

# CONCENTRATING PHOTOVOLTAIC MULTIJUNCTION (MJ) MODULE ELECTRICAL LAYOUT OPTIMISATION BY A NEW THEORETICAL AND EXPERIMENTAL "MISMATCH" ANALYSIS INCLUDING SERIES RESISTANCE EFFECTS.

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## INTRODUCTION

Modeling outdoor photovoltaic behavior of a CPV MJ module with reference to the electro-optical mismatches and series resistance effects is necessary for its electrical lay-out optimization. The presence of soiling effects, optic defective parts, cell non uniform behavior owing to solar tracker misalignment, can introduce current mismatch among the solar cells penalizing the module photovoltaic performances.

The presented analysis is useful for:

- **Modelling** and simulating mismatch operating conditions for all the possible circuital module and topology, e.g. considering a number  $M$  of cell per receiver, a number  $N$  of series-connected receivers and number  $L$  of strings;
- **Predicting the I-V curve** and maximum power point of the module considering a given mismatch condition, its series resistance value and the resistance value of cables connecting the module to the inverter;
- Determining the **best module electrical layout** in relation to the number of mismatched cells, to their distribution in the module and to the mismatch percent value presented by each cell;
- **Identifying** the module receivers mismatch values starting from the experimental I-V curve of modules consisting of only one string with series-connected receivers.

The modeling has been validated on a tested module in outdoor conditions by generating on purpose mismatch losses.

## MODELLING

A CPV receiver can be shown equivalent to a single-junction solar cell characterized by 4 equivalent parameters:

- $I_{oeq\_r}$  = the equivalent inverse saturation current
- $n_{eq\_r}$  = the equivalent ideality factor
- $R_{seq\_r}$  = the equivalent receiver series resistance
- $I_{ph\_r}$  = the equivalent receiver photovoltaic current

If the receivers within a string are sorted in function of their photovoltaic current value, from the highest one to the lowest one, the following equation describes the I-V curve of the string:

$$V_{st}(I) = \sum_{j=1}^N \left( \sum_{z=1}^j \frac{KT}{q} n_{eq\_r} \ln \left( 1 + \frac{I_{ph\_rz} - I}{I_{oeq\_r}} \right) - (NR_{seq\_r} + R_c) \right) +$$

Voltage contribution of the  $j$ - active receivers

$$- \sum_{z=j+1}^N \frac{KT}{q} n_{by} \ln \left( 1 + \frac{I - I_{ph\_rz}}{I_{oby}} \right) \cdot w_j(I)$$

Voltage drop on the by pass diodes of the  $N$ -j passive receivers

where:

$$w_j(I) = \begin{cases} 1 & \text{if } I_{ph\_r(i+1)} < I \leq I_{ph\_r(j)} \\ 0 & \text{for all others } I \text{ values} \end{cases}$$

$n_{by}$  = ideality factor of the bypass diode;

$I_{oby}$  = reverse saturation current of the by-pass diode;

$I$  = current load

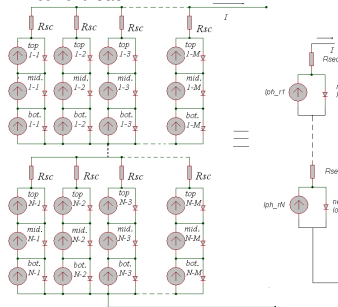


Figure 1 Equivalent circuit of one string consisting of  $N$  series-connected receivers.

The typical mismatch quantities are defined by the following terms:

- The **j-Cell and i-Receiver Mismatch** (within each string):

$$M_{ri} = \frac{I_{ph\_r\_max} - I_{ph\_ri}}{I_{ph\_r\_max}} \quad M_{rj} = \frac{I_{ph\_r\_max} - I_{ph\_rj}}{I_{ph\_r\_max}}$$

where:

$I_{ph\_r\_c\_max}$  = maximum receiver, cell photocurrent

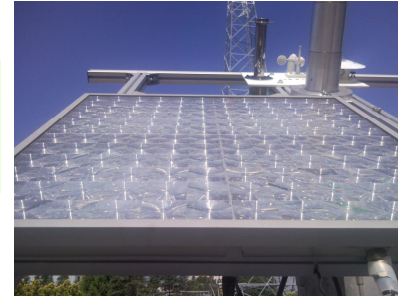
$I_{ph\_r\_c\_i,j}$  = photocurrent of the  $i$ -receiver,  $j$ -cell

- **Module power loss:**  $LP\% = 100 \frac{P_{max} - P_{meas}}{P_{max}}$

- **Mismatch receiver order  $k$** , with  $k=1...N$ . The receivers mismatches are sorted, with the  $k$  index decreasing, in function of their current mismatch value: the receiver with  $k=1$ ,  $Mr(1)$ , has the highest current mismatch value, while the receiver with  $k=N-1$  has the lower current mismatch value. The receiver with  $k=N$  is considered without mismatch.

## TESTED MODULE

**Specifications**  
Single string, N.144 cells assembled in N.16 series-connected receivers, each one having N.9 parallel-connected cells



CPV SolarTec Int. module used for modeling validation

## PREDICTING I-V CURVE

A CPV MJ module with any mismatched receivers is characterized by an I-V curve presenting some current steps and a P-V curve with some extra power peak  $P_k$ . The fig.2 shows an example of I-V and P-V curves predicted by theory related to the layout of the tested module.

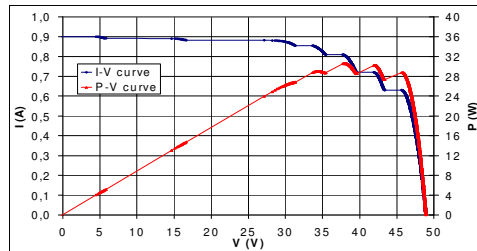


Figure 2 I-V and P-V curves predicted by the model in the case of a CPV MJ consisting of only one string with (N=16;M=9) layout, assuming a given receivers mismatch condition.

A **critical receiver mismatch** value  $Mrcr$  can be defined. When  $Mr(1) > Mrcr$  it exists a power extra-peak whose value is higher than the canonical power peak:  $P_k > P_0$ . If  $Mr(1) > Mrcr$  the by pass diode allows to partially recover the string electrical power.  $Mrcr$  value depends on the module layout.

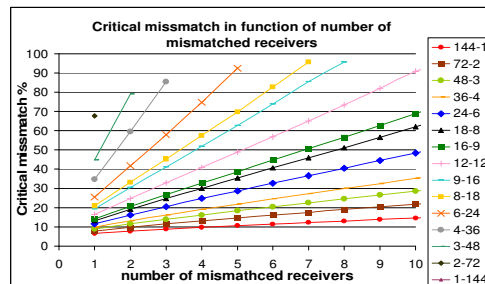


Figure 3 The  $Mrcr$  values in function of the number of mismatched receivers, for different module layout configurations are depicted.

## VALIDATION

The new theoretical approach is validated on the SolarTec Int. module. In order to experimentally control the mismatched condition 3 cells of the module are on purpose blinded and the module experimental P-V curve detected. The results of the comparison between the theoretical and experimental P-V curves are reported in figure 4.

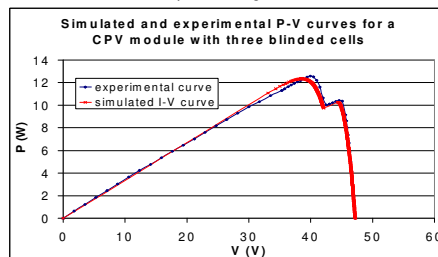


Figure 4 Simulated and experimental P-V curves of the SolarTec Int. CPV MJ module having blinded 3 solar cells (receiver mismatch of 33%).

## BEST MODULE ELECTRICAL LAYOUT

Two possible mismatched cells distributions are considered:

1. **uniform** (mismatched cells are distributed among different receivers minimizing the number of mismatched cell in each receiver).
2. **not-uniform** (mismatched cells are ordered maximizing the number of mismatched cells in a single receivers, that is, the mismatched cells are grouped to fill one by one the receivers).

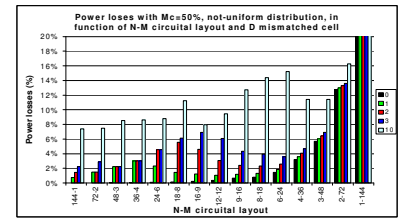


Figure 5 CPV MJ Module power losses in relation to the electrical layout, with not-uniform mismatch distribution.

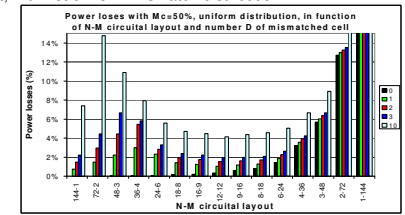


Figure 6 CPV MJ Module power losses in relation to the electrical layout, with uniform mismatch distribution.

## IDENTIFYING

An original procedure is developed to identify the module receivers mismatches starting from any experimentally detected I-V curve. As test-case, the mismatch identification procedure has been applied to SolarTec Int. module, using one of its experimental mismatched I-V curves determined when the solar tracker was misaligned (see fig. 7).

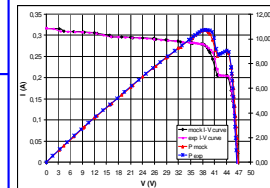


Figure 7 Experimental and identified (I-V), (P-V) curves of a SolarTec of the Solartec module, which module (tracker misaligned).



Figure 8 Soiling effect on the lenses (I-V), (P-V) curves of the Solartec module, which introduced a  $Mr(1)$  value of 15%.

## CONCLUSION

Current mismatch among cells of a CPV MJ module is produced by soiling effects, optic defective parts, cell non uniform behavior and solar tracker misalignment. Considering different electrical module layout, we have investigated the effect on the module photovoltaic performances of two possible mismatched cells distributions, uniform and not-uniform, which can simulate the above mismatching causes. The work allows optimizing the module electrical layout to minimize the power losses, and make the module more robust to the different mismatch causes. The new modeling gives a deep understanding of the mismatch effects, allowing predicting the I-V curve of mismatched CPV MJ module and also identifying from the experimental module I-V curve the mismatch values of its receivers.

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