PHOTOVOLTAIC MODULE PARAMETERS ESTIMATION USING FUZZY LOGIC ANALYSIS

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Abstract. Photovoltaic (PV) energyisan essential alternativeenergy resource for remote sites; PV is also characterized by itslow pollution level compared to traditional energy sources. One of the challenges in accurately estimating electric PV module performance is the uncertainty of the model equivalent circuit parameters. Parameters estimation for the PVmodule equivalent circuit model is challenging due to the implicit transcendental relationship of the I-V characteristics of the module cells. The model parameters change with temperature and irradiance, are the source of uncertainties.This paper presents a fuzzy logic based study for estimating the uncertainty of PV cell Module parameters. The approach is performed on practical data and the results of the analysis provide the estimation of the PV cell parameters. Results of this research yielding better estimated parameters compared with other methods using the Absolute Mean Error (AME).

Keywords: Photovoltaic module, Estimation,Parameter sensitivity, Fuzzy logic, Diode model.

I. INTRODUCTION

With the increasingglobal high demand of energy sources, renewable energy is gaining more interest in recent years and will be an important part of power generation in the coming years [1].Photovoltaic (PV) system provides an alternative renewable energy source that has advantagesof many promising features: it is natural available resource depending on the sun radiation, environment friendly with negligible pollution,and ease of insulation. It generates electricity on-site in remote and isolated areas without transmission losses orgreenhouse gas emissions.

Normally,photovoltaic modules are assembled by arranging photovoltaic (PV) cells in an array on a mounting system-board. The PV systemis capable of producing electric currentwhen the sun radiation strikes its surface. The electricalproperties of the PV modules determine the cost andperformance of PV plants. The use of accurate PV model parameters representing effective PV systemis necessary for accurate performance evaluation and control. Due to degradation and ageing of the PV modules, theactual values of module parameters dynamically differ fromthose provided by the manufacturer. Moreover, the PV cell is a semiconductor material which exhibits a non-linear transcendental characteristictogether with the unpredictable of the operating conditionscomplicatesthe modeling process.

PV systems normally comes with a manufacturer datasheet that provides a limited tabular data measured under theStandard Test Conditions (STCs), conforming to an irradiance of 1000W/m2 at 1.5 airmass spectral distributions with a celltemperature of 25∘C. Practically, PV systemsalmost always operate under environments far from the STCs [2].Accordingly; the datasheet does not represent the accurate actual working performance of the PV system. Moreover, due to the high initial cost of a PV system,much research work is directed to optimally predictthe working performance of the PV system [3].

For consumers to get the best performance of the PV system and accordingly maximize the cost effectiveness; it is essential to estimate and predict the PV system performance in the actual operating environment which is usually different from STC conditions.

An exact equivalent circuit and its associated mathematical model are essential for providing accurate I-V characteristics of the PV module.The mathematical model formulate PV generatedcurrent (*I*) as a function of the environmental variables, such as the operatingvoltage (*V*), the ambient temperature (*T*), and the irradiance(*G*). The estimation of the PV module parameters helps to design more efficient PV modules and predicting their performance and efficiency. Several models have been proposed to describe the solar cell characteristics. [2]-[8]. A Double-diode solar cell model is considered in this paper with the same identity factor. A lumped parameter equivalent circuit is used to model the solar cell. The solar cells are assembled in a 2D array to form a PV module. The main parameters to simulate the *I-V* terminal characteristics of the PV module are, photo current, saturation current, shunt resistance, series resistance, and diode identity factor. The electrical current produced by a solar PV module depends on the intensity of the incident light and on its intrinsic properties. An accurate estimation of the cell parameters required for accurate performance evaluation [4]-[5].

Several methods are proposed in the literature toestimate model PV parameters. In [6] PV parameters estimation of the equivalent model current voltage characteristics using least squares fitting method is effectivelyapplied with minimal errors. A Simulated annealing based approach is proposed in [7] for optimal estimation of solar cell model parameters. In [8], a numerical curve fitting procedures are used to estimate the cell model parameters: a non-linear two-point interval division was applied to extract local parameters from the current-voltage data at search measurement point.In [9] a methodology based on radial basis function neural networks to estimate the electrical characteristic curves of PV modules from the environmental operating conditions is presented. Particle swarm optimization (PSO) was effectively applied to extract the solar cell parameters in [10]-[11]. A genetic algorithm utilizing isolated points obtained experimentally is used to determine the PV external current-voltage characteristic curve of a solar cell is presented in [12]. Using data commonly provided by panel manufacturers, measured environmental parameters, and semi-empirical equations, a theoretical approach is presented in[13] to evaluate the uncertainty of the PV cell modelparameter.A new parameters extraction method based on the differential evolution technique is introduced [14]. The method fits the I-V curve better than genetic algorithm having a lower fitness value and faster execution time.

In [15], the adaptive neuro-fuzzy inference systemsas anartificial intelligence technique which combines the advantages of fuzzy logicand adaptive networks, is applied for PV parametersestimation. The adaptive neuro-fuzzy inference systems is also used in [16] for parameter estimation of one diode equivalent circuit model of PV modules.

In this paper, afuzzy-based methodologyfor the parameters estimation of PV module is presented. Using the of the PV equivalent circuit, Figure 1, the PV cell five equivalent circuit parameters: series resistance, shunt resistance, diode photo current, diode reverse saturation current and diodeideality factor, are assumed to be a fuzzy parameters. Measurement I-V data of the PV cell are used to form a set of equations with fuzzy parameters. Least square methods are used to obtain the optimum parameters. Theproposed technique could be applied to estimate the parameters of PV modules in order toaccount for ageing, performance degradation, and changesof operating conditions. The results obtained are compared with other techniques in the literature.

2 PV modeling

Accurate estimation of the equivalent circuit parameters is important for control and performance evaluation of the PV cell. Manufacturer datasheet parameters are nominal values that are measured in factory under specific temperature, illumination, and weather conditions. The parameters values changes with time due to aging and the nonlinear transcendental nature of the PV cell. Therefore, forPC cells in different weather and degradation conditions the parameters must be estimated to obtain more accurate values than that given in the nominal manufacturing datasheet.

Solar photovoltaic power generation employs solar panels also called modules that composed of a number of solar cells containing semi-conductor photovoltaic diode(s) which converts solar radiation into electric current. Mathematically, the solar photovoltaic cell is modeled by current voltage relationship (*I-V*) which exhibits a non-linear relationship due to the semi-conductor behavior of the cell. This (*I-V*) characteristic of the solar cell can be presented by a single diode model [4], [5] and [7] shown in Fig. 1, and mathematically presented by Eq. (1) and Eq.(2).

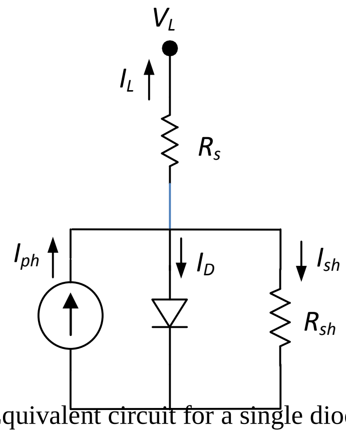

Fig. 1. Equivalent circuit for a single diode lumped circuit.

$$I_L = I_{ph} - I_D - I_{sh} \quad (1)$$

$$I_L = I_{ph} - I_{SD}\left[e^{\left(\frac{\cdots R_s)}{nkT}\right)} - 1\right] - [G_{sh}(V_L + I_L R_s)] \quad (2)$$

Where $I_p, I_{SD}, n, R_s, G_{sh} = (1/R_s)$ being the photocurrent, the diode saturation current, the diode identity factor, the series resistance and the shunt conductance, respectively. I_L and V_L are the terminal Current and voltage respectively; (q/kT) is the inverse thermal voltage, where k is Boltzmann's constant (1.3806503 x 10-23 *J*/*K*); q is the electronic charge (1.602176565 x 10-19 *C*) and T is the cell absolute temperature in Kelvin.

The photovoltaic solar module consists of series and parallel solar cells arranged as N_p parallel lines; each line consists of N_s diodes connected in series. The series connection to boosts the module terminal output voltage, while the tandem connection boosts the module terminal output current. The relation between the terminal current and voltage is mathematically expressed in Eq.(3). A bypass diode is connected in parallel, but with opposite polarity, to a solar cell as shown in Fig. 2. The Purpose of the bypass diode is to reduce the destructive effects of hot-spot heating. The bypass diode will be reverse biased and will effectively be an open circuit under normal operation of the cell.

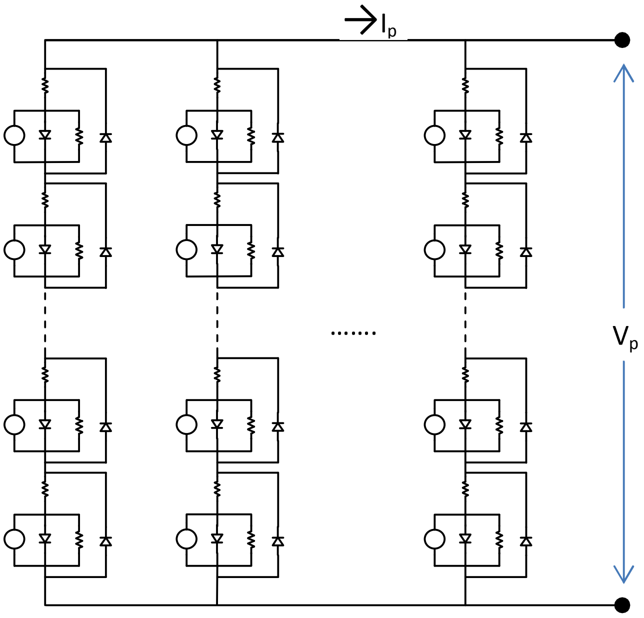

Fig. 2. Equivalent circuit model of the PV module

$$I_L = I_{ph}N_p - I_{SD}\,N_p\left[e^{\left(\frac{q\left(\frac{V_L}{N_S}+I_L\frac{R_S}{N_P}\right)}{nkT}\right)} - 1\right] - \left[G_{sh}\left(V_L\frac{N_p}{N_s} + I_L R_s\right)\right]$$

Basically, due to presence of device diode(s) in circuit models the photovoltaic solar cell (*I-V*) characteristics is nonlinear. The models exhibit transcendental function of the overall current and voltage. The models have 5 parameters ($I_p, I_{SD}, n, R_s, and\ G_{sh}$) that determine the behavior of the cell. Accurate estimation of the model parameters is crucial for providing precise modeling and accurate performance evaluation of the cell. In the next section a mathematical programming approach for estimating the 5 solar photovoltaic cell parameters is addressed.

II. FUZZY LOGIC ALGORITHM

The research idea is based on the fact thatsystem parameters could be deduced if their values are bounded by using a fuzzy logic algorithm. Using measured data together with fuzzy logic, a set of equations are formed with fuzzy input fuzzy parameters. Then Least squares are used to obtain the optimal parameters based on the formulation in [19] and [20]. In this algorithm, PV input current and voltage has been taken as input, and error between the estimated values of the input current and the calculated one has been calculated as output. The flow chart of Fig 3 represents the basic concept of the algorithm.

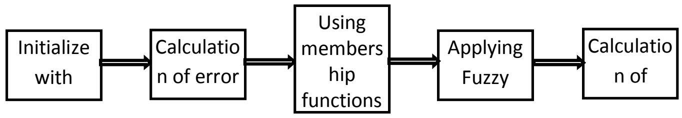

Fig. 3. Fuzzy logic algorithm

The equation of error and signal is given below as follows:

Δ [illegible] (4)

Where, I_L is the measured PV terminal current, and $\hat{I}_L$ is the estimated current.

A triangular shaped membership function is used for the input parameters. The range of the signal has been selected appropriate to each variable. Fig4 represents the graphical view of the membership function for R_s.

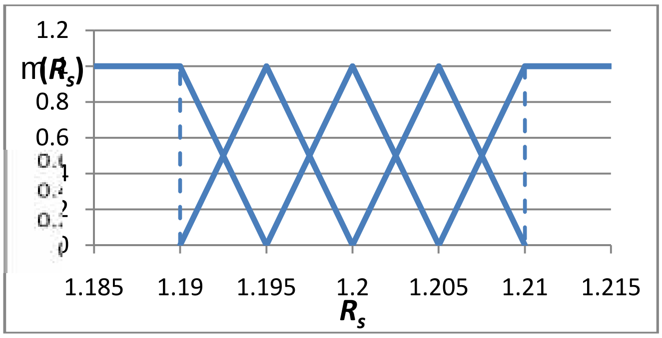

Fig.4Graphical views of the membership function for R_s.

III. RESULTS

Estimation of the five parameters of the PV module is illustrated in this section. Real photovoltaic solar module terminal data (V_{Li}, I_{Li}) for $i = 1, \dots, N$ are considered in this testing [7]. The resulting parameters with comparison with previous work using other techniques are presented in Table 1. The comparison is based on the Absolute Mean Error (AME). For each method the estimated resulting parameters along with current the measured terminal are used to calculate the terminal voltage. The AME of the calculated and measured voltages are computed and presented in Table 1.

Table 1. Comparisons of estimated parameters by this technique and previous work

	Ref. [17]	**Ref. [18]**	**Ref. [7]**	**This work**
I_{ph}(A)	1.0313	1.0339	1.0331	1.0337
I_{sd} (A)	3.1756	3.076	3.6642	3.5590
R_s ( )	1.2053	1.203	1.1989	1.1991
G_{sh} ( )	0.0014	0.0018	0.0012	0 .0016
n	48.2889	48.1862	48.8211	48.8111
Error(MAE)	0.175367	0.183851	0.026887	0.018136

IV. CONCLUSIONS

A mathematical model with 5 parameters is used to represent the equivalent circuit of the model. Five PV cell equivalent circuit parametersare modeled by fuzzy parameters. A fuzzy-logic based technique is applied to estimate the equivalent circuit parameters of PV module.Measurement *I-V*data of the PV module terminalare used to form a set of equations with fuzzy parameters. Least square methods are used to obtain the optimum parameters. The proposed technique could be applied to estimate the parameters of PV modules in order to account for ageing, performance degradation, and changes of operating conditions. The feasibility of the proposed method has been validated by comparing the estimated parameters with those of other techniques in the literature. It successfully yielding better estimated parameters compared with other methods using the Absolute Mean Error (AME).

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