Shading Effect on A PV Solar Energy System Performance Using MATLAB/SIMULINK

Otman Imrayed[1], Eljaroshi M. Diryak[2], Ahmed M. Alturas[3], I. Daho[4], and Hussain S. Algabaly[5]

***Abstract*—This paper shows mathematical modelling and its simulation of a real photovoltaic (PV) panel in order to estimate it's physical and electrical behavior under variation of two environmental parameters of irradiance and temperature. Based on the manufacturer datasheet of that real solar system, The general mathematical model of PV system is built in MATLAB/SIMULINK, which accepts irradiance and temperature as variable parameters and outputs the V-I, I-P and V-P characteristics under both steady-state and at shading effect . This system can be used to improve the PV module performance for different engineering applicant.**

***Key Words*— Photovoltaic, Shading effect, Mathematical modeling.**

I. INTRODUCTION

ONE of the most important interests in the power sector is the significant increase of power demand due to the growth of the population and lack of resources to reach the requirements of mankind such as clean water, clean air and electrical energy. Many researches claim that fossil based energy sources are nearly running out and are harmful to the environment (global warming, ozone hole and etc.). Therefore, in the last decade people have paid more attention to renewable energy such as solar, wind, biomass and hydro. These types of energy sources are advantageous, because they never run out and have no effect on the environment. Solar energy is the most important over other renewable energies. It is a steadily grown energy and is common because it is easily accessible and also it is free. DC power is produced directly by Photovoltaic array and then DC electricity can be converted to the AC energy by the inverters or increased/decreased to DC energy level by DC/DC converter. Photovoltaic arrays are used in many applications such as water pumping, street lighting in rural town, battery charging and grid connected PV systems. The basic device of a photovoltaic system is the photovoltaic cell. Solar cells convert solar energy into electrical energy. This phenomenon occurs in materials, which have the property of capture photon and emit electrons. Chan and Phang [1] reported that the main material used in the photovoltaic industry is silicon polycrystalline thin films and single- crystalline thin film. A solar cell is a p-n junction semiconductor diode and ne solar cell alone can produce approximately 1 to 2 Watt by [2]. To increase power at certain level, more solar cells are concatenated serially and parallel to make PV array (panel). The I-V curve characteristic of a solar cell has an exponential characteristic. Solar cell V-I, V-P curves are highly non-linear. These curves have the main role in solar energy system. Many researches have been done for a long time to design a comprehensive model of PV module. In 2005 Longatt [3] developed a complete PV system model to simulate the electrical behavior of the PV model connected with grid system . To study the effect of the solar irradiance and Cell Temperature on the performance of the whole model, a generalized PV model has been developed by Tsai et.al. To find the parameters of the nonlinear I-V equation, A mathematical model of PV system in Matlab/Simulink is carried out by Kumari and Babu [4]. They consider three operating conditions: open circuit, maximum power, and short circuit points . Using Matlab simulation, the effect of the environment on electrical characteristics of PV Array under different temperature values has been studied by Bhatt and Thakker in 2011 [5]. Several researchers have investigated the characteristics of PV modules and the factors that affect them. However, recently the effect of shading on the PV characteristics has been considered. Often, the PV arrays get shaded, completely or partially, by the passing clouds, neighbouring buildings, towers and trees. The large PV installations such as those used in distributed power generation schemes is a noteworthy case. The PV characteristics get more complex with multiple peaks in case of partial shading. The output of the PV modules and the supplementary change in their I–V characteristics under the effect of shading have been reported by Kawamura [6]. The effect of partial shading on the I–V characteristics of the PV module has been experimentally carried out by Garcıa-Alonso et.al. The main aim of this paper is to provide the reader with the fundamental knowledge on design and building the blocks of PV module based on the mathematical equations using Matlab/Simulink. The parameters values of the model are taken from data sheet of a real PV module. The numerical results show the behaviour of PV module under variation of two environment parameters. Also, the shading effects have been studied through this paper using Simpower blocks.

[1,2,4,5] Electrical & Electronics Department, Faculty of Engineering, University of Sirte, Libya.
[3] College of Engineering, University of Misurata, Libya.
O.Imrayed @su.edu.ly[1]

II. Modeling of PV Systems

The solar cell is the basic unit of a photovoltaic module and it used as the PN union, whose electrical characteristics are represented by the equation of Shockley.

$$I_d = I_{rs}\left(exp\left(\frac{qV}{A.k.T}\right) - 1\right) \quad (1)$$

Many PV cells have been modelled and simulated in different ways such as single diode and single resistance, two diode and two resistances. The main equivalent circuit of a PV cell is shown in Figure 1.

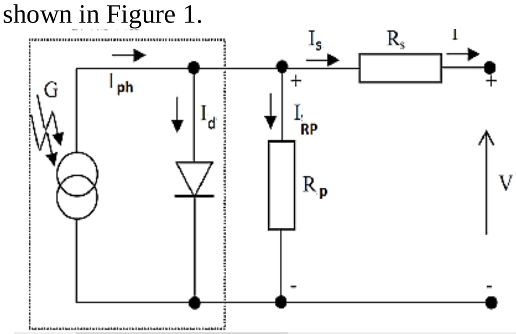

Fig.1. Electrical equivalent model of a photovoltaic cell

III. Mathematical Model of PV Cell

A mathematical equation for PV cell has been studied in many publications. They usually used to neglect the value of the series resistance R_s and shunt resistance R_P. by using Kirchhoff`s current law , the output current of a PV cell shown in Figure 1 was derived by [3][7][8].

PV output current

$$I = I_{ph} - I_d - I_{R_p} \quad (2)$$

$$I = I_{ph} - I_{rs}.\left(exp\left(\frac{q(V+IR_S)}{A.k.T}\right) - 1\right) - \left(\frac{V+I_SR_S}{R_P}\right) \quad (3)$$

$$I = I_{ph} - I_{rs}.\left(exp\left(\frac{qV}{A.k.T}\right) - 1\right) \quad (4)$$

In order to increase the power the more cells connected in series to increase the output voltage and more cells connected in parallel to increase the output current.

$$I = N_pI_{ph} - N_pI_{rs}.\left(exp\left(\frac{qV}{A.k.N_S.T}\right) - 1\right) \quad (5)$$

Where, I_{ph} : Insulation current or photocurrent, I : Cell output current, I_{rs}: Reverse saturation current, V:Cell output voltage, R_s: Series resistance, R_p: Parallel resistance, K: Boltzman constant, A: p-n junction ideality factor, N_s: number of cells in series, N_p: number of cells in parallel, q: the charge of electron.

The factor A in equation(3,4 and 5) determines the cell deviation from the ideal p-n junction characteristics; it ranges between 1-5 but for our case A= 2.46. The cell reverse saturation current I_{rs} varies with temperature according to the following equation:

saturation current

$$I_{rs} = I_{rr}.\left(\frac{T}{T_r}\right)^3.exp\left(\frac{q.E_g.\left(\frac{1}{T_r}-\frac{1}{T}\right)}{Ak}\right) \quad (6)$$

Where, T_r: cell reference temperature, I_{rr}: cell reverse saturation temperature at T_r,. E_g: band gap of the semiconductor used in the cell.

The temperature dependence of the energy gap of the semiconductor is given by

Band gap energy

$$E_g = E_g(0) - \frac{\alpha.T^2}{\beta+T} \quad (7)$$

Temperature $T = T + T_r$

Reverse saturation current

$$I_{rr} = \frac{I_{scr}}{exp\left(\frac{q.V_{OC}}{A.N_S.k.T}\right)-1} \quad (8)$$

The photo current I_{ph} depends on the solar radiation and cell temperature as follows:

photo-current

$$I_{ph} = \left(I_{scr} + K_i(T-298)\right).\frac{S}{1000} \quad (9)$$

Where, I_{scr}: cell short-circuit current at reference temperature and radiation, K_i: short circuit current temperature coefficient, S: solar radiation intensity W/m^2, α:the current temperature coefficient (mA/ºC), β: voltage temperature coefficient (V/ºC),

IV. Simulation Results

In order to study the characteristic behaviour of the PV module, the mathematical model of the PV array represented by the equations between Eq. (1) to Eq. (9) has been built in MATLAB/SIMULINK package program. The manufacturer's data sheet of PV module is shown in Table I are used in this simulation. the whole Model of a PV system is consist of several separate blocks as shown in Figure 2. the closed-up of the all separated sub-models has been shown in Figure 3.

Table I manufacturer's data sheet of PV panel

N_s	60	V_{oc}	35
N_p	4	I_{sc}	3.75
q	1.6022*10^{-19}	$E_{g(0)}$	1.166
K	1.3806*10^{-23}	α	0.473
A	2.15	β	636
K_i	0.00023		

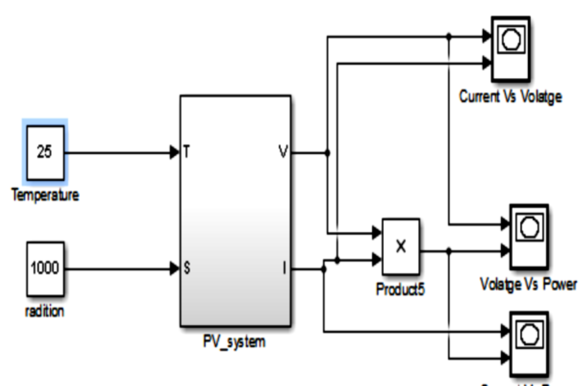

Fig.2. The general model of The PV array

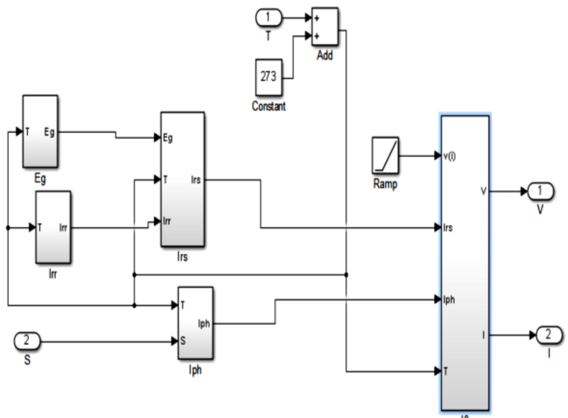

Fig.3. The underneath of the PV array Simulink

A. The effect of varying radiation values with constant temperature

With increase in the solar irradiation, it is clear that the short circuit current and the open circuit voltage (Voc) increased as it shown in Fig.4. This is due to the fact that, when more sunlight incidents on to the solar cell, the electrons are supplied with higher excitation energy, thereby increasing the electron mobility and thus more power is generated as shown in Figure 5 and Figure 6.

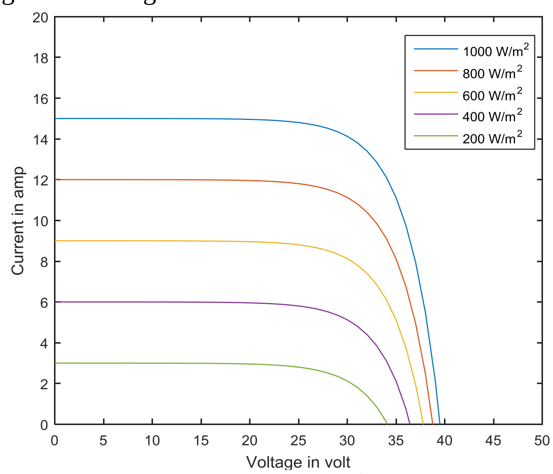

Fig.4. V-I curves under variation of irradiation values

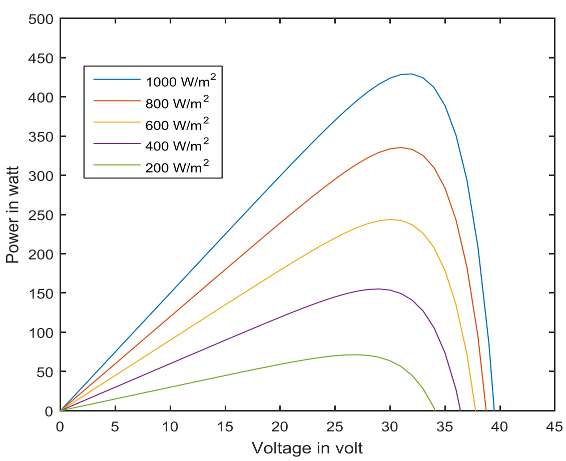

Fig.5. V-P curves under variation of irradiation values

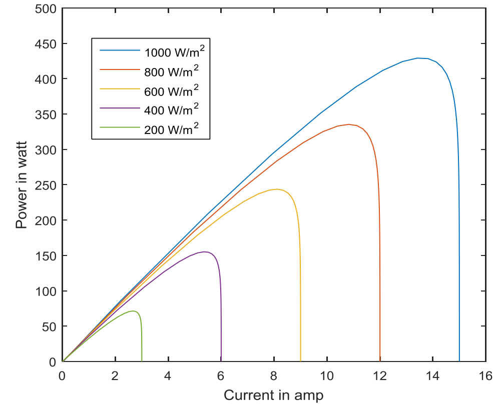

Fig.6 I-P curves under variation of irradiation values

B. The effect of the Temperature on the characteristic of PV system with fixed irradiation

The increasing of the temperature around the solar cell has a negative impact on the power generation capability. Increasing in the temperature is accompanied by a decrease in the open circuit voltage value as shown in Figure7. Increase in temperature causes increase in the band gap of the material and thus more energy is required to cross this barrier. Thus the output power will be decreased and hence the efficiency of the solar cell is reduced. Figure 8 & Figure 9 show the *V-P* and *I-P* curves when the temperature of the cell is varied.

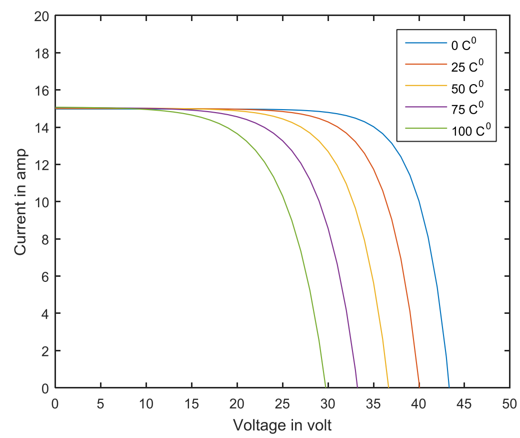

Fig.7. V-I curves under variation of temperature values

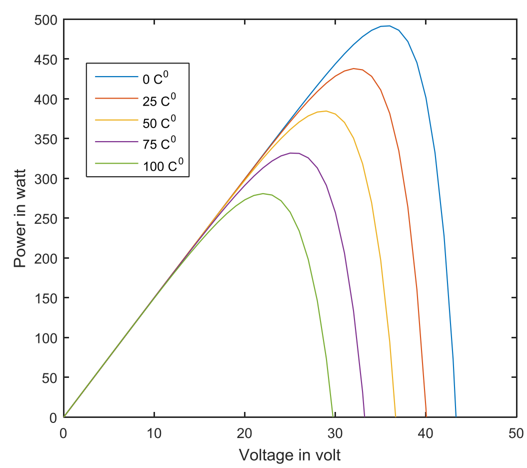

Fig.8 V-P curves under variation of temperature values

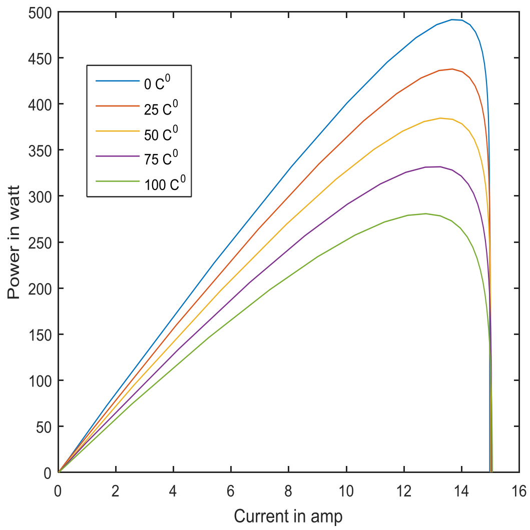

Fig.9. I-P curves under variation of temperature values

C. Effect of shading on the characteristic of PV system

Partial shading is a frequent phenomenon that occurs when some cells within a module or array are shaded under different causes. It is well known that the short-circuit current of a PV cell is proportional to the insolation level, the photocurrent for the shaded PV cells is reduced due to the partial shading effect while the un-shaded cells continue to operate at a higher photocurrent. Since the string current must be equal through all the series-connected cells, the result is that when light current reaches the shaded cells it will not allow too much current to pass through it, so all unshaded cells in the same series string try to force large current to conduct shaded one and hence, it will lose a lot of voltage. and then the bad cell operates in the reverse bias region, and instead of producing power, it dissipates power. If reverse bias exceeds the breakdown voltage of the shaded solar cell, the cell will be fully damaged, and an open circuit exists at the serial branch where the cell is connected. To relieve the stress on shaded cells, bypass diodes and block diodes are added across the modules. Figure 10 illustrates how the string current flow through all the series-connected cells including shaded and un-shaded .The bypass diode is connected in the opposite polarity of the cell, so the string current will flow through the bypass diode shaded cell no 3 without losing much voltages because as soon the bad cell will operate in reverse region the bypass diode becomes forward bias . In order to study the effect of this phenomenon on the performance of the system, the same model of PV panel shown in Figure 2 is rebuilt using Simcaps blocks as shown in Figure 11. the bypass diodes are connected parallel to the each 12 cells to limit the reverse voltage and one block diode is connected in each string . all the cells are received the uniform radiation except the cells which marked by black color are shaded. It is seen from the I–V characteristics of PV panel shown in Figure 12 that there are multi regions of power. the first region started at 12 V (0.6V*24 cells) and so on for the second and third region at 21 and 28 V for 36 and 48 cells respectively of the remained un-shaded cells of the strings. Figure 13&Figure 14 reveals that the array having these diodes introduces multiple peaks of power in the V–P & I-P characteristics under the partially shaded conditions.

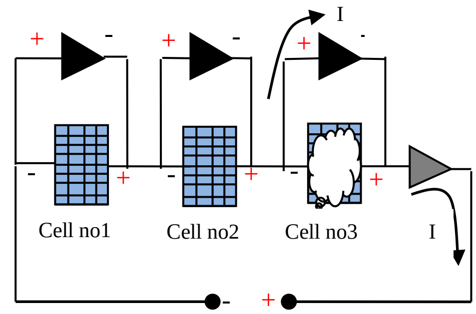

Fig.10. Connection of bypass diode across the arrays

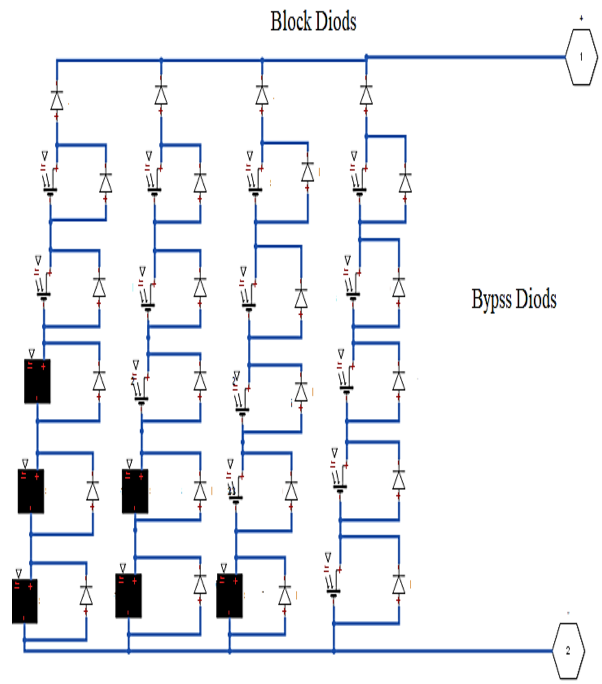

Fig.11. PV panel system under shading condition

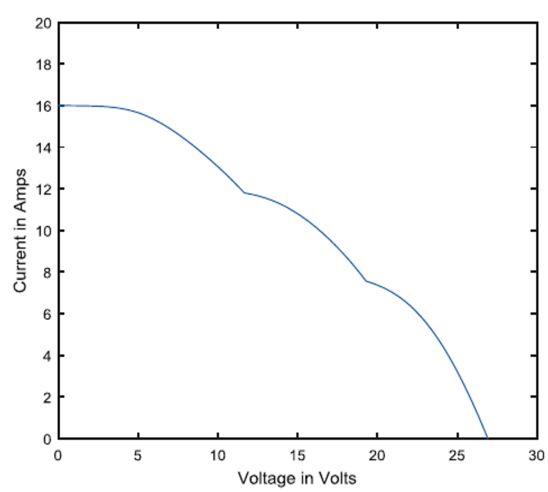

Fig.12. V-I curve under shaded condition with bypass diodes

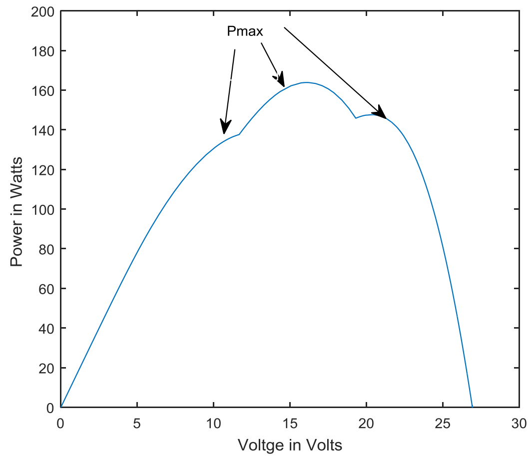

Fig.13. V-P curve under shaded condition with bypass diodes

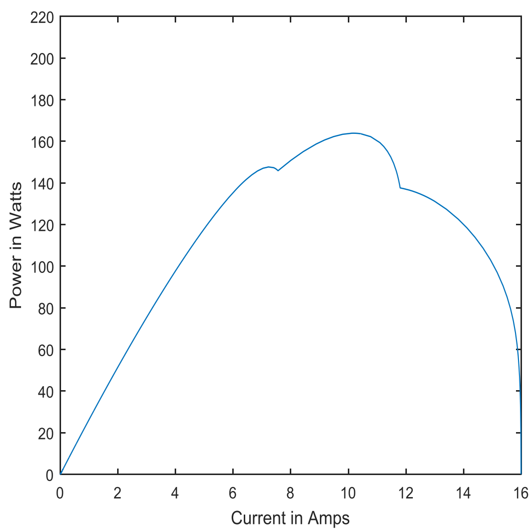

Fig.14. I-P curve under shaded condition with bypass diods

V. CONCLUSION

In this paper the model for the real PV solar cell array was developed and presented based on the fundamental circuit equations of a PV solar cell using Matlab/simulation. The simulation results are validated by the manufacturer's datasheet and taking into account the effect of sunlight irradiance and cell temperature on the electrical characteristics (V-I, V-P and I-P curves). it has been observed that the open circuit voltage got decreased with the variation of the values of the cell temperature while the value of irradiance are constant. Also it has been noticed that the voltage produced by the PV array at open circuit and the short circuit current are increased by increasing of the solar irradiance level. A model of PV system under shaded condition with bypass and blocking diodes is investigated using Simpower blocks. V-I and V-P and I-P characteristics curves show multiple peaks under partially shaded conditions

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