www.ijecs.in
International Journal Of Engineering And Computer Science ISSN:2319-7242
Volume 4 Issue 1 January 2015, Page No. 9888-9891

Solar Radiation Prediction with Single Diode Photovoltaic Module

T.Pearson[1], S.Bhuvaneswari[2], S.Abish Samuel[3]

[1]Professor, PITAM, Anna University, Chennai
pearsonin@gmail.com

[2]Assistant Professor, PITAM, Anna University, Chennai
bhuvana_eswari42@yahoo.com

[3]PG Scholar, PITAM, Anna University, Chennai
abishsam@gmail.com

Abstract: ***This paper proposes a novel simplified model of a photovoltaic module and also the modeling of hourly cloudless solar radiation of a particular site to achieve optimal operation. This model uses standard specifications along with actual solar radiation and temperature. This proposed work develops a matlab/simulink model to generate simulation of solar radiation of any location to provide the insolation on a photovoltaic module of any orientation and for any time of the year. A single diode model for current voltage characteristics and maximum power operation of a photovoltaic module is also presented which models the effect on VI characteristics of varying climate conditions. The combined model of solar radiation and PV module provide a tool to investigate the effect of meteorological conditions on the performance of a PV module generator. The predicted solar radiation and the experimental data are in good compliance.***

Keywords: Solar energy, Solar cell, Photovoltaic module, Single Diode model, Photovoltaic.

1. Introduction

Solar energy is the source of all energy on the earth. It is a renewable source of energy alternative to the conventional fossil fuel electricity generation. A simple and elegant method of harnessing the sun's energy is photovoltaic. Solar cells directly convert solar radiation in to electricity. The electricity generation by the solar cells is based on the principle of photovoltaic effect. The process of conversion of sunlight in to electricity using solar cells is called photovoltaic. Manufacturers define specifications of the solar module only at standard conditions. Solar radiation in a particular area is not available instantly. The simulation model of PV module is very essential to analyze the performance of the solar cell. The solar radiation prediction models are given in [1]. The single diode model using the Shockley diode equation is given in [2]. This model investigates the variation of maximum power point with temperature and insolation levels. The model based on a behavioral cell model is given in [3]. This model is based on the electro-physics of the PV cell. The electro-physics of the PV model is too difficult to determine. Among the various mathematical models the simplest one is the single diode model without resistances. The VI characteristics at MPPT are not very accurate. The PV module performance is improved by adding series and shunt resistance [4]. The values of series and shunt resistance are determined by an incremental conductance algorithm. The carrier recombination losses in the depletion region are not considered. In this paper a simplified single diode model with negligible shunt resistance is proposed. It also develops a matlab/simulink model to generate solar radiation. The generated solar radiation is given as input to the single diode model along with the operating temperature of the area. The VI and PV characteristics of the model are calculated.

2. Methodology

The block diagram of proposed system is given in figure 1. It has solar radiation block and the PV module block. The model is designed using the matlab/simulink software. The solar radiation block generates the solar radiation for the given inputs at any location and for any time of the year. The inputs to the solar radiation block are day number, with January 1 as 1 to December 31 as 365, azimuth angle of the panel, latitude of the location for which the solar radiation is to be calculated, and the hour of the day. The generated solar radiation is given to the single diode photovoltaic module. The single diode photovoltaic module calculates the PV and IV characteristics for the given solar radiation and temperature.

2.1 Cloudless solar radiation

The total solar radiation on a flat panel is,

$$G_{TR} = G_{BR} + G_{DR} + G_{RR} \quad (1)$$

Where G_{TR} is the total radiation on a flat panel, G_{BR} is the direct radiation on the panel, G_{DR} is the diffuse solar beam radiation on the panel, G_{RR} is the reflected radiation from the surface of the earth.

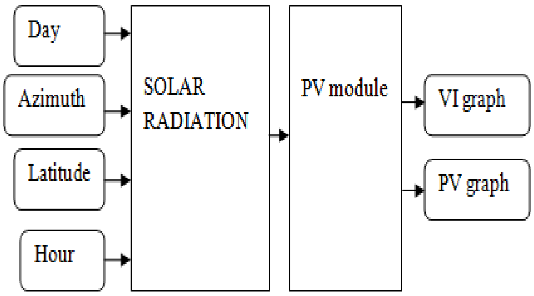

Figure 1: Block diagram

2.1.1 Direct solar beam radiation

The direct solar beam radiation is the radiation travelling on a straight line from the sun down to the surface of the earth, is given as follows,

$$G_{BR} = G_b \cos\theta_i \qquad (2)$$

Where θ_i is the incidence angle, G_b is the beam radiation.
The beam radiation on the given surface is maximum when the sun's rays hitting the panel at a 90° angle and is given by the expression,

$$G_b = G_o \exp(-k/\sin\beta_z) \qquad (3)$$

Where G is the extraterrestrial radiation, k is the optical depth
The optical depth is given as,

$$k = 0.174+0.035\sin[360*(n-100)/365] \qquad (4)$$

The extraterrestrial radiation is given as,

$$G_o=1160+75\sin[360*(n-275)/365] \qquad (5)$$

Where n is the day number.
The incident angle and the altitude angle are calculated as,

$$\sin\beta_z=\cos L*\cos d*\cos H+\sin L*\sin d \qquad (6)$$

Where φ_A is the azimuth angle of the sun, φ_p is the azimuth angle of the panel, φ_s is the slope of the panel. L is the latitude of the location, d is the declination angle, H is the hour angle.
The azimuth angle of the sun is given as,

$$\sin\varphi_A = \cos d*\sin H/\cos\beta_z \qquad (7)$$

The declination angle is,

$$d = 23.45\sin[360*(284-n)/365.25] \qquad (8)$$

The hour angle is given by the expression,

$$H = 15(12-h) \qquad (9)$$

Where n is the day number, h is the hour of the day.

2.1.2 Diffuse and reflected radiation

Diffuse radiation is sunlight that has been scattered by molecules and particles in atmosphere but it again reaches the surface of the earth
The model for the diffuse radiation is expressed as,

$$G_{DR} = C*G_b(1+\cos\varphi_s)/2 \qquad (10)$$

Where C is the sky diffuse factor which is given as,

$$C=0.095+0.04\sin(360*(n-100)/365) \qquad (11)$$

Reflected radiation is the amount of radiation reflected by the earth's surface.
The model for the reflected radiation is given as,

$$G_{RR} = \rho*G_B*(\sin\beta_Z+C)(1-\cos\varphi)/2 \qquad (12)$$

Where, ρ is the ground reflectance called albedo.
The total radiation are obtained by adding up the equations (2), (10), (12) and implemented in matlab/simulink to generate the hourly solar radiation at any location and for any time of the year.

2.2 Single Diode PV module

The single diode PV module is developed in this paper using the matlab/simulink. The equivalent circuit of the model is given in figure 2. PV cells are grouped together to form PV modules. The cells are arranged in series and parallel. The number of cells in series is denoted by N_s and the number of cells in parallel is denoted as N_p. Manufacturers provide electrical specifications of the solar panel only at standard conditions, namely solar radiation of 1000 W/m^2 and cell temperature of 25 °C. The circuit consists of a current source $I_{ph,}$ a parallel connected diode D and a series resistor R_s.
The photocurrent of the module is,

$$I_{ph} = (I_{sc} + K(T-298))\lambda/100 \qquad (13)$$

Where I_{ph} is the photo current, I_{sc} is the short circuit current.
The reverse saturation current of the module is,

$$I_{rs} = I_{sc} / (\exp(q*V_{oc}/N_s kAT)-1) \qquad (14)$$

Where A is the diode ideality constant, q is the electron charge.

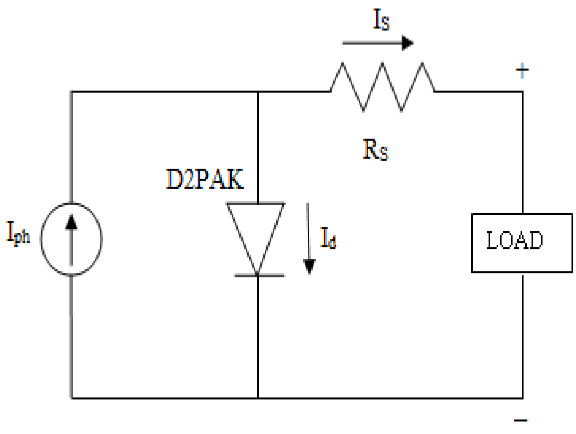

Figure 2: Equivalent circuit of single diode model

The saturation current of the module varies with the cell temperature and is given as,

$$I_o = I_{rs}(T/T_r)^3\exp(qE_g/Bk(1/T_r-1/T)) \qquad (15)$$

Where T_r is the reference temperature i.e. 25°C, T is the operational temperature.
The output current of the PV module is,

$$I_{pv}=I_{ph}-I_o[\exp(q(V_{pv}+R_s)/N_sAkT)-1] \quad (16)$$

Where I_{ph} is the photo current, I_{pv} is the photovoltaic current, V_{pv} is the photovoltaic voltage, R_s is the series resistance.

Table 1: Electrical specifications of Solkar 36W solar panel

Electrical characteristics	**Data**
Voltage at maximum power	16.56 V
Current at maximum power	2.25 A
Open circuit voltage	21.24 V
Short circuit current	2.55 A
Number of cells in series	36
Number of cells in parallel	1

The single diode model with solar radiation is implemented using matlab/simulink. The model is designed for Solkar 36W module. The electrical specifications of the solar panel are given in the table 1.

3. Result and Discussion

The prediction of solar radiation and the model of single diode PV module are designed by matlab/simulink software. The matlab/simulink model of the solar module is designed for the inputs given in table 2.
The module calculates the declination, zenith, azimuth and hour angle for the given inputs and using these values the direct, diffuse and reflected radiation is calculated. These values are summed up to obtain the total radiation, which is the solar radiation of the particular area.

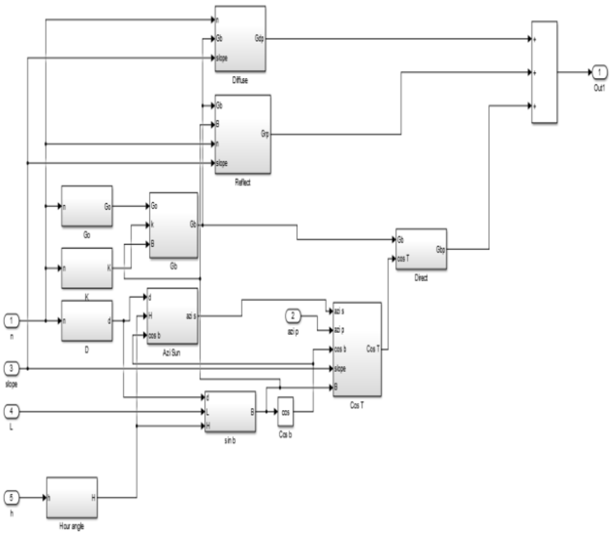

Figure 3: Matlab/Simulink diagram of the solar module.

The matlab/simulink model of the single diode PV module given in figure 4 is designed for the solar radiation calculated by the solar module and the operating temperature of the area. The PV module generates the voltage-current (V-I) and power-voltage (P-V) characteristics of the single diode PV module. The output current of the PV module is calculated using the diode saturation current and the photo current. The output power is obtained from current and voltage.

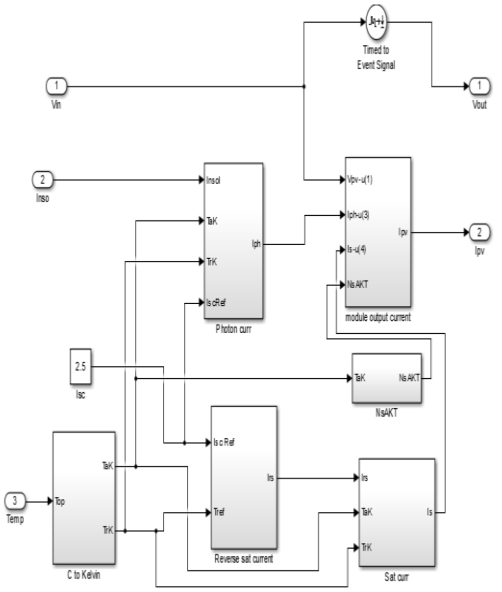

Figure 4: Matlab/Simulink diagram of single diode model

Table 2: Inputs to the model

Input	**Value**
Day of the year	77
Time	9.30 AM
Slope	36.86
Latitude	9.52 N
Temperature	31 °C

The VI characteristics of the single diode model given in figure 5 are calculated for the voltage and current generated by the PV module.

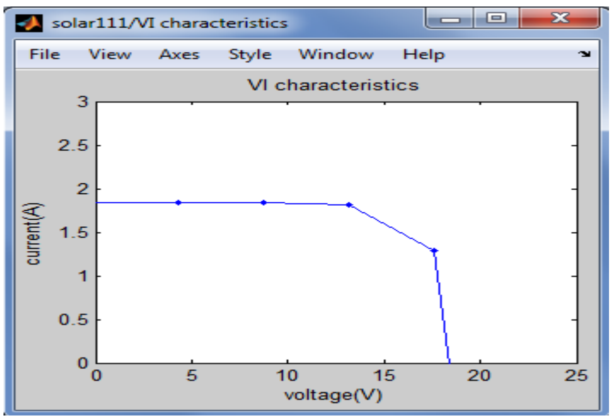

Figure 5: VI characteristics of single diode model

The PV characteristics of the single diode model are given in figure 6 are calculated using the power and voltage generated by the PV module.

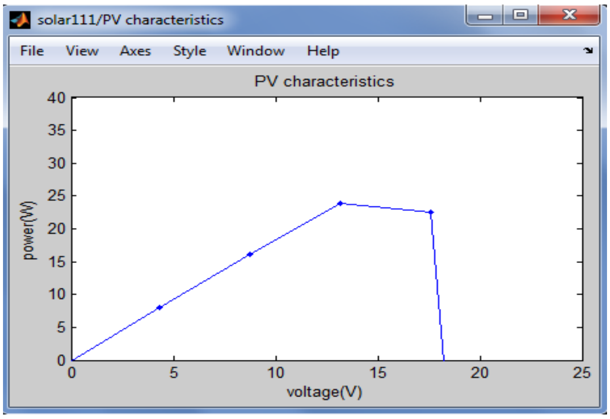

Figure 6: PV characteristics of single diode model

From the above graphs we observe that, When the radiation increases,

1.The current output increases

2.The voltage output also increases.

3.This results in net increase in power output with increase in radiation at constant temperature.

When the operating temperature increases,

1.The current output increases

2.The voltage output decreases.

3.This results in net reduction in power output with rise in temperature.

4. Conclusion

This paper provides an innovative model to predict the performance of a PV module of any orientation and for any time of the year for a particular area. The model uses empirical equations to predict the solar radiation. The solar radiation is used by the PV module to develop the VI and PV characteristics of the Solkar 36W PV module. The developed single diode model has slight variations with the increase in temperature. This error can be improved by the two diode model.

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Authors

First Author – Dr.T.Pearson.,M.E.,Ph.D.,IETE., LMISTE., is currently working as Professor, Department of Electronics and Communication Engineering, Prathyusha Institute of Technology and Management, Chennai, India.

Second Author – Mrs.S.Bhuvaneswari.,M.E., is currently working as an Assistant Professor, Department of Electronics and Communication Engineering, Prathyusha Institute of Technology and Management, Chennai, India.

Third Author – Mr.S.Abish Samuel.,(M.E)., is a Post Graduate student, Department of Electronics and Communication Engineering, Prathyusha Institute of Technology and Management, Chennai, India.

Correspondence Author – Mr.S.Abish Samuel, Email: abishsam@gmail.com, contact number: 9952538073.