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Investigation on Effect of Partially Shaded Photovoltaic System

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Abstract

When only a portion of the photovoltaic (PV) array is shaded, different amount of sunshine exposure happen, leading to non uniform shading. This uneven distribution of light reaching the PV array result in a noticeable decrease in power output. Consequently, the occurrence of the hotspot leads to the formation of multiple maximum power points (MPPs), posing challenges for conventional tracking methods in accurately tracking the overall peak power point. To successfully track the global peak power regardless of whether the system is working under normal or partially shadowed conditions, the maximum power point tracking (MPPT) methodologies need to be improved. Two factors, temperature and Irradiance were used in this study to find out the current- voltage (I-V) and power- voltage (P-V) curves. The temperature range under the consideration was 0^0C to 75^0C with interval of 25^0C. It was found that for I-V curve an increase in temperature resulted in a small increase in current (9A, 9.1A, 9.2A, 9.3A) but a large decrease in voltage (41V, 38V, 34V, 30V) . Similarly, the P-V curve also exhibited a decrease in voltage (42V, 38V, 34V, 30V) of a PV module. When the irradiance level was raised from200 W/m^2 to 1000 W/m^2, a slight increase voltage, (36.8V, 36.8V, 37V, 37V, 38V) and linear increases current (2A, 3.9A, 5.9A, 7.85A, 9.5A) were observed. This occurrence can be explained by the fact that more carriers are excited by a higher irradiance level, which increases output overall.

Keywords: Partial shading, irradiance, temperature, current-Voltage curve and Power - Voltage curve

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1.0 Introduction

In order to address the world's energy needs in an environmentally responsible manner, Photovoltaic (PV) systems have emerged as crucial renewable energy source. However, a variety of environmental conditions have significant impact on how well these systems function, with partial shadowing being a particularly significant in lowering their efficiency. Partial shading occurs due to various reasons such as foliage, nearby buildings, or cloud cover, leading to non-uniform irradiance across the PV modules. This non-uniformity causes variations in the electrical characteristics of the modules, resulting in mismatch losses and decreased overall power output.

The challenge of partial shading has prompted the need for effective strategies to mitigate its adverse effect on PV systems (Yadav *et al.*, 2021; Akinyemi*et al*., 2022). The improvement of PV system performance in such conditions is dependent upon the development of a robust peak power monitoring technique. MPPT are vital as they continuously track and adjust operating point on the PV curve, ensuring that PV systems operate at their highest power output (Lapsongphon *et al*., 2021)

Conventional and Traditional MPPT algorithms including Incremental Conductance (INC), perturb and Observe (P &O) have been widely used. However, these algorithms may encounter difficulties in rapidly and accurately tracking the global MPPT under of partial shading condition, resulting in suboptimal system performance. Recent research has revealed various approaches aimed at addressing the challenges presented by Partial shading in PV systems and improving MPPT efficiency. Some research efforts have focused on artificial intelligence (AI)-based algorithms such as genetic algorithms, particle swarm optimization, and neural networks for MPPT under partial shading. These approaches exhibit promising results by optimizing the

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tracking process and mitigating the impact of shading on overall system performance (Yusuf *et al.*, 2022). .

2.0 Literature review

(Farid *et al., 2017)*conducted a comparative analysis on three methods: modified particle swarm optimization (MPSO), grey wolf optimizer (GWO) and Flower pollination algorithm (FPA), in term of how well they maximizing MPPT for a sepic converter operating on dynamic partial shading (PS) conditions. Simulation results demonstrated that all three methods effectively addressed partial shading problem with high degree of accuracy. Furthermore, the simulation result indicates that the FPA method outperforms the other two proposed methods in several aspects. Additionally, the MPSO method exhibits superior or tracking accuracy compared to the other proposed methods as revealed by simulation's result. It result into complex computation

(Jirada *et al.*, 2018) research and development effort have led to the creation of an optimized MPPT system for power generation using PV systems. The system is design to accurately track the highest power point on PV characteristics curves, ensuring efficient power generation. However, the presence of PS conditions poses challenges for MPPT development as it alters the shape of the curves and introduces multiple power peaks. Despite the challenges posed by shading conditions, MPPT technology provides excellent efficiency and rapid power tracking capabilities. Extensive testing, encompassing both short term and long term durations, has been carried out to simulate diverse weather conditions and evaluate the performance of the system. The results demonstrate a remarkable 9.09% increase in power generation when compared to tradtional tracking method.

(Boni *et al.*, 2020) carried out an enhanced approach for MPPT in the presence partial shading condition. This method present the benefits of avoiding excessive computational load, making it highly suitable for real-time applications, all while maintaining a commendable level of tracking efficiency. The experimental outcomes showcased satisfactory performance, exhibiting exceptional dynamic behaviour and achieving exceeding high efficiency. But it takes longer time for tracking.

3.0 PV Cell Model Design

A mathematical model can be used to represent a PV cell employing a single diode equivalent circuit. This model incorporates various parameters, such as load current (I_{PV}), voltage (V_{PV}) and other parameters as depicted in Fig 1.

The model includes a series resistor, a parallel resistor, and photo –conductive current sources in parallel with a p-n junction diode,. The light-dependent current sources represent the photoelectric current generated by the photon energy from the sun. The diode accounts for electron-hole recombination at the p-n junction diode and reverse saturation current of the module. The parallel resistance represents corresponds to the diode leakage current, while the series resistance represent the internal resistance present within the PV module(Tan & Teow, 2016). A mathematical relationship between PV output current (I_{PV}), photoelectric current (I_{ph}), the diode branch current (I_D), and current through parallel resistor (I_p) can be obtained by applying Kirchhoff's current law to Fig. 1 as given in Eq. 1.

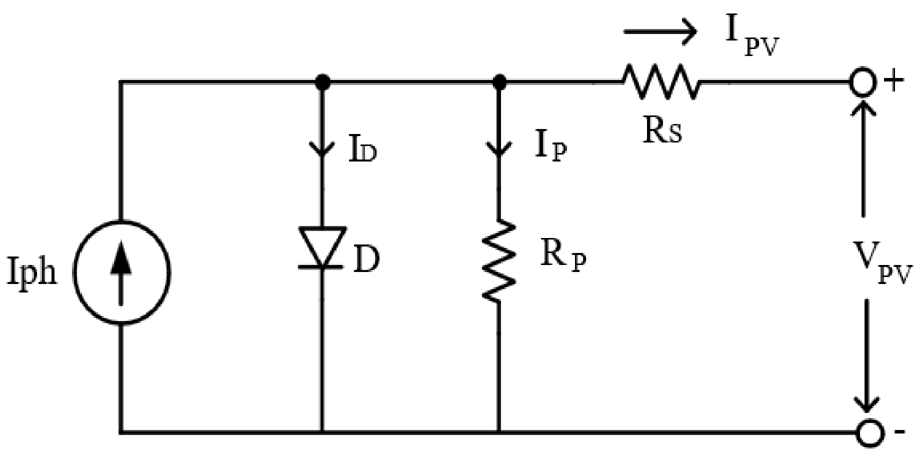

Fig. 1: Equivalent Single diode circuit of a PV system

$$I_{PV} = I_{ph} - I_D - I_p \quad (1)$$

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From Equation 1, the diode current I_D and current through the parallel resistances I_p are given by Equation 2 and equation 3 respectively.

$$I_D = I_o \left[\exp\left(\frac{V_{PV} + I_{PV}R_s}{AV_t}\right) - 1\right] \quad (2)$$

$$I_p = \frac{V_{PV} + I_{PV}R_s}{R_p} \quad (3)$$

Putting Equation 2 and equation 3 into equation 1 gives the I-V characteristics of a PV module as presented in Equation 4.

$$I_{PV} = I_{ph} - I_o \left[\exp\left(\frac{V_{PV} + I_{PV}R_s}{AV_t}\right) - 1\right] - \frac{V_{PV} + I_{PV}R_s}{R_p} \quad (4)$$

Where the voltage and current produced by PV panel are represented by V_{PV} andI_{PV}. The parameter I_{ph} is the light-dependent current generated by the incidence of light, I_o is the saturation current through the diode, while R_p and R_s are parallel and series resistances respectively. V_t is the thermal voltage of a junction diode which is defined as given in Eq. 5 and the factor A is the diode-modified quality factor which is usually assumed to be unity.

$$V_t = \frac{N_s nkT}{q} \quad (5)$$

where N_s is the number of PV cells in series to form the PV module, k is the Boltzmann's constant with value of $1.3805 \times 10^{-23} J/K$, n denotes diode ideality factor, which typically falls between 1 and 2 for real diode, q signifies charge of an electron with value of $1.602 \times 10^{-19} C$ and T is the PV cell temperature in Kelvin.

The photo-conductive current I_{ph} is determined by the irradiance intensity G and temperature of the cell T as presented in Equation 6. The diode saturation current I_o is a function of temperature as expressed in Equation 7. The reverse saturation current $I_{rs}$and parallel resistance current $I_p$are given by Equation 8 and equation 9 with short circuit current (I_{sc}) and open circuit voltage (V_{oc}).

$$I_{ph} = \frac{G}{G_n}[I_{sc} + K_i(T - T_n)] \ (6)$$

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$$I_o = I_{rs}\left(\frac{T}{T_n}\right)^3 \exp\left[\frac{qE_{go}}{nk}\left(\frac{T - T_n}{T \times T_n}\right)\right] (7)$$

$$I_{rs} = \frac{I_{sc}}{\exp(\frac{V_{oc}}{V_t} - 1)} \ (8)$$

$$I_p = \frac{V_{PV} + I_{PV}R_s}{R_p} \ (9)$$

To achieve maximum power matching, the process involves iteratively increasing the R_s while simultaneously calculating R_p using Equation 10, which is developed from Equation 4 under peak power point conditions.

$$R_p = \frac{V_{mp}(V_{mp} + I_{mp}R_s)}{V_{mp}\left(I_{ph} - I_o[\exp\left(\frac{V_{PV} + I_{PV}R_s}{nV_t}\right) - 1]\right) - P_{mp}} \quad (10)$$

where I_{sc}, K_i, G_n and T_n are the short circuit current, short circuit current coefficient at a temperature of $25° \, C$ and irradiance of $1000 \, W/m^2$, PV module irradiance and nominal temperature at standard testing condition (298K), respectively. G and T are the PV module surface irradiance in W/m^2 and temperature in Kelvin. E_{go}, I_{mp}, V_{mp}, and P_{mp} are the band energy gap, maximum current, voltage, and power respectively. For commercially available PV module, the number cells N_s, current (I_{sc}) and voltage (V_{oc}), maximum current (I_{mp}), and maximum power voltage (V_{mp}) at temperature of $25° \, C$ and irradiance of $1000 \, W/m^2$ are usually specified in the manufacturer datasheet(Zhu et al., 2019).

PV cells are designed to convert sunlight into electrical energy. However, individual PV cell typically generate a relatively low voltage, typically around 0.6 V. In order to achieve the desired voltage levels for different applications, PV cells are interconnected in both series and parallel configurations. This process forms a PV module, which is the building block of a PV array. In order to incorporate the evaluation of both series and parallel configurations within the PV array, Equation 4 can be transformed into Equation 11 to represent the I-V relationship.

$$I_{PV} = N_p * I_{ph} - N_p * I_o\left[\exp\left(\frac{V_{PV} + I_{PV}R_s * N}{nV_t * N_s}\right) - 1\right] - \frac{V_{PV} + I_{PV}R_s * N}{R_p * N} \quad (11)$$

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$$N = \frac{N_s}{N_p} \quad (12)$$

where N_{pp} and N_{ss} represent the number of PV panels connected in parallel and series respectively. By substituting Equation 9 in Equation 11, we have Equation 12.

$$I_{PV} = N_p * I_{ph} - N_p * I_o \left[\exp\left(\frac{V_{PV} + I_{PV}R_s * N}{nV_t * N_s}\right) - 1\right] - I_p \quad (13)$$

4.0 Graphical Mathematical Model Design

The mathematical model of a stand-alone PV module is represented by the graph in Fig. 2. The blocks operate with only mathematical functions to build the PV model. The blocks in green estimate the thermal voltage (V_t) of the diode. The plain blocks compute the photoelectric current (I_{ph}), the diode branch current (I_D) and the PV output current (I_{PV}). The constant blocks in yellow are the parameters of the PV module which are to be supplied by the user. The red block is the solar irradiance with a unit value ($1000\ W/m^2$). Following simulation, the I-V and P-V characteristics curve of PV are displayed using the two X-Y scopes. The simout block was used to save the simulation results to workspace for further analysis and plotting.

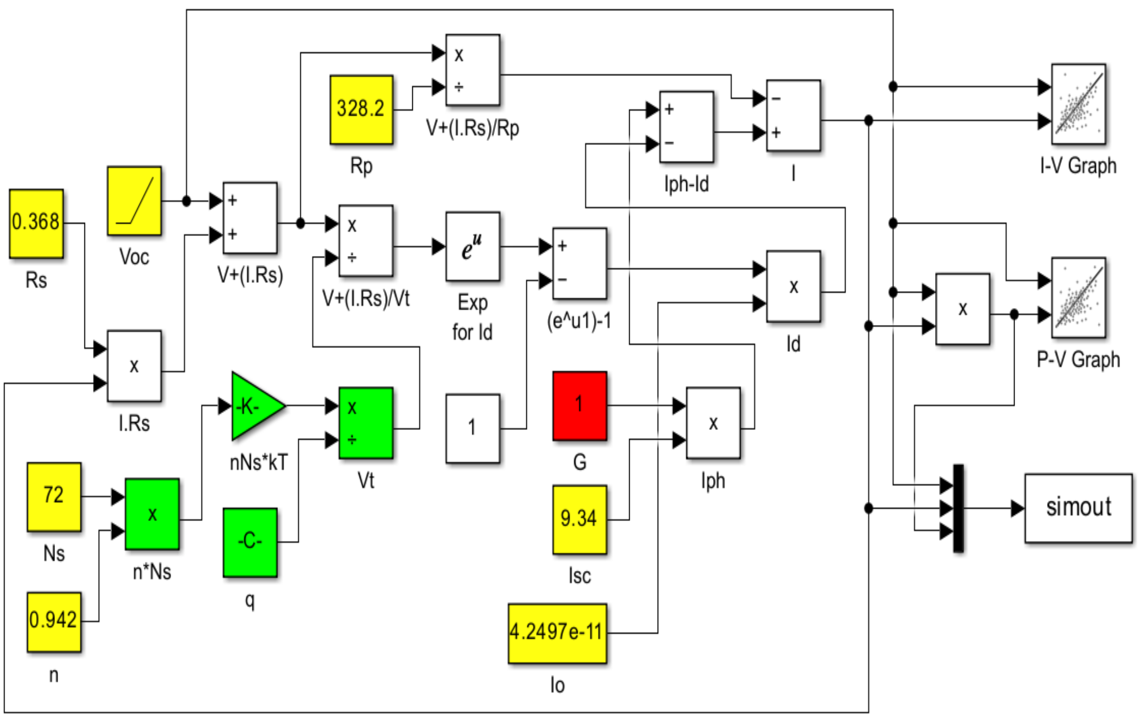

Fig. 2: Graphical model of a standalone PV module

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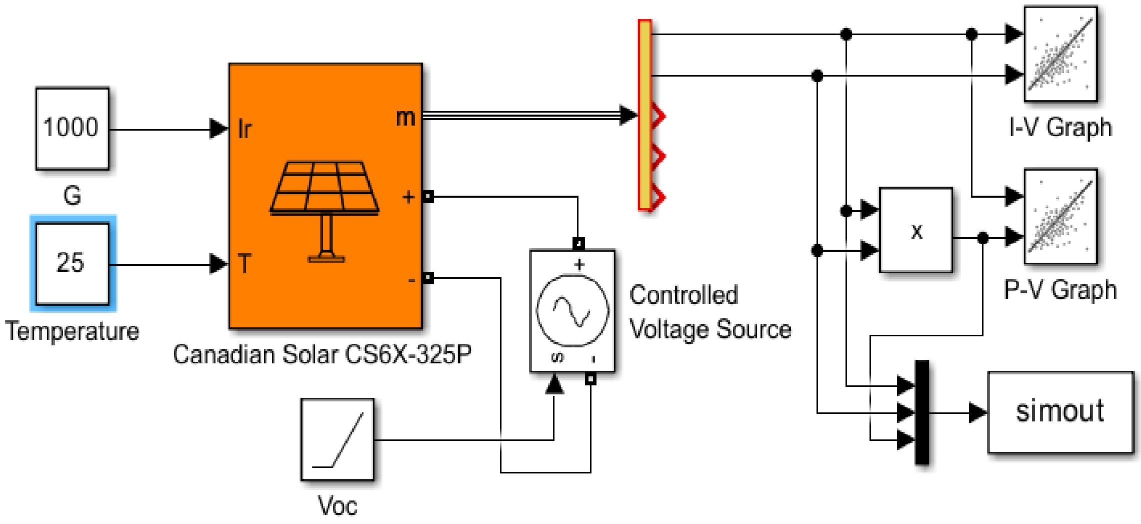

Fig. 3: Simscape functional model of a standalone PV module

To validate the model, a single-diode model of a PV module is simulated under standard test conditions (STC) using Matlab-Simulink(Yin & Babu, 2018). The reference PV module chosen for this study was a Canadian Solar CS6X-325P PV module and its schematic is shown in Fig. 3. Table 1 and Table 2 present the electrical, temperature and model specifications of the PV module.

Table 1: Electrical and temperature parameters of Canadian Solar CS6X–325P at STC

Parameter	**Datasheet value**
Short circuit current (I_{sc})	9.34 A
Open circuit voltage (V_{oc})	45.5 V
Nominal Maximum Power (Pmp)	325W
Maximum current (I_{mp})	8.78 A
Maximum voltage (V_{mp})	37V
Number of cells per module	72
Temperature coefficient of V_{oc}	-0.3071 %/°C
Temperature coefficient of I_{sc}	0.047398 %/°C

Table 2: Model parameters of Canadian Solar CS6X–325P at STC

Model parameter	**Value**
Photoelectric current (I_{ph})	9.3505 A
Diode saturation current (I_o)	4.2497×10^{-11}A

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Parallel resistance (R_p)	328.191 Ω
Series resistance (R_s)	0.36779 Ω
Diode ideality factor (n)	0.94233

5.0 Simulation Result

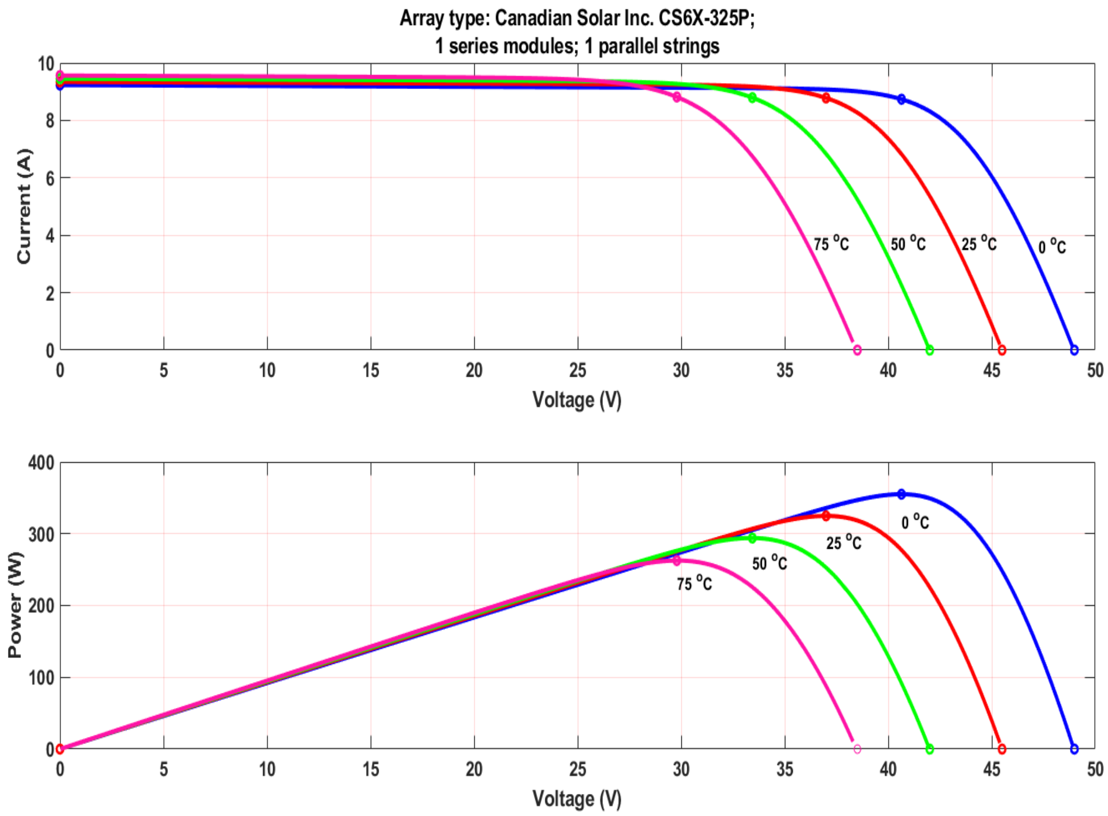

Fig. 4: Current -Voltage and Power-Voltage curves of a PV Module at different temperatures

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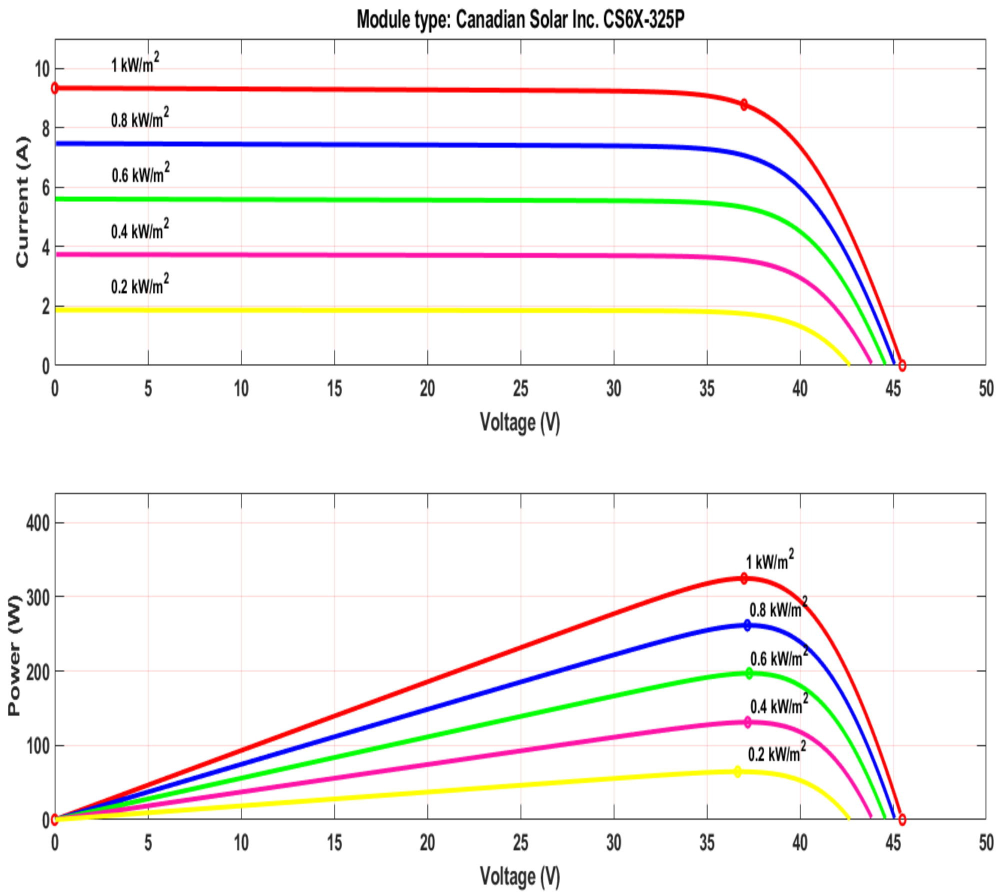

Fig. 5: Current-Voltage and Power -Voltage curves of a PV Module at different irradiances

5.1 Discussion of Simulation Result

Temperature and PV module irradiance levels are two of the many variables that affect current-voltage and Power –Voltage curves of the PV module. Temperature has relatively minor impact on the current of the PV module. However, it has a significant effect of the voltage causing a decrease in voltage as the temperature rise and vice versa.

Fig 4 illustrates the I-V and P-V curves of a Canadian Solar CS6X-325P PV module at different temperatures and constant irradiance level of$1000\ W/m^2$. As the temperature increases from $0°\ C$ to $75°\ C$ at an interval of $25°\ C$, there is a negligible increase in short circuit current, I_{sc} (9A, 9.1A, 9.2A, 9.3A) while the open circuit voltage, V_{oc} (41V, 38V, 34V, 30V) experience a substantial decrease. Similarly, the P-V curve also demonstrate a decline in open circuit voltage, V_{oc} (42V, 38V, 34V, 30V), consistent with the observed I-V characteristics. Consequently these results contribute to a reduction in the output power (350W, 310W, 300W, 280W) of the PV module.

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Fig. 5 shows the corresponding I-V and P-V characteristic curves of a PV module under different irradiance levels of200 W/m^2 to 1000 W/m^2at an interval of 200 W/m^2 and at constant temperature of $25°\,C$. When the irradiance level was increased from 200 W/m^2 to1000 W/m^2, the open circuit voltage, V_{oc} (38V, 37V, 37V, 36.8V, 36.8V) increases slightly whereas the short circuit current, I_{sc} (2A, 3.9A, 5.9A, 7.85A, 9.5A) increase linearly. This phenomenon occurs since more carriers are excited when the irradiance level was increased which resulted in net increase in the output power.

6.0 Conclusion

Temperature and irradiance are two parameters utilized to assess the effect of partial shading on PV system. When considering temperature, a noticeable decrease in short circuit current is not observed. However, there is significant increase in open circuit voltage along the I-V curve, resulting in a reduction in output power as the temperature rises from 0^0C to 75^0C. On the other hand, the short circuit current increases as the irradiance increase from 200W/m^2 to 100W/m^2, and a relatively insignificant rise in the open circuit voltage. Consequently, this leads to an overall increase in the output power generated by the PV system.

7.0 Recommendation

It is recommended that robust technique should be employed to be able to track maximum power point so as to have better output power.

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