An Improved Partial Shading Detection and Smooth Maximum Power Point Tracking of PV Arrays under PSC

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Abstract
An enhanced examination of maximum power point tracking (MPPT) amidst incremental conductance (IC) of sunlight hinged photovoltaic cluster under incomplete shaded condition is suggested here. Suggested framework is basic and savvy. Under PSC, P-V normal for PV exhibits will have different pinnacle focuses; just one is worldwide most extreme. This paper suggests an IC technique is employed; it is employed to track MPPT purpose of PV source. MPPT can limit framework cost and boost exhibit productivity. Regular MPPT techniques do not separate greatest power in this condition. This paper suggests novel two-arrange MPPT strategy is displayed to defeat this disadvantage. In primary stage, a technique is suggested to decide event of PSC, and in second stage, using a new algorithm that is hinged on ramp change of duty cycle and continuous sampling from P-V characteristic of array, global MPPT of array is reached. Open circle operation of suggested technique makes its execution shabby and straightforward. IC calculation was intended to supervise obligation cycle of Buck Boost converter and to guarantee MPPT work at its maximum proficiency. By utilizing replication comes about we can dissect suggested strategy.

Keywords: PSC; IC; MPPT; PV.
INTRODUCTION
There has been increasing interest in photovoltaic (PV) systems as a renewable energy source in recent years. PV systems can be operated as grid-connected or stand-alone structures. The main element of a PV system is PV array that is a set of PV modules connected in series and parallel. In a PV array, voltage and current have a nonlinear relation, and only in one operating voltage, maximum power is generated. Therefore, extracting maximum power from a PV system in all operation conditions is the main target of its control.

To date, numerous maximum power point tracking (MPPT) techniques have been presented and implemented. Some of the conventional and most popular ones are perturb and observe (P&O), incremental conductance (IC), and short circuit current and open circuit voltage. Some techniques are also presented based on artificial intelligence, such as fuzzy logic and neural network, but have more computation load [1].

A condition in which the entire modules of an array do not receive the same solar irradiance is called partial shading condition (PSC). PSCs are inevitable especially in solar systems installed in urban areas and in areas where low moving clouds are common [2]. If the control system cannot detect and react to this situation, the PV system will be diverted from the optimal operation mode. In PSC, because of bypass diodes in parallel with each module, P-V characteristic of the array has multiple peak points [3]. Conventional MPPT techniques are unable to identify the global maximum power point (GMPP) in PSC, and usually track local peaks. Therefore, developing new MPPT techniques for dealing with PSC is necessary.

The method proposed in [14] has good performance, but it is required to measure the voltage of each module. The method proposed in [15] is based on IC and sampling the P-V characteristic of the array in distances of. It limits the search area for GMPP as in [11], and yields suitable results; but needs high sampling number. Reference [12] proposes two methods: the first approach samples the P-V curve and limits the search area based on short circuit current of the modules and the highest local power. As it is mentioned in [12], this method has high accuracy with low speed. Therefore, a second approach is proposed that estimates the local MPP power by measuring the currents of bypass diodes of the modules. Although the speed of tracking is improved, its implementation cost is high.
Studying MPPT as an optimization problem resulted in using evolutionary optimization methods such as particle swarm, simulated annealing and colony of flashing fireflies to find the GMPP [16-21]. In these methods, GMPP is obtained by sampling different points of the array P-V characteristic. These methods are mostly successful, but their sampling number is high. Since the GMPP can occur in a wide range of the P-V characteristic, initial sampling must cover the entire curve. Boost converters experience some transients to settle the voltage of the PV array [22, 23]. Then, as the sampling number increases, the speed of MPPT decreases. In [16, 19], a typical version of PSO algorithm is used that has low speed. In [18] the PSO method is modified to improve its speed and complexity.

A method based on firefly algorithm is proposed in [20] that has better speed and efficiency in comparison to PSO-based algorithms. The proposed method in [21] uses the simulated annealing algorithm for MPPT under PSC. It is clear from the presented results that the samplings number is high and speed of GMPPT is even lower than the PSO-based method, while its accuracy is higher.

**PROPOSED ALGORITHM FOR MPPT UNDER PSC**

Heuristic algorithm-based methods such as PSO, as well as most of other methods for MPPT in PSC, need to sample the P-V characteristic of the array in different voltages of the search area. Noting to the settling time of boost converter to step commands, these methods have low speed in GMPPT. MPPT is a time varying optimization problem, in which the objective function evaluation is done physically; i.e. by applying specific voltages to the array, its output power is measured after settling its voltage, whereas in the numerical optimization problems, function evaluation is done numerically and imposes calculation burden on the processor.

As mentioned in Sec. III, sampling time period for MPPT must be greater than the settling time of the boost converter. This settling time depends on the design and operating point of PV array. Maximum settling time of the boost converter used in experiment and simulations of this paper is about 20ms.
Fig.1 Flow chart of the proposed algorithms for MPP tracking under PSC
According to Sec. II, under PSC, the GMPP is in the following voltage region that must be searched for GMPPT:

\[ V_{(mpp-mod)} < V < V_{(oc-arr)} \] \hspace{1cm} (1)

A straight solution for GMPPT with minimum steps is that sampling from P-V characteristic of the array be done only in specific points [13]. In practice, these methods rely on approximations and cannot guarantee the GMPPT.

When sampling from the array power is done in and, respectively; indeed the array voltage experiences all voltages between and continuously. This is due to the fact that the voltage of the parallel capacitor with the array cannot change steeply.

According to the above discussion, two important facts inspire using ramp voltage as the command signal of converter to search the voltage region for GMPPT:

1. In contrast to the response of the boost converter to step commands, settling time and transient of the boost converter to ramp command is nearly zero

2. PV arrays do not have considerable dynamics and can be assumed static.

Unlike dynamic systems, then, the measured power at each moment is related to the array voltage at the same moment, corresponding to a point on the P-V characteristic of the array.

SIMULATION AND EXPERIMENTAL RESULTS

In this section, performance of the proposed method for GMPPT in PSC is evaluated in various aspects using simulations and experiments.

SIMULATION RESULTS

The proposed method is compared with the PSO-based algorithm with 3 primary particles presented in [19] using simulation in MATLAB/SIMULINK software. It is also compared with the method of [11], which is one of the best intelligent MPPT methods that is referenced very often. The simulated system configuration was described here.

All parts of the presented system in Fig. 3 are considered in the simulations. For the sake of brevity, control of grid-connected inverter is not described here. In this study, the array is initially under uniform radiance, and then it passes to the PSC patterns.
Simulation results are presented in Error! Reference source not found. (a-d), and the efficiency of the proposed MPPT algorithm is compared with the PSO-based method in [19] and the proposed method in [11]. In the simulation of the proposed method, analog to digital conversion time of processor in measuring the voltage and current of the array is considered 0.5ms, which is achievable by a low-speed microcontroller. Also, the voltage ramp for searching the GMPP is set to 4000 V/s. The proposed algorithm tracks the GMPP in all cases rapidly in lower than 70ms. Because of the lower speed of two other
methods, the time interval between PSC pattern changes is increased to 2s for them. Changing the array voltage with ramp, not only increases the speed of tracking and reduces its transients and stress on the converter, but also has extra benefits in terms of interaction with the connected grid. In the grid-connected PV system (Fig. 3), the inverter must deliver all generated PV power to the grid rapidly for regulating the voltage of the output capacitor of boost converter. Therefore, changing the array power leads to changing the injected power to the grid, and it yields voltage transients at the point of grid connection (in Fig. 3). Step changes in the array voltage, and consequently, the array power impose greater voltage transients, while changing the array voltage with ramp yields lower transients and much better power quality. PCC voltage waveforms with different MPPT algorithms are compared in Error! Reference source not found. (e) and (f). High transient voltage caused by the two other algorithms is harmful for the system, especially in micro-grid applications. Efficiency of the methods such as the one presented in [11]

![Fig. 4PV Output MPPT process with the proposed Method](image)
Fig. 5 Vin MPPT process with the proposed Method.

Fig. 6V Output MPPT process with the proposed Method.

Table 1 Comparisons of three MPPT methods.

| Criteria                        | The new proposed method | PSO base method in [19] | Proposed method in [11] |
|---------------------------------|-------------------------|-------------------------|-------------------------|
| Speed of tracking               | 40 ms (increaseable)    | About 500 ms            | More than 500 ms        |
| Transients and stress on converter | Low                     | High                    | Medium                  |
| Imposed transient voltages on the grid | Low                     | High                    | Medium                  |
Since sampling from the array P-V characteristic in these methods are done with specific intervals (e.g.) which depend on the model of modules, non-identical modules in the array affect their efficiency. In contrast, the proposed MPPT algorithm is completely independent from the modules make and model. In Table I, features of the three afore-mentioned methods are compared with each other in different aspects.

### CONCLUSION

In this paper, firstly a partial shading condition detection algorithm is presented and its performance is studied in different situations. The proposed algorithm determines whether the system operates at uniform irradiance or not. A novel simple and fast algorithm is then presented for MPPT under PSC that operates as direct control method and needs no feedback control of current and voltage. The algorithm is based on ramp change of PV array voltage and simultaneous sampling of its voltage and current continuously. Simulation and experimental results validate the performance of the proposed method in speed and accuracy. The proposed GMPPT method has the following benefits: 1- It is simple and can be implemented with a cheap microcontroller like AVR; 2- It has a high adjustable speed; 3- Because of the smooth change of power in comparison with other methods, it has minimum negative impact on the connected power system; and 4- Its efficiency is guaranteed and is not dependent to the model of modules.

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