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Investigation the effect of the temperature and irradiance on the output parameters of solar cell

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Abstract:-

It is important to investigate the effect of the irradiance and temperature on the output performance of the solar cell. Hence, it is possible to estimate the I-V and P-V curves of solar panel under different environmental conditions. The present paper focused on single-diode photovoltaic cell model. Our results have implemented by using MATLAB Simulink. It is indicated that a decrease in the output power and output voltage of the PV module due to the increasing of ambience temperature while decrease sun's irradiation . The best performance of solar cells to be in sunny and cold day.

Keywords:- Solar cells , Matlab/Simulink, IV curves, temperature, irradiance.

Introduction:-

There are several studies have focused on effect a temperate and irradiance on performance of a photovoltaic cell which is include output voltage and output power.

A photovoltaic cell or photoelectric cell is a semiconductor device that converts light into electrical energy using photovoltaic effect (Kanchan and Vinay, 2014). Cells may be grouped to form panels or modules. Panels can be grouped to form large photovoltaic arrays. The term array is usually employed to describe a photovoltaic panel (with several cells connected in series and/or parallel) or a group of panels (Rustemli and Dincer, 2011). Photovoltaic effect is a phenomenon through which a collection of light-generated carries by the P-N junction causes a movement of electrons to the N-type side and holes to the P-type side of junction (J.Hernanz et al., 2012). If the energy of photon of light is greater than the band gap then the electron is emitted and the flow of electrons creates current (Sangita and Vaidya, 2012 and Pradhan and Panda, 2017). The current versus voltage (I-V) as well as P-V (Power versus Voltage) characteristics are highly non-linear. During absence of light energy, these cells produce what is known as dark current that has exponential characteristic I-V curves. The amount of energy harvested by them depends on the sun's irradiation and the ambient temperature. Researches have presented successfully the construction of mathematical model for a photovoltaic cell using the MATLAB/ Simulink software (Subarto et al., 2013). In this paper, a Simulink model using single diode with shunt and series resistor is constructed based on the mathematical equations available i.e. this paper carried out a MATLAB/ Simulink model of PV cell performance under different solar radiation and different ambient temperature. We can use this model to get characteristic curves of any solar cell under different environmental conditions.

Basic principle of solar cell:-

Photovoltaic cell models (photovoltaic arrays) have long been a source for the description of photovoltaic cell behavior. The most common model used to predict energy production in photovoltaic cell modeling is the single diode lumped circuit model. In the single diode model, there is a current source parallel to a diode. The current source represents light-generated current I_{ph} that varies linearly with solar irradiation. This is the simplest and most widely used model as it offers a good compromise between simplicity and accuracy. Figure 1 shows the single diode equivalent circuit model of PV cell which is commonly used in many studies and provides sufficient accuracy for most applications (Dominique et al., 2013) In practical solar cells, the voltage loss on the way to the external contacts is observed. This voltage loss is expressed by a series resistance R_s. Furthermore, leakage current is described by a parallel resistance (shunt resistance) R_{sh} (Amit and Akella, 2016).

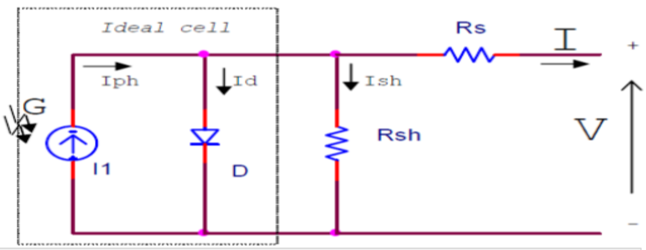

Fig (1): Single Diode Model of a Solar Cell (J.Hernanz et al, 2012)

Characteristics of Solar Cell:-

Solar cells (photovoltaic arrays) naturally demonstrate anonlinear I-V and P-V characteristics which vary with the solar irradiation and cell temperature. The photocurrent is indeed a reverse bias current because electrons movement toward the cathode and the holes flow to the anode. If we start applying a voltage i.e. it will start recompensing for that reverse photocurrent and finally, you will reach point where the current goes to zero. At this point, it is indicated to as an open-circuit voltage V_{oc} because even with applying a voltage, there is no current. The typical I-V and P-V characteristics of solar cell are presented in Fig(2) (Singla and Garg, 2013 and Subarto et al., 2013).

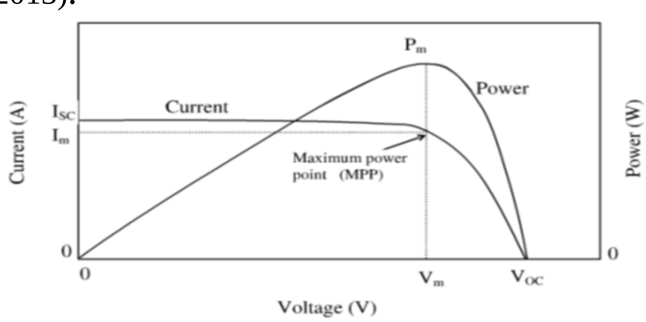

Fig (2): Characteristics of solar cell

Where, its output current, I, can be written (Wafaa et al., 2013 and Ravinder and Muralidharan, 2014).

$$I = I_{ph} - I_d \quad (1)$$

$$I = I_{ph} - I_o\left(\exp\left(\frac{qV}{nkT}\right) - 1\right) \quad (2)$$

We have I output current , I_{ph} represents the current generated by the incident light (the photo-generated current), $I_d$is the diode current and $I_o$is the reverse saturation current of the diode, q is the electrical charge, k is the Boltzmann constant, T is the temperature of the p-n junction, and 'n' is the diode ideality factor . An improvement of the model includes the effects of a shunt resistance R_{sh} and another in series R_s(Mahfoud et al., 2015 and Dominique et al., 2013) Series resistance is very little, which grow from the ohmic contact between metal and semiconductor internal resistance. The shunt resistance is a resistance which takes into account the unavoidable leakage of current that occurs between the terminals of a solar cell. In common, when the shunt resistance is very high, its effect is felt especially in the generation of power, noting that in ideal case R_s is 0 and R_{sh} is ∞ .By figure 1, applying Kirchhoff's law to the node where I_{ph}, R_{sh} and R_s meet, and one get (Wafaa et al., 2013):

$$I = I_{ph} - I_d - I_{sh} \quad (3)$$

$$I = I_{ph} - I_o\left[\exp\left(\frac{V+IR_s}{nV_T}\right) - 1\right] - \left[\frac{V+IR_s}{R_{sh}}\right] \quad (4)$$

Where $V_T = \frac{N_s \times k \times T}{q}$ is the thermal voltage of a PV module having N_s cells represent in [12]. The photo-generated current I_{ph} a function of the irradiance (G) and is formulated as (B.Pranahita et al., 2014).

$$I_{ph} = [I_{sc} + K_i(T_c - T_{ref})]\frac{G}{G_{ref}} \quad (5)$$

Where: I_{sc} is solar cell short-circuit current, G_{ref} is reference solar insolation in W/m^2, T_{ref} is reference temperature, K_i is short-circuit current temperature coefficient and T_c is the cell's working temperature. On the other hand, the cell's saturation current I_o varies with the cell temperature, which is represented by:

$$I_o = I_{o\_STC}\left(\frac{T}{T_{STC}}\right)^3 \exp\left[\frac{qE_g}{nk}\left(\frac{1}{T_{STC}} - \frac{1}{T}\right)\right] \quad (6)$$

Where, I_{o_STC} is the reverse saturation current at a reference temperature and a solar radiation and E_g is the band-gap energy of the semiconductor material used. The reverse saturation current I_{o_STC} is given by (B. Pranahita et al., 2014 and Amit and Akella, 2016):

$$I_{o\_STC} = \frac{I_{sc}}{\exp\left(\frac{qV_{oc}}{nkT_c}\right)-1} \qquad (7)$$

Open circuit voltage V_{oc} correspond to the voltage drop across the diode (p-n junction), when the output current is I = 0 (El-Shaer et al., 2014).
Noting that in the case study parameters of Simulink are $K_i = 0.0032$, n = 1.62 , E_o =1.12 ev, R_s = 0.221 Ω , R_{sh} = 415.405 Ω , T_{ref} = 298 K , V_{oc} =21.1 V, I_{sc} = 5.48 A , N_s = 72 and G_{ref} = 1000 W/m^2. All the values are provided by the datasheet.

Results:-

In this paper the single diode model has been created in MATLB/ Simulink based on Equation (4). As outlined in the introduction the output characteristics of solar panel depends mainly on the solar irradiance, the cell temperature and output voltage of solar cell module. Since it has nonlinear characteristics as discussed previously, the results are divided into three parts as follows:

Variation of Solar Irradiance:-

The effect of the irradiance on the current-voltage (I-V) and power-voltage (P-V) characteristics is evidenced in figures(3-4) respectively. Where the temperature is maintained constant at 25^{o}C and by varying the irradiation(200 W/m^2, 400 W/m^2, 600 W/m^2, 800 W/m^2, 1000 W/m^2), to illustrate better effect of the irradiance on the V-I and V-P curves, can be explained in the Figs (3) and (4).

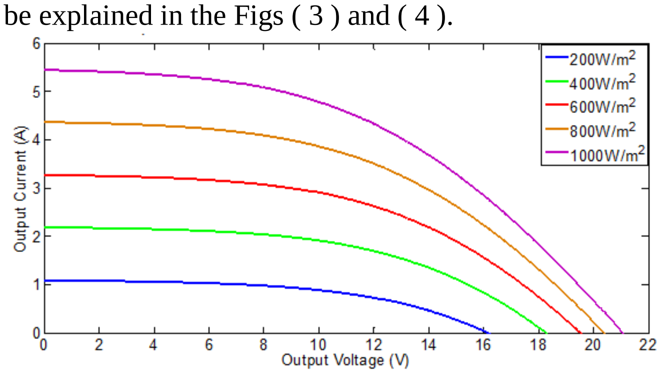

Fig (3): I-V Output Characteristics of solar cell at different irradiance.

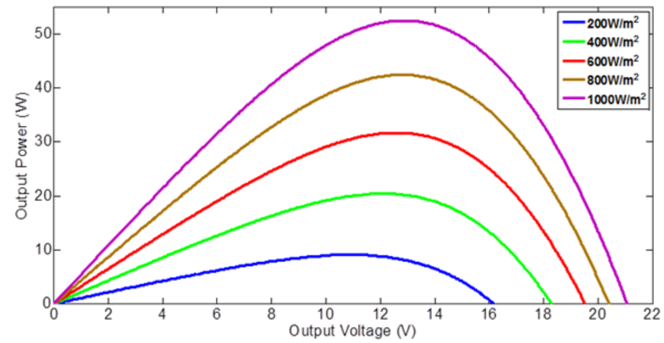

Fig (4): P-V Output Characteristics of solar cell at different irradiance

Variation of ambient temperature:-

The effect of temperature variation on the I-V characteristics and P-V characteristics curves are demonstrated in below figures 5-6 respectively. The irradiation is fixed at 1000 W/m^2 and varying temperature at (0°C, 10°C, 20°C, 30°C, 40^{o}C, 50^o) have been generated the characteristic curves.

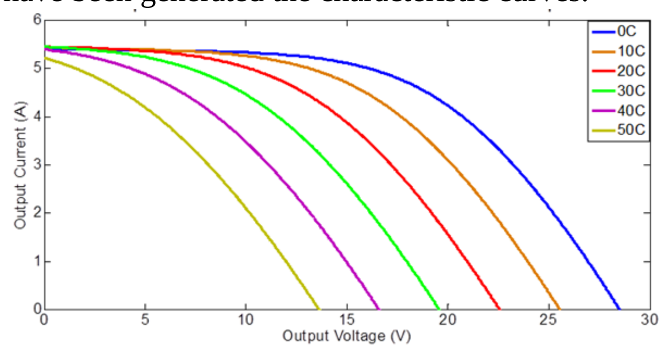

Fig (5): I-V Characteristics of solar cell at different temperature

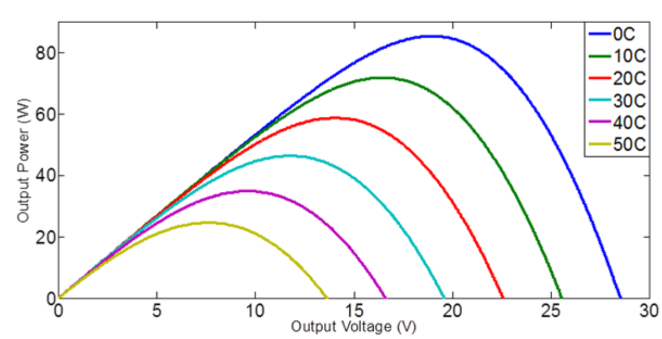

Fig (6): P-V output characteristics of solar cell at different temperature

Effect irradiance and temperature on I_{ph}:-

Table (1) shows the effect of an ambient temperature and solar irradiance on the photo-generated current I_{ph}, can be observed in Equation (5).

Table (1): Effect temperature and irradiance on the I_{ph}

T_CC	I_{ph}(A)				
	$200W/m^2$	$400W/m^2$	$600\ W/m^2$	$800\ W/m^2$	$1000W/m^2$
0	0.905	1.811	2.716	3.621	4.526
10	0.9117	1.823	2.735	3.647	4.568
20	0.9181	1.836	2.754	3.672	4.59
30	0.9245	1.849	2.773	3.698	4.622
40	0.9309	1.862	2.793	3.724	4.654
50	0.9373	1.857	2.812	3.749	4.686

Also Figs (7) and (8) are show the I-V and P-V characteristics of solar cell model with various irradiance and temperature (25^oC) and (50^oC). These figures are cleared the effect of change of temperature levels on these characteristics.

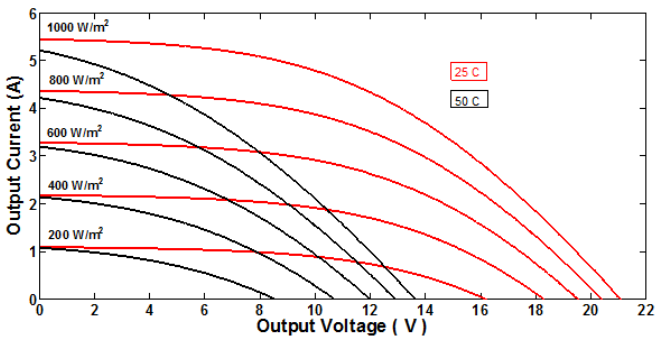

Fig (7): I-V Output Characteristics of solar cell at different temperatures and irradiance

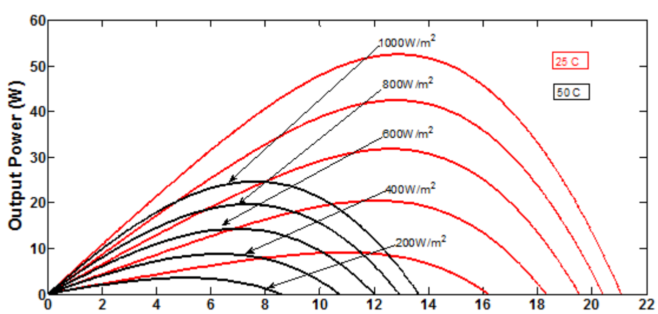

Fig (8): P-V Output characteristics of solar cell at different temperatures and irradiance

Discussion:-

Our results have included an effect irradiance and temperature on operation of solar cell based on single-diode model and it has been facilitated by Matlab software therefore both I-V and P-V output characteristics of solar cell model at various irradiance are shown in Figs(3) and (4). We note the output current and power of solar cell depend on solar irradiance. According to Schottky equation, both I_{sc} and the V_{oc} are dependent on the solar irradiance. The current at short circuit increases linearly as the irradiance increases, since the photon-to-current conversion rate increases. On the other hand, the open-circuit voltage increases logarithmically, following the distribution of the energy states in the semiconductor as well with (Wafaa et al., 2014). Figs(5) and (6) illustrate the dependence of I-V and V-P characteristics on temperature: i.e. With the increase in temperature the rate of photon generation and increases due to the reverse saturation current increases rapidly and this results on reduction in band gap while the open-circuit voltage decreases with increases temperature .Hence this leads to marginal changes in current but major changes in voltage. Temperature acts like a negative factor affecting solar cell performance in good agreement with (Pradhan et al., 2013). Our country is characterized by a long summer climate and temperatures reach up to 50^oC.

Conclusion:-

Precise knowledge of solar cell performance during the measured I-V and P-V characteristics which is very important to the quality control and the performance of solar cell. Our results are in general agreement with previous studies therefore short circuit current and maximum current are increase linearly with increasing solar irradiation. So, the maximum power output had found at 200 W/m^2 to 1000 W/m^2 .On the other hand, it has been observed that ambient temperature has a dramatic effect on voltage parameters. Open circuit voltage and maximum voltage are decrease with increasing ambient temperature 10^o C to 50^oC. Because of these, the degradation in performance due to high temperature operation and irradiance must be accounted when evaluating the actual amount of electrical power a PV module can produce. Future work should focus on the efficiency of PV panel and appropriate for the local environment.

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