  - We consider two extrem cases for both variants, series and parallel connection of ***N* – 1** identical good cells and one bad one:

    1. The bad cell has a very large series resistance and no noticeable shunt resistance
    2. The bad cell has a regular series resistance and a very small shunt resistance.

- Let's see what will happen in the parallel world. All we have to do is to image that the series reistor of cell No. ***N*** is very large, or that the whole cell is just a small resistor in parallel to the load. What will happen?
  - In the *first* case you simply loose most of your voltage at the high series resistance of the defective cell. The power output will go down dramatically, or simply proportionally to the added series resistance. It will also matter which one of the ***N*** cells is the defective one.
  - In the *second* case you just add another parasitic load resistor to the intended load, funneling off some of the current. Again, the power output will go down dramatically, proportional to $1/R_{SH}$.
- Let's see what will happen in the serial world.
  - In the *first* case you simply loose most of your voltage at the high series resistance of the defective cell, and it doesn't matter which cell it is. You can consider the surplus resistance as a parasitic addition to the load resistor. The power output will go down dramatically, again proportionally to the added series resistance.
  - In the *second* case you just loose the power not generated by the defective cell. The current of all the other cell passes through the (small) shunt resistance without much of a voltage drop.
- Again, we have compelling reasons to go with series connections. We also see that we must watch out for high series resistance **-** it does more damage on the whole than the occasional shunt.
- The most important insight, however, is that one bad cell in an array of, let's say **100** cells, may bring down the total efficieny of the module **-** that's essentially what we are discussing **-** quite disproportionally, i.e. not by just **1 %**, but by far more.

Third Basic Question

- We take a number ***N*** of solar cells; assuminng that *all* oft them are perfectly identical, but that *one* of them is completely shaded because a big leaf or a splash ot birds shit comßpletely covers it surface.
  - In other words: We take out the constant current generator of one cell.
    What happens?

- Ans so on. By now you get it.

**Moduel technology is tricky
and needs attention!**