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Necessity to Design a Controller for PV Module

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Abstract*: *Solar power is future of our planet due to the depletion of non-renewable sources of energy. We all are directly dependent on non-renewable source which will only last for 1 or 2 decades. The PV cell exhibit non linear I-V and P-V characteristics. In this paper it is discussed about the factors which will affect the PV module performance. Some factors will decrease the solar cell performance while some factors will improve the efficiency and increase its output power. The performance characteristics of PV module are modeled mathematically and simulated under different atmospheric conditions. The simulation model is obtained using MATLAB software and stimulated under different values of input parameters of PV module that include irradiance and temperature. The variations of these parameters were recorded under different atmospheric conditions. The input parameters of solar cell like solar irradiance and ambient temperature was evaluated. It observed that the maximum power produced fluctuates with both irradiance and temperature. Since the conversion efficiency of PV array is exceptionally low, it requires maximum power point tracking (MPPT) control techniques. The MPPT is the programmed controlled method used to guide the solar cell to achieve the maximum power output, during minute to minute variations of atmospheric changes like irradiance and temperature. The MPPT controller is used to provide maximum power output from PV module against changes in temperature and irradiance. Results obtain by simulation are presented and discussed.

Keywords: PV module, temperature, irradiance, MATLAB

I. INTRODUCTION

Now a days as the world population is expanding quickly, consequently demand of electricity is also additionally expanding and the available energy sources are not adequate to fulfill this need. With a spurt in the utilization of nonconventional energy sources, utilization of solar panels are progressively improved in few applications, for example distributed power generation and stand-alone systems. However, major challenge in using a PV source is to tackle its nonlinear output performance which vary with temperature and solar irradiance from sun[1]. Solar panel is the fundamental energy conversion component of photovoltaic (PV) system. Due to variation in the temperature and the sun intensity levels the current-voltage and power-voltage properties of PV array leads to exhibit the non-linear characteristics [2-3]. Electrical characteristics of a PV arrays are non linear V-I characteristics.

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This V-I characteristics have a maximum power point at which power obtained is maximum at that point. This point depends on different environmental condition. These conditions changes and their effects are also different depending on the seasons [4].

Photovoltaic (PV) period is increasing its importance as a renewable source due to its remarkable advantages. Specifically, energy conversion from solar cell arrays (SCAs) got significant attention from the last two decades [5].The linear V-I characteristics cannot be achieved by the PV module and that to point at which the power obtained is maximum will varies with atmospheric conditions like temperature and irradiance. The unique point at which the maximum power is obtained should not ne vary and these can be achieved at particular solar insolation. [6-7] Therefore, to get maximum efficiency it is necessary to design a controller for PV module such that the maximum power can be obtained even the irradiance and temperature fluctuates. In this present paper **section II** discussed about photovoltaic cell; **section III** explained PV cell is modeled mathematically; **section IV** deals stimulation of PV module is done in MATLAB with different input parameters; section V results obtained from stimulation are tabled and plotted graphically.

II. PHOTOVOLTAIC CELL

Photovoltaic modules are devices that convert solar radiation into electricity without producing any pollution or don't require any kind of fuels for their operation. Photovoltaic technology can produce power from milli watts to megawatts and it is cost-effective for remote applications. At present, PV modules have a life about 25 to 30 years.

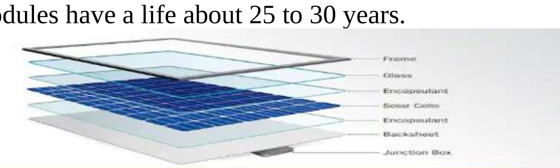

Fig. 1.Photovoltic cell

Types of Photovoltaic cells:

- Monocrystalline silicon cell
- Polycrystalline silicon cell
- Thin film cells
- High efficiency cells
  - Gallium Arsenide
  - Multi Junction cells

III. MATHEMATICAL MODEL OF PV CELL

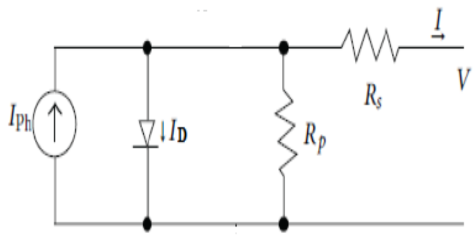

Fig. 2 Equivalent circuit diagram of a solar PV cell

$$I_{ph} = I_D + I_{Rp} + I \quad \text{--- (1)}$$

$$I = I_{ph} - I_D - I_{Rp} \quad \text{--- (2)}$$

An equation that represents I -V characteristics of a solar array is given by the following mathematical equation as

$$I = I_{ph} - I_0\left(e^{\frac{q(V+IRs)}{nkT}} - 1\right) - \left(\frac{V + IR_s}{R_p}\right) \quad \text{--- (3)}$$

Where,

$$I_D = I_0\left(e^{\frac{q(V+IRs)}{nkT}} - 1\right) \quad \text{--- (4)}$$

$$I_{Rp} = \left(\frac{V + IR_s}{R_p}\right) \quad \text{--- (5)}$$

Equation (1) is used in computer simulations to obtain the output characteristics of a solar cell. But PV array consists of modules in with cells are connected in series and parallel. A PV mathematical model having Np cells in parallel and Ns cells in series is obtained as below eq:

$$I = N_p I_{ph} - N_p I_0\left(e^{\frac{q(V+IRs)}{nkTNs}} - 1\right) \quad \text{--- (6)}$$

The PV power, P is then calculated as follows

$$P = VN_p I_{ph} - VN_p I_0\left(e^{\frac{q(V+IRs)}{nkTNs}} - 1\right) \quad \text{--- (7)}$$

Where, V - output voltage of PV module; I - output current of PV module; R_s - series resistance of cell (Ω); Rsh - shunt resistance of cell (Ω); q - electronic charge (1.602 *10-19 C); Isc - light-generated current; K - Boltzmann constant (1.38 * 10-23 J/k); T - temperature (K); N_S - number of PV cells connected in series; N_P - number of PV cells connected in parallel; I_o - reverse saturation current which depends on the ambient temperature; m - diode factor (usually between 1 to 2);

Table- I: Specifications of the PV panel

Number of cells in PV module = 60		
Open circuit voltage	V_{OC}	36.3V
Short circuit current	I_{SC}	7.84A
Voltage at max power	V max	29V
Current at max power	I max	7.35A
Max power	P max	213.1W
Temperature coefficient of Voc		-0.36009%/^{0}C
Temperature coefficient of Isc		0.102%/^{0}C

The PV module can be operated in any point on the I-V curve between the I_{sc} and the Voc. However, the power from the PV module is different in every operating point as shown in the P-V curve in figure 2.

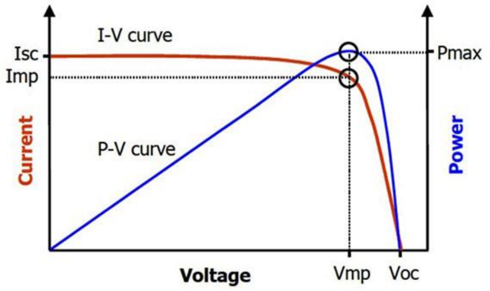

Fig. 3. PV array I –V and P–V characteristics.

When the irradiation and temperature from the sun are constant that is irradiance=1000W/m^2 and temperature=25^{o}C which are defined as standard testing conditions (STC).From this condition the obtained plot of I-V and P-V is represented in Fig. 4.

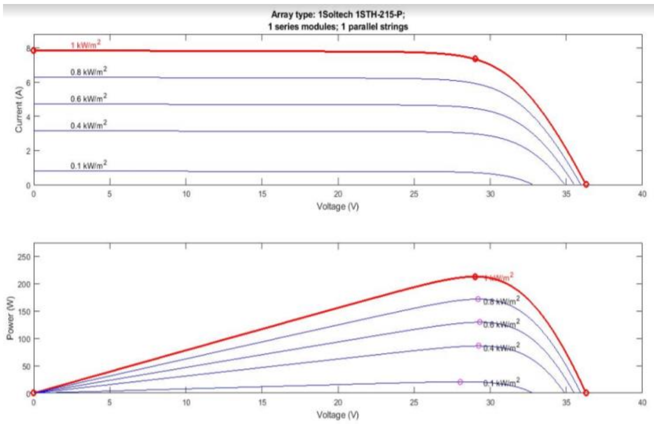

Fig. 4. PV array I –V and P–V characteristics at constant temperature.

IV. MATLAB SIMULATION MODEL

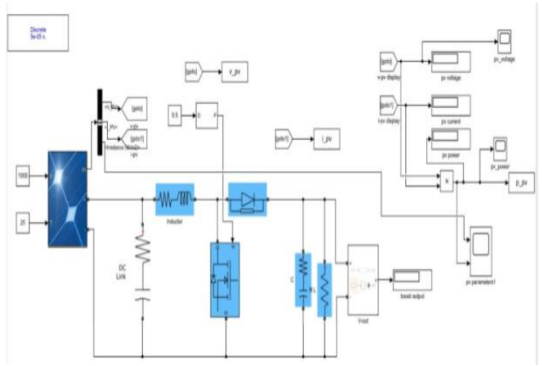

Fig. 5. Matlab simulink model of PV module and boost converter.

The simulation of PV cell is done at different input parameters i.e. by varying irradiance and temperature. The PV module is connected with boost converter. The results are obtained by taking different temperature and irradiance values are shown below.

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V. RESULTS REGARDING SIMULATION

A. Values of PV module for change in irradiation at standard temperature (25^0C):

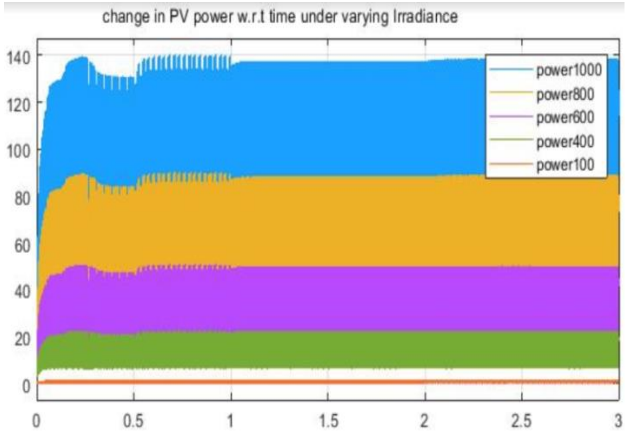

Fig. 6.Change in PV power under varying Irradiance

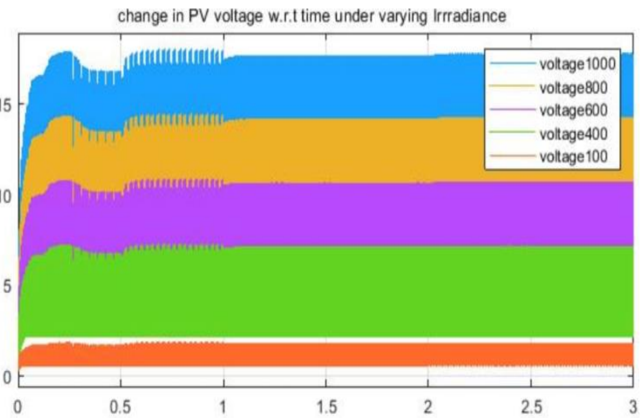

Fig. 7.Change in PV voltage under varying Irradiance

Table-II: Change in irradiance at constant temperature (25^0C)

Irradiance (W/m^2)	*PV voltage (V)*	*PV voltage at MPP*	*PV power (W)*	*Max PV power (W)*
1000	16.49	132.0	125.6	213.1
800	13.21	84.74	80.6	171.8
600	9.920	47.80	45.46	129.5
400	6.624	21.31	20.26	86.26
100	1.659	1.337	1.27	20.68

The table-II shows the PV power and voltage at different values of irradiance. For a particular value of irradiance say 600 W/m^2 the obtained PV voltage is 9.920V and PV power is 45.46W but at maximum power point the PV voltage and is 47.80V and 129.5W respectively.

B. Values of PV module for change in temperature at standard irradiation (1000 W/m^2):

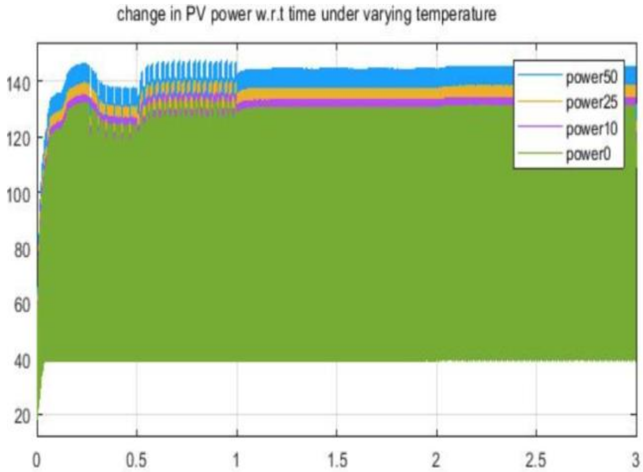

Fig. 8. Change in PV power under varying temperature

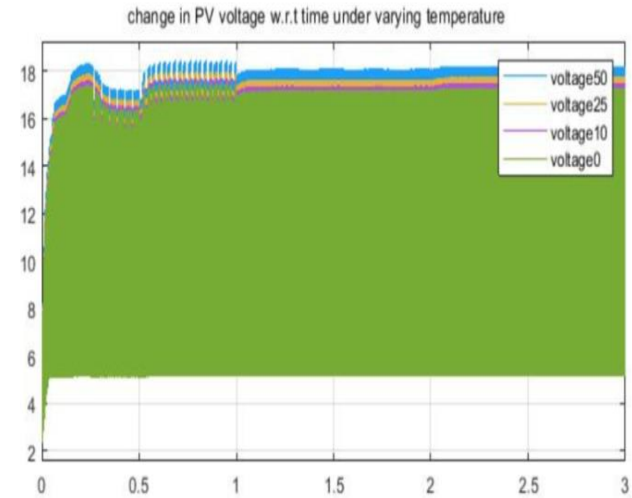

Fig.9. Change in PV voltage under varying temperature

Table- III: Change in temperature at constant irradiation (1000 W/m^2)

Temperature (^0C)	*PV voltage (V)*	*PV voltage at MPP*	*PV power (W)*	*Max PV power*
0	15.67	32.37	119.3	233.8
10	15.84	31.02	121.8	225.6
25	16.08	29	125.6	213.1
50	16.49	25.68	132	190.9

The table-III shows the PV power and voltage at different values of temperature. For a particular value of temperature say 10^oC the obtained PV voltage is 15.84V and PV power is 125.6W but at maximum power point the PV voltage and power is 31.02V and 225.6W respectively.

C. Values of PV module for change in irradiance at temperature (0^0C,10^0C,25^0C,50^0C):

Table- IV: Change in irradiance at constant temperature (0^0C)

Irradiance (W/m²)	*PV voltage (V)*	*PV power (W)*
1000	15.67	119.3
800	12.56	76.55
600	9.430	43.18
400	6.296	19.25
100	1.577	1.206

Table-V:Change in irradiance at constant temperature (10^0C)

Irradiance (W/m²)	*PV voltage (V)*	*PV power (W)*
1000	15.84	121.8
800	12.69	78.16
600	9.529	44.09
400	6.361	19.65
100	1.594	1.233

Table-VI: Change in irradiance at constant temperature (25^0C)

Irradiance (W/m²)	*PV voltage (V)*	*PV power (W)*
1000	16.06	125.6
800	12.88	80.6
600	9.67	45.46
400	6.46	20.26
100	1.61	1.27

Table- VII: Change in irradiance at constant temperature (50^0C)

Irradiance (W/m²)	*PV voltage (V)*	*PV power (W)*
1000	16.49	132.0
800	13.21	84.74
600	9.920	47.80
400	6.624	21.31
100	1.659	1.337

From the table-IV to VII the values of PV voltage and power for change in irradiance at different temperatures are tabulated. These values are obtained from the above simulation model under different irradiance and temperatures values. it can be observed that the power and voltage of PV module increases with increase in irradiance at any temperature. The rate of increasing in PV power is increasing with rise in irradiance but the rate of voltage is constant for any change in irradiance. and graphs are plotted with these values in **Fig. 10** and **Fig. 11.**

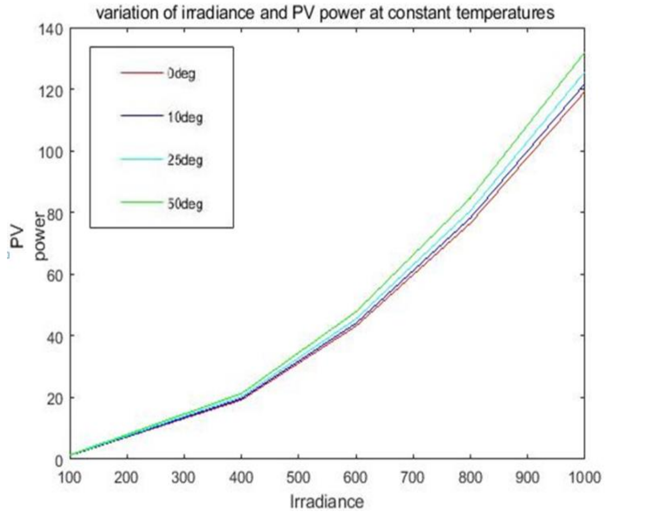

Fig. 10. Variations of PV power with change in irradiance at different temperatures

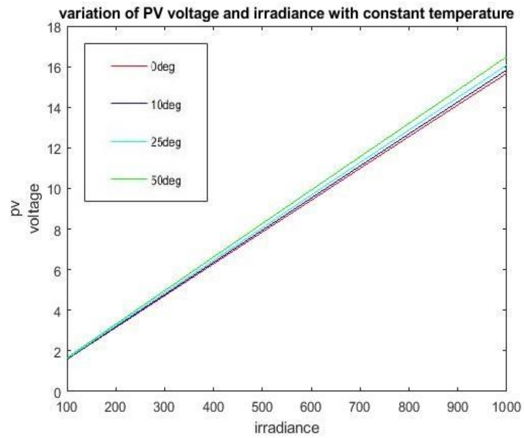

Fig. 11. Variations of PV voltage with change in irradiance at different temperatures

D. Values of PV module for change in temperature at irradiance (1000, 800,600,400,100 W/m²).

Table- VIII: Change in temperature at constant irradiance (1000 W/m²)

Temperature (ºC)	*PV voltage (V)*	*PV power (W)*
0	15.67	119.3
10	15.84	121.8
25	16.08	125.6
50	16.49	132

Table- IX: Change in temperature at constant irradiance (800 W/m²)

Temperature (ºC)	*PV voltage (V)*	*PV power (W)*
0	12.56	76.55
10	12.69	78.16
25	12.88	80.60
50	13.21	84.74

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Table- X: Change in temperature at constant irradiance (600 W/m^2)

Temperature (ºC)	*PV voltage (V)*	*PV power (W)*
0	9.430	43.18
10	9.529	44.09
25	9.676	45.46
50	9.922	47.80

Table- XI: Change in temperature at constant irradiance (400 W/m^2)

Temperature (ºC)	*PV voltage (V)*	*PV power (W)*
0	6.296	19.25
10	6.361	19.65
25	6.460	20.26
50	6.624	21.31

Table-XII: Change in temperature at constant irradiance (100 W/m^2)

Temperature (ºC)	*PV voltage (V)*	*PV power (W)*
0	1.577	1.206
10	1.594	1.233
25	1.618	1.272
50	1.659	1.337

From the table-VIII to XII the values of PV voltage and power for change in temperature at different irradiations are tabulated**.** These values are obtained from the above simulation model. It can be observed that PV output power and voltages are increasing with increase in temperatures and also by increasing the irradiance and graphs are plotted with these values in tables which are shown in **Fig.12** and **Fig.13**

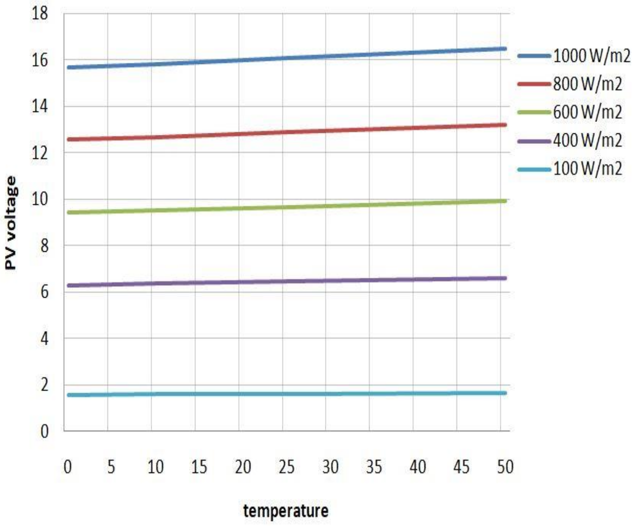

Fig. 12. Variation of PV voltage with change in temperature at different irradiance

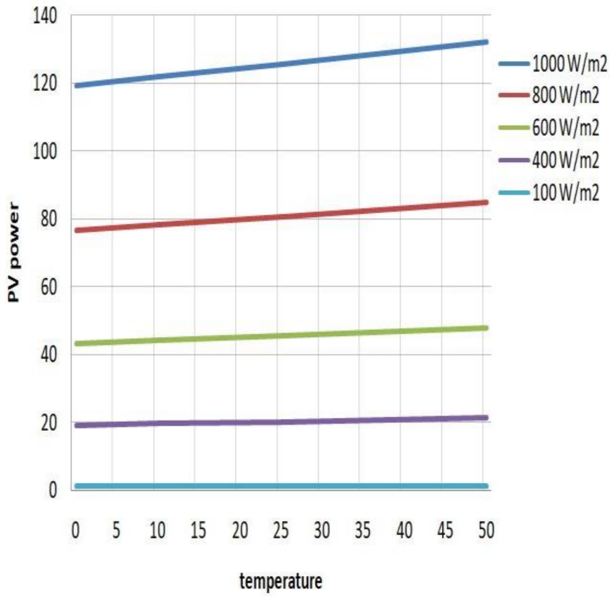

Fig. 13. Variation of PV Power with change in temperature at different irradiance

VI. CONCLUSION

The PV module is simulated by providing temperature and irradiance as input parameters. The simulation is done by taking different values of input parameters which are temperature and irradiance and results are obtained. PV module is simulated at Standard Testing conditions(STC) and it can be observed that the obtained PV output power and voltage are exponentially low compared to PV voltage and power at maximum power point. The PV module is also simulated at different values of temperature and irradiance. From figures It can be observed that PV output power and voltages are increasing with increase in temperatures and also by increasing the irradiance. Due to variations of PV power output with atmospheric changes the performance and efficiency is decreased. Hence to remove the variations of PV output a controller is necessary. Therefore the optimum output from the PV module is achieved by employing a Maximum power point tracker.

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