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Parameter estimation for photovoltaic system under normal and partial shading conditions: A survey

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ABSTRACT

Solar energy has been one of the environmental friendly sources of energy. The low cost solution with minimal maintenance motivates towards photovoltaic (PV) cells based energy harnessing methods to meet energy demands. However, majority of conventional PV systems suffer from low energy conversion ratio (ECR) due to improper selection of the PV parameters and maximum power point tracking (MPPT) algorithm. Even ECR is adversely affected under varying environmental conditions. Therefore, accurate estimation of PV parameter can be of paramount significance for efficient PV model design. In addition, the development of a robust MPPT algorithm in conjunction with the effective PV design parameter can enable optimal ECR achievement. In this review paper, a number of literatures pertaining to PV parameter estimation and MPPT algorithms are discussed. Different methods including analytical, iterative and evolutionary computing algorithms are assessed for their efficacy towards PV parameter estimation. This review paper revealed that the analytical approaches suffer from singularity problem as well as limited mathematical calculation that confine its efficacy for optimal PV parameter estimation under dynamic irradiation pattern. The iterative approaches too are limited due to dynamic environment conditions. Our study has revealed that the evolutionary computing approaches, such as genetic algorithm (GA), particle swarm optimization (PSO), differential evolution (DE), etc. have played vital role in PV design parameter estimation and classical approaches suffer from local minima and convergence issues. This manuscript reveals that to enable an optimal PV design parameter estimation there is an inevitable need to incorporate either evolutionary computation schemes or apply an efficient multi-objective optimization measures. This as a result can not only alleviate local minima and convergence issues but can also enable swift and precise parameter estimation to assist optimal PV design and augmented ECR performance.

1. Introduction

The demand for electrical energy is vigorously increasing due to increased population and industrialization. This rising energy demand has alarmed scientific societies to develop efficient and environmental friendly source of energy [1]. Energy consumption signifies the critical indication of resource used and its impact on the environment. Sustainable energy generation technologies based on solar, wind, tidal, geothermal, biomass and hydro are considered to be clean, eco-friendly and freely available in nature [2].

Harnessing solar energy to the maximum extent can significantly help in resolving energy crisis situations. The photovoltaic (PV) system that converts solar energy to the electrical power is renewable energy sources, has a long term economic prospect and ease of maintenance. However, due to high initial cost, the optimal energy conversion efficiency is of paramount significance. In last few decades, PV system has become common in grid-connected applications. Still, unlike traditional power plants, cost and performance of PV systems strongly depend on the electrical properties of the modules as well as environmental conditions, especially solar radiation and temperature. Maximum power available from a panel depends on illumination but the percentage of power supplied to load depends on nature of the load. To deal with these situations, MPPT technique has emerged as a potential solution. In fact, solar PV trackers and MPPT trackers are completely different from each other. However, PV tracking can be used in conjunction with MPPT to increase the performance. MPPT is a high frequency dc- dc converter that optimizes the panel voltage to the required battery voltage. It doesn't have a mechanical movement instead it varies the operating point of the PV modules to extract the maximum available power. In spite of many advantages like reduced hardware implementation, estimating climatic parameter, fast tracking capability, MPPT suffers from a drawback of mean error of 2% with a response

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time of 1.7 ms that can further be improved to reduce the error to 0% along with reduced response time. The enhancement in MPPT techniques and its dynamic or adaptive scheduling can enable better performance [109]. Despite the intricacies caused due to dynamism of the electricity generation, the estimation of PV parameters and development of maximum power point tracking algorithm has gained significant attention across academia-industries. It is because, PV systems modelling have been introduced to characterise I-V relationship in PV cells. Typically, lumped parameter circuit model is applied to simulate the behaviour of PV cells under diverse operating conditions. In general, there are two predominant types of PV circuit models used to characterize the I-V characteristics. Single and double diode models are the two predominant types of PV models and their key parameters are the generated photocurrent, saturation current, series resistance, shunt resistance, and diode idealist factor. Irrespective of the type of models, there is an inevitable need to estimate optimal parameters of these models to reflect the performance of actual PV. Improper selection of these parameters can lead major problem in developing MPPT algorithm. Hence, the optimal parameter selection can enable appropriate design of controller of the PV systems. On the other hand, since the energy efficiency of the PV system is proportional of the solar radiation, and therefore events such as shading can reduce power generation rate. In some cases, the conventional PV system obstructs complete power generation process due to shading. It demands the optimal PV model design, which can be done by means of effective PV parameter selection and allied functional unit optimization such as MPPT to enable undisrupted power generation even under partial shading conditions [8].

Considering the significance of optimal PV parameter estimation for PV model design, this survey paper emphasizes on assessing various existing approaches pertaining to PV design parameter estimation. The strengths as well as limitations of the different techniques are discussed in this survey paper, which can be vital to derive a more robust and efficient PV model design. Realizing the innovations and efforts made in last few years, in this survey paper the key literatures published during 2000–2017 are discussed for their respective strengths as well as limitations. A number of PV design estimation methods, such as iterative methods, analytical methods [3–6] and evolutionary algorithms [7–10] have been proposed in the past; however, in-depth analysis reveals that still majority of the approaches are limited and hence requires further optimization to enable optimal PV model design [11–13]. As stated, amongst various approaches such as analytical methods, iterative methods and recently proposed evolutionary algorithms, have been found more efficient to provide optimal or sub-optimal solutions [7–10,16]. However, their inherent limitations such as local minima and convergence make it confined to be used, particularly during dynamic conditions where swift or fast decision (say, solution retrieval) is inevitable. Thus, analysing various available evolutionary algorithms and respective pros and cons can help in alleviating the limitations to achieve more efficient solution. With this motivation, this survey paper discusses various at-hand and recent literatures discussing PV design parameter estimation to enable audiences understand key limitation and future scopes for further optimization.

The remaining sections of the presented manuscript are divided as follows: Section II briefs the single diode and double diode PV model and the derivation of optimization parameters. Section III presents various literatures discussing PV design parameter estimation, which has been followed by the discussion of literatures discussing MPPT techniques for better energy conversion under solar irradiance conditions in Section IV. Considering strengths as well as limitations of the various existing approaches, the conclusion and future scopes towards enhanced PV model parameter estimation and optimization is discussed in Section V. The references used are presented at the last of the manuscript.

Before discussing the circuit design for single and double diode PV models and different approaches proposed for PV design parameter estimation as well as MPPT, a list of abbreviations being used in this manuscripts and its definition is given in Table 1.

Table 1
Abbreviations.

Abbreviation	Definition
PV	Photovoltaic
ECR	Energy Conversion Ratio
MPPT	Maximum Power Point Tracking
MPP	Maximum Power Point
GA	Genetic Algorithm
PSO	Particle Swarm Optimization
DE	Differential Evolution
KCL	Kirchhoff's Current Law
KVL	Kirchhoff's Voltage Law
NRM	Newton Raphson Methods
STC	Standard Test Condition
EC	Evolutionary Computing
PS	Pattern Search
STFT	Special Trans-Function Theory
SA	Simulated Annealing
ABC	Ant Bee Colony
AIS	Artificial Immune System
BFO	Bacterial Forging Optimization
CS	Cuckoo Search
NM	Nelder-Mead
CPSO	Clustering Based Particle Swarm Optimization
CS-NM	Cuckoo Search With Nelder-Mead
ICA	Imperialist Competitive Algorithm
GPUs	Graphical Processing Units
DSC	Dye-Sensitised Solar Cells
FTDNN	Focused Time-Delay Neural Network
SCE	Shuffled Complex Evolution
LS	Linear Square
HC	Hill Climbing
PO	Perturb & Observe
FLC	Fuzzy Logic Control
NN	Neural Network
ANN	Artificial Neural Network
MODE	Multi-Objective Differential Evolution
MOGA	Multi-Objective Genetic Algorithm
R_s	Series resistance
R_{sh}	Shunt resistance
I_0	reverse saturation current of the diode
I_{ph}	photocurrent generated by cell
V_t	Thermal voltage
k	Boltzmann constant ($1.38064852 \times 10^{-23}$ J/K)
T	current temperature of $p - n$ junction (K)
v_{pv}	output voltage of the given PV cell
I_{d1}	current of diode D1
I_{d2}	current of diode D2
a	Ideality factor of diode

2. Photovoltaic cell modelling

This section briefs the PV model and its electrical parameters to be optimized. The performance of a PV cell primarily relies on the selection of PV model and associated parameters. Considering PV cell circuit design and its usefulness, in practice two predominant types of PV circuit designs are taken into consideration. These are single diode PV model [14] and double diode PV models [15]. In some literatures [15,16], authors have found that double diode PV model is computationally expensive than the single diode model, but it is preferred because of its I–V characteristics which resembles the practical physical model.

A brief of the two dominant PV models, single diode and double diode model is given as follows:

2.1. Single diode PV model

The simplicity and accuracy make the single diode model as the simplest PV model that comprises five components; a current source, one diode and two resistors including series resistance and shunt