A Maximum Power Point Tracking Method Based on Perturb-and-Observe Combined With Particle Swarm Optimization

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***Abstract*—Conventional maximum power point tracking (MPPT) methods such as perturb-and-observe (P&O) method can only track the first local maximum point and stop progressing to the next maximum point. MPPT methods based on particle swarm optimization (PSO) have been proposed to track the global maximum point (GMP). However, the problem with the PSO method is that the time required for convergence may be long if the range of the search space is large. This paper proposes a hybrid method, which combines P&O and PSO methods. Initially, the P&O method is employed to allocate the nearest local maximum. Then, starting from that point on, the PSO method is employed to search for the GMP. The advantage of using the proposed hybrid method is that the search space for the PSO is reduced, and hence, the time that is required for convergence can be greatly improved. The excellent performance of the proposed hybrid method is verified by comparing it against the PSO method using an experimental setup.**

***Index Terms*—Global optimization, maximum power point tracking (MPPT), photovoltaic (PV) array, partial shading.**

I. INTRODUCTION

OVER the few past decades, many algorithms to track the maximum power point (MPP) have been proposed. Among these, perturb-and-observe (P&O), hill-climbing (HC), and incremental conductance (INC) are the most widely used methods [1]–[3]. As shown in [4] and [5], these methods are essentially different ways of envisioning the same fundamental concept, and rely on determining the gradient of the power with respect to the current or voltage using the perturbation method in each iteration. When the first local maximum point (LMP) is reached, the algorithms stop progressing to the next maximum point (if there is any). Consequently, the main drawback of these methods is that they tend to converge to a single LMP, which is only appropriate under uniform insolation conditions.

Under partially shaded conditions, the shaded cells in a module become reverse biased and behave as a load, leading to the hot spot problem. To avoid this, bypass diodes are used to conduct the current that is generated by the nonshaded cells within a module. However, the connection of bypass diodes will change the uniform current–voltage (*I*–*V*) and power–voltage (*P*–*V*) characteristics of the module, resulting in multiple peaks [6]. To maximize the efficiency of the module, it is necessary to track the global maximum point (GMP). Two approaches are generally used to reduce or counteract the shading effect. The first is based on hardware fixtures, such as adaptive reconfiguration schemes for the PV arrays [7] and multilevel converter systems [8] that allow each PV source to be controlled separately. This approach is complex and costly [9]. The second approach is to track the GMP by developing advanced control algorithms, and this will be the focus of this paper.

Kobayashi *et al.* [10] have proposed a two-stage method to track the GMP. In the first stage, the operating point of the photovoltaic (PV) system moves into the vicinity of the GMP by estimating the equivalent load line. Then, the INC method is employed to converge to the MPP in the second stage. Because the equivalent load line in the first stage is estimated under uniform insolation conditions, some partial shading conditions (PSCs) may cause an LMP to be tracked in the second stage [11]. In [9], a scanning process is first utilized to detect the regions which contain the GMP. After that, a P&O algorithm is used to find the GMP. Although this method can successfully find the GMP, the tracking speed is limited because almost all LMPs must be found and compared to obtain the GMP. A Fibonacci search (FS) method was proposed in [12]. However, as this is a linear search method, a GMP still cannot be guaranteed. The “DIRECT” (dividing rectangles) algorithm, which is proposed in [7], is based on a Lipschitz condition to find the maximum point. To ensure that the GMP is found, the search areas to be divided must be selected with care; otherwise, false GMP may be found. Lei *et al.* [13] proposed a sequential extremum seeking control strategy for GMP tracking. However, this process requires the variation bound for the turning-point voltage to be found. This in turn requires knowledge of the *P*–*V* or *P*–*I* characteristics under variable-shading circumstances, which may be difficult to obtain in practice. Researchers have also used artificial intelligence algorithms to develop maximum power point tracking (MPPT) methods. In [6], a radial basis function and a three-layered feedforward neural network are used to track the GMP. However, the accuracy of this scheme depends on the volume of training data, and considerable computational effort is needed to ensure reliability and accuracy under any shading condition.

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