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Efficiency study of different photovoltaic plant connection schemes under dynamic shading

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ABSTRACT

An important growth in the power of the photovoltaic systems connected to a grid has recently been observed. In spite of the advances in module technology, the problems in the system design increased, especially regarding the surface of the earth they occupy. In this work we propose a complete model for plant simulation with different wiring diagrams and under dynamic shading. Results obtained from simulations showed that the configuration with the lowest performance was that of only one serial-parallel group, whereas the highest efficiency corresponded to a design of groups of modules in parallel connected then in series. In general, a higher efficiency was obtained diminishing the quantity of modules in series and increasing their number in parallel. The simulation model proposed allows exploring different alternatives of wiring modules and finding the most efficient configurations for photovoltaic plants of medium and high power.

1. Introduction

Among photovoltaic systems, stand-alone or isolated systems and those connected to an electrical grid can be distinguished. When the system connected to a network is a large power plant, there is a considerable number of constituent modules. The energy generated is a function of climatic variables such as radiation and temperature [1]. The search algorithms of the point of maximum power are generally based on the assumption that the power curve generated has a single peak [2]. Shading makes the output power of the panel array to present several maximum points, and the efficiency to fall significantly [3].

The choice of a wiring design maximizing the efficiency of modules and inverters, considering dynamic shading effect, is a scarcely studied aspect. Works referred to simulation of photovoltaic systems, without considering the shading effects can be found in the bibliography [4]. Other studies considered this effect but at the level of a single module [3,5], or started from the equation of each panel in order to simulate the behavior of an array when affected by a cloud of static type [6], at the expense of a considerable calculation time. There are also studies which considered how to obtain the highest power, in an attempt to achieve optimum dimensioning of the system by means of the ratio between the installed peak power of the array and the rated power of the inverter, without taking into account shading [7].

This work proposes a new model for the simulation of photovoltaic plants formed by a great quantity of modules. This model allows not only studying the system behavior in the presence of static shading but also in the presence of shading varying in time. The model also considers the effect of

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the cloud at individual level on each panel. There follows the description of the model, as well as the efficiency measures used and the results and discussion for the different configurations.

Conclusions are summarized in the last section.

2. Model for simulation

The proposed model for simulation can be represented in a block diagram as shown in Fig. 1. In this figure those blocks corresponding to the influence of the cloud having radiation as input and effective radiation as output, the photovoltaic panel array having effective radiation and temperature as input, and tension and array current as output can be seen. Then, at the stage of conversion of power of continuous current the maximum power point tracking takes place and its output is the power curve and the MPP. Finally, the DC-to-AC converter has the current power as input and the alternating power as output. All input and output variables of these blocks are functions of time.

The cloud is modeled in a way that each panel receives a certain radiation in a given time. The degree of cloudiness exerts an influence as it decreases the radiation that is effectively received by each module independently.

$$G_e = G(x, y, t)n(x, y, t) \quad (1)$$

where $G_e(\cdot)$ is the effective radiation; $G(\cdot)$ is the total radiation and $n(\cdot)$ is the cloud influence. Coordinates (*x*,*y*) identify the position of each module in the array. Clouds are simulated with images moving in different directions in relation to the field of panels. Grey levels in the image are in a range of 0–255 and are normalized at the range of 0–1.

Effective radiation received by each module decreases proportionally with the grey level of the pixel corresponding to the cloud.

A photovoltaic cell may be represented by an equivalent circuit [8]. This cell model may be extended to a module considering the type of connection and the number of its constituent cells. Fig. 2 shows curves *V–I* and *V–P* of a module obtained from the mathematical model given by the following equations:

$$I = I_L - I_0 - \frac{V + IR_s}{R_{sh}}, \quad (2)$$

$$I_0 = I_{01}\left(e^{\frac{V+IR_s}{m_1 V_t}} - 1\right) - I_{02}\left(e^{\frac{V+IR_s}{m_2 V_t}} - 1\right), \quad (3)$$

where I is the electric current supplied by the solar cell; I_L is the photogenerated current; I_{01} and I_{02} are currents representing diffusion phenomena in neutral areas and recombination phenomena in the charge area, respectively; V_t is the thermal voltage ($V_t = kT/e$, being k Boltzmann constant, T temperature in Kelvin degrees and e the electron charge); m_1 and m_2 are factors representing diffusion and recombination phenomena [9,10]; R_s is the series resistance; and R_{sh} the parallel resistance.

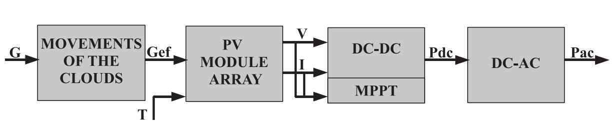

Fig. 1 – General design of the simulation.

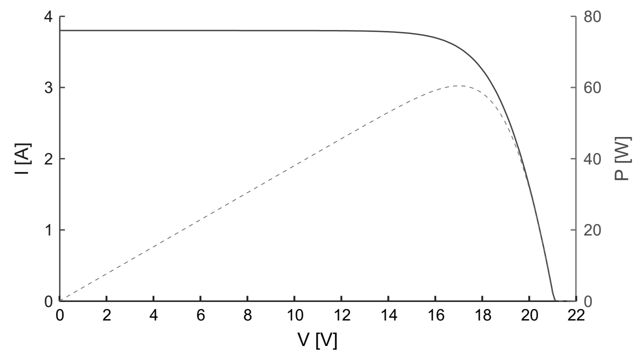

Fig. 2 – Curves *V–I* and *V–P* from a photovoltaic module.

This model has seven unknown parameters which must be obtained solving a system of nonlinear implicit equations for each operating condition. It is important to notice that these conditions vary in time and, in addition, a large plant is constituted by thousands of panels, thus the resolution of the system increases the computational cost considerably.

2.1. *Neural model of the panel*

This work proposes modeling each module by a neural network in a way that the computational cost decreases, both at module and array level, thus obtaining useful results in an application in real time. The network is Multilayer Perceptron (MLP), which has two entries given by temperature and radiation variables, 9 neurons in the hidden layer and 40 nodes in the output layer (Fig. 3). The net output is a vector of 40 components, 20 of which form a voltage vector of the module and the other 20 components correspond to a current vector. Each pair of components (v_k, i_k) gives the coordinates of the operating point of the panel for a particular charge. Functions of activation of neurons in the hidden layer are sigmoid and those in the output layer are linear [11]. Hidden neurons may be modeled as

$$h_j = g\left(\sum_{i=1}^{I} w_{ji} x_i + b_j\right) \quad j = 1, \ldots, J \quad (4)$$

where $g(\cdot)$ is the sigmoid function, h_j is the output of the hidden neuron and b_j is the bias of this neuron.

The output function of the network is given by

$$z_k = \sum_{j=1}^{J} w_{kj} x_j + b_k \quad k = 1, \ldots, K \quad (5)$$

The modeled panel is Solartec M75 and curve *I–V* data used in the training were obtained from tests carried out in our laboratory under different radiation and temperature conditions. Measurements of tension and current compliant with IEC-904 norm as to equipment used, measuring conditions and procedures were carried out. Cell temperatures of 25 °C–65 °C in steps of 5 °C and radiations of 400, 500, 600 and 750 W/