A Single Diode Model of a PV System Using MATLAB/Simulink

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ABSTRACT

In the design, construction, and fabrication of PV systems, the choice of a suitable model is an important issue for PV cells and modules in predicting their behaviour. Most of the researchers adopted a single diode model which delineates the basic characteristics of I-V and P-V of solar models. Irrespective of any type of modelling, it is observed that the output energy depends on solar radiation, the temperature of the cell, and the voltage produced in the photovoltaic module. This research work examined the characterization of a single diode model of a PV System. The Current-Voltage IV and Power-Voltage PV characteristics curves were obtained and studied. The equivalent circuit of a single diode was modelled and simulated using MATLAB/Simulink. This model will support energy maximization and provides reasonable accuracy in the simulation of I-V and P-V characteristics. The simulation results for the modelling were obtained and presented.

Keywords: PV system, Single diode, IV and PV characteristics, MATLAB/Simulink,

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1. INTRODUCTION

Electricity availability is one of the performance indicators for industrious and advanced countries. Different types of research are currently being conducted in the domain of power supply in poor countries, with a particular focus on solar power technologies to reduce power supply instability. Solar technology is dependent on the availability of sunshine radiation. According to studies, cloudy weather, temperature, solar irradiance, and other factors all contribute to these weather variations (Awodugba *et al*., 2013). The effects of most of these elements further contribute to low efficiency and rapid collapse of these systems in a short period. these problems have always been key barriers to the adoption of solar power technology (Salim *et. al.,*2020). As a result, there is a disadvantage to using solar power technology as a solution to the unstable power supply because many people are discouraged from embracing this alternative power supply source due to the rapid collapse of most of the installations.

This research work aimed at providing a solution to PV cell designs through modelling of a Single Diode Equivalent Circuit of a PV System. According to *Abatan et al., (2019),* comprehensive analysis of photovoltaic systems depends solely on the photovoltaic (PV) modules parameters. This implies that the I-V and P-V characteristics curves are important factors in photovoltaic (PV) modules design.

This study focused on carrying out analyses on the effects of variations in irradiance and temperature condition at different points on the performance of PV system designs. This will enable designers and manufacturers of PV cells in manufacturing a more durable and environmentally adaptive system. This paper investigates the performance of a single diode model of a PV system as it affects energy deliveries.

2. REVIEW OF RELATED WORKS

Related works on different models of equivalent circuits for a PV System was discussed below according to the authors, years of publication, title of paper/journal, methodology, findings and knowledge gag.

Table 1: Reviewed related work

Author	Year	Title	Method used	Findings	Gap
Salim et al	2020	Monitoring and Analysis of Solar PV based on GUI	Single diode model of PV cell was simulated using Lab-VIEW	Simulation results was achieved successfully. Graphical user interface was created for real time monitoring	Performance of solar panel improved.
Jiabin Liu et al	2017	Study and design Process of Solar PV System	Simulates a model of PV cell using a single diode	Graphical curves of IV and PV was generated. This revealed the effects of temperature and irradiance on PV cells	It is a straightforward approach to simulate a model for PV cell designers.
Chandani Sharma et al	2014	Solar Panel Mathematical Modelling using Simulink	Single diode model of PV cell was simulated using MATLAB/Simulink	The ideal characteristics of a solar array was verified at standard test conditions obtaining IV and PV graphs	The methodology does not involve complex mathematical parameters. Easy to model.
Awodugba, A.O. et al	2013	Photovoltaic Solar Cell simulation of Shockley Diode parameters in MATLAB/Simulink	Newton – Raphson Algorithm and Single diode model of PV cell	The simplest and most widely used equivalent circuit of a solar PV cell is a current source in parallel with a diode	Simplicity in programming it and do not have ambiguity in parameters etc.

Author	Year	Title	Method used	Findings	Gap
Salmi et al	2012	MATLAB/Simulink Based Modelling of Solar	Simulates a model for PV cell using a single diode equivalent circuit.	It provides a tool to predict the behavior of solar PV cell under different physical parameter changes	It also makes available some parameters like ideality factor which are not always provided by the manufacturers.
Shen Weixiang et al	2011	Development of a Mathematical Model for Solar Module	Utilization of two diodes model to represent the PV cell. Linear least square method was used to analyze data	Two diode model was simplified into one diode model where Id2 is omitted according to Shockley theory	This creates computational burdens
Zainal Salam et al	2010	An Improved Two-Diode Photovoltaic (PV) Model for PV System	Utilization of two diodes model to represent the PV cell. Iteration method was also used	It has accuracy at low irradiance level which allows for more accurate prediction of PV system performance	Requires computation of several parameters, leading to several assumptions that are not always true.
Yuncong Jiang et al	2010	Improved Solar PV Cell Matlab Simulation Model and Comparison	Simulates a model for PV cell using a single diode equivalent circuit.	The new model is able to accurately simulate real PV module I-V and P-V characteristics	Elimination of drawbacks of existing models.

2.1 Single Diode Model

In practice, the single-diode model is a common equivalent circuit model. It primarily entails connecting a current source, a diode, and a shunt resistance in sequence. This is then connected in series with another resistance (i.e. series resistance) as shown in figure 1

$$I = I_L - I_D - I_{sh} \quad (1)$$

The single diode model is usually referred to as a five-parameter model because certain parameters such as the IL, IO, Rs, Rsh, and nid are crucial for PV systems performance analysis. Such analysis is useful for developing solar photovoltaic simulation models.

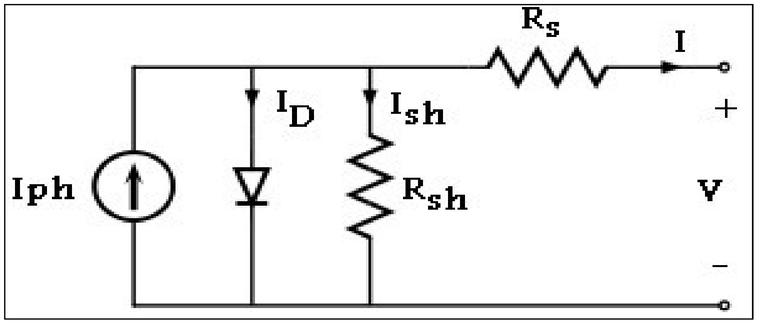

Figure 1: A PV cell equivalent circuit (Salmi, 2012)

2.2 Double Diode Model of the Polycrystalline Cell

The standard double diode model of a typical polycrystalline PV cell as depicted in figure 2.6 expresses the *V-I* characteristic of a cell by the following equation:

$$\mathrm{I} = I_{ph} - I_{S1}\left[e^{\left(\frac{V+IR_S}{v_t}\right)} - 1\right] - I_{S2}\left[e^{\left(\frac{V+IR_S}{Av_t}\right)}\right] - \frac{V+IR_S}{R_p} \qquad (2)$$

3. METHODOLOGY

The mathematical model of a single diode equivalent circuit of a PV system will be derived. A Simulink model of a single diode equivalent circuit of a PV system was developed. The developed model was simulated under varying irradiance and temperature. The IV and PV characteristic curves was obtained. The was validated under Standard Test Condition based on the PV cells manufacturer's datasheet.

3.1 The Solar PV Cell Model

From the equivalent circuit in figure 1, other mathematical model equations were further derived as follows.

$$I = I_L - I_D \qquad (3)$$

In practice, the IV and PV characteristics of PV modules should include the current through the shunt resistor, I_{sh}.
The equation now becomes

$$I = I_L - I_D - I_{sh} \qquad (4)$$

I_D can further be represented as

$$I_D = I_o\left(exp^{\frac{q.V_C}{n.N_S.K.T}} - 1\right) \qquad (5)$$

Therefore, substitute for I_D in equation (2) and make $I_L = I_{ph}$

$$I = I_{ph} - I_o.\left[exp\left(q.{}^{(V + I\,.\,R_s)}/_{n\,.\,K\,.\,N_s\,.\,T}\right) - 1\right] - I_{sh} \qquad (6)$$

The current (I) to the load is expressed as:

$$I = I_{ph} - I_o.\left[exp\left(q.{}^{(V + I\ .\ R_s)}/_{n\ .\ K\ .\ N_s\ .T}\right) - 1\right] - I_{sh} \quad (7)$$

Where I_{ph} is the photo-current (A), I_o is the saturation current (A), K_i is the short-circuit current of the cell at 25°C and 1000W/m², q as electron charge (C), R_s as series resistance, V is the output voltage and I as the output current.

3.2 Model Diagrams

The model diagrams for the simulation was obtained from the mathematical model earlier derived.

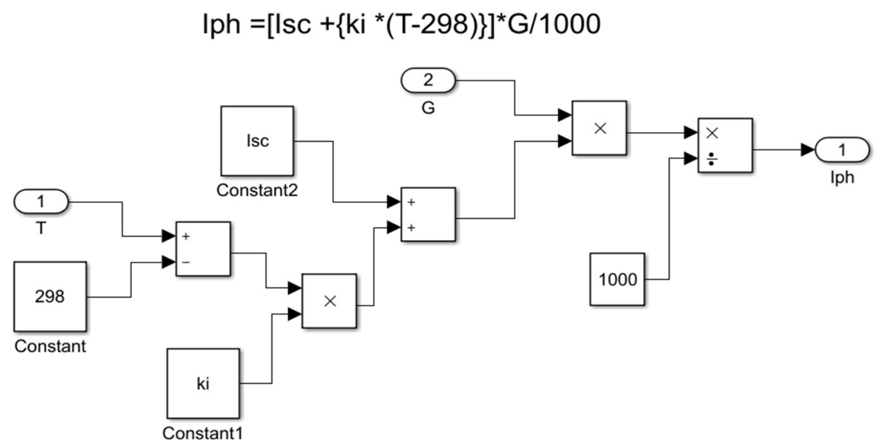

Figure 2: Simulation diagram of the Phase Current (I_{ph})

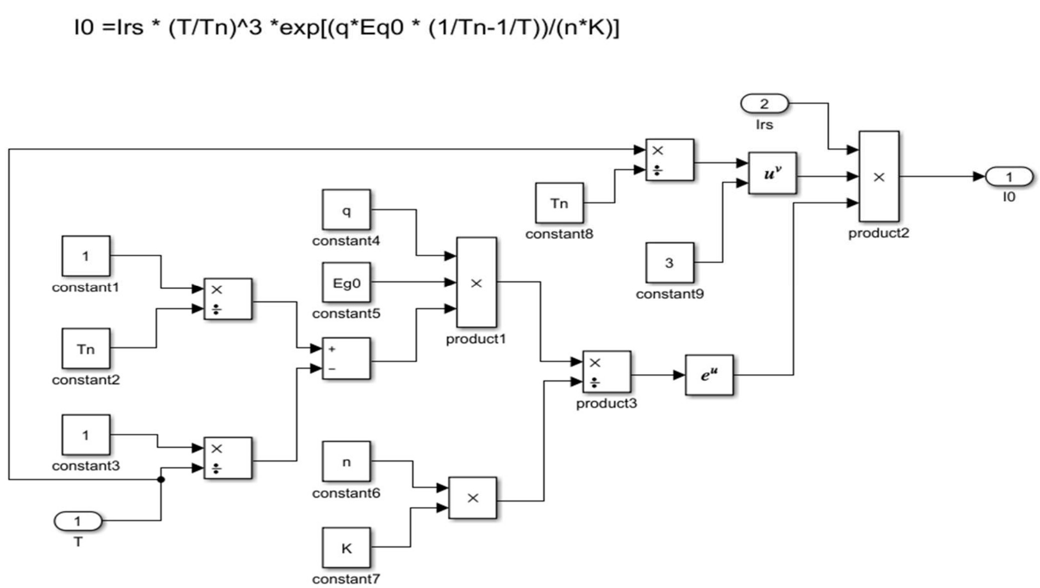

Figure 3: Simulation diagram of the Saturation Current (I_o)

Irs = Isc/[exp (q*Voc/(n*Ns*K*T)) -1]

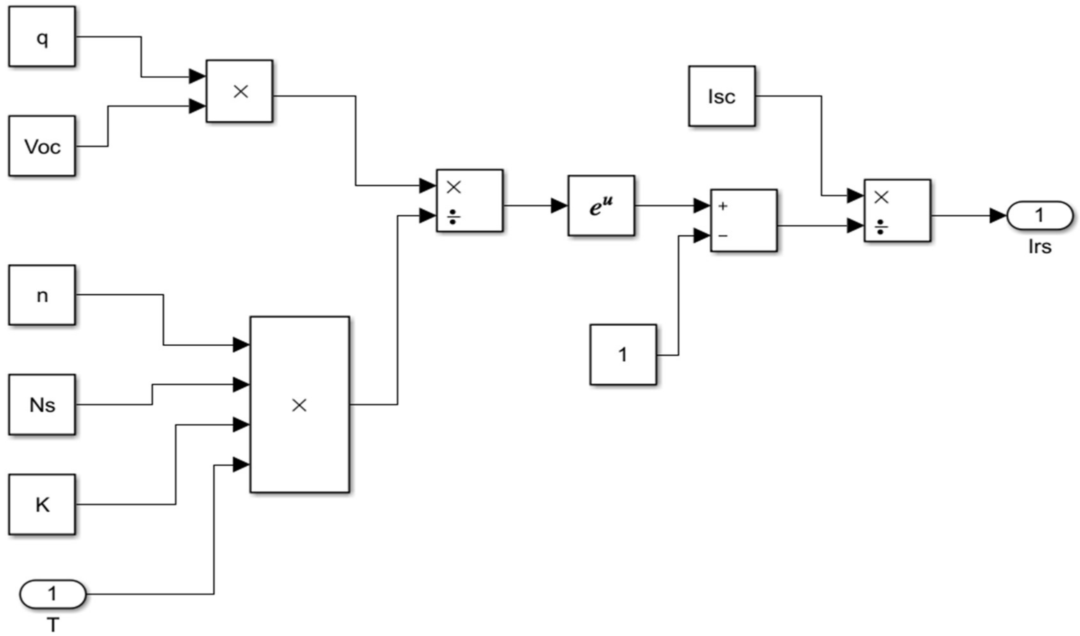

Figure 4: Simulation diagram of the Reverse Saturation Current (I_{rs})

I=Iph - I0*[exp{(V+I*Rs)*q/(n*K*T*Ns)}-1]-Ish

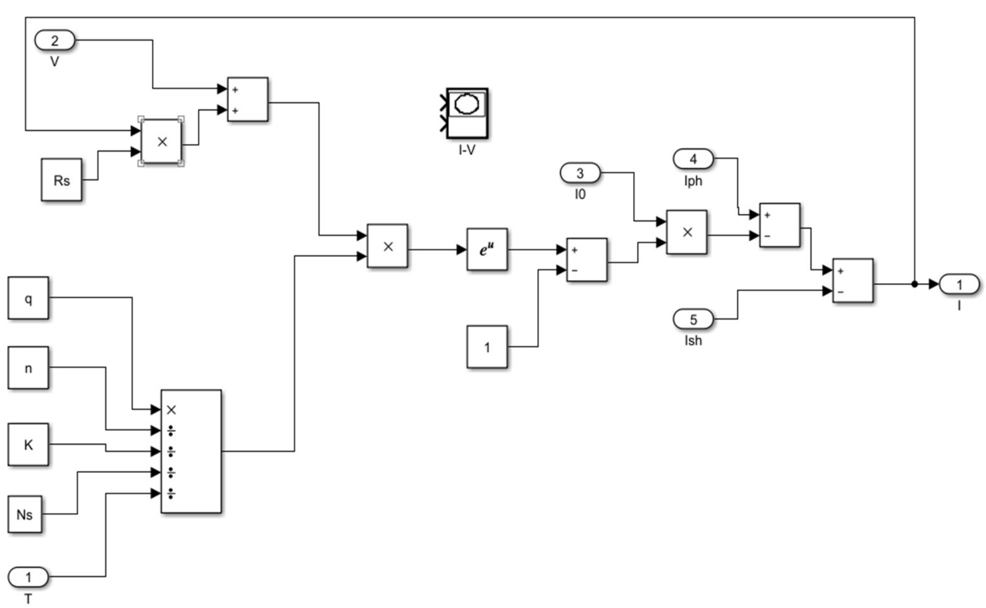

Figure 5: Simulation diagram of the Final Output Current (I)

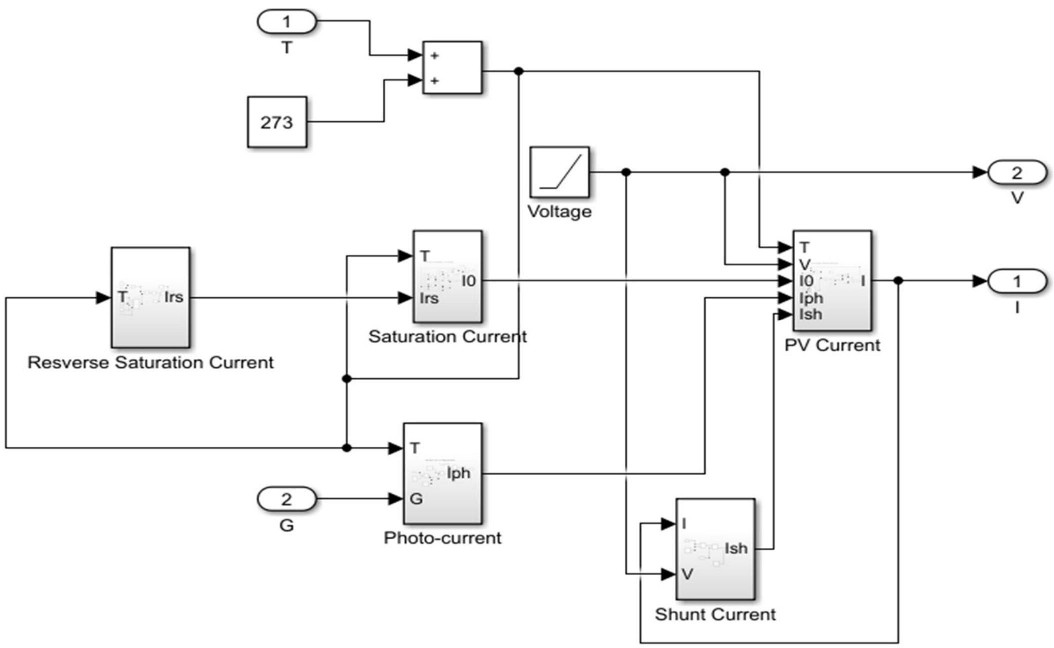

Figure 6: Simulation diagram for all sub-systems for I-V and P-V

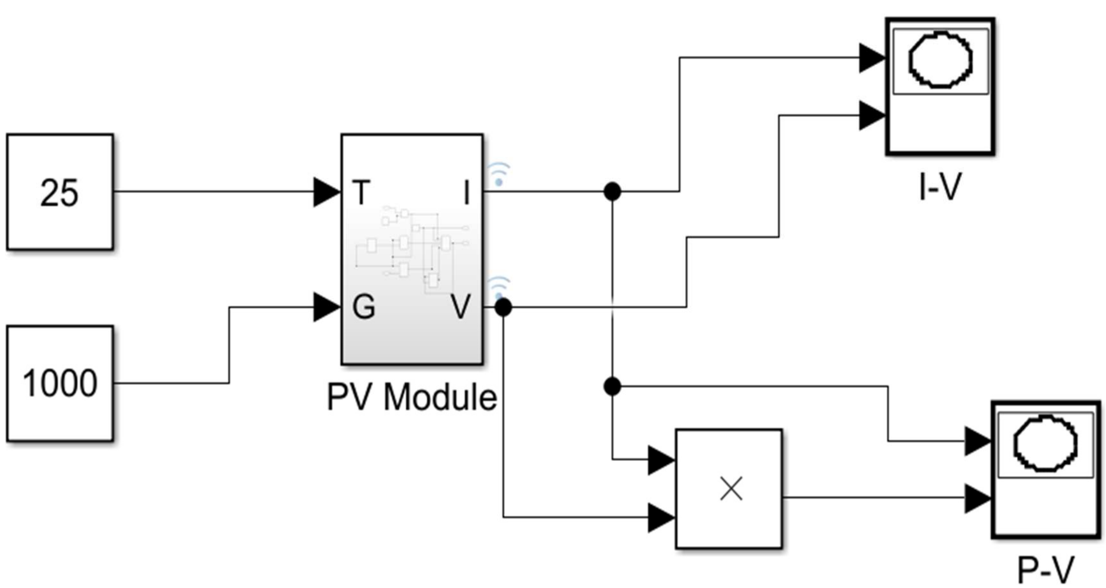

Figure 7: Simulation diagram under Standard Test Condition for PV cell

Table 2: Parameters Descriptions and values

Parameter	Description	Value
I_{ph}	photo-current (A)	Iph
I_{sc}	short-circuit current (A)	Isc
K_i	short-circuit current of cell at 25^0C and $1000W/m^2$	.0032
T	operating temperature (K)	T
T_n	nominal temperature (K)	298
G	solar irradiance W/m2	G
Q	electron charge (C)	1.6×10^{-19}
V_{oc}	open circuit voltage	Voc
N	the ideality factor of the diode	1.3
K	Boltzmann's constant (J/K)	1.38×10^{-23}
E_{g0}	band gap energy of the semiconductor (eV)	1.1
Ns	number of cells connected in series	Ns
N_p	number of cells connected in parallel	Np
R_s	series resistance Ω	0.221
R_{sh}	shunt resistance Ω	415.405
V_t	diode terminal voltage	-

4. RESULTS AND DISCUSSION

Table 2: I-V Characteristics at an irradiance of 1000W/m2 and varied temperature

Serial number	Temperature in °C	Output Voltage (V)
1	45	47
2	35	49
3	25	52
4	10	55

Table 3: P-V Characteristics at different temperature levels

Serial number	Temperature in °C	Power in Watts (W)
1	45	850
2	35	900
3	25	980
4	10	1050

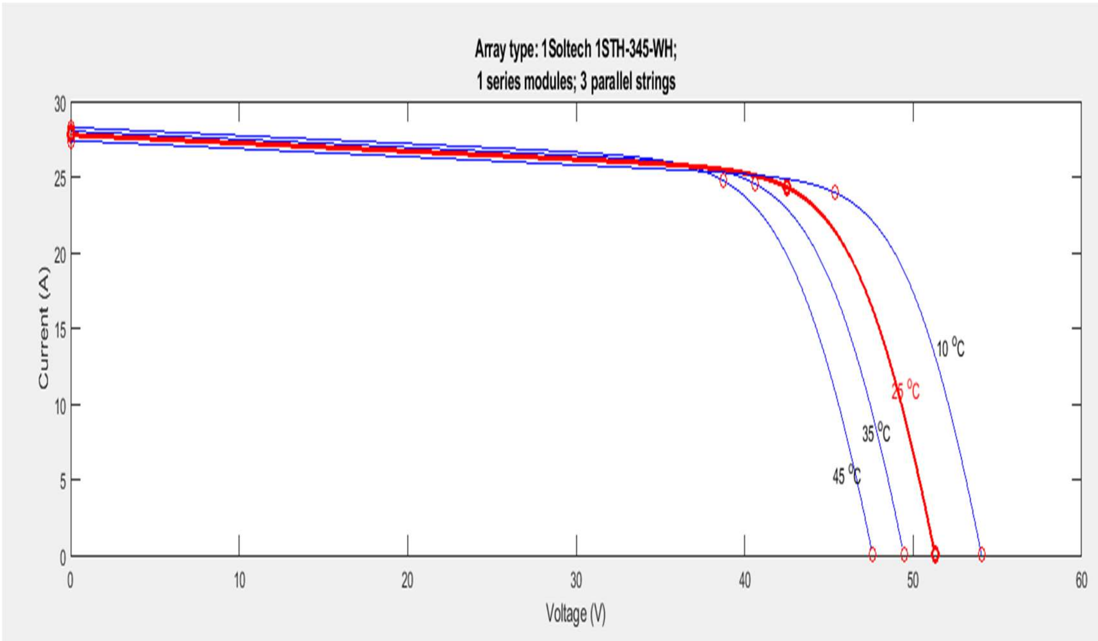

Figure 5: I-V characteristics curve for temperature levels at an irradiance of 1000W/m2

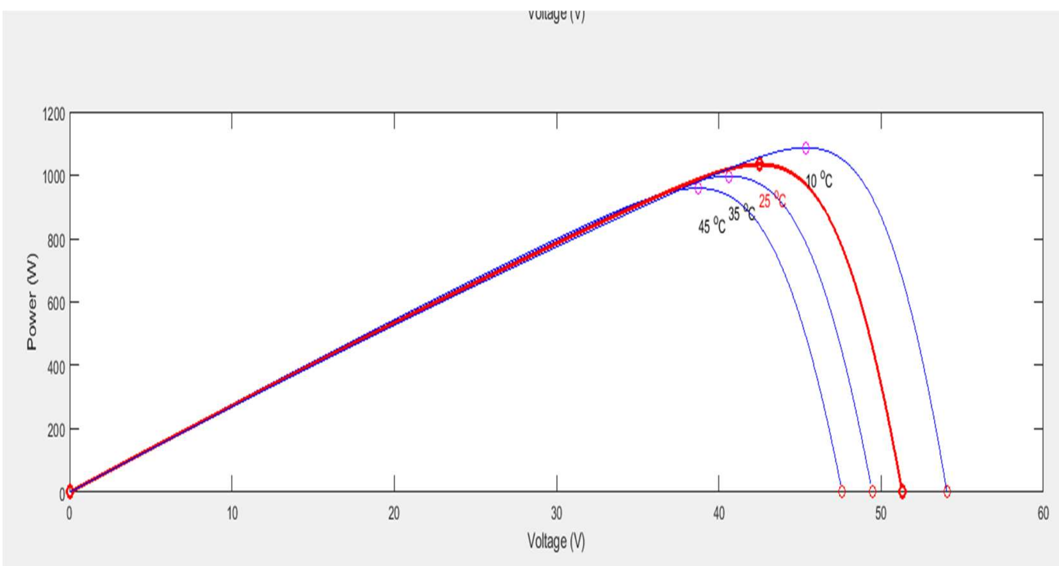

Figure 6: P-V characteristics curve for temperature levels at an irradiance of 1000W/m2

Graph of Current and Voltage at different temperature points and irradiance of 1000W/m^2 showed that solar panels perform much better at low temperature. At temperature higher temperatures, the output voltage of the PV panel reduces. Table 3 further explained the model validation under Standard Test Condition based on manufacturers data sheet of irradiance level is 1000W/m^2 with temperature of 25^{0}C. However, temperatures below 25^{0}C e.g. 20^{0}C, 15^{0}C, 10^{0}C and 5^{0}C with constant irradiance of 1000W/m^2 gave more output Voltages (V) and Power (W). The I-V characteristics curve for different temperature levels at an irradiance of 1000W/m^2 is shown in table 2. Figure 5 explained the performance of the PV system under varying temperature and constant irradiance of 1000W/m^2.

The recommended maximum temperature level of 25^{0}C was marked with a thick line and labelled 25^{0}C. At this temperature, the output voltage (V) is 52V compared to 49V and 47V as generated by temperatures 35^{0}C and 45^{0}C respectively. This evidently showed a good performance in output voltage as a result of reduction in temperature of the solar panel. It also showed what will be obtainable as an output voltage under Standard Test Condition. The temperature was further reduced to 10^{0}C which gave an output voltage of 55V. The more the output voltage, the more the power generated as output from the solar cell.

Similarly, table 3 showed the values for power (P) in watts and the voltage (V) in respect to different temperature levels at an irradiance of 1000W/m^2. Figure 4.84 also showed the Power-Voltage (P-V) characteristics curve for different temperature levels at an irradiance of 1000W/ m^2. Findings recorded in table 4.2 was generated from the graph as presented in figure 4.84. Under Standard Test Condition (STC) of 25^{0}C temperature level and irradiance of 1000W/m^2, the output power was 980 Watts (W). Comparing this with output power for temperature levels of 35^{0}C and 45^{0}C, their outputs power are 900watts and 850 watts respectively. Higher temperature levels above 25^{0}C pose a great challenge to the output power generated from the solar cell. Also from table 4.2, lower temperature of 10^{0}C and irradiance of 1000W/m^2 recorded an output power of 1050 Watts. This is remarkable as reduction in temperature gave more output power compared to higher temperature levels of 25^{0}C, 35^{0}C and 45^{0}C.

5. CONCLUSION

Solar energy is affected by external conditions like solar irradiance and temperature. These are pointed out to be affecting PV cell output to a much greater extent than other conditions. Therefore, understanding the modelling of PV cells is necessary. The model was designed from the mathematical equations derived in the methodology from the model of a single diode equivalent circuit. This was simulated in rea-time under varying irradiance and temperature levels. The performance and behaviour of the PV system under several environmental conditions were determined and analysed. The rate of charging of the battery under maximum power point tracking was modelled and simulated in Simulink.

The results show that PV systems output power is greatly affected by environmental conditions. As such, designers of PV systems must ensure research is focussed towards an adaptive designs of PV cells that can adjust to different and diverse environmental conditions while keeping constant the recommended temperature and irradiance level (1000W/m^2 at 25^{0}C) for maximum output power and enhanced performance. The single diode model used to achieve the simulation is a simplified simulation structure that is easy to implement. It takes less simulation time and reduces ambiguity and assumptions. Thus, the results in this research work can be used for further research works on PV systems fabrications.

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