PREDICTING THE BEHAVIOR OF MONOCRYSTALLINE PV CELL

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***Abstract*—This study presents a Matlab/SIMULINK model of a solar cell and Maximum Power Point Tracking. The cell model is represented using the mathematical current equation that includes a photocurrent source, a diode, a seires resistor, and a shunt resistor. The created model can be used to forecast how a photovoltaic cell will behave under different physical and environmental conditions. The physical characteristics of a cell as a function of temperature and solar radiation can also be extracted using the model. A study about array under different atmospheric conditions can be done using the extracted physical characteristics. The real-time tracking of Maximum Power Point using Perturb and Observe Method is also discussed in this study.**

***Index Terms*—PV, Matlab, SIMULINK, Module, Array, Solar Cell, MPPT**

I. INTRODUCTION

The dire status of chemical industrial fuels like oil, gas, and others is driving ongoing advancements in the creation of new energy sources. As a result, the share of renewable energy sources in the world's total energy consumption has increased. During the previous 20 years, there has been a 20 % to 25 % growth in demand for solar energy [1]. Research is being done in an effort to further improve the cost, efficiency, and reliability of PV systems in order to reap the benefits of their deployment.

With the use of photovoltaic cells, solar energy may be turned into electrical power without emitting any pollutants. PN junctions make up this structure. Photons from the sun's rays are absorbed by semiconductor atoms in the cell, releasing electrons into free space. The liberated electron then travels via an external circuit from the negative layer to the positive layer, producing an electric current.

A PV cell may typically produce 0.5V to 0.8V, depending on the type of semiconductor utilized and the construction quality [3] A PV module is formed by connecting the cells in series, ranging from 36 to 72 cells. A solar panel is created by connecting these PV modules in parallel and/or series [3]. The current stays constant when the voltage is added if the modules are connected in series. Additionally, if it is connected in parallel, the voltage stays constant as the current increases.

PV cells are divided into three families. That refers to monocrystalline, polycrystalline, and thin film technologies [4]. This paper focuses on a model of a monocrystalline PV cell using Matlab/SIMULINK under various external and internal parameters such as solar radiation, cell temperature, shunt resistor, series resistor, because monocrystallines have higher efficiency than the other two (ranges from 10 to 15 %) [4].

II. PV CELL MODEL

The physics of the PN junction is the source of the single exponential equation (1) that models a photovoltaic cell and is widely acknowledged to represent the typical behavior of the cell. For the polycrystalline silicon cells, a double exponential equation might be applied [2].

$$I = I_{\text{ph}} - I_{\text{s}}(exp\frac{q(V + R_{\text{s}}I)}{NKT} - 1) - \frac{(V + R_{\text{s}}I)}{R_{\text{sh}}} \quad (1)$$

Here, I_{ph} is the photocurrent, I_s 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 R_s and R_{sh} are the series and shunt resistors of the cell, respectively.

From this equation, an equivalent circuit can be configured, which is shown in Fig. 1. Using (1), a model of PV cell

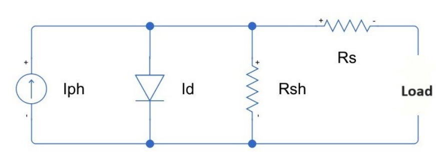

Fig. 1. PV Cell Equivalent Circuit

is developed using Matlab/SIMULINK which is shown in Fig. 2. The IV and PV characteristics of the model for a given radiation, temperature, R_s and R_{sh} are given in Fig. 3 and Fig. 4.

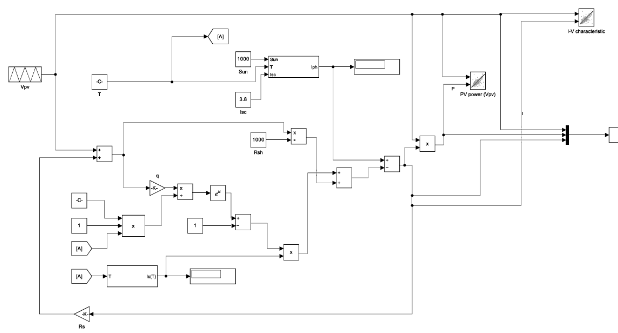

Fig. 2. Matlab/SIMULINK model of PV cell

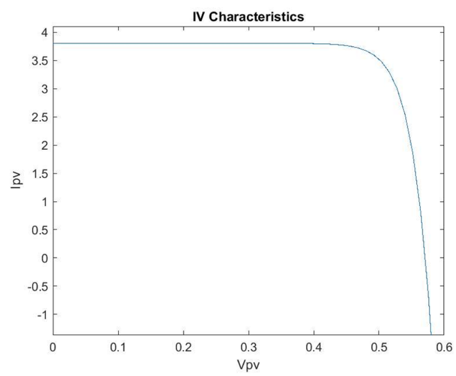

Fig. 3. IV curve for a given cell

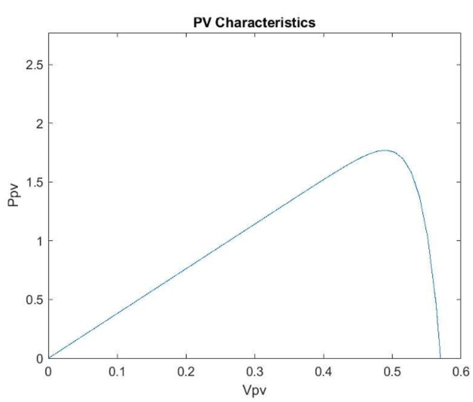

Fig. 4. PV curve for a given cell

III. Effect of Solar Radiation Variation

The above model Fig. 2 has two subsystems. According to equation(2) it calculates the photocurrent of the PV cell which depends on radiation and temperature. [3]

$$I_{\text{ph}} = [I_{\text{sc}} + K_{\text{i}}(T - 298)]\frac{\beta}{1000} \tag{2}$$

where β is the solar radiation and Ki=0.0017 A/°C is the short circuit current temperature coefficient of the cell.

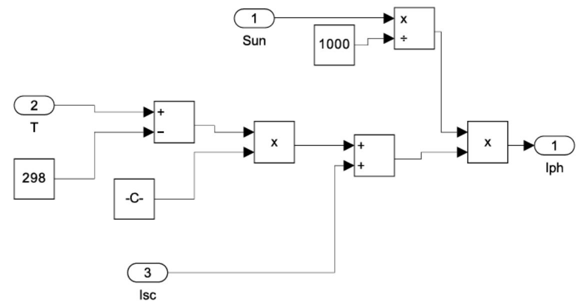

Fig. 5. Matlab/SIMULINK subsystem for varying cell temperature and solar radiation.

The subsystem of Fig. 5 is created using the equation (2), and Fig. 6 and Fig. 7 representing the IV characteristics and PV characteristics of the model simulation. Fig. 6 and Fig. 7 demonstrate how closely the PV cell current depends on solar radiation. Nonetheless, as solar radiation increased from 400 W/m^2 to 1000 W/m^2, the voltage and power has a increase of 50mV and 1W respectively.

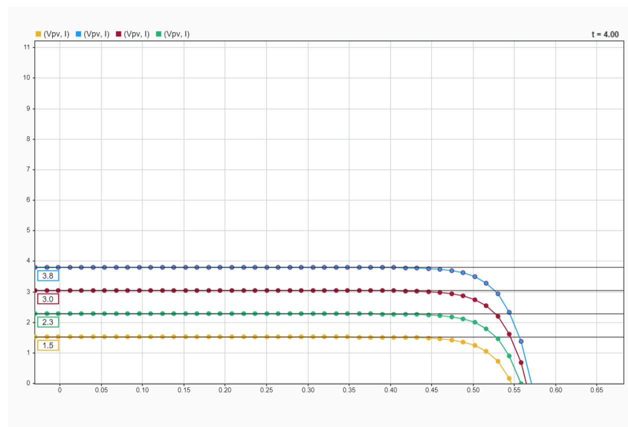

Fig. 6. IV curve for the varying solar radiation

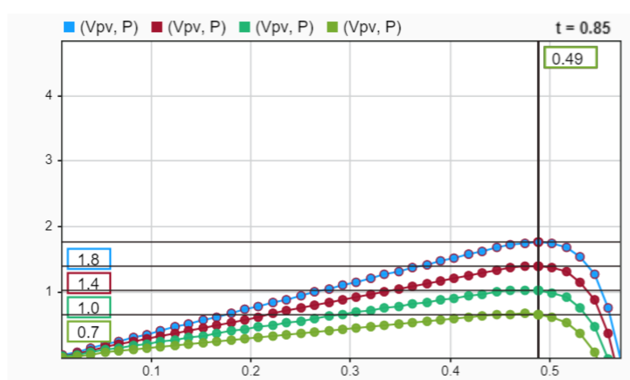

Fig. 7. PV curve for varying solar radiation

IV. Effect of Varying Cell Temperature

The diode reverse saturation current varies as a cubic function of the temperature and it can be expressed as equation (3) [3]

$$I_s(T) = I_s[\frac{T}{T_{nom}}]^3 e[(\frac{T}{T_{nom}} - 1)\frac{E_g}{N.V_t}] \tag{3}$$

where T_{nom} is the nominal temperature, I_s is the diode reverse saturation current, E_g is the semiconductor's band gap energy, and V_t is the thermal voltage. The reverse saturation current of a PV Cell can be considered as (3).

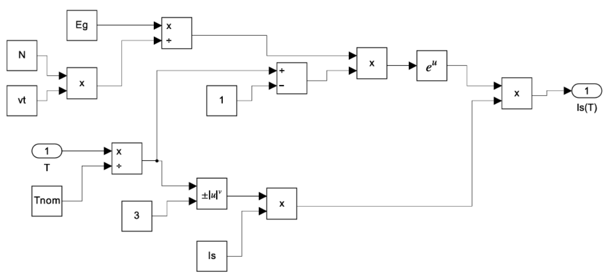

Fig. 8. Matlab/SIMULINK temperature effect subsystem on diode reverse saturation current.

In normal circumstances, when the temperature of the cell rises for a given amount of solar energy, the open circuit voltage V_{oc} decreases slightly while the short circuit current increases [3].

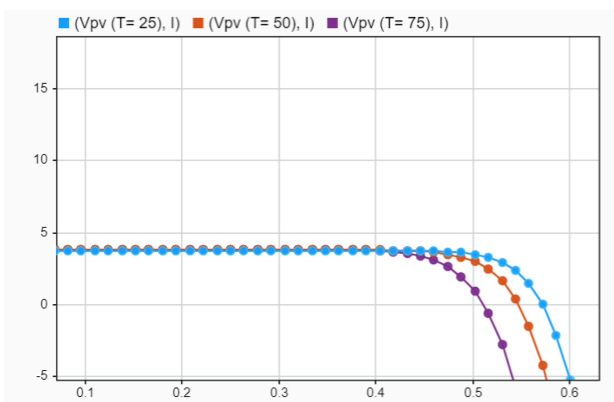

Fig. 9. IV curve for varying cell temperature

To study the effect of Temperature variation on PV cell output, temperature is taken as one of the variable in addition to the voltage [4]. V-I characteristics and power curves are obtained as shown in Fig. 9 and Fig. 10. Fig. 8 show the detailed diagram of subsystem I_s which is obtained after simulating equation (4).

V. Effect of varying R_S

The PV cell's series resistance is negligible and occasionally can be disregarded. Nonetheless, this resistance may be changed, and its impact on the PV cell outputs can be predicted, making the model appropriate for any specific cell.

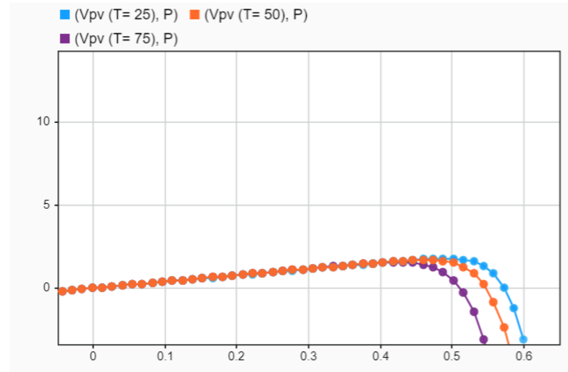

Fig. 10. PV curve for varying cell temperature

The fluctuation in R_s influences the I-V curves' slope angle, which causes a divergence from the maximum power point, as shown in Fig. 11 and Fig. 12.

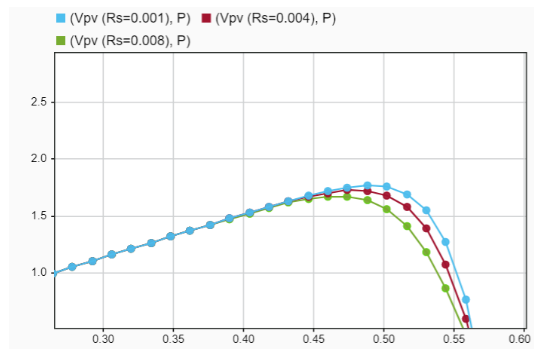

Fig. 11. IV curve of varying R_s

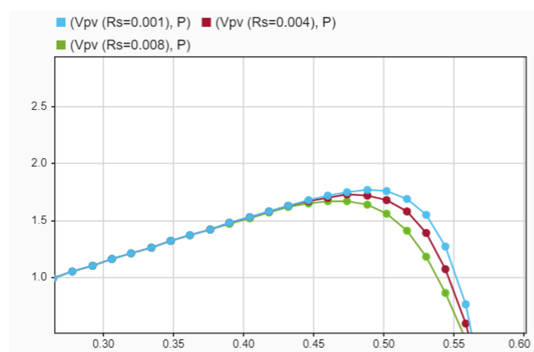

Fig. 12. PV curve of varying R_s

Three distinct values of Rs—1m, 4m, and 8m were used to run the simulation. Higher values of Rs have been demonstrated to lower the PV cell's power output. When Rs increases, the fill factor, as provided by (4) decreases.

$$FF = \frac{P_{max}}{V_{oc} I_{sc}} \tag{4}$$

FF is the fill factor used to evaluate the efficiency of a PV Cell defined by the ratio of the maximum power from the solar cell to the product of the open-circuit voltage V_{oc} and the short-circuit current I_{sc} [5].

VI. Effect of Varying R_{SH}

Any PV cell should have a shunt resistance big enough to support increasing fill factor and output power. In actuality, the PV cell current drops more sharply with a low shunt resistor, resulting in a lower fill factor and more power loss. These findings are displayed in Fig. 13 and Fig. 14.

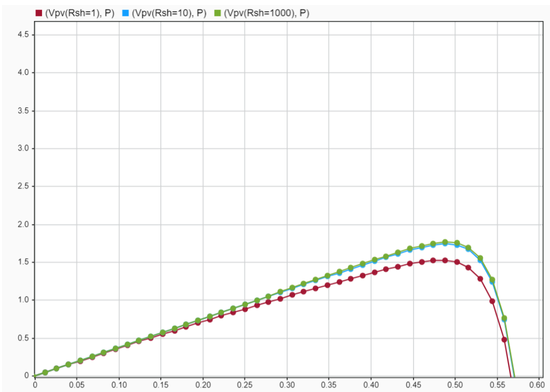

Fig. 13. IV curve of varying R_{sh}

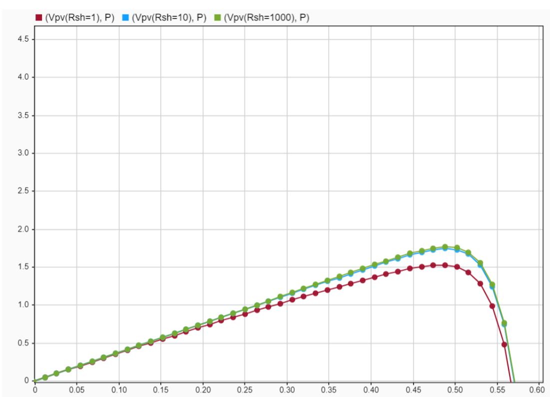

Fig. 14. PV curve of varying R_{sh}

VII. PV Module

The Matlab/SIMULINK block diagram of a photovoltaic module is displayed in Fig. 15. This model has an external control block that makes it possible to easily change the settings of the model. One module in this style is formed by the series connection of 36 PV cells. Consequently, the total module current is equal to the current in one cell, and the module voltage is calculated by multiplying the cell voltage by the number of cells. The IV and PV Characteristics are represented in Fig. 16 and Fig. 17.

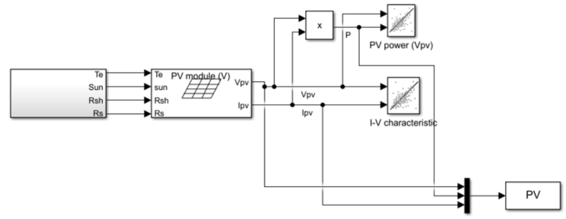

Fig. 15. SIMULINK model of a PV module

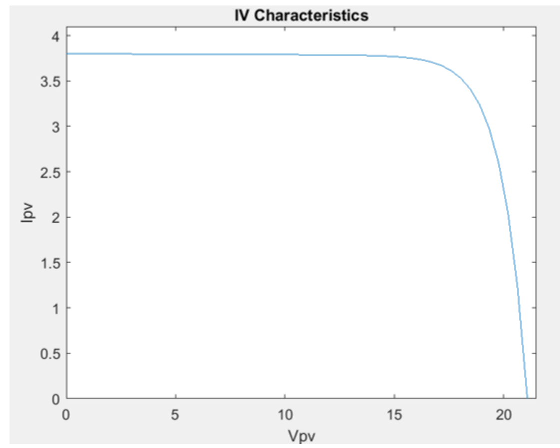

Fig. 16. IV curve of module

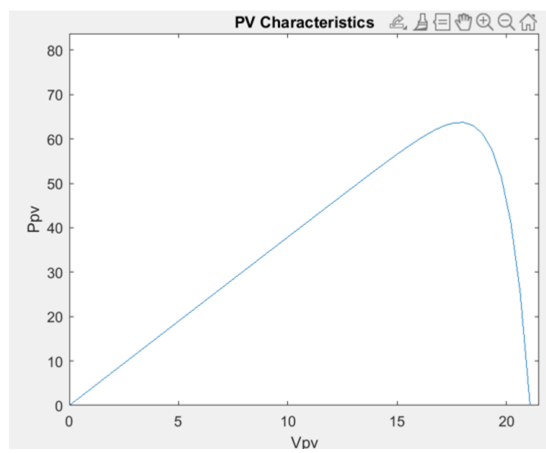

Fig. 17. PV curve of module

VIII. PV Array

An array of six PV modules has been built in order to profit from these created models. As seen in Fig. 18, all of these PV modules were connected to the external control block by means of a series connection.

The PV array and PV module models were simulated in a manner identical to each other, and the power gotten from three types of weather (which is sunny, part cloudy and cloudy) are displayed in Fig. 19, Fig. 20 and Fig. 21, respectively.

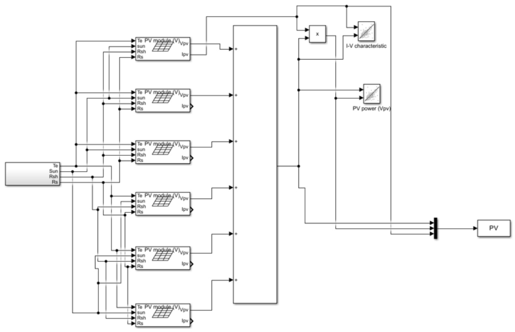

Fig. 18. SIMULINK model of a PV Array

A. Case 1: Sunny day

During sunny day, the radiation which passes on the PV cell will be higher. have a maximum solar irradiance. The maximum ambient temperature, Maximum irradiance and average irradiance is taken into consideration for the PV curve of the model Which is represented on Fig. 19. The maximum irradiance 963 W/m^2, average irradiance 599 W/m^2 and the maximum ambient temperature is 29.6° [6].

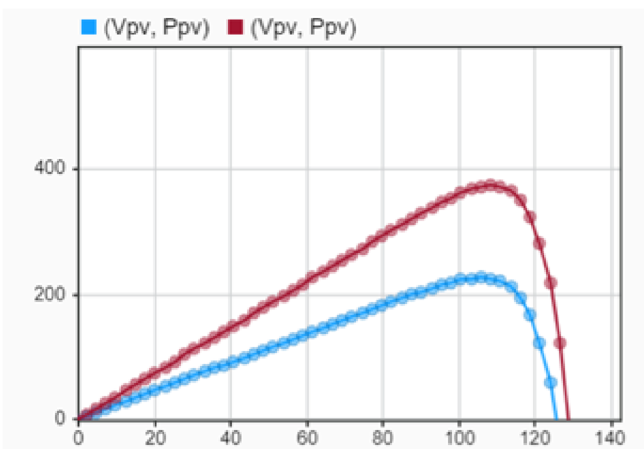

Fig. 19. PV curve of a sunny day at 31.9°

B. Case 2: Part cloudy day

For part cloudy day, the maximum irradiance is 930W/m^2, Average irradiance is 224 W/m^2 and the maximum ambient temperature is 14.3° [6].

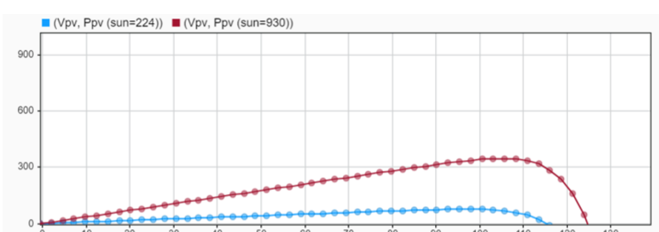

Fig. 20. PV curve of a mid cloudy day at 21.2°

C. Case 3: cloudy day

For cloudy day, the maximum irradiance is 509W/m^2, the average irradiance is 148 W/m^2 and the maximum average temperature is 24.6° [6].

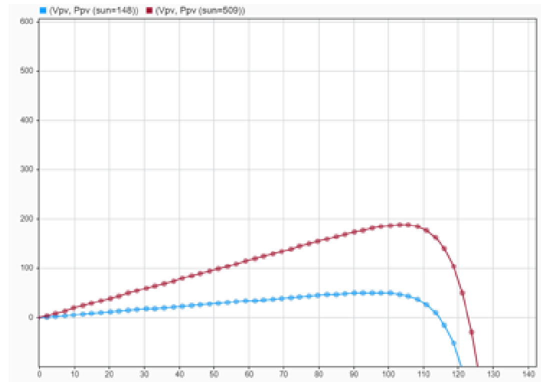

Fig. 21. PV curve of a cloudy day at 27.7°

IX. Maximum power point tracking

PV system naturally exhibits a nonlinear characteristics which vary with the radiant intensity and cell temperature [2]. In order to extract maximum power, the PV panel should be operated at a voltage that is consistent with Maximum Power Point(MPP). Thus, a DC-DC converter regulated with MPPT controller is used to achieve load matching, extract the most extreme power as well as improve the PV module efficiency [8].

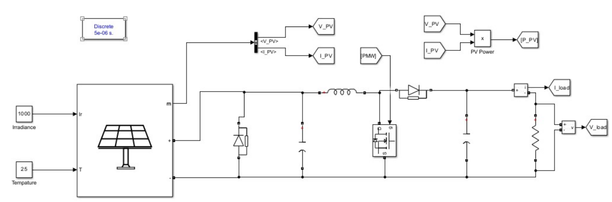

Fig. 22. PV Array with DC-DC Boost Converter

The DC-DC boost converter alongside with MPPT controller is embedded amidst the load and the PV module to ensure that the PV system will be operating close to MPP. Then, the DC-DC converter will transfer the DC voltage with suitable voltage level to the load [7]. Maximum power point trackers(MPPTs) extract maximum power output (MPP) achievable despite variations in temperature and irradiance [2].

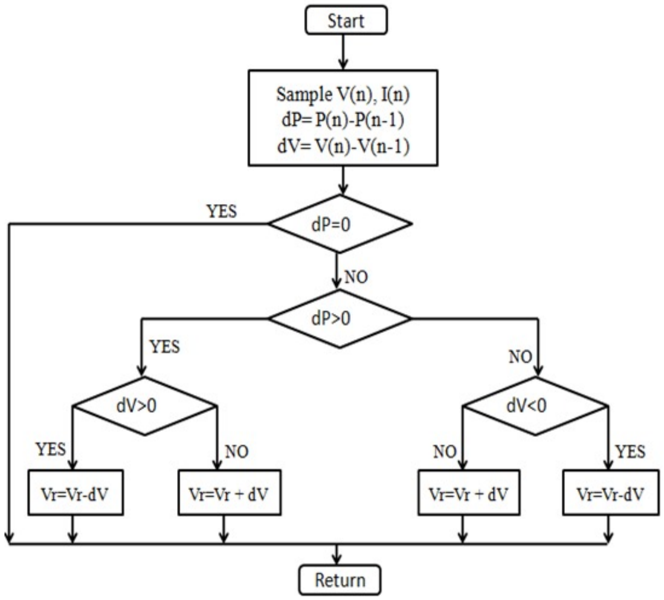

Fig. 23. P and O algorithm flowchart

Fig. 22 shows the integration of DC-DC Boost Converter with PV array having six modules in series connection. MPPT Algorithm P and O will switch the power switching device in converter to ensure PV system is operating close to MPP. Fig. 23 represents the Perturb and Observe Algorithm flowchart.

Fig. 24. P and O algorithm as MATLAB function

Fig. 24 P and O algorithm is implemented as a MATLAB function and fed to PWM for the switching of IGBT in the converter. The PV curve of PV array under maximum irradiance and 25°C cell temperature is shown in Fig. 25. The MPP is obtained as 333W.

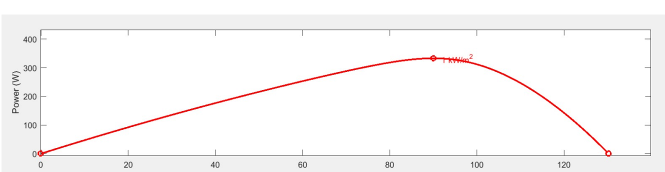

Fig. 25. PV cure of the PV array

The PV curve of Fig. 22 using DC-DC Boost Converter is shown in Fig. 26. The MPP is maintained throughout using P and O algorithm.

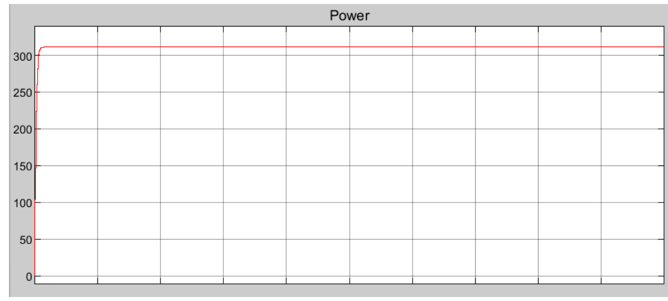

Fig. 26. Optimizing Power from PV array

CONCLUSION

This study presents a Matlab/SIMULINK model for the solar PV cell, modules, and array. This model takes into consideration the effects of physical and environmental elements, such as solar radiation and cell temperature, Series resistance and shunt resistance based on the basic circuit equations of a solar PV cell. The Power obtained is maintained using MPPT P and O algorithm. The Matlab/SIMULINK program is used to simulate the PV Array model.

The model developed as a consequence of the study can be used as a photovoltaic generator in the Matlab/SIMULINK toolbox for solar PV power conversion systems. Furthermore, with changes in climatic and physical conditions, the behavior of every solar PV cell, module, and array might be predicted with the help of such a model.

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