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Experimental and simulation-based comparative analysis of different parameters of PV module

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A B S T R A C T

Renewable Energy (RE) has been rapidly growing day by day as a need of the world due to the energy crises and environmental effects. In recent years, the use of solar systems for the generation of electricity has gained considerable popularity. This increase mainly results from a scarcity of other energy sources, such as fossil fuels. As a result, there is a pressing need to transition to more dependable and long-term resources, such as photovoltaic (PV) systems. To improve the performance of PV proper design and development have been required for adequate extraction of their essential parameters. This study proposed the implementation and behaviour of a photovoltaic module (PVM) and describes the individual main equation situated on the Shockley diode to enable a detailed study of semiconductor physics and PV occurrence. The environmental performance of a PVM is represented using MATLAB which can be illustrative of the PVM for simple use in the simulation phase. The model was designed in MATLAB, an easy-to-use icon and dialog box that depends on the effect of solar radiation (SR) and cell temperature, output current (I) versus (vs) voltage (V), and power vs. Voltage. PVM is made with the simulated models are simulated and optimized. These models have been used to analyze the outcome of variations in various specifications on the PVM, including the operating temperature and the level of SR. The observed results have been compared with outcomes characteristics of PV, which are specified on the technical datasheet of the PVM. Simulation results have been obtained by using MATLAB software. From the results, it can be seen that at insolation 900W/m^2 the output power of PVM is 280 but at 10°C the power of PVM is 270.

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Introduction

This Sun is the universal origin of illumination and intensity with the exhaustion of normal sources, solar energy is used more and more to generate energy [3,12,19,22] Energy is the main function of the latest evolution of self-control. All accessible missions, healthcare, agriculture, education, and necessary energy must function properly [17]. A country cannot be successful without the right use of energy. It is seen as the economy is the principal part of a country [22,28]. Due to current growth, and assisting its large societies, the government requires an enormous quantity of energy to keep everything on track [8,27].

However, the energy supply is inadequate and the country is in the demolition of its energy hassle. The space between supply and requirement for electricity has widened in recent years and is very evident through the sunny season [2,24,27] which has resulted in electricity being turned off completely in urban areas for 10 to 12 hours and between 4 and 6 p.m. has been in rural areas [14–16,33]. Electricity is essential for our everyday life. Generations of electricity are two types from which one is a conventional or unconventional energy resource. Now a day's electricity is generated from nuclear power, diesel, and coal. The major drawback of these sources is that they produce and care for wastes like ash in coal power plants, nuclear waste in nuclear power plants. The waste is very expensive and also harms nature. Nuclear waste is also extremely unhealthy to humans. Conventional energy resources are used up every daytime. Shortly, it will entirely disappear from the globe, so we should have to alternate methods to generate electricity. There are multiple unconventional energy assets like Geothermal, solar, tidal, wind. Energy from Tidal has drawbacks because it can only be used on coasts. Whereas is energy from geothermal takes a specific easy step to reproduce heat from the earth. Wind and Sun are accessible in all conditions. Unconventional energy resources such as solar and wind can be good alternative sources and are reliable, environmentally friendly, and economical [21,25,29].

[11] investigated in-depth five of the most recent mathematical one-diode models for estimating the I–V curve of a photovoltaic cell, which consider variations in irradiance as well as electrical load and operating temperature. These models simplify the problem by requiring only the estimation of five parameters: photocurrent, diode saturation current, ideality factor, and series and parallel resistances. The process for computing these five electrical characteristics is at the heart of the models investigated, and this work allows for their evaluation in terms of the underlying premise, data availability, and findings reliability. A one-diode equivalent circuit made up of linear and non-linear components can be used to simulate the I–V characteristics of a photovoltaic PV module. Using photovoltaic panels (PV) to model and simulate them in a virtual environment can aid in the design and performance study of solar-powered power systems [13,18] . The models that are now accessible are examined from two separate perspectives. The first aspect is based on the electrical properties of the PV panel, which is achieved through the use of an electrical equivalent circuit or a set of mathematical formulae. In addition, the characteristics of a PV panel under various environmental circumstances are considered in the second component. Temperature fluctuations and non-uniform solar irradiation as a result of partial shadowing are examples of environmental circumstances. As external circumstances change, the operating point of the PV panel, which corresponds to the Maximum Power Point, changes in a continuous manner (MPP). As a result, an accurate PV panel model that is created with rigorous control and incorporates various environmental circumstances would undoubtedly increase the overall performance of the solar power system. The current–Voltage (I–V) characteristic of a photovoltaic (PV) cell/module, which is dependent on the circuit model parameters, can be used to predict the behavior of the cell/module [1]. It is important to extract appropriate circuit model DC parameters so that one can conduct accurate solar PV system performance investigations and control studies; yet, this is a difficult, nonlinear, and non-convex optimization issue that is subject to severe constraints.

[6] presented the once diode equivalent circuit-based modelling method to a discussion about VI, PV under only two levels 1000 W/m^2 and 200 W/m^2 of irradiance indoor illumination. In the reported research work (Razzaq 2020) VI characteristics of the PV system have been proposed and solicited to resolve the system of five nonlinear equations by Newton Raphson Method at five levels of irradiance. (Anani 2020) revealed the literature-based methods to modify the single diode model to analyze the PV Module under different weather conditions of temperature and irradiance. And parameter alteration techniques were experienced by three commercially accessible PVM of distinct PV expertise, i.e. multi-crystalline, monocrystalline, and thin-film types have been presented.

[23] presented A variant of Particle Swarm Optimisation (PSO) is used with Enhanced Leader, called Enhanced Leader PSO (ELPSO). In ELPSO, the leader is optimized through a five-step sequential mutation strategy, which alleviates the early convergence problem, thereby obtaining more accurate circuit model parameters in the PV module/cell parameter estimation problem. [23] revealed the Time varying acceleration coefficients particle swarm optimisation (TVACPSO) optimisation algorithm for PVMs to validate and estimate the parameters of PVM by using the proposed algorithm. Jordehi,(2017) bestowed the parameter estimation problem of photovoltaic cells; a Gravity Search Algorithm (GSA) with linearly decreasing gravity constant has been proposed. In the proposed GSA variable, the gravitational constant has been used as a control parameter in exploring and development, decreasing linearly during the development algorithm. Fan [13] proposed a PSOCS algorithm based on the basic components of PSO and a re-randomization strategy for parasite nests that emerged during cuckoo hunting. The parameters of the single diode model and the diode model were determined based on multiple experiments. Comprehensive comparison, the results show that the developed PSOCS algorithm has higher convergence accuracy and better stability than original PSO, original cuckoo search, and other censorship algorithms. Similar study Using a five-stage mutation technique, the problem of premature convergence in the PV cell/module parameter estimation problem is

alleviated, resulting in more accurate circuit model parameters [9,23]. The case studies of this research include the RTC France silicon solar cell, the STM6-40/36 module with monocrystalline cells, and the PVM 752 GaAs thin film cell.

Based on the above analysis with to other researchers, none of the researchers has been reached MATLAB and experimental as well as a mathematical algorithm to analyze the VI, PV relationship and parameters of PV system under different levels of temperature and insolation/irradiance. The model is verified by contrasting the simulation results with the experimental results. The outcomes manifest that the comparison result provided by the PVM model using the equivalent circuit diagram of medium complexity is that the viability of all models in the linear range is slightly consistent in the non-linear range, but not in the saturation range of the observation range results.

Furthermore, VI, VP characteristics of a PV system have been proposed using experimental data and Modelling of PV done in MATLAB, and to validate the proposed mathematical algorithm (Newton Raphson's Method) with the other existing controllers to show its effectiveness. For this purpose, the various parameter extraction approaches are summarising and compared at different levels of temperature and insolation/irradiance. Furthermore, the most often encountered types of equivalent electrical circuits have been thoroughly explored and implemented.

The following is the structure of this paper: Section 2 offers an overview of the PV systems various types of PV systems were studied. Section 3 examines, discusses, summarises, and explains the modelling of PV systems including mathematical expression: simulation models implementation as well as the results and discussion that are considered to be quite valuable for researchers in the subject at the end of the chapter.

PV system

The increasing use of PVM has contributed significantly to the increasing use of renewable energy technologies for power generation worldwide. While fossil fuels remain the main source of electricity generation, this situation is expected to change over the next 30 years and renewable energy generation (REG), particularly through PVM, will be the key source for generating electrical energy [21]. Photovoltaic systems are made up of interconnected components and are designed to achieve specific goals. The arrangement of PV systems is illustrated in Fig. 1.

PV module

When operating a single PV cell, the output voltage generates is less than 1 V (around 0.6 V for crystalline silicon (Si) cells), so that several PV cells are connected in series for the desired output voltage. Cells are in series combinations

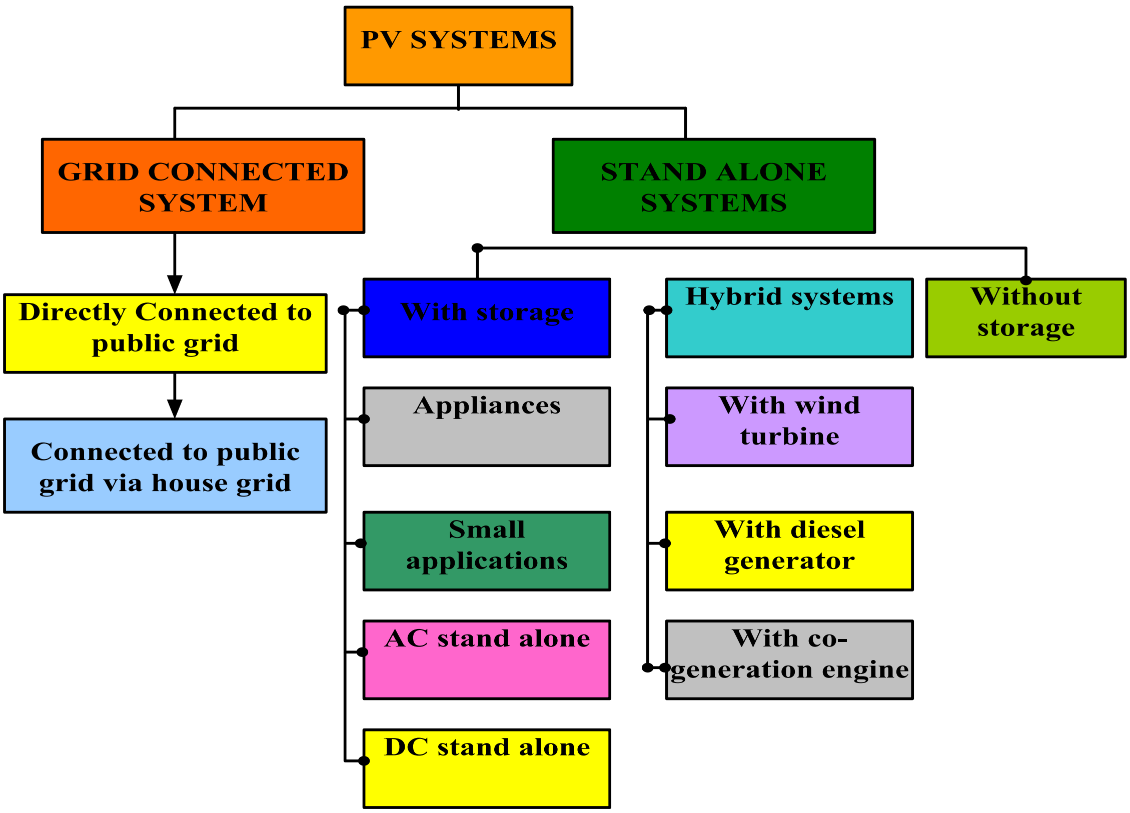

Fig. 1. Arrangement of PV Systems.

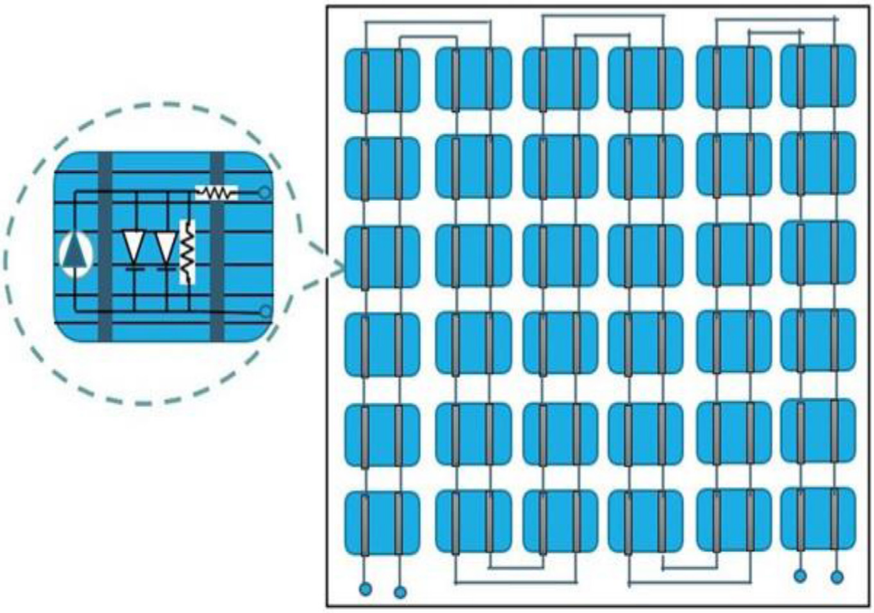

Fig. 2. PVM with 36 cells connected in series.

located in a frame called PVM. Mainly 36/72 cells joined in a series of commercially available crystalline cells in PVM. Most PV systems used to have batteries reserves to work without sunlight. Grid-connected PV systems do not use batteries. In addition, the development of highly efficient DC to DC converters has increased the demand for PVM with specific voltages. The output current of the PV cell is like that of the single array in a series combination, whereas voltage output is the sum of different cell voltages as shown in Fig. 2.

Modelling of PV

Mathematically based modelling of PV

Fig. 3. illustrates the single diode module widely used for modeling PVM.

The current I and the voltage V at the module's terminals are connected by the entire numinous equation [20]. Mathematical models can appropriate various formations comprise, but not narrow to, statistical models, dynamic systems, differential equations. These models may overlap with other models, and specific models contain various abstract structures [31].

$$I_{pv} = I_{ph} - I_{rs1}\left(e^{\frac{q(V_{pv}+I_{pv}R_s)}{KT}} - 1\right) \quad (1)$$

$$I_{pv} = I_{ph} - I_o\left(e^{\frac{q(V_{vp}+I_{pv}R_s)}{AKT}} - 1\right) \quad (2)$$

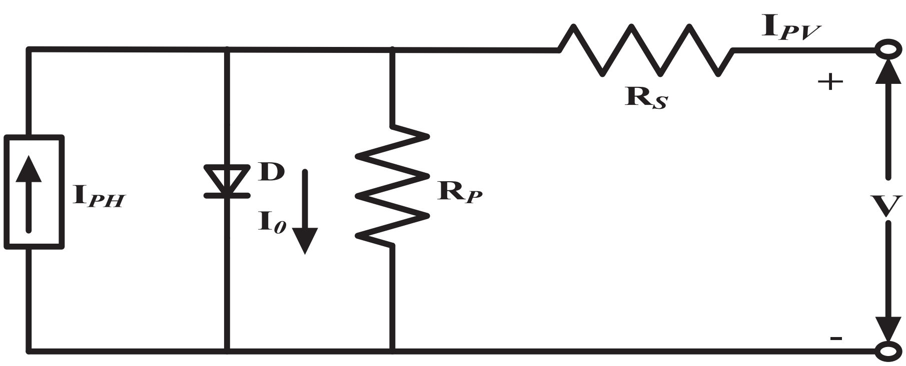

Fig. 3. Single diode model.

Where:
I_{PV} is the output cell current,
V_{pv} represent PV voltage, given as
Module voltage ÷ number of cells connected in series,
T shows PV temperature

$$I_{ph\_T} = I_{ph\_Tref}\left[1 + \alpha\left(T - T_{ref}\right)\right] \tag{3}$$

Where:
I_{ph_T}= solar generated current
T_{ref} refer as PV cell temperature
α illustrates the coefficient temperature of I_{ph}
Iph at a given irradiance (G) can be written as

$$I_{ph\_G} = \left[\frac{G}{G_r}\right]I_{ph\_Gr} \tag{4}$$

$$I_{rs} = \frac{I_{ph}}{\left(e^{\left(\frac{qV_{oc}}{AKT}\right)} - 1\right)} \tag{5}$$

The reverse saturation current (Irs) depends upon the temperature of PV, and it is deliberate beyond the equation given below [4,5].

$$I_{rs\_T} = I_{rs\_Tref}\left[\frac{T}{T_{ref}}\right]^{\frac{3}{T}} e^{-\frac{qE_g}{AK}}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right) \tag{6}$$

Series resistance (SR) of the PVM greatly influences the incline of the IV characteristics virtually Voc. Therefore assessment of SR is determined by analyzing the incline of the IV curl at Voc [30].

$$I_{pv} = I_{ph} - I_o\left(e^{\frac{q(V_{pv}+I_o)}{AKT}} - 1\right) \tag{7}$$

Then, by solving the equation (1) at V=Voc also by taking the value of output PV current I=0.

$$I_{pv} = O - I_o\left(e^{\frac{q(V_{pv}+I_o)}{AKT}} - 1\right) \tag{8}$$

The equation evaluating for Rs, differentiate equation (8) with respect to IPV the and after that reduce equation in Rs terms.

$$dI_{pv} = -I_o q\left(\frac{dV_{pv} + I_{pv}R_s}{AKT}\right)e^{\frac{q(V_{pv}+I_{pv}R_s)}{AKT}} \tag{9}$$

$$\frac{dI_{pv}}{I_o e^{\frac{q(V_{pv}+I_{pv}R_s)}{nkT}}} = -q\left(\frac{dV_{pv} + I_{pv}R_s}{AKT}\right) \tag{10}$$

$$\frac{dI_{pv}}{qI_o e^{\frac{q(V_{pv}+I_{pv}R_s)}{nkT}}} = -\frac{dV_{pv}}{AKT} - \frac{I_{pv}R_s}{AKT} \tag{11}$$

$$\frac{dI_{pv}}{qI_o e^{\frac{q(V_{pv}+I_{pv}R_s)}{nkT}}} + \frac{I_{pv}}{AKT} = -\frac{dV_{pv}}{AKT} \tag{12}$$

$$\frac{dI_{pv}AKT}{qI_o e^{\frac{q(V_{pv}+I_{pv}R_s)}{nkT}}} + I_{pv}R_s = -\frac{dV_{pv}}{AKT} \tag{13}$$

$$R_s = -\frac{dV_{pv}}{dI_{pv}} - \frac{AKT/q}{I_o e^{\frac{q(V_{pv}+I_{pv}+R_s)}{AKT}}} \tag{14}$$

$$R_s = -\frac{dV_{pv}}{dI_{pv}}\Big| - \frac{AKT/q}{I_o e^{\frac{qV_{oc}}{AKT}}} \tag{15}$$

Finally, we solve equation (7) for the I-V properties. By solving the Newton Raphson method, it may be likely to find the final output through easy iterations [7,26,32]. Newton's Raphson technique is represented as follows:

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \tag{16}$$

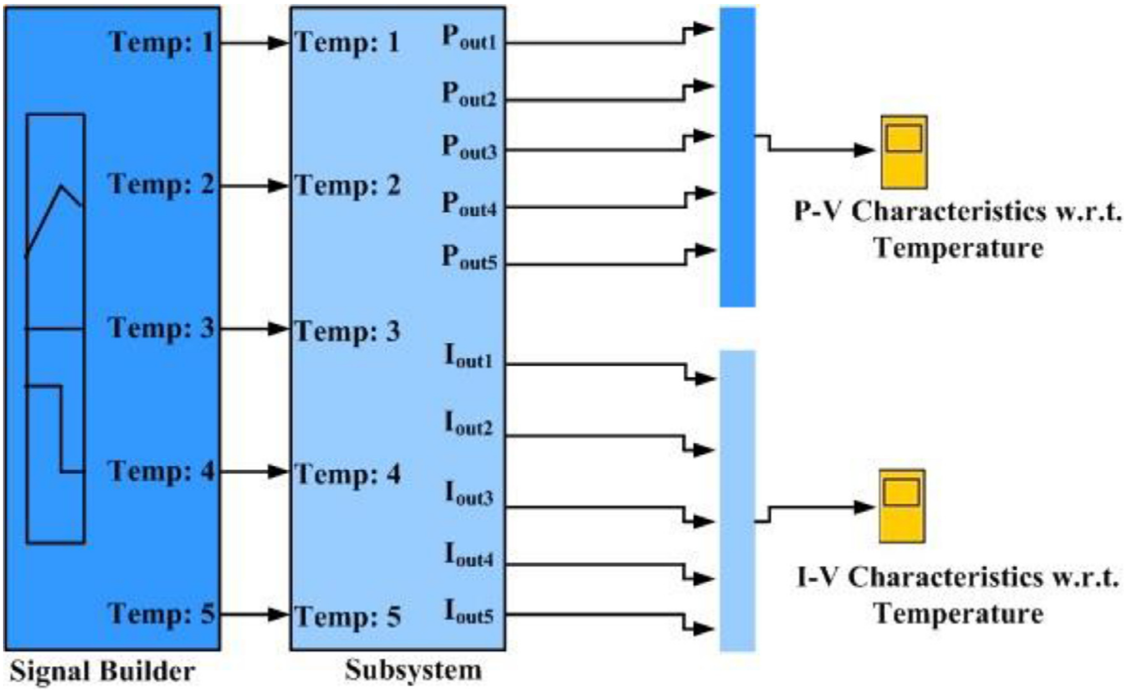

Fig. 4. Simulink based Model of PV for V-I and V-P characteristics w.r.t Temperature.

From equation 7

$$f(I_{pv}) = I_{ph} - I_{pv} - I_o\left(e^{\frac{q(V_{pv}+I_{pv}R_s)}{AKT}} - 1\right) \tag{17}$$

Differentiate with respect to I_{pv}

$$f'(I_{pv}) = \frac{d}{dx}\left(I_{ph} - I_{pv} - I_o\left(e^{\frac{q(V_{pv}+I_{pv}R_s)}{AKT}} - 1\right)\right) \tag{18}$$

$$f'(I_{pv}) = 0 - I - I_o\left(e^{\frac{q(V_{pv}+I_{pv}R_s)}{AKT}} - 1\right)\frac{d}{dx}\left(\frac{q(V_{pv}+I_{pv}R_s)}{AKT}\right) \tag{19}$$

$$f'(I_{pv}) = 0 - I - I_o\left(e^{\frac{q(V_{pv}+I_{pv}R_s)}{AKT}} - 1\right)\left(\frac{q}{AKT}\right)\frac{d}{dx}(V_{pv}+I_{pv}R_s) \tag{20}$$

$$f'(I_{pv}) = -1 - I_0\left(e^{\frac{q(V_{pv}+I_{pv}R_s)}{AKT}} - 1\right)\left(\frac{q}{AKT}\right)(0+R_s) \tag{21}$$

$$f'(I_{pv}) = -1 - I_o\left(\frac{qR_s}{AKT}\right)\left(e^{\frac{q(V_{pv}+I_{pv}R_s)}{AKT}} - 1\right) \tag{22}$$

Put equations 17 and 21 in Newton Raphson methods formula we find [7,10]

$$I_{pv(n+1)} = I_{pv(n)} - \frac{I_{ph} - I_{pv(n)} - I_o\left(e^{\frac{q(V_{pv}+I_{pv}R_s)}{AKT}} - 1\right)}{-1 - I_o\left(\frac{qR_s}{AKT}\right)e^{\frac{q\left(V_{pv}+I_{pv(n)}R_s\right)}{AKT}}} \tag{23}$$

MATLAB based modelling of PV

It is considered a moderately complex PV module model, which includes the temperature independence of the photocurrent source, the saturation current of the diode, and the series resistance based on the Shockley diode equation. Under the irradiation of solar radiation, photovoltaic cells directly convert part of the photovoltaic Voltage into electrical energy with current, Voltage, and power output relationships. By mathematically equations, Simulink modelling is completed in the succeeding following steps.

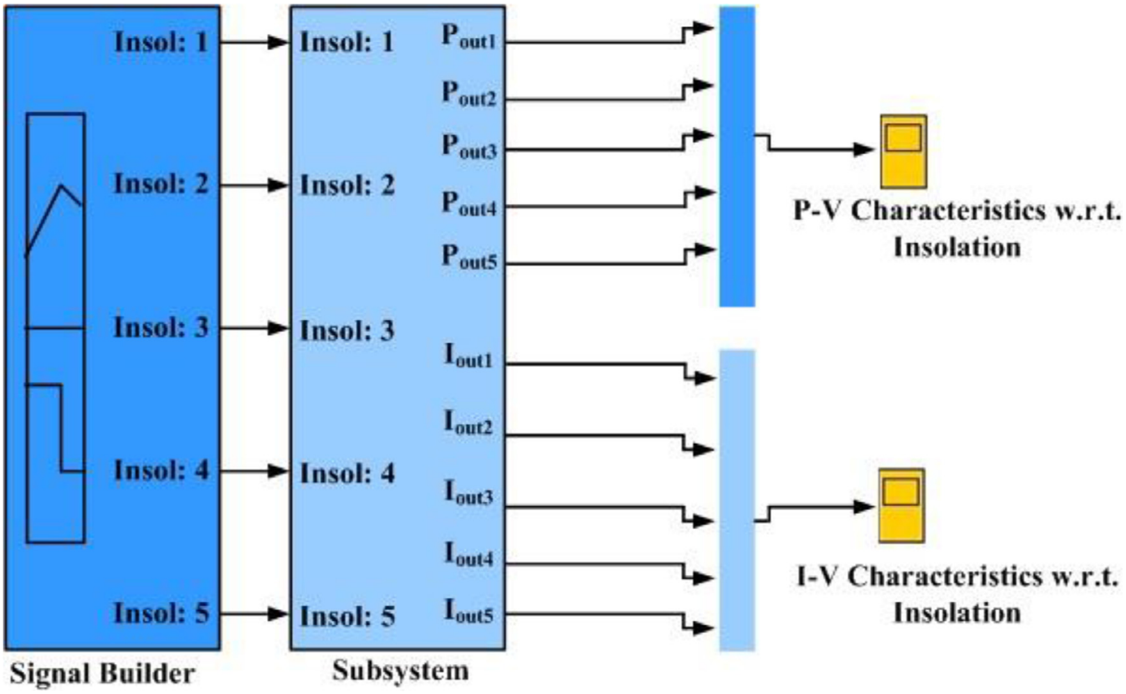

Fig. 5. Simulink based Model of PV for V-I and V-P characteristics w.r.t Insolation.

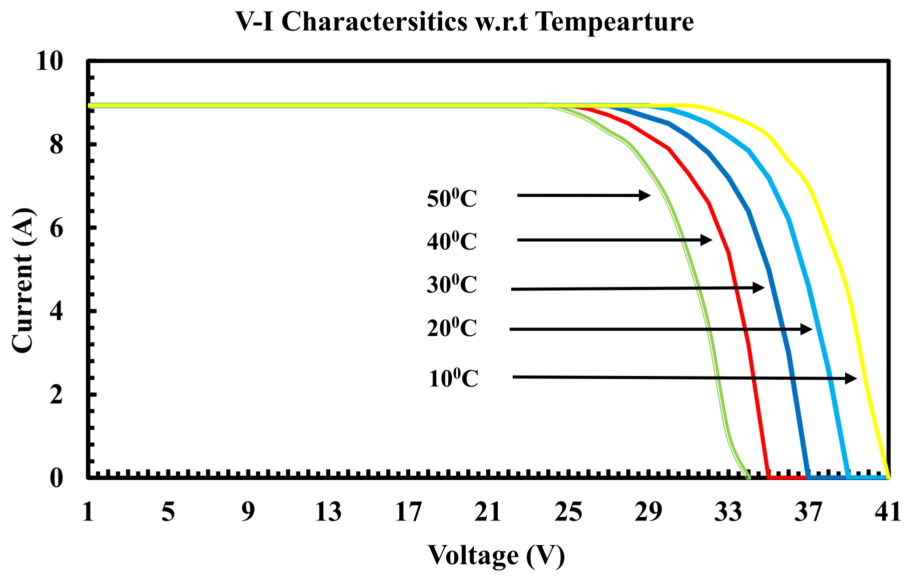

Fig. 6. Simulated V-I Characteristics w.r.t Temperature.

Simulations at distinct temperature situations

Relations between current, Voltage, and power have been analyzed at the different situations of the temperature of the PV module presented in Fig. 4. In this model, there are two boxes from which the first shows the signal builder and the second box shows the output of power.

Simulations at distinct situations of insolation

Relations between current, Voltage, and power have been analyzed in the different situations of insolation of PV module presented in Fig. 5. In this model, there are two boxes from which the first shows the signal builder in which input of insolation and the second box is a subsystem which shows about the output of power and current have been presented to shows the relationship between these parameters of PV.

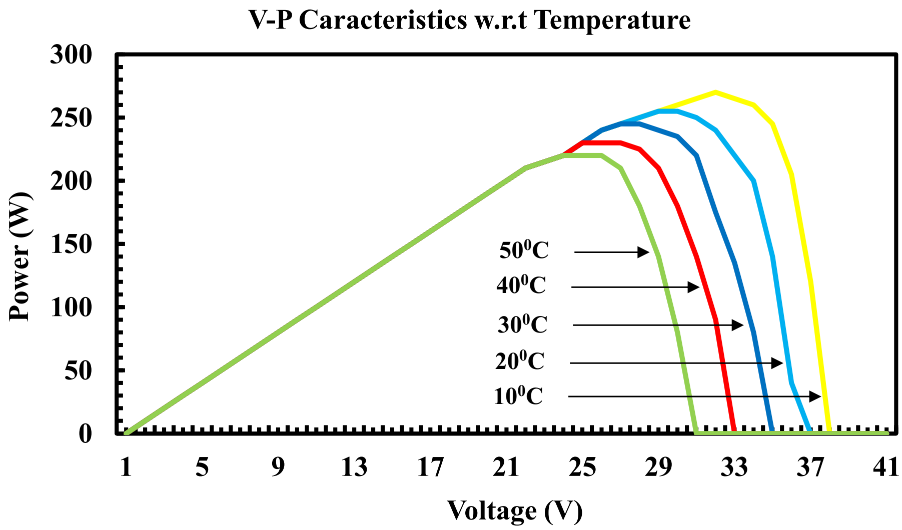

Fig. 7. Simulated V-P Characteristics w.r.t Temperature.

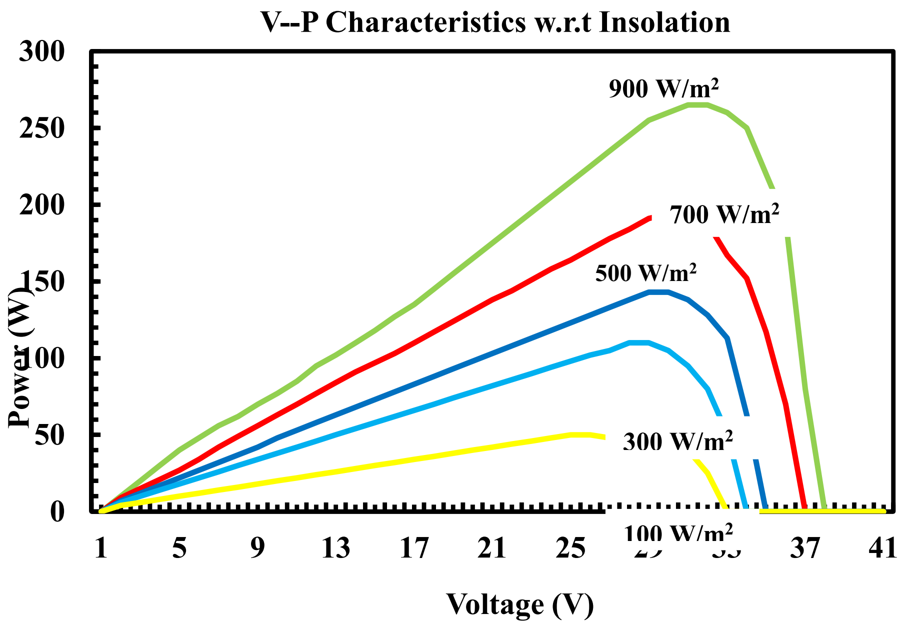

Fig. 8. Simulated V-P Characteristics w.r.t Insolation.

Result and discussion

Simulink distinguishes the mathematical model of the applied photovoltaic system. Simulation is a program that produces a graph-based user interface for creating models. The advantage of Simulink is to create hierarchical models as the system can be visualized at distinct levels. It arranges the ability to develop models, which means that models can be linked to simulate specific systems.

MATLAB based V-I and V-P characteristics of PV

A mathematical model to authenticate the PV model is simulated by MATLAB for the simulation proceeding a thirty-six number cells are joined in series and are retained for the validation of the suggested model and the particulars of this model under standard test conditions are illustrated in Table 1.

Table 1
PV Characteristics [5].

P_{max}	250 W
V_{oc}	34.41V
I_{sc}	8.61A
R_s	0.22 Ohms
R_p	415 Ohms

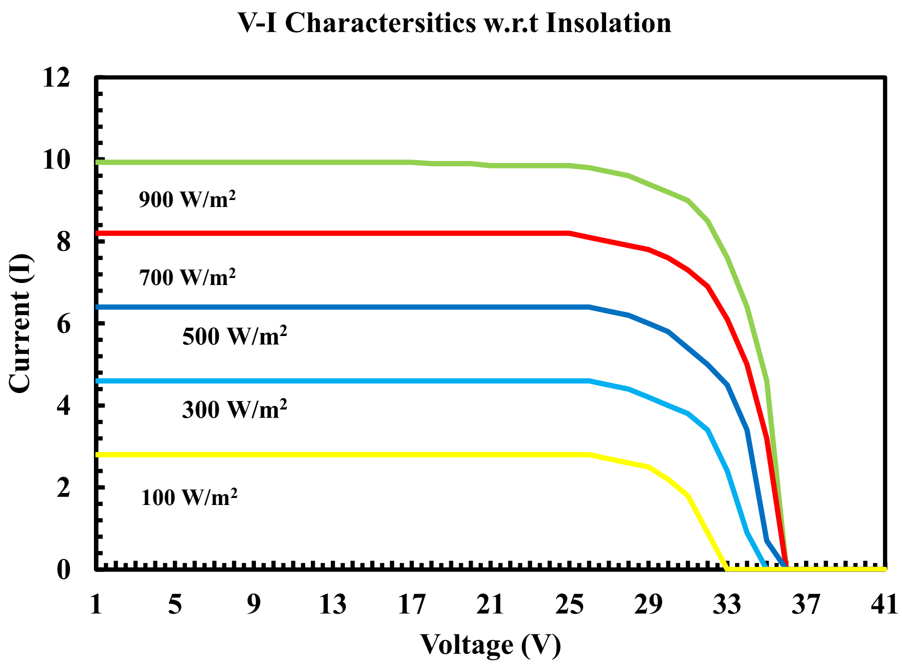

Fig. 9. Simulated V-I Characteristics w.r.t Insolation.

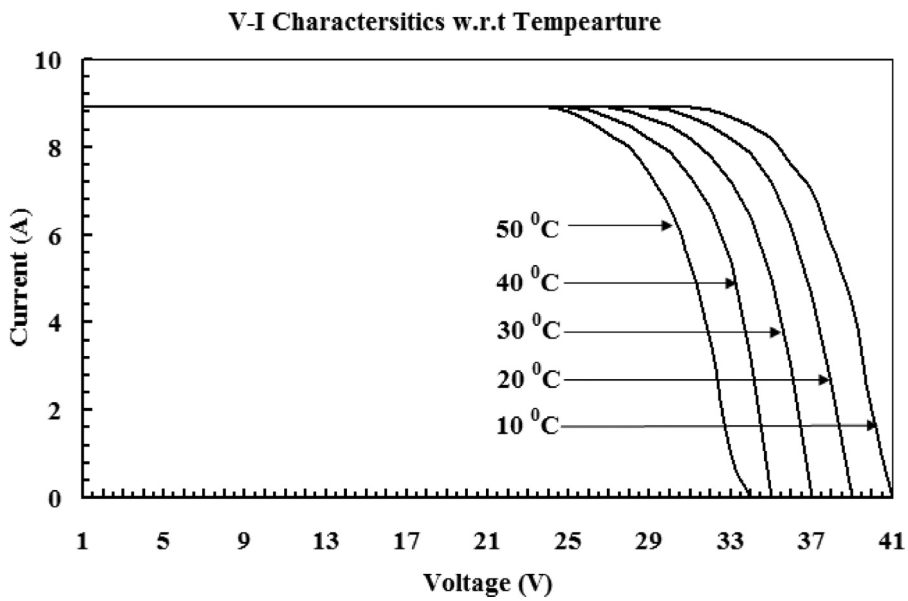

Fig. 10. Experimental based V-I Characteristics w.r.t Temperature.

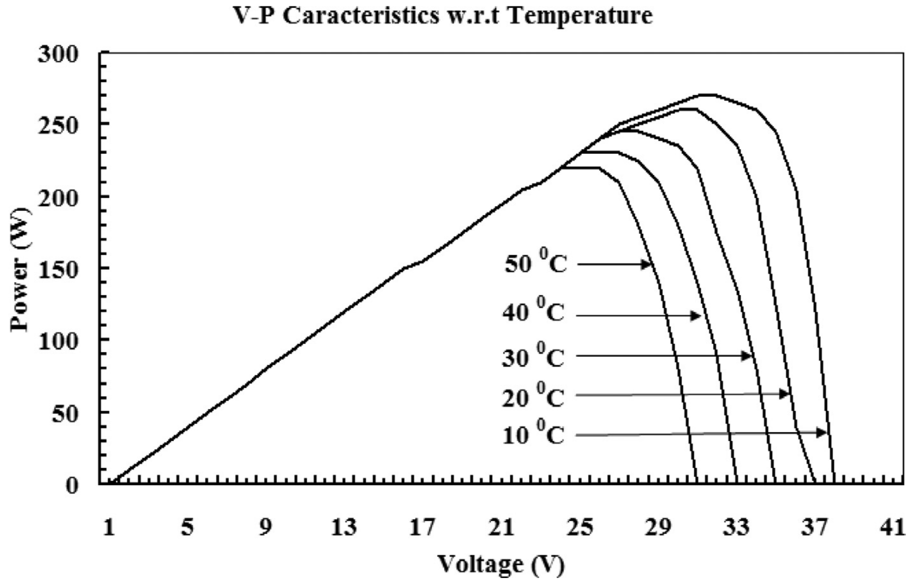

Fig. 11. Experimental based V- P Characteristics w.r.t Temperature.

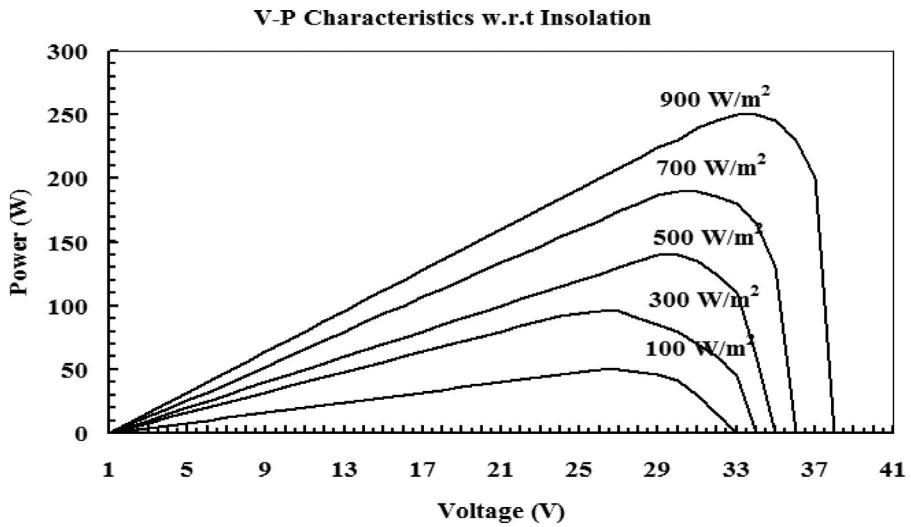

Fig. 12. Experimental based V- P Characteristics w.r.t Temperature.

To analyze the PV model's relationship, five assessments VI and VP curves of single PVM under distinct input situations of temperature have been analyzed. There are different temperature levels as 10 °C, 20 °C, 30 °C, 40 °C, and 50 °C respectively as shown in Figs. 6 and 7, in which the lines illustrate the simulation curves at distinct irradiances levels.

The results obtained show that an increase in temperature leads to an increase in short-circuit current, and an increase in radiation leads to an increase in open- circuit voltage and output power. However, the performance of the device under these conditions is inefficient because all the measured parameters are obtained with low output power at low output. This is due to the effect of radiation on the output power of photovoltaic modules, so even at low temperatures, high radiation will cause the output power to increase.

To analyze, the relationship of the PV model, five assessments VI and VP curves of single PVM under distinct input situations of insolation have been analyzed. There are different insolation levels namely 100 W/m^2, 300 W/m^2, 500 W/m^2, 700 W/m^2, and 900 W/m^2 respectively as shown in Figs. 8 and 9, in which the lines illustrate the simulation curves at distinct insolation levels.

The highest temperature found at maximum solar irradiance is 900 W/m2, and the lowest level observed at low irradiance is 100 W/m2. The temperature difference between these two different levels of solar illuminance is about 49.43%. In addition, solar radiation is also a key factor for photovoltaic panels to generate electricity. It can be seen from Fig. 8 that the maximum output energy increases as the number of solar radiation increases.

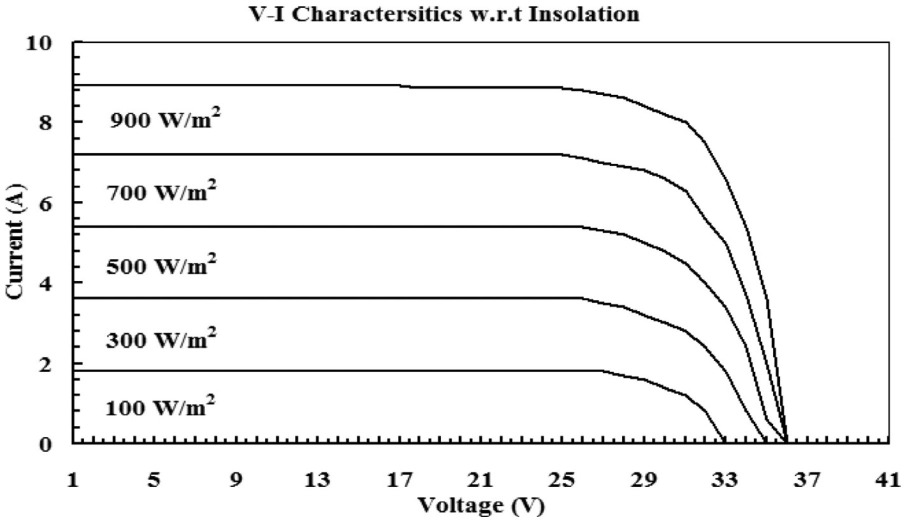

Fig. 13. Experimental based V- I Characteristics w.r.t Insolation.

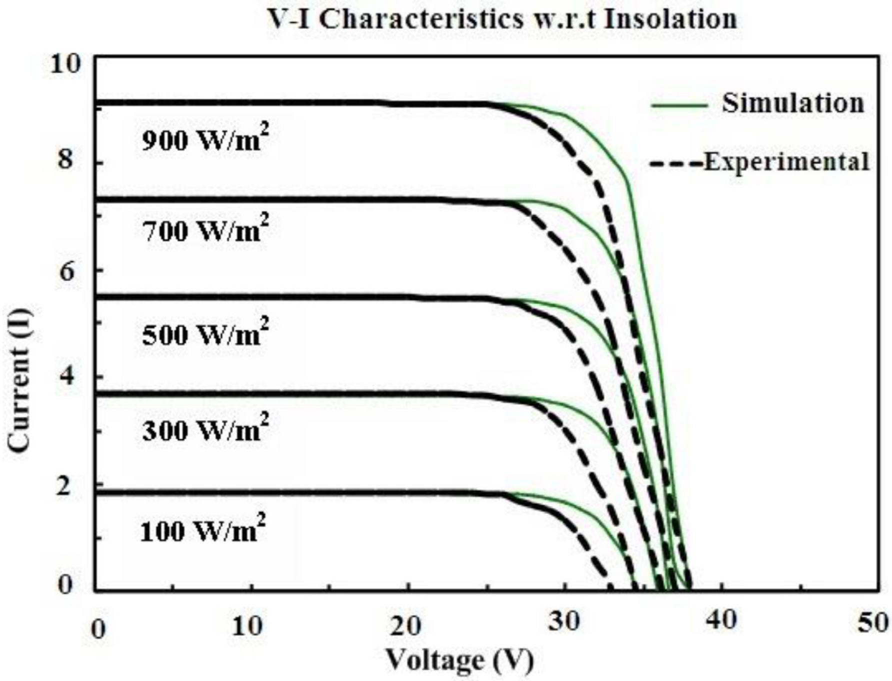

Fig. 14. Comparison V-I Characteristics w.r.t Insolation.

Experimental based V-I and V-P characteristics of PV

Experimental-based analysis the relationship of the PV model at different temperature levels has been presented in Figs. 10 and 11. From the results, there are five readings of VI and PV curves of single PVM under distinct input situations of temperature levels as 10 °C, 20 °C, 30 °C, 40 °C, and 50 °C. At different temperature situations different values of power have been achieved, at 10 °C maximum power and current were 270 W and 9.1 A in 37 and 41 V respectively.

Experimental- based analysis of the relationship of the PV model at different insolation levels has been presented in Figs. 12 and 13. From the results there five readings of VI and VP curves of single PVM under distinct input situations of insolation levels at 100 W/m^2, 300 W/m^2, 500 W/m^2, 700 W/m^2, and 900 W/m^2 have been achieved. At different insolation situations different values of power have been achieved, at 10 °C maximum power and current were 265 W and 8.1 A in 37.5 V respectively.

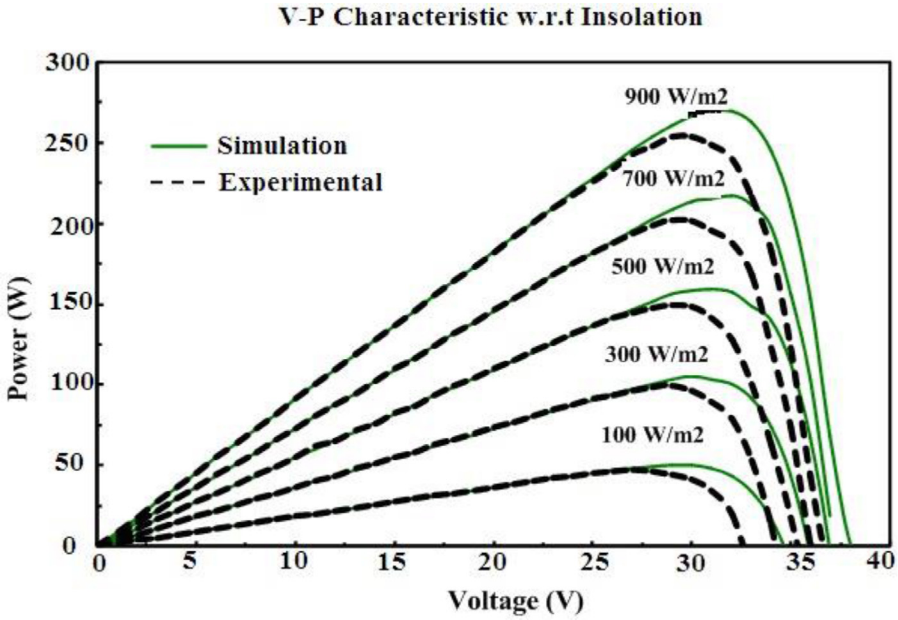

Fig. 15. Comparison V- P Characteristics w.r.t Insolation.

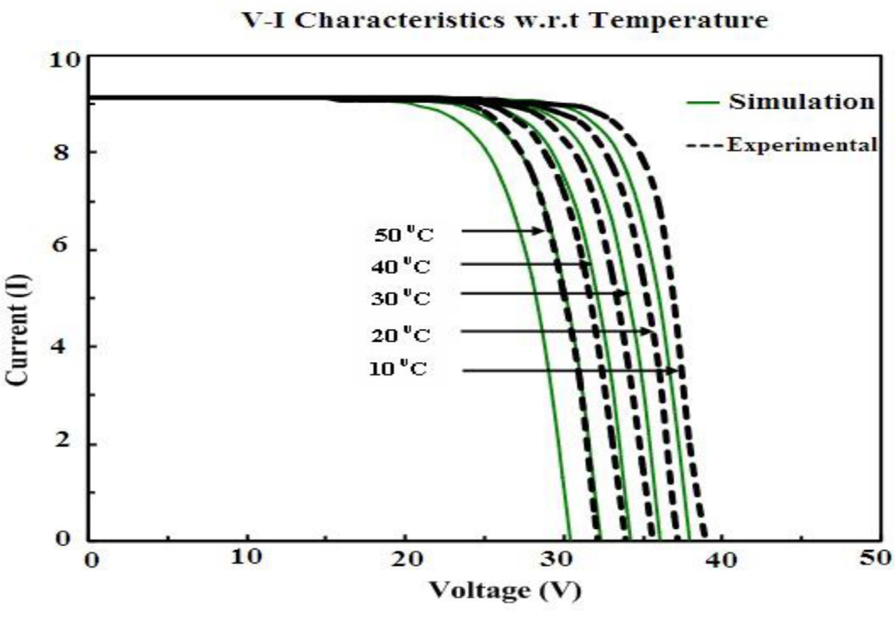

Fig. 16. Comparison V-I Characteristics w.r.t Temperature.

Simulation and experimental based comparison of PV

From the simulation results of the PVM model and the comparison with the experimental results, it can be seen that the effectiveness of these model results corresponds to the linear region and slightly corresponds to the non-linear region, but does not correspond to the saturated region of the experimental results. In the I-V characteristics under different saturation and temperature conditions, the experimental values in the saturation zone are all covering the model values. Variously, in the photovoltaic relationship under different sunshine and temperature conditions, the experimental value in the saturation region is lower than the model value has been presented in Figs. 14 to 17 respectively.

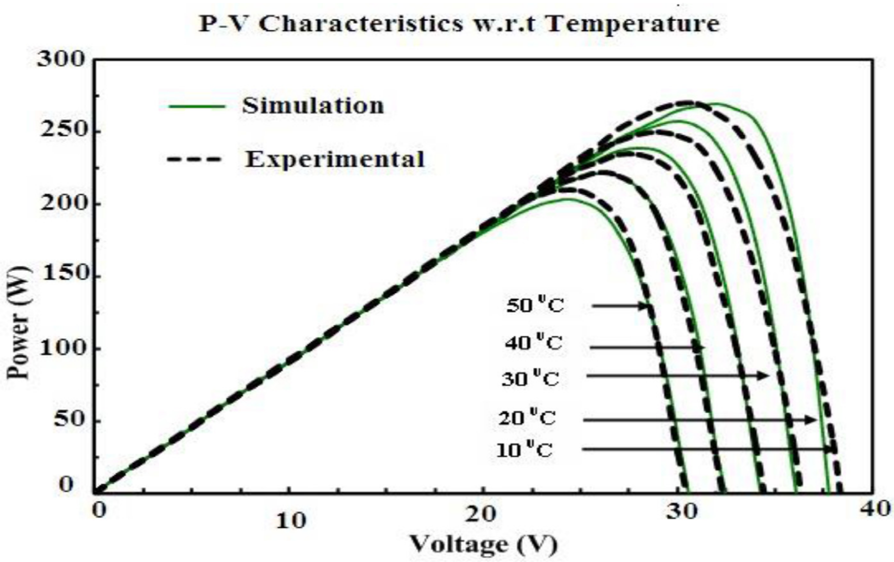

Fig. 17. Comparison P-V Characteristics w.r.t Temperature.

Conclusion

The model developed with the most important electrical parameters applies to the measured I-V properties and can be operated with a few input parameters that demonstrate the graphical and numerical representation of the behavior of a solar model (Figs. 15 and 16).

In this study, a scenario was suggested to simulate a mathematical model of a PVM in MATLAB. The model is verified by contrasting the simulation results with the experimental results. The outcomes manifest that the comparison result provided by the PVM model using the equivalent circuit diagram of medium complexity is that the viability of all models in the linear range is slightly consistent in the non-linear range, but not in the saturation range of the observation range results.

In this paper experimental and MATLAB SIMULINK -based PVM model has been compared. Parameters of the PVM module can be settled independently by applying numerous levels of temperature and insolation to the proposed model. Simulation of the PV model allows enabling and analyses the relationship between V-I, P-V under variability of temperature and insolation for five special assessment results of PVM are discussed. Furthermore, the PV model is recommended only not for performance but it can also be legitimized by Maximum Power Point Tracking (MPPT) in the future.

Declaration of Competing Interest

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