String fuses in Solar PV systems

Overcurrent protection for a string of solar panels is only necessary when we connect them up in parallel. One string of solar panels connected in series means that the total current will be the same as one panel, but the voltage will be multiplied by the number of panels in the string.

We could add another string with the same number of panels; however, if we route each string into different channels in the inverter, we now have double the power because we have twice as many panels, but each string is 1 x the current and the voltage is as before, multiplied by the number of panels.

This is standard practice, and most inverters prefer lower current and higher voltage. In this case string fuses will not be needed because the current is below the threshold of damage; most panels can withstand a certain level of current before damage occurs.

It is only when we start to connect the strings in parallel when the current is doubled and if we have sub-arrays in a larger installation the current can be sufficient to cause damage to a string which has failed; this string will receive current from the other strings and can cause damage or even fire if it is not protected against this.

Solar Panel facts and terminology.

A solar panel is a current limiting device. Unlike AC systems, when it is shorted out, the current increases only by a small amount, meaning that Automatic Disconnection of Supply (ADS) will not work at all; there is insufficient current to cause breakers or fuses to operate.

The protective measure of double insulation is the only measure suitable. This double insulation must be maintained throughout the system, so that all cables and MC4 connectors must be double insulated. It is this reason that single-core SWA is not appropriate, because when the conductors are stripped back for a termination, they now have only single insulation!

Standard test conditions. (STC) These are the conditions assumed to determine base figures for performance.:

- **Irradiance 1000 W/m^2**
- **Atmosphere 1.5**
- **Cell temperature 25^{0}C**

V_{OC} This is the open-circuit voltage. We test this value, and it tends to vary with temperature.

I_{SC} This is the short-circuit current. We test this value, and it tends to vary with irradiance (Sunshine).

The above parameters are the subject of multiplication factors to take account of atmospheric phenomenon which can cause the system to produce more power than expected and are used in design for rating components.

$$V_{OC\,STC}\ x\ 1.2 = \ U_{OC\_MAX}$$

$$I_{SC\,STC}\ x\ 1.25 = I_{SC\_MAX}$$

Solar panels have a max series fuse rating or reverse current rating, and this parameter is given the following terminology:

$$I_{MOD\_MAX\_OCPR}$$

For the following example, a value of 25 A will be assumed for the above!

Regulation 712.431.101 In a PV array with Ns strings (above 2 strings) in parallel, protective devices shall be provided to protect each PV string where the following condition is met:

$$1.35\ I_{MOD\_MAX\_OCPR} < (N_s - 1)I_{SC\,MAX}$$

This means that if the first part of the equation is **less** than the second part, then we need to provide fuses.

N_s is simply the number of strings in parallel. If we have two strings in parallel and take one away, we have one for purposes of the calculation. It stands to reason that we must have upwards of two strings connected in parallel before we need to worry about fitting string fuses.

For example: we have connected 3 strings in parallel, each panel has a $I_{sc\,(STC)} = 13.87\ A$.

The maximum series fuse or $I_{MOD\_MAX\_OCPR} = \ 25\ A$

$$I_{SC\,MAX} = 13.87\ x\ 1.25 = 17.33\ A$$

$$(3 - 1)17.33 = 34.67A$$

$$1.35\ I_{MOD\_MAX\_OCPR} = 1.35\ x\ 25 = 33.75A$$

$$1.35\ I_{MOD\_MAX\_OCPR} < (N_s - 1)I_{SC\,MAX}$$

$$33.75\ A\ < 34.67A$$

$$Because\ 1.35\ x\ 25 = (33.75A)\ is\ LESS\ THAN\ (N_s - 1)I_{SC\,MAX}\ = 34.67A.\ Fuses\ are\ required!$$

If we re-run the calculations with 4 strings connected in parallel.

$$I_{SC\,MAX} = 13.87\ x\ 1.25 = 17.33\ A$$

$$(4 - 1)17.33 = 52A$$

$$1.35\ I_{MOD\_MAX\_OCPR} = 1.35\ x\ 25 = 33.75A$$

$$1.35\ I_{MOD\_MAX\_OCPR} < (N_s - 1)I_{SC\,MAX}$$

$$33.75\ A\ < 52A$$

$$Because\ 1.35\ x\ 25 = (33.75A)\ is\ LESS\ THAN\ (N_s - 1)I_{SC\ MAX}\ = 52A.\ Fuses\ are\ required!$$

Now that we have established that string fuses are required, we need to fit them on the positive and the negative, so two per parallel string.

There are some parameters to consider in order to establish the I_n value of the fuses.

The Code of Practice for Grid-Connected Solar Photovoltaic Systems quote the following in **Section 5.5.2**

The string overcurrent protective device shall be selected with a rated current (I_n) such that all of the following conditions are met:

(a) To meet the requirements of BS IEC 62548

I. $I_n > 1.5\ x\ I_{SC\ MOD}$
II. $I_n < 2.4\ x\ I_{SC\ MOD}$
III. $I_n \leq I_{MOD\_MAX\_OCPR}$

(b) To meet the requirements of BS 7671

IV. $1.1\ I_{SC\ MAX}\ of\ the\ string\ \leq I_n \leq I_{MOD\_MAX\_OCPR}$

All of these different parameters can get a little confusing, so a good idea is to set them out in tabulated form, so that it can be used when required.

$1.35\ I_{MOD\_MAX\_OCPR} = 33.75A$ $(N_s - 1)I_{SC\ MAX} =\ x\ 17.33 = 34.67A$	$I_{MOD\_MAX\_OCPR} = 25\ A$ $I_{SC\ MOD} = 13.87A$
$I_n > 1.5\ x\ I_{SC\ MOD}$	$25 > (1.5\ x\ 13.87A) = 20.8A$
$I_n < 2.4\ x\ I_{SC\ MOD}$	$25 < (2.4\ x\ 13.87A) = 33.29A$
$I_n \leq I_{MOD\_MAX\_OCPR}$	$25A \leq 25A$
	$1.1\ x\ (\ 13.87\ x\ 1.25) = 17.33A$

$1.1 I_{SC\ MAX}\ of\ the\ string\ \leq I_n \leq I_{MOD\_MAX\_OCPR}$	$17.33 \leq 25A\ \leq 25\ A$

In this case, a 25A fuse will satisfy all the parameters.