POWER PREDICTION OF PHOTOVOLTAIC SYSTEM USING FOUR PARAMETER MODEL

[1]MANISH KUMAR, [2]NITIN KUMAR, [3]S.S. CHANDEL

Center for Energy and Environmental Engineering, NIT Hamirpur (H.P) 177005
Email: naik.manish17@gmail.com

Abstract—The output power of a solar cell can be predicted using some basic cell parameters. Different parameters are used for modeling of solar cell such as: light generated current, diode saturation current, diode ideality factor, series resistance, shunt resistance, etc. This study presents the effect of four parameters (light generated current, diode saturation current, diode ideality factor and series resistance) of a solar cell on the output power of PV system (series connection of two PV Modules of maximum power 18 watt peak each). It is concluded from literature survey that four parameter method of solar cell characterization is quite accurate. The output power of system is estimated using program developed in MATLAB Software and the results are validated using experimental data. Experimental results shows that estimated output power of four parameter model is very close to real one.

I. INTRODUCTION

Solar cells generate electricity when exposed to sunlight. When sunlight is absorbed by a semiconducting surface then generation of electron-hole pairs takes place. Due to asymmetry in the P-N junction, the generated electrons tend to flow from P-side to N-side and the generated holes from N-side to P-side resulting in separation of charge carriers which can flow in external circuit delivering work to the load [1].
Solar panel consists of series connection of number of solar cells. Power delivered by a single panel is not sufficient to meet the power demands for the vast majority of practical purposes. So, a number of PV module are connected in both series and parallel connections to achieve the desired output. Prediction of output power is carried out using manufacturer datasheet. A lot of study has been done on the power prediction of PV Array. Accuracy of predicted output power of PV system has always been a big concern. For power prediction, one, two and three diode models have been developed by researchers. Usually one diode model is preferred as it is less complicated. Although one diode model is not much accurate. Complexity of solar cell model increases with increase in no. of diodes, so does the accuracy. A three parameter model includes: light generated current, diode saturation current and diode ideality factor. Four parameter considers series resistance in addition to three parameter model. By adding shunt resistance to previous four parameters, five parameter model is developed. In this study one diode model with four parameters is used. Most mathematical models developed for output power prediction are based on current and voltage relationships which are simplification to double diode model developed by chan and phang [2]. One diode model considers antiparallel diode with current source. Desoto et al. [3] and Jain and Kapoor [4] developed this type of mathematical model. For the most part shunt resistance is very large and draws minimum current through it so it can be neglected. This is the simplification to current voltage relationship of five parameters and structures the premise for four parameters. Series resistance offers more realistic behavior for photovoltaic system concluded by Bikaneria et al. [5]. Salmi et al. [6] focuses on Matlab model and describe that series resistance increases then voltage–current (V-I) curve reduce to origin Accurate model that predict voltage–current (V–I) curves, power–voltage (P–V) curves, maximum power point values for different panel type developed by Tian et al. [7]. Chenni et al. [8] carried out the comparative study of different technologies of panel like thin film, copper indium diselenide, multicrystalline silicon and mono crystalline silicon and Paulescu et al. [9] performance analysis is based on four parameter and also consider difference between response time of pyranometer and PV module in power estimation. King et al. [10] precisely estimate power with an algebraically simple model however it obliges parameters that are ordinarily not accessible from manufacture Sandia National Laboratories [11] provided a database of model parameter for different array. This paper shows a model which utilizes just information that is given by manufacturer for power estimation.

SOLAR CELL

Solar cells are the building blocks of a PV Array. These are made up of semiconductor materials like silicon etc. A thin semiconductor wafer is treated to form an electric field, positive on a side and negative on the other. Electrons are separated from the atoms of the semiconductor material when illuminated. If an electrical circuit is made by joining a conductor to the both sides of the semiconductor, electrons flow will start generating an electric current. Duffie and Beckman [12] provides equivalent circuit for single solar cell. Equivalent circuit is represented by current source in antiparallel with diode as shown in Fig. 1 [13].

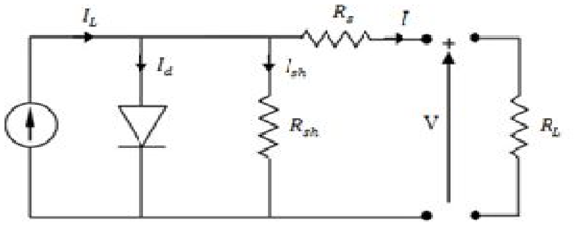

Fig.1. Equivalent circuit of solar cell.

According to Kirchoff's current law,

$$I = I_L - I_d - I_{sh} \quad (1)$$

Where I_L is the light generated current or irradiance current, which is produced when the cell is irradiated. I_L varies linearly with solar radiation at certain cell temperature. Current flowing through the anti-parallel diode is denoted by I_d, is responsible for the non-linear characteristics of the solar cell. I_{sh} is shunt current flowing through the shunt resistor R_{sh}.

Substituting appropriate expressions for I_d and I_{sh}, we get

$$I = I_L - I_o[e^{(\frac{q(V+IR_S)}{nKT})} - 1] - \frac{V+IR_S}{R_{sh}} \quad (2)$$

Where I_d is diode current modeled by the equation for a Shockley diode, I_o is saturated reverse current or leakage current, q is electron charge (1.602 × 10-19 C), K is boltzmann constant (1.38 x 10 -23 J/K), T is cell operating temperature, n is diode ideality factor, R_S is series resistance and R_{sh} is shunt resistance.

II. IMPORTANT MODELLING PARAMETER

A. Photo current I_L

The Photo current I_L depends on the solar radiation S and cell temperature T. Dev and Jeyaprabha [14] presented equation for I_L

$$I_L = [I_{sc,ref} + \alpha(T - T_{ref}]\frac{S}{100} \quad (3)$$

Where T_{ref} is temperature at standard test condition or at reference, $I_{sc,ref}$ is short circuit current at reference and α is short circuit current temperature coefficient which represents that short circuit current is changes with temperature.

B. Reverse Saturation current I_o

In a solar cell, the reverse saturation current is because of the diffusive flow of minority electrons from the p-side to the n-side and the minority holes from the n-side to the p-side. I_o (Reverse Saturation current) is primarily dependent on the temperature of the cell [15] [16]

$$I_o = I_{o,ref}\,[\frac{T}{T_{ref}}]^3\; e^{\frac{qE_g}{nK}\left[\frac{1}{T_{ref}}-\frac{1}{T}\right]} \quad (4)$$

Where $I_{o,ref}$ is reverse saturation current at standard test condition or at reference and is given by (5)

$$I_{o,ref} = \frac{I_{sc,ref}}{\left[e^{\frac{qV_{oc,ref}}{nKT}} - 1\right]} \quad (5)$$

E_g is the band gap energy

$$E_g = 1.6 - 4.3 * 10^{-4}\frac{T^2}{T+636} \quad (6)$$

C. Temperature of Cell (T)

Cell temperature changes due to changes in the ambient temperature as well as changes in the radiation [7]. It is defined as:

$$\mathrm{T} = \mathrm{T_{amb}} + (\frac{\mathrm{NOCT}-20}{0.8})\mathrm{S} \quad (7)$$

Where $\mathrm{T_{amb}}$ the ambient temperature and NOCT is nominal operating cell temperature which is generally provided by manufacturer.

D. Ideality factor

The n (Ideality factor) is defined as how closely the diode follows the ideal diode equation. Ideality factor generally depends upon material used for solar cell. The parameter n is taken as 1 if the transport process is purely diffusion and n is taken as 2 if it is primarily recombination in the depletion region.

There are some research papers which suggested the value of n for different materials used for solar cell. Bashahu and Nkundabakura [17] reviewed different test methods for determination of ideality factor and suggested n lies in between 1.26 to 1.5. Rajapakse and Muthumuni [18] suggested n is 1.3 for silicon material used for solar cell. In this paper, n is assumed to be related only to the material of the solar cell and considered as independent of temperature and solar radiation.

E. R_s (Series resistance)

Series resistance of solar cell comes in to picture due to following reasons: the movement of current through the emitter and base of the solar cell, the contact resistance between the metal contact and the silicon and the resistance of the top and rear metal contacts.

R_S (Series resistance) is defined as [19] [16]

$$R_S = -\left(\frac{dV}{dI}\right)_{V=V_{OC}} - \frac{1}{X_V} \quad (8)$$

Where

$$X_V = I_o\frac{q}{nKT}e^{\frac{qV_{oc,ref}}{nKT}} \quad (9)$$

Where R_{so} is reciprocal of the slope at the open-circuit point

$$R_{so} = -\left(\frac{dV}{dI}\right)_{V=V_{OC}} \quad (10)$$

Celik et al. [20] and Chan and Phang [2] calculated series resistance in different manner

$$R_S = R_{so} - \left[\frac{nKT}{qI_O} e^{\left(\frac{-qV_{OC}}{nKT}\right)} \right] \quad (11)$$

F. R_{sh} (Shunt resistance)

R_{sh}, are typically due to manufacturing imperfections, instead of poor solar cell design. Low shunt resistance is a reason for power losses in solar cells by providing an alternate current path for the light-generated current. Such a diversion decreases the amount of current flowing through the solar cell junction and decreases the voltage from the solar cell. At low light levels the effect of a shunt resistance is particularly severe, since there will be less light-generated current. The diversion of this current to the shunt therefore has a larger impact. Shunt resistance is calculated as [20] [21]

$$R_{sh} = R_{sho} \quad (12)$$

Where R_{sho} is the reciprocal of the slope at short-circuit point

$$R_{sho} = -\left(\frac{dV}{dI}\right)_{I=I_{SC}} \quad (13)$$

III. MODELLING OF PV ARRAY

To reduce the complexity in one diode model different combination of parameters are taken into consideration to develop various model. Solar cell model using I_L Photocurrent, I_o Reverse saturation current, n Diode ideality factor and R_S series resistance is developed which is given below [13] [19].

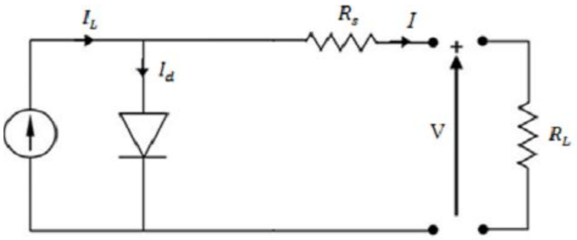

Fig. 2. Circuit diagram of solar cell using four parameters

Diode current is given by

$$I_d = I_o[e^{\left(\frac{q(V+IR_S)}{nKT}\right)} - 1] \quad (14)$$

Celik et al. [20], Ahmad et al. [21] and Kim et al. [22]. carried out study in modeling of PV solar cell using four parameters Net output current is written as

$$I = I_L - I_o[e^{\left(\frac{q(V+IR_S)}{nKT}\right)} - 1] \quad (15)$$

Above equation of solar cell expands to PV module and PV array

$$I_A = N_P I_{rr} - N_P I_o \left[e^{\left(\frac{q\left(V_A - I_A \frac{N_S}{N_P} R_S\right)}{N_S nKT}\right)} - 1 \right] \quad (16)$$

IV. EXPERIMENTAL SETUP

In this study one diode model using four parameters is used for the prediction of output power of PV array. The model require the input parameter as solar radiation, module temperature. For validation of results an experimental setup was built. Experiments were performed at outdoor condition by using two series connected Maharishi Solar Technology PV modules were kept on optimum tilt angle on the roof of the building at the National Institute of Technology Hamirpur campus. A photograph of experimental set up is shown in Fig. 3. Experimental data was taken at different solar radiation and cell temperature. Solar radiation was measured using Hukseflux model LP02-05 pyranometer and cell temperature was measured by a K type thermocouple joined to the back surface of the PV module.

A CRIO-9072/3/4 data logger was used for the logging of solar radiation, module temperature. The values from the data logger are given as the input parameters in the four parameters model which is developed in Matlab. A four parameters model Matlab program was developed that uses manufacturer data which is given in I, II for output power prediction of PV Array. The output power is the predicted and compared the actual one for the same values of solar radiation, module temperature.

I. Manufacturer data sheet of Maharishi Solar Technology Model No N2317002051 PV Module at reference condition

Current Temperature Coefficient	0.0015 Amp/Kelvin
Short Circuit Current	1.276 Amp
Open Circuit Voltage	23.16 Volt
Maximum Power Point Current	1.186 Amp
Maximum Power Point Voltage	18.76 Volt
Series Resistance	0.015 ohm
Slope at Short Circuit Current	512 ohm
Slope at Open Circuit Voltage	1.79 ohm
Number of solar cells in series	36

II. Manufacturer data sheet of Maharishi Solar Technology Model No N2317002001 PV Module at reference condition

Current Temperature Coefficient	0.0015 Amp/Kelvin
Short Circuit Current	1.261 Amp
Open Circuit Voltage	23.17 Volt
Maximum Power Point Current	1.176 Amp
Maximum Power Point Voltage	18.78 Volt
Series Resistance	0.015 ohm
Slope at Short Circuit Current	523 ohm
Slope at Open Circuit Voltage	1.78 ohm
Number of solar cells in series	36

Fig. 3. Pictorial View of experimental setup

V. RESULTS AND DISCUSSION

One diode four parameter model had been developed in Matlab. In these models two parameter, module temperature and solar radiation are given as input. These inputs are the real time measured values. For each set of input values output power is predicted and validated. The table shows the output power of one diode four parameter model along with measured one for different levels of solar radiation and temperature. Results shows the consistency of the measured power with the predicted power at various temperature and solar radiation levels. The predicted power differs by a large amount at lower radiation. At high radiation predicted power is comparable to the measured power. In four parameter model shunt resistance is not taken under consideration as a result predicted power is over estimated. Shunt resistance has a negative impact on power at low radiation. That's why in four parameter model mean error is increased at low radiation. Mean percentage error between experimentally measured and estimated power is expanded in extent to the decrement in solar radiation.

III. Maximum power values predicted from Matlab and compared with measured value along with error percentage at different solar radiation and module temperature

Input parameters		output power		Error in models	
Module temperature	Solar radiation	Four parameter	Measured	Four parameter	Error in %
44.18	1000.34	39.00	38.45	-0.01443	-1.443
49.33	960.196	35.63	35.68	0.001395	0.1395
47.40	949.283	35.85	35.26	-0.01697	-1.697
48.34	943.796	35.33	35.95	0.01721	1.721
44.89	716.388	27.07	30.3	0.106425	10.6425
44.71	668.843	25.19	27.33	0.078285	7.8285
42.42	568.406	21.56	18.58	-0.16043	-16.043
41.10	524.341	19.98	17.21	-0.1615	-16.15
38.67	449.58	17.33	17.03	-0.01813	-1.813
36.23	371.955	14.44	17.72	0.184621	18.4621
36.95	168.648	6.13	7.321	0.161618	16.1618
31.89	45.1437	1.56	1.337	0.167837	16.7837
			Total average	0.00085	2.8827

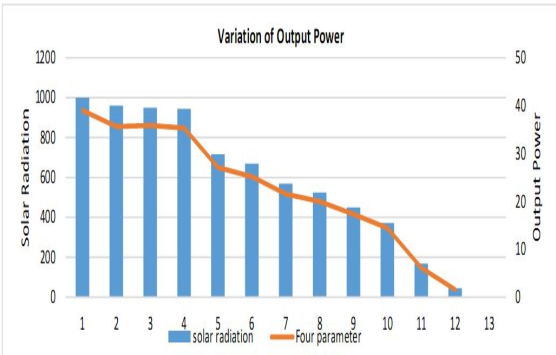

Fig. 4 Predicted output power at different solar radiation

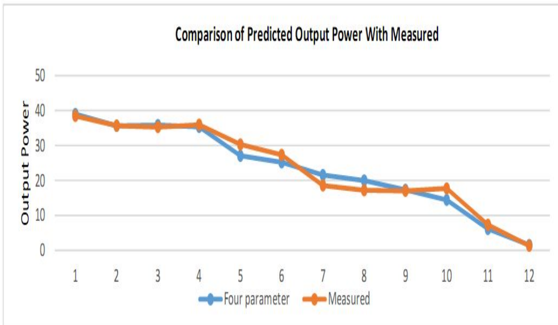

Fig. 5 Predicted output power is compared with measured output power

Graph shows that yielded results are reliable with exploratory information gave by makers under an extensive variety of cell temperatures and illumination values.

CONCLUSION

In this study four parameters model were used to predict the output power of PV Array, with the measurement carried out under real operating condition at NIT Hamirpur. The four parameters model used in this paper utilizes just information gave by manufacturer with equations to estimate output power for any operating condition. Comparison with experimental data it is found that four parameter model is quite accurate and can be an accurate tool for power prediction of PV Array.

REFERENCES

[1] [1] C. S. Solanki, "Solar Photovoltaics: Fundamentals Technologies and Applications," Prentice-Hall of India Pvt. Limited, 2009.

[2] [2] D.S.H. Chan, J.C.H.Phang, "Analytical methods for the extraction of solar-cell single- and double-diode model parameters from I–V characteristics," IEEE Transactions on Electron Devices 34, 286–293. Feb 1987.

[3] [3]] W. De Soto, S.A. Klein, W.A. Beckman," Improvement and validation of a model for photovoltaic array performance," Solar Energy Volume 80, 78–88, January 2006.

[4] [4] Amit Jain, Avinashi Kapoor, "A new method to determine the diode ideality factor of real solar cell using lambert w-function," Solar Energy Materials and Solar Cells 85, 391–396, January 2005.

[5] [5] Jitendra Bikaneria, "Surya Prakash Joshi, A.R. Joshi; Modeling and Simulation of PV Cell using One-diode model," International Journal of Scientific and Research Publications, Volume 3, Issue 10, October 2013.

[6] [6] Tarak Salmi, Mounir Bouzguenda, Adel Gastli, Ahmed Masmoudi,"MATLAB/Simulink Based Modelling of Solar Photovoltaic Cell," International Journal of Renewable Energy Research, Vol.2, No.2, Feb 2012.

[7] [7] Hongmei Tian, Fernando Mancilla-David, Kevin Ellis, Eduard Muljadi, Peter Jenkins," A cell-to-module-to-array detailed model for photovoltaic panels," Solar Energy 86 2695–2706. September 2012.

[8] [8] R. Chenni, M. Makhlouf, T. Kerbache, A. Bouzid,"A detailed modeling method for photovoltaic cells," Energy 32 1724–1730, September 2007.

[9] [9] Marius Paulescu, Viorel Badescu, Ciprian Dughir,"New procedure and field-tests to assess photovoltaic module performance," Energy 70, 49-57, June 2014.

[10] [10] D.L. King, J.A Kratochvil, W.E. Boyson, W.I. Bower," Field Experience with a New Performance Characterization Procedure for Photovoltaic Arrays,“ 2nd World Conference and Exhibition on Photovoltaic Solar energy Conversion, Vienna, Austria, 6–10, July 1998.

[11] [11] Sandia National Laboratories, Database of Photovoltaic Module Performance Parameters. Available from: <http:// www.sandia.gov/pv/docs/Database.htm>, 2002.

[12] [12] J.A. Duffie, W.A. Beckman,"Solar Engineering of Thermal Processes, third ed. John Wiley & Sons Inc.,New York, 2006.

[13] [13] J.Nelson, "The Physics of Solar Cells," Imperial College Press, London, 2003.

[14] [14] Alex Dev and S. Berclin Jeyaprabha," Modeling and Simulation of Photovoltaic Module in Matlab," Proceedings of the International Conference on Applied Mathematics and Theoretical Computer Science – 2013.

[15] [15] R.A. Messenger, J. Ventre, "Photovoltaic Systems Engineering," second ed. CRC Press LLC, Boca Raton, FL. 2004.

[16] [16] Francisco M. González-Longatt, " Model of Photovoltaic Module in Matlab," 2do congreso iberoamericano de estudiantes de ingeniería eléctrica, electrónica y computación , 2005.

[17] [17] A.D. Rajapakse, D. Muthumuni," Simulation tools for photovoltaic system grid integration studies," Electrical Power Energy Conference (EPEC), IEEE, pp. 1–5, 2009.

[18] [18] M. Bashahua, P. Nkundabakura, "Review and tests of methods for the determination of the solar cell junction ideality factors," Solar Energy 81 856–863. 2007.

[19] [19] A.O. Awodugba, Y.K. Sanusi, and J.O. Ajayi," Photovoltaic solar cell simulation of Shockley diode parameters in matlab," International Journal of Physical Sciences, Vol. 8(22), pp. 1193-1200, June 2013.

[20] [20] Ali Naci Celik, Nasır Acikgoz, "Modelling and experimental verification of the operating current of mono-crystalline photovoltaic modules using four- and five-parameter models, "Applied Energy 84 1–15, 2007.

[21] [21] G.E. Ahmad, H.M.S. Hussein, H.H. El-Ghetany, "Theoretical analysis and experimental verification of PV modules," Renewable Energy 28 1159–1168, 2003.

[22] [22] Seul-Ki Kim, Jin-Hong Jeon, Chang-Hee Cho, Eung-Sang Kim, Jong-Bo Ahn, "Modeling and simulation of a grid-connected PV generation system for electromagnetic transient analysis," Solar Energy 83 664–678, 2009.

★★★