MODELING AND CIRCUIT-BASED SIMULATION OF PHOTOVOLTAIC ARRAYS

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ABSTRACT:

Day-by-day the rate of energy demand is increasing, nonrenewable sources also decrease day by day that why it is necessary to increase the renewable sources for fulfilling the demand of energy. After some year some state that by 2050 the energy demand will triple. The majority of the energy requirements is satisfied by fossil fuels. By the using photovoltaic systems, it could help in supplying the energy demands. In this paper, we have a deal with a problem that results with the modeling of the photovoltaic device. For determination of unknown parameters various parameters are used in modeling of various methods have been introduced in the system. Primarily two of the proposed methods are being studied and then compared. This can give a brief idea to the manufacturers or designer who designs power electronics products about the easy-to-use modeling methods that can be used in the simulation of photovoltaic arrays.

Methods for the modeling of photovoltaic arrays present an easy and accurate method in this paper. Whatever the method is used for obtaining the parameters of the array model using information from the datasheet. In this paper, the photovoltaic array model can be simulated with any circuit simulator. The equations of the model are presented in details and the model is validated with experimental data and then simulation examples are presented. This paper is useful for power electronics designers and researchers who need an effective and easiest way to model and simulate photovoltaic arrays. From that paper, the basic idea of simulation of photovoltaic arrays is clear for the researcher and power electronic designer.

INTRODUCTION:

In solar energy, a photovoltaic (PV) system directly converts solar energy into electrical energy. Solar energy is totally dependent on the sun or we can say as totally depend on the radiation of the sun. Also, the obtained energy depends on solar radiation, the temperature of the cell and the voltage produced by the photovoltaic module. The main device in the solar system is PV system is the photovoltaic (PV) cell. The photovoltaic module is to connect the PV cell in series or parallel.The photovoltaic module represents the conversion unit in the generating system. An array is a result of associating a group of photovoltaic modules in series and parallel manner. The voltage and current at the terminals of a PV device may directly feed small loads. It means whatever the energy is generated is directly connected to the load and generated energy is utilized directly without conversion or storing. More sophisticated applications require electronic converters to process the electricity from the PV device. These converters used to regulate the voltage and the current at the load mainly to track the maximum power point of the device. The photovoltaic array may directly feed small loads such as lighting systems and DC motors. It means that for some application, it is directly connected to the array. Some applications require electronic converters to process the electricity from the photovoltaic device. Maximum power point (MPP) can be track by using these converters. These converters are also used to regulate the voltage and current at the load and to control the power flow in grid connected systems. Photovoltaic arrays present a nonlinear I-V characteristic with several parameters that need to be adjusted from experimental data of practical devices. The mathematical model of the photovoltaic array may be useful in the study of the dynamic analysis of converters, in the study of maximum power point tracking (MPPT) algorithms and mainly to simulate the photovoltaic system and its components using circuit simulators. The aim of this paper is to provide the reader with all necessary information to develop photovoltaic array models and circuits that can be used in the simulation of power converters for photovoltaic applications.

WORKING A PV CELL

A photovoltaic cell is basically a p–n junction semiconductor diode in which junction is exposed to light. By using different manufacturing processes photovoltaic cells are made with several types of semiconductors material. The monocrystalline and polycrystalline silicon cells are found at commercial PV cell at the present time. Silicon PV cells are made up of a thin layer of bulk Si or a thin Si film connected to electric terminals. One of the sides of the Si layer is doped to form the p–n junction. A thin metallic grid is placed on the Sun-facing surface of the semiconductor to get interact with light. Fig. 1 roughly illustrates the physical structure of a PV cell. The incidence of light on the cell generates charge carriers that circulate an electric current if the cell is short circuited. When the energy of the incident photon is sufficient to detach the covalent electrons of the semiconductor then charges are generated —this phenomenon depends on the semiconductor material and the wavelength of the incident light. Basically, the PV phenomenon may be described as the absorption of solar radiation, the generation and transport of free carriers at the p–n junction, and the collection of these electric charges at the terminals of the PV device. The rate of generation of electric carriers depends on the flux of incident light and the capacity of absorption of the semiconductor. The capacity of absorption depends mainly on the semiconductor band gap, on the reflectance of the cell surface, on the intrinsic concentration of carriers of the semiconductor, on the electronic mobility, on the recombination rate, on the temperature, and on several other factors. The solar radiation is contained of photons of different energies. Photons with energies lower than the energy gap of the PV cell are useless and there is no voltage or electric current generation. Photons with energy superior to the generate electricity, but only the energy corresponding to the energy gap is used—the remaining energy is dissipated as heat in the body of the PV cell. Semiconductors with lower energy gaps may take advantage of a larger radiation spectrum, but the generated voltages are lower. Si is not the only, and probably not the best, semiconductor material for PV cells, but it is the only one whose fabrication process is economically feasible in large scale. Other materials can achieve better conversion efficiency but at higher and commercially unfeasible costs. For the study of electronic converters for PV systems, it is sufficient to know the electrical characteristics of the PV device (cell, panel, and array). The manufacturers of PV devices always provide a set of empirical data that may be used to obtain the mathematical equation of the device I–V curve.

MODELING OF PHOTOVOLTAIC ARRAYS:

IDEAL PHOTOVOLTAIC CELL:

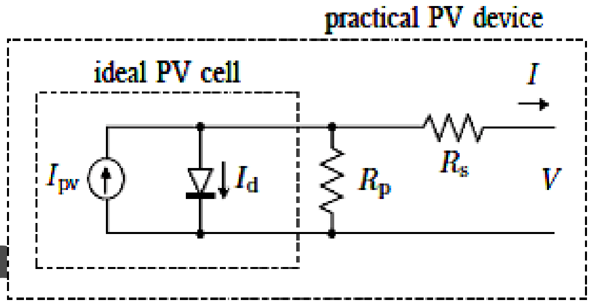

Fig. 1. Single-diode model of the theoretical photovoltaic cell and equivalent circuit of a practical photovoltaic device including the series and parallel resistances.

Fig. 1 shows the equivalent circuit of the single-diode model of the theoretical photovoltaic cell and equivalent circuit of a practical photovoltaic device including the series and parallel resistances. The basic equation from the theory of semiconductors that mathematically describes the I-V characteristic ofthe ideal photovoltaic cell is:

$$I = I_{pv,cell} - \underbrace{I_{0,cell}\left[\exp\left(\frac{qV}{akT}\right) - 1\right]}_{I_d}$$

where I_{pv}, cell is the current generated by the incident light(it is directly proportional to the Sun irradiation), I_d is the Shockley diode equation, $I_{0,cell}$ is the reverse saturation or leakage current of the diode [A], q is the electron charge [1.60217646 x10^{-19}C], k is the Boltzmann constant[1.3806503 x10^{-23}J/K], T [K] is the temperature of the p-n junction, and a is the diode ideality constant. Fig. 2 shows the I-V curve originated from (1).

The basic equation (1) of the elementary photovoltaic cell does not represent the I-V characteristic of a practical photovoltaic array. Practical arrays are composed of several connected photovoltaic cells and the observation of the characteristics at the terminals of the photovoltaic array requires the inclusion of additional parameters to the basic equation whereI_{pv} and I_0 are the photovoltaic and saturation currents of the array and $V_t = N_s kT/q$ is the thermal voltage of the array with Ns cells connected in series. Cells connected in parallel increase the current and cells connected in series provide greater output voltages. If the array is composed of N_p parallel connections of cells the photovoltaic and saturation currents may be expressed as: $I_{pv}=I_{pv,cell}Np$, $I_0=I_{0,cell}N_p$.In (2) Rs is the equivalent series resistance of the array and R_p is the equivalent parallel resistance. This equation originates the I-V curve seen in Fig. 3, where three remarkable points are highlighted: short circuit (0, I_{sc}), maximum PowerPoint (V_{mp}, I_{mp}) and open-circuit (V_{oc}, 0).Eq. (2) describes the single-diode model presented in Fig.1. Some authors have proposed more sophisticated models that present better accuracy and serve for different purposes. For example, in [2]–[6] an extra diode is used to represent the effect of the recombination of carriers. In [7] a three-diode model is proposed to include the influence of effects which are not considered by the previous models. For simplicity the single-diode model of Fig. 1 is studied in this paper. This model offers a good compromise between simplicity and accuracy [8] and has been used by several authors in previous works, sometimes with simplifications but always with the basic structure composed of a current source and a parallel diode [9]–[23]. The simplicity of the single-diode model with the method for adjusting the parameters and the improvements proposed in this paper make this model perfect for power electronics designers who are looking for an easy and effective model for the simulation of photovoltaic devices with power converters.

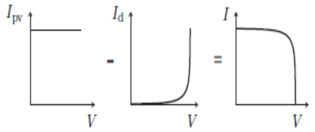

Fig. 2. Characteristic I-V curve of the photovoltaic cell. The net cell current I is composed of the light-generated current I_{pv} and the diode current I_d.

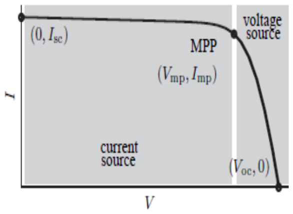

Fig. 3. Characteristic I-V curve of a practical photovoltaic device and the three *remarkable points*: short circuit $(0, I_{sc})$, maximum power point (V_{mp}, I_{mp}) and open-circuit $(V_{oc}, 0)$.

$$I = I_{pv} - I_0 \left[\exp\left(\frac{V + R_s I}{V_t a} \right) - 1 \right] - \frac{V + R_s I}{R_p}$$

CONCLUSION:

This paper has analyzed the different method for the mathematical modeling of PV arrays. The objective of the method is to fit the mathematical I–V equation to the experimental Remarkable points of the I–V curve of the practical array. Whatever the information is required for analysis or information required for the operation is given from the array datasheet: open circuit voltage, short-circuit current, maximum output power, voltage and current at the MPP, and current/temperature and voltage/temperature coefficients. I–V curve to the three (V, I) remarkable points without the need to guess or to estimate any other parameters except the diode constant a. This paper has proposed a closed solution for The problem of finding the parameters of the single-diode model equation of a practical PV array. Other authors have tried to propose single-diode models and methods for estimating the model.

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