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Identification of relevant input variables for prediction of 1-minute time-step photovoltaic module power using Artificial Neural Network and Multiple Linear Regression Models

Amit Kumar Yadav[a,b,*], S.S. Chandel[a]

[a] Centre for Energy and Environmental Engineering, National Institute of Technology, Hamirpur, Himachal Pradesh 177005, India
[b] Electrical and Electronics Engineering Department, National Institute of Technology Sikkim, Ravangla, Barfung Block, South Sikkim 737139, India

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ABSTRACT

In photovoltaic (PV) modules manufacturer provides rating under standard test conditions (STC). But STC hardly occur under outdoor conditions so it is important to investigate PV power by experimental analysis. In this study extensive literature survey of PV module electrical characteristics by conventional methods and ANN techniques are carried out. It is found that experimental analysis of PV modules maximum power under outdoor conditions remains a major research area. For this measurement of 75 Wp PV module are performed under outdoor conditions at Centre for Energy and Environmental Engineering, National Institute of Technology, Hamirpur, India. To find most influencing variables for PV power prediction, five different sets of parameters are served as inputs to establish five Artificial Neural Network (ANN) models and Multiple Linear Regression (MLR) Models which is novelty of this paper. The results shows that solar radiation and air temperature are found to be most influencing input variables for ANN based prediction of maximum power produced by PV module with mean absolute percentage (MAPE) of 2.15 %. The mean absolute percentage (MAPE) errors for ANN models are found to vary between 2.15 % to 2.55 % whereas for MLR models it varies from 13.04 % to 19.34 %, showing better prediction of ANN models.

1. Introduction

The photovoltaic (PV) module is a reliable technology directly converts solar radiation (SR) into power. The PV installed capacity is increasing globally with more than 40% since 2009 and its growth increases all over the world [1]. The PV installed capacity will reach 3000 GW in 2050, providing 4 500 TWh per year (covers 11 % of global electricity production) and it is beneficial for socio-economic development by reducing carbon dioxide emission. In first decade the PV generation cost is expected to reduce by more than 50 %. The PV commercial and residential systems will achieve the first level of grid parity by 2020 in many regions.

A PV module contain solar cells which convert SR into electricity by photovoltaic effect [2]. When sunlight is incident on solar cells, photons energy more than band-gap energy of a semiconductor are absorbed and generate electron-hole pairs. Due to influence of p-n junction electric field charge carriers (electron-hole pairs) are accelerated and create photocurrent which is directly proportional to SR. A solar cell has nonlinear electrical characteristics which vary with SR intensity and cell temperature. The equivalent circuit of single diode model of solar cell is shown in Fig. 1 with parallel resistor denoting leakage current, series resistor denoting internal resistance for current flow, diode and photo current. The $I-V$ equation of solar cell is expressed as:

$$I = I_L - I_o\left\{\exp\left(\frac{q}{akT_c}(V + IR_s)\right) - 1\right\} - \frac{V + IR_s}{R_{sh}} \quad (1)$$

where I_L is photon current, I_o is diode reverse saturation current, a is ideality factor, q charge on electron (1.6×10^{-19}C), k is Boltzmann constant (1.38×10^{-23}J/K), T_c is cell temperature, R_s is series resistance and R_{sh} is shunt resistance , R_{sh} has large value and R_s is small so it can be neglected in the analysis.

Solar cells are connected in parallel and series combination in a PV module. The $I-V$ characteristics [3] of a PV module are given by equation:

$$I = n_pI_L - n_pI_o\left[\exp\left(\frac{qV}{kT_can_s} - 1\right)\right] \quad (2)$$

where n_p is number of module connected in parallel, n_s is number of

* Corresponding author at: Centre for Energy and Environmental Engineering, National Institute of Technology, Hamirpur, Himachal Pradesh 177005, India.
E-mail address: amit1986.529@rediffmail.com (A.K. Yadav).

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Nomenclature

ANN	Artificial Neural Network
BSMT	Back Surface Module Temperature (ºC)
I	Current (A)
I_{max}	Current at maximum power point (A)
I_{sc}	Short Circuit Current (A)
MAPE	Mean Absolute Percentage Error (%)
MLR	Multiple Linear Regression
P_{max}	Power at maximum power point (W)
R	Correlation coefficient
RMSE	Root Mean Square Error
SR	Solar Radiation (W/m^2)
T	Air Temperature (ºC)
V	Voltage (V)
V_{max}	Voltage at maximum power point (V)
V_{oc}	Open Circuit Voltage (V)
WS	Wind Speed (m/s)

module in series, a is ideality factor which varies from 1 to 2 and indicates solar cell deviation from the ideal p-n junction characteristics [4]. The cell reverse saturation current I_o varies with temperature according to equation [5]:

$$I_o = I_r\left[\frac{T_c}{T_{ref}}\right]^3 \exp\left[\left(q\frac{e_g}{ka}\right)\left(\frac{1}{T_{ref}} - \frac{1}{T_c}\right)\right] \tag{3}$$

where I_r is the reverse saturation current at T_{ref}, T_{ref} is the cell reference temperature and e_g is the band gap energy of semiconductor used in the cell. The photo current I_L depends on SR and the cell temperature is given by:

$$I_L = [I_{scref} + K_{isc}(T_c - T_{ref})]\left[\frac{SR}{1000}\right] \tag{4}$$

where I_{scref} is the cell short circuit current at reference temperature and radiation, K_{isc} is the short circuit current temperature coefficient and SR in W/m^2. The PV array power can be calculated by [6]:

$$P = I \times V \tag{5}$$

$$P = n_p I_L V - n_p I_o V\left[\exp\left(\frac{qV}{kT_c a n_s} - 1\right)\right] \tag{6}$$

Maximum power point voltage [7] V_{max} can be calculated by setting $(\frac{dP}{dV}) = 0$ and V_{max} is calculated using equation:

$$\exp\left(\frac{qV_{max}}{kT_c a n_s}\right)\left[\left(\frac{qV_{max}}{kT_c a n_s}\right) + 1\right] = \frac{(I_L + I_o)}{I_o} \tag{7}$$

PV module output voltage is a function of photo current which is calculated by load current and is given by equation:

$$V = \left(\frac{akT_c}{q}\right)\ln\left[\frac{I_L + I_o - I}{I_o}\right] - R_s I \tag{8}$$

Therefore, maximum power of PV module is influenced by ambient temperature, SR and back surface module temperature so modeling of PV cells and modules becomes an important research area in photovoltaics. PV modeling mainly incorporates explicit $I = f(V)$ and implicit $I = f(I,\ V)$ models for estimating maximum power [8]. The explicit model is simple analytical equations based on assumptions and requires less computational time. The implicit model is more accurate than explicit model and incorporates several parameters such as diode ideality factor, diode reverse saturation current, photon current, shunt resistance and series resistance which are difficult to obtain from PV cells manufacturers. In addition the manufacturers provide rating of

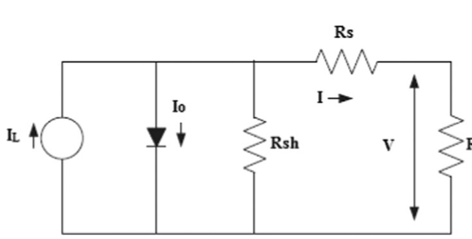

Fig. 1. Solar cell equivalent circuit.

PV modules maximum power in STC with SR of 1000 W/m^2 and temperature 25 ºC. The STC rarely occurs under outdoor conditions so more accurate models are required to estimate maximum power by PV modules under outdoor conditions.

The main objective of this study is to identify most influencing variables for ANN based prediction of PV maximum power under outdoor conditions. For this purpose five ANN models (ANN-1, ANN-2, ANN-3, ANN-4 and ANN-5) are developed to predict maximum power by a 75 Wp Si- multi crystalline PV module. The input variables to ANN models are five different combinations of irradiance, air temperature, back surface module temperature, maximum voltage and maximum current. To evaluate the prediction accuracy of ANN models a comparison with five Multiple Linear Regression (MLR) Models is also carried out.

The paper is organized as follows: a brief literature survey on PV module electrical characteristics is presented in Section 2. Methodology is described in Section 3. Results and discussion are presented in Section 4 and conclusions are given in Section 5.

2. Literature review of PV module electrical characteristics parameters evaluation

The performance of PV system is influenced by SR and temperature therefore to design an accurate PV system electrical characteristic model under real operating condition is necessary. This section reviews various methodologies for determining electrical characteristics of PV modules using conventional and Artificial Neural Network based methods.

2.1. Conventional models

Conventional models compute $I - V$ characteristics to determine maximum power using Eqs. 1 to 8. A MATLAB simulink model is used for calculating current (I) – voltage (V) and power (P)-voltage (V) characteristics of PV module using 60Wp and 125Wp solar modules to find maximum power [9,10]. Tsai [11] also used simulink model for obtaining electrical characteristics of a Siemens SM46 PV module and studied the effect of SR on PV power and cell temperature. The simulation and experimental results are found close to each other. Marion et al. [12] used bilinear interpolation method to translate $I - V$ curve of PV module to required value of SR and T by using four reference $I - V$ curve. This method is applied to PV module of seven different technologies and root mean square error is 1.4% for maximum power,1.3% for maximum voltage, 0.8% for maximum current, 0.5% for open circuit voltage, 0.3% for short circuit current, and 2% for fill factor.

Ishaque et al. [13] proposed a MATLAB simulink model using a double diode model of solar cell. The model is freely downloadable from web site (http://sites.google com/site/drkishaque/Downloads) gives better accuracy at low irradiance and is useful for performance of PV module under partial shading conditions. The accuracy is verified for multi-crystalline, mono-crystalline and thin-film PV modules. It is found that less computational time is required for calculating power.

Celsa and Tina [14] used PLC technique to simulate non uniform