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A novel maximum power point tracking technique based on fuzzy logic for photovoltaic systems

Sadeq D. Al-Majidi, Maysam F. Abbod, Hamed S. Al-Raweshidy*

Department of Electronic and Computer Engineering, College of Engineering, Design and Physical Sciences, Brunel University London, Uxbridge UB8 3PH, United Kingdom

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ABSTRACT

Maximum power point tracking (MPPT) techniques are considered a crucial part in photovoltaic system design to maximise the output power of a photovoltaic array. Whilst several techniques have been designed, Perturb and Observe (P&O) is widely used for MPPT due to its low cost and simple implementation. Fuzzy logic (FL) is another common technique that achieves vastly improved performance for MPPT technique in terms of response speed and low fluctuation about the maximum power point. However, major issues of the conventional FL-MPPT are a drift problem associated with changing irradiance and complex implementation when compared with the P&O-MPPT. In this paper, a novel MPPT technique based on FL control and P&O algorithm is presented. The proposed method incorporates the advantages of the P&O-MPPT to account for slow and fast changes in solar irradiance and the reduced processing time for the FL-MPPT to address complex engineering problems when the membership functions are few. To evaluate the performance, the P&O-MPPT, FL-MPPT and the proposed method are simulated by a MATLAB-SIMULINK model for a grid-connected PV system. The EN 50530 standard test is used to calculate the efficiency of the proposed method under varying weather conditions. The simulation results demonstrate that the proposed technique accurately tracks the maximum power point and avoids the drift problem, whilst achieving efficiencies of greater than 99.6%.

Introduction

In recent years, the global demand for energy has increased dramatically due to population growth. In addition, the phenomenon of global warming has been intensified owing to the CO_2 emissions from fossil fuels. To solve this complex challenge, many studies have called for the use of renewable energies to face the issue of lack of energy in future years and to minimise the side effects of burning fossil fuels. Hence, developing renewable energies has been become a worthy research topic in the last decade. A solar photovoltaic (PV) systems, wind turbines, hydropower, biomass and geothermal power are the major renewable energy resources. The solar PV arrays are considered one of the most attractive renewable energy resources due to their provision of sustainable, clean and safe energy [1]. However, the efficiency of a PV system is low, because the output power of a PV array is dependent on irradiance and temperature, i.e. weather conditions, which can result in a loss of energy of up to 25% [2]. The most effective way to improve the efficiency of a PV system is to employ a maximum power point tracking MPPT

* Corresponding author.
E-mail address: Sadeq.Al-Majidi@brunel.ac.uk (S.D. Al-Majidi).
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technique with it, as shown in Fig. 1, thereby achieving maximum power production under varying weather conditions. Basically, The MPPT technique is an electronic system, which feeds an appropriate duty cycle (D) to a power conversion system for the output and/or input of the PV module to achieve continuous maximum power production. In general, there are several issues that are key when aiming to design the best MPPT technique for a PV system, including cost, efficiency, lost energy, and type of implementation [3,4]. Taking an account of these, many types of MPPT methods have been developed for PV systems, which can be divided into two types: classical methods, such as Perturbation and Observation (P&O) [5], Incremental Conductance (IC) [6], and Fractional Open Circuit Voltage [7]; and artificial intelligent techniques, for instance, Neural-fuzzy ANFIS [8], Fuzzy Logic (FL) [9], genetic algorithms (GAs) [10], particle swam optimism (PSO) [11], sliding mode [12] and Neural Networks (NNs) [13]. The P&O-MPPT is a popular method for PV-MPPT owing to its low cost and simple implementation [14]. However, it poses many challenges, such as lower converging speed, high oscillation around a maximum power point MPP, and a drift problem associated with rapidly changing irradiance [5,15]. Several modifications have been introduced based on a Power (P)–Voltage (V) curve [16–20], but they are considered as insufficient solutions for addressing all of these problems. Consequently, artificial intelligent techniques based on MPPT have been proposed to solve the significant problems of the classical MPPT methods [21]. In addition, these techniques do not need accurate parameters or complex mathematics when managing the system [22,23]. In particular, the FL-MPPT technique is one of the most powerful controllers for a PV system due to its high converging speed and low fluctuation around the MPP [24,25]. Moreover, it does not require training data, thus resulting in its working for various types of PV module with the same MPPT design. However, the main disadvantages are the aforementioned drift problem associated with changing irradiance and complex implementation when compared with the classical MPPT methods [26,27].

Several types of modification have been proposed to address those issues. Among them, the authors in Ref. [28] used the PSO algorithm to adjust the duty cycle of the boost convertor in the right direction for conventional FL-MPPT when the input solar irradiance changes rapidly. In Ref. [29], the authors designed a gain controller based on the FL approach for online adapting of the step size of conventional FL-MPPT. In Ref. [30], the author developed a novel FL-MPPT

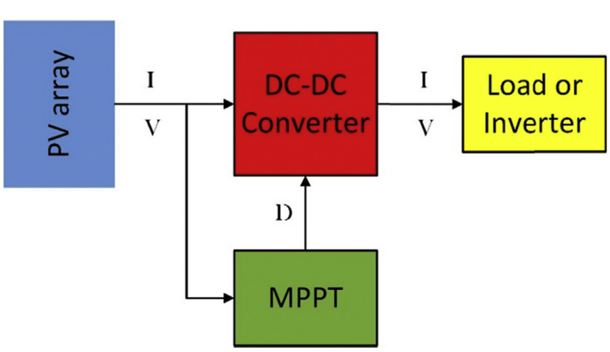

Fig. 1 – Diagram of PV system based MPPT.

based on a hill climbing algorithm for a stand-alone PV system. In Refs. [31,32], the researchers presented an improved maximum power point tracking technique using the Fuzzy-IC algorithm for a PV array and fuel cells. The authors in Ref. [33] improved the conventional FL-MPPT method by adding fuzzy cognitive networks. Whilst these proposals reduce the oscillations around the MPP and avoid the drift problem during changing irradiance, their implementation becomes more complex due to an additional step control unit. Hence, the authors in Ref. [34] used a GA algorithm to optimise the designed membership functions of the conventional FL-MPPT controller for which the fuzzy base had already been created. Similarity, the author in Ref. [35] presented maximum power point tracking based on an asymmetrical fuzzy functions process to minimise the longer processing time of conventional FL-MPPT. With the same idea, the researcher of [36] presented maximum power point tracking by modelling the fuzzy logic algorithm using an M5P model tree. In Ref. [37], the authors used a Hopfield NN to tune the designed membership functions of FL-MPPT automatically, instead of adopting the trial-and-error approach. Similarity, the scholars in Ref. [38] designed improved maximum power point tracking based on an indirect fuzzy for PV systems. The results in Refs. [34–38] report that the optimised fuzzy controller achieved improved performances, fast responses with less oscillations as well as avoiding the drift problem. However, the implementation of all these methods is more complex than for the classical MPPT techniques.

In this paper, a novel FL-MPPT technique based on a modified P&O algorithm is designed. The proposed design takes into account two key issues. First, whilst the conventional P&O-MPPT is a suitable method for the PV system under a slow change of irradiance, it faces significant challenges under a fast one. The second issue, is that the complex engineering problems of a fuzzy system become diminished when the designed membership functions are few. The fuzzy rules of the proposed method are obtained from a modified P&O-MPPT algorithm. The proposed technique accurately tracks the maximum power point and avoids the drift problem. Moreover, our simplified FL-MPPT method, when applied to a grid-connected PV system, achieved efficiencies greater than 99.6% under the EN 50530 standard test. The rest of this paper is organised as follows. Section Modelling of solar PV covers the basic modelling of a solar PV cell, whilst Sections Power conversion system and MPPT technique explain the workings of a power conversion system and MPPT controller, respectively. Section Conventional P&O-MPPT and Conventional FL-MPPT discuss the P&O and FL –MPPT, respectively. In Section Proposed method, the proposed method is presented, whilst the simulated results are provided and discussed in Section Simulation results. The EN 50530 standard test results for comparative analyses are provided in Section The EN 50530 standard test of MPPT efficiency, with Section Conclusion containing the conclusion.

Modelling of solar PV

Solar cell is an electrical device that converts the light energy into electricity by the photovoltaic effect. In ideal PV cell,

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