The Use of Matlab/Simulink for Modeling of Photovoltaic Module

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Abstract—This paper describes a modeling method of a photovoltaic (PV) module, using Matlab Simulink. This method is inspired from a PV panel model presented in Matworks. It consists in using a series resistance (R_s) computing algorithm introduced in previous research works. This algorithm permits to reduce the value of R_s compared to the series resistance used in the PV panel model presented in Matworks. Consequently, the losses power is reduced, the PV module efficiency is increased and the maximum power (MP) is increased.

Keywords—Photovoltaic, PV module, PV Cells, I-V Characteristic, P-V Characteristic

I. INTRODUCTION

Conventional energy sources are not capable to meet the growing demand for energy worldwide. Consequently, alternative energy sources like wind, biomass and sunlight, come into mind. In this context, photovoltaic energy is a source of attractive energy; it is inexhaustible, non-polluting and renewable. Furthermore it is employed as energy sources in various applications [1, 2]. However due of its low efficiency and high cost, energy contribution is less than other energy sources. It is thus necessary to have flexible and effective models, to allow you to perform simple manipulation of certain data (temperature and irradiance) investigate how getting its performance as maximum as possible. The employment of these simple models gives enough accuracy for analyzing the behavior of the solar cell and has proven to be efficient in most cases. A solar cell permits to convert solar energy into electrical energy. This phenomenon occurs in materials having the property of capturing photon and emitting electrons. Silicon is the main material used in the photovoltaic industry. For understanding better the PV module, the mathematical model is incessantly updated. The output characteristics of PV module depend on [3]:

- The solar Insolation,
- The cell Temperature,
- The Output Voltage of PV Module.

The characteristic I (V) is a non-linear equation having many parameters classified as follows: those known as constants, those provided by constructors and those have to be determined. From time to time, searchers develop simplified techniques where, some unidentified parameters can't be computed. Hence, they are supposed constant. As an example, in [4], the parallel resistance R_p was not included but only the resistance series R_s was included for a model of moderate complexity. The same supposition was adopted in [5- 8], by considering the parallel resistance very large. In other research works, the authors neglect series and parallel resistances because the former due to being very small and the latter being very large. On the other hand, in other research works such as [9-14] these two internal characteristics of the PV module are very important and should be computed in accurate manner. In addition to the parallel and series resistances and according to the authors, two or three other parameters are to be computed; the ideality factor (n), the photo current (I_{ph}) and the saturation current I_0. The of this paper is organized as follow: in section II, we will deal with PV Generator, in section III, we will be interested in implementation and simulation of the proposed PV Module and finally results and discussion are given in section IV.

II. PV GENERATOR

A photovoltaic generator is the whole assembly of solar cells, connections, supports, protective parts etc. In the present modeling, the focus is only on cell/module. Solar cells consist of a p-n junction fabricated in a thin wafer or semiconductor layer (typically silicon). In the dark, the I-V output characteristic of a solar cell has an exponential characteristic similar to that of a diode. When photons hit the solar cell, with energy superior to the band gap energy of the semiconductor, electrons are knocked loose from the atoms in the material, creating electron-hole pairs. These carriers are swept apart under the influence of the internal electric fields of the p-n junction and produce a current proportional to the incident radiation. When the cell is short circuited, this current flows in the external circuit; when open circuited, this current is shunted internally by the intrinsic p-n junction diode. The characteristics of this diode consequently set the open circuit voltage characteristics of the cell.

A. Modeling the Solar Cell

The simplest equivalent circuit of a solar cell is a current source in parallel with a diode. The output of the current source is directly proportional to the light falling on the cell (I_{ph}: photocurrent). The solar cell isn't an active device during darkness and it works as a diode, i.e. a p-n junction. It provides neither a voltage nor a current. Though, if it is connected to an external supply (large voltage) it generates a current ID, named diode (D) current or dark current [15]. The diode determines the I-V characteristics of the cell.
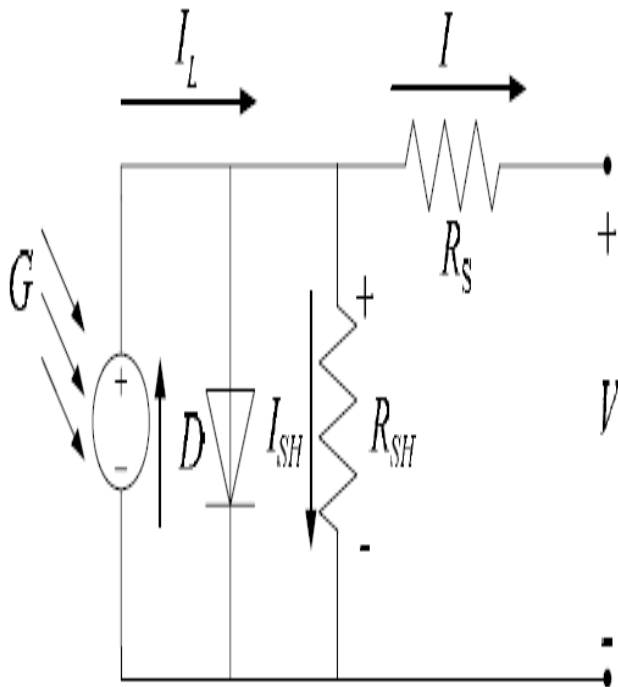

Fig. 1 Circuit diagram of the PV model [15]

Increasing sophistication, complexity and accuracy can be introduced to the model by adding in turn [4]:

- Series resistance R_s which permits to have a more accurate shape between the maximum power point and the open circuit voltage. This represents the internal losses due to the current flow

- Temperature dependence of the photo current I_L.

- Temperature dependence of the diode saturation current I_0.

- Shunt resistance R_{sh}, in parallel with the diode, this corresponds to the leakage current to the ground and it is commonly neglected.

- Either allowing the diode quality factor n becoming a variable parameter (instead of being fixed at either 1 or 2) or introducing two parallel diodes with independently set saturation currents.

In an ideal cell, $R_{sh} = R_s = 0$, which is a relatively common supposition. In [3], was used a model of moderate complexity. The net current of the cell is the difference of the photocurrent, I_L and the normal diode current I_0:

$$I = I_L - I_0 \left(e^{\frac{q(V + I \cdot R_S)}{nkT}} - 1 \right) \tag{1}$$

The model included temperature dependence of the saturation current of the saturation current of the diode I_0 and the photo-current I_L.

$$I_L = I_L(T_1) + K_0(T - T_1) \tag{2}$$

$$I_L(T_1) = I_{SC}(T_{1,nom}) \frac{G}{G(nom)} \tag{3}$$

$$K_0 = \frac{I_{sc}(T_2) - I_{sc}(T_1)}{T_2 - T_1} \tag{4}$$

$$I_0 = I_0(T_1) \times \left(\frac{T}{T_1} \right)^{\frac{B}{n}} e^{\frac{qV_g(T_1)}{nk}\left(\frac{1}{T} - \frac{1}{T_1}\right)} \tag{5}$$

$$I_0(T_1) = \frac{I_{sc}(T_1)}{e^{\frac{qV_{oc}(T_1)}{nkT_1}} - 1} \tag{6}$$

The series resistance R_s represents the resistance inside each cell in the connection between cells.

$$R_s = -\frac{dV}{dI_{V_{oc}}} - \frac{1}{X_V} \tag{7}$$

$$X_V = I_0(T_1) \frac{q}{nkT_1} e^{\frac{qV_{oc}(T_1)}{nkT_1}} - \frac{1}{X_V} \tag{8}$$

A Photovoltaic Module is a group of PV cells which are electrically connected in series and parallel circuits for generating the required voltage and current. The equivalent circuit for the PV module arranged in Ns series and Np parallel PV cells is illustrated in Fig. 2.
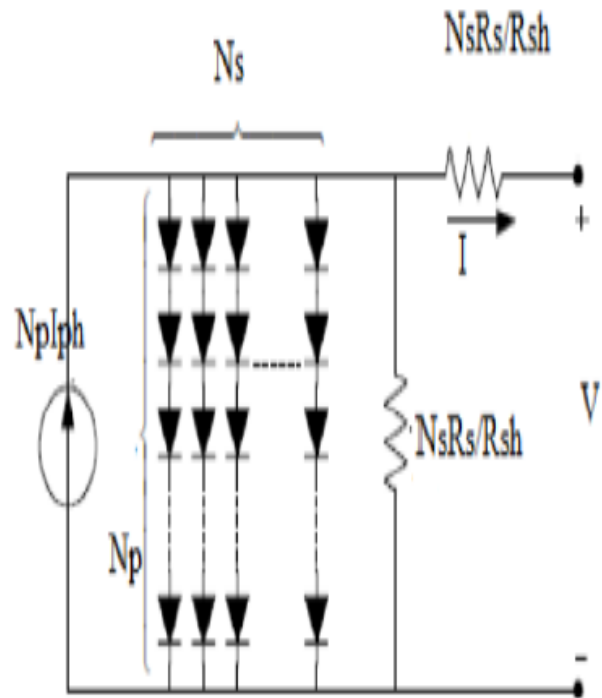

Fig. 2 Equivalent circuit of a PV module [1]

R_{sh} is inversely related with shunt leakage current to the ground. Generally, the Photovoltaic efficiency is insensitive to the R_{sh} variation and the shunt-leakage resistance can be supposed to approach infinity without leakage current to ground. Conversely, a small R_s variation will considerably influence the Photovoltaic output power.

III. IMPLEMENTATION AND SIMULATION OF THE PROPOSED PV MODULE

In this paper, we have used the method of computation of series resistance Rs proposed in [15] and this method is given in details in this section. According to [15], Rs is given by the following equation:

$$R_S = \frac{0.575}{N_S} - \frac{1}{X_v} \tag{9}$$

Where N_S is the number of PV cells connected in series and in this work, it is equals to 36. The quantity X_v is expressed as follow:

$$X_v = \frac{q \cdot I0\_T1}{n \cdot k \cdot T1} \cdot exp\left(q \cdot Voc\_T1 + \frac{T1}{n \cdot k \cdot T1}\right) \tag{10}$$

Where $Voc\_T1 = \frac{Voc}{N_S}$ with Voc is the voltage in open circuit and in this work is equals to 21.1. $I0\_T1$ is expressed as follow:

$$I0\_T1 = I_{SC}/exp\left(\frac{q \cdot Voc\_T1}{n \cdot k \cdot T_1} - 1\right) \tag{11}$$

and $T1$ is the temperature in Kelvin and is expressed as follow:
$$T1 = 25 + 273.15 \tag{12}$$
k is the Boltzmann constant and equals to $1.38 \cdot 10^{-23} J/K$ and q is electron charge $(1.602 \times 10^{-19} C)$.

By using the equation (5), (6), (7) and (8), we construct the subsystem of R_S computation, given at Fig. 2.
In (a) and (b) of Fig. 3, the inputs are the open circuit voltage V_{oc}, and the diode quality factor $n_2 = n$.

The overall system of the PV module, proposed in this work, is represented in Fig. 4.
Where the inputs of the PV panel 1 are the voltage V, the irradiance G, the temperature T_{op}, the series Resistance, the parallel resistance R_p and the diode quality factor n.

- The voltage V is a periodic triangular signal.
- The irradiance G. The series resistance, R_s is determined (Fig.2 and paragraph III) using the previous mention method proposed in [15].
- The parallel resistance, R_p is selected to be equals to 360.002.
- The diode quality factor n is chosen to be equals to 1.38.

The output of the overall system is the current delivered by this PV module and is represented in Fig. 4 by the interrupted arrow.
The PV panel 1 (Fig. 4) is constitutes of the following subsystems:

- The subsystem computing the Thermal voltage (Fig. 5).
- The subsystem of Diode current Id (Fig. 6).
- The subsystem of Shunt current Ish (Fig. 7).
- The subsystem of phase current Iph (Fig. 8).
- The subsystem of load current I (Fig. 9).
- The subsystem of reversed saturation current (Fig. 10).
- The subsystem of reversed saturation current at Temperature Top (Fig. 11).

All these subsystems are represented in Figs. 5 to 13.
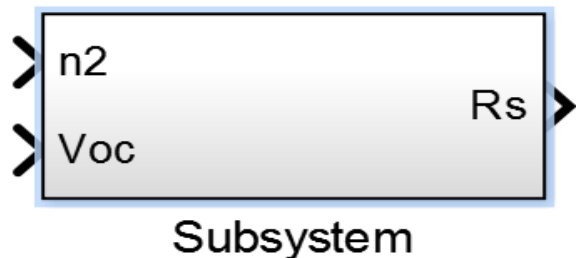
(a) The masked overall subsystem of Rs computation
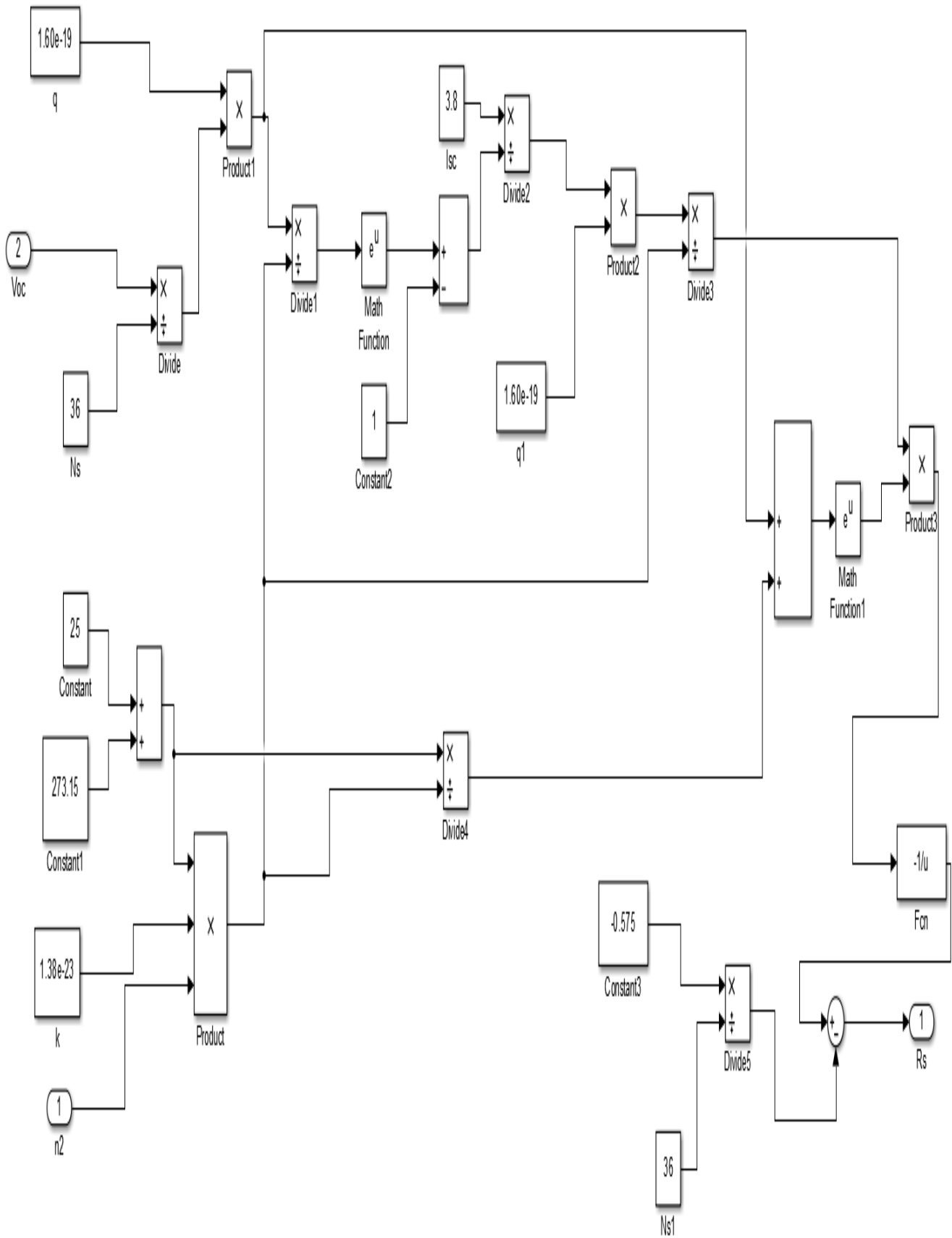
(a) The detailed subsystem.
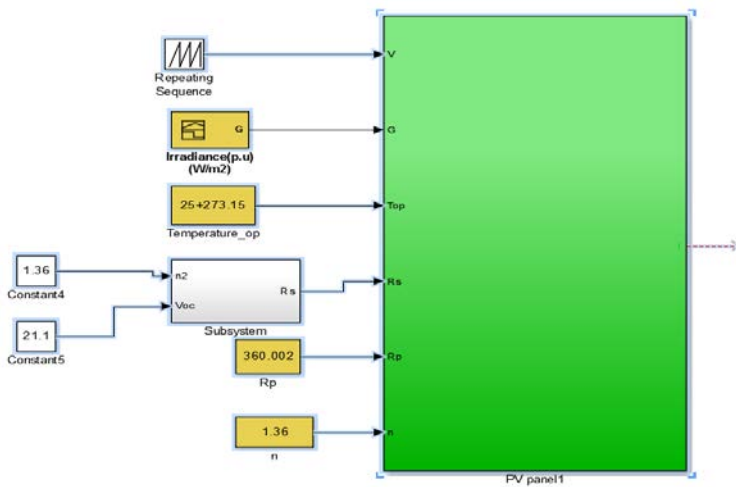Fig. 3 The Subsystem of Rs computation: (a) and (b)

Fig. 4 The proposed overall system of PV module

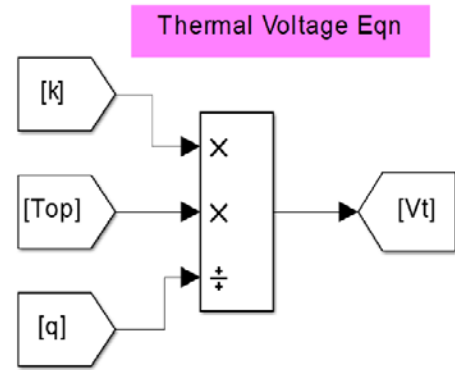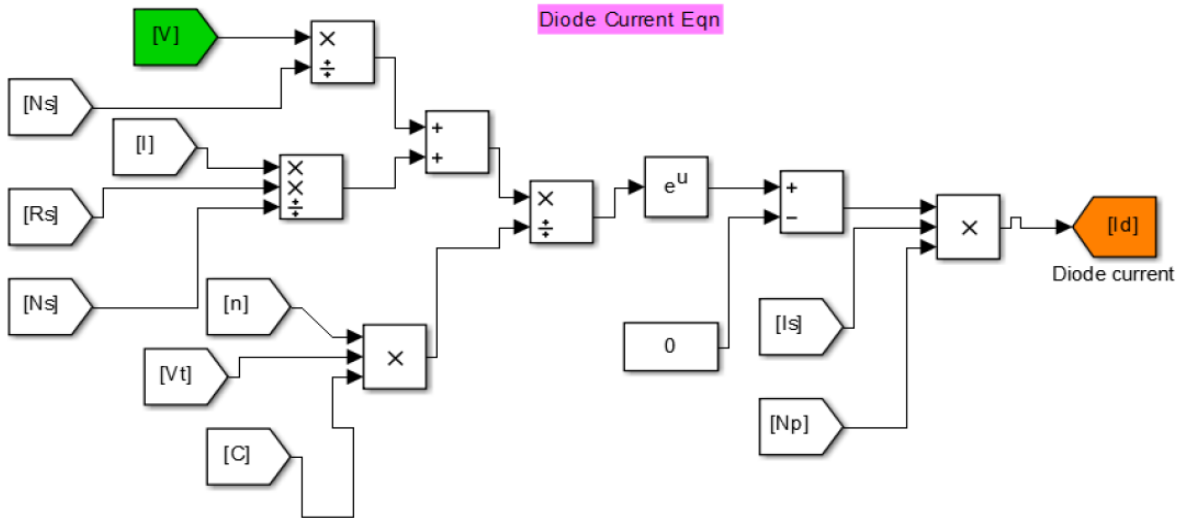

Fig. 5 The thermal voltage, Vt.

Fig. 6 The diode current, I_d

Fig.6. The diode current.

In this computation subsystem of the diode current, I_d (Fig. 6), we have replaced 1 by 0 because we have made the approximation: $exp(u) - 1 \approx exp(u)$ since $exp(u) \gg 1$. This approximation is also made in [16].
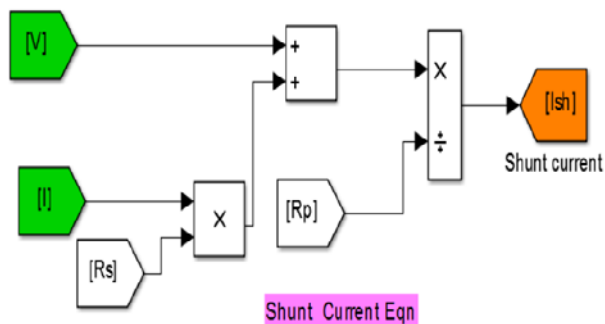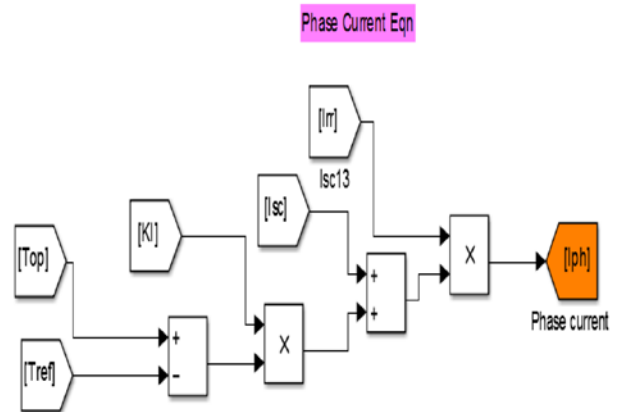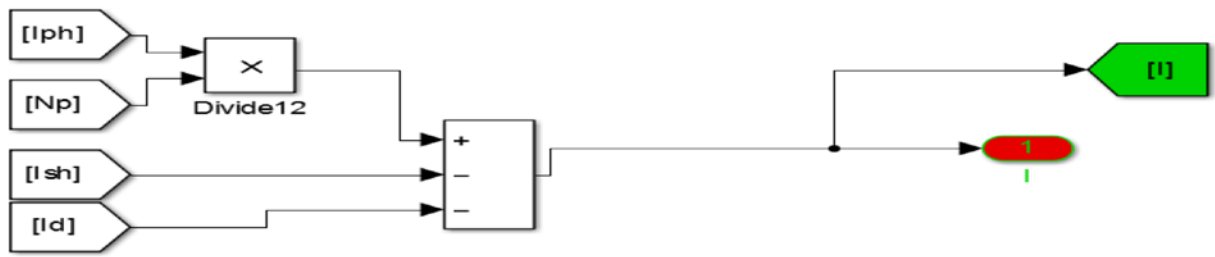

Fig. 7. The shunt current, I_{sh}.

Fig. 8 The phase current, Iph

Load Current Eqn

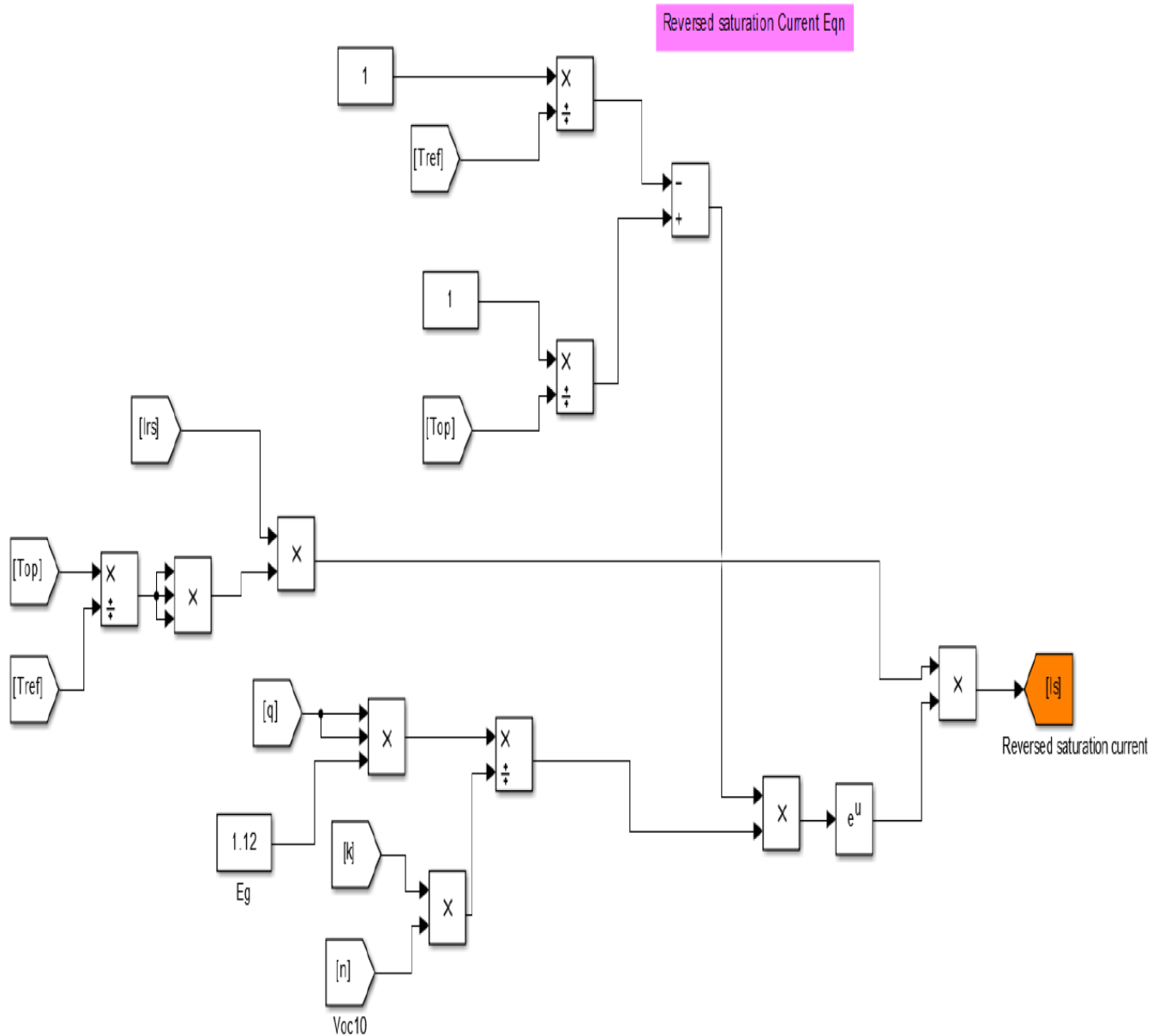$$I = \{(Iph.Np) - Id - Ish\}$$

Fig. 9 The subsystem of load current, I

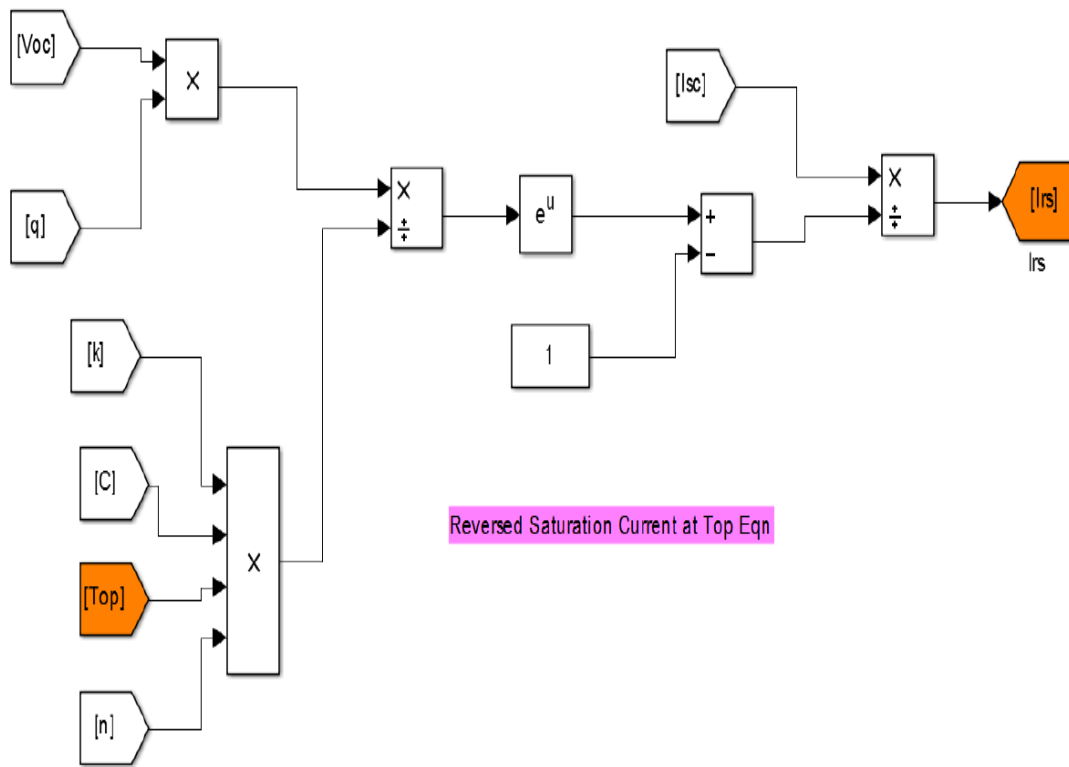Fig. 10 The reversed saturation current, Is
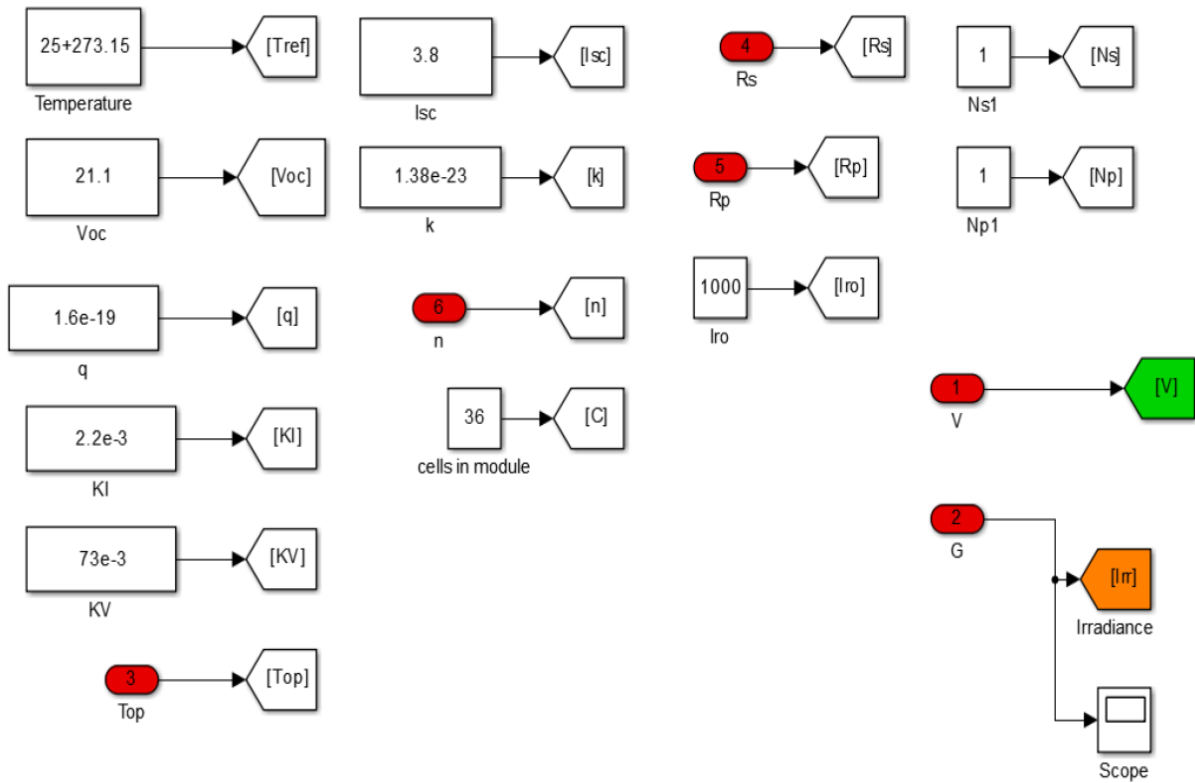
Fig. 11 The reversed saturation current at Top

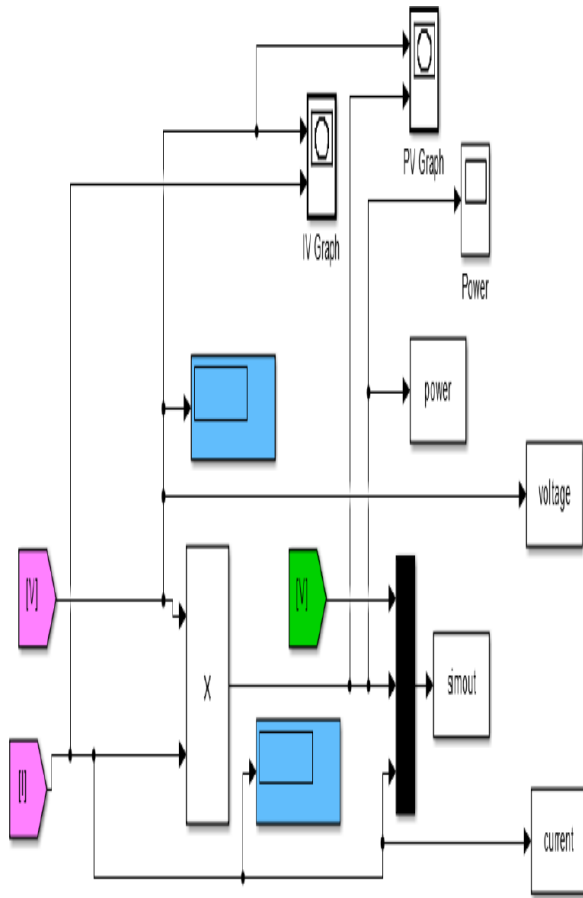Fig. 12 The inputs of the PV panel 1 and constants of the overall system

Fig. 13 Results and characteristics presentation

IV RESULTS AND DISCUSSION

For the simulation experiments we have used the two models of a PV Module; the proposed model (Fig. 4) and the model proposed in [17]. Figs. 14 to 17 show the P-V and I-V characteristics obtained by the proposed Model (Fig. 4) and those obtained by the model proposed in [17].
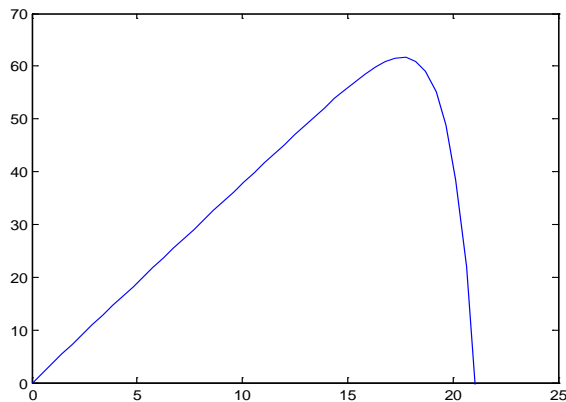

Fig. 14. P-V characteristic obtained by the proposed Model where the value of Rs is determined from the Subsystem of Rs computation (Fig. 3: (a) and (b)).

Fig. 15. P-V characteristic obtained by the Model proposed in [17] where Rs =0.18Ω.

Fig. 16. I-V characteristic obtained by the proposed Model where the value of Rs is determined from the Subsystem of Rs computation (Fig. 3: (a) and (b)).

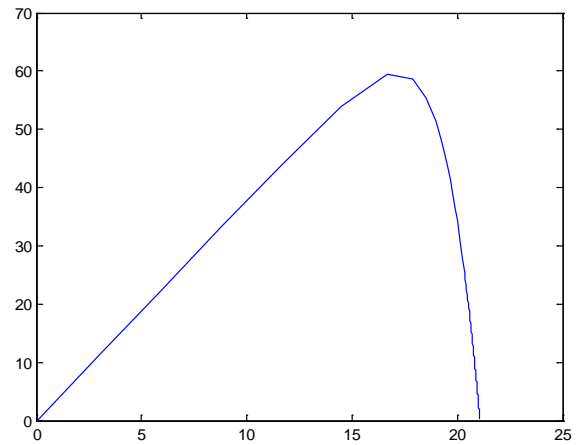Fig. 17. I-V characteristic obtained by the Model proposed in [17] where Rs =0.18Ω.

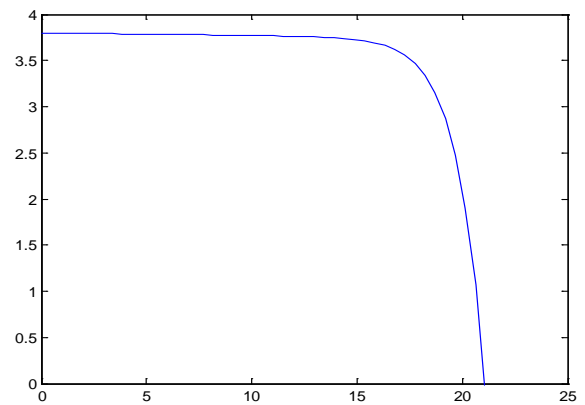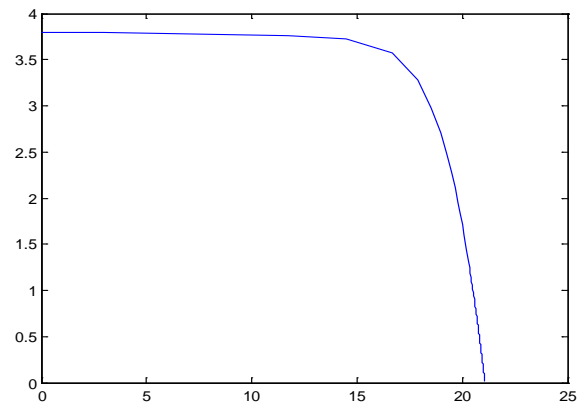These figures show clearly that the proposed model of PV module (Fig. 4) permits to obtain a MP greater than 60W whereas the MP obtained by the model presented in [17] is inferior to this value.

V. CONCLUSION

A modeling method of PV panel, using Matlab/Simulink, is presented. This method is inspired from a PV panel model presented in Matworks. It consists in using a series resistance (R_s) computing algorithm introduced in previous research works. According to the I-V and P-V characteristics obtained by simulation of the two Models (the proposed model and the Matworks one), we conclude that the proposed model permits to reduce the losses power, to increase the maximum power and consequently the efficiency is improved.

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