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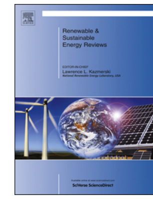

A comprehensive review of photovoltaic systems

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ABSTRACT

Renewable energy sources are considered as the alternative energy sources because of rising environmental concerns and depleting conventional energy resources. Solar energy has a significant role for meeting the increased requirement of electricity with the reduced environmental impact. The power generation from a Photovoltaic (PV) system gets affected as the optimum operating point changes due to the variation in the environmental factors such as temperature, solar insolation, etc. In spite of the fluctuations, to achieve maximum power from solar energy system, maximum power point tracking (MPPT) technique is essential. In this paper, a comprehensive review of PV system is presented consisting of modelling of PV cell, DC–DC converter topology and maximum power point tracking methods.

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1. Introduction

Renewable energy sources are particularly rational because of accessibility and pollution free environment for power generation. Recently, power generation from solar energy using Photo Voltaic (PV) systems noticed a fast development. It has the advantages of low repair cost, nonexistence of moving or rotating parts and no global impact. But, the solar energy to electricity conversion efficiency is lower i.e. approximately 18–23% [1]. Moreover, the power generation of PV system depends on the solar insolation and surrounding temperature. When the solar insolation is uniform, the output of a PV system demonstrates a single operating point where the power generated is maximum [2].

The solar insolation which falls on the PV panel differ largely by the direction of sunlight and shading by clouds, plants, birds, dusts, buildings etc. The variation of these external factors highly affects the output power characteristics of PV generators. Hence, the system reliability and the utilization efficiency are decreased [3]. To maximize the conversion efficiency of PV panel, several methods are developed by considering the factors of environment such as sun trackers and maximum point trackers [4]. The sun trackers are the devices which improve the efficiency of solar energy systems when the insolation strength of earth changes by diurnal and seasonal moving of sun. The power consumption of the sun tracking system is 2–3% of the increased energy and it is not suitable for operation under partially shaded conditions [5].

The maximum power point tracking (MPPT) methods are introduced to extract maximum available power from the PV panels. Commonly, the MPPTs observe the PV parameters and produce control signal to power converters [6]. The conventional methods are the short circuit current method, the stable voltage method, the hill climbing method, incremental conductance method and the perturb and observe method [7]. Due to simplicity, easy execution, and low cost of the conventional methods, they are directly used in practical applications. But, the voltage and the current of PV system measured by these methods are with a single sampling time. Therefore, the time required to reach exact power tracking direction is delayed in the tracking process and if the climatic parameters change before reaching the tracking path, tracking direction will be incorrect [8].

In order to solve the drawbacks of conventional tracking methods, Artificial Intelligence (AI) techniques and optimization algorithms are employed. Within AI techniques, the fuzzy logic control (FLC) and neural network (NN) are used individually and as hybrid with conventional methods [9–12]. These techniques are preferred to get an exact operating point and are capable to handle nonlinearity without the need of a precise mathematical model. Moreover, the working of these techniques is much related to the characteristics of PV panel and system behaviour [13]. The FLC based tracking consists of a process which includes fuzzification, rule based interference system design and defuzzification. It gives stable action in the complete operating region of the PV panel and the resultant fluctuation around the operating point [14]. The NN technique solves the complex real time problems and is a recognized method. It is also used to estimate the real conditions online since the determination of maximum power of a PV module is based on the measurement of atmospheric parameters [15]. Due the simple structure of network, the convergence of this technique is faster and the tracking accuracy is high [16].

Under partially shaded condition, the power characteristic of PV panel has multiple operating points. Therefore evolutionary algorithms are considered as alternate options to optimize the operating points. The working of this algorithm is based on biological evolution and algorithms such as the genetic algorithm (GA), the particle swarm optimization (PSO), the firefly algorithm (FA), and the cuckoo search (CS) are employed. But, in these algorithms, the stochastic variables are used. The random variables increase the uncertainty of the solution which decrease the tracking efficiency considerably. Moreover, there is possibility to miss the desired maximum operating point. While searching a new operating point, the random number changes the parameter solution. Therefore, the performance of control variables of power converter such as current, voltage and duty cycle results is small change in terms of solution parameters of the algorithms. Recently, the drawbacks of these algorithms are neglected and used by deterministic methods [17–22].

Further in literatures, numerous works are presented for modelling of PV cell and DC–DC converter topology. In this paper, a detailed review of PV system is carried out which incorporates PV cell modelling, DC–DC converter topology and tracking techniques. The overview of PV system and the model of PV cell are detailed in Sections 2 and 3. The types of DC–DC converters and the topologies are reviewed in Section 4. The review of tracking methods are presented in Section 5 and Section 6 conclude the review paper.

2. The overview of PV system

PV systems used for high power generation consists of several combinations of series and parallel PV modules. It consists of three basic parts the PV panel, the power converter and the tracking controller. The connection of the series and parallel combination of modules varies as per the requirement or rating of the connected load. A typical configuration of two series and four parallel connected systems with DC–DC boost converter and tracking controller is given in Fig. 1.

2.1. PV system characteristics

The PV system characteristics depend on the environmental condition, insolation, temperature, capacity of the system, etc. In order to understand the behaviour of the PV system and to develop an efficient MPPT controller, Power–Current (*P–I*), Voltage–Current (*V–I*) and Current–Duty cycle (*I–D*) characteristics are crucial. The characteristics of PV system are investigated with respect to the inputs and output of tracking controller. Fig. 2(a)–(c) illustrates the characteristics of *P–I*, *V–I* and *I–D* at different solar insolations, 250 W/m^2, 500 W/m^2, 750 W/m^2, and 1000 W/m^2.

Fig. 2(a) shows the *P–I* characteristics in which the optimum power points are indicated. The average value of MPP voltage, the open circuit voltage and the short circuit current corresponding to different solar insolation and the impact of converter duty cycle on

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