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Modelling and Simulation of PV Modules with Voltage Feedback in MATLAB/Simulink

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Abstract: *A modeling and simulation of PV module with voltage feedback is presented in this paper. The modeling is done in Matlab/Simulink environment using general photovoltaic (PV) solar cell equations. For the equivalent solar cell circuit, single-diode circuit is used excluding the shunt resistance (R_p). The I-V and P-V curves are obtained with voltage feedback inside the PV module which is connected to a DC-DC boost converter. The control of the boost converter is provided with maximum power point tracker (MPPT) using the basic Perturb and Observe (P&Q) algorithm. The temperature and solar irradiation effects are taken in consideration and these effects are analyzed. The efficiency of the PV module and the proposed general system is investigated, the results are presented.*

Keywords: *Photovoltaic solar cell, DC-DC boost converter, maximum power point tracker (MPPT),*

1. Introduction

Being one of the renewable energy sources, solar energy applications have been on the rise day by day. Having extensive practice field, ability to gain without using much effort and money are some of the reasons which make solar energy more attractive.

PV cell is the basic component of solar energy generation systems. These cells generate electricity when exposed with sunlight. By combining PV cells in series and parallel the intended power can be obtained [1]. The temperature and solar irradiation also affect the generated power. The PV output voltage and current change depending on these effects.

Many studies have been done on PV cells and their applications in the literature. A research has been done on I-V and P-V characteristics of PV arrays under non uniform insulation due to partial shading [2]. PV array model for Matlab/Simulink GUI environment has been done by Altas et al. by using circuit equations [3]. This model includes the temperature and irradiation effects. In another research, a PV module has been implemented in Matlab script file with high accuracy results [4]. Pandiarajan and Muthu have presented a mathematical model of PV systems in Matlab/Simulink [5]. In this model the voltage input is given as a repeating sequence externally. Huan-Liang Tsai et al. have composed a PV module in Simulink using the input voltage as the output voltage [6].

In this paper, modelling and simulation of a PV module is done in Matlab/Simulink environment. The presented modelling uses voltage feedback to obtain the input voltage value. A single-diode circuit is used for the equivalent photovoltaic solar cell circuit. The I-V and P-V curves are obtained from the modelled PV module for different solar irradiation and temperature values. The results are compared with datasheet values. In the proposed system, the modelled PV module is connected to a DC-DC boost converter which is controlled with maximum power point tracker (MPPT) using the basic Perturb and Observe (P&Q) algorithm. The efficiency analyze of this general system is done by comparing the PV module output and the boost converter output.

2. Modelling the General System

2.1. Mathematical Model of the PV Module

PV modules are composed of series and parallel solar cells. These solar cells differ by the number of diodes, the series and parallel resistances in the cell. In this paper, the equivalent circuit obtains only one diode and a series resistance (single diode model). The mentioned circuit is shown in Fig. 1.

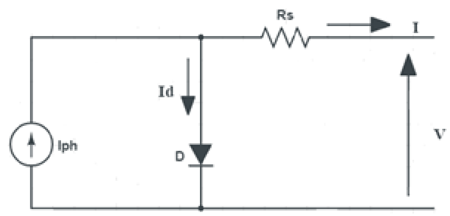


Fig. 1: The model of the single diode solar cell.

Using just one solar cell does not devote substantial values. By connecting the cells in series and parallel, the output power can be raised up to acceptable and desired values. The more the cell is connected in series, the more the output voltage increases and the more the cell is connected in parallel, the more the output current increases. Based on the equivalent circuit, the mathematical expressions of the PV module can be described as below [7];

$$I = N_p I_{ph} - N_p I_d \tag{1}$$

$$I = N_p I_{ph} - N_p I_0 \left\{ \exp\left[\left(\frac{V}{N_s} + \frac{R_s I}{N_p} \right) \frac{q}{nkTc} \right] - 1 \right\} \tag{2}$$

$$I_0 = I_{rs} - \left(\frac{T_c}{T_{ref}} \right)^3 \exp\left[\frac{E_g q}{nk} \left(\frac{1}{T_{ref}} - \frac{1}{T_c} \right) \right] \tag{3}$$

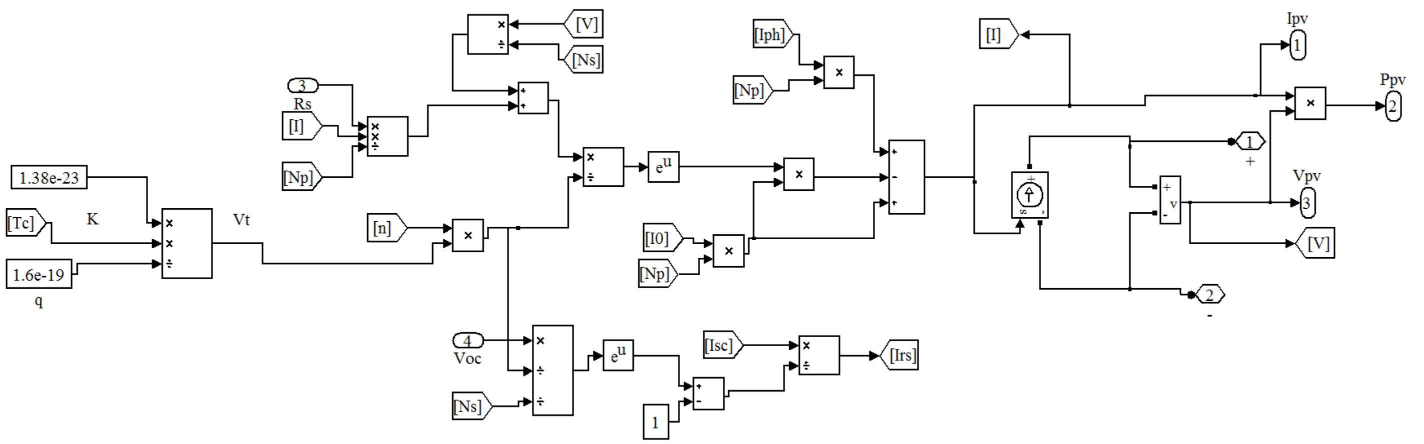
$$I_{rs} = I_{sc} / \left[\exp\left(\frac{V_{oc} q}{nkT_c N_s} \right) - 1 \right] \tag{4}$$

$$I_{ph} = \left[I_{sc} + \alpha \left(T_c - T_{ref} \right) \right] \frac{S}{S_{ref}} \tag{5}$$

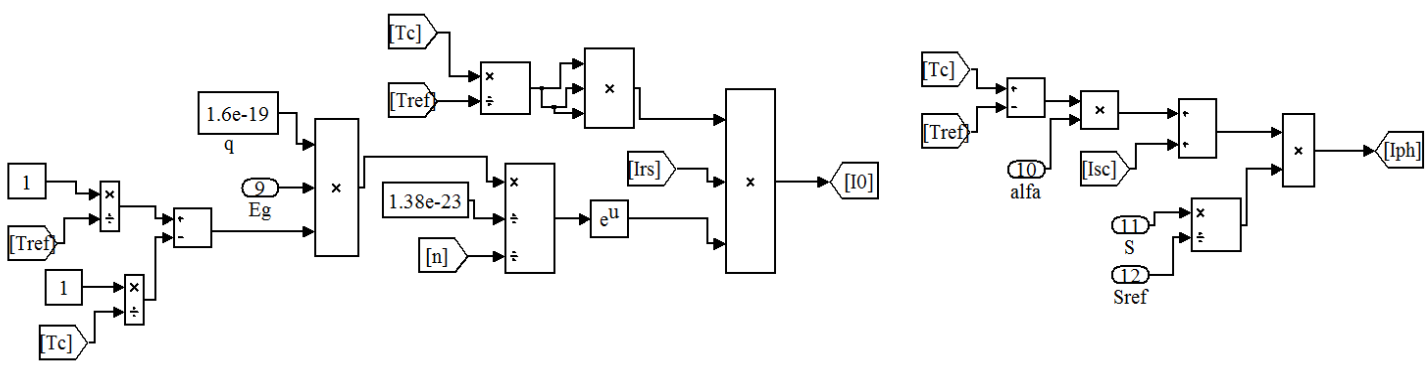
Where ; I (A) is the output current of the cell, V (V) is the output voltage, I_d (A) is the diode saturation current, I_0 (A) is the temperature dependence of the diode saturation current, I_{rs} (A) is the reverse saturation current, I_{sc} (A) is the short circuit current at reference conditions, V_{oc} (V) is the open circuit voltage at reference conditions, I_{ph} (A) is the photocurrent, n is the diode ideality factor, T_c (˚C) is the cell temperature, T_{ref} (˚C) is the reference temperature, I_{ph} (W/m^2) is the solar irradiance, S_{ref} (W/m^2) is the reference solar irradiance, N_s stands for the number of cells in series, N_p is the number of cells in parallel, E_g is the band gap energy, α (A/˚C) is the temperature coefficient of the short circuit current, q is the electron charge ($1.602\mathrm{x}10^{-19}$°C), k is the Boltzmann's constant ($1.381\mathrm{x}10^{-23}$J/K) and R_s (Ω) represents the series resistance.

Proposed PV module is modelled in MATLAB/Simulink as shown in Fig. 2 using the equations (1)-(5). The output current and reverse saturation current are modelled in Fig. 2a. The output voltage of the PV module is obtained with connecting a controlled current source to the current output and the voltage is given back to the module as an input. As it is seen in the equations and from the modelling, the short circuit current and the open circuit voltage have an effect on the reverse saturation current used in the general module.

The modelling of the photocurrent and the temperature dependence of the diode saturation current are presented in Fig. 2b. The values of T_{ref} and S_{ref} in the proposed model are 25° C and 1000 w/m^2 respectively. The temperature coefficient of short circuit current α has a very significant affect on the photocurrent and if the unit of α is not as should be, it may cause false responses.



(a) The PV output current I and the reverse saturation current I_{rs} modelling



(b) The temperature dependence of the diode saturation current I_0 and the photocurrent I_{ph}

Fig. 2: The simulated PV Module

2.2. Boost Converter

Boost converters are systems which enhance the input value and transfer it to the output. The main reason for the boost converters to be used in PV system is to regulate the PV module output voltage. The basic model of a DC-DC boost converter is presented in Fig. 3. As the switch turns on, the current flows through the inductor (L) and the switch, while the energy is stored in the inductor. In this period the load (R) is fed by the capacitor (C). When the switch is turned off, the current flows through the inductor, diode (D), capacitor and the load. In the output, a sum of the source voltage and the inductor voltage is seen.

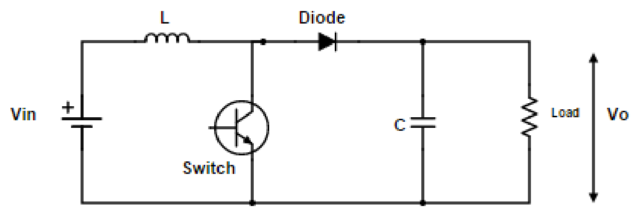


Fig. 2: The basic boost converter model

In this paper equations (1)-(3) are used to obtain the component values of the presented boost converter [8].

$$\frac{V_o}{V_{in}} = \frac{1}{(1-D)} \tag{1}$$

$$L = \frac{V_{in}}{f_s \Delta I_L} D \tag{2}$$

$$C = \frac{I_o}{f_s \Delta V_o} D \tag{3}$$

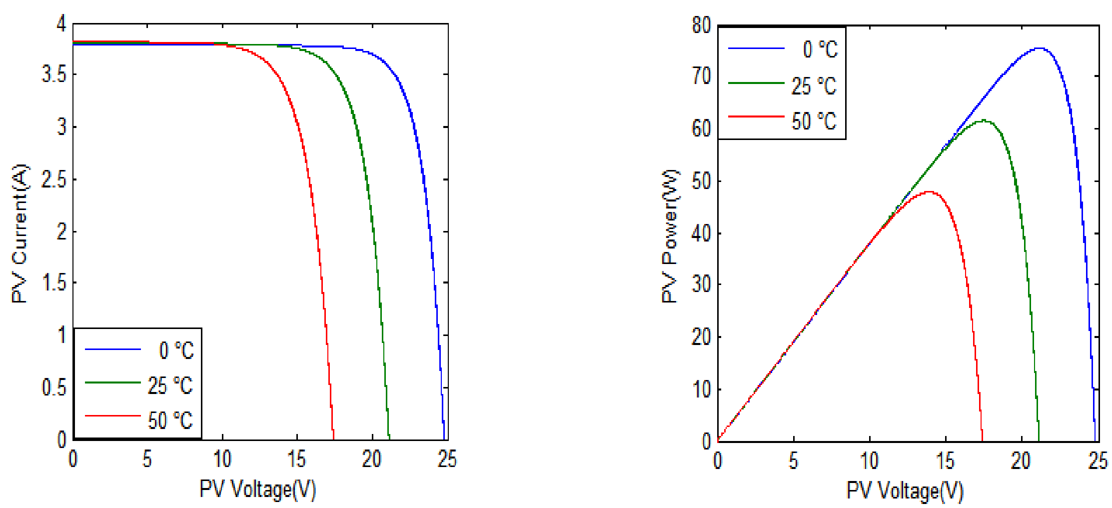
V_0(V) is the output voltage, V_{in} (V) is the input voltage, L (H) is the inductor, D is the duty cycle, C (F) is the capacitor, I_0 (A) is the output current, f_s(Hz) is the switching frequency, ΔV_0(V) is the output voltage ripple and ΔI_L(A) is the input current ripple.

In this paper, P&Q algorithm which uses the P-V characteristic curves, is used as the MPPT algorithm [9]. A slightly change is performed in the PV operating voltage and for this; the change in the power is measured. If ΔP is positive, the voltage value is increased so that the operating point of the PV panel becomes the maximum power point. If ΔP is negative, the direction of the voltage increasement is altered and the operating point is tried to move closest to the maximum power point.

3. Simulation Results

3.1. I-V and P-V Characteristics of The Simulated PV Model

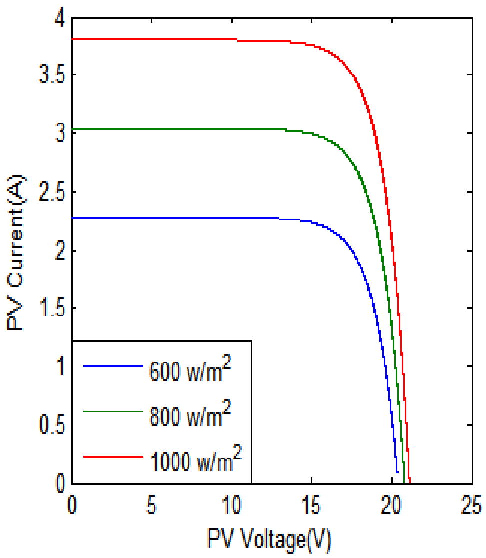
The I-V and P-V characteristics for the PV module BPMSX60 [10] are obtained from the simulated PV model. In Fig. 6(a) and (b)., the increase in the temperature (from 0º C to 50º C) causes a decrease in the voltage value and the generated power, a very little change in the current.

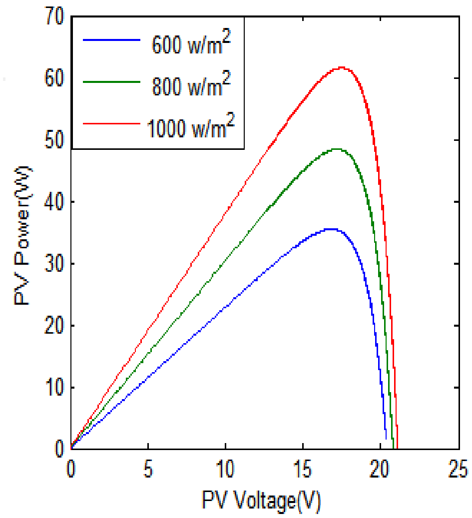


(a): I-V Characteristics (b): P-V Characteristics

Fig. 6: The Characteristics for different temperature values with constant irradiation(S=1000 w/m^2)

The effect of the solar irradiation on PV voltage, current and power is shown in Fig. 7(a) and 7(b). While the irradiation level increases from 600 w/m^2 to 1000 w/m^2; the current and power increases, the voltage slightly changes.





(a): I-V Characteristics (b): P-V Characteristics

Fig. 7: The Characteristics for different irradiation values with constant temperature (T=25º C)

The accuracy of the model is given in Table 1 by comparing the simulation results with the datasheet values [10]. The comparison is done with the main PV module parameters P_{max}, I_{sc}, and V_{oc}. The results show that, while the I_{sc}, and V_{oc} values match perfectly, the P_{max} values differ with a % 3 average value.

TABLE I: Comparison of the datasheet values and the simulation values (T=25C°, S=1000w/m^2)

Parameters	BP MSX60 Datasheet Value	BP MSX60 Simulation Value	BP MSX64 Datasheet Value	BP MSX64 Simulation Value
Maximum power , P_{max}	60 W	62 W	64 W	66 W
Short circuit current , I_{sc}	3.8 A	3.8 A	4 A	4 A
Open circuit voltage , V_{oc}	21.1 V	21.1 V	21.3 V	21.3 V

3.2. The Analyze of The Proposed General PV System

The proposed system is designed in Fig. 8. The model contains a resistive load, a DC-DC boost converter and a MPPT. The boost converter current and voltage output are measured; later on the power is obtained.

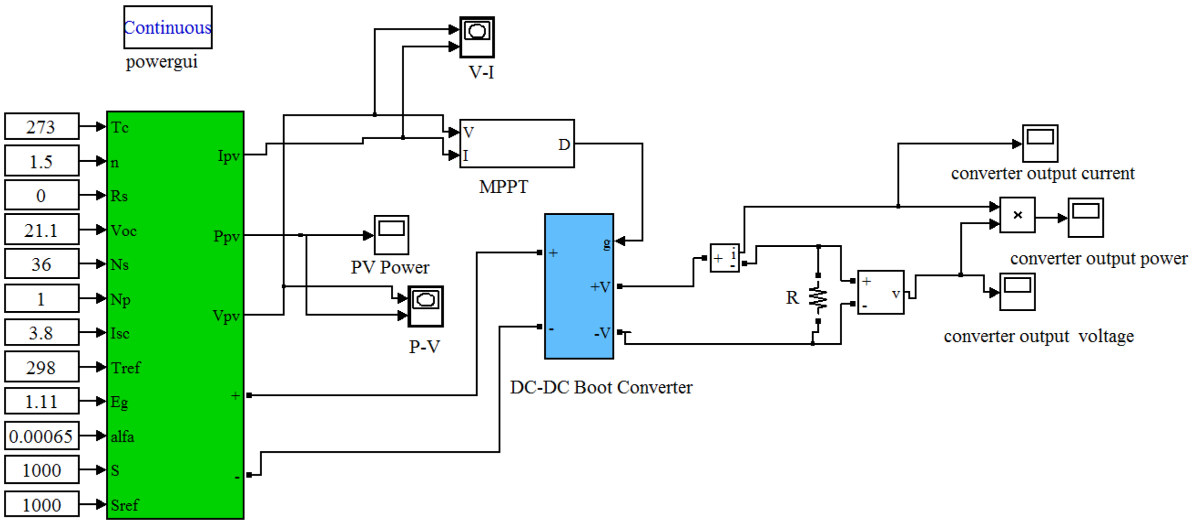


Fig.8: The proposed general PV system modeled in Matlab/Simulink

In Table 2 the efficiency analyze is presented by comparing the output power of the simulated PV model with the boost converter output and it is seen that the simulated PV system has an average efficiency value of %93.

TABLE II: The efficiency analyze of the general system for different temperature values

Temperature Valuse	**Simulated Model Output Power (W)**	**Boost Converter Output Power (W)**	**Efficiency (%)**
0 ° C	67.99	64.88	95.42
25 ° C	56.45	52.64	93.25
50 ° C	44.57	41.13	92.28

4. Conclusion

In this paper, a simulation model of PV array with voltage feedback is presented. The I-V and P-V characteristic curves are obtained under different solar irradiation and temperature values.

When the simulated PV module is analyzed, it is seen that the results give high accuracy and the model can be used for any other PV module. The proposed system with boost converter is also analyzed and it is seen that the boost converter power output follows the PV module power output with high efficiency.

5. References

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