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Performance Analysis of Different Solar Models Based on the Solar cell Parameters

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In this paper author present performance analysis between solar models based on accuracy, temperature, solar irradiance, resistances, output voltage and ideality factor of solar cell. In past literature various model of solar cell are presented, like one diode model and double diode model. This paper describes a comparative analysis between one-diode, two-diode and three-diode models of PV cell. To examine the accuracy of each model from information given through the past researcher, this paper differentiates the current-voltage (I-V) and power-voltage (P-V) characteristics performance at standard test condition (STC). The utmost frequently used models are one-diode and two-diode models, as they offer healthier relationships with a real solar cell. Authors compared different solar cell models based on above parameter and found that one-diode model provides supplementary accurate result as related to two-diode model for high intensity solar irradiation. While two-diode model is further correct for short intensity solar irradiation.

Keywords: PV, Diode models, Cell parameters, Solar irradiance

1 Introduction

A PV system is a function conversion of energy, which directly converts solar radiation into electricity with the help of solar cell. A group of solar cells form a panel or an array. Power electronic converters help in converting solar energy to electricity from PV system[1]. Environment issues and global customers awareness pushing for sustainable neat and clean energy sources. The sun is contributing secure renewable energy, which is infinite and free from CO_2 emission[2]. To assemble the solar cell, silicon material is used, it produces inadequate power because of low conversion efficiency. In a PV based power system, improvement of conversion efficiency is very important[3]. The accuracy mainly depends on the modelling of PV cell[4-7]. Generally, a PV segment is designed by joining PV cell in sequences of series-parallel and PV panels are formed via involving these PV segments again in sequences of series-parallel. A group of PV panels form a PV array[8]. To upsurge the productivity of PV structure, the PV structure must be run near/at maximum tracking power point (MPPT). When solar irradiation decreases, short circuit current is also decrease and at the same time power at the MPPT is also decreases with increase in the temperature[9]. Simulation modelling of the solar model is required to analyse the real behaviour of one diode, two diode and three diode models under different environment conditions and solar parameters. Different solar models have been used at various solar irradiation and temperature for study of complete PV system[10]. This paper presents different models with different parameter extraction. The solar parameters extraction is photocurrent (I_{ph}), saturation current (I_0), shunt resistance (R_{sh}), series resistance (R_{se}) and ideality factor of diode (*n*). The accuracy of the system characterizes the complexity of the model.

An analysis of the performance characteristics of 1-diode model, 2-diode model and 3-diode model is important to decide the model type to be used[11]. In this work, the performance analysis of PV cell model are taken under standard test condition (STC) with insolation of 1000 W/m^2. Performance of the model is evaluated by the structure of the equivalent circuit and electrical parameters of its circuit model. P-V and I-V characteristics performance of the solar model is analysed through the parameter values provided by the manufacturer signifying various cell parameters.

2 Modelling of PV cell

Three forms of models used in PV cell modelling. These models are one diode, two diode and triple diode based. Mostly one diode and two diode model for PV cell are used to study output characteristic of PV module[12]. While this paper has extended the analysis with the inclusion of three diode model.

2.1 Practical form of One Diode Model

One diode model is also known as five parameters ($I_0, R_{sh}, R_{se}, I_{ph}, n$) model and consists of series-parallel

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resistances connected with diode and current source as depicted in Fig. 1.

Mathematical equation as:

$$I_d = I_0\{e^{(V_d/nV_T)} - 1\} \quad \ldots (1)$$

$$V_T = \frac{kT}{q} \quad \ldots (2)$$

Where V_d is diode output voltage and V_T is terminal voltage. The charge of the electron (q = 1.6×10^{-19} C) and Boltzmann constant (k =1.3805 × 10^{-23} *J/K*).

$$I = I_{ph} - I_d - I_{sh} \quad \ldots (3)$$

$$V_d = V + IR_{se} \quad \ldots (4)$$

$$I = I_{ph} - I_o\{e^{(V+IR_{se}/nV_T)} - 1\} - I_{sh} \quad \ldots (5)$$

Where *V* is output voltage. If quantity of cells N_s are allied in series then *I* become as,

$$I = I_{ph} - I_o[e^{\{q*(V+IR_{se})/N_s knT\}} - 1] - I_{sh} \quad \ldots (6)$$

Series resistance (R_{se}), is connected to account the voltage drop and internal losses while shunt resistance is connected to account for the leakage current[13-15].

2.2 Double Diode Model

Two diode Model as shown in Fig. 2, consist of two parallel diodes connected across the current source. R_{sh}, R_{se}, I_{d1} are identical as used in one diode model. Diode current I_{d2} is recombination current of I_{d1} and I_{ph} in a region of space charge. Current equation of double diode model is,

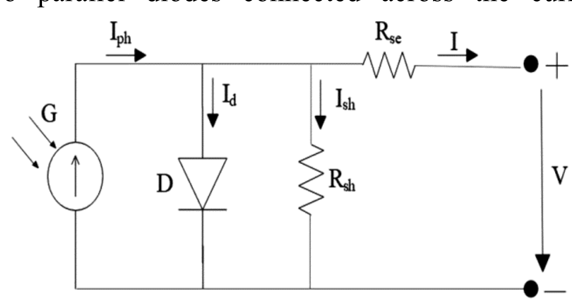

Fig. 1 — Practical form of one diode model

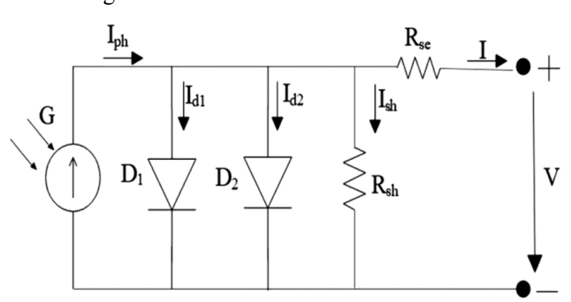

Fig. 2 — Two diode model

$$I = I_{ph} - I_{d1} - I_{d2} - I_{sh} \quad \ldots (7)$$

$$I_{d1} = I_{o1}\{e^{(V_d/n_1V_T)} - 1\} = I_{o1}\{e^{(qV_d/n_1kT)} - 1\} \quad \ldots (8)$$

$$I_{d2} = I_{o2}\{e^{(V_d/n_2V_T)} - 1\} = I_{o2}\{e^{(qV_d/n_2kT)} - 1\} \quad \ldots (9)$$

$$I = I_{ph} - I_{o1}\{e^{(qV_d/n_1kT)} - 1\} - I_{o2}\{e^{(qV_d/n_2kT)} - 1\} - I_{sh} \quad \ldots (10)$$

For N_s cells in series then the Eq. 10 becomes,

$$I = I_{ph} - I_{o1}[e^{\{q*(V+IR_{se})/N_s n_1 kT\}} - 1] - I_{o2}[e^{\{q*(V+IR_{se})/N_s n_2 kT\}} - 1] - I_{sh} \quad \ldots (11)$$

Where I_{o1} and I_{o2} are overload current of diode first and second respectively.

2.3 Three Diode Model

Three diode model is as illustrated in Fig. 3.

$$I = I_{ph} - I_{d1} - I_{d2} - I_{d3} - I_{sh} \quad \ldots (12)$$

$$I_{d1} = I_{o1}\{e^{(V_d/n_1V_T)} - 1\} = I_{o1}\{e^{(qV_d/n_1kT)} - 1\} \quad \ldots (13)$$

$$I_{d2} = I_{o2}\{e^{(V_d/n_2V_T)} - 1\} = I_{o2}\{e^{(qV_d/n_2kT)} - 1\} \quad \ldots (14)$$

$$I_{d3} = I_{o3}\{e^{(V_d/n_3V_T)} - 1\} = I_{o3}\{e^{(qV_d/n_3kT)} - 1\} \quad \ldots (15)$$

$$I = I_{ph} - I_{o1}\{e^{(qV_d/n_1kT)} - 1\} - I_{o2}\{e^{(qV_d/n_2kT)} - 1\} - I_{o3}\{e^{(qV_d/n_3kT)} - 1\} - I_{sh} \quad \ldots (16)$$

For N_s cells in series then the Eq. 16 becomes,

$$I = I_{ph} - I_{o1}[e^{\{q*(V+IR_{se})/N_s n_1 kT\}} - 1] - I_{o2}[$$

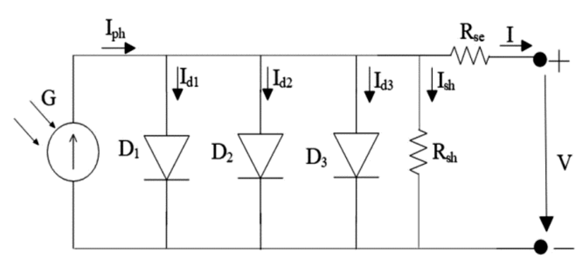

Fig. 3 — Three diode model

$$e^{\{q*(V+IR_{se})/N_s n_2 kT\}} - 1] - I_{o3}[$$
$$e^{\{q*(V+IR_{se})/N_s n_3 kT\}} - 1] - I_{sh} \quad \text{... (17)}$$

2.4 Other Parameter Equation of PV Cell Model

Other parameters of PV cell are saturation current (I_0), I_{ph} and inverse saturation current (I_{0r}) being function of temperature (T) and solar radiation (G). They are described as:

(1) Implementation of saturation current (I_0) is given by Eq. (18)

$$I_0 = I_{0r}\,(T/T_a)^3\, e^{\left[\frac{qE_g}{nk}\left\{\frac{1}{T_a}-\frac{1}{T}\right\}\right]} \quad \text{... (18)}$$

Where T_a is ambient temperature. Energy band gap (E_g) is taken as 1.12 eV.

(2) Reverse saturation current is given by Eq. (19)

$$I_{0r} = I_{sc}/[e^{(qV_{oc}/nkT)}-1] \quad \text{... (19)}$$

Where I_{sc} and V_{oc} are responsible to increase or decrease respectively the I_{0r}.

(3) Implementation of Photo generated current (I_{ph}) is also depend on temperature. It shows a linear relationship with solar irradiance of PV cell.

$$I_{ph} = \{I_{sc} + k_i(T - T_a)\}\frac{G}{1000} \quad \text{... (20)}$$

Where G and k_i denote solar radiation and temperature coefficient of solar cell, respectively.

3 Simulation Model of PV cell

MATLAB simulation models of PV cell are depicted in Figure 4 to 6 with the help of mathematical equations described before. The key specifications of Solarex MSX 60, shown in Table 1, was taken for modelling of PV cell. The experimental data for PV module are collected from manufacturer data[16] shown in Table 2.

4 Result and Discussion

Simulation model of triple diode, two diode and one diode models are developed on MATLAB to analyze behaviour of the models and plot characteristics of I-V and P-V curve under variation of certain parameters of models. During simulation single parameter is alteration at one time and remaining parameters are kept constant.

4.1. Effect of T

I-V and P-V curve obtained from the simulation models, depicted in Fig. 7, illustrate the temperature effect. Ideality factor is taken 1.2 for one diode model, $n_1 = 1, n_2 =$1.8 for double diode model and

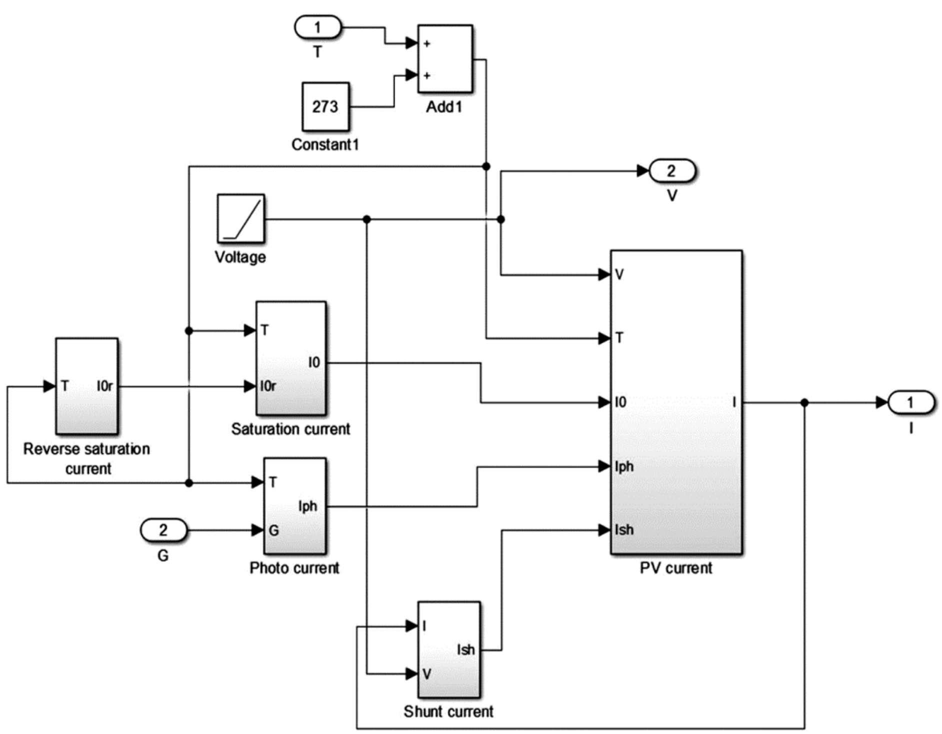

Fig. 4 — Simulation model of one diode

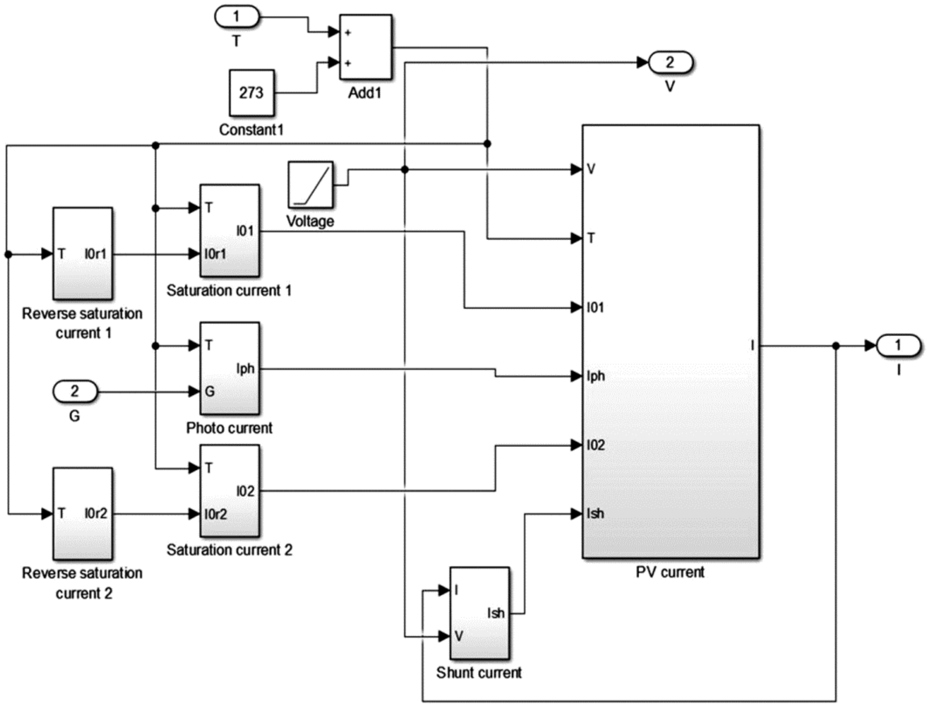

Fig. 5 — Simulation model of two diode model

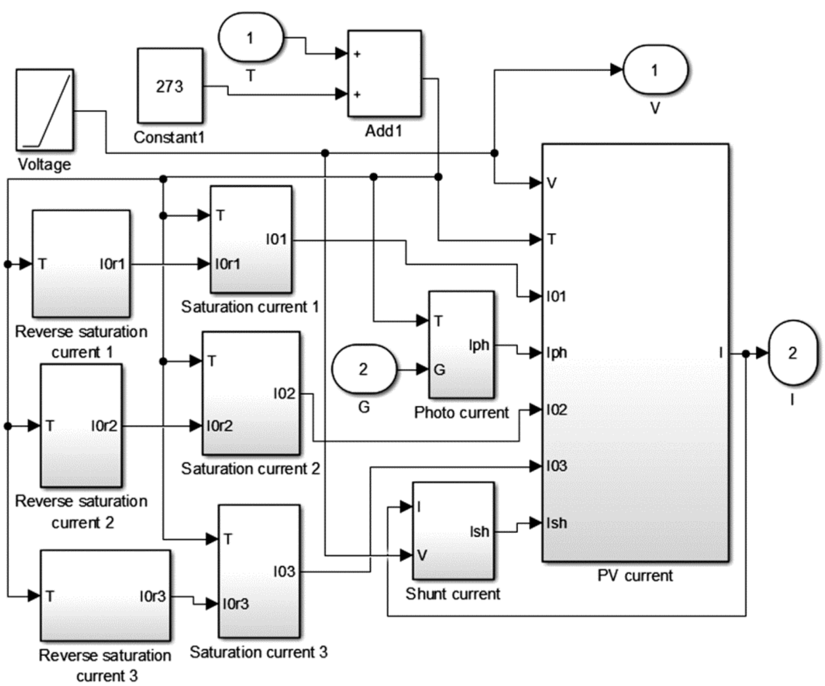

Fig. 6 — Simulation model of 3-diode model PV cell

$n_1 = 1, n_2 = 1.8, n_3 = 2$ for triple diode model. G is taken as 1000 W/m^2 and variation of temperature $0°C, 25°C, 50°C, 75°C$. It is observed that power is maximum at $0°C$ and gradually declines with rise in T. Decline of output power of triple diode and two diode model is slightly more as related to single diode model with variation of temperature.

4.2. Effect of G

I-V and P-V curve of one diode, two diode and three diode models, as shown in Figure 8 and illustrate the effect of the $G = 600\ W/m^2$, 800 W/m^2, 1000 W/m^2 and 1200 W/m^2 at $25°C$. While ideality factor for all the models is kept constant as described in 4.1 before. It realized that the output increases through escalation of solar irradiances. Single diode has large output power as compared to others diode models.

4.3. Effect of Ideality factor (*n*)

Diode ideality factor determines the type of recombination and junction feature of a solar cell[17]. Different Simulation models are run at STC with varying ideality factor. For one diode model n is varied from 0.5 to 1.2, for two diode model from 1 to 1.8 and for three diode model from 1 to 2. The output characteristics are shown in Fig. 9. As compared to two and three diode model, one diode model output is more affected and it's gradually decreases in comparison to other models.

Table 1

Parameters	Value
Peak power (P_{max})	60 W
Peak voltage (V_m)	17.1 V
Peak current (I_m)	3.5 A
O.C. voltage (V_{oc})	21.1 V
S.C. current (I_{sc})	3.8 A
k_i (A/°C)	3×10^{-3}
Number of series connected cell (N_s)	36

Table 2

Parameters	Manufacturer value
Photo generated current (I_{ph})	3.8084 A
Series resistance (R_{se})	0.3692 Ω
Shunt resistance (R_{sh})	169.0471 Ω
Ideality factor (n)	$1 \leq n \geq 2$

4.4. Effect of R_{se}

The voltage drop for the same amount of current is increased as increase in series resistance between the terminal voltage and junction voltage[18]. The effect of the R_{se} is observed through I-V and P-V curve as depicted in Fig. 10. Temperature and irradiance considered under STC. With increase in the value of R_{se}, output power decreases for all models. Variation in R_{se} is considered as $0.1\ \Omega$, $0.3\ \Omega$, $0.5\ \Omega$ and $1.0\ \Omega$.

4.5. Effect of R_{sh}

The voltage drop in ideal diode model is zero at no load because of the absence of the shunt and series resistances[19]. However, to study the variation of R_{sh}, T and G were taken $25°C$ and 1000 W/m^2 respectively and R_{sh} takes the value $10\ \Omega$, $25\ \Omega$, $50\ \Omega$ and $100\ \Omega$. The I-V and P-V curve for 1-diode, 2-diode and 3-diode models, as shown in Fig. 11, illustrate that the output power is increasing with increase in R_{sh}. While this increase in output power is more prominent in single diode model.

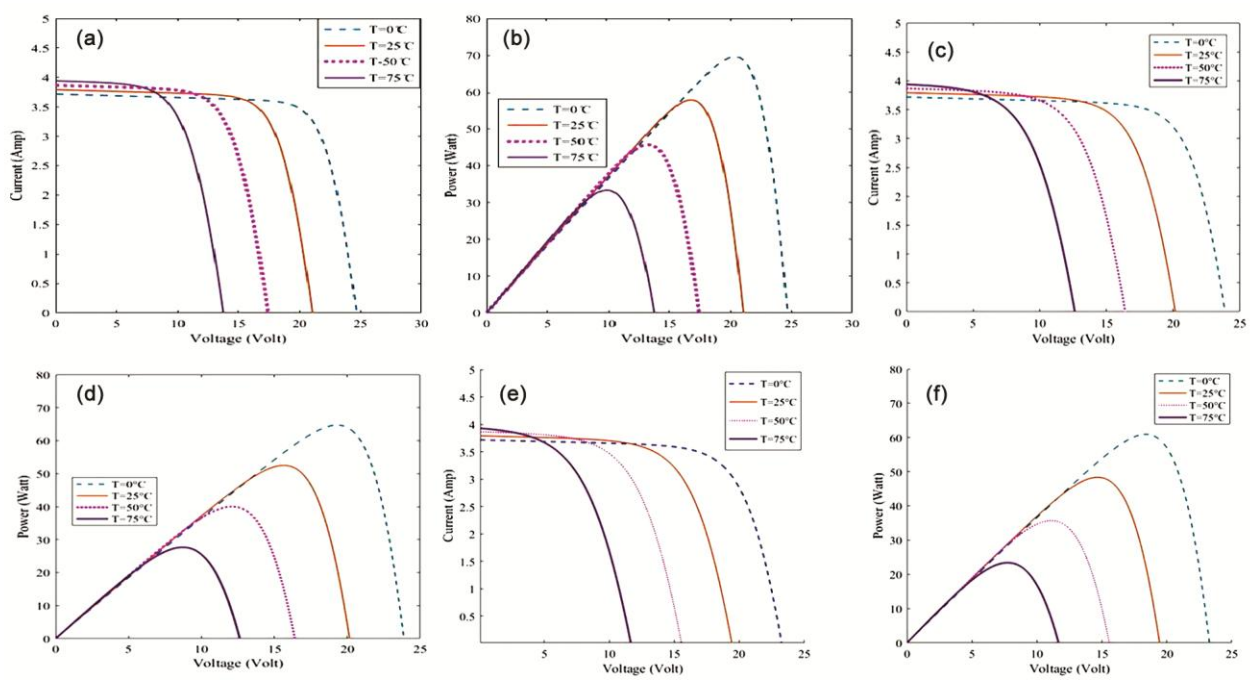

Fig. 7 — Effect of T on I-V and P-V curve: one diode (a, b); double diode (c, d); triple diode (e, f)

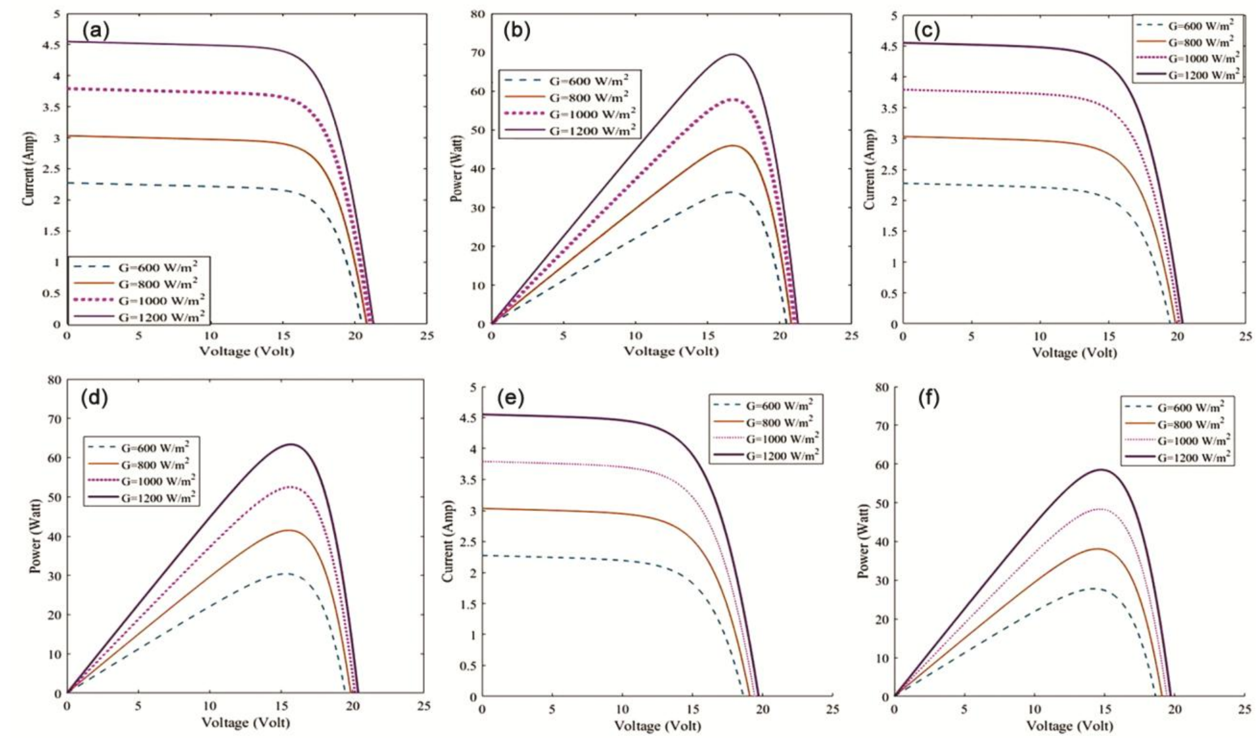

Fig. 8 — Effect of G on I-V and P-V curve: one diode (a, b); double diode (c, d); triple diode (e, f)

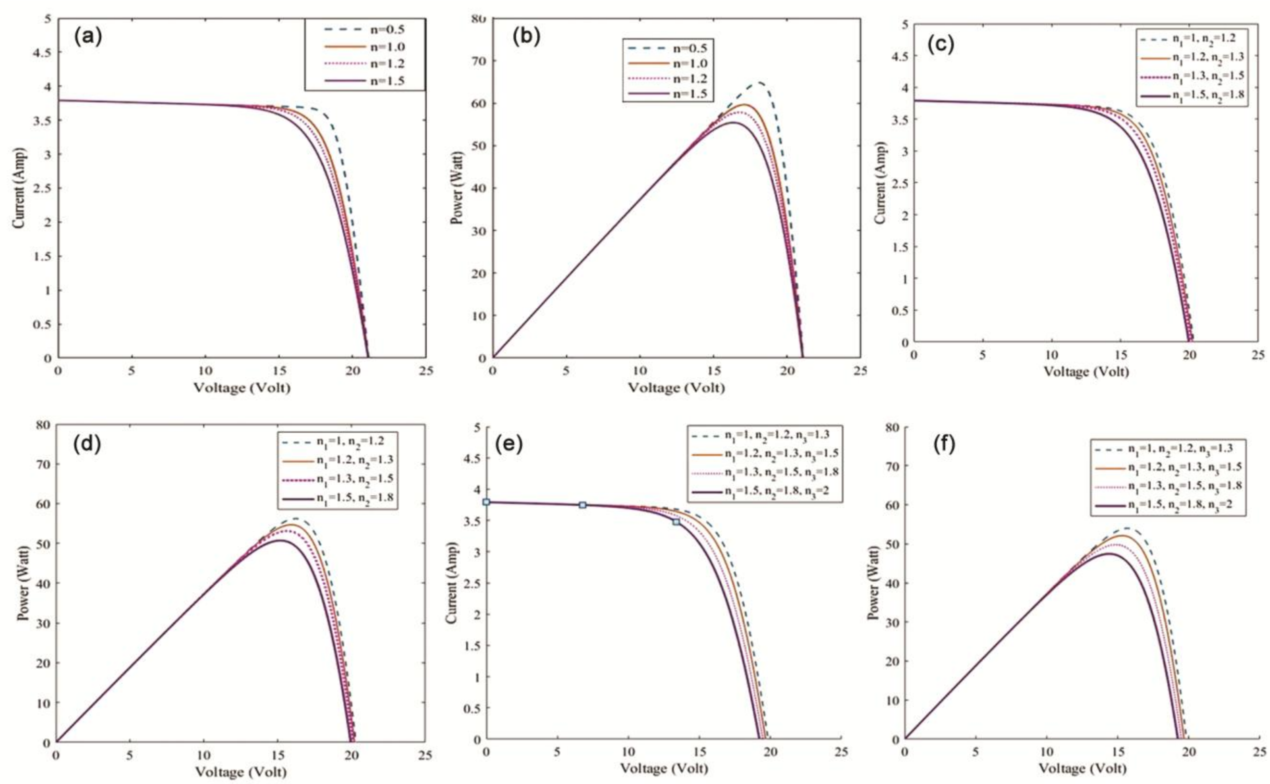

Fig. 9 — Effect of ideality factor on I-V and P-V curve: one diode (a, b); double diode (c, d); triple diode (e, f)

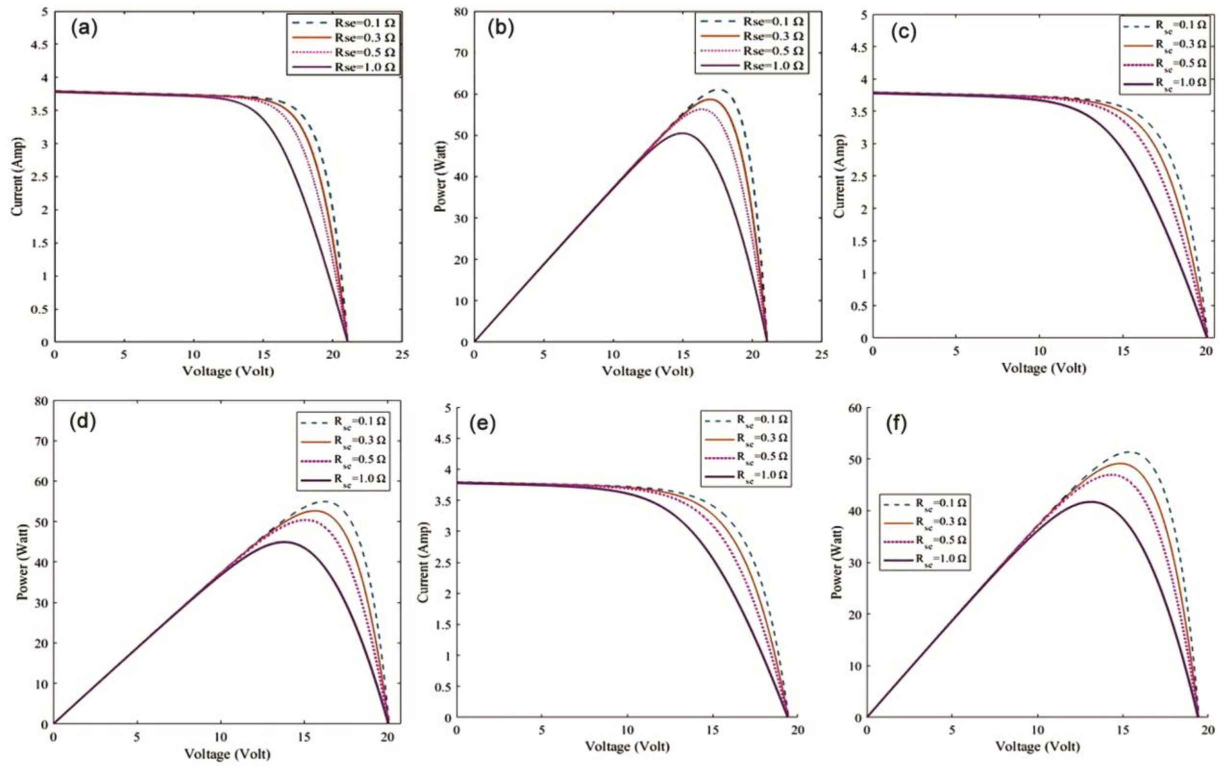

Fig. 10 — Effect of series resistance on I-V and P-V curve: one diode (a, b); double diode (c, d); triple diode (e, f)

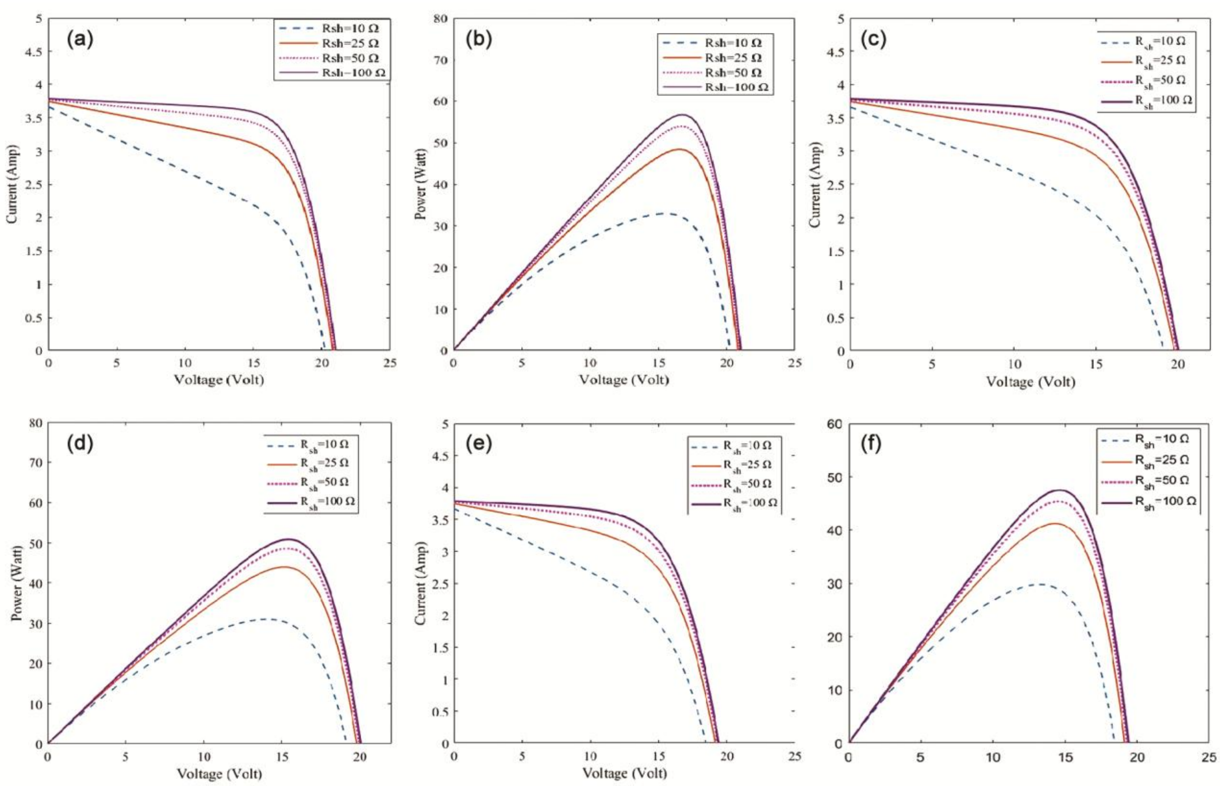

Fig. 11 — Effect of shunt resistance on I-V and P-V curve: one diode (a, b); double diode (c, d); triple diode (e, f)

5 Concluding Remarks

This work present MATLAB simulation model of one diode, two diode and three diode models in order to compare their performance under varying conditions. These models are developed with the help of mathematical equation of their equivalent circuits. I-V and P-V characteristics curve of one diode, two diode and three diode models under varying parameters revealed that single diode model furnishes better performance in comparison of two diode and three diode models. Hence, comparative performance analysis through MATLAB simulation models justify the practice of use of single diode model for most of the PV system based power system simulation studies. As single diode model is better representation of practical PV cell.

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