Methods for Increasing the Efficiency of Solar and Wind Power Generation: A Systematic Review

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***Abstract*—** Photovoltaic (PV) and wind turbines, as renewable energy sources, play a vital part in the sector's power production. As a result, it is promoted to consumers. These systems' output forces are very non-linear and rely on the system's I-P and V-P properties, as well as the irradiation circumstances. As a result, a number of research initiatives have been carried out in order to improve performance and maximise capacity from PV and wind turbines. This article presents a quick review of the literature on the Maximal Power Point Tracker (MPPT) for these systems. The PV circuit architecture with its mathematical model is presented for this purpose. The latest articles on design approaches are then evaluated.

I. INTRODUCTION

Technological advancements, environmental concerns, increasing demand for energy worldwide, and public policyhave all contributed to increasing interest in renewablesources of energy. Amongst various sources of renewableenergy, PV is a popular one. Given the fact that the PVpanels do not contain any moving parts, they lead to asignificantly lower maintenance cost of compared to othersystems. Moreover, the PV system can be easily used for stand-alone purposes [1]. However, nonlinear nature of thePV system originating from its dependency on weatherconditions, such as irradiation and temperature, makes itdifficult to operate on maximum power points in terms of*I -P* and *V -P* characteristics. As a result, many maximum power point tracker (MPPT) algorithms have been introducedby researchers to operate the system at optimum operatingpoint [2], [3].

Generally, MPPT technique can be divided into two separate categories: direct and indirect approaches [1]. The directapproach of the MPPT algorithm is not required to have aprior knowledge about the PV characteristics. Perturb andObserve method [4], [5], incremental conductance method[6], [7], fuzzy logic (FL) method [8], [9] and neural network (NN) method [10] are considered as direct methods.

The indirect approach uses the mathematical relationships ofthe system to maximize the power. The indirect approach

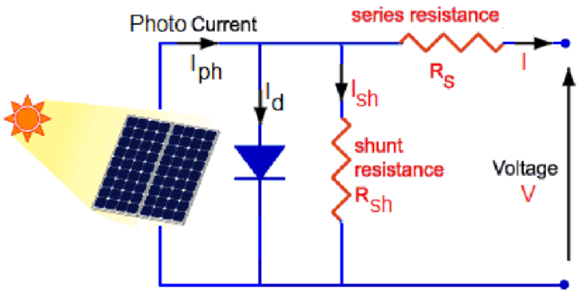

Fig. 1: An equivalent circuit of the PV.

Includes open-circuit PV voltage method [11], short circuitsPV current method [12]. In addition to the above, another distinction is made byconsidering the exchange of information, i.e., offline versusonline approaches. The offline or open loop MPPT approachapplies the historical testing data of the system like opencircuit voltage or short circuit current of the PV panel.There are numerous methods in this group such as neuralnetwork [13], [14], genetic algorithm [15–17]. The online approach considers real-time data from the system. Thus, itprovides a better accuracy in results. The online approachconsists of variety of algorithms such as perturbation andobservation (*P&O*) [18–20], incremental conductance [21],[22], and ripple correlation control (RCC) [23].In this literature review, we focus on the PV panel andvarious methods for the MPPT. The main goal is to provide recent technology achievements on the PV panels. The paper is organized as follows: Section II illustratesa model of the PV panel and provides its mathematicalformulation. In Section III, a review of direct and indirect methods is provided. Then, various online and off-linemethods are illustrated in Section IV. Finally, related designproblems, conclusions, and future guidelines are discussed in Section V.

II. SYSTEM DESCRIPTION

PV arrays consist of a large number of series and parallelsolar cells [24]. Such a system can be modeled by a currentsource, a shunt diode, and series resistor. Figure 1 shows anequivalent circuit of the PV system.The single diode model can be a simple equivalent circuitto illustrate the PV cell. A current source is in parallel witha diode and it is directly proportional to the irradiation. Thecurrent of the PV cell, which is known as a Shockley diode equation.

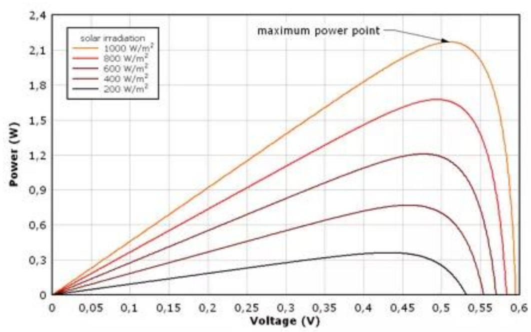

Fig. 2: Relationship between output voltage and power of the PV cell under different irradiation conditions

It is clear from Figure 2 that under a certain irradiation,there is a unique maximum point located at the knee ofthe curve. Furthermore, this value changes with respect tovariation in the irradiation.

III. VARIOUS METHODS FOR MPPT IN THEPV AND WIND PANELS

In this section, various direct and indirect methods aredemonstrated.

A. Direct methods

Direct methods use the measurement data and computation techniques to maximize the power in the system. The mostfamous methods in this category are reviewed as follows:

1) Perturb and Observe (P&O) methods:The main mechanism for the perturb and observe method is simple. Thismethod measures voltage and current of the PV panel andcalculates the power. Then, it compares the result with theprevious power. After this, the controller changes the dutycycle of the pulse width modulation to enhance the powerin the system. The design procedure is straight forward.

If the computed power is greater than the previous one,the controller holds the same direction for the duty cycle.However, if the power declines, the controller changes thedirection of the duty cycle. In some research works, theperturb and observe method is also known as hill climbing(HC) algorithm [26]. It must be noted that the performance of the perturb and observe controller is high in the environment withoutdisturbance. However, the controller provides a slow tracking which does not have a proper performance in rapidlychanging conditions [27]. Therefore, the perturb and observemethod often combines with other methods to improve the performance of the method in the presence of the disturbanceand varying environments.A new start-stop mechanism based on the perturb andobserve method is introduced in [28] to remove thesteadystate oscillations in the power response and maximize thepower. The main aim is to improve the power performance byreducing the perturbation magnitude. However, this methodreduces the speed of the system in fast irradiation conditions.Therefore, a tradeoff is made between the speed and steadystate oscillation in the system. The proposed method is evaluated in a subMICs-based PV system and the experimental test scenarios show the performance of the system.An integrated method using the perturb and observe methodand fuzzy logic technique is developed in [29] to operate atmaximum power output in the presence of variation in solarradiation. The proposed method shows a high performanceunder varying irradiation conditions. A modified perturb andobserve algorithm is presented in [30] to solve the problemof local maximum for the MPPT. The suggested methodadds a checking algorithm to the conventional perturb andobserve method to monitor all existing maximum powersand then decide how to change the controller to achieve a higher power in the system. The proposed method isvalidated in two environments consisting of constant andvarying irradiation conditions.

2) Incremental conductance (IC) method: The Incremental conductance method is developed to address the drawbackof the perturb and observe method. The method reducesthe tracking time and enhances the power in varying environments [31]. The IC method considers the relationship between current and voltage (*-VI* or *-ddVI*) to adjust the controller and achieve the maximum power [31]. However, afixed step mechanism is considered to modify the controllerwhich may take relatively long time to reach the maximumpower. Therefore, the performance is still slow in varying conditions. A new IC method is proposed in [32] for nonlinear load.The proposed IC method considers a combination of theconductance and the rate of the conductance to deal with nonlinearity of the load. The suggested method can easily dealwith the voltage ripple and provide the MPPT. Simulation results show that the suggested method enhances the maximumpower in the PV panel. In [33], An IC method using a PIcontroller is developed for optimizing power in the PV panel.The method uses a converter with a V-shaped impedancecomponent to generate a higher voltage in comparison with other conventional converters. For test study, three casesincluding various temperatures, light intensity changes, andload uncertainty are considered. The test results indicate aproper response of the PV panel in all cases.

3) Fuzzy logic (FL) methods: Fuzzy logic is an intelligentmethod which can describe a system with linguistic rulesusing membership functions [34]. The fuzzy logic can be considered in the PV panels to model uncertainty and nonlinearity in the system and formulate the MPPT problem.

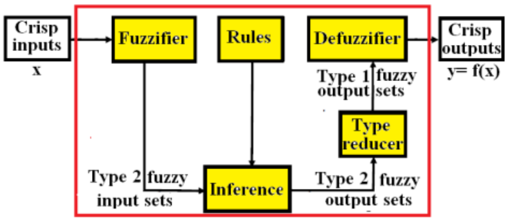

Fig. 3: Type 2 fuzzy inference system structure

A combination of fuzzy logic technique and the perturband observe method is designed to improve the maximumpower in PV panel in [35]. The proposed method utilizespower variation and voltage variation as input to the fuzzysystem instead of using error and its variation which enhancethe performance of the method. Then, an implementation isperformed using the dsPIC digital signal controller (model:*dsPIC*33*FJl*6*GS*502). The experimental test results validatethe effectiveness of the method. Furthermore, the fuzzy logic-based controller provides a faster tracking in comparisonwith conventional fixed step perturb and observe method. Afuzzy logic controller via incremental conductance methodis introduced in [36] to optimize the power point trackingin PV panel. The main purpose is to build some fuzzyrules based on conductance formula to achieve the maximumpower for the PV panel in varying irradiation and temperatureconditions. The simulation results show the capability of the proposed system in various weather conditions. A type 2fuzzy controller is considered in [37] to achieve the MPPTin a solar cell. Simulation result shows a fast responseunder changes in the atmospheric conditions. Fuzzy logictype 2 controller (FLC) is designed based on fuzzy logictheory. Figure 5 illustrates type 2 fuzzy inference system structure. The type 2 fuzzy system includes fuzzifier, rulebase, DE fuzzifier, inference engine and type reducer. Thisstructure is similar to type 1 fuzzy inference system. Theonly difference is the type reducer which is added to thetype 2 fuzzy system. It means the method can be formulatedin the same way that a type 1 fuzzy system is developed. Dueto this fact, this method is also known as interval type 2 fuzzylogic controller (IT2FLC) [38]. The appropriate modeling ofuncertainty helps the type 2 fuzzy system achieve a higher accuracy.

4) Artificial Neural network (ANN) methods: Artificialneural networks are intelligent methods which can modela system with available input-output data without knowingabout the physic of the system. Therefore, the neural networks are known as a block box system [39]. The ANNsare considered to model highly nonlinear systems and reachmore accuracy in estimations.An Intelligent technique using feed-forward and

Elmanneural networks is presented in [40] to forecast the powerof the PV panel. Two-year data from the PV panel is used to train and test the proposed method. The structure ofthe networks must be selected with respect to the natureof the data. The simulation results show that both of thenetworks have a proper performance. An adaptive NeuroFuzzy inference system (ANFIS) is presented in [41] forthe high-performance tracking in PV panel. The proposedmethod combines the learning capability of the ANN andFL to improve the accuracy of the system. Therefore, thesuggested method is suitable to handle a nonlinear load or varying conditions. Several simulation tests show a higheraccuracy of the ANFIS method in comparison with the fuzzylogic.

IV. RELATED DESIGN PROBLEMS, CONCLUSIONS AND FUTURE GUIDELINES

This paper examines the most current control methods for maximising capacity in PV and wind turbines. The fundamental principles of strategies and their benefits and weaknesses have been demonstrated. Some findings and potential recommendations are presented as follows:

1-The approaches of disruption, observation, and progressive conductivity may be effectively applied and provide reasonable success in healthy environments. However, their efficiency is poor under differing conditions. Techniques may be mixed with other methods, such as fuzzy logic, genetic algorithms, artificial neural network, and so on, to be appropriate for rapid use.

2-Recently, innovative control technology, such as siding mode and feedback control for the PV device, has been found owing to its reliable performance. Adaptive and innovative management strategies are also strongly regarded when working with various forms of control conditions, such as weather fluctuations or irradiation.

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