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Enhancing the tracking techniques for the global maximum power point under partial shading conditions

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ABSTRACT

The partial shading is one of most critical problems facing the Maximum Power Point Tracking (MPPT) techniques for photovoltaic systems. This paper provides a review of challenges and opportunities regarding the problem of partial shading. In addition, it introduces a new technique for tracking the Global Maximum Power Point (GMPP) under different Partial Shading Conditions (PSC). The technique utilizes a two-stage algorithm to accomplish the tracking process efficiently. In the first stage, it applies a Genetic Algorithm (GA) to get the nearest point to the GMPP. In the second stage, it utilizes a new and fast MPPT algorithm to search for the target GMPP starting from the nearest point fetched in step one. In order to evaluate the new technique, a complete microcontroller based prototype is implemented and tested. The experimental results show that the new technique reaches directly to the GMPP in very short time and with limited steady state oscillations. Accordingly, the new technique has a significant improvement in energy extraction efficiency from the photovoltaic array to the load.

1. Introduction

The moving objects between the sun and photovoltaic PV arrays shadow them partially or wholly. Consequently, the PV characteristics get more complex with more than one peak [1]. Normally, there are multiple local peaks in the P-V curve of the shaded photovoltaic system rather than one peak only for curve without shadowing. However, there is only one global point that is the highest peak.

There are very strong ageing effects may be induced by external factors causing continuous or severe damage to the module. These effects are including overlaying dust, dirt and bird droppings, surrounding vegetation or fence, causing continuous partial or total shading and localized temperature increase. These may lead to more permanent optical and physical cell degradation phenomena [2].

Shading is not always taken into account and can be more easily overlooked by the designer / installer. Therefore, it is important to perform detailed solar resource predictions, taking into account the orientation, inclination and all potential shading by surrounding trees and/or buildings. On the other hand, it should be a technical solution for resolving the partial shading problem to maximize the extracted power. There are many techniques have been developed for resolving this problem. They can be organized into firmware and hardware approaches. The firmware approaches consist of software algorithm that controls the GMPP tracking operation based on the input parameters and the measurements corresponding to the partial shading condition. While the hardware approaches rely on keep changing the configuration of array connections in order to cope with shading in contrast to the traditional series–parallel layout.

On the other hand, there is a smart module technology which is so called Module Level Power Electronics (MLPE). It has a power optimizer embedded into the solar module at the time of manufacturing embedded in the junction box of the solar module [3]. The main role of the optimizer is to provide increased power controls and intelligent disconnect upon detection of current loss. Also, there is a built in MPPT microcontroller based embedded within the module [4]. This technology can dynamically bypass for strings and substring isolation instead of traditional bypass diode and can overcome the hot spot problem. Therefore, it can compensate losses due to shading. However, this power optimization is localized within the modules while the proposed new technique can optimize the power of all panels.

There are many methods of tracking the maximum power point. However, most of these methods may fail to track the global maximum power point under some complicated cases of PSC [1]. The next few lines address the knowledge gap by compiling most available publications on partial shading from a database of scientific literature.

Bai, Attila et al., presented a review on the technical and economic

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effects of cooling of PV modules as one of the possibilities for improving the PV module efficiency. The review showed the relationship between temperature change and efficiency change of monocrystalline and polycrystalline. In addition, the study showed how the cooling systems could increase the efficiency and productivity of PV modules. However, the cooling systems are around 10–15% more expensive than the cost of systems without cooling [5].

M. Chandrasekar, S. Rajkumar and D. Valavan studied the effects of increasing the operating temperature of the PV modules that result in lower both electrical power yield and conversion efficiency. Also, this research presented a review on various thermal regulation techniques used to control the temperature of the PV panels including the mechanism of cooling and the challenges involved in the construction of various cooling techniques [6].

M. M. Rahman, M. Hasanuzzaman and N. A. Rahim showed that the partial shading influences most of the perilous hot spot in PV module which is liable for total power dissipation and causes degradation in the performance of practical PV module. In addition, this work showed that the solar modules containing non-homogeneous hot spot in elemental concentration and the reverse current due to partial shading could increase the module temperature up to 130 °C and consequently irreversibly damage the PV modules. Furthermore, it described the application of bypass diode model in PV device to overcome the power degradation due to hot spot and temperature effect under partial shading conditions [7]. Nevertheless, bypass diodes do not solve the problem of the reduction in the generated power of the PV-PP under partial shading conditions.

The produced hot spot and the increased in modules temperature limit the current energy production in the short-term and accelerate the ageing of solar modules in the long-term [8,9]. The previous studies presented very important considerations that should be taken into considerations in the PV module design stages to overcome the ageing and degradation of the power production. However, these previous studies did not introduce any contributions for the applications of PV power generation while the proposed new GMPP tracking method presented an optimized technique for maximizing the extracted power under partial shading conditions.

Yasser E. Abu Eldahab, Naggar H. Saad and Abdalhalim Zekry presented recently a new MPPT technique based on a genetic algorithm [10]. This method is characterized by fast and accurate tracking of the MPP. Furthermore, this new method is utilized for designing a battery charger controller for photovoltaic and wind energy systems [11]. However, this new technique is not capable to track the global peak in the cases of practical shading conditions.

Carlos R. et al., introduced a simulation model representing the PV array under partial shading conditions [12]. It is useful for studying and sizing the PV panels. Jubaer Ahmed, and Zainal Salam presented an evaluation of the performance of various types of MPPT algorithms under partial shading [13]. Also, Kashif Ishaque and Zainal Salam conducted a good review of the MPPT of PV systems for uniform insolation and partial shading conditions [14]. This study provided researchers with valuable information to start with MPPT. Ahmed Fathy presented a modified artificial bee colony based approach for mitigating the power loss in the PV module under partial shading effect [15]. This paper reviewed and discussed the partial shading conditions, PSC, without any treatment of the maximum power point tracking.

Jubaer Ahmed and Zainal Salam introduced a MPPT technique using the Cuckoo search [16]. This method was able to track the GMPP under some partial shading conditions. Santi Agatino Rizzo and Giacomo Scelba presented a MPPT method based on an Artificial Neural Network (ANN) [17]. It is faced with the tradeoff between the number of preselected power to voltage characteristic scansions, the size of the ANN and its prediction accuracy. Maria Carmela Di Piazza and Gianpaolo Vitale introduced a photovoltaic field emulator [18]. It was very useful to study the photovoltaic characteristics under different operating conditions, including some partial shading conditions. M.C. Alonso-García, J.M. Ruiz, and W. Herrmann presented a simulation of the shading effects on PV arrays [19]. The shading was run on a string of cells. It yielded some recommendations. This class of papers provided recommendations and solutions for the maximum power point tracking but without any hardware implementation.

Kashif Ishaquea et al. showed a direct control based maximum power point tracking method [20]. It utilized a particle swarm as an optimization algorithm. It was tested successfully under some partial shading conditions. In addition, Shubhankar Niranjan Deshkar et al., introduced a genetic algorithm based method to reconfigure the electrical connections between panels in order to fetch the optimum MPP [21]. These publications presented a complete hardware implementation. However, they did not include most complicated cases of partial shading conditions when the irradiance is distributed non-uniformly on the solar panels.

Phimmasone et al., investigated several conditions of partial shading and the speed of insolation variations [22]. While Miyatake et al. studied continuous partial shading and un-shady conditions [23]. Keyrouz F, and Georges S focused in the continuous partial shading and un-shady conditions [24]. These publications presented the possible shading patterns and the conditions of shading as well as the corresponding effects on the output efficiency of the photovoltaic arrays.

EloyDı´az-Dorado et al., presented a discrete I–V model for partially shaded PV-arrays [25]. It provided a complete analysis of current, voltage, and power in several PV systems under partial shading. Punitha et al., proposed an ANN based on incremental conductance algorithm for GMPP tracking under PSC [26]. The simulation results showed a significant improvement in tracking via ANN compared to fuzzy based hill climbing and P & O algorithms. Kamarzaman, and C.W. Tan reviewed the characteristics and performances of artificial intelligence based MPPT. They showed that, the algorithm structures of the FLC and ANN are complex, whereas the sensitivity of GA to the environmental changes is moderate [27].

M. Miyatake et al., presented a particle swarm based MPPT technique for multiple photovoltaic arrays [28]. Moreover, H. Taheri et al., developed a novel MPPT technique under partial and rapidly fluctuating shadowing conditions. It utilized a differential evolution technique [29]. However, these methods have high implementation cost and are unable to discriminate between local and global MPP.

Dezso Sera and Yahia Baghzouz analyzed a mechanism of partial shading on a number of PV cells connected in series and/or in parallel with and without bypass diodes in simple terms [30]. It was useful to determine the impact of some shading geometry on PV system. de Oliveira et al., presented a comparative analysis, among different arrays of PV modules under partial shading conditions [31]. The power extraction under partial shading in parallel and series PV arrays was evaluated.

As shown from reviewing dozens of research work contributions and challenges regarding partial shading problem, it is found that more research contributions are required to track the right global peak accurately, fast and not trapped at one of the local peaks. This paper introduces a new reliable technique for tracking the GMPP under all possible partial shading conditions of the photovoltaic systems. The novelty of the proposed method is that, it utilizes a new technique for fetching the closest point to the global peak based on the genetic algorithm to minimize the distance to the target global peak and it then applies a new MPPT method to reach the GMPP rapidly and accurately. In other words, the new technique not only optimized the search path to be minimum but also it utilizes a new search algorithm for minimizing the search time speed and maximizing the search accuracy. Therefore, the new technique has a very fast response, a very limited steady state error, and zero oscillation around the target. In order to validate the proposed technique and investigate its tracking performance, a complete hardware prototype is implemented and tested. All possible partial shading conditions are included in the experimental