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Si Photovoltaic Semiconductor Devices Operating in Total and Partial Illumination

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Power photovoltaic applications, as photovoltaic power plants or building integrated photovoltaic systems, are mainly built using parallel or serial photovoltaic modules strings. Daily usage of such systems usually produces non-uniform string connected behavior due to partial or total shading. In these conditions, less illuminated cells transform into power receivers, thus producing supplementary losses and local panel heating. This phenomenon, called hot-spot, may evolve into producing zonal or total destruction of the solar modules. For these purposes this paper will submit to your attention simulation and experimental results of the partial and total illumination phenomenon, targeting specific information in the effect evaluation of any photovoltaic panel.

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1. Introduction

A very important aspect of a photovoltaic (PV) source is represented by its modular state. This characteristic makes possible electrical interconnectivity (serial and/or parallel) of different PV modules.

Power losses can occur based on different performance of elementary unit connection or due to different illumination and operating temperatures of string interconnections.

In the case of one shaded cell from a PV module, the cell is reversely polarized causing local overcharge by dissipating energy as heat. This phenomenon causes the apparition of hot-spots on the shaded cells surface, and possible permanent damage, represented as white spots [1].

The partial shading of a PV module changes the I–V characteristic entirely, dramatically reducing the maximum power P_{MPP}, fill factor FF and efficiency η, but it does not significantly change the open circuit voltage V_{OC} and the short circuit current I_{SC} [2].

The reversed voltage of a shaded solar cell may be limited at 0.6 V with help of a "by-pass diode" [3]. Theoretically, this phenomenon can be eliminated by connecting by-pass diodes for each cell, but in reality this is economically inefficient, thus two diodes are connected for a module (one for every 18–24 series cells) [4].

This paper presents the modeling and simulation of a Photowatt PWX500 solar module with 36 cells and a maximum power of 50 W at partial shading, and the experimental characteristics of the same module at the same partial shading. Some measurements are compared and derived from an on-line PV power plant installation.

2. Experimental layout

Modeling of the photovoltaic cell was accomplished using 2 different equivalent schemes:

— the equivalent electrical circuit for the illuminated cell presented in Fig. 1a, used for determining the direct characteristic (generator) of the cell;

— the equivalent electrical circuit for the shaded cell presented in Fig. 1b, used for determining the reversed characteristic (receiver) of the cell.

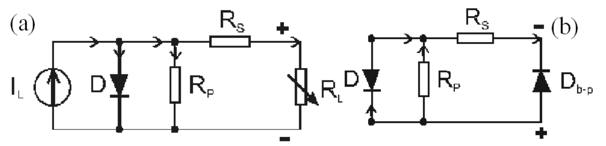

Fig. 1. (a) The equivalent electrical circuit for the illuminated cell; (b) the equivalent electrical circuitry for the shaded cell with by-pass diode.

In the first case, using the Kirchhoff theorem we obtain the following currents equations:

$$I = I_{\mathrm{L}} - I_{\mathrm{S}}\left[\exp\left(\frac{q(V + R_{\mathrm{S}}I)}{kT}\right) - 1\right] - \frac{V + R_{\mathrm{S}}I}{R_{\mathrm{P}}}. \tag{1}$$

At short-circuit ($R_{\mathrm{L}} = 0 \Rightarrow V = 0$), current $I_{\mathrm{L}} = I_{\mathrm{SC}}$ is directly proportional and in linear variation with the solar radiation [5]. For the second case the generator current is not used; the cell becoming a power receiver, the current at its leads will shift polarity, thus the following equations are obtained:

$$I = I_L - I_S\left[\exp\left(\frac{qV}{kT}\right) - 1\right] - \frac{V + R_S I}{R_P}. \quad (2)$$

I_{SC} is the short-circuit current of every cell from the module at the simulation radiation, I_L — illumination current (generated current from a single cell based on radiation), I_S — saturation current of D diode, V — voltage across the cell, R_P — parallel internal resistance, R_S — serial internal resistance, R_L — load resistance, q — elementary charge of an electron ($q = 1.6 \times 10^{-19}$), k — the Boltzmann constant, T — cell temperature [6].

3. Conditional simulation

The Photowatt PWX500 module simulation was accomplished using the upper equations and with the symbolic analyses module integrated in the MATLAB software application. Resolving these equations resulted in a 200-element vector (from 0 to I_{SC} = 3.1 A — value at STC's), the voltage being also a vector of the same dimension.

The direct characteristic was obtained from Eq. (1) and the reverse one from Eq. (2). Binding these results the total characteristic of a cell was obtained and used in determining the direct characteristic of the entire photovoltaic module. The results of these simulations are presented in Figs. 2a, 2b and 3.

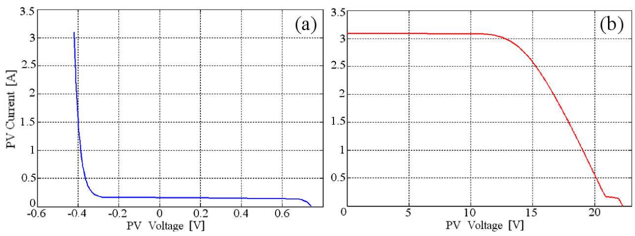

Fig. 2. (a) The I–V characteristic of a partial shaded cell from a Photowatt PWX500 module, at R_S = 0.005 Ω, R_P = 2000 Ω, (b) the I–V characteristic of a entire Photowatt PWX500 module with one partial shaded cell, at R_S = 0.005 Ω, R_P = 2000 Ω.

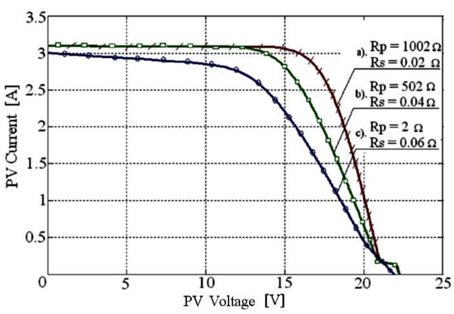

Fig. 3. The I–V characteristic is much more affected when the module is efficient.

Simulation results at different intrinsic parameters R_P and R_S are shown in Fig. 3.

4. Experimental results

The experimental measurements were done on a 10Kwp PV power plant developed at Valahia University as a result of the FP3/ICOP DEMO-4080-98 project [7]. As seen from Fig. 4a and 4b the hot-spot effect leads to PV modules delaminating at first around the junction box location and later on, along the electrical contacts of the rows.

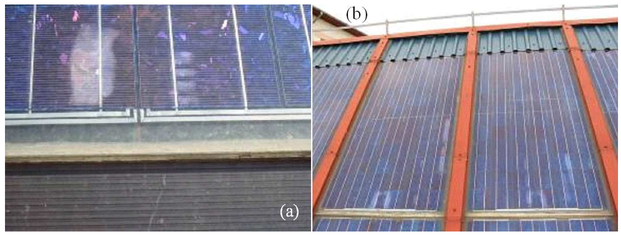

Fig. 4. (a) Junction-box delaminating effects; (b) other hot-spot induced module delaminating effects.

To determine the real characteristic of a PWX500 PV module the electrical scheme from Fig. 5 was used together with a National Instruments AT-MIO-16E-10 Data Acquisition Card and a software application developed in the LabView environment.

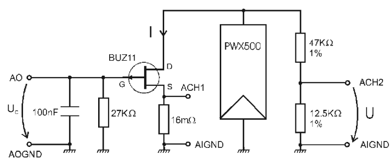

Fig. 5. Electrical scheme of the characterization application for the PWX500 modules.

The application *"caracterizare IV.vi"* has the possibility of saving acquisition data in Excel file format, for easier data analysis. Based on this .xls file and using a MATLAB application there were determined the real reversed characteristic of the shaded cell from the PV module, keeping its integrity.

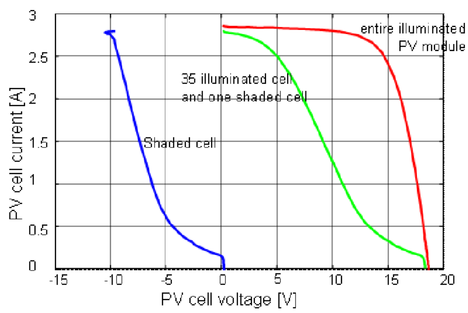

Fig. 6. Characteristics of a PWX500 module in total illumination condition, one shaded cell condition and determined reverse characteristic of the shaded cell.

In Fig. 6 there is represented the characteristic of a shaded cell, determined from the characteristic of the entire module with one shaded cell and the other illuminated. Here we can observe the difference between a by-pass diode simulated and a real one.

5. Conclusions

Partial shading of solar generators may cause big losses and unbalanced performance ratings. Shaded cells are frequently involved in negative ranges of voltages. If there are no measurements taken, like implementing derivation diodes, a simple shading situation may induce the destructive effect of hot-spot on cells due to high localized intensities. High temperatures on the cells surface that overcome the designed supported critical temperature result in encapsulation damage and in delaminating effects at the module level.

Based on the results obtained by shading a single cell from 36, we observed important lowering of the MPP (P_{MPP} drops at 10 W and U_{MPP} with 7 V). In case of two serialized cells shaded from the same module we noticed that the panel is dropped from the energetic scheme of the entire installation, P_{MPP} reaching appreciatively 3 W.

In the semitransparent sandwiched PV modules case we observed that large working ΔT variations caused vacuum penetration through the junction-box contacts insertion and delaminating effects localized at the level of the hot-spot effect appearance in regard to the panel's entire surface.

References

[1] W. Herrmann, W. Wiesner, W. Vaaßen, *Hot spot investigations on PV modules — New concepts for a test standard and consequences for module design with respect to bypass diodes*, IEEE, Anaheim (CA) 1996.

[2] V. Quaschning, R. Hanitsch, in: *25th IEEE Photovoltaic Specialists Conf. Washington DC*, Washington 1996, p. 1287.

[3] E. Molenbroek, D.W. Waddington, K.A. Emmery, *Hot Spot Susceptibility and Testing of PV Modules*, IEEE, Las Vegas 1991.

[4] H. Schmidt, in: *Photovoltaic Training Course for the Candidate Countries*, Fraunhofer Institute for Solar Energy Systems ISE, Freiburg 2004, p. 347.

[5] I. Băncuţă, D.-D. Leţ, A. Stancu, A. Gheboianu, Gh. Valerică Cimpoca, in: *Nano-Sol-Net International Symp.*, 2008, p. 178.

[6] A. Stancu, D. Leţ, Z. Bacinschi, *J. Sci. Arts* **9**, 316 (2009).

[7] O. Nicolae, F. Ispas, G. Măntescu, E. Văduva, L. Olteanu, D. Le, in: *19th Europ. Photovoltaic's Solar Energy Conf., Paris*, Palais des Congres, 2004, p. 2935.