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Parameter identification of the photovoltaic cell model with a hybrid Jaya-NM algorithm

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ABSTRACT

This paper proposes a hybrid computational intelligence algorithm for identifying parameters of the photovoltaic (PV) cell model. In the proposed algorithm, Jaya algorithm is applied to perform the global search while Nelder–Mead (NM) algorithm is employed to conduct the local search. The integration of Jaya and NM algorithms provide the ability to find the global optimum solution in a multidimensional optimization problem. To validate the effectiveness of the proposed Jaya-NM algorithm, current and voltage data from a commercial PV cell are utilized and the single diode model parameter are identified. The results show that the proposed algorithm outperforms recently published identification methods.

1. Introduction

Solar energy has attracted growing interest from both of the academia and industry. To better monitor and control photovoltaic (PV) systems, accurate modelling of PV cells is highly desired. Two main phases are typically considered in modelling PV cells. In the first phase, a parametric model is formulated to describe the dynamic behaviors of PV cells. Next, parameters of the parametric model are identified based on collected experimental data. In literature, numerous models have been presented to obtain the relationship between currents and voltages of a PV cell. Among these models, the single diode (SD) model is widely utilized due to its simplicity and effectiveness. Since PV cell models are parametrized by different parameters, it is required to estimate model parameters accurately. Recently, the advances in computational intelligence (CI) have made CI algorithms outperform conventional deterministic algorithms in identifying PV cell model parameters. Different CI algorithms, including Genetic Algorithms (GA) [1], Particle Swarm Optimization (PSO) [2], Artificial Bee Swarm optimization (ABSO) [3], Artificial Bee Colony (ABC) [4], Harmony Search (HS) [3], and Teaching-learning Based Optimization (TLBO) [5], have been applied in parameter identification of PV cells. However, generic CI algorithms introduce algorithm-specific parameter into the identification process. Improper algorithm-specific parameter settings have a significant influence on the identification performance and tuning these parameters leads to more computational cost. Therefore, it is valuable and meaningful to develop a CI-based method without algorithm-specific parameters for parameter identification of PV cell models.

In this paper, we propose a hybrid CI algorithm by integrating Jaya algorithm [6] and Nelder-Mead (NM) algorithm [7] (Jaya-NM algorithm) for identifying PV cell model parameters. Having the same property of Jaya algorithm, the proposed Jaya-NM algorithm

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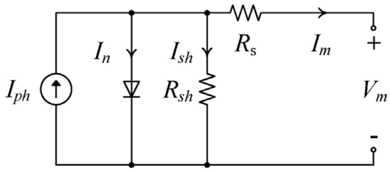

Fig. 1. Equivalent circuit of the single diode model.

does not contain any algorithm-specific parameters. In the proposed Jaya-NM algorithm, Jaya algorithm is firstly applied to search global best solution via the global search and next NM algorithm is employed to further improve the solution through a local search. To assess the performance of the proposed Jaya-NM algorithm, experimental data of a real PV cell are collected and the model parameters are identified. Furthermore, the proposed Jaya-NM algorithm is benchmarked with six recently published CI-based method.

2. Photovoltaic cell model

As a frequently used PV cell model, the SD model is considered in various researches on PV cell model parameter identification. Therefore, the SD model is also utilized in this study. The equivalent circuit of the SD model is shown in Fig. 1.

The current is obtained in (1) based on the circuit in Fig. 1.

$$I_m = I_{\mathrm{ph}} - I_n \times \left[\exp\left(\frac{q \times (V_m + R_s \times I_m)}{\alpha \times k \times T}\right) - 1\right] - \frac{V_m + R_s \times I_m}{R_{\mathrm{sh}}} \tag{1}$$

where I_m is the terminal current, I_{ph} denotes the photo-generated current, I_n is reverse saturation current of the diode, R_s and R_{sh} are the series and shunt resistances repetitively, V_m stands for the terminal voltage, q is the electric charge of an electron, k is the Boltzmann constant, T is the temperature of the cell in Kelvin, I_{sh} is the shunt resistor current, and α is the diode ideality factor. To determine the SD model, five parameters I_{ph}, I_n, R_s, R_{sh}, and α are required to identify according to (1). Once the model parameters are determined, the predicted current, $\hat{I}$, is yielded based on (1).

3. Problem formulation

The identification of PV cell model parameters can be converted into an optimization problem. The objective is to minimize the difference between the predicted current from the SD model and the observed current. Thus, a widely-used metric, the root mean squared error (RMSE) is considered as the objective function, described in (2).

$$\mathrm{RMSE} = \left\{\frac{1}{N}\sum_{i=1}^{N}[\hat{I}_i(\boldsymbol{p}) - I_i]^2\right\}^{0.5} \tag{2}$$

where $\boldsymbol{p}$ are the model parameters, and N is the number of observed current data.

4. Hybrid Jaya-NM algorithm

Two types of search, global search and local search are included in the proposed Jaya-NM algorithm. In the global search, a generic Jaya algorithm is applied to search solutions close to the optima. Next, the optimum solution is obtained based on NM algorithm.

Jaya algorithm [8,9] is a swarm intelligence algorithm and the iterative updating rule is presented in (3).

$$p'_{j,k,i} = p_{j,k,i} + R_{1,j,i}(p_{j,\mathrm{best},i} - |p_{j,k,i}|) - R_{2,j,i}(p_{j,\mathrm{worst},i} - |p_{j,k,i}|) \tag{3}$$

where $p_{i,k,j}$ is the value of the jth parameter of the kth candidate parameter vector at iteration i, $p_{i,best,j}$ denotes the value of the jth parameter of the best parameter vector, $p_{i,worst,j}$ denotes the value of the jth parameter of the worst parameter vector, and $R_{1,j,i}$ and $R_{2,j,i}$ are two independent random number generated from $U(0, 1)$. A parameter vector p^* close to the global optima is yielded after the pre-defined number of iterations is executed. p^* is further updated using NM algorithm to achieve the global optima.

Table 1
Specifications of the platform.

Component	Specification
CPU	Inter Core i5@3.2 GHz
Memory	4 GB
Programming language	Python 3.6.3
Operating system	Windows 10

Table 2
The bounds of PV model parameters.

Parameter	Lower	Upper
R_s (Ω)	0	1
R_{sh} (Ω)	0	100
I_{ph} (A)	0	1
I_n (μA)	0	1
α	1	2

Table 3
RMSE values of different algorithms.

Algorithm	RMSE (10^{-4})
MABC	9.8610
GOTLBO	9.8744
HS	9.9510
ABSO	9.9124
ABC	9.8620
EO-Jaya	9.8603
Jaya-NM	**9.8602**

The smallest value is in bold.

NM algorithm is a generally used optimization algorithm for non-linear multidimensional problems. Four procedures, reflection, expansion, contraction, and shrinkage, are considered in NM algorithm. Through these four procedures, the global optimum solution is obtained. In this study, the shrinkage procedure is described in (4).

$$\boldsymbol{p}_i = \boldsymbol{p}_{\text{best}} + \sigma(\boldsymbol{p}_i - \boldsymbol{p}_{\text{best}}) \tag{4}$$

where $\boldsymbol{p}_i$ is a parameter vector, $\boldsymbol{p}_{best}$ is the best parameter vector at the current iteration and σ is shrink coefficient, which is set to 0.5.

Integrating Jaya algorithm and NM algorithm, the identification procedures are demonstrated in Algorithm 1.

Algorithm 1. Jaya-NM algorithm.

Input: Population size: n;
Output: Solution: $\boldsymbol{p}^{\#}$;
for $k := 1$ *to* n **do**
  Initialize $\boldsymbol{p}_{k,1}$;
end
Get $\boldsymbol{p}_{best,1}, \boldsymbol{p}_{worst,1}$;
Set $i = 1$;
repeat
  Obtain two random numbers from $(0, 1)$;
  Update $\boldsymbol{p}_1, \boldsymbol{p}_2, ..., \boldsymbol{p}_n$ according to (1);
until *termination criterion satisfied*;
Get the output $\boldsymbol{p}*$;
Update $\boldsymbol{p}*$ using NM algorithm to $\boldsymbol{p}^{\#}$;
return $\boldsymbol{p}^{\#}$;

5. Case study

In order to assess the identification performance of the proposed Jaya-NM algorithm, data records of current and voltage form a silicon PV cell are collected. The PV cell is manufactured by R.T.C France and standard test conditions were used to conduct the experiment. To identify the SD model parameters, the population size of Jaya algorithm is set to 150 and the number of iterations is 10,000. The specifications of the platform to implement the proposed Jaya-NM algorithm are listed in Table 1.

Jaya-NM is applied to identify the SD model parameters and the upper and lower bounds of the SD model parameters are listed in Table 2. The computed RMSE value is shown in Table 3. To further assess the identification performance, RMSE values of six recently published methods, MABC [10], GOTLBO [5], HS [3], ABSO [3], ABC [4], and EO-Jaya [11] are also presented in Table 3.

It can seen from Table 3 that the proposed Jaya-NM algorithm outperforms other algorithms in terms of RMSE. Besides, EO-Jaya algorithm achieves the second best performance. The biggest RMSE value is 9.9124×10^{-4} by using ABSO algorithm.

6. Conclusions

A hybrid Jaya-NM algorithm was introduced for accurately identifying PV cell model parameters in this paper. Two types of search, global search and local search, were incorporated in the propose algorithm. Having the same property as the generic Jaya algorithm, Jaya-NM algorithm was also free of algorithm-specific parameters. Real experimental data from a commercial PV cell were utilized to validate the performance of the proposed algorithm and parameters of the SD model were identified.

The computed RMSE values confirmed that Jaya-NM algorihtm dominated all six identification methods. Therefore, it is applicable to apply to the proposed algorithm to identify the PV cell model parameters.

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