

Development and Simulation of Stand Alone Photovoltaic Model Using Matlab/Simulink

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ABSTRACT

This paper presents the implementation of a generalized photovoltaic model using Matlab/Simulink software package, which can be representative of PV cell, module for easy use on simulation platform. The proposed model is designed with a user-friendly icon and a dialog box like Simulink block libraries which makes the generalized PV model easily simulated and analyzed in conjunction with power electronics. Taking the effect of sunlight irradiance and cell temperature into consideration, the output current and power characteristics of PV model are simulated and optimized using the proposed model. The proposed model enables the dynamics of PV power system to be easily simulated, analyzed and optimized.

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1. INTRODUCTION

With increasing concerns about fossil fuel deficit, skyrocketing oil prices, global warming and damage to environment and ecosystem, the promising incentives to develop alternative energy resources with high efficiency and low emission are of great importance [1]. Among the renewable energy resources, the energy through the photovoltaic (PV) can be considered the most essential and prerequisite sustainable resource because of the ubiquity, abundance and sustainability of solar radiant energy. Regardless of the intermittency of sunlight, solar energy is widely available and completely free of cost. Recently, photovoltaic array system is likely recognized and widely utilized to the forefront in electric power applications [1]. It can generate direct current electricity without environmental impact and contamination when is exposed to solar radiation. Being a semiconductor device, the PV system is static, quite, and free of moving parts, and these make it have little operation and maintenance costs [2],[3]. Even though the PV system is posed to its high capital fabrication cost and low conversion efficiency, the skyrocketing oil prices make solar energy naturally viable energy supply with potentially long-term benefits.

PV module represents the fundamental power conversion unit of a PV generator system. The output characteristics of PV module depends on the solar insolation, the cell temperature and output voltage of PV module. Since PV module has nonlinear characteristics, it is necessary to model it for the design and simulation of maximum power point tracking (MPPT) PV system applications [4]-[6]. The mathematical PV models used in computer simulation have been built for over the past four decades. Almost all well-developed PV models describe the output characteristics mainly affected by the solar insolation, cell temperature, and load voltage. However, the equivalent circuit models are implemented on simulation platforms of power electronics, such as SPICE. Recently, a number of powerful component-based electronics

simulation software package have become popular in the design and development of power electronics applications. However, the SimPowerSystem tool in Matlab/Simulink package offers wind turbine models but no PV model to integrate with current electronics simulation technology. Thus, it is difficult to simulate and analyze in the generic modeling of PV power system [7]. This motivates me to develop a generalized stand-alone model for PV cell, module using Matlab/Simulink.

The main contribution of this paper is the implementation of a generalized stand-alone PV model in the form of masked block, which has a user-friendly icon and dialog in the same way of Matlab/Simulink block libraries or other component-based electronics simulation software packages, such as Caspoc. The remainder of this paper is organized as follows. For easy presentation, the traditional PV models are addressed in Section II. And the nonlinearity of PV current versus voltage (I-V) and power versus voltage (P-V) characteristics are shown as well. Section III demonstrates the implementation and simulation results for the proposed model using Matlab/Simulink software package.

2. THE PROPOSED DESIGNED OF PHOTOVOLTAIC MODELS

Solar cell is basically a p-n junction fabricated in a thin wafer or layer of semiconductor. The electromagnetic radiation of solar energy can be directly converted electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater than the band-gap energy of the semiconductor are absorbed and create some electron-hole pairs proportional to the incident irradiation [8]. Under the influence of the internal electric fields of the p-n junction, these carriers are swept apart and create a photocurrent which is directly proportional to solar insolation. PV system naturally exhibits a nonlinear I-V and P-V characteristics which vary with the radiant intensity and cell temperature [9].

A general mathematical description of I-V and P-V output characteristics for a PV cell has been studied for over the past four decades. Such an equivalent circuit based model is mainly used for the MPPT algorithms [10],[11]. The equivalent circuit of general model which consist of a photo current a diode, a parallel resistor expressing a leakage current and a series resistor describing an internal resistance to the current flow, is shown in Figure 1.

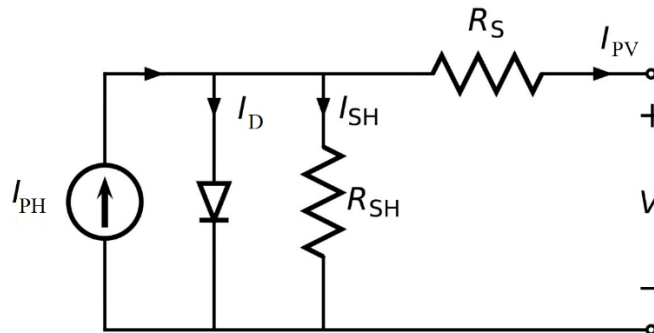


Figure 1. Single diode equivalent circuit of solar cell

The voltage- current characteristics equation of a solar cell is given as

$$I_{PV} = I_{PH} - I_S \left[\exp\left(\frac{q(V + R_S I_{PV})}{AkT_c}\right) - 1 \right] - \frac{V + R_S I_{PV}}{R_{SH}} \quad (1)$$

where, I_{PH} is a light-generated current or photocurrent, I_S is the cell saturation of dark current, q ($= 1.6 \times 10^{-19} \text{C}$) is an electron charge, k ($= 1.38 \times 10^{-23} \text{J/K}$) is a Boltzmann constant, T_c is the cell's working temperature, A is an ideal factor, R_{SH} is a shunt resistance and R_S is a series resistance [12],[13]. The photocurrent mainly depends on the solar insolation and cell's working temperature, which is described as

$$I_{PH} = [I_{SC} + K_I(T_c - T_{Ref})] \lambda \quad (2)$$

where, I_{sc} is the cell's short-circuit current at a 25°C and $1\text{kW}/\text{m}^2$, K_I is the cell's short-circuit current temperature coefficient, T_{Ref} is the solar insolation in kW/m^2 . On the other hand, the cell's saturation current varies with the cell temperature, which is described as

$$I_s = \left[I_{RS} \left(\frac{T_c}{T_{Ref}} \right)^3 \left\{ \exp \left(\frac{-q \frac{E_g}{Ak}}{\frac{1}{T_c} - \frac{1}{T_{Ref}}} \right) \right\} \right] \tag{3}$$

Where I_{RS} is the cell's reverse saturation current at a reference temperature and a solar radiation, E_g is the band-gap energy of the semiconductor used in the cell. The ideal factor A is dependent on PV technology. An even more exact mathematical description of a solar cell, which is called the double exponential model as in Figure 2, is derived from the physical behavior of solar cell constructed from polycrystalline silicon. This model is composed of a light-generated current source, two diodes, a series resistance and a parallel resistance. However, there are some limitations to develop expressions for the V-I to curve parameters subject the implicit and nonlinear nature of the model. Therefore, this model is rarely used in the subsequent literatures and is not taken into consideration for the generalized PV model.

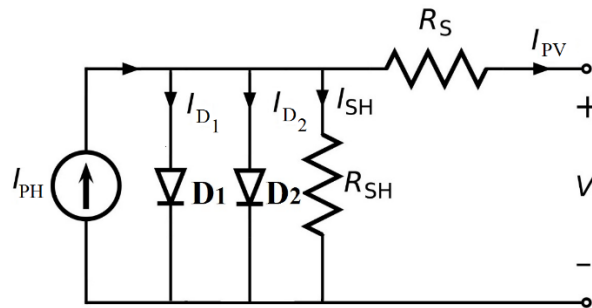


Figure 2. Double diode equivalent circuit of solar cell

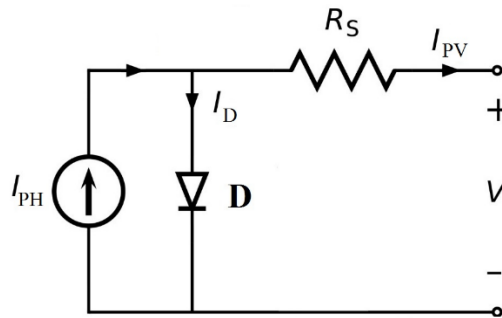


Figure 3. Single diode equivalent circuit with $R_{SH} = \infty$ of solar cell

The shunt resistance R_{SH} is inversely related with shunt leakage current to the ground. In general, the PV efficiency is incentive to variation in R_{SH} and the shunt-leakage resistance can be assumed to approach infinity without leakage current to ground. On the other hand, a small variation in R_S will significantly affect the PV output power. The appropriate model of PV solar cell with suitable complexity is shown in Figure 3. Equation (1) can be rewritten as

$$I_{PV} = I_{PH} - I_s \left[\exp \left(\frac{q(V + R_s I)}{AkT_c} \right) - 1 \right] \tag{4}$$

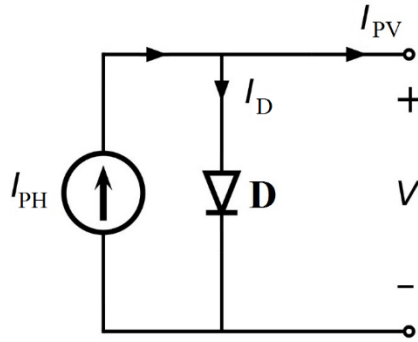


Figure 4. Single diode equivalent circuit with $R_{SH} = \infty$ and $R_S=0$ of the solar cell

For an ideal PV cell, there is no series loss and no leakage to ground, i.e., $R_S = 0$ and $R_{SH} = \infty$. The above equivalent circuit of PV solar cell can be simplified as shown in Figure 4. The Equation (1) can be rewritten to be

$$I_{PV} = I_{PH} - I_S \left[\exp\left(\frac{qV}{AkT_c}\right) - 1 \right] \tag{5}$$

The Fig 1 to Fig 4 explains with and without series loss and leakage loss equivalent circuit based model of the PV cell. Such an equivalent circuit based model is mainly used to find the maximum power point in the experiment.

3. RESEARCH METHOD FOR BUILDING OF SOLAR PV MODEL

Stand-alone photovoltaic power systems are electricity generating photovoltaic systems that are not connected to the electrical grid. This type of PV system may exclusively use solar panels or use them in conjunction with other electricity supplying devices, such as diesel generators and wind turbines [14].

The Matlab/Simulink model of standalone PV module illustrates and verifies the nonlinear voltage-current and power-voltage output characteristics of an arbitrary module using a one-diode equivalent circuit. Model inputs are the irradiance intensity and ambient temperature. Simulink is a simulation program, which provides a graphical interphase for building models as block diagrams [15]. It offers the advantage of building hierarchical models, namely to have the possibility to view the system at different levels.

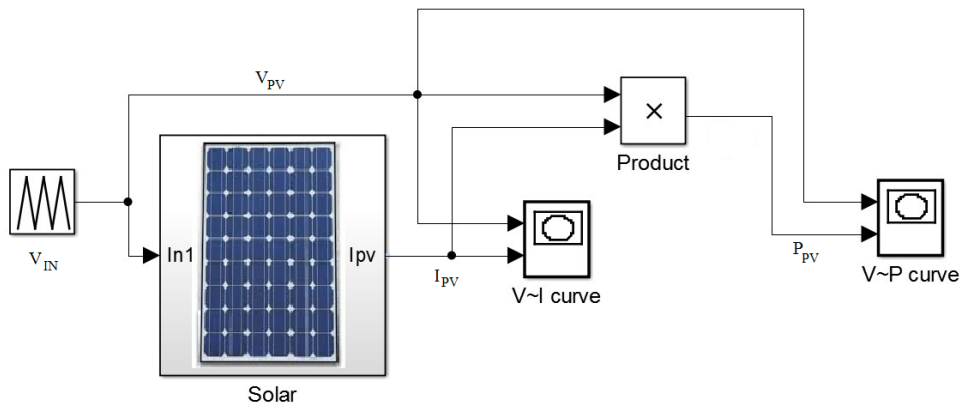


Figure 5. Basic model solar PV system

A model of PV module as shown Figure 5 with moderate complexity which includes the temperature independence of the photocurrent source, the saturation current of the diode and a series

resistance is considered based on the Shockley diode equation. It is important to build a generalized model suitable for all of the PV cell, module and array, which is used to design and analyze a maximum power point tracker. Being illuminated with radiation of sunlight, PV cell converts part of the photovoltaic potential directly into electricity with both I-V and P-V output characteristics [16].

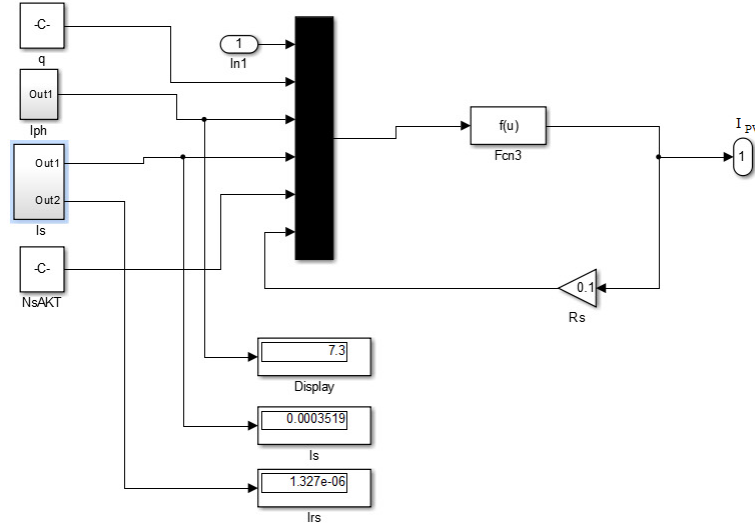


Figure 6. Current through the load, I_{PV}

A generalized PV model is built using Matlab/Simulink to illustrate and verify the nonlinear I-V and P-V output characteristics of PV module. The proposed model is implemented and shown in Figure 6, 7, 8 and 9 respectively. The Figure 6 is drawn with the help of the Equation (1). The display in the Figure 6 shows the value of the different parts of the Equation 3. The values of I_S and I_{PH} and going into the function Fcn3 to give the value of I_{PV} . The I_{PV} is also using as a feedback as showing the Equation (3). Two constant blocks are using in the circuit showing in the Figure 6 which are q ($= 1.6 \times 10^{-19}C$) and $N_S A k T$.

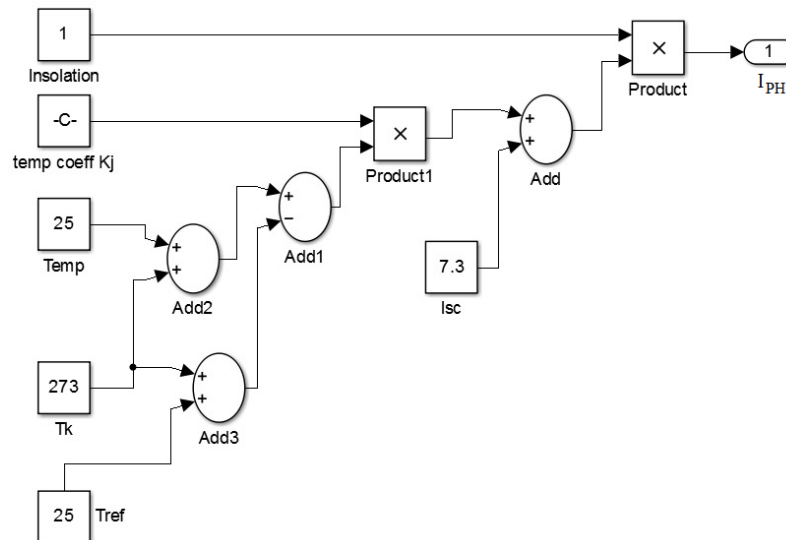


Figure 7. Input current, I_{PH}

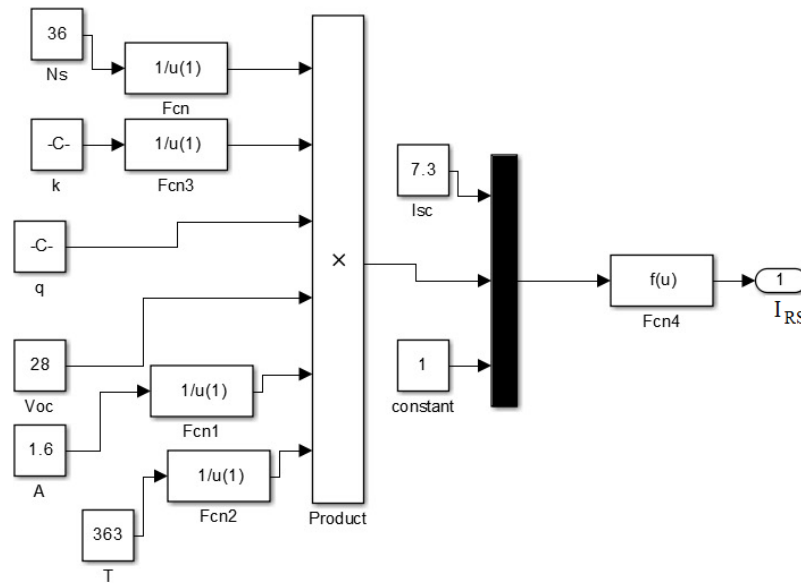


Figure 8. Cell's reverse saturation current, I_{RS}

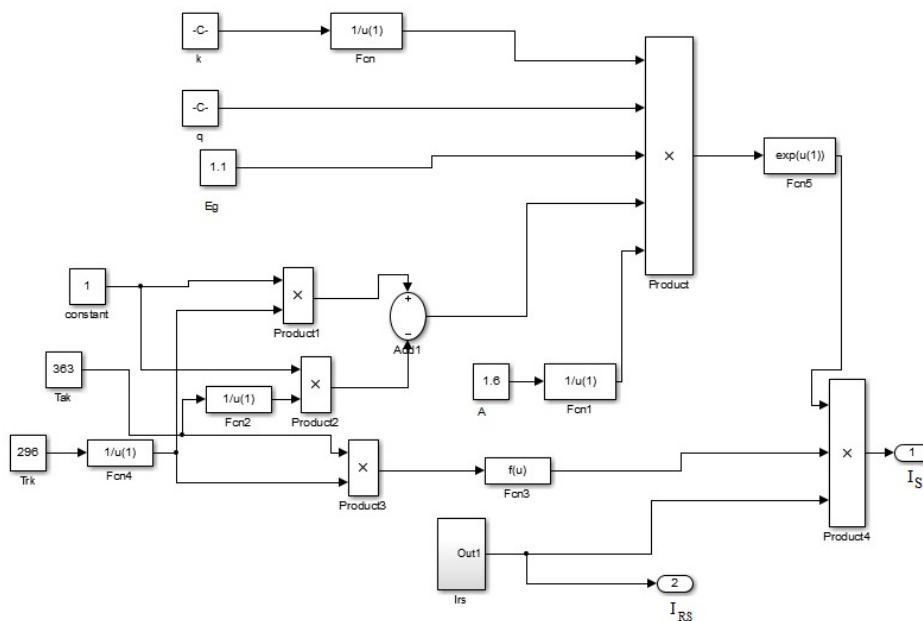


Figure 9. Cell saturation of dark current, I_S

The Figure 7, 8 and 9 show the internal circuit of the subsystems in the Figure 6. In order to make the generalized model easier to use and understand, the image file of PV icon as a masking icon has been used.

4. RESULTS AND DISCUSSION

For a PV cell with an ideal I-V characteristic, its open-circuit voltage and short circuit current are given as $V_{oc} = 17.5V$ and $I_{sc} = 7.2A$, respectively. Both I-V and P-V output characteristics of generalized PV module are shown in Figs 10 and 11 respectively. The nonlinear nature of PV cell is apparent as shown in the figures, i.e. the output current and power of PV cell depend on the cell's terminal operating voltage and temperature,

and solar insolation as well. It is been observed that with increase of working temperature, the short-circuit current of the PV cell increases, whereas the maximum power output decreases. As much as the increase in the output current is much less than the decrease in the voltage, the net power decreases at high temperatures. On the other hand, with increase of solar insolation, the short-circuit current of the PV module increases and the maximum power output increases as well. The reason is the open-circuit voltage is dependent on the solar irradiance, yet the short-circuit current is directly proportional to the radiant intensity. Both I-V and P-V output characteristics of PV module at various insolation and temperature are carried out. It also see that the increase of working temperature, the short-circuit current of the PV module increases, whereas the maximum power output decreases. The increase in the short-circuit current is much less than the decrease in the open-circuit voltage and the effect makes maximum power decreasing by about 0.45%/°C at high temperatures. Furthermore, it is also been observed that with increase of solar insolation, the short- current and the maximum power output of the PV module increases [16]. The reason is that the open-circuit voltage is logarithmically dependent on the solar irradiance, though the short-circuit current is directly proportional to the radiant intensity.

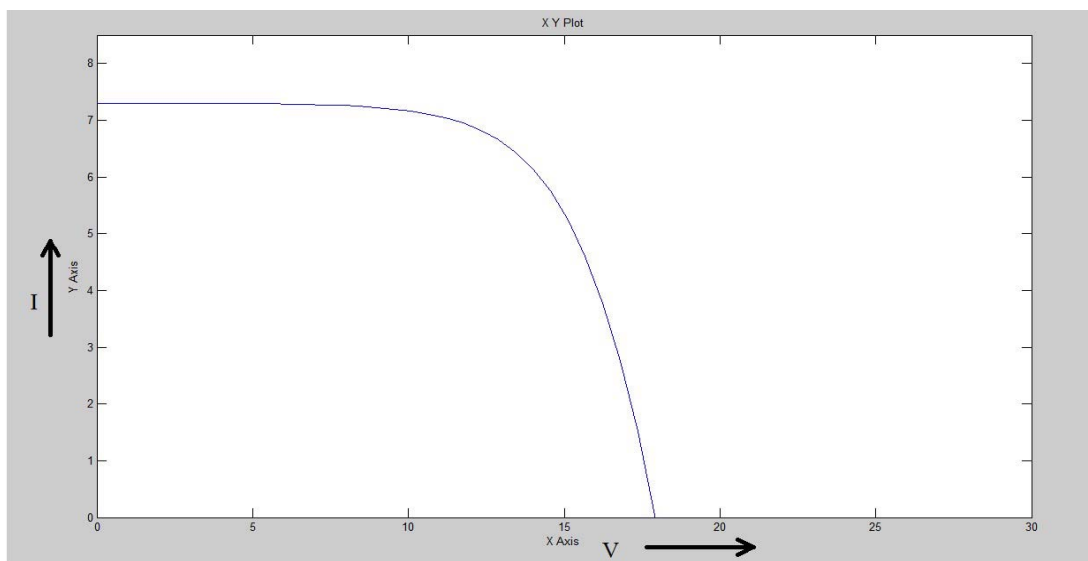


Figure 10. I – V output characteristics across the load

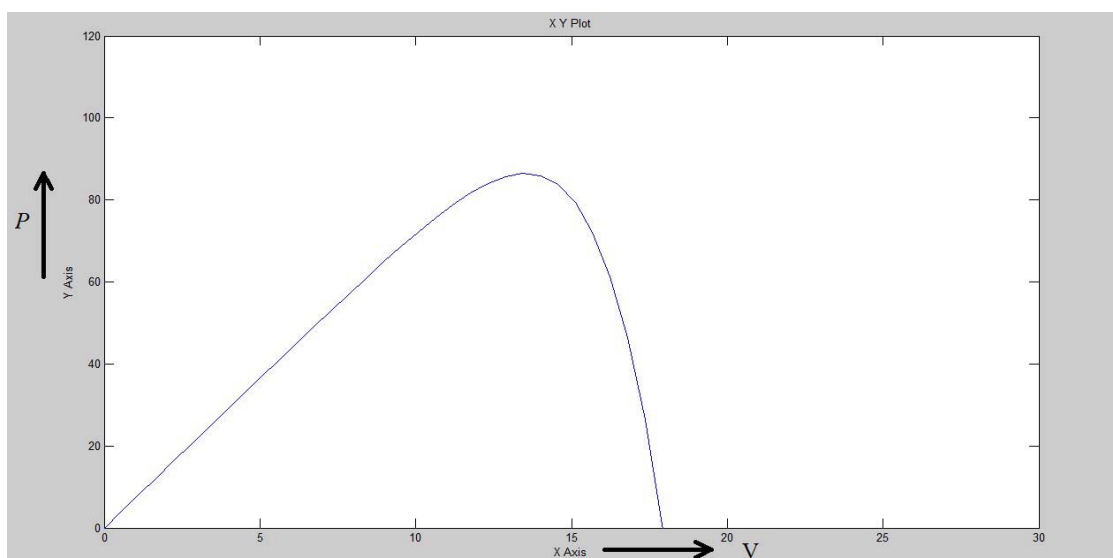


Figure 11. P – V output characteristics across the load

5. CONCLUSION

A generalized PV model which is representative of the all PV cell, module, and array has been developed with Matlab/Simulink and been verified with a PV cell and a commercial module. The proposed model takes sunlight irradiance and cell temperature as input parameters and outputs the I-V and P-V characteristics under various conditions. This model has also been designed in the form of Simulink block libraries. The masked icon makes the block model more user-friendly and a dialog box lets the users easily configure the PV model. Such a generalized PV model is easy to be used for the implementation on Matlab/Simulink modeling and simulation platform. Especially, in the context of the SimPowerSystem tool, there is now a generalized PV model which can be used for the model and analysis in the field of solar PV power conversion system.

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REFERENCES

- [1] O. Wasynczuk, “Dynamic behavior of a class of photovoltaic power systems”, *IEEE Transactions on Power Apparatus and Systems*, vol/issue: PAS-102(9), pp. 3031-3037, 1983.
- [2] Zvonimir Glasnovic, Jure Margeta, “A model for optimal sizing of photovoltaic irrigation water pumping systems”, *Solar Energy*, vol/issue: 81(7), pp. 904-916, 2007.
- [3] JCH. Phang, DSH. Chan, JR. Philips, “Accurate analytical method for the extraction of solar cell model parameters”, *Electronics Letters*, vol/issue: 20(10), pp. 406-408, 1984.
- [4] M. Veerachary, T. Senjyu, K. Uezato, “Voltage-based maximum power point tracking control of PV system”, *IEEE Transactions on Aerospace and Electronic Systems*, vol/issue: 38(1), pp. 262-270, 2002.
- [5] J. Surya Kumari, Ch. Saibabu, “Maximum Power Point Tracking Algorithms for Grid-Connected Photovoltaic Energy Conversion System”, *International Journal of Power Electronics and Drive Systems (IJPEDS, ISSN: 2088-8694, a SCOPUS indexed Journal)*, vol/issue: 3(4), pp. 424-43, 2013.
- [6] CC. Hua, CM. Shen, “Study of maximum power tracking techniques and control of dc-dc converters for photovoltaic power system”, *Proceedings of 29th annual IEEE Power Electronics Specialists Conference*, vol. 1, pp. 86-93, 1998.
- [7] Kodanda Ram RBPUSB, Venu Gopala Rao Mannam, “Operation and Control of Grid Connected Hybrid AC/DC Microgrid using various RES”, *International Journal of Power Electronics and Drive Systems (IJPEDS, ISSN: 2088-8694, a SCOPUS indexed Journal)*, vol/issue: 5(2), pp. 195-202, 2014.
- [8] JA. Gow, CD. Manning, “Development of a photovoltaic array model for use in power-electronics simulation studies”, *IEEE Proceedings- Electric Power Applications*, vol/issue: 146(2), pp. 193-199, 1999.
- [9] Himanshu Sharma, Nitai Pal, Pradip Kumar Sadhu, “Modeling and Simulation of Off-grid Power Generation System using Photovoltaic”, *TELKOMNIKA Indonesian Journal of Electrical Engineering (ISSN: 2302-4046, e-ISSN: 2087-278X)*, vol/issue: 13(3), 2015.
- [10] Shagar, BM., Vinod, S., Lakshmi, S., “Design of DC-DC converter for hybrid wind solar energy system”, *Computing, Electronics and Electrical Technologies (ICCEET)*, 2012 International Conference, pp. 429 – 435, 2012.
- [11] Jeya Selvan Renius, K. Vinoth Kumar, Arnold Fredderics, Raja Guru, Sree Lakshmi Nair, “Modelling and Simulation of Variable Frequency Synchronous DC-DC Buck Converter”, *International Journal of Power Electronics and Drive Systems (IJPEDS, ISSN: 2088-8694, a SCOPUS indexed Journal)*, vol/issue: 5(2), pp. 237-243, 2014.
- [12] Seul-Ki Kim, Eung-Sang Kim, Jong-Bo Ahn, “Modeling and Control of a Grid-connected Wind/PV Hybrid Generation System”, *Transmission and Distribution Conference and Exhibition, 2005/2006 IEEE PES*, pp. 1202 – 1207, 2006.
- [13] O. Wasynczuk, “Modeling and dynamic performance of a line commutated photovoltaic inverter system”, *IEEE Transactions on Energy Conversion*, vol/issue: 4(3), pp. 337-343, 1989.
- [14] Omid Palizban, MA. Rezaei, Saad Mekhilef, “Active and Reactive Power Control for a Hybrid System with Photovoltaic Panel, Wind Turbine, Fuel Cells, Electrolyzer and Super Capacitor in Off-grid Mode”, *IEEE International Conference on Control System, Computing and Engineering*, pp. 404–408, 2011.
- [15] Qi Zhiyuan, Liu Yongxin, Liu Haijiang, Hao Zhengqing, “Power Control for Off-grid Wind Power System Basedon Fuzzy PID Controller”, *Power and Energy Engineering Conference (APPEEC), Asia-Pacific*, pp. 1–4, 2010.

- [16] Hamadi, A., Rahmani, S., Addoweesh, K., Al-Haddad, K., "A modeling and control of DFIG wind and PV solar energy source generation feed", Industrial Electronics Society, IECON 2013 - 39th Annual Conference of the IEEE, pp. 7778 – 7783, 2013.

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