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Parameter extraction of solar photovoltaic modules using various optimization techniques: a review

Parameter extraction of solar photovoltaic modules using various optimization techniques: a review

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Abstract: Parameter extraction of the solar module is essential for performance analysis, efficiency calculation and maximum power point tracking (MPPT) in the PV system. This paper makes a detailed analysis of parameter extraction from the solar PV system through application of optimization techniques based on single and two-diode models. The characteristics of PV panel are investigated using power-voltage (P-V) and current-voltage (I-V) curves. To identification of circuit model parameters of PV panel has been done by its representation of an electrical equivalent circuit which consists of a current source in parallel with diodes. The important parameters of solar PV system are Photo current (I_{ph}), Reverse saturation current ($I_o/I_{o1}$and I_{o2}), Diode ideality factor ($A/A_1$and A_2), Series resistor (R_S) and parallel resistor (R_P). The difficulties in extracting parameters from solar PV modules are referred to as parameter estimation problems and form the focus for many researchers. This paper may be useful for researchers and PV panel designers in making precise PV panels with the help of suitable optimization techniques available in the literature.
Keywords: Single-diode model, Two-diode model, Optimization techniques, Parameter extraction, Solar PV system.

1. Introduction

Today the demand of electricity is a crucial problem all over the world due to increasing population, industrial demands and digital technology developments. Renewable energy (RE) resources play a prominent role in the satisfaction of the electricity demand. Solar, hydel, wind, geothermal and tidal energies are some RE sources [1-3]. Out of these, solar energy is the most significant system due to its reliability, clean and harmless emissions to the environment [4-5]. The low conversion efficiency of solar PV module has triggered a constant focus for the improvement of its conversion efficiency in the name of maximum power point tracking (MPPT) with the help of the parameter extraction process [6-8]. In the past years, some numerical and analytical methods have been used for the extraction of parameters from PV panel using a manufacturer's data sheet. Consequently, these parameter values lead to inaccuracy [9-13]. Optimization techniques, namely genetic algorithm(GA), particle swarm optimization(PSO), simulated annealing(SA), evolutionary algorithm(EA), differential evolution(DE), artificial neural network(ANN), artificial immune system(AIS), fuzzy logic(FL), adaptive neuro-fuzzy(ANF), neural network(NN), bacterial foraging algorithm(BFA), bird mating optimizer(BMO), artificial bee swarm optimization(ABSO), flower pollination algorithm(FPA), pattern search(PS), harmony search(HS), cuckoo search (CS), fireworks explosion optimization algorithm (FEOA), moth-flame optimization algorithm(MOA), voltage band method(VBM) and water cycle algorithm (WCA)

have been discussed in literature. Genetic algorithm (GA) proposed for the extraction of solar PV parameters by Jervase et al. (2001) [14] needs identification of chromosomes from an initial condition of the population, but it makes the solution more complicated with no guarantee of accuracy. Particle swarm optimization (PSO) is explained in Ye et al. (2009), it has been compared with the GA method and its performance has been seen as better [15, 16].Simulated annealing (SA) method involves the maintenance of temperature and cooling conditions [17]. Evolutionary algorithm (EA) and differential evolution (DE) provides only complicated and inaccurate solutions owing to mutation, cross over and selection process. Particle swarm optimization (PSO) method provides better results compared with GA, EA and DE [18]. ANN and AIS methods provide good agreement with simulation and experimental results [19]. The Significant advantages of FL and ANF methods are short running time and small memory space [20]. Neural network (NN) needs less computational time and provides a compact solution for nonlinear equations [21]. Some other methods, namely BFA [22], BMO [23] and artificial bee swarm optimizations (ABSO)[24]are good at convergence period and provide good accuracy. Cuckoo search (CS) (Ma et al., 2013) is a good performer compared to GA, DE, ABC, and BFA [25]. Flower pollination algorithm (FPA) has been proposed by Xin-She Yang et al. (2013) for nonlinear multi objective functions [26, 27]. Pattern search (PS) [28] and Harmony search (HS) [29] optimization algorithms are very useful and perform better in comparison with conventional methods. Ultimately fireworks explosion optimization algorithm (FEOA) in Qing Zhang et al. (2016) [30], moth-flame optimization algorithm (MOA) in Dalia Allam et al. (2016) [31], voltage band method (VBM) in K Sangeetha et al. (2016) [32] and water cycle algorithm (WCA) in Dhruv Kler et al. (2016) [33] provide better and effective performance in the solar PV modeling system.

2. Modeling and PV cell models

2.1 Ideal model

The ideal model is depicted in Fig.1 consists of a current source in shunt with single diode having three parameters, namely, I_{Ph}, A and I_o. Without solar irradiation, the functions of PV cells are similar to P-N junction diode [34].

$$I_D = I_o[\exp(\frac{q*V_D}{AKT}) - 1] \quad (1)$$

Nomenclature

I_{ph}	Photo current (A)	T_{STC}	Temperature at STC
I_o, I_{o1} and I_{o2}	Reverse saturation current (A)	$I_{ph,\ STC}$	Photo current in STC
A, A_1 and A_2	Diode ideality factor	I	PV output current
R_S	Series resistor (Ω)	V_t, V_{t1} and V_{t2}	Thermal voltage
R_P	Parallel resistor (Ω)	V_{OC}	Open circuit voltage
$I_{D,}$ I_{D1} and I_{D2}	Diode current (A)	I_{sc}	Short circuit current
V_D	Diode voltage (V)	V_{mp}	Maximum voltage at MPP
K_i	Temperature current coefficient	I_{mp}	Maximum current at MPP
K	Boltzman constant	P_{mp}	Maximum power at MPP
Q	Electric charge		
STC	Standard test condition		
G	Solar irradiance (W/m^2)		
G_{STC}	Irradiance at STC condition (1000 W/m^2)		
T	Temperature (K)		

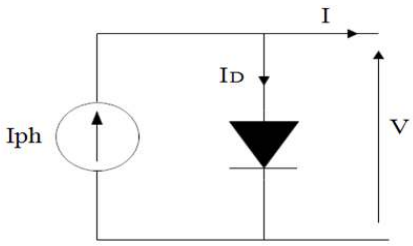

Figure.1. Ideal model

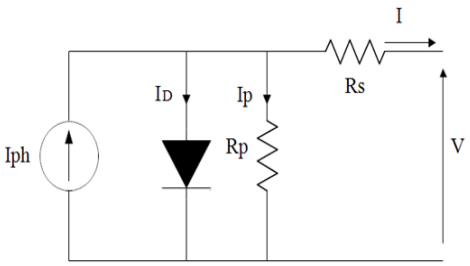

Figure.2 single diode R_P model

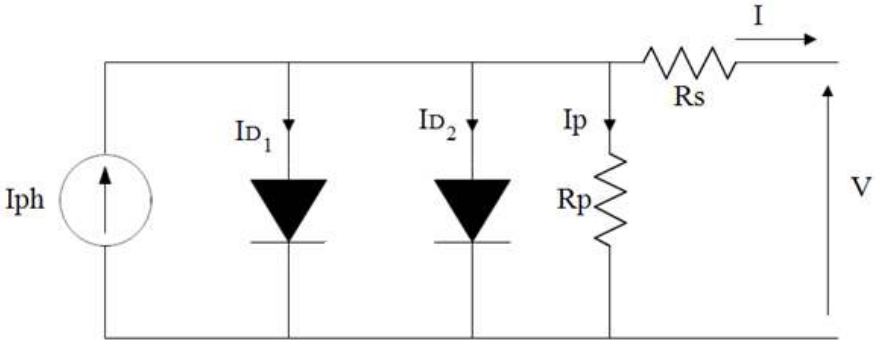

Figure.3. Equivalent electrical circuit of double diode R_P model

2.2. Single diode R_P model

A shunt resistance R_P is added in the PV circuit for understanding the effect of leakage current in PN junction. A series resistance R_S is added consider its internal resistance. An equivalent electrical circuit of single diode R_P model is shown in Fig.2 [35-36].

The mathematical expression for single R_P model is expressed as,

$$I = I_{ph} - I_0[\exp(\frac{V_{ph} + I_{ph} \cdot R_s}{V_t}) - 1] - \frac{V_{ph} + I_{ph} \cdot R_s}{R_p} \quad (2)$$

2.3. Double diode R_P model

This model indicates the exact characteristics curve of PV cell when compared to a single diode model but it is more complex in the determination of the unknown values due to the presence of two exponential equations. Some basic equations of this model are given below [37-38]. An equivalent electrical circuit of diode R_P model is shown in Fig.3.

The mathematical expression for double diode R_P model is expressed as,

$$I = I_{ph} - I_{01}[\exp(\frac{V_{ph} + I_{ph} \cdot R_s}{V_{t1}}) - 1] - I_{02}[\exp(\frac{V_{ph} + I_{ph} \cdot R_s}{V_{t2}}) - 1] - \frac{V_{ph} + I_{ph} \cdot R_s}{R_p} \quad (3)$$

3. Parameter estimation works on PV models

The accuracy of the PV model is based on the precise values of PV cell parameters. The difficulty in determining the parameters from solar PV model are based on the manufacturers' data sheet information or else I-V curve of experimental results is referred to as a parameter extraction problem of PV array. So, this problem of finding parameters from solar PV panel is highly attractive for researchers. In general, this approach can be classified into two methods, one the analytical method and the other the numerical method [39]. Tables 1&2 provide information relating to specified works done on both diode models.

Table 1. Specified works carried out on parameter estimation of Single diode model.

Authors	Remarks
Ulaganathan.M et al.[40] Mohamed A. et al.[41] Nicolai Moldovan et al.[42] XueLingyun et al.[43] M.S. Ismail et al.[44]	* **Genetic algorithm** is extensively used for extracting unknown parameters in single diode model. *Nicolai Moldovan et al. [42] deliberated the advantages of GA are simple coding and accurate global points. * Environmental changes can reduce the voltage, current and power. * A genetic algorithm is solved through nonlinear equations and power derivative function problems. * Objective function is involved for identifying optimum value of parameters. ›bjective function is noted as, F (I_{PV}, R_s,R_{sh}, I_{rs}, A) = $\sum_{j=1}^{M}(I_{co} - I_{mo})^2 I_{pv}$ i *Author (Hengsi Qin et al.) pointed out that related solar PV model equations are non-linear and transcendental which makes very complex to solve nonlinear equations by numerical methods.
Hengsi Qin et al.[45] Sangram Bana et al.[46] Model Tiew On Tinga et al.[47] Jing Jun Soon et al.[48] Erees Queen et al.[49] Huang Wei et al.[50]	* **Particle swarm optimization** algorithm is applied to determine the unknown values of single diode model. * In PSO algorithm each particles position and velocity are updated for every iteration by the following equations given below, x_i(k+1) = V_i(k) + x_i(k) x_i(k) represents position of the i-th particle. V_i(k) Represents velocity of the i-th particle.
Neeraja Krishna kumar et al.[51] Dong Hwa Kim et al.[52] BadrAldwane et al.[53] G. Petrone et al.[54] BasimAlsayid et al.[55]	* **Bacteria Foraging Algorithm** (BFA) is approached for extracting optimal parameters value. *****Initial conditions for making equations, short circuit point (0,I_{SC}) where, cell voltage should be 0; Open circuit point (V_{OC}, 0) where, cell current should be 0. Maximum power MPP (V_{mp} ,I_{mp}).
T. Bendib at el.[56] Elhagry et al.[57]	*Parameter R_S and R_{sh} values are determined using fuzzy logic (FL) technique based on I-V characteristics of PV panel. *In **fuzzy logic,** system extracts the parameters based on the range of each parameter values on the I-V curves. The following values are (R_S *and* R_{sh}) extracted from fuzzy rules.

EnginKaratepe at el.[58]	* **Artificial neural network technique (ANN)** is helped to extract five parameters presented in single diode model (R_S,R_P,I_{PV},I_0 and A). *The ANN technique has monotonically active function. It should increase from left to right, smoothly and differentially. The range of data should be present {-1; 1}. *The output and input relations are denoted as follows. The input constraints are temperature and irradiance. jth hidden unit is defined as, $n_j^1 = \sum_{i=1}^{2} W_{ji} X_i + b_j^1$
T Sudhakar Babu et al.[59]	*T Sudhakar Babu et al. proposed a new **flower pollination optimization** technique for the extraction of unknown parameter values from solar PV system. *Single diode R_S& R_P PV cell model has five unknown parameters (I_{PV}, R_s,R_p, I_0 and a). *The number of initial pollens n= 20. R_s,$R_p$and a parameters are extracted. Global pollination equation is denoted as follows, $x_i^{t+1} = x_i^t + \gamma L\ (\lambda)$ (gbest - x_i^t)
Zahi M. Omer et al.[60] Wei Peng et al.[61] Dhiaa Halboor Muhsen [62]	*Zahi M Omer et al. investigated the use of e**volutionary algorithm** and found unknown parameter values to make accurate simulation model for large PV system. *The EA optimization provides population for initial conditions, $S^G = [S_i^G]$, G=0 The above initial conditions are picked randomly and are uniformly distributed in the given search region.

Table 2. Specified works carried out on parameter estimation of double diode model.

Authors	Remarks
L. Zhang et al.[63] ParamjitSaha at el.[64]	* Double diode R_P PV cell model has seven unknown parameters (I_{ph}, R_s,R_{sh}, I_{S1},I_{S2}, $n_1$andn_2). *In equivalent circuit, current source connected with two parallel diodes along with different diode saturation current $I_{S1}$and I_{S2}. This two diode model is more precise. At the same time it is more complex.
KashifIshaque at el.[65]	* Double-diode model has greater accuracy compared with single diode model.*These parametersare extracted using **evolutionary algorithms** (EA) namely; The EA optimization provides the population for initial conditions.

M.K. Munji at el.[66] L. Sandrolini et al.[67] Erees Queen B at el.[68]	*Author (M.K. Munji at el.) contributed related to solar PV model equations and stated that the equations are non-linear and transcendental. It is very difficult to solve nonlinear equations by numerical and analytical methods. ***Particle swarm optimization** algorithm is applied to determine the unknown values of double -diode model.
L. Zhang at el.[69]	***Radial basis function neural network (RBFNs) method** is used to make accurate PV model as well as to track maximum power point.*Genetic Algorithm based on RBFNs scheme helps to get optimum value for accurate PV model.
Vun Jack Chin et al.[70] Kashif Ishaque et al.[71] Wagner Teixeira et al.[72] Kashif Ishaque et al.[73]	*Kashif Ishaque et al. proposed **differential evolution** which needs few control parameters and convergence speed is high.*The DE optimization provides population for initial conditions, $X_{i,G} = [X_{1,i,G}, X_{2,i,G}, X_{3,i,G} \ldots, X_{j,i,G}, \ldots. X_{D,i,G}]$ The above initial conditions are picked randomly and uniformly distributed in the given search region.

4. Different optimization techniques in parameter estimation

There have been many soft computing techniques developed over the years which are used for solving or the analysis of various engineering problems.

4.1 Genetic algorithm

Sheeba PS et al. [74]GA has been used for parameter extraction in PV modeling using single diode model to identify unknown parameters. The objective function is to define the absolute errors between actual current or datasheet current value and calculated current value. This absolute error values are calculated on different voltage values under environmental conditions. Moreover, cost function when once reaches the desirable level after subsequent iterations, the unknown parameters are identified.
Joseph A Jervase et al.[75] extracted parameters from double diode model. The error of simulate range varied from 2% to 36%. This total performance is analyzed by existing quasi-Newton method.

4.2 Particle swarm optimization

S. Kumar, A. Singh, and A. Dhar et al. [76] presented PSO method for parameter extraction process. For perfect design, high quality fabrication process and accurate parameter estimation is needed. He developed global PSO approach for accurate parameter estimation purpose for different solar models.
Huang Wei et al. [50] utilized PSO and numerical method to identify the parameters for different solar cell models. Chaotic PSO method was introduced for local and global convergence or global level performance. This CPSO provides optimal parameters value without complicated limitations. Finally, it showed better accuracy than other published works. Manufacturer's datasheet gives only limited information. However, simulating the PV characteristics accurately is slightly complex.

4.3 Differential evolution

Kashif Ishaque et al. [65]deliberated two types of DE methods. i) Boundary based DE. ii) Penalty based DE. It has been involved smoothly for nonlinear functions of complicated derivative sequence and effectively evaluated the parameter extraction of two diode model, eventually to compare DE method with GA and PSO and provides better results. Kashif Ishaque at el. [71] presented Penalty based DE method to extract the unknown parameter at different environmental conditions for two diode model. Based on synthetic I-V data the analysis shows proposed P based DE output performs.

4.4 Artificial Immune System

Chellaswamy C et al.[77] applied a new approach of adaptive differential evolution technique for extraction of parameters from various types of PV models. Basil Jacob et al.[78] proposed same AIS approach for double diode system. This obtained value has put in MATLAB/Simulink model and validated the performance characteristics. This proposed method compared with GA and PSO.

4.5 Simulated Annealing

M. R. AlRashidi et al.[79] proposed SA algorithm and used it to estimate the unknown parameters for solar PV models. Parameters are extracted from single diode model and validate the output performance effectively. Among different parameters extraction techniques, this proposed approach provides good effective performance. M. R. AlRashidi, K. M. El-Naggar et al.[80] applied SA approach for single diode model to determine the optimal value of photovoltaic characteristics. Extracted parameters are given in this paper for user analysis. This measured date values are a good deal with PV characteristics. SA is reliable and robust. K.M. El-Naggar et al.[17] applied SA technique in parameter identification for getting optimal solution value for both single and double diode models. Analytical solution had some failures and due to this failure, the proposed SA technique was used to solve derivate functions by using I-V curve relationship.

4.6 Bacteria Foraging Algorithm

Swagatam Das et al. [81] employed BFA algorithm mainly focused for global peak value optimization and current problem for distributed optimization system and control techniques. Its working behaviour looks like E-coli bacteria. The application of BFA is increasing due to its accuracy and efficiency. Hybridization of BFA with other optimization techniques provides significant outcomes. N. Rajasekar et al. [22] approached BFA for single diode model of PV system. PV system research is increased due to its non-polluting nature. Manufacturers data sheet provides only four values such as, $V_{mpp}I_{mpp}$, V_{oc} and I_{sc}. BFA optimization is very effective for non-linear problems.

4.7 Artificial Bee Swarm Optimization

Alireza Askarzadeh et al. [82] ABSO provided accurate results for single diode model and double diode model comparing the above techniques. This precise model will be very helpful for optimization of solar system and control strategy.

4.8 Harmony search

Alireza Askarzadeh[29] applied HS to extract the parameters for making accurate solar PV modeling of current-voltage vs power-voltage for characteristics analysis purpose. The conventional PV modeling has some drawbacks due to in accuracy. The HS method is proposed to overcome the drawbacks and making accurate PV modeling. These results are in good agreement with conventional optimization algorithms.

4.9 Cuckoo search

Xin-She Yang et al.[83] applied CS for solving optimization problems. It works on the basis of behaviour of breeding of some cuckoo species and combined different characteristic of levy fight behaviour of cuckoo species. The author validated this algorithm against some conventional one. Jieming Ma et al.[84] presented CS algorithm for estimating the parameters from solar PV models with high accuracy. Both simulation results and hardware data shown are reliable as compared with existing algorithms.

5. Discussion and future scope

Variations in the output of solar panel are made due to the presence of different irradiation levels leading to efficiency loss. Hence, parameter extraction and MPPT algorithm are used for increasing the overall efficiency. Installation cost of PV panel is quite high. Therefore, modeling of solar panel in simulation is very useful for finding the characteristic of solar PV under different environmental conditions like temperature (k) and irradiation (w/m^2). In this paper, parameter extractions using various optimization techniques suggested by different authors have been summarized. Difficulty seen in formulating the objective function for optimization and the extraction of accurate values are discussed in the twenty-five optimization algorithms for extracting the parameters and help in designing an accurate PV model. In the past few decades, the focus of researchers has been an analytical and numerical method for parameter extraction. In future, optimization algorithms with defined objective functions will find extensive use in accurate parameter extraction. Both analytical and optimization techniques are used for determining parameter extraction for solar PV cell as seen in literature [85]. A single diode model has five unknown parameters, three of which are extracted using the optimization technique and the other two parameters are extracted using analytical methods. Some researchers have mitigated the problem of difficult by neglecting Rs or Rp from the model by making some assumptions. The diode ideality factor (A) has a great impact on the process of making PV model. It should be 1<a<2 gives more precise. In future, addition of some coefficients for determination of the aging of different solar PV panel is suggested as highly helpful for consumer in getting knowledge of aging and degradation of the different panels for installation purpose. This kind of work provides a better understanding of PV panel in the long run. Abdelghani Harrag et al. [86] presented a modified PSO algorithm for parameter extraction from three, five and seven electrical equivalent circuit models respectively. The effect of proposed algorithm is accurate and validated.

This review of different optimization, analytical and numerical methods will be very helpful for current researchers who are working on PV parameter extraction techniques. In future, new algorithms like whale optimization algorithm (WOA), ant lion optimizer (ALO) and mine blast algorithm (MBA) may be implemented for parameter extraction. Also, a novel technique for finding the aging and degradation of various PV panels is very important topic for upcoming researcher.

6. Conclusion

This article carries a review of PV modeling and parameter extraction using various optimization algorithms for different solar PV models seen in literature. It highlights the concept of objective works, merits and demerits of the different PV models namely, single diode and two-diode model. In addition, some new soft computing techniques have been summarized on the basis of their effective results. Necessary initial parameters that require consideration during the designing of solar PV model have been identified for both diode models. A study of the specified considerations has been made and details have been presented. Moreover, the results of each algorithm have been tabulated to facilitate decision-making and technique selection. The suggested solar PV models with suitable optimization technique help improvement of the overall performance efficiency and maximum power extraction of the solar PV system. The other parameters of aging and degradation have been identified as torch bearers to be carried out in future. This paper will help researchers in identifying suitable PV models with appropriate techniques for parameter estimation.

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