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A Review on Maximum Power Point Tracking Techniques under Partial Shading Condition

Rishi Kumar Gupta[1], Nita Vishwakarma[2]

[1]Student, [2]Assistant Professor,
[1,2]Oriental Institute of Science & Technology, Bhopal, Madhya Pradesh, India

ABSTRACT

Partially shaded condition (PSC) is one of the major problems in large photovoltaic generation systems. It causes losses in output power and hot spot effects. Under PSC, PV characteristic curve exhibits multiple peaks having one global maximum power point and multiple local maximum power points. Tracking the global maximum power point is one of the main challenges the design engineers have to face. The paper presents the recent work done on the development of Global Maximum Power Point Tracking (GMPPT) algorithms under partial shading condition and their comparative analysis. To have focus on GMPPT techniques used in PSC, traditional MPPT techniques that cannot distinguish GMPP from local maximum power points have not been discussed.

***KEYWORDS:** Partial Shading Condition (PSC), Global Maximum Power Point Tracking (GMPPT), P-V characteristics*

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I. INTRODUCTION

The problem of partial shading in the area of solar photovoltaic systems (SPV) has generated interest in the research community since 20 years. Partial shading occurs when the modules connected in series and parallel doesn't receive same illumination and the result is different power generation by the different modules for the same rating of the panel. And if same power doesn't flow through all the modules, the modules which are generating lower power will act as sink and the power will be absorbed from the modules which are generating more power leading to hotspot formation and consequent irrelevant damage of the PV module. To overcome this problem diodes are generally connected in parallel with the PV panel. Some manufacturers provide inbuilt bypass diodes with the PV module. Normally bypass diodes are provided in parallel with series connected PV cells as shown in figure 1. But it introduces complexity in the non- linear PV characteristic curve with multiple maxima under PSC. Even large PV plants are being built in a fixed series- parallel configuration and modules have bypass diode included in different configurations. To extract maximum power from the PV system MPPT is employed [1].

Various review papers for MPPT methods are available for solar PV power generating systems till date. Some papers have discussed both traditional methods as well as those suitable for partial shading condition (PSC) [2-5]. Some have discussed only MPPT methods for partial shading condition [6-8]. For further optimization of the PV system, partial shading has to be taken into consideration by the researchers. In this paper a comprehensive review of the papers on maximum power point tracking under PSC has been presented. A comparative analysis based on the advantages and shortcomings has also been included.

II. PARTIAL SHADED CONDITION(PSC) PROBLEM

To enhance the power handling capacity of solar PV generating systems, the solar PV modules are connected in series (to enhance voltage level) and/or parallel (to enhance current level) with each other.

Under uniform solar insolation on these modules the complete PV generating unit has a unique maximum power point that can be tracked using various gradient search based conventional methods. But under different insolation (due to clouding, tree or building shade etc.) the IV characteristics in series connected modules differ resulting in mismatch in the operating point. This causes some of the modules which are heavily shaded to act as load consuming power thereby giving rise to a situation called hotspot formation as shown in figure 1 which ultimately results in irreversibly damage of the module. To overcome this problem bypass diodes are connected across the module. The current thus bypasses the shaded module. Figure 1 shows a PV array composed of three modules in a string and its characteristic curves under uniform insolation and partial shading condition (with and without bypass diode). Two local MPPs can be seen on the PV characteristic curve other than the GMPP (global maximum power point). The popular gradient search or hill climbing method employing the logic of finding zero gradient (dp/dv=0) fails as the algorithm sticks and start operating in local maximum power point. Thus an efficient algorithm to track global maxima under PSC is required.

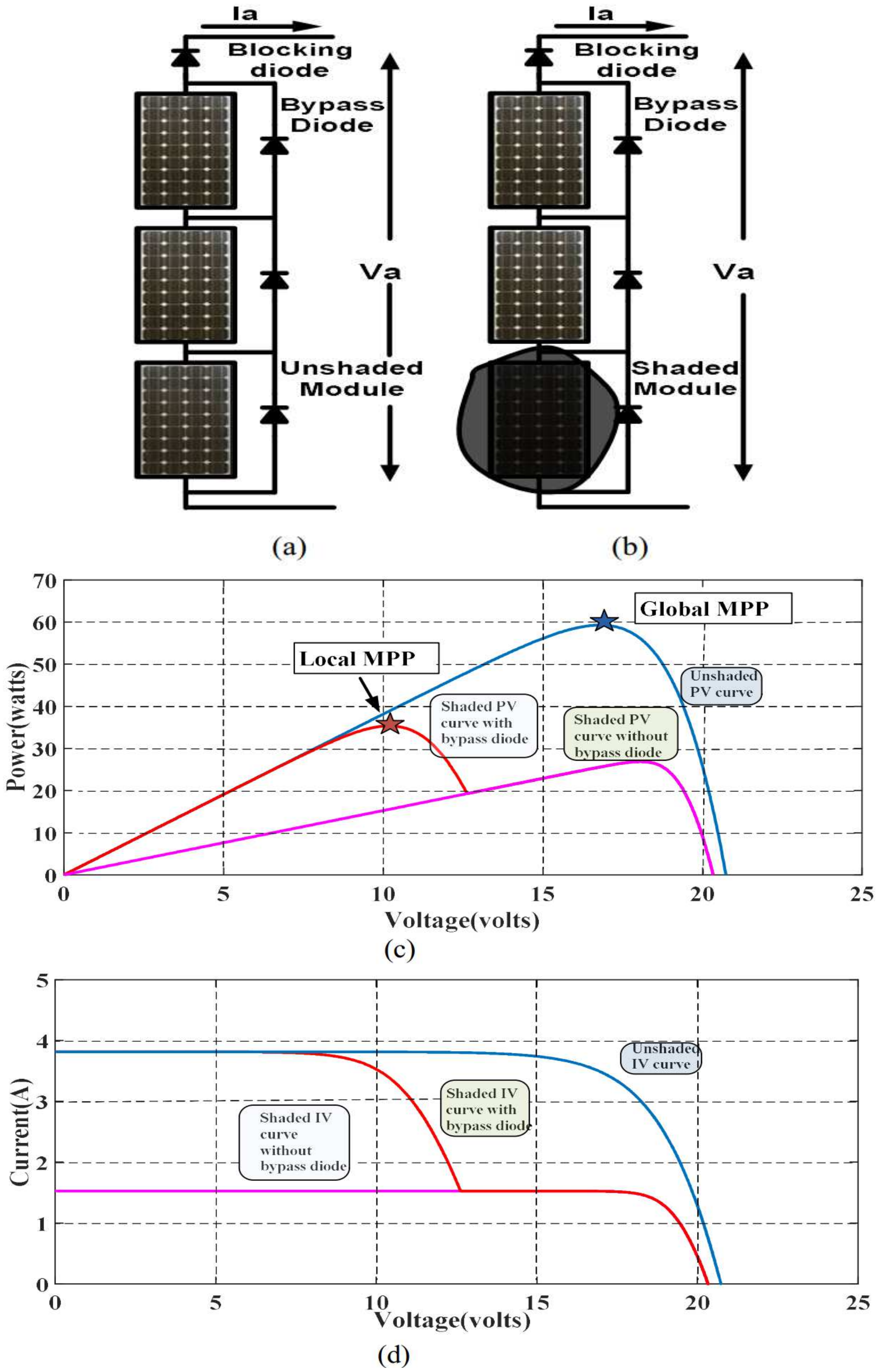

Fig1. (a) PV array under uniform insolation. (b) PV array under PSC. (c) PV characteristic for (a) and (b). (d) IV characteristic for (a) and (b).

III. GLOBAL MAXIMUM POWER POINT TRACKING TECHNIQUES UNDER PSC

Recent algorithms for Global MPP tracking can be classified as follows.

1. Modified conventional MPPT
2. Utilizing the features of the characteristic PV curve
3. Metaheuristic nature inspired methods

1. Modified conventional MPPT

1. Two stage searching method: Search for the GMPP location interval is done in the first stage and then by using traditional MPPT methods in the second stage precise GMPP location is found out [6]. H. Patel and V. Agarwal [9] used this method with the basic search rules. They took 0.85 Voc, all (total O.C voltage of the system) as the P&O search starting point. Then they used the peak value found in step 1 as the basis to move the operating point one large step to the left. If the peak value obtained was greater than the previous one, step 2 was repeated, if it was smaller, then previous peak value was considered GMPP.

Advantage of this method is that its implementation is easy and it can be integrated into conventional Power Generating System. Its disadvantages are that it can fail to track GMPP in some cases. It is successful in cases when we move from start or from VOC (as shown in figure 2). Also probability of the GMPP being tracked is dependent on value of the large step. Its tracking speed is also less as maximum power point of each curve has to be obtained using P&O method. Works in [10-12] has similar methods. Authors employed a large interval for the entire P–V characteristic curve and determined the largest peak value. Then a refined search is done near this peak value to locate the GMPP. Flowchart of the method is given in figure 3.

2. System characteristic curve method: Works in [13-15] used a preset function (linear) to move the operating point near the GMPP. Flowchart in figure 4 describes the principle of this method. The linear function depends on various system parameters such as O.C voltage and S.C current. The tracking speed reported in the work is quite fast. But for obtaining O.C voltage and S.C current, open or short circuits are required which can lead to power loss or safety concerns. Moreover, this method fails under complex shading pattern.

3. Current sweeping method: In this method maximum power point is tracked using PV output current instead of PV output voltage. Most of the MPPT algorithms adjust the duty ratio of the DC to DC converter which indirectly adjusts the output voltage. However, changing the duty ratio affects both the output voltage and current. By utilizing the dynamics of the DC to DC converter, Tsang and Chan [16] used current sweeping method to develop a good current controller for the DC to DC converter by having a firm control on the output current. Then a prompt current sweeping signal can be sent for the converter making it possible to track the GMPP very quickly. Authors have included simulation & experimental results. The performance reported is satisfactory.

4. Distributed MPPT (DMPPT): The output of every PV module has its own DC to DC converter in this method. These DC to DC converters operate at low power levels since they supply only the equalization current. Thus power losses are significantly reduced [17-18]. For multiple strings in parallel without the loss of their MPPs, this current equalization topology is extended as shunt-series compensation in [19]. Each output of the DC to DC converter is connected in series to form the PV string. These strings are connected at the output of every module. Every DC to DC converter processes the whole power produced by the corresponding modules and then tracks the MPP for that individual module. The total available MPP power of the array is somewhat increased. But as separate DC to DC converter is there for every module, its implementation becomes complex.

5. Electrical PV array Reconfiguration: Works in [20] and

[21] showed that immediate adjustment of the PV array configuration with respect to the pattern in shading can reduce the power losses caused by the partial shading condition. Although reconfiguration method can minimize effects of PSC, it requires use of a switching matrix to effect the changes in architecture. Therefore, the system becomes costly and the complexity of the controller design also increases. Moreover, reconfiguration technique can fail to track GMPP in some shading patterns.

2. Utilizing the features of the characteristic PV curve

1. Direct method: P–V characteristic curve resembles Lipschitz characteristics and hence peak values can be found by dividing rectangle (DIRECT) technique [22]. Here "direct" means to divide the searching area into three different areas with equal intervals and to find potentially optimal intervals using mathematical equations. Its merit is that it has a strong mathematical foundation and has good tracking speed. Its demerit is

that it fails to track the GMPP under some shading pattern, and this method cannot be integrated directly into conventional power generating system. Flowchart of the method is shown in figure 5.

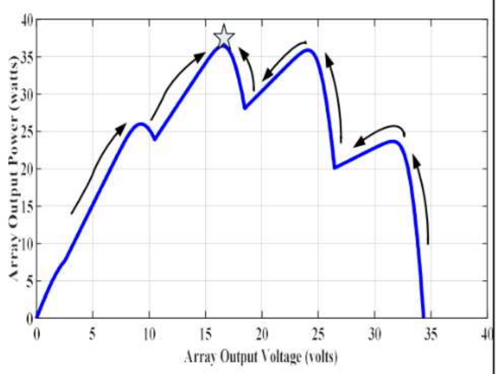

Fig 2. Two stage searching method

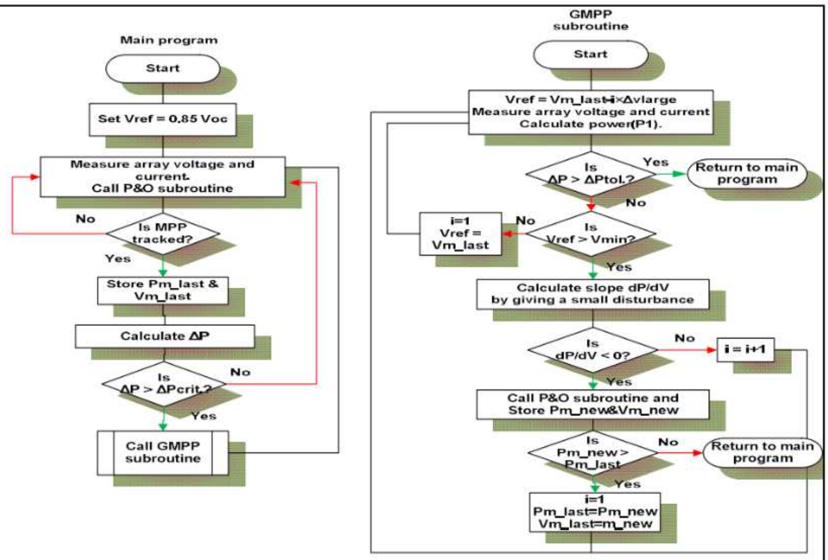

Fig. 3. Flowchart of Two stage searching method

3. Fibonacci methods: Fibonacci sequence which is used as the mathematical basis for segmentation is the main difference between Fibonacci method and DIRECT method. The Fibonacci search method search for a sorted array by using an algorithm of divide and conquer, narrowing down possible locations using Fibonacci numbers. It continuously narrows down the range having the optimal point always within that range. It has strong mathematical foundation and good tracking speed. Its disadvantage is that it fails to track the GMPP under some shading pattern, and it cannot be integrated directly into conventional power generating system. A random number method is used in [23] where power values have been randomly sampled under six well defined voltages, and then the new search range is obtained using that point which has the highest power value. Repeated random sampling was done with new search range for getting convergence.

3. Metaheuristic nature inspired methods

1. Fuzzy Logic Control (FLC): To understand the system to be controlled, traditional control system design uses accurate mathematical models for describing the system. But when the system to be controlled becomes very complex, system identification method cannot establish a system model. However, FLC converts the linguistic values into automatic control action with the help of expert knowledge using the fuzzy set theory. Its advantages are that there is no need of precise mathematical model. It is also suitable for systems which are nonlinear and vary with time. Systems whose complete model is unknown can also be dealt with this method. Therefore PSC (partially shading condition) problems can be dealt with FLC. Karatepe et al. [24] utilized FLC in place of traditional MPPT methods. Since each converter has an MPPT controller, tracking of GMPP is guaranteed.

2. Ant colony optimization: It is one of the evolutionary computation methods and has been widely used in image processing [26], scheduling [27], power electronic circuit design [28] and many other fields. Its main advantage is that it adjusts the command values very fast according to environmental changes. Thus, this technique is suitable to track MPP under varying environmental condition. In this method a random path is selected by each agent at first. If the path chosen is short, the agent drops concentrated pheromone on that path. Then in the next iteration, the path is chosen on the basis of the concentration of pheromone on that path. The probability of the path to be chosen by the agent depends on the concentration of the pheromone. Jiang et al. [29] used this method to develop MPPT control scheme for PV systems under partial shading condition. Single current and voltage sensors were used which simplified the system and reduced its cost. It also provides fast convergence independent of the initial condition. But only the simulation results were provided in [29].

3. Differential Evolution (DE): It is a population based, stochastic evolutionary algorithm [30]. It differs from GA in the context that it relies on mutation process rather than crossover. Mutation operation is used as a search mechanism and selection operation for directing the search towards the prospective regions of the

search space. This method has three advantages (1) locates accurate GMPP without depending on the initial values taken (2) convergence is fast (3) utilizes few control parameters, hence easy to use. [30] and [31] showed simulation results based on DE.

4. Particle swarm optimization (PSO): Among the various Evolutionary Algorithm techniques, PSO has one of the simplest structures that can be used to track MPP under PSC. The main advantage of the method proposed in [32] is the use of direct duty cycle control method by removing PI control loops. The PSO algorithm proposed in [33] took about 1 to 2 seconds to find the GMPP. More importantly, the response time was almost independent of the search space dimensions taken and partial shading pattern.

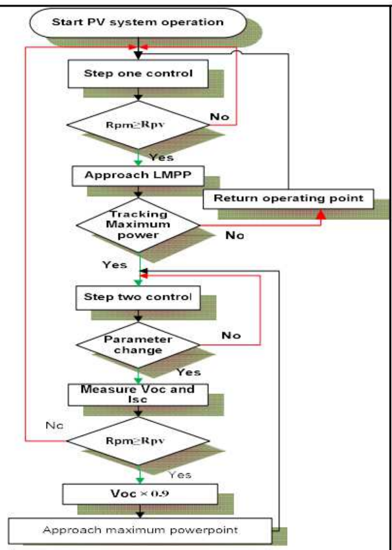

Fig. 4. Flowchart of System characteristic curve method

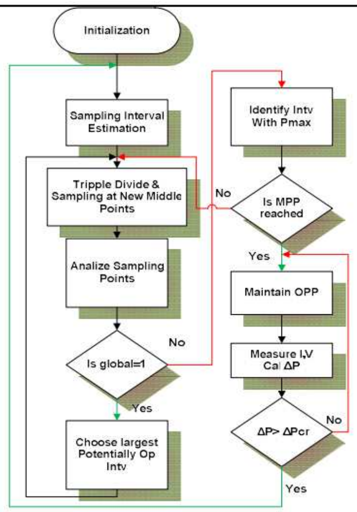

Fig. 5. Flowchart of DIRECT method

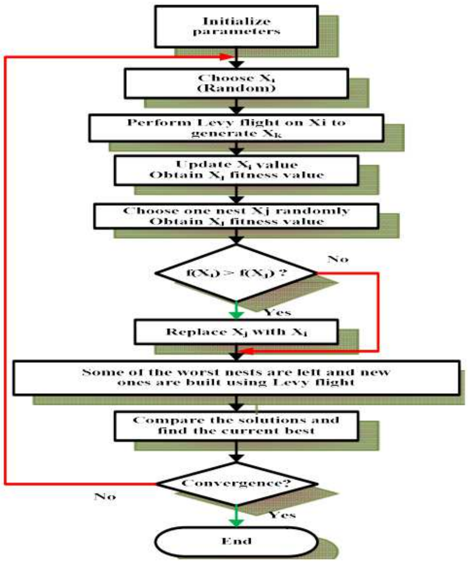

Fig. 6. Flowchart of Cuckoo search algorithm

5. Chaos search (CS) method: It is a stochastic search method which uses chaos theory as its basis. Its search results are much better than those of the search methods which use pure random numbers. In [34] control variables are randomly produced using dual carrier with the help of this method. Then output power is measured using the control variables which is used to find the GMPP. According to [34], dual- carrier Chaos Search can accurately track the GMPP under PSC, the search efficiency is improved, has good precision and system robustness and has a simple control mode.

6. Simulated Annealing method: In [35-36] a simulated annealing-based global MPPT method designed for PSC has been proposed. It is based on following the heating and cooling processes in metals to find the global optimum solution. The energy measured during the heating and cooling process is compared to the ongoing state and if the new operating point has more energy, the new working point is selected as the new one. The algorithm achieves objective but with some increment in computational complexity as compared to the P&O technique and it has also fewer parameters stored in the memory than the PSO technique. Starting value of the algorithm is not an issue for tracking the GMPP.

7. Grey- Wolf optimization: The Grey-Wolf optimization (GWO) method is proposed in [37-38] as an algorithm that overcomes problems such as steady-state oscillations, lower tracking efficiency, which have been seen in P&O and PSO methods. This method detects the shading pattern variations and is faster to converge to the global maximum, and has less steady-state oscillations. This algorithm has some disadvantages also. It has a complex initialization part and there are lots of unknown parameters which have to be determined by the designer himself.

8. Artificial bee colony algorithm: An artificial bee colony (ABC) algorithm for global MPP has been proposed in [39- 40]. The proposed method takes less tracking time for GMPP, compared with PSO and enhanced P&O (EPO). It has fewer control parameters and its convergence doesn't depend on initial conditions. The comparison results indicate that, ABC method is slightly better than PSO and EPO in efficiency, convergence and GMPP time parameters. But the implementation complexity of this method is quite high as compared to the other methods.

9. Cuckoo Search (CS) algorithm: It is an optimization algorithm based on parasitic reproduction strategies of cuckoo birds [41]. Yang and Deb introduced this method in 2009 [42]. Several birds of cuckoo family perform brood parasitism, i.e. Firstly, each cuckoo lays one egg in every iteration, and then a nest is randomly chosen by it to lay its egg in. Secondly, the best nest having the top quality solution will be carried forward to the next generation. Thirdly, there are fixed number of host nests and the probability of alien eggs being discovered by a host bird is pa ∈ [0, 1]. It has several advantages such as higher efficiency, fast convergence and fewer tuning parameters [41]. Among them the most pronouncing is the dependence of PS size on random numbers. Its flowchart is shown in figure 7.

IV. CONCLUSION

Recent work on the topic of GMPPT tracking suggests it to be a popular & hot area of research. In this study various GMPPT methods have been discussed with their merits and demerits from diverse references. Table I sums up the advantages and disadvantages of these methods reported in literature.

Table I

Classification	Methods	Advantages	Disadvantages
Modified conventional MPPT	System characteristic curve method	Good tracking speed	Requirement of open or short circuits can cause power loss or safety concerns, method fails in some cases
	Two stage searching method	Its implementation is easy and it can be integrated into traditional PGS	It can fail to track GMPP in some cases
	Current sweeping method	Fast tracking speed	Requires periodical tracking of the MPP
	Electrical PV array Reconfiguration	Compensate the power losses caused by PSC	Expensive and the controller design is also complex, fail to track GMPP in some shading patterns
	Distributed MPPT (DMPPT)	total available MPP power of the PV array is increased	Implementation complexity is high
Methods based on utilizing the features of the characteristic PV curve	Direct method	Based on a strong mathematical foundation and good tracking speed	Cannot be directly integrated into conventional PGS
	Fibonacci methods	Based on a strong mathematical foundation	Fail to track GMPP in some cases and cannot be directly integrated into conventional PGS
Metaheuristic nature inspired methods	Fuzzy logic control	No need of precise mathematical model, it is very suitable for use in non-linear, time-varying and systems without complete models	high hardware cost
	Genetic Algorithm	Can optimize parameters of other algorithms such as FLC	Its implementation is complex and difficult to achieve using low cost microcontroller
	Ant colony optimization	Fast convergence and convergence independent of the initial condition	Implementation is difficult
	Differential Evolution	Fast convergence and convergence independent of the initial condition, easy to use	Some parameters may not guarantee optimal solution
	Particle swarm optimization	Simpler structure than other EA techniques	Optimization performance depends on parameter selection

	Chaos search method	Improved search efficiency, precision, and system robustness	High complexity
	Simulated annealing	Requires fewer parameters to be stored, independent of initial condition	Slight more complex
	Grey- Wolf optimization	Less oscillations, high efficiency, high speed	complex initialization part, more unknown parameters
	Artificial bee colony (ABC) algorithm	Less tracking time, fewer control parameters, independent of initial condition	Implementation complexity is high
	Cuckoo search	Fast convergence, high efficiency, fewer tuning parameters	Unknown parameters

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