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MATLAB/Simulink Based Mathematical Modeling of Solar Photovoltaic Cell

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Abstract: Day-by-day the energy demand is increasing and thus the need for a renewable source that will not harm the environment are of prime importance. Some projections state that by 2050 the energy demand will triple. Yet majority of the energy requirements is satisfied by fossil fuels but by the use of photovoltaic systems could help in supplying the energy demands The physical modeling of the system is not that much efficient so the analysis is done through the mathematical modeling approach. In this paper mathematical analysis is done for the single diode model. Single diode model is employed to investigate the I-V and P-V characteristics .The effect of irradiation and temperature is also considered. The analysis is done in MATLAB/SIMULINK environment. This mathematical analysis approach is a very flexible to change the parameters of the system.

Keywords-Matlab, SIMULINK, PV, solar cell model, solar array model, solar radiation, maximum power point.

1. Introduction

The development of new energy sources is continuously enhanced because of the critical situation of the chemical industrial fuels such as oil, gas and others. Thus, the renewable energy sources have become a more important contributor to the total energy consumed in the world. In fact, the demand for solar energy has increased by 20% to 25% over the past 20 years [1] . The market for PV systems is growing worldwide. In fact, nowadays, solar PV provides around 4800 GW. Between 2004 and 2009, grid connected PV capacity reached 21 GW and was increasing at an annual average rate of 60% [2] . In order to get benefit from the application of PV systems, research activities are being conducted in an attempt to gain further improvement in their cost, efficiency and reliability.

The first purpose of this paper is to present a brief introduction to the behavior and functioning of a PV device and write its basic equations, without the intention of providing an in depth analysis of the PV phenomenon and the semiconductor physics. The introduction on PV devices is followed by the modeling and simulation of PV arrays, which is the main subject of this paper.

With no pollutant emission, Photovoltaic cells convert sunlight directly to electricity. They are basically made up of a PN junction. Figure 1 shows the photocurrent generation principle of PV cells. In fact, when sunlight hits the cell, the photons are absorbed by the semiconductor atoms, freeing electrons from the negative layer. This free electron finds its path through an external circuit toward the positive layer resulting in an electric current from the positive layer to the negative one.

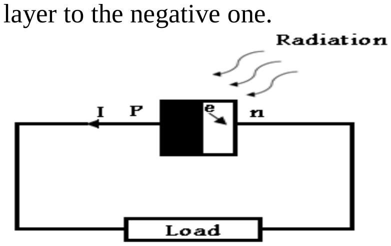

Fig.1. Photo current generation principle.

Typically, a PV cell generates a voltage around 0.5 to 0.8 volts depending on the semiconductor and the built-up technology. This voltage is low enough as it cannot be of use. Therefore, to get benefit from this technology, tens of PV cells (involving 36 to 72 cells) are connected in series to form a PV module. These modules can be interconnected in series and/or parallel to form a PV panel. In case these modules are connected in series, their voltages are added with the same current. Nevertheless, when they are connected in parallel, their currents are added while the voltage is the same.

Three major families of PV cells are monocrystalline technology, polycrystalline technology and thin film technologies. The monocrystalline and polycrystalline technologies are based on microelectronic manufacturing technology and their efficiency is in general between 10% and 15% for monocrystalline and between 9% and 12% for polycrystalline. For thin film cells, the efficiency is 10% for a-Si, 12% for CuInSe2 and 9% for CdTe [3] . Thus, the monocrystalline cell that has the highest efficiency is the focus of this paper. This paper carried out a Matlab/SIMULINK model of monocrystalline PV cell that made possible the prediction of the PV cell behaviour under different varying parameters such as solar radiation, ambient temperature, series resistor, shunt resistor, diode saturation current, etc.

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2. PV cell model

The equivalent circuit of a PV cell is shown in Fig. 2. It includes a current source, a diode, a series resistance and a shunt resistance [4, 5]

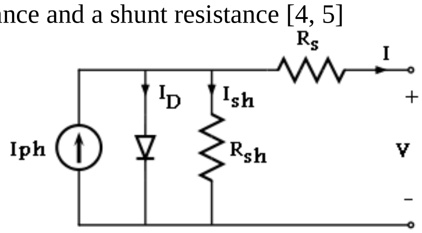

Fig. 2.PV cell equivalent circuit.

$$I = I_{sh}-I_s(\exp q(V+R_s*I)/NKT -1) - (V+R_s*I)/R_{sh}$$

In this equation, *Iph* is the photocurrent, *Is* is the reverse saturation current of the diode, *q* is the electron charge, *V* is the voltage across the diode, *K* is the Boltzmann's constant, *T* is the junction temperature, *N* is the ideality factor of the diode, and *Rs* and *Rsh* are the series and shunt resistors of the cell respectively .Based on above equation, the Matlab/SIMULINK model of Fig.3 was developed. For a given radiation, temperature, *Rs* and *Rsh*, the *I-V* and *P-V* curves are generated as shown in Fig.4.

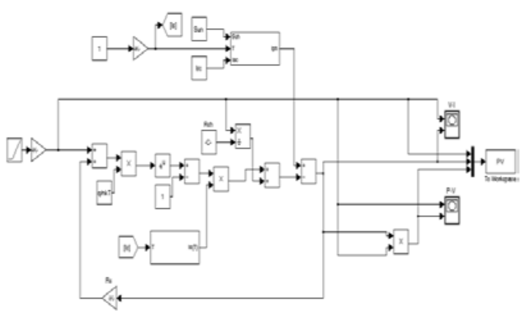

Fig. 3. PV cell Matlab/SIMULINK model

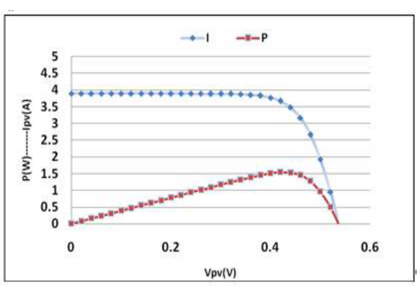

Fig. 4.*I-V* curves and *P-V* curves for a given PV cell

Effects of Solar Radiation Variation

The above model includes two subsystems: one that calculates the PV cell photocurrent which depends on the radiation and the temperature according to equation

$$Iph = \{Isc + Ki(T-298)\}\beta/1000$$

where *Ki*=0.0017 A/◦C is the cell's short circuit current temperature coefficient and *β* is the solar radiation (W/m2). Based on the above equation, the subsystem of Fig. 5 is obtained and the model simulation results are shown in Figs

As it can be seen from Figs.6 and 7, the PV cell current is strongly dependent on the solar radiation. However, the voltage has a 50 mV increase as the solar radiation increasedfrom 400 W/m2 to 1000 W/m2.

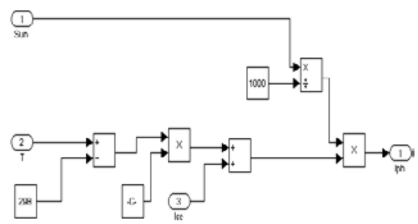

Fig. 5. *Iph* Matlab/SIMULINK subsystem for varying cell temperature and solar radiation.

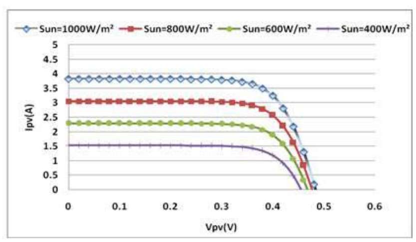

Fig.6.*I-V* curves for different solar radiations.

Effect of Varying Cell Temperature

The diode reverse saturation current varies as a cubic function of the temperature and it can be expressed as:

$$Is = Is[T/T_{nom}]^3 \exp [T/T_{nom} -1]Eg/N.Vt$$

where *Is* is the diode reverse saturation current, *Tnom* is the nominal temperature, *Eg* is the band gap energy of the semiconductor and *Vt* is the thermal voltage.The reverse saturation current subsystem shown in Fig.7 was constructed based on above equation

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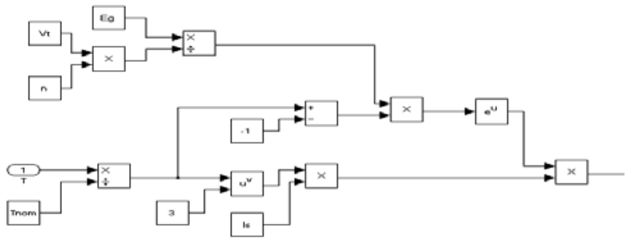

Fig. 7. Matlab/SIMULINK temperature effect sub system on diode reverse saturation current

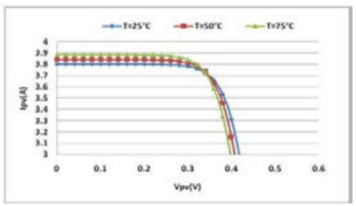

Fig.8.*I-V* curves for different cell temperatures.

In general, for a given solar radiation, when the cell temperature increases, the open circuit voltage *Voc*, drops slightly, while the short circuit current increases. This behaviour is validated and presented in Figs. 8 and 9.

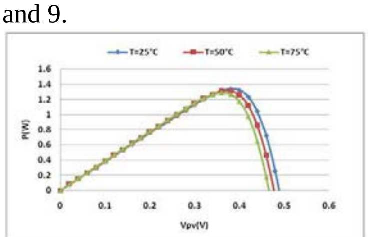

Fig.9.*P-V* curves for different cell temperatures

Effect of Varying *Rs*

The series resistance of the PV cell is low, and in some cases, it can be neglected [3]. However, to render the model suitable for any given PV cell, it is possible to vary this resistance and predict the influence of its variation on the PV cell outputs. As seen in Figs.10and 11, the variation of *Rs* affects the slope angle of the *I-V* curves resulting in a deviation of the maximum power point.

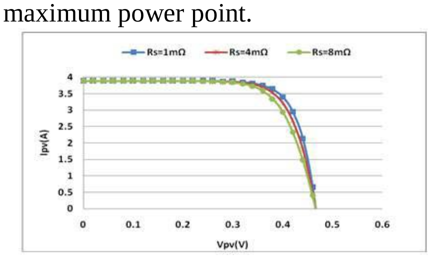

Fig.10 .*I-V* curves for different Rs

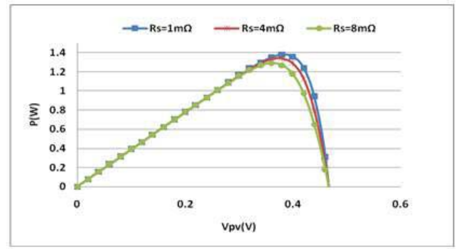

Fig.11.*P-V* curves for different Rs

The simulation was performed for three different values of *Rs*, namely 1mΩ, 4mΩ and 8mΩ. It was shown that higher values of *Rs* reduce the power output of the PV cell. According to equation as written below, the fill factor, given by equation , decreases as *Rs* increases.

$$FF = Pmax / Voc\ Isc$$

Effect of Varying *Rsh*

The shunt resistance of any PV cell should be large enough for higher output power and fill factor. In fact, for a low shunt resistor, the PV cell current collapses more steeply which means higher power loss and lower fill factor. These results can be seen in Figs.12 and 13**.**

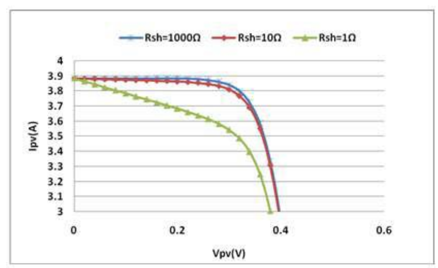

Fig.12.*I-V* characteristics for different Rsh

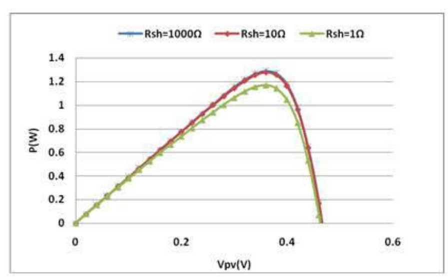

Fig.13.*P-V* curves for different Rsh

PV Module

As previously mentioned, a PV module is a connection of tens of PV cells. Figure 14 shows the bloc diagram of Matlab/SIMULINK model of a PV module. This model contains an external control block permitting an uncomplicated variation of the models' parameters. In this model, 36 PV cell are interconnected in series to form one module. As a result, the module voltage is obtained by multiplying the cell voltage by the cells number while the total module current is the same as the cell's one. The results are shown in Figs.15 and 16.

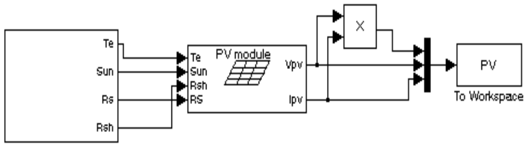

Fig.14. SIMULINK model for the PV module

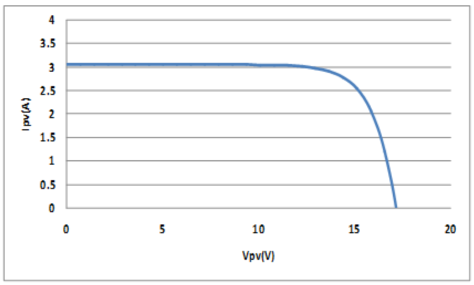

Fig.15.*I-V* curves of the PV module model

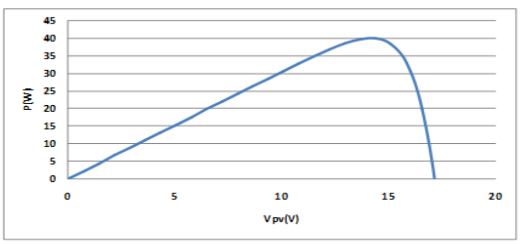

Fig.16.*P-V* curves of the PV module model

Experimental Results and Validation

In this study, the Matlab/SIMULINK model not only helps to predict the behavior of any PV cell under different physical and environmental conditions, also it can be considered a smart tool to extract the internal parameters of any solar PV cell including the ideal factor, series and shunt resistance. Some of these parameters are not always provided by the manufactures.

The Matlab/SIMULINK model was evaluated for the PVL-124 solar panel. On the other hand, the experimental results for a solar radiation of 540 W/m2. The *I-V* and *P-V* simulation and experimental results show a good agreement in terms of short circuit current, open circuit voltage and maximum power. the below fig.17 characteristics shows the output power Vs time.

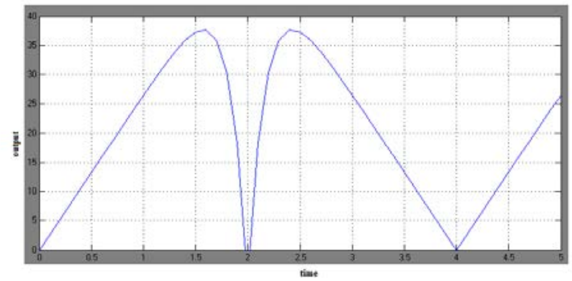

Figure 17. Output Power Vs Time.

Conclusion

A Matlab/SIMULINK model for the solar PV cell, modules and array was developed and presented in this paper. This model is based on the fundamental circuit equations of a solar PV cell taking into account the effects of physical and environmental parameters such as the solar radiation and cell temperature. The module model was simulated and validated experimentally using the high efficient PVL-124 solar laminate panel. As a result of the study, one can benefit from this model as a photovoltaic generator in the framework of the Sim- Power-System Matlab/SIMULINK toolbox in the field of solar PV power conversion systems. In addition, such a model would provide a tool to predict the behaviour of any solar PV cell, module and array under climate and physical parameters changes.

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