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RESEARCH ARTICLE - ENGINEERING

Modeling, simulation and implementation of photovoltaic panel model by proteus software based on high accuracy two-diode model

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Abstract

The outcome of the present work is to propose a high accuracy two-diode , photovoltaic (PV) panel model. This model is analyzed based on mathematical equations that describe the analogous of the two-diode PV panel circuit. This circuit includes the source of photocurrent, two diodes, a parallel resistor, and a resistor in series. Since, the Proteus software provides in its library many electronic models and microcontrollers, the associated model is modeled and simulated by this software instead of Matlab/ Simulink. Moreover, the proposed model is tested by this more accurate and nearest software for implementation; then the total hardware implementation is built after getting a satisfied simulation result for same components circuit. The proposed model is confirmed by emulating its specification through experimental measurement information. Hence, this PV panel model is linked to the Arduino board with sensors for current and voltage to obtain and monitor the PV panel model parameters. To validate the propose PV panel experimentally, a real component of a 120W prototype PV panel was implemented and the results drawn with its corresponding simulation results. By studying these results, the theoretical analysis of proposed model is very accurate and efficient in extract PV panel parameters comparison with one-diode PV model. Therefore, the obtained proposed simulation and experimental results are very close.

Keywords: Proteus software simulation; Arduino microcontroller; Two-diode PV model; PV experimental set up.

1. Introduction

The rapid worldwide increase in interesting renewable energy is due to active, profit and civilized electrical power sources. Renewable energy has less pollution and inexhaustible nature than traditional energy sources. Moreover, photovoltaic (PV) panel is readily available in most regions. A reliable and accurate emulation of the build PV panel requires a specific and accurate simulation of the desired PV panel prior to implementation. Moreover, the nonlinear characteristic and intense credence depend of PV panel on the solar radiation and ambient temperature demonstrates an important point for researchers in the modeling of the PV panel. For this

Nomenclature			
A/D	Analogue to Digital	K_i	Short circuit current temperature coefficient
DC	Direct Current	N	Multiplication of the diode constant and number of series cells
DSP	Digital Signal Processing	N_s	Number of series cells
LCD	Liquid Crystal Display	$P_{max,e}$	Experimentally maximum power of PV panel from datasheet
NST	National Solar Technologies	P_{pv}	Output power from PV panel
STC	Standard Test Condition	Q	Electron charge
PV	Photovoltaic	R_1	Resistance number one for voltage divider
Symbols		R_2	Resistance number two for voltage divider
G	Solar radiation	R_{s0}	Reference value of the series resistance
G_{STC}	Solar radiation at STC	R_s	Series resistance
I_0	Diode saturation current	R_{p0}	Reference value of the parallel resistance
I_{0-STC}	Diode saturation current at STC	R_p	Parallel resistance
I_{01}	Reverse saturation current for first diode	T	Ambient temperature
I_{02}	Reverse saturation current for second diode	T_{STC}	Ambient temperature at STC (25°C)
I_D	PV panel diode current	V	Output voltage of PV panel
I_{D1}	PV panel first diode current	V_d	Voltage of divider voltage
I_{D2}	PV panel second diode current	V_{mp}	PV panel voltage at MPP
I_{mp}	PV panel current at MPP	$V_{mp,STC}$	PV panel voltage at MPP for STC condition
$I_{mp,STC}$	PV panel current at MPP for STC condition	V_{oc}	Open circuit voltage of PV panel
I_{ph}	Source of photo–current	V_{oc-STC}	Open circuit voltage of PV panel at STC
I_{ph-STC}	Source of photo–current at STC	V_{T1}	Thermal voltage of PV first diode
I_{pv}	Output current of PV panel	V_{T2}	Thermal voltage of PV second diode
I_{sc}	Short circuit current	α	Diode constant
I_{sc-STC}	Short circuit current at STC	α_1	Constant of first diode
K	Boltzmann's constant	α_2	Constant of second diode
K_v	Open circuit voltage temperature coefficient	ΔT	The difference between $(T - T_{STC})$

reason, the simulation of the behavior of a specific PV panel depends on a mathematical model. There are different mathematical models available in the literature, which can be used to make theoretical models. These models will only be approximations to the behavior of the PV panel and the accuracy of the models depends on how many internal phenomena are considered [1,2]. Huan-Liang Tsai, et.al. [1] proposed a generalized model for pv panel based on "Matlab/Simulink" software. This can be improve the PV model characteristic under different weather conditions with simple procedures on simulation platform. S. Chowdhury, et. al. [2] have developed a new theoretical model based on polycrystalline PV panel in "Matlab/Simulink" software and its execution analysis is implemented under different weather conditions, this model represent the voltage source characteristic. M. G. Villalva [3] proposed PV array modeling and simulation using "Matlab/Simulink" program to determine the PV array quantities under three states to provide its characteristics through short circuit current, open circuit voltage and maximum power states for one-diode PV model. A. M. Muzathik [4] modeled and simulated one-diode PV panel in "Matlab/Simulink" for operating cell temperature estimation so as to analyze the influence of weather conditions (cell temperature) on the mathematical equations and the behavior of PV panel. Generally, a two diodes PV model representation is used to obtain the high accuracy characteristics such as current-voltage (I-V) and power-voltage (P-V) curves at different solar irradiation [5-7]. Moreover, these studies used "Matlab/Simulink" tools, which do not contain an electric board or a microcontroller to write the codes and the algorithm for testing the performance of PV model. For this reason, Proteus is a well known simulation software for many designs for electrical and electronics. Moreover, the software does not contain a PV model. Therefore, Saad Motahhir, et. al. [8] focused on a Proteus Spice model of single-diode model of pv panel. In this paper, an accurate and efficient theoretical two diodes PV panel model is suggested by Proteus simulation software. The remarkable contribution here is the introduction of a two diodes PV panel model as the main importance of the proposed paper. The introduced model is confirmed by equating its specification and experimental data. Therefore, by using Proteus software, the mathematical PV model algorithm is simulated, and then the proposed system is implemented under a real component of a 120W prototype PV panel. By connecting the PV panel to the Arduino microcontroller with voltage and current sensors, the voltage, current and power of the PV panel are achieved and observed on LCD screen.

2. Mathematical two diodes PV model

It is assumed in a one-diode representation that the recombination loss is neglected in the depletion region. Furthermore, the substantial loss cannot be exactly modeled [8,9]. Therefore, a real PV model representation of two-diode model is chosen [10]. Fig. 1 shows the two diodes PV model circuit, which consists of a source of photocurrent, two diode currents, a parallel R_p resistor and a resistor in series R_s . The PV output current, I_{pv} is described as [11,12]

$$I_{pv} = I_{ph} - I_{D1} - I_{D2} - \left(\frac{V + I_{pv}\, R_s}{R_p}\right) \tag{1}$$

$$I_{D1} = I_{01}\left[\exp\left(\frac{V + I_{pv}\, R_s}{\alpha_1 V_{T1}}\right) - 1\right] \tag{2}$$

$$I_{D2} = I_{02}\left[\exp\left(\frac{V + I_{pv}\, R_s}{\alpha_2 V_{T2}}\right) - 1\right] \tag{3}$$

Where I_{ph} is the photocurrent, I_{01} and I_{02} are the "reverse saturation currents" for diode 1 and diode 2 respectively. $V_{T1}(= \alpha_1 \times N_s K\, T/q)$ and $V_{T2}(= \alpha_2 \times N_s K\, T/q)$ are the thermal voltages with N_s number of series cells. α_1 and α_2 are the diode constants of diode1 and diode2 respectively. K is a "Boltzmann constant", (1.3806503×10^{-23} J/K) and T is the ambient temperature of in K°. q is the "electron charge"($1.60217646 \times 10^{-19}$C). As mentioned before, high accuracy can be realized using two diodes model, therefore the computation of seven parameters for PV panel I_{ph}, I_{01}, I_{02}, α_1, α_2, R_s and R_p are required. The nonlinear and implicit equations given by equations. (1–3) are solved using iterative method (Newton Raphson method) to find the seven parameters.

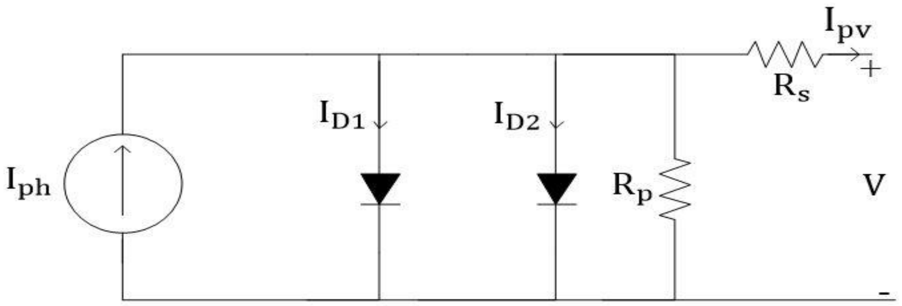

Fig. 1 Mathematical two diodes PV model circuit.

3. Computation process of PV panel model

3.1 Computation of the saturation currents

The photo-current can be expressed as [11-14]

$$I_{ph} = \left(I_{ph\text{-}STC} + K_i\, \Delta T\right)\frac{G}{G_{STC}} \tag{4}$$

Where I_{ph-STC} is the photocurrent at standard test conditions (STC), $\Delta T = T - T_{STC}$ ($T_{STC} = 273$°K), G is the radiation and G_{STC} (1000W/m²) is the radiation at STC. K_i is the coefficient for temperature.

The "diode saturation current" can be expressed as:

$$I_0 = I_{0-STC}\left(\frac{T_{STC}}{T}\right)^3 \exp\left[\frac{q\, E_g}{\alpha\, K}\left(\frac{1}{T_{STC}} - \frac{1}{T}\right)\right] \tag{5}$$

E_g is the energy of band gap of the p-n junction and I_{0-STC} is the diode saturation current at STC condition. Moreover, a modified equation that describes the current in saturation as follows:

$$I_0 = \frac{\left(I_{sc-STC} + K_i \Delta T\right)}{\exp\left[\left(V_{oc-STC} + K_v \Delta T\right)/\alpha V_T\right] - 1} \tag{6}$$

Where V_{oc-STC} is the "open circuit voltage" at STC, I_{sc-STC} is the "short circuit current" at STC and K_V is the constant of temperature coefficient. Furthermore, the values of currents for two diodes model (I_{01} and I_{02}) are computed using newton Raphson method from Eqs.(6-8) [6]. In general, I_{01} is about 3–7 orders larger than that of I_{02}. In order to simplify the calculation, α_1 and α_2 are taken to be 1 and 2 respectively. Therefore, these currents can be calculated as.

$$I_{01} = \frac{\left(I_{sc-STC} + K_i \Delta T\right)}{\exp\left[\left(V_{oc-STC} + K_v \Delta T\right)/\alpha_1 V_{T1}\right] - 1} \tag{7}$$

$$I_{02} = \frac{\left(I_{sc-STC} + K_i \Delta T\right)}{\exp\left[\left(V_{oc-STC} + K_v \Delta T\right)/\alpha_2 V_{T2}\right] - 1} \tag{8}$$

3.2 Computation of series and parallel resistances

The series and parallel resistances are not provided in data sheet of PV panel, it can be evaluated independently, and then the result will be unsatisfactory [9]. In this paper, R_s and R_p are computed simultaneously by matching the point for mathematical maximum power (P_{mp}) and experimental maximum power provided in the datasheet of the PV panel ($P_{max,e}$) by iteratively, increasing the value of R_s while simultaneously computing R_p . In this paper, PV panel from national solar technologies NST-120 is used. Table 1 presents the parameters of PV panel model. At maximum power point condition, the parallel resistance R_p is calculated according to Eq. (1) as follows [10]:

$$R_p = \frac{V_{mp,STC} + I_{mp,STC} R_s}{\left\{ I_{ph} - I_{01}\left[\exp\left(\frac{V_{mp,STC} + I_{mp,STC} R_s}{\alpha_1 V_{T1}}\right) - 1\right] - I_{02}\left[\exp\left(\frac{V_{mp,STC} + I_{mp,STC} R_s}{\alpha_2 V_{T2}}\right) - 1\right] - \frac{P_{max,e}}{V_{mp,STC}} \right\}} \tag{9}$$

The reference conditions for compuing both resistances are expressed as follows:

$$R_{s0} = 0;$$
$$R_{p0} = \frac{V_{mp,STC}}{I_{sc,STC} - I_{mp,STC}} - \frac{V_{oc,STC} - V_{mp,STC}}{I_{mp,STC}} \tag{10}$$

The reference value of the parallel resistance, R_p is the slope of the line section between peak power points and short circuit current. The parallel resistance, R_p is determined simultaneously for every iteration using Eq. (9). The computed values of the proposed PV model resistances are obtained (R_s =0.18 Ω and R_p =360 Ω). The flowchart that computes the resistances by matching PV power is indicated in Fig. 2.

Table 1. Parameters of the PV panel NST-120

Parameter	Value	Unit
V_{oc}	23.8	V
I_{sc}	7.14	A
V_{mp}	18.9	V
P_{mp}	120	W
I_{mp}	6.40	A
K_i	2	mA/°C
K_V	-70	mV/°C
I_{01}	5.31050e-11	A
I_{02}	1.947234e-5	A
I_{ph}	7.17	A
α_1	1	-
α_2	2	-

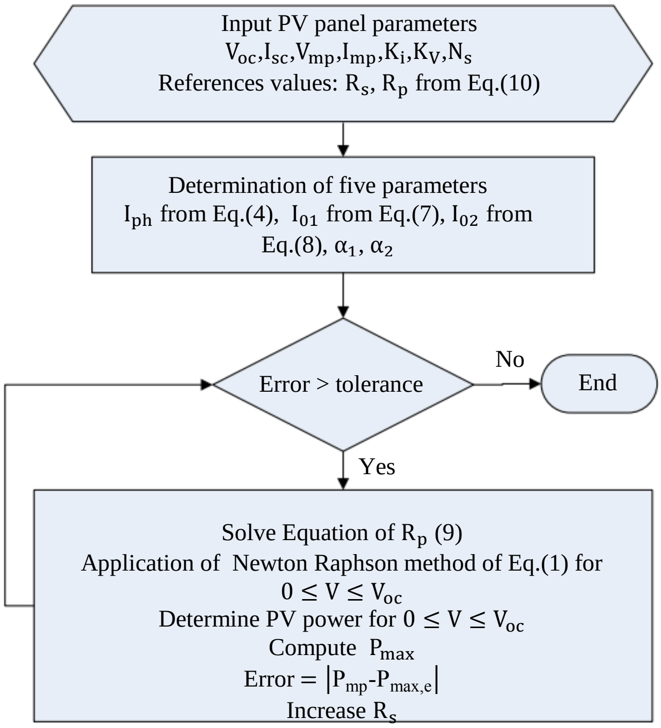

Fig.2 The flowchart of matching PV power.

4. Modeling two-diode PV model in proteus software

To simulate a robust model of PV panel in Proteus software, the two-diode model equivalent circuit should be considered with a striped current source to represent the photocurrent source, two-diode with modified spice code, a series and parallel resistances. Figs. 3 and 4 represent the PV panel model in Proteus software with one and two-diode model respectively. The following steps has been used:

I. A "Voltage controlled current source" it is controlled by "DC voltage source" block. It is utilized to model the photocurrent of PV panel. It was found that the "DC Voltage Source" have to be selected to a value of 7.17 V to verify the photocurrent under STC.

II. A modified spice code is used to represent the main model parameters for the two diodes PV model in Proteus software, as presented in Fig. 4. This code is written to confirm the values of PV model parameters such as the saturation currents (I_{01} and I_{02}), the diode constants ($\alpha_1$and α_2), number of cells (N_s), the p-n junction temperature (T) and energy of band gap (E_g) according to the specification of NST-120. The value of N is determined by the multiplication of the diode constant and number of series cells, therefore for diode number one, N is set to 36 ($\alpha_1 \times N_S$) and diode number two N is set to 72 ($\alpha_2 \times N_S$).

III. A "DC voltage Source" it is added to represent the value of the variable resistive load. In order to simulate the two-diode PV model "DC SWEEP ANALYSIS" graph is used with "sweep variable" equal to the variable load as in Fig.4, it is mentioned that the range simulation value of "sweep variable" should be between (0V-23.8V).

IV. A series and parallel resistors are used in order to model PV panel; their values are mentioned in the section **3**

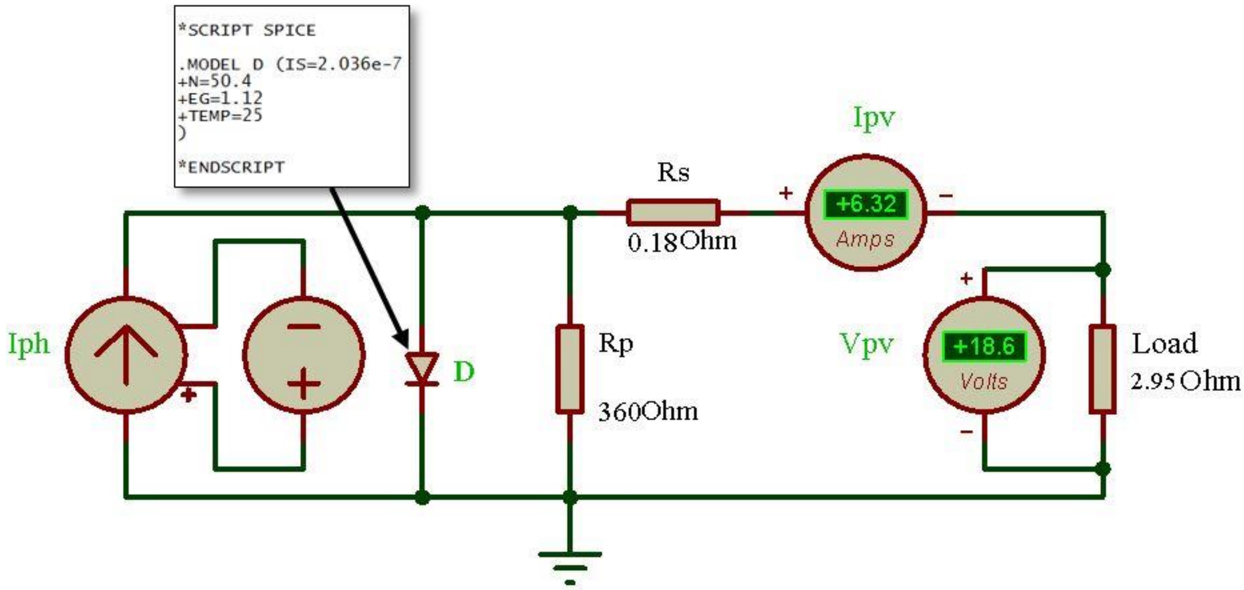

Fig. 3 The one-diode PV model in Proteus software.

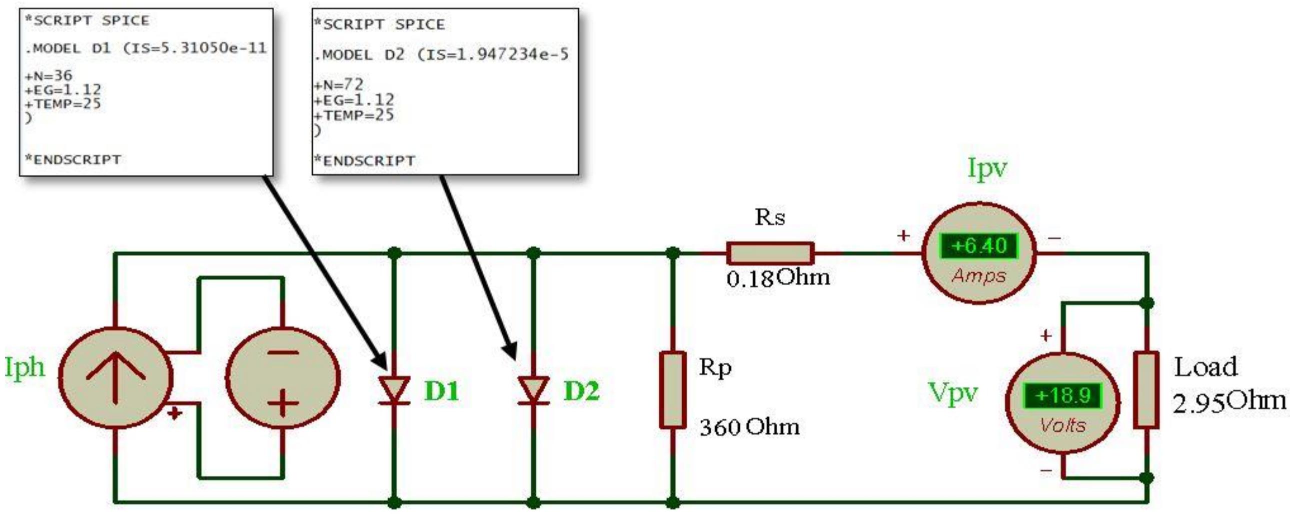

Fig.4 The proposed two-diode PV model in Proteus software.

In order to simplify the PV panel model, a sub-circuit in Proteus is created as shown in Fig. 5. Furthermore, the proposed PV panel model is linked to resistive load value 2.95 Ω; this value represents the optimum load that achieves the maximum power point (V_{mp} / I_{mp}).

Any microcontroller, such as microprocessor or DSP can control the PV panel modelled in Proteus software. In this paper, Arduino uno and Proteus software will realize a compatible and successful PV panel model, which is close to reality as shown in Fig. 6. Therefore, the PV panel characteristics is achieved by computing the voltage, current and power values of the PV panel which can be supervise easily, which represent one of the aims of this work.

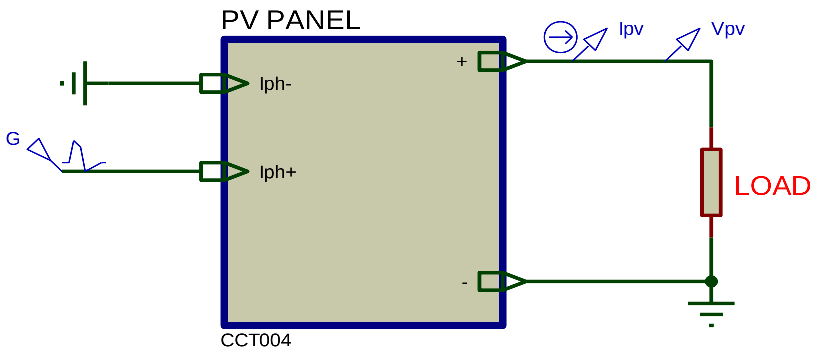

Fig. 5 The sub-circuit diagram for proposed model in Proteus software.

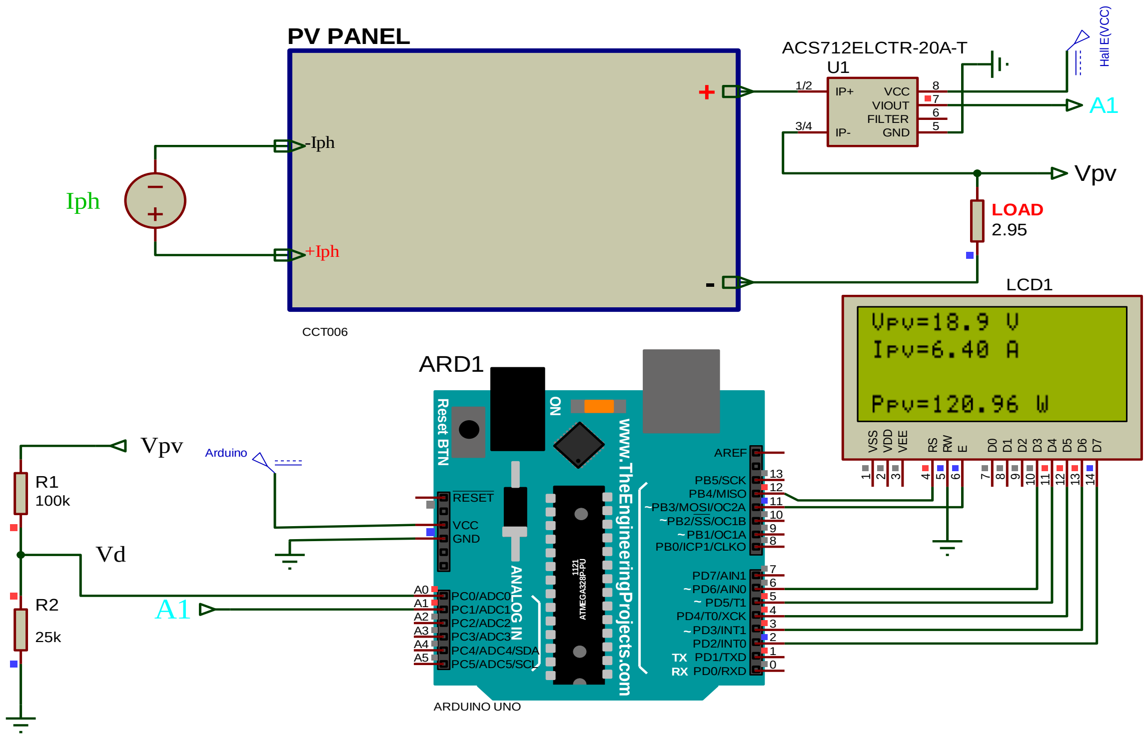

Fig. 6 The proposed PV panel model components under Proteus software.

5. Experimental set up for the proposed two diodes PV model

As shown in the section 4, so as to implement the performance of PV panel during real experience, various realistic components are used apart PV panel like Arduino uno board, LCD, voltage sensor and current sensor as shown in Fig. 7 as follows:

Microcontroller: The expansion microcontroller board utilized here is the Arduino uno, in which the ATMega 328 microcontroller is inserted. It provides a wide range board with low cost.

Current sensor: The Hall-effect current sensor No. ACS712ELCTR-20A-T is used in this work to sense the PV panel current as shown in Fig. 8.

Voltage sensor: The two resistances are used as a voltage divider to represent the voltage sensor. Moreover, due to the incapability of Arduino microcontroller board to read input voltage exceeding 5V for A/D pins, therefore the input PV panel voltage is reduced to another voltage (V_d) between (0-5V).

$$V_d = (R_2/(R_2 + R_1))*V_{PV} \tag{9}$$

The range of PV panel voltage which is used in this work is about 0 – 23.8V, therefore voltage divider voltage (V_d) should be lower or equal to 4.76V. Hence, the high power resistors are required to depress the absence of energy (as voltmeter). Since, the values of $R_1$and R_2 are selected with a value equal to 100k Ω and 25k Ω respectively.

LCD Screen: In this paper, the 16×4 (liquid crystal display) LCD screen is used to show the PV panel current, voltage and power values under different weather conditions.

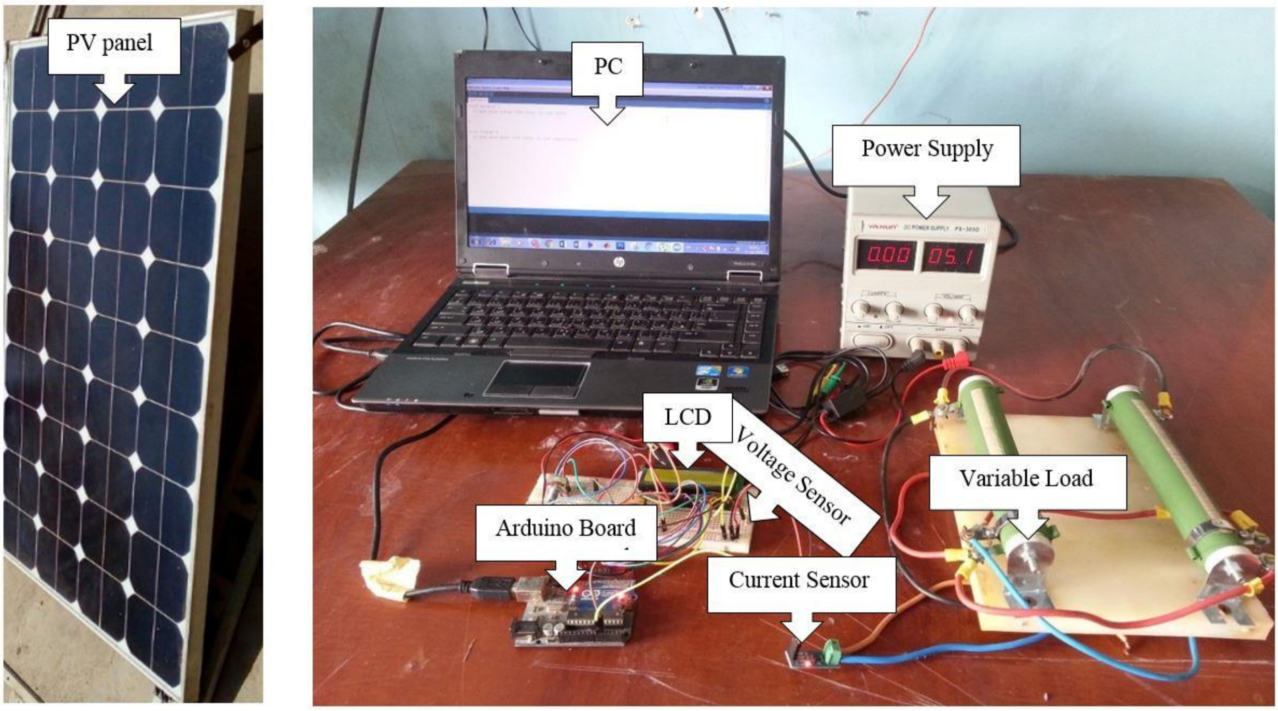

Fig. 7 Hardware implementation set-up for experimental test.

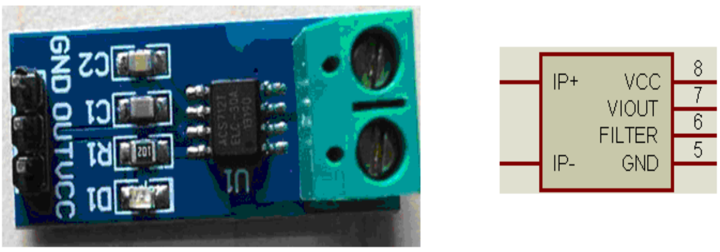

Fig. 8 Hall-effect current sensor.

6. Results and discussions

The simulation mathematical model for PV panel using two-diode model is presented using Proteus simulation software. The proposed circuit is joined to a resistive load. Hence, the voltage and current of the PV panel are handled and then the PV power is computed according to changing weather conditions. Therefore, the results of the proposed model parameters is presented on the 16x4 LCD screen. The simulation results for I–V and P–V curves for the proposed two–diode model are given in Figs. 9 and 10. It is clear that a high accuracy proposed mathematical model is achieved in computation of the PV panel parameters which are near to the data sheet parameters. Moreover, Fig. 11 shows the solar irradiance level (Pwlin Generator) under Proteus software which is calculated to represent 1kW/m². Fig. 12 shows the voltage, $V_{pv} = 18.7$ V and current, $I_{pv} = 6.4$ A values of the PV panel model under Proteus software at G=1 kW/m² and ambient temperature T=25 °C. Figure 13 shows the output power from the PV panel model, $P_{mp} = 120$ W under Proteus software at G=1 kW/m² and T=25 °C. In order to test the proposed model under different solar irradiation, the step changed irradiance level (Pwlin Generator) for values (1 kW/m²,0.5 kW/m²,0.5 kW/m²) is used as shown in Fig.14. Fig. 15 shows the voltage and current values of the PV panel model at the step changed irradiation level. The output power of the PV panel model at the step changed irradiance level is shown in Fig.16. The characteristics of PV panel that is obtained here verify exactly the specification of the data sheet. To confirm the operation and execution of the developed experimental set up, a 120 W prototype PV panel has been implemented. The experiment data have been collected in a sunny day, (Iraq, Baghdad on 21 February 2018), test conditions of irradiance equal to G=320 W/m² and operating temperature, T=18 °C. It is mentioned that the same irradiance and operating temperature are used in Proteus to compare the I-V and P-V curves with that in the experimental proposed model as presented in Figs.17 and 18.

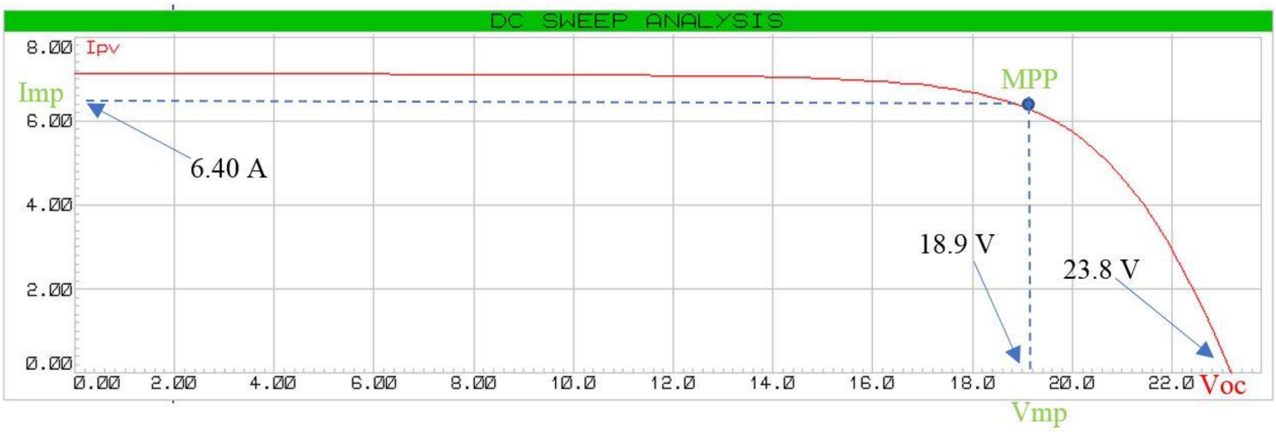

Fig. 9 I-V curve for proposed PV panel under Proteus software.

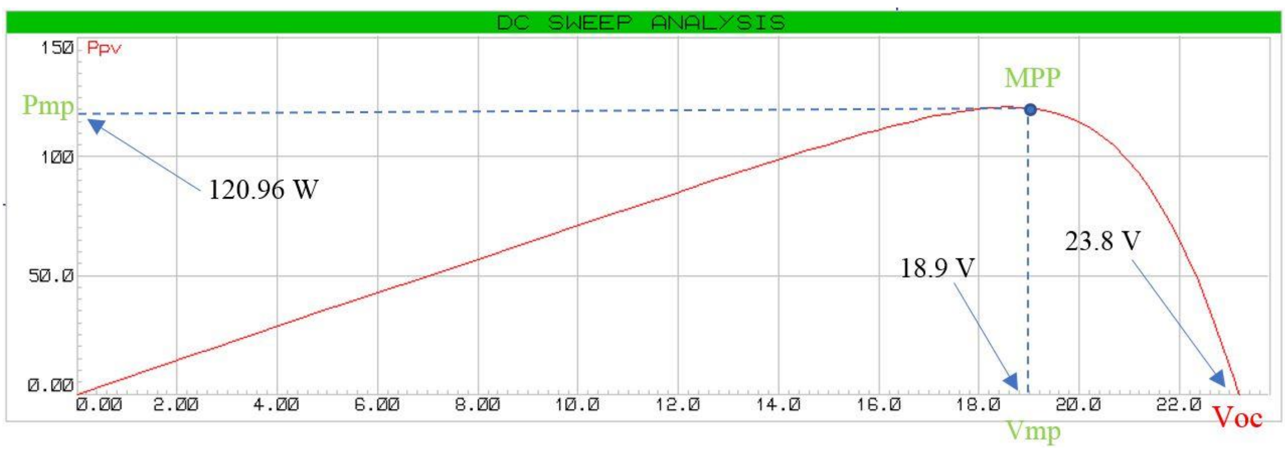

Fig. 10 P-V curve for proposed PV panel under Proteus software.

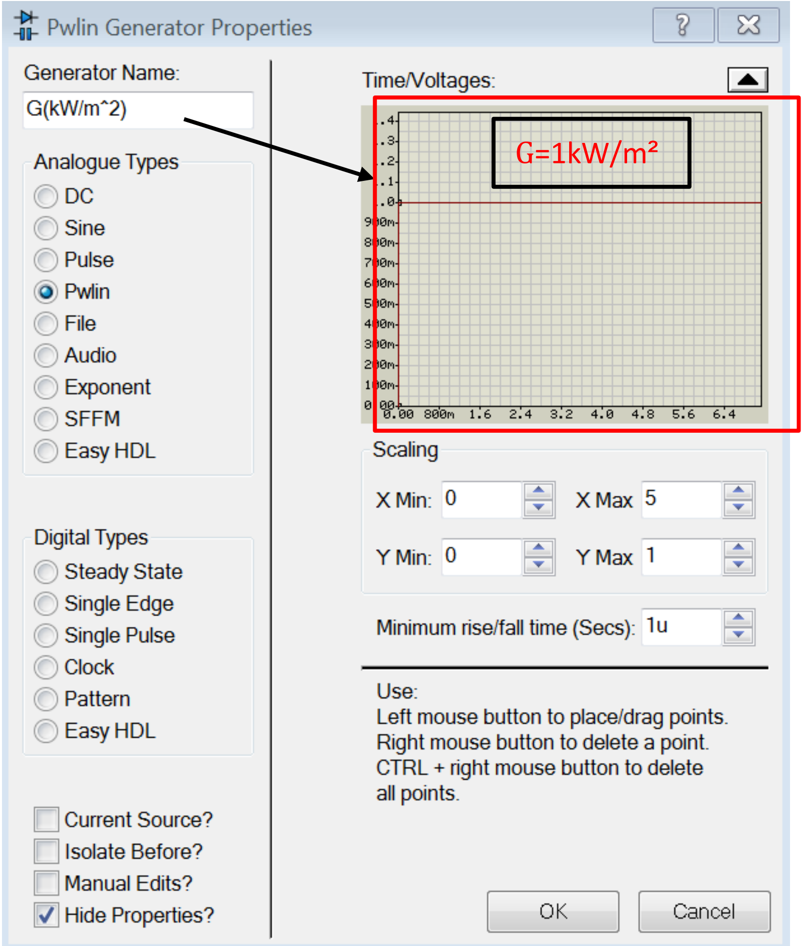

Fig.11 Constant solar irradiance level, G=1 kW/m² under Proteus software.

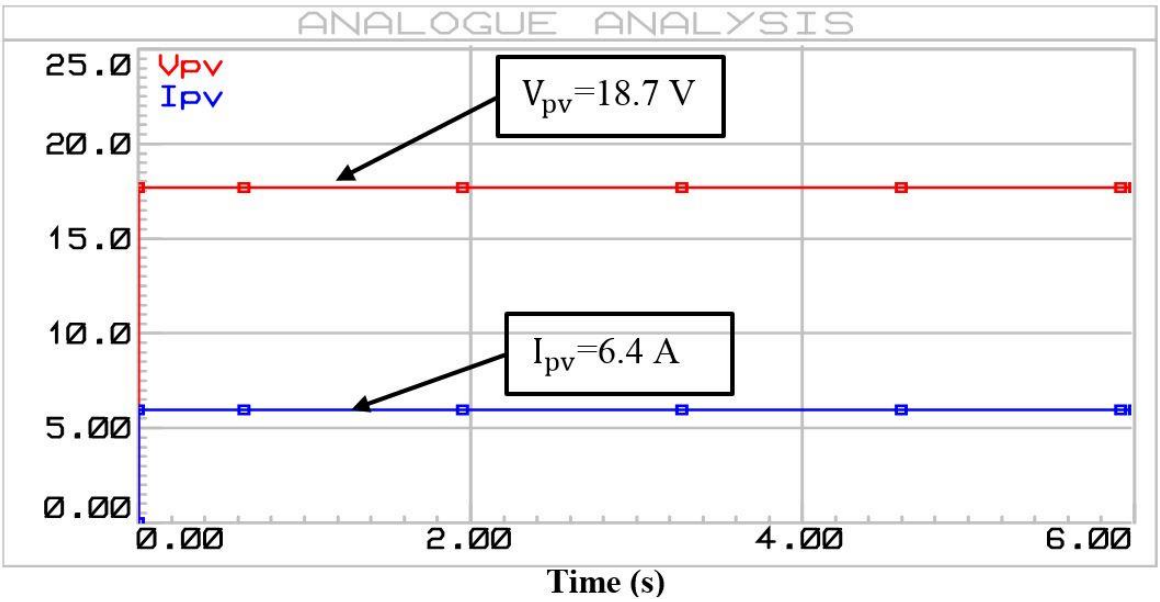

Fig. 12 Voltage and current values of the proposed PV panel under Proteus software at G=1kW/m² and T=25 °C.

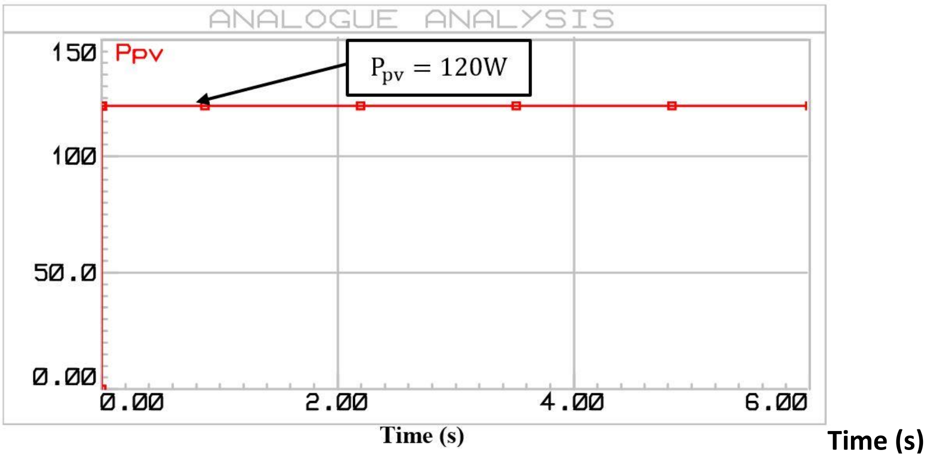

Fig. 13 The PV output power under constant irradiance in Proteus software.

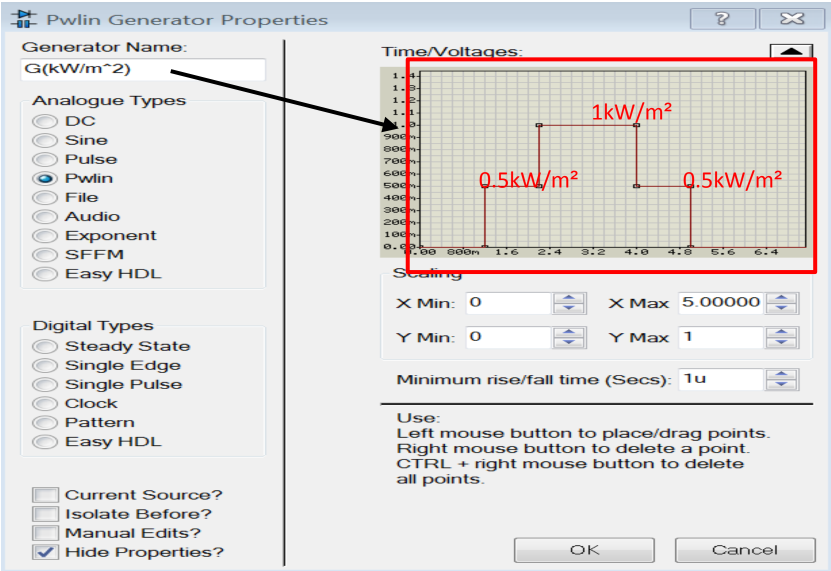

Fig.14 Step changed irradiance in Proteus software.

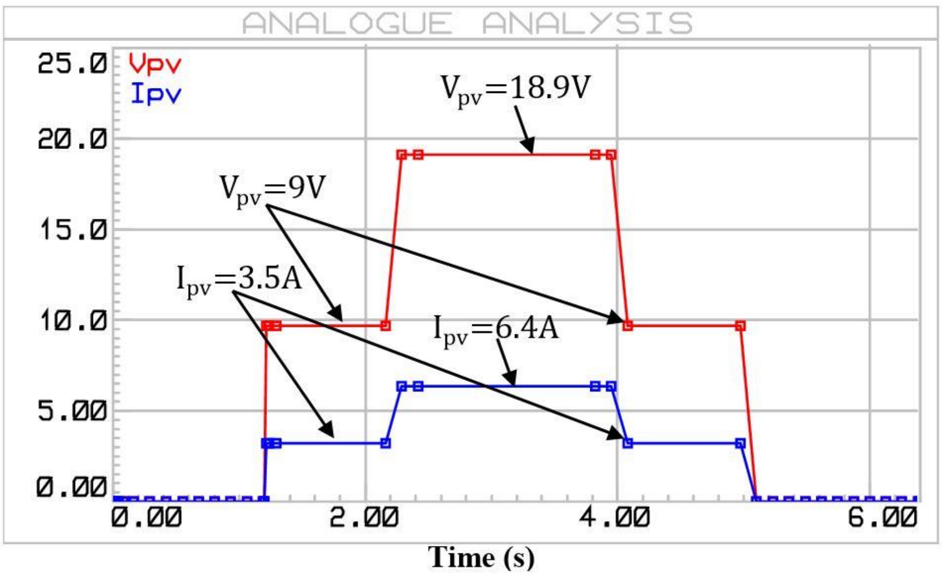

Fig. 15 The proposed model response (voltage and current) under fast changing irradiance.

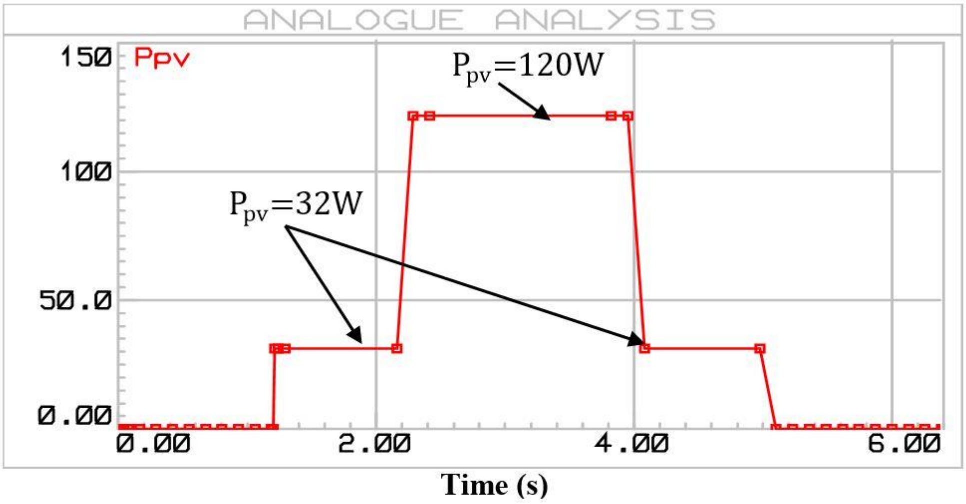

Fig. 16 The proposed model response (power) under fast changing irradiance.

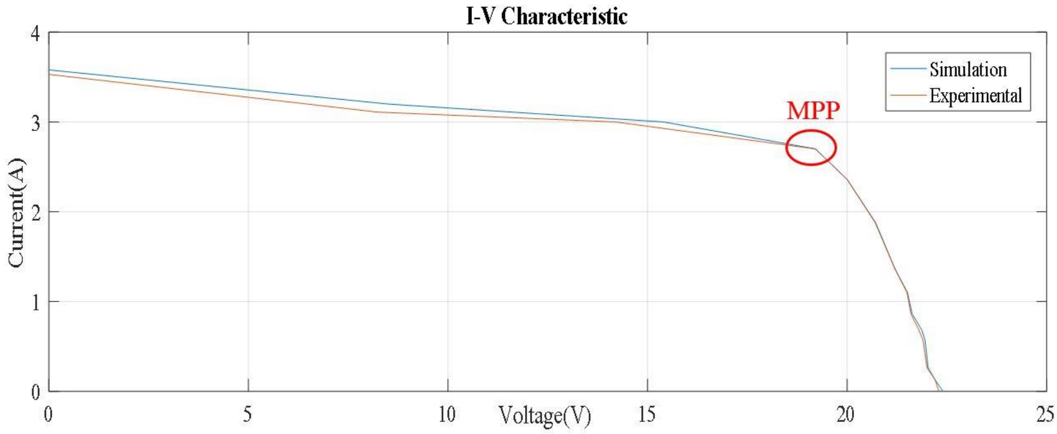

Fig.17 I-V curve of proposed PV panel model for G=320 W/m² and T=18 °C (simulation and experimental results).

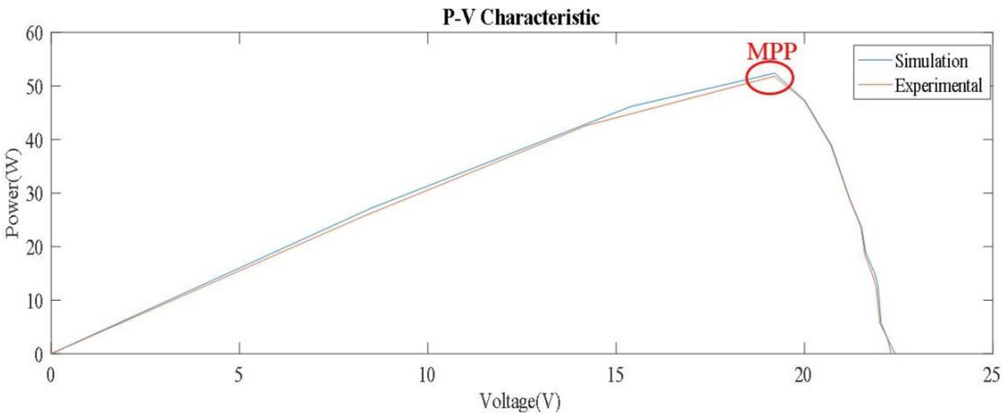

Fig.18 P-V curve of proposed PV panel model for G=320 W/m² and T=18 °C (simulation and experimental results).

7. **Conclusion**

In this paper, a PV panel model based on a high accuracy mathematical two diodes model is presented. The present PV model is also confirmed by emulating its specification with practical data for a 120W PV panel prototype. Hence, theoretical analysis of the proposed PV model realized more accurate and efficient than the model of single-diode in mathematical representation for PV panel. Experimental set up is done using real PV panel components with the same Arduino code that is used in Proteus software. By using Proteus software, the time adjust for treating decreases run time errors through the experiment. For this reason, Proteus software is used instead of Matlab/Simulink. Therefore, a good performance is achieved in modeling of the PV panel, because the same Arduino code algorithm and components are used in both simulation and experiment. Furthermore, the theoretical analysis of the proposed model circuit is obtained, which lead to more accurate results in extract PV panel parameters used in the modeling process. Finally, simulation and experimental results are obtained to be in close agreement with the theoretical analysis.

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