Simulation of the Effect of Shading on Monocystalline Solar Module Technology under Hot Spot Condition

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***Abstract* — This paper focuses on the monocrystalline PV module technology subjected to operation conditions with some cells partially or fully shaded. A shaded cell under hot-spot condition operating at reverse bias are dissipating power instead of delivering power. A thermal model allows analyzing the temperature increase of the shaded cells of the module under hot-spot condition with or without protection by a bypass diode. A comparison of the simulation results for a monocrystalline PV module without shading and with partial or full shading is presented.**

Keywords: Hot-spot, PV systems, shading effect, breakdown voltage, modelling, simulation.

I. INTRODUCTION

The demand for energy, the shortage of fossil fuels and the need for carbon footprint reduction have resulted in a global awareness of the importance of energy savings and energy efficiency [1] and computer programs on the Demand-side Management have been developed in order to assist consumers on energy usage. Also, renewable energy sources coming from wind and solar energy sources are attractive to go into exploitation, considering not only large scale systems, but also micro and mini scale conversion systems [1], Disperse Generation owned by consumer.

A photovoltaic (PV) system directly converts solar energy into electric energy. The main device of a PV system is a solar cell. Cells may be grouped to form modules and arrays. A PV module is composed by group of cells connected in series. A PV array may be either a module or a set of modules connected in series or parallel to form large PV systems. These systems may have or not a tracking system in order to achieve higher values of energy conversion during sunny days due to the diverse perpendicular positions to collect the sun´s irradiation. The performance of the PV array depends on the operating conditions especially on solar irradiation, temperature, array configuration and shading. The shading on PV arrays occurs due to the dust, bird droppings, leaves, snow or shadowing caused by near buildings, near trees or a passing cloud. The shading can be partial or full with respect to a PV cell or a PV module [3].

The hot spot occurs when a cell, or group of cells in a PV module, operates at reverse bias, dissipating power instead of delivering to the electric grid and, therefore, operating at abnormally high temperatures. Cells exposed to higher temperatures will degrade at a higher rate than others and, if operation at high temperatures occurs during a prolonged time, then can cause irreparable damage to the solar cell; forcing it to permanently work in reverse bias and rendering useless the rest of the cells under the same bypass diode [2].

This paper is considered with the exposition to shading of a monocrystalline PV module and as a consequence subjected to condition of hot-spot. A thermal model is used in order to allow estimating the temperature of the area subjected to the condition of hot-spot.

II. MODELING

For the forward bias cell the I-V characteristic is formulated by an implicitly function [2] given by,

$$I = I_S - I_0 (e^{\frac{V+IR_S}{mV_T}} - 1) - \frac{V + IR_S}{R_p} , \qquad (1)$$

where I is the output current at the terminals of module, I_S is the photo generated electric current, I_0 is the diode reverse bias saturation current, V is the output voltage at the terminals of module, R_p and R_S are respectively the equivalent shunt and the series resistances, m is the ideality factor, V_T is the *p-n* junction thermal voltage. For the reverse bias module the I-V characteristic is formulated by an implicitly function [2] is given by,

$$I = I_S - I_0 (e^{\frac{V+IR_S}{mV_T}} - 1) - \frac{V + IR_S}{R_p} [1 + a (1 - \frac{V + IR_S}{V_{bd}})^{-b}], \qquad (2)$$

where α is the fraction of ohmic current involved in avalanche breakdown, V_{bd} is the breakdown voltage and b is the avalanche breakdown factor. The thermal model allows estimating the temperature (THS) of the cell area under hot-spot condition [2,3]. For time $t \geq t_{HS}$ the function $T_{HS}(t)$ is given by,

$$T_{HS}(t) = T_{amb} + i + ii \;, \tag{3}$$

where *i* and *ii* are given by,

$$i = R_{TH}\, A\, G[\gamma + (1-\gamma)e^{-(\frac{t-t_{HS}}{R_{TH}C_{TH}})}] \;, \tag{4}$$

$$ii = P_{diss} R_{TH-HS} [1 - e^{-(\frac{t-t_{HS}}{R_{TH}C_{TH-HS}})}] \;, \tag{5}$$

where T_{amb} is the ambient temperature, R_{TH} and C_{TH} are the module thermal resistance and capacitance, A is the cell area under hot-spot condition, G is the solar irradiance, γ is the relative gap in the irradiation between the shaded and the non shaded cells, P_{diss} is dissipated power on the R_p resistor, R_{TH-HT} and C_{TH-HT} are constants parameters and depend on the materials composing the upper layers of the PV cells.

III. SIMULATION RESULTS

The models for the PV module forward biased, for the PV module reverse biased and the thermal model that allows estimating the temperature of the area under hot-spot condition are implemented in Matlab/Simulink. Considering the module partially shaded (MPS) or fully shaded (MFS) connected in series with one non-shaded module, if the shaded module is a MPS his irradiance is 500 W/m^2 and if shaded module is MFS his irradiance is 0 W/m^2. For the module Isofotón I-53 without bypass diode: the I-V curves without shading (black) and simulated with partially shaded (red) or fully shaded (blue) are shown in Figure 1.

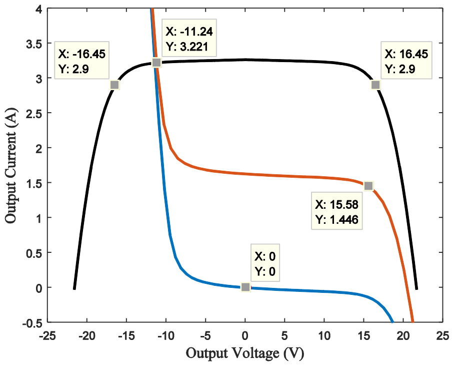

Fig. 1. I-V curves without shading (black) and with partially shaded (red), fully shaded (blue).

Figure 1 reveal that the maximum power dissipation occurs when the module is reverse biased with a voltage of -11.24 V and a current of 3.221 A. For the module Isofotón I-53 partially shaded the curves of the temperature for the area under hot-spot condition in function of the time: with bypass diode (green) and without bypass diode (blue) are shown in Figure 2.

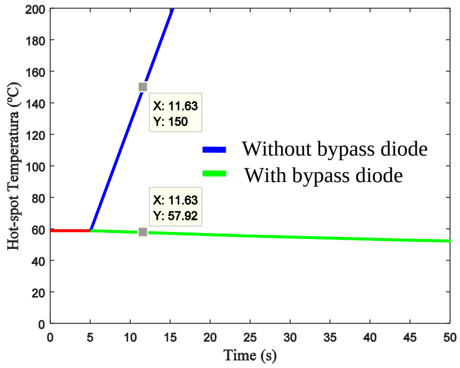

Fig. 2. MPS, temperature on the area of hot-spot condition.

Figure 2 reveal that the module without bypass diode at the time of 11.63 s reaches the critical temperature of 150 ºC while the module with bypass diode reaches the temperature of 57.92ºC.

IV. CONCLUSION

An addressing of a model for PV module under hot-spot condition. The addressing allows to conclude that when a module operates at reverse bias due to the non-uniform illumination of a cell, the module is subjected to a temperature increase and power loss. Also, allows to quantify the advantage of using the diode for bypass protection.

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