Guide to best practice - Managing mismatches when replacing panels and using panels with different power ratings in a string

Mismatches in panel characteristics is a common phenomenon in electrical systems. A mismatch is caused by the interconnection of parts which do not have identical properties or which experience different electrical or environmental conditions from one another.

A mismatch is the name given to differences in the characteristics of an electrical system and is especially relevant to solar installations, where the overall power production capability of the installation is determined by the lowest performing panel. An analogy would be a team of rowers in a boat: if one rower is not in sync with his strokes, then the power and progress of the entire team and boat is reduced.

In solar installations, the typical causes of mismatch include non-identical electrical characteristics, shading, and differences in operating temperature. Besides these well-known causes, one emerging issue in the industry that has not yet been fully addressed is the availability of like for like panel replacements.

Panel manufacturers, including REC, are generally engaged in continuous and incremental product improvements, meaning a gradual increase in the watt classes produced and a progression of available watt classes upwards. Over time, this means that the exact panel specifications previously purchased by installers - and those purchased today - may not be available indefinitely. So what is the best course of action if panels do ever require replacement. The scenarios below provide some general guidelines that can minimize the adverse effects of panel mismatches on a system level.

Image 1: Panel strings in a utility installation

The situations and recommendations listed below are made for a certain type of mismatch caused when a like for like panel replacement is unavailable. Note that mismatch is a general problem seen in all electrical systems and therefore the following recommendations cannot guarantee the complete elimination of mismatch. The purpose of these recommendations is to reduce the risk of severe mismatch induced problems:

1. **Replacing the panel with a higher power rated panel from the same product line**
   Regardless of any differences in rated power, the mechanical characteristics within the product line should be the same. When a like for like replacement is not possible, the next best option is to utilize another panel from the same product series.

   The current output for a circuit of dissimilar devices in series is limited to the current of the lowest performing device in the entire string. If a lower rated panel is installed as a replacement, that panel will drag the overall system output down, therefore a higher-rated panel from the same product line should be used as the replacement where required. The higher rated panel will have a higher current rating at I_{MPP} and as such will not lessen the Maximum Power Point (MPP) current.

⚠ **Products from different manufacturers, cell sizes or technologies must not be combined. Always check and ensure the string voltage is still within inverter limits**

2. **Re-arrange existing panels for better performance**
   If the existing system has significant mismatch problems caused by shading or other issues, it is recommended to consider rearranging the panels so that the replacement (the one with higher power rating) can be placed in the area with shading. By doing this, the mismatch in the existing system can be compensated and made less severe.

3. **Current mismatch in the same string**
   Current mismatch occurs when the current output (I_{MPP}) of panels in the same string is different. When currents are mismatched, the lowest performing panel in the string will reach its 'saturated state' first and thereafter limit the current of the whole string. Any extra energy from sunlight will then heat up the panels, in particular the lowest performing one. To reduce the risk of problems caused by current mismatch, the I_{MPP} deviation should be less than 10%. Note that this type of current mismatch may make existing problems such as micro-cracks and faulty bypass diodes more severe, so it is suggested to do a thorough check in the whole string before replacement.

4. **Voltage mismatch between parallel strings**
   Voltage mismatch is where two parallel strings produce different voltages when measured independently. The replacement panel (the one with higher power rating) will cause the voltage mismatch. When there is a mismatch in voltages, the strings normally settle on the output of the lowest performing one. A severe voltage mismatch makes the panels operate far from their MPP, which has a negative impact on the efficiency of the inverter. As the peaks of the PV curve in the inverter change due to the mismatch, the electronics that track the MPP can become confused, causing the inverter to choose to operate for long periods of time well outside the optimal output range. A V_{MPP} deviation of less than 10% is recommended.

5. **Changing the whole string when 50% of panels need replacing**
   When 50% (or more) of the panels in the same string need to be replaced, it is recommended that the whole string is replaced. This reduces the risk of severe mismatch problems.

⚠ **When the whole string is replaced by higher rated panels, check the string voltage to see if it is within the limits of other system components e.g., combiner box and/or inverter.**

6. **Limits set by inverter and fuse ratings**
   For strings operating on dedicated MPPT, mismatch across different strings is not possible; the only concern is the inverter rating. Total P_{MAX} and I_{MPP} must not exceed the recommended inverter ratings and string voltages must remain within the inverter MPPT window. For inverters with numerous strings on a single MPPT, the mismatch will be very small, but checks should be carried out on V_{OC} and I_{SC}.

   A further concern is the fuse rating. When higher rated panels are installed in the strings, the total I_{SC} must not exceed the existing fuse rating; if this is the case, new fuses need to be chosen to ensure the panel and other system components are adequately protected.

Summary

Mismatches can cause issues between panels in a string, however, following the advice above, mismatches in a string can be overcome and the installation can work at its optimum level. Care must be taken to ensure that the system continues to work as planned and that other components are not affected by the replacement.

An example:

Below is an example of the replacement of several panels in a string detailed in simple form. Determining the electrical operating parameters in the event of a mismatch requires advanced modeling. This example offers a simplified guideline for ensuring the safety of the system is met upon panel replacement:

- There are two strings connected in parallel
- Each string has 10 panels of REC225PE (225 Wp)
- Several panels in one string need replacing, but 225 Wp panels are no longer produced and so will be replaced with higher rated panels
- For current mismatch concerns, the I_{MPP} deviation needs to be less than 10%

According to Table 1, REC225PE panels can be replaced by those with a power rating between 225 Wp to 260 Wp:

Table 1: Data sheet and I_{MPP} deviation

ELECTRICAL DATA @ STC	REC225PE	REC235PE	REC245PE	REC255PE	REC260PE	REC265PE
Nominal power - P_{MPP} (Wp)	225	235	245	255	260	265
Watt class sorting - (W)	0/+5	0/+5	0/+5	0/+5	0/+5	0/+5
Nominal power voltage - V_{MPP} (V)	28.9	29.6	30.1	30.5	30.7	30.9
Nominal power current - I_{MPP} (A)	7.79	7.96	8.23	8.42	8.50	8.58
Open circuit voltage - V_{OC} (V)	36.2	36.7	37.1	37.6	37.8	38.1
Short circuit current - I_{SC} (A)	8.34	8.51	8.80	8.95	9.01	9.08
Panel efficiency (%)	13.6	14.2	14.8	15.5	15.8	16.1
I_{MPP} difference (%)	-	2.18	5.65	8.09	9.11	10.14

In the case of there being a voltage mismatch between two strings, if the REC260PE is picked for the replacement, the string voltage can be estimated as following:

- I_{MPP} of the whole string will be settled at 7.79 A (the value of the lowest performing panel i.e., 225 Wp)

So, for 260 Wp panels:

- The new V_{MPP} will be 260/7.79 = **33.4 V**
- Voltage of the string = 28.9 x (quantity of REC225PE) + 33.4 x (quantity of REC260PE)

Table 2 shows the string voltage deviation according to the number of panels for different ratings:

Table 2: V_{MPP} deviation

	REC225PE	REC260PE	String Voltage (V)	Deviation with another string (%)
Number of panels	10	0	289	-
	9	1	293.5	1.56%
	8	2	298	3.11%
	7	3	302.5	4.67%
	6	4	307	6.23%
	5	5	311.5	7.79%
	4	6	316	9.34%
	3	7	320.5	10.90%
	2	8	325	12.46%
	1	9	329.5	14.01%
	0	10	307	6.23%

From Table 2, six REC225PE panels could be replaced by REC260PE within the voltage deviation limit. However, for a 10-panel string, if more than five panels need replacing, it is recommend that the entire string is replaced. By replacing the whole string with 260 Wp panels, the I_{MPP} of the string will be 8.5 A (260 Wp panel rating), and so the voltage of the string can be estimated as 30.7 x 10 = **307 V**. Compared to another string (225 Wp panels), the voltage deviation will be 6.23%.

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