Model of stand-alone photovoltaic module

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***Abstract*-- The energy from a stand-alone photovoltaic (PV) generation system is based on energy conversion in photovoltaic cells. It is defined as a semiconductor device which converts sunlight into electricity. In this paper, we demonstrate how to create a complete implementation of a photovoltaic module using mathematical equations in order to study their I-V and P-V characteristics. Also, introducing the manufacturer's datasheets after sizing step. The chosen model consists of current source in parallel to the diode and the resistor connected in series represents the resistance of the contacts. Another one in parallel called shunt resistor, representing the leakage currents. The detailed model shows properly the impact of the weather condition, the irradiance and the temperature, on the production of maximum power-output to our electric vehicle.**

***Index Terms*-- Irradiance, Maximum Power, Temperature, Photovoltaic cell, P–V and I–V characteristic.**

1. Introduction

Ecological studies have shown that increasing energy consumption due to thermal vehicles is accompanied by an enormous increase in the emission of toxic gases into the atmosphere, which causes air and water pollution. For this purpose, electric vehicle development are rapidly involved and having an economic system [1]-[2]. The growing interest in renewable energy resources sector encourage scientists to increase the benefits of electric vehicle when storing energy in electric batteries through photovoltaic panels. Solar energy is an inexhaustible energy as it comes from the sun and respects nature and environment. It is the most reliable energy because there is no risk of rupture [2]. Moreover, the photovoltaic module refers to the number of cells connected in series and formed by semiconductor material with two interfaces: the positively doped P and the other negatively doped N. It's the PN junction [3]. Photovoltaic cells convert light into electricity and it have different available technologies including monocrystalline, polycrystalline and thin-film which can be all used to produce the Photovoltaic panel. On the other hand, to obtain higher power output, you must choose the monocrystalline technology with many cells connected in series to increase the open circuit voltage of PV panel.

In addition, the maximum energy produced by photovoltaic module depends on many parameters (irradiation, temperature, series resistance ...). This latter has large fluctuations then it is very difficult to make an exactly calculation of power production. Therefore, on the market, there are many software to estimate this production by giving us all parameters of any type of panel and in any domain after choosing the constraint (roof area available, electricity consumption or budget) [4]. There are a number of studies about the optimization and sizing of PV system equipped with the electrical grid utilize the conventional type of panel because there are no constraint of surface [5], Also H. Belmili highlights the criterion (quality / price) than the power generated or the surface of his standalone photovoltaic installation for lighting and pumping [6]. On the other hand, in our work, we are interested in the panels that will be installed on the roof of vehicles. Therefore, the choice of module type must check the constraint of the surface limitation by guaranteeing the maximum power generated. Sizing software has allowed us to select the desired cell type, battery type and the proper converter. For that we are chosen the best panel "SPR-455J-WHT-D "of SunPower Manufacturer with 455W.

In this paper, after the dimensioning phase of the system and the providing of all electric characteristic of the appropriate panel, we propose a simple model of our panel using the step-by-step modeling procedure to present the simulation results in the next step.

2. Modeling of Photovoltaic Panel

A. Specification

A solar cell of "SPR-455J-WHT-D "is basically a PN junction fabricated in a monocrystalline of semiconductor which has the faculty of transforming the irradiation solar to electricity.

As appears in Fig. 1, the equivalent circuit of a PV cell is composed of current source, which models the photocurrent, associated in parallel with diode represents the PN junction, to determine the voltage source. The two preceding components represent the equivalent circuit of an ideal photovoltaic cell, which is developed in several papers [6]-[7], and regardless the dissipation phenomena at the cellular level caused by the increase of temperature. In this paper, to solve this problem and having an effective model with exactly values of power, we added two resistances Rs and Rp, representing the losses of the cell, to obtain the complete equivalent circuit of photovoltaic cell and with more performance and persuasion at any time.

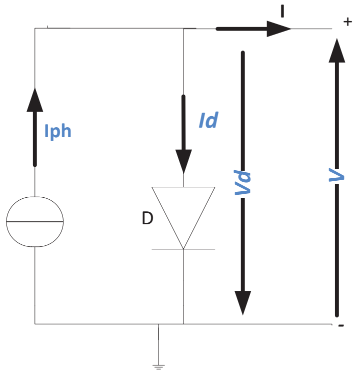

Fig. 1. Ideal single diode Model

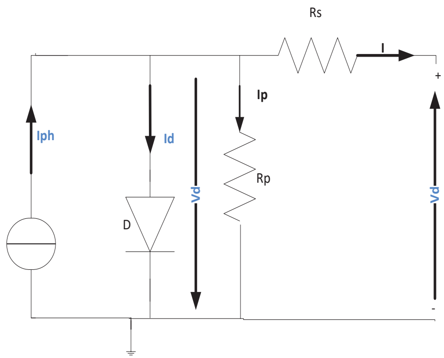

Fig. 2. Equivalent circuit of a photovoltaic cell

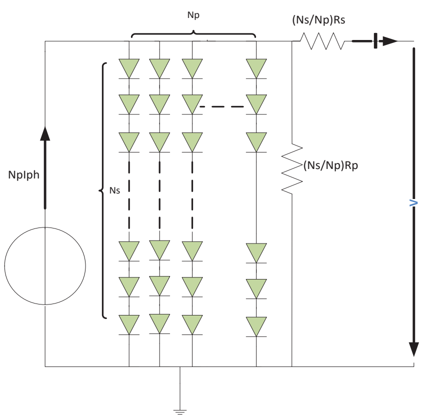

Fig. 3. Equivalent circuit of PV module

The output power of photovoltaic module depends on the irradiance of sunlight and the temperature. The simulation of the proposed model of PV panel or module consists of validating the relationship between voltage-current and voltage-power, in addition to give the operating range of optimal power [8].The equivalent circuit of PV module is shown in Fig.3.

The table below recapitulates the value of all PV parameters of "SPR-455J-WHT-D ".They represent all the input parameters of our model.

TABLE I

Electric characteristic of SPR-455J-WHT-D of SunPower Manufacturer

Symbol	Parameters	Value
Pnom	Peak Power at STC (manufacturer)	455Wc
	Technology	Si-mono
Sm	Total surface of the module	2.16m²
Nb	Cells number	128
Tref	Reference Temperature	298K
G	reference Irradiance	1000 W/m²
Vco	the voltage at open circuit	90.5V
Isc	the current at short circuit	6.32 A
T_coef	Temperature Coefficient at Isc	3.5 mA/°C
Rp	Parallel resistance	4591ohm
Rs	Series Resistane	0.58 ohm

According to Kirchhoff's current law applied to Fig. 3. :

The output current *I* [A], of PV module is expressed by:

$$I = Np(I_{ph} - I_d - I_p) \tag{1}$$

Where Np is the number of PV cells connected in parallel (=1), I_{ph} is the photocurrent [A], I_p is the photocurrent [A] and I_d is the diode current [A] measured as:

$$I_d = I_0\left(e^{\frac{qV_d}{ANsKT}} - 1\right) \tag{2}$$

Here, I_0 is the reverse bias saturation current (or scale current), V_d is the voltage across the diode, k is the Boltzmann constant, T is the absolute temperature of the PN junction, q is the magnitude of charge of an electron and N_s is the number of PV cells connected in series [9].

A is the diode ideality factor or the quality factor or sometimes emission coefficient. It depends on the fabrication process and semiconductor material as shown in table below.

TABLE II

Ideality factor (A) [10]

Technology	A
Si-mono	1.2
Si-poly	1.3
a-Si-H	1.8
a-Si-H tandem	3.3
a-Si-H triple	5
cdTe	1.5
CTs	1.5
AsGa	1.3

The reverse saturation current I_0 depends on the cell temperature (T) and defined by:

$$I_o = I_{0\_ref} \left(\frac{T}{T_{ref}}\right)^3 \exp\left(\frac{qE_G}{Ak}\left(\frac{1}{Tref} - \frac{1}{T}\right)\right) \quad (3)$$

By using [6]:

$$I_{0\_ref} = I_{sc_{ref}} \left(e^{\frac{qV_d}{ANsKT}} - 1\right) \quad (4)$$

$$I_p = \frac{V_d}{NpR_p} = \frac{V + R_s I}{Np R_p} \quad (5)$$

The photocurrent illustrated in [11]

$$I_{ph} = (I_{ph,ref} + K_i \Delta T)\frac{G}{G_{ref}} \quad (6)$$

Here, K_i is the coefficient temperature of short circuit current (A/K), G is the input irradiance of model (W/m²), G_{ref} is the irradiance at Standard Test Condition STC (G=1000W/m² and T=25°C), $\Delta T = T - T_{ref}$, T_{ref} is the nominal temperature at STC= 298 K, $I_{ph,ref} = I_{sc,ref}$ is the nominal photocurrent.

B. I-V and P-V characteristics of our panel

To study the environmental conditions effect (temperature and solar irradiance) in the maximum power generation, we have interested to model our module with using all mathematics equations which is illustrated above.

The two curves, Fig. 4 and Fig. 5, show the simulated and measured characteristic of I-V and P-V in the standard test condition (T=25°C and G=1000 W/m²) in order to establish the efficiency of our model.

In the simulation graph of P-V characteristic, we have the maximum power point P_{mpp} equal to 450W and voltage at maximum power V_{mpp} equal to 75.64 V, on the other hand, P_{mpp} up to 455.5 W and V_{mpp} up to 75.8 V in the measured graph.

The convergence between the two power values indicates that the error margin between simulated and measured graph is very weak. So we can rely to our model for giving us the real behavior.

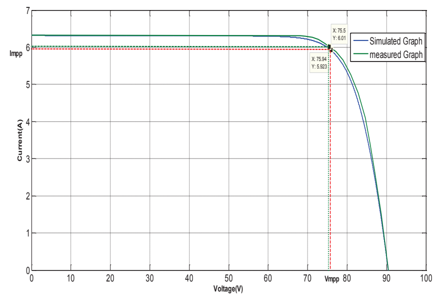

Fig. 4. I-V characteristic of PV module.

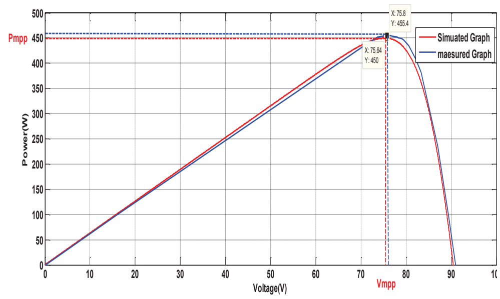

Fig. 5. P-V characteristic of PV module.

3. SIMULATIONS

The simulations of solar Panel is based on mathematical equations given in the section above with the input parameters shown in the TABLE I.

Our proposed model is presented in Fig.6. The inputs are both, the weather data irradiance and the temperature, while the outputs represent the variation of the PV electrical quantity as a function of current, voltage and power.

All the variables of the mathematical equations are as follows:

- *k = 1.3805*10-23 J/K;*
- *q = 1.6*10-19C;*
- *A = 1.2;*
- *K_i = 0.0035 A/°C;*
- *I_{sc_ref} = 6.32 A;*

- *Ns = 128,*
- *Eg (Material band gap energy) = 1.12 eV.*

- Module photon-current I_{ph} is given by Eq. (6) and modeled as Fig.7 with detailed information

- Module reverse saturation current $I_{0\text{-}ref}$ is given by Eq. (4) and modeled as Fig. 8.

- Module saturation current I_0 is given by Eq. (3) and modeled as Fig.9.

- Module PV output current *I* is given by Eq. (1) and modeled as Fig.10.

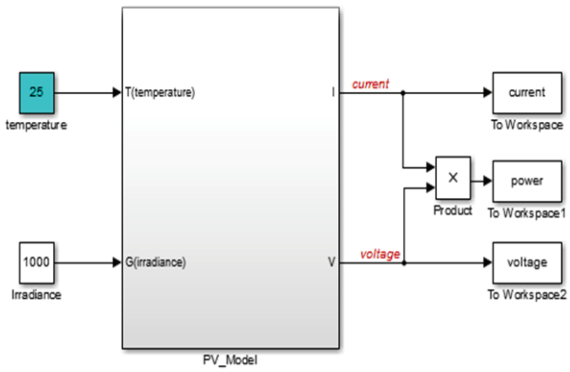

Fig. 6. The complete model of our PV module

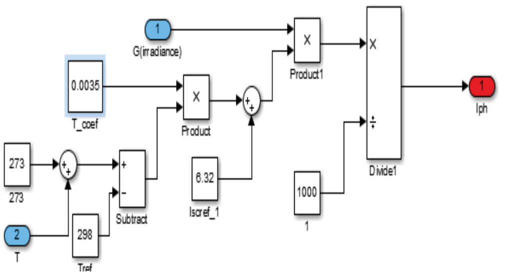

Fig. 7. Simulink Bloc of detailed I_{ph} simulation

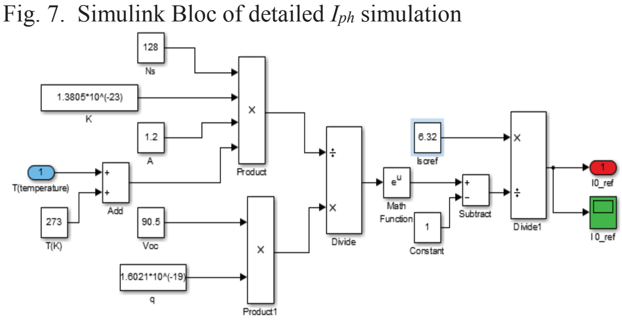

Fig. 8. Simulink Bloc of detailed $I_{0\text{-}ref}$ simulation

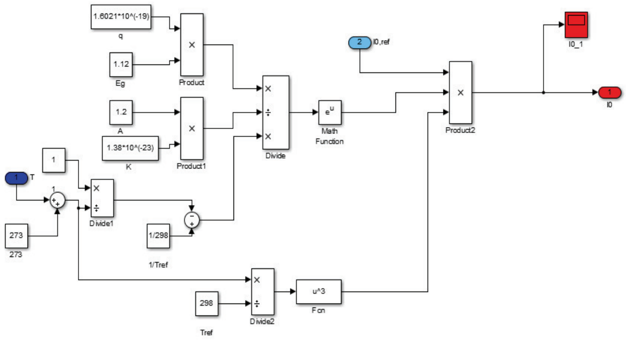

Fig. 9. Simulink Bloc of detailed I_0 simulation

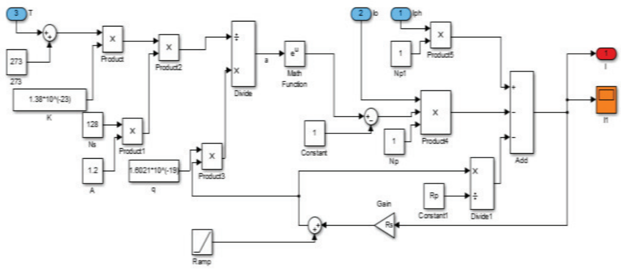

Fig. 10. Simulink Bloc of detailed *I* simulation

4. Results and Discussion

All simulations are completed and performed by using the commercial software MATLAB® (Simulink) which validate the previously described model.

In the first step, we represent the results of photovoltaic module with the following series and parallel resistance: Rs = 0.17 Ω and Rp = 250 Ω. After validating our model with best running, we are going to show the influence of irradiation and temperature in the response of the outputs.

A. Irradiance effect

In the following two curves (Fig.11 and Fig.12), our Simulink model is running for various values of sun intensity levels as 1000 W/m², 800 W/m², 650 W/m² 450 W/m², and 200W/m². When the irradiance increases, the current intensity increases too and with an increase in sunlight voltage, the production of electric power of the photovoltaic module increases also.

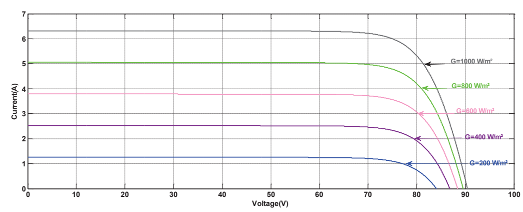

Fig. 11. I-V characteristic by varying irradiance.

And the same for the P-V characteristic in the following figure.

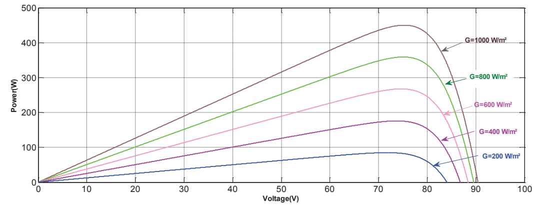

Fig. 12. P-V characteristic by varying irradiance.

B. Temperature effect:

The evolution of the I-V and P-V characteristic depending on the temperature, showing in Fig.13 and Fig.14, takes various values as 0°C, 25 °C, 45 °C, 60 °C, and 70°C. It shows a decrease in the open circuit voltage with a short current system almost constant throughout the change.

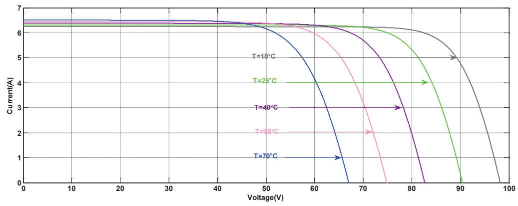

Fig. 13. I-V characteristic as a function of temperature.

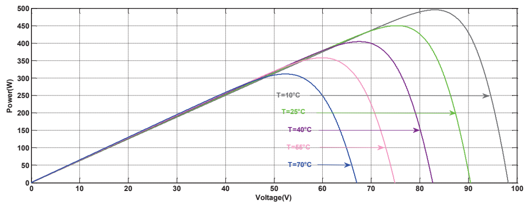

Fig. 14. P-V characteristic as a function of temperature.

To compare our calculated results of maximum power point values and those published by the manufacturer, it is evident that they are in a good agreement. It is found that the temperature and irradiation conditions of the panel "SPR-455J-WHT-D of SunPower" modify the characteristic I-V and P-V and also the values of Vmax, Imax and Pmax. For this reason, founding the maximum power point is difficult because it is related to the fluctuation of climatic conditions. Indeed, there are lots of researches proposing adjustment real-time algorithms of the operating point MPP where maximum power output is achieved[12]-[13] .

4. Conclusion

This procedure of PV modeling with MATLAB/SIMULINK is very helpful to all users of photovoltaic domain because it serves researchers and developers to understand the behavior of any solar PV cell and how to extract the maximum power. With any type and technology panel, the performance of a PV module is strongly influenced by climatic conditions especially solar irradiation and temperature which makes it possible very useful in our country even then with more performance.

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