

New Technologies in Photovoltaic Technology: Reconfiguration Systems for Photovoltaic Plants

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OUTLINE

- Introduction
- Basic concepts of reconfiguration's systems
- Case Study
- Experimental evaluations
- Discussion
- Conclusions

INTRODUCTION

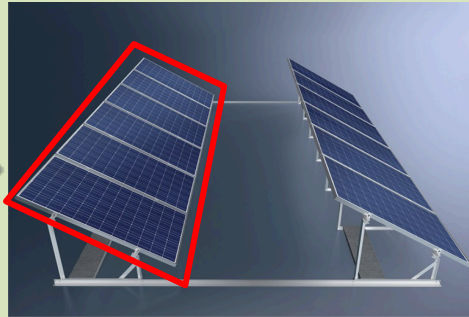
- Normally the PV plants are statically connected and the most used topology is series-parallel (SP).
- The presence of mismatch due to shading of some cells of the module causes the reduction of total power output of a PV array.
- The maximum power point is detected by the inverter.
- Monitoring systems are used in order to track the performances of the generation plant.
- Recently many solutions have been proposed to optimize the power output under non-optimal irradiance conditions, adopting dynamic reconfiguration systems for PV modules interconnection.



Cell



Module

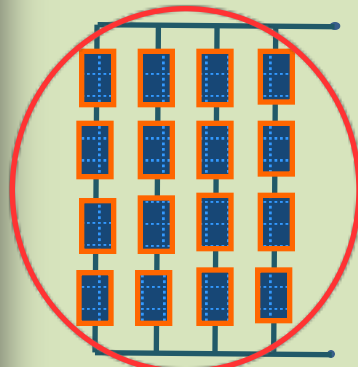
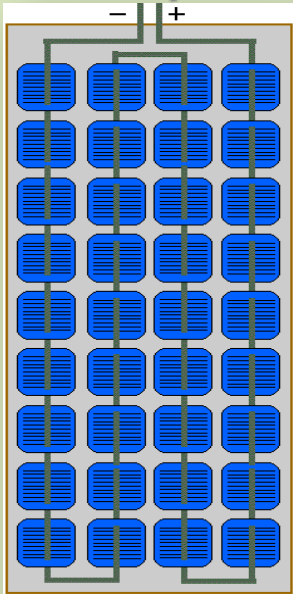


String



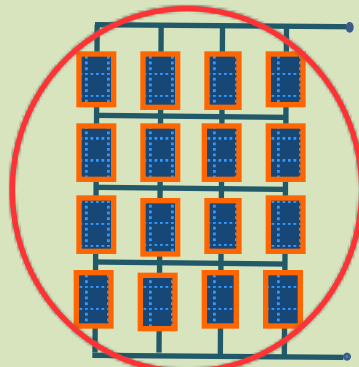
Kagoshima Power Plant: 290.000 PV Modules

PV array



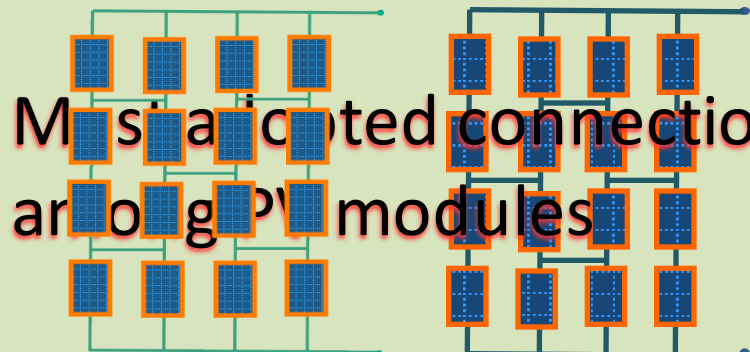
Series-Parallel array

SP



Total-Cross-Tied array

TCT



Bridge-Link array

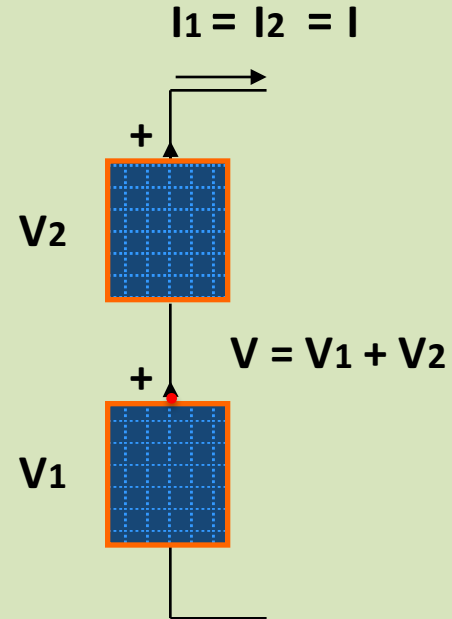
BL

Honey-Comb array

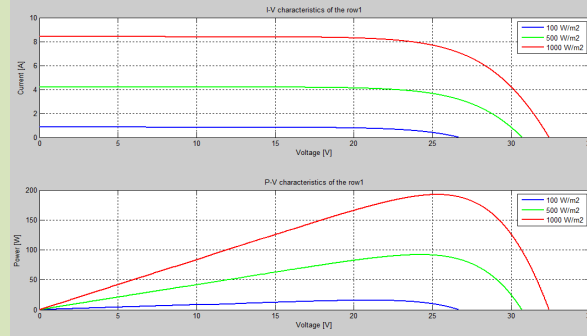
HC

Most adopted connections among PV modules

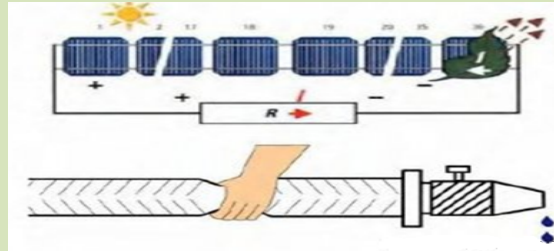
Series connection



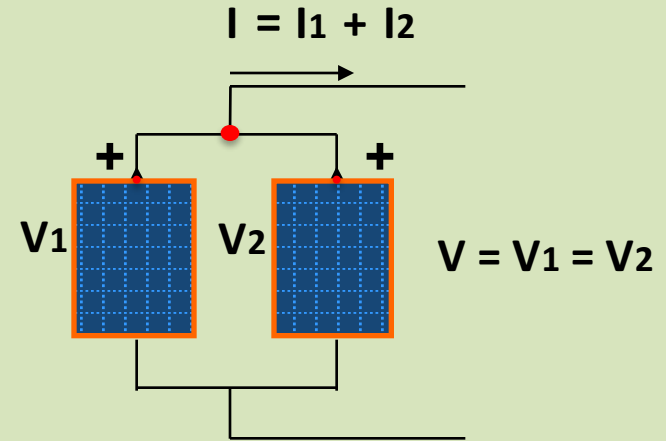
I-V, P-V curves for different irradiance values.



Pipe effect



Parallel connection



- ❑ The current is the same and equal to the minimum between those produced by the panels
- ❑ The voltage is given by the sum of the voltages of the individual panels of the series

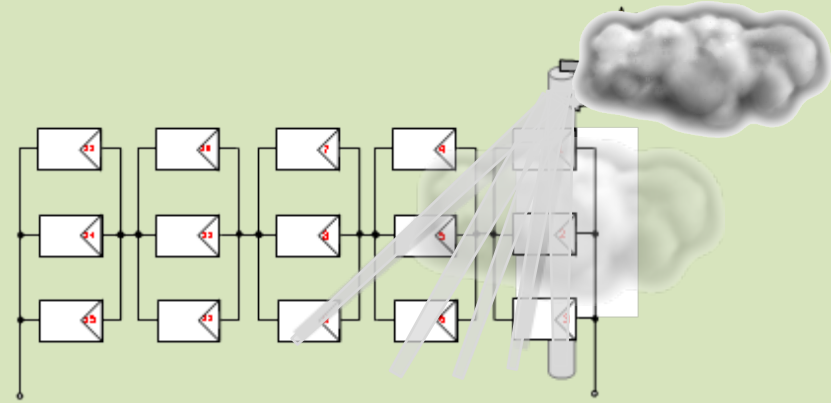
- ❑ The current is given by the sum of the currents produced by the panels
- ❑ The voltage is the same and equal to the minimum between those produced by the panels

Shadows and mismatch problems



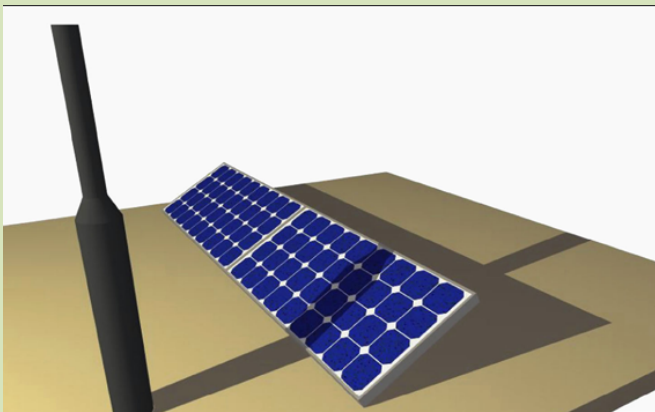
❑ Fixed obstacle

Surrounding buildings, poles, trees, wires, leaves...



❑ Weather conditions

Passing clouds, rain, ...

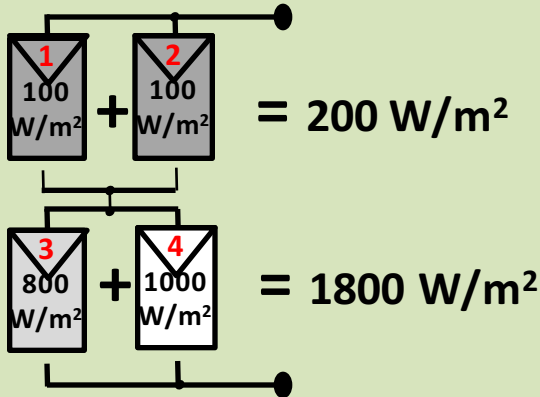


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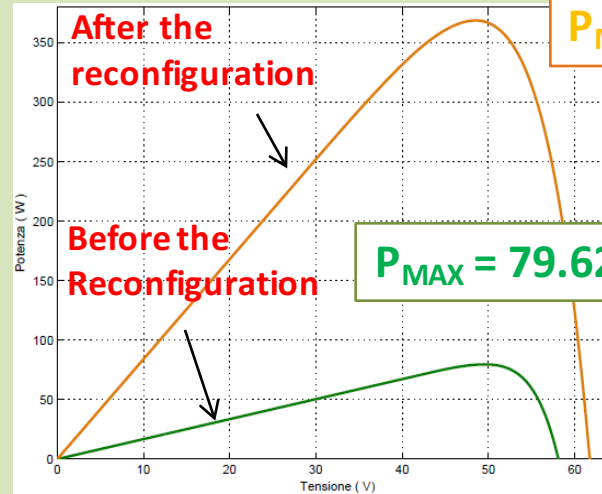
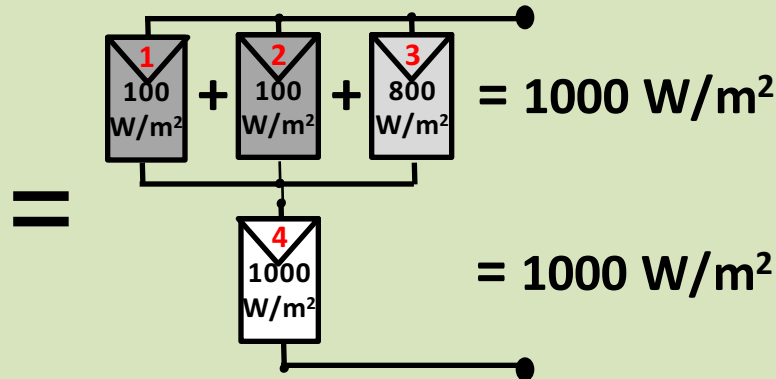
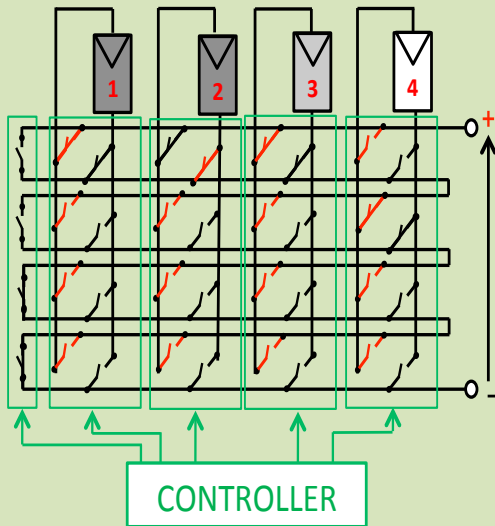
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TCT Reconfiguration scheme

Static Configuration



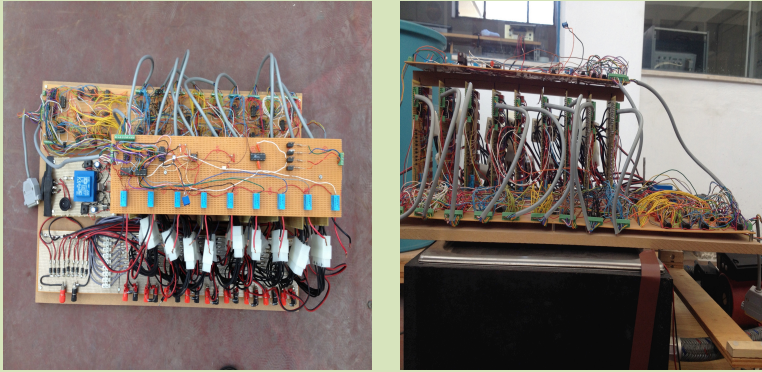
Dynamic Configuration



[R. Candela, E. R. Sanseverino, P. Romano, M. Cardinale and D. Musso, "A Dynamic Electrical Scheme for the Optimal Reconfiguration of PV Modules under Non-Homogeneous Solar Irradiation," *Applied Mechanics and Materials*, vol. 197, pp. 768-777, 2012]

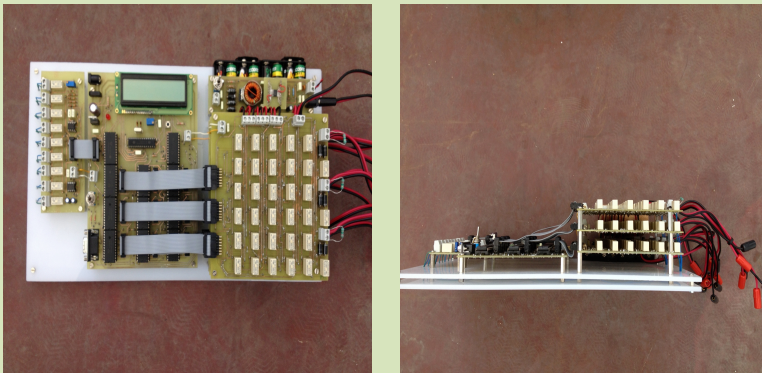
PROTOTYPES OF PV TCT RECONFIGURATOR

PROTOTYPE 1 (9 MODULES)

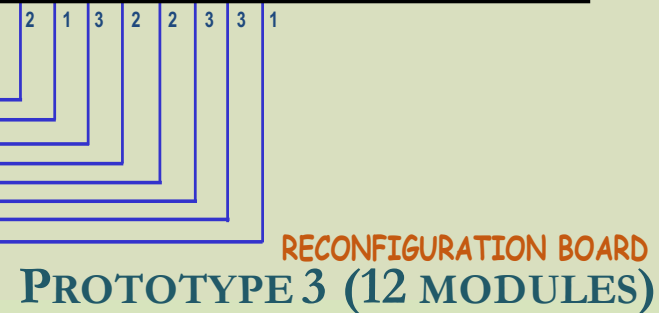
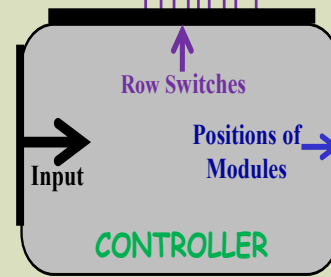
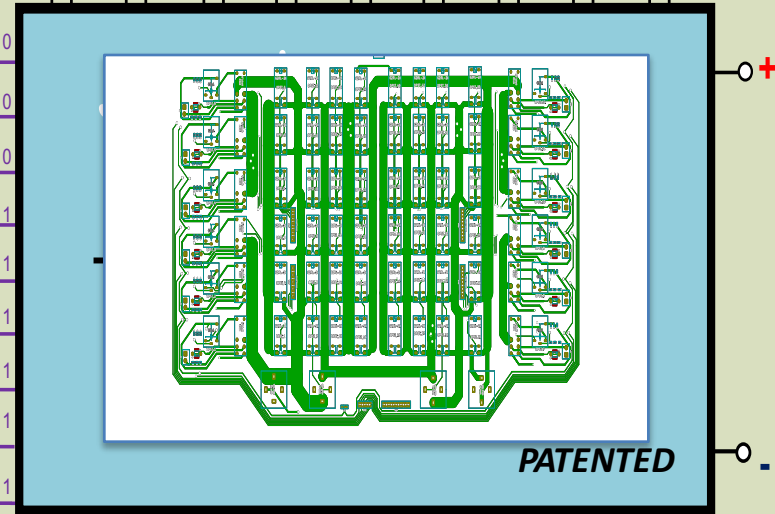


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PROTOTYPE 2 (9 MODULES)



1	2	3	4	5	6	7	8	9
100 W/m ²	200 W/m ²	300 W/m ²	200 W/m ²	300 W/m ²	400 W/m ²	300 W/m ²	400 W/m ²	500 W/m ²



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Case study



PROBLEMS

- The choice of the place in which to install the PV modules is very important and can seriously affect the energy output of the PV generator.
- Total absence of any sort of fixed obstacles, closely around the PV plant, would be required.
- In a fixed PV plant, the shadows of such obstacles, over one or more modules, could cause undesirable prolonged module PV power output reductions.
- In the practical applications, the installation due south is not always possible and even when it is possible, there can be a lot of factors that can affect the performances of the PV plant such as the presence of dormers, chimneys, satellite dishes or trees.

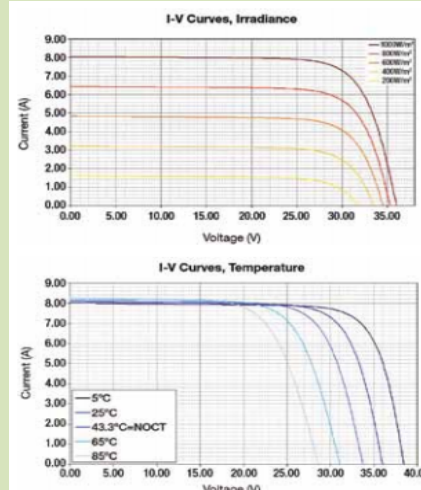
SOLUTION

- In all of these adverse cases, the deployment of a modules reconfiguration technique can represent a solution that is able to maximize the PV plant output power.

Thechnical data of phovoltaic modules (2007)

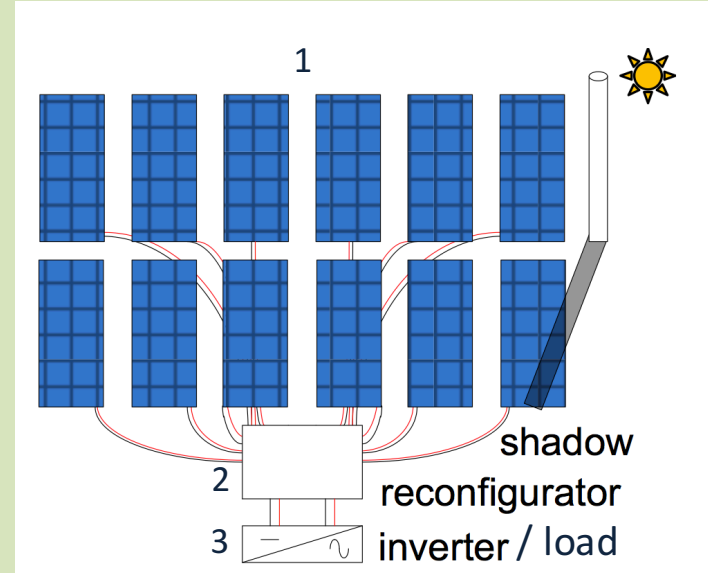
Conergy E 215P
Serial No.: 1000231611

Rated power (P_{max}) ¹	215W
Power tolerance	-0/+2.5%
Module efficiency	13.21%
Maximum power voltage (V_{mp})	28.80V
Maximum power current (I_{mp})	7.54A
Open circuit voltage (V_{oc})	36.00V
Short circuit current (I_{sc})	8.04A
Nominal Operating Cell Temperature (NOCT)	44.3°C/110.1°F
Temperature coefficient (P_{max})	-0.45%/°C
Temperature coefficient (V_{oc})	-0.34%/°C
Temperature coefficient (I_{sc})	0.05%/°C
Operating temperature range	-40°C - +85°C/ -40°F - +136°F
Maximum system voltage	600V (UL)/1000V (IEC)
Maximum Series Fuse Rating	20A



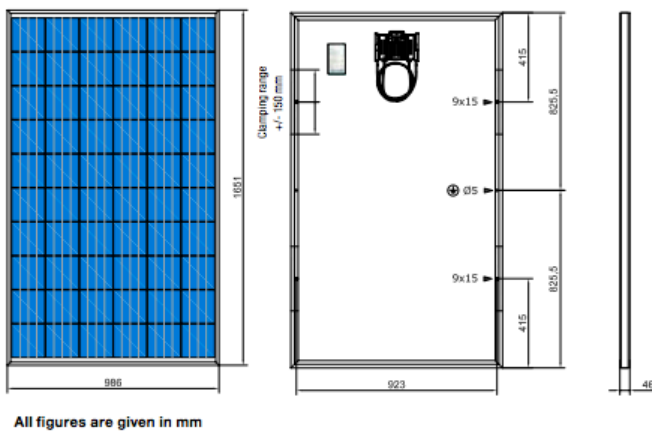
PV System

- 1 – PV Array (Two strings of six modules)
- 2 – Reconfigurator®
- 3 – Inverter/Load



Without considering any shading, each panel shows the same behavior, and the reconfigurator creates two identical strings.

Ⓟ Patent: SWITCHING APPARATUS FOR PHOTOVOLTAIC PANELS
P. Romano · R. Candela · E. Riva Sanseverino · M. Cardinale · D. Musso
Ref. No: WO2013140373, Year: 09/2013



Module dimensions (L x W x H)	1,651 x 986 x 46 mm (65 x 38.8 x 1.8 in)
Cell dimensions	156 x 156 mm (6.14 x 6.14 in)
Number of cells	60
Module weight	22 kg (48.5 lb)
Static wind/snow load	5400Pa /112.8psf
Glass	4mm/0.16in structured solar glass
Junction box	Huber+Suhner Solarbox HA3
Cable	2-1000mm/39" Huber+Suhner RADOX® PV wire (UL), 4mm ²
Connector	Huber+Suhner RADOX® Twist-Lock (UL)
Certifications	
Operating certifications	cULus, IEC 61215 Ed.2, IEC/EN 61730, IEC 61701
Fire safety classification	Class C
Warranty	
Material and workmanship warranty	10 years
Power warranty 1	92%/12 years
Power warranty 2	80%/25 years

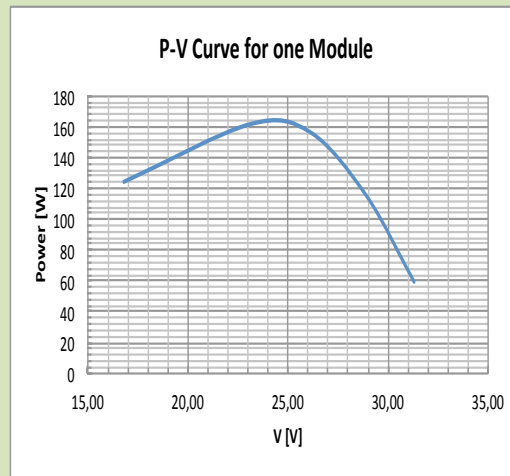
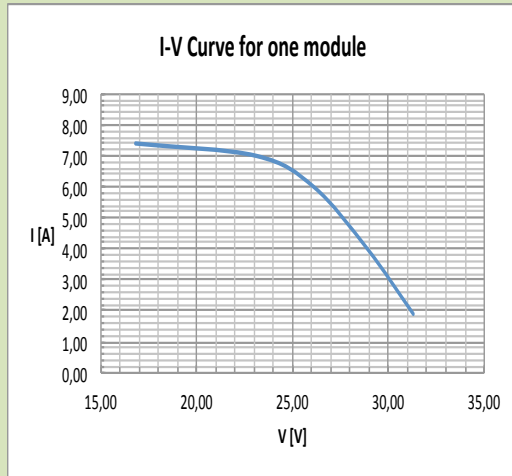
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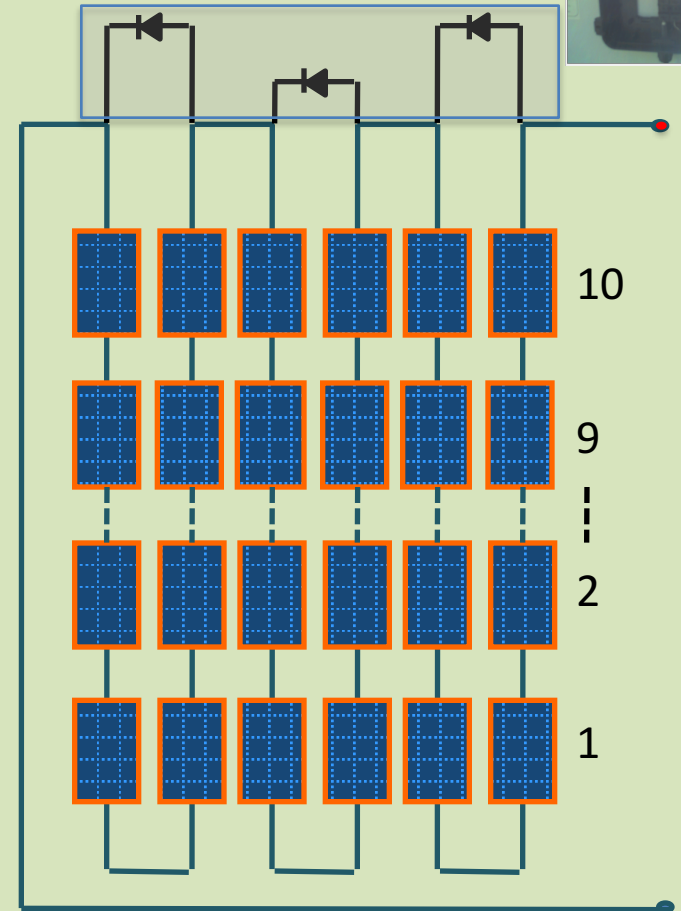
Performance of the Modules without shading and with different load conditions A, B, C and D

	load A	load B	load C	load D	load E
Voltage [V]	31.3	28.9	26.1	23.1	16.8
Current [A]	1.9	4.0	6.0	7.0	7.4
Power [W]	59.5	115.6	156.6	161.7	124.3



I-V and P-V Curves for every single module

Bypass diodes box



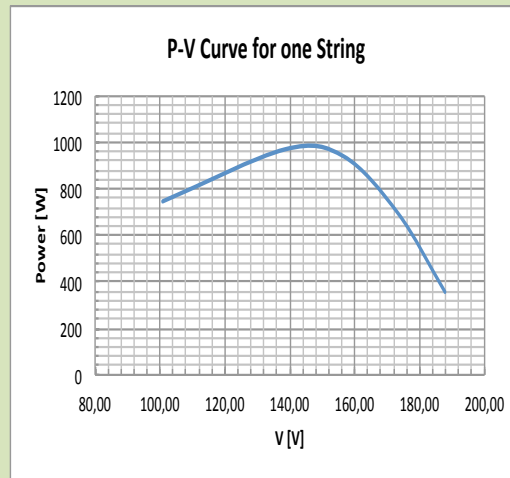
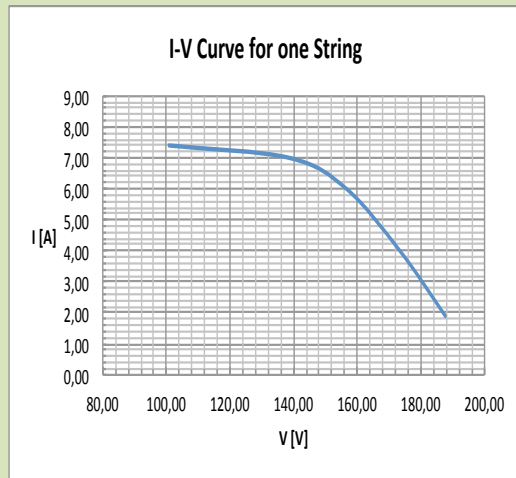
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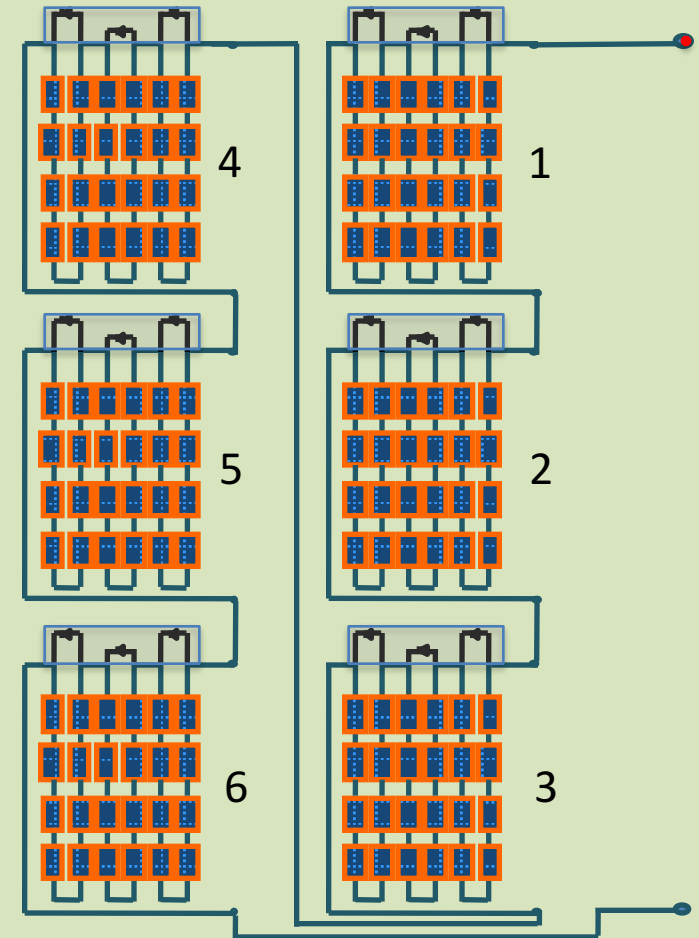
Performance of the Strings without shading and with different load conditions

	load A	load B	load C	load D	load E
Voltage [V]	187,8	173,4	156,6	138,6	100,8
Current [A]	1.9	4.0	6.0	7.0	7.4
Power [W]	357.0	693.6	939.6	970.2	745.8



I-V and P-V Curves for every single string

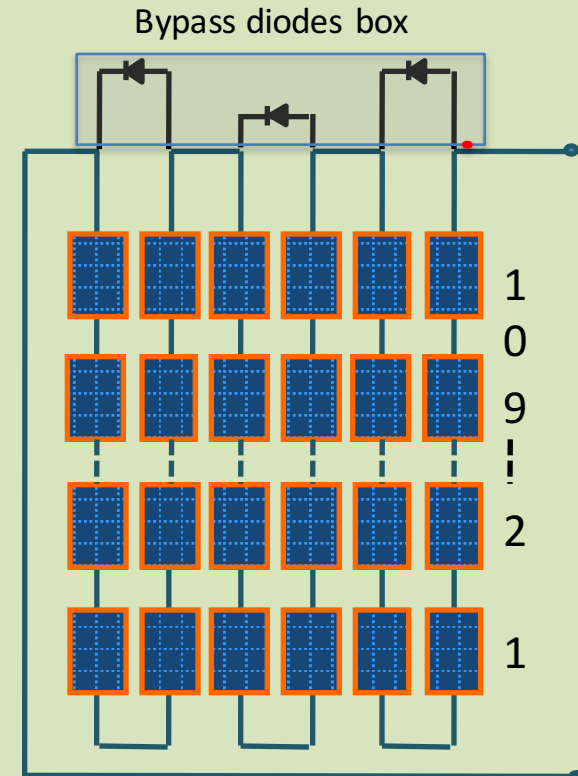
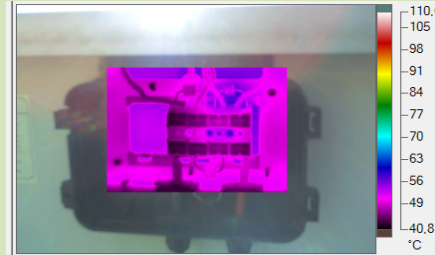
One of two strings



In order to test the algorithm an artificial shadow has been created.
0 case: all modules not shaded.

string 1: 1-5: not shaded; 6: not shaded

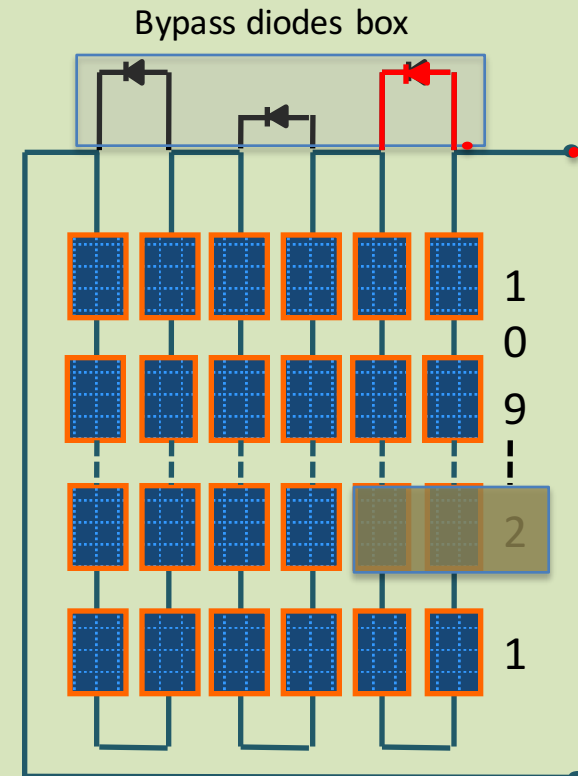
		V ₁₋₅ [V]	V ₆ [V]	I [A]	P ₁₋₅ [W]	P ₆ [W]	P _{string} [W]
load A	Not shadow	31.3	31.3	1.9	59.5	59.5	357.0
	Case 1	31.6	20.2	1.6	50.5	32.3	285.1
	Case 2	31.8	9.0	1.2	38.1	10.8	201.6
load B	Not shadow	28.8	28.8	4.0	115.2	115.2	691.2
	Case 1	29.2	18.7	3.3	96.6	61.7	543.5
	Case 2	30.1	8.2	2.6	78.3	21.3	412.6
load C	Not shadow	26.1	26.1	6.0	156.6	156.6	939.6
	Case 1	27.7	17.1	5.0	138.5	85.5	778.0
	Case 2	29.1	7.4	4.2	122.2	31.1	642.2
load D	Not shadow	23.1	23.1	7.0	161.7	161.7	970.2
	Case 1	25.9	15.6	6.4	165.7	99.8	928.6
	Case 2	27.7	6.8	5.2	144.0	35.4	755.6
load E	Not shadow	16.8	16.8	7.4	124.3	124.3	745.9
	Case 1	16.8	11.0	7.4	124.3	81.4	703.0
	Case 2	16.8	4.2	7.4	124.3	31.1	652.6



In order to test the algorithm an artificial shadow has been created.
1st case: one module shaded.

string 1: 1-5: not shaded; 6: shaded (1 diode on)

		V ₁₋₅ [V]	V ₆ [V]	I [A]	P ₁₋₅ [W]	P ₆ [W]	P _{string} [W]
load A	Not shadow	31.3	31.3	1.9	59.5	59.5	357.0
	Case 1	31.6	20.2	1.6	50.5	32.3	285.1
	Case 2	31.8	9.0	1.2	38.1	10.8	201.6
load B	Not shadow	28.8	28.8	4.0	115.2	115.2	691.2
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	Case 1	16.8	11.0	7.4	124.3	81.4	703.0
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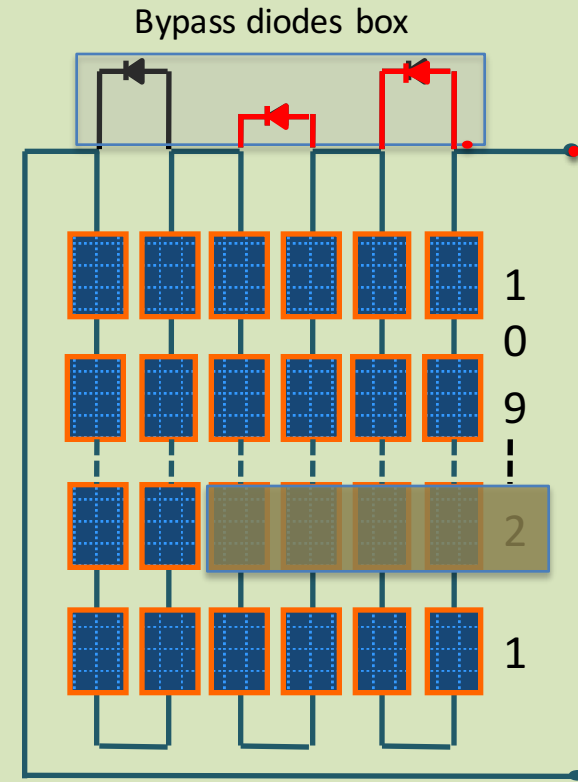
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In order to test the algorithm an artificial shadow has been created.
2nd case: one module shaded.

string 1: 1-5: not shaded; 6: shaded (2 diodes on)

		V ₁₋₅ [V]	V ₆ [V]	I [A]	P ₁₋₅ [W]	P ₆ [W]	P _{string} [W]
load A	Not shadow	31.3	31.3	1.9	59.5	59.5	357.0
	Case 1	31.6	20.2	1.6	50.5	32.3	285.1
	Case 2	31.8	9.0	1.2	38.1	10.8	201.6
load B	Not shadow	28.8	28.8	4.0	115.2	115.2	691.2
	Case 1	29.2	18.7	3.3	96.6	61.7	543.5
	Case 2	30.1	8.2	2.6	78.3	21.3	412.6
load C	Not shadow	26.1	26.1	6.0	156.6	156.6	939.6
	Case 1	27.7	17.1	5.0	138.5	85.5	778.0
	Case 2	29.1	7.4	4.2	122.2	31.1	642.2
load D	Not shadow	23.1	23.1	7.0	161.7	161.7	970.2
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	Case 1	16.8	11.0	7.4	124.3	81.4	703.0
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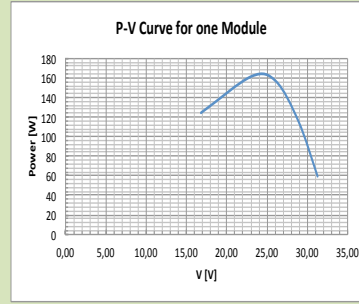
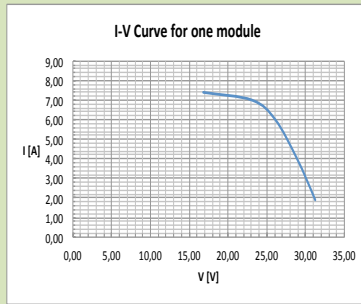
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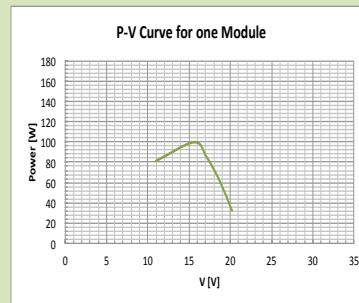
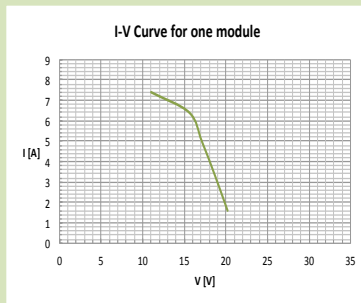
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All tree cases are considered in static configuration

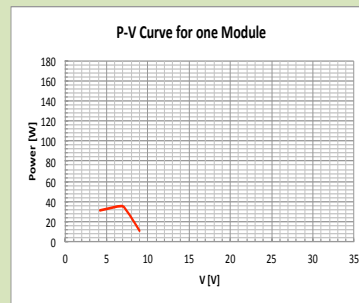
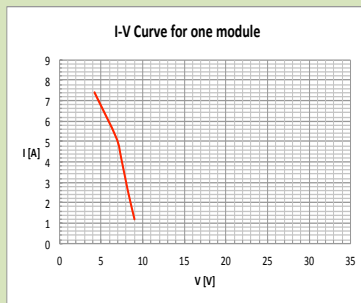
0 case



1st case



2nd case



		V ₁₋₅ [V]	V ₆ [V]	I [A]	P _{1-P5} [W]	P ₆ [W]	P _{string} [W]
load A	Not shadow	31.3	31.3	1.9	59.5	59.5	357.0
	Case 1	31.6	20.2	1.6	50.5	32.3	285.1
	Case 2	31.8	9.0	1.2	38.1	10.8	201.6
load B	Not shadow	28.8	28.8	4.0	115.2	115.2	691.2
	Case 1	29.2	18.7	3.3	96.6	61.7	543.5
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load D	Not shadow	23.1	23.1	7.0	161.7	161.7	970.2
	Case 1	25.9	15.6	6.4	165.7	99.8	928.6
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load E	Not shadow	16.8	16.8	7.4	124.3	124.3	745.9
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	Case 2	16.8	4.2	7.4	124.3	31.1	652.6

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The reconfigurator is able to regroup similar irradiated panels (irradiance equalization algorithm) in order to have string of panels, parallel connected, in series with other strings with similar current value (TCT configuration).

In this experiment, by setting reconfigurator with the option to exclude the shaded panels, only one has been excluded from six panels string. In this condition 16.7% of loss compared to the static case with no shadow effects have been obtained.

	Power String (Not shaded) [W]	Loss (case 1) %	Loss (case 2) %	Power String (Reconfigured) [W]	Loss (reconfigured) %	$\Delta P1$ %	$\Delta P2$ %
load A	357.0	20.0	43.4	297.3	16.7	+3.5	+26.9
load B	691.2	21.4	40.3	576.0	16.7	+4.8	+23.7
load C	939.6	17.2	31.6	783.0	16.7	+0.6	+15
load D	970.2	4.3	22.2	808.5	16.7	-12.3	+5.6
load E	745.9	5.7	12.5	621.6	16.7	-10.9	-4.1



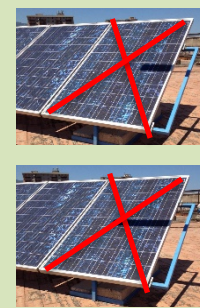
Not shaded



1st case



2nd case



Reconfigured

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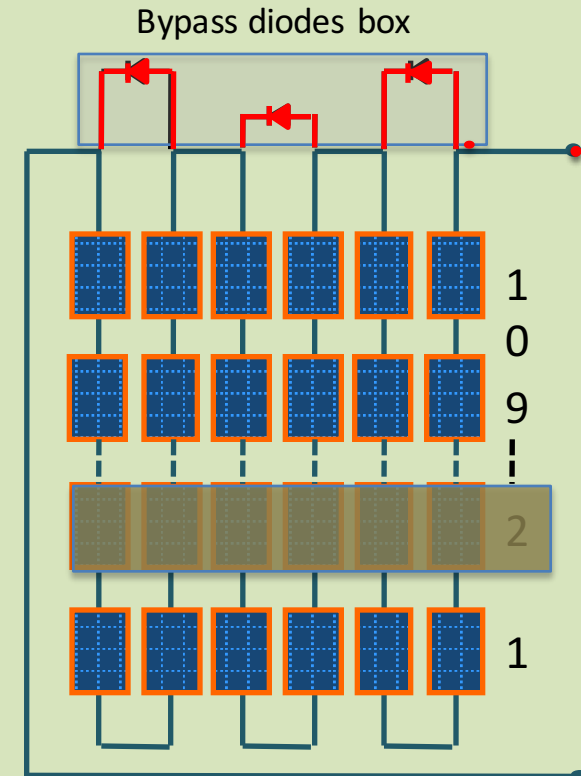
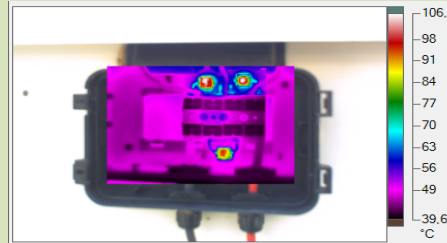
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In order to test the algorithm an artificial shadow has been created.
3rd case: one module shaded.

string 1: 1-5: not shaded; 6: shaded (3 diodes on)

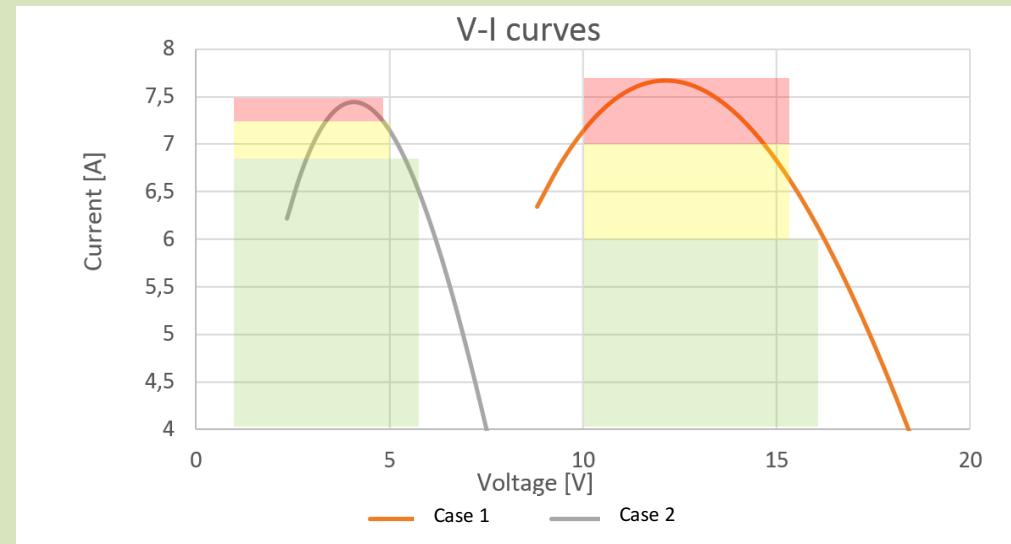
		V ₁ -V ₅ [V]	V ₆ [V]	I [A]	P ₁ -P ₅ [W]	P ₆ [W]	P string [W]
load C	Not shaded	26.1	26.1	6.0	156.6	156.6	939.6
	Case 3	26.7	-2.9	5.1	136.1	-14.8	665.7
	reconfigured	26.1	open	6.0	156.6	-	783.0
load D	Not shaded	23.1	23.1	7.0	161.1	161.1	970.2
	Case 3	23.7	-3.0	6.5	154.0	-19.5	750.7
	reconfigured	23.1	open	7.0	161.1	-	808.5
load E	Not shaded	16.8	16.8	7.4	124.3	124.3	745.9
	Case 3	17.4	-3.1	7.4	128.7	-21.5	620.8
	reconfigured	16.8	open	7.4	156.6	-	621.5



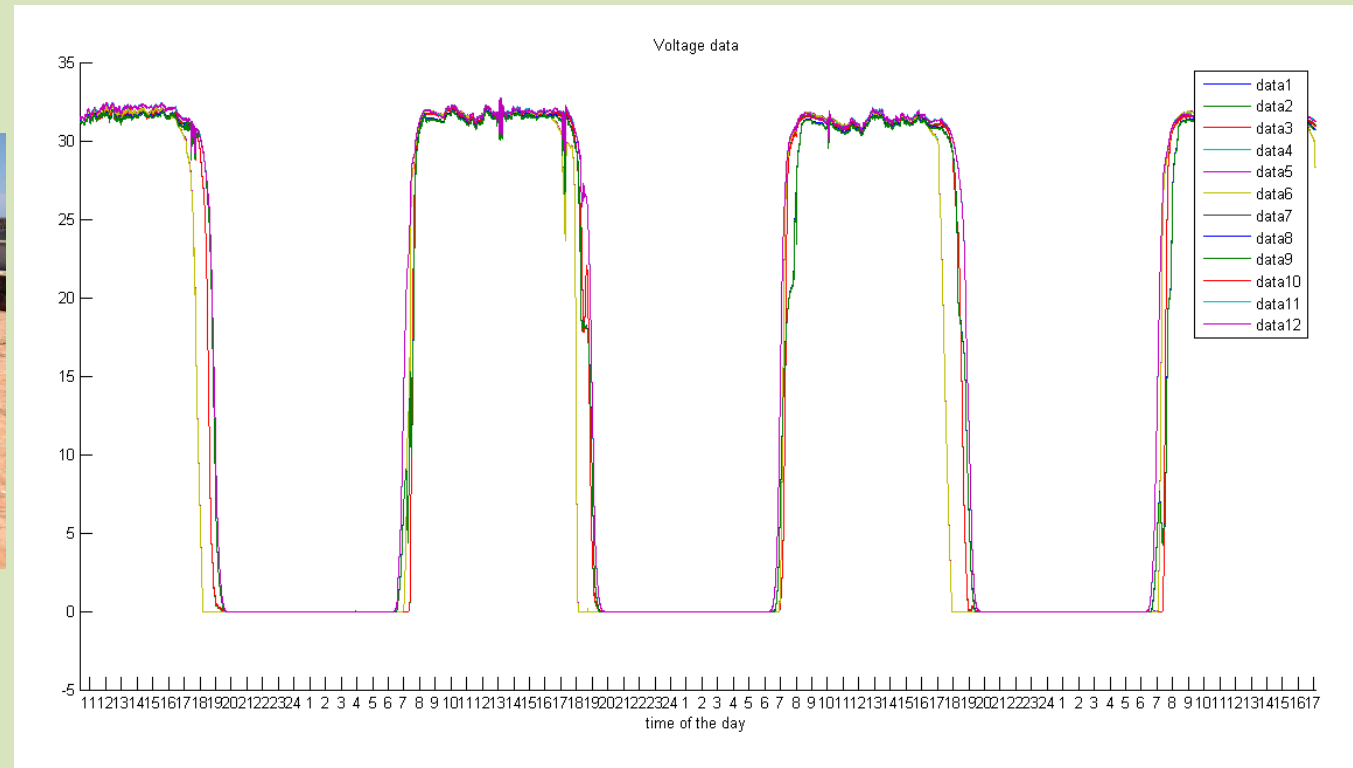
DISCUSSION

This survey has achieved the goal of studying the case where a PV system is in the condition of shading.

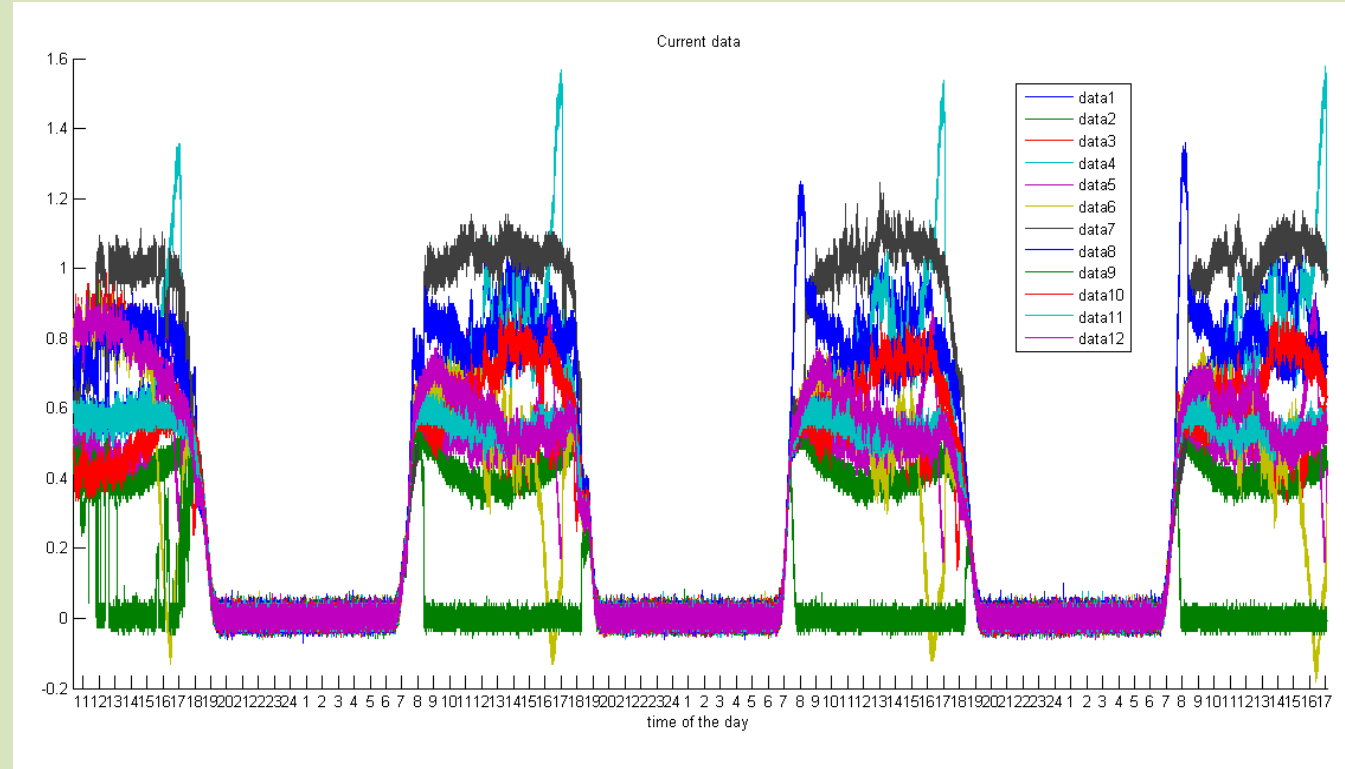
- If the panel is totally shaded, as shown in case 3, the action of the reconfigurator, which exclude the shadowed panel from the active string, is always appropriate.
- The figure shows the areas in which the power increases as a result of the exclusion of the panel shaded (green areas);
- if the current produced exceeds a certain value, the exclusion of the panel could reduce the power of the entire string (yellow areas);
- finally, with the red color it is marked the area on which the exclusion of the panel brings always a decrease to the power of the string.
- If two diodes are direct biased (case 2), the action of the reconfigurator is almost always desirable;
- If only one diode is direct biased (case 1) a green area is reduced and the effect of reconfiguration is less positive.



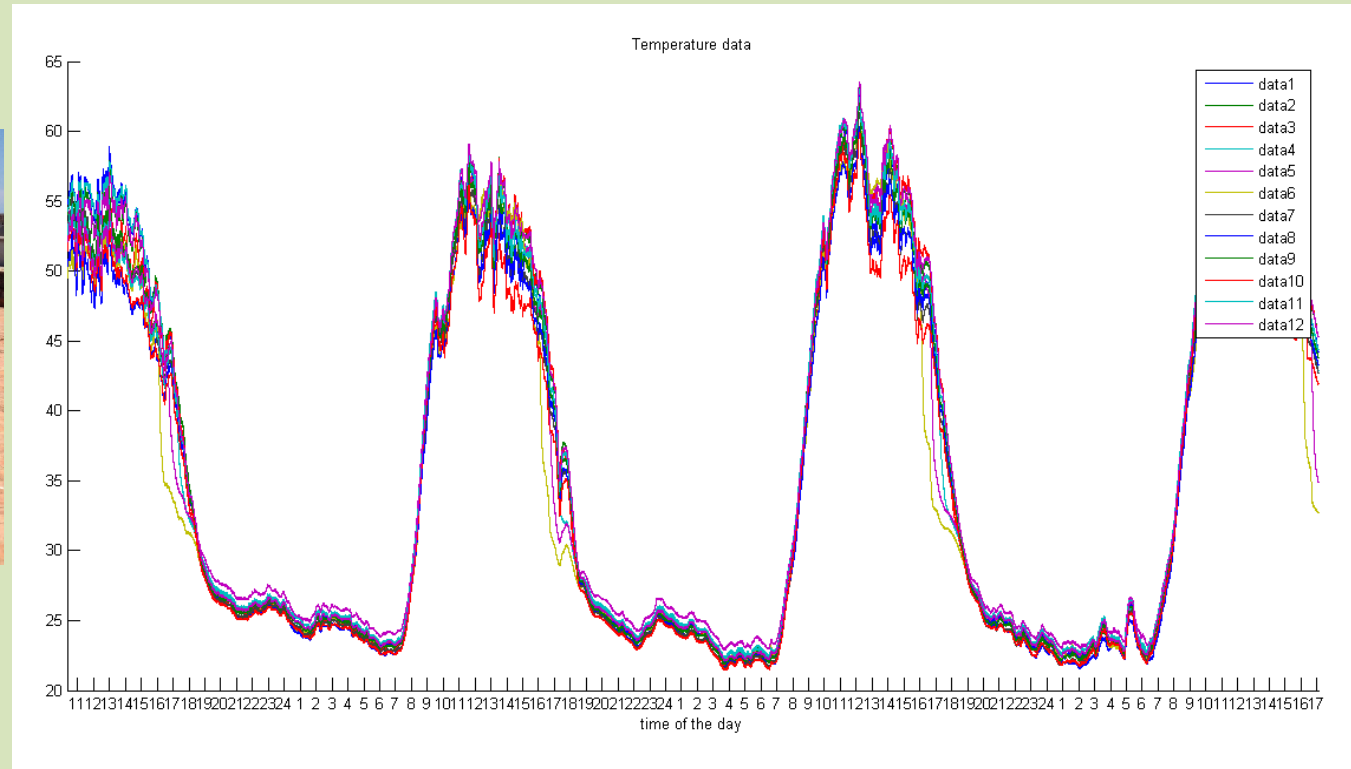
Voltage on load



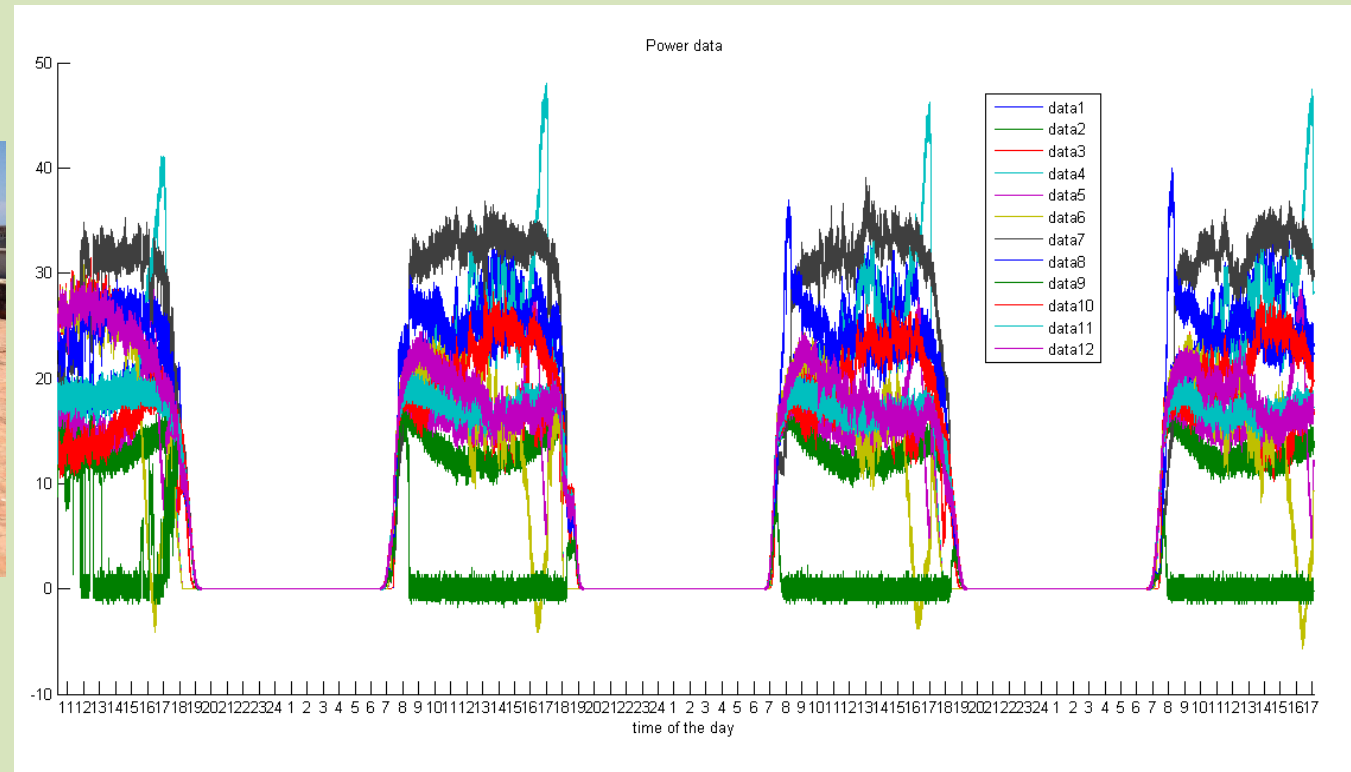
Current on load



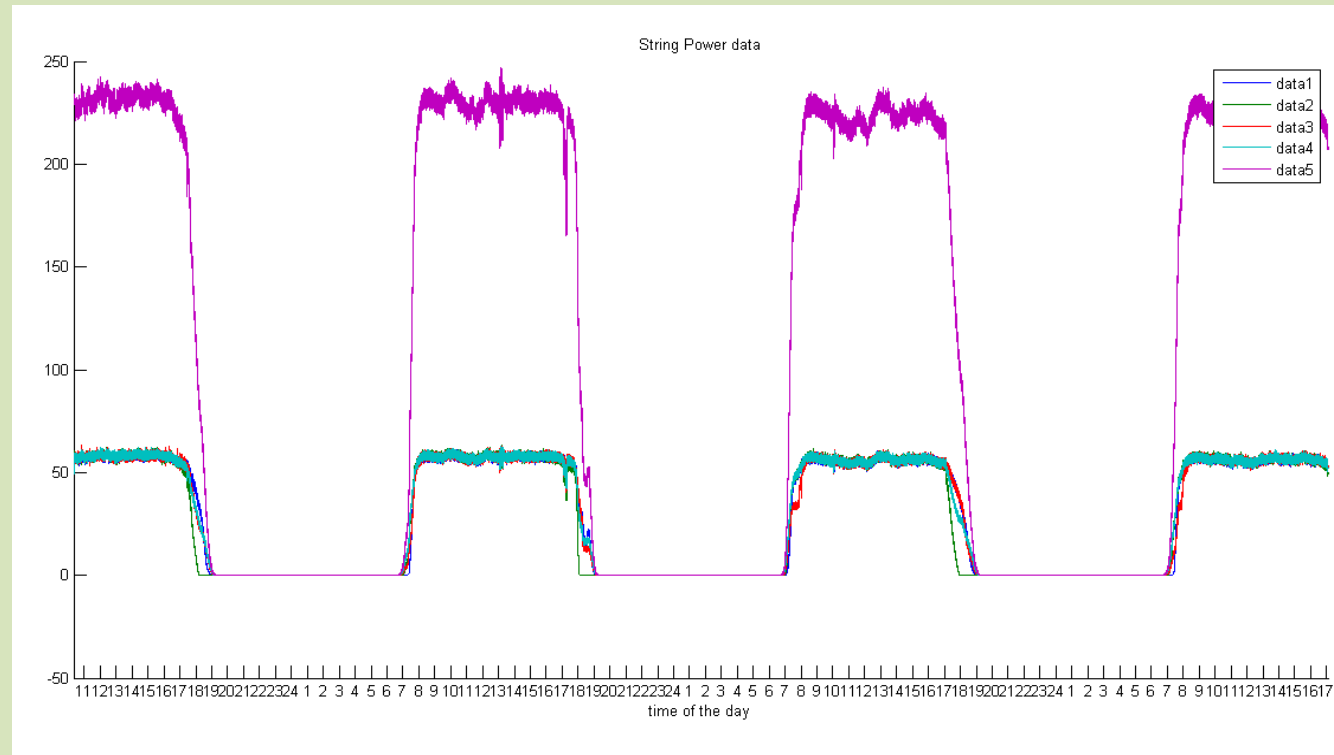
Temperature of PV Modules



Power of PV Modules



String Power and total power of PV Modules



CONCLUSIONS

- In this paper a survey on the performance of a PV system under shadow projection on PV panels has been faced.
- The reconfiguration techniques evaluates the case in which it is necessary or not vary the layout of the PV plant by physically changing the connections among modules.
- The adopted reconfiguration technique excludes the shaded module.
- When two or three diodes are direct biased is almost always convenient reconfigure the array putting out the shaded panel.
- When only one diode is direct biased, reconfiguration is convenient only for low current values.

Thanks for your attention

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