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Experimental assessment of new fast MPPT algorithm for PV systems under non-uniform irradiance conditions

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HIGHLIGHTS

- A new MPPT method for PV systems under non-uniform irradiance conditions is proposed.
- The proposed MPPT is composed of a novel identifying-loop and a tracking loop.
- Comparison with three classical MPPTs as well as six global MPPTs is carried out.
- High capability to extract the GMPP under non-uniform irradiance conditions.
- Fast convergence and low complexity are the main advantages of the proposed MPPT.

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ABSTRACT

The paper carries out an experimental investigation of a new Maximum Power Point Tracking (MPPT) method for standalone Photovoltaic (PV) systems. The new method combines a novel mechanism of global maximum power point identifying loop when the system undergoes multiple maximum power points and the use of adaptive variable step Hill Climbing (HC) MPPT technique to track the identified Global Maximum Power Point (GMPP). To figure out the advantages of the proposed method, it is implemented together with three local MPPTs (e.g., two conventional MPPTs and fuzzy logic-based one) and compared with six recently developed Global MPPT methods. Obtained experimental results as well as comparison outcomes show that the proposed MPPT technique is fast while tracking GMPP (around 2.4 s) and resilient against perturbations that may occur during the operation of the PV system. Moreover, the proposed MPPT method boasts other advantages such as ease of implementation, no dependence on the PV system and requires only two conventional sensors of voltage and current respectively.

1. Introduction

With the rapid growth in industrial sector worldwide as well as ever increasing sophistication of modern lifestyles; the world energy supply tends to be subject of tremendous strain. Furthermore, most of power plants are based on conventional energy sources (i.e., coal, petroleum and natural gas, etc.) that experience a fast depletion and cause serious environmental issues (global warming, climate change and weakening). These phenomena have driven nations and power producers/suppliers around the world, seeking alternative energy sources that are sustainable, green and more efficient [1]. Electrical energy extracted from renewable sources has been targeted as an effective optimal pathway to cope with the aforementioned critical challenges [2]. It is worth mentioning that sunlight is considered as an interesting renewable source to produce electricity. In developing countries, for population living in remote areas and having no access to grid

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utility while solar radiation is abundantly available (i.e., South Asia, Southeast Asia, and Sub-Saharan Africa) [3], solar energy becomes critically important.

The primary energy of Photovoltaic (PV) based conversion systems is the sunlight and its conversion to electric energy involves no moving parts. This process of conversion needs only the use of semiconductors and no fuel burning is required. This fact results in several advantages when using such PV systems in producing electricity such as noiseless, safe, green, environmentally friendliness and almost no maintenance is required [4]. Moreover, PV systems can be effectively utilized in unused spaces, such as rooftops of homes, universities, shopping malls and factories in order to harvest solar energy [5–7]. In addition to the PV systems ability in supplying the rural areas. Hence, using PV in distributed generation or solar power plant as well as standalone systems has recently known a big grow and attention [3]. From the other side, as any human being made system, they have drawbacks and one of the most important of them is the very low conversion efficiency. Large part of the power loss is due to the process of harvesting solar energy that is related to the conversion of limited wavelengths of photons being absorbed by the semiconductors. In other words, photons having less energy and those having energy greater than the band-gap energy of the semiconductor contribute in overheating rather than generating electricity [8].

Besides other factors, such as structure defects of the PV cell and the area of contacts on the top of PV cell, the load to which is connected the PV affects a lot its conversion efficiency. To this, many models to predict this efficiency as well as the electrical behavior of PV module/string/array under different working conditions are now available [9–12]. These models have been employed in the performance evaluation of Maximum Power Point Tracking (MPPT) algorithms [13,14] as well as in analyzing the PV system performance (e.g., energy yield prediction, efficiency estimation, performance assessment of PV array arrangements, etc.) [15–17]. Considering the uniformity of irradiance, there is only one point on the Power–Voltage (Ppv–Vpv) characteristic of PV system where maximum electric power can be extracted and hence maximum operation efficiency is obtained [18]. To ensure that PV systems work at their Maximum Power Point (MPP), a chopper or inverter with voltage or current control are inserted between the PV and the load and a MPPT algorithm is run every time to seek this point. However, considering real life situations, the sunlight striking the PV system being constituted of many PV modules connected in series or/and in parallel can be non-uniform. It is worth mentioning that non-uniformity of irradiance is one of the major sources of reduction in energy yield of PV systems as confirmed by many studies [12,16]. As a matter of fact, the energy productivity of shaded PV systems can drop down to 20% of that of the unshaded PV systems [19]. Shaded cells inhibit power generation from other fully illuminated series-connected cells and become hot spots. Therefore, to protect the shaded cells from thermal destruction, bypass diodes should be integrated within the PV module [20]. However, adding bypass diodes in parallel to some set of cells or modules within PV string will result in multimodal Ppv–Vpv characteristic [21,22].

Looking for places without frequent shadowing to install PV systems can be an effective solution to alleviate the impact of Partial Shading (PS) but cannot totally get rid of it. Many factors lead to PS problem, for instance, in building integrated PV installations, PV cells/modules can be subjected to shadows cast by both predictable surrounding objects, which may be nearby trees/antenna, utility towers, power lines, or unpredictable sources, e.g., fallen leaves or bird dung covering parts of PV module surface. In large PV plants occupying a wide area of land, where PV modules are usually placed far from any surrounding obstacles, different orientations of PV modules belonging to the same PV string, moving clouds and the shadows of adjacent rows of PV modules also lead to PS problem. Furthermore, PS effects can take place if there is a mismatch between modules composing the same PV system. This mismatch is the result of connecting together PV modules with different technologies or electrical characteristics [23]. This phenomenon is called as mismatching losses [24]. To this, manufacturers set the tolerances in PV module characteristics to reduce the power losses as this problem continuously exists due to the uneven aging of PV modules that belong to the same PV string. Regarding PS problem, many solutions have been proposed to improve the efficiency of PV system. These solutions can fall within two main groups, hardware and software solutions.

Hardware solutions include array connections [12,16,25,26], PV system architectures [27–29] and circuit topologies [30,31]. These techniques aim to mitigate the PS effects. Array connections define how PV modules of an array are connected. Choosing, instead of series-parallel connections, total-cross-tied or bridge-linked PV modules allow decreasing the current that flows through shaded PV cells and hence keep the bypass diodes reverse biased. This would improve the MPP of the PV system. PV system architecture pertains to the way the chopper/inverter is connected. Unlike centralized architecture where all PV modules are connected to the main converter (chopper & inverter), in series and parallel-connected micro-converter architectures, each PV module is connected to its own converter. The latter connections allow tracking the MPP of individual PV modules and hence improving the overall efficiency. The third solution that is circuit topologies consists in using different topologies of converters together with their connections to PV modules and are well investigated in the work of Bidram et al. [30]. Important improvement of efficiency has been obtained by using circuit topology methods. Obviously, hardware solutions are not cost effective and require controllers that are more complex.

Software solutions are pertaining to the upgraded MPPT methods that properly identify the Global MPP (GMPP) of the PV system [21,32]. Conventional MPPT techniques such as Perturb & Observe (P&O) [33], Incremental Conductance (InCond) [34] and Hill Climbing (HC) [35] as well as enhanced conventional MPPT techniques such as Variable Step Size Incremental Conductance (VSS-InCond) [36], improved InCond [37], improved P&O [38] and two-steps based P&O [39] are all based on pursuing the point on the Ppv–Vpv characteristics at which the derivative of power with respect to either voltage or duty cycle is null. Therefore, when used to track the MPP of partial shaded PV modules, they would fail to track the appropriate MPP and subsequently extra power losses result [40]. This explains the need to develop suitable MPPT algorithm that is able to cope with the PS problem and subsequently ensuring better efficiency and reliability. In this context, some conventional MPPT techniques have been modified or combined with other methods to escape Local Maximum Power Points (LMPPs) and hence properly identified the GMPP on the Ppv–Vpv characteristics. In [41] a modified version of P&O is presented. The algorithm runs P&O at different specific locations, which depend on the number of bypass diodes, and compares their power peaks until all the range is scanned. The algorithm effectively converges to GMPP, however, an accurate condition to terminate searching process is not provided. The work in [42], an Artificial Neural Network (ANN) has been hybridized with InCond to track the GMPP of the PV system. The ANN is used to automatically predict the GMPP of the PV generator. According to numerical simulations, it can be observed that ANN-based-MPPT provides a good robustness to parameter variations of PV system. However, high robustness requires a huge database which burdens the computation and the memory.

Sundareswaran et al. [43] combined Genetic Algorithm (GA) with P&O in order to accelerate convergence and decrease the inherent oscillation due to the evaluation of chromosomes. The