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Global MPPT Control Algorithms for Solar PV Systems under Non-uniform Solar Radiation

Ramalingam Senthil

Abstract: Maximum power point tracking (MPPT) of solar PV systems is vital under the variable solar radiation and panel as well as ambient temperatures. Various control algorithms are used in the standalone and grid-connected solar photovoltaic systems. Several MPPT controls have been investigated with sensors and sensor-less approaches. Tracking accuracy under shading conditions is essential to provide the constant power output of solar PV systems. Such controls should be economical for standalone and grid-connected PV systems. Recent advances in the control algorithms and methodologies for global MPPT and the future scope of such controls are discussed here.

***Index Terms*: Control algorithms, MPPT, Solar photovoltaics, partial shading, tracking accuracy.**

I. INTRODUCTION

Solar photovoltaics (PV) are deployed for domestic and industrial applications. Environmental concern is minimal regarding the operation of solar PV systems. Hence, solar PV is the recently discussed much by the power generation community due to the renewable and sustainable nature. Solar energy power generation is the easiest installation with a shorter installation periods among all the power plants. There is a good scalability of PV plant. Further, PV plant requires almost zero water requirement compared to thermal power plants for the plant operation. The solar radiation is the main input to the PV and PV plant produces maximum power during the sunny days. However, the variable solar irradiance and environmental conditions affect the electrical power output of PV panels. Power output of PV systems are greatly affected by the variable solar radiation intensity and the climate conditions like ambient temperature, moisture and wind speed at the site. Degradation of the actual performance of PV is expedited through the adverse ambient conditions like the snow, dust and arid climates etc. The factors affecting the power output of a PV system are the solar radiation, moisture level in the air, air velocity, dust level, panel and ambient temperature. Further to solar irradiance, the panel temperature at the hot climate leads to the internal short circuit for electrical connections due to localized heating of the solar PV panels. The wind velocity is also an important parameter which removes the heat of the PV panels and maintains the thermal control mainly during the noon time. The dust cleaning is vital in the regions where the wind velocity is higher and the poor soil conditions. The significant effects of non-uniform radiation and weather conditions are present in solar PV systems. Therefore, the power outputs are greatly fluctuating, and it leads to the instability of power supply to the battery or grid-connected systems. Thus, the drawbacks lead to non-linearity issues in the MPPT as well as in all the balance of systems. The power quality degrades, and the performance and productive life of the electrical components are also becoming issues. Optical and thermal management of outdoor PV systems lead to the better performance. Figure 1 shows the MPPT control in solar PV systems with pulse width modulator (PWM) and DC-DC converters.

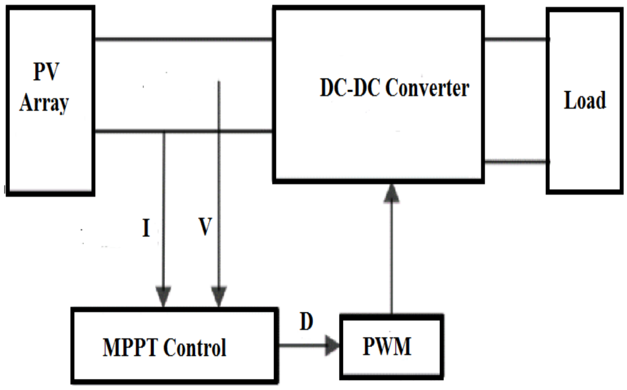

Fig. 1. Solar PV system with MPPT control

Controls are required to smoothen the operation and power of PV systems under undesirable environmental conditions like passing clouds, shades from trees and tall buildings and from the neighbor panels. This article reviews the various control techniques used in the global MPPT and the future scope is also reported.

Figure 2 shows the single peak MPPT in the Power-Voltage characteristics due to the uniform solar radiation on PV arrays. Figure 3 shows the multiple peaks in the Power-Voltage characteristics due to the non-uniform solar radiation like the partial shading of PV panels. Th smooth power curve was obtained under uniform solar radiation and disturbed power curve with multiple peak power was observed with the non-uniform solar radiations due to partial or complete shading.

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***** Correspondence Author
R. Senthil*, Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur, Chennai, India.

II. CONTROLS FOR PARTIAL SHADING

The partial shading of solar PV array leads to the lower overall efficiency and more power loss from the panels. In this section, the literature is focused on the techniques for minimizing the effect of partial shading over the PV arrays.

Belhaouas et al. [1] investigated the effect of shifted PV array arrangement to avoid the multiple peaks in Power-Voltage (P-V) characteristics over the series-parallel (SP) configuration. The array spacing optimized as per the partial shading and its patterns and improved the electrical power output significantly over the other two configurations as from 19 to 140% compared to SP. Thus, the complicated control algorithms eliminated in a cost-effective way.

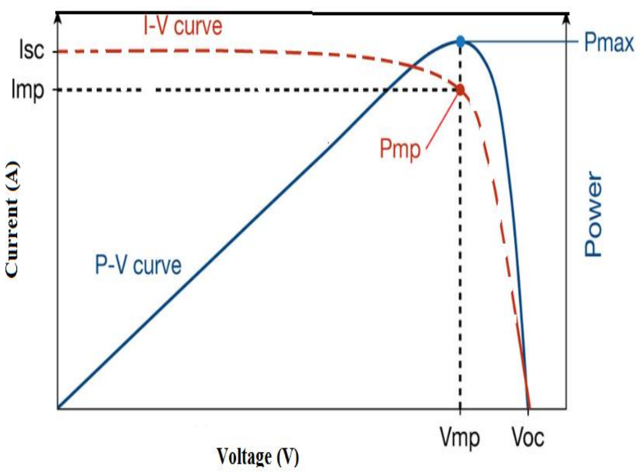

Fig. 2. MPPT in Power-Voltage and Current-Voltage characteristics of a PV array under uniform solar radiation.

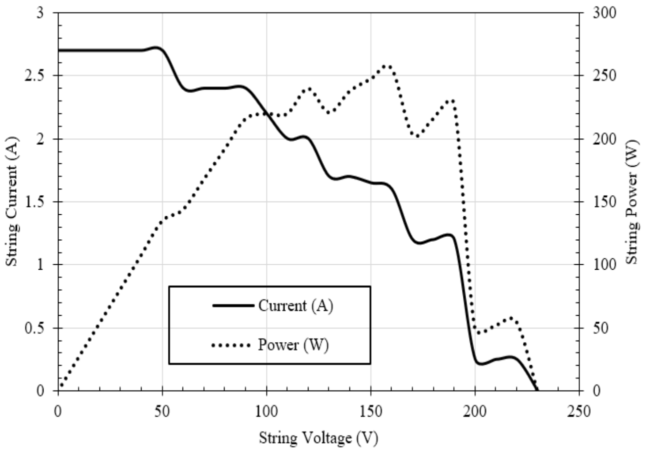

Fig. 3. Effect of partial shading over PV array and the corresponding multiple peak power characteristics under non-uniform solar radiation conditions.

Chaieb and Sakly [2] developed an efficient MPPT control algorithms to reduce the hardware and software requirements by combining the accelerated Particle Swarm Optimization (PSO) and Hill Climbing (HC) algorithm. The proposed technique was validated to avoid multiple peaks in P-V curve and global MPPT during the partial shading.

A golden search algorithm was investigated by Ahmed et al. [3] for tracking of global MPP. Fast changing solar radiation and temperature results in sub-optimal operation with more power loss. This algorithm is used to identify the local peaks and selects the global peak of P-V curve. The proposed algorithm was implemented in a loop using a microcontroller and a DC-DC boost converter. This converter is illustrated in Fig. 4.

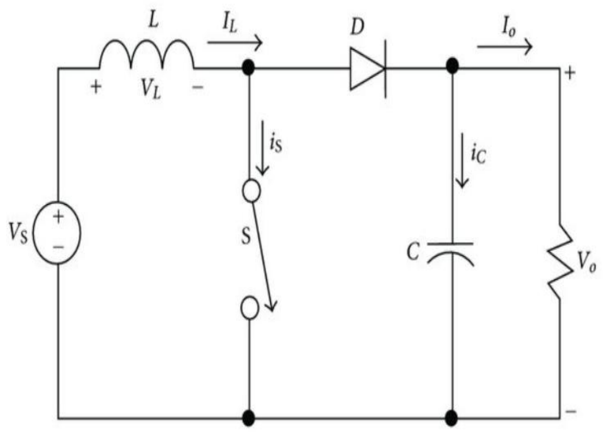

Fig. 4. DC-DC Boost Conerter

Ramyar [4] proposed a MPPT method for PV systems under both partial shading conditions (PSCs) and uniform conditions using Hill Climbing method. The proposed method tracked all local maximum power points to make the global peak and evaluated through simulations.

Panda et al. [5] proposed a modified particle swam optimization (PSO) algorithm for MPP from the multilevel inverter PV systems for varying environmental conditions. multi-level inverter (MLI) are selected over conventional two-level inverters for power quality improvement and reduction of the filter size.

Table 1. Accuracy level of MPPT controls.

Control algorithm	Tracking accuracy (%)	Investigators
Current-starved voltage-controlled oscillator	99%	Mondal and Paily [6]
Reference voltage perturbation	99.4%	Aniruddha et al. [7]
Incremental conductance cascade control	80-99%	Lekshmi and Umamaheswari [8]
Perturb and Observe and Fuzzy logic (FL)	99.6%	Al-Mazidi et al. [9]
Artificial Bee Colony (ABC) algorithm	99.5%	Pilakkat and Kanthalakshmi [10]

Tracking accuracy of the MPPT using various control algorithms is significantly efficient through the majority of MPPT control algorithms. The accuracy is around 99% [6-10].

Table 1 indicates the tracking accuracy of MPPT in the range between 99 and 99.6%. Artificial bee colony and fuzzy logic with Perturb and Observe (P&O) are the most efficient control algorithms when compared to the other methods. The useful life and economics of the control systems are considered during the selection of several methods which are almost equally efficient systems. Sellami et al. [11] proposed a stepped MPPT through a scanning algorithm to track the real MPPT and then switched to P&O algorithm to follow the GMPP.

III. SENSORLESS CONTROLS

The need of MPPT in PV is due to the variations in solar irradiance and local weather, the temperature and humidity. MPPT is used to ensure the harvest ing of the maximum power. The robust sensors are used in MPPT of solar PV systems. Such sensor-based controls are costlier when compared to the sensorless techniques to provide MPPT in solar PV arrays.

Voltage and current sensors are normally required to track the power of a PV system to produce optimum power. Fathabadi [12] proposed a novel online sensorless sun tracker through MPPT. The operation is a dual-axis mode. Sun tracker is a closed-loop system which tracks the sun direction. Very low tracking error of 0.11° was obtained with an increase of captured energy by 28.8%-43.6% depending on the seasons.

Metry et al. [13] used a model-based predictive control principle without the current sensor. This technique operates without the expensive sensing instruments and the required networks for solar irradiation changes. The adopted test standard is EN 50530 for unsteady operations.

A power reserve control on a 3-kW two-stage single-phase grid-connected PV system was tested by Sangwongwanich et al.]14]. A MPPT control is employed to estimate the available PV power. The cost of control was reduced considerably due to the sensorless approach. Das et al. [15] reduced the overall cost of the system through Luenberger observer technique without any current sensor.

Kermadi and Berkouk [16] compared the performance and the implementation cost of the developed MPPT controllers. The parameters studied are tracking speed, the average tracking error, the variance and the efficiency. The estimation of the implementation cost determined based on the type of the used sensors, circuitry and the software complexity. The tested PV systems contains a PV module, a DC-DC Buck-Boost converter and a DC load.

Zurbriggen and Ordonez [17] investigated a direct duty cycle control MPPT algorithms. Merits of this control are the simplicity, straightforward with a high tracking efficiency due to the elimination of a converter to achieve steady state in between MPPT updates. The natural oscillations occurring in the converter to obtain extreme dynamic tracking improvements without temperature or irradiance sensors. MPPT with a large-signal geometric control is a reliable. Further, it provides a high-performance solution for the rapidly changing irradiance. Figure 5 indicates the P & O algorithms for MPPT. The power output from the panels is calculated from the measured values of current and voltage sensors.

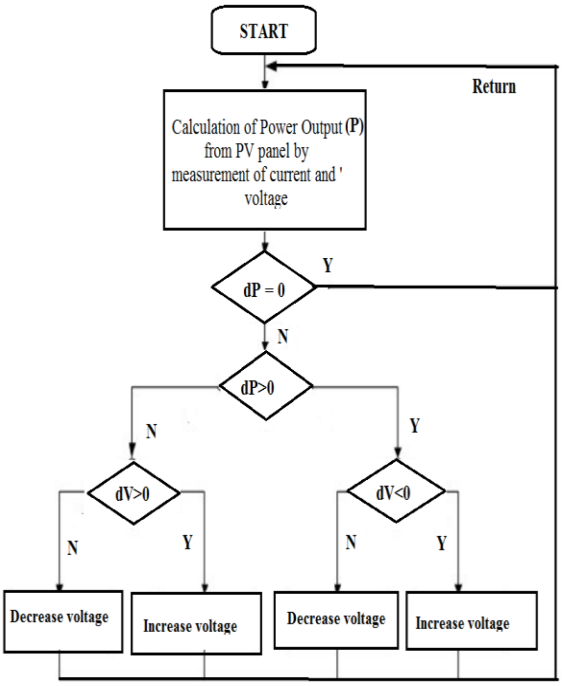

Fig. 5. Flowchart of P&O algorithm

Sreenivasa Reddy et al. [18] implemented the P&O method with the boost converter system for the better tracking capability under the uniform and non-uniform irradiation conditions. Barkavi et al.]19] investigated on incremental conductance algorithm for MPPT in PV systems to augment output power irrespective of temperature, solar irradiation and load characteristics.

Kermadi et al. [20] investigated a string of twelve series-connected modules. The string feeds a variable DC load through a buck-boost converter for the continuous operation. Figure 6 indicates the PV system used for simulation. The proportional-integral (PI) voltage controller is embedded in the control loop to match the voltage perturbation computed by the MPPT algorithm by enhance the tracking GMPP performance under complex shading conditions. For grid-connected PV, the simplicity of implementation and fast response are there for P&O algorithm with Boost converter.

This method was examined against four well-established MPPT controllers in the literature, namely the modified incremental conductance, the search skip judge, the hybrid PSO and the modified cuckoo search.

There are significant improvements in speed and accuracy to track the true GMPP regardless of the shading complexity. The simple electrical circuits, convergence speed, sensor costs, easy operation and maintenance are the major points to be considered in the selection of methods to manage the non-uniform radiation and other climatic conditions.

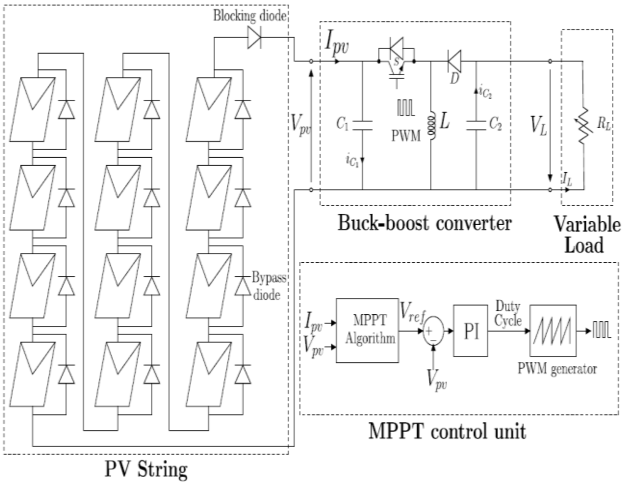

Fig. 6. PV system structure used for simulation [20].

MPPT control algorithms used for the normal solar radiations is not producing the maximum under the partial shading conditions. Hence, a proper MPPT control algorithm is useful to work under non-uniform solar radiation conditions.

IV. CONCLUSION

Partial shading is one of the major causes for the power loss in the solar PV systems. Standalone and grid connected PV systems with proper MPPT systems are capable of the maximum power from the incident solar energy. The most effective MPPT control algorithms for solar PV systems are artificial bee colony and fuzzy logic with Perturb and Observe. Rapid convergence is an essential factor in the MPPT control algorithms.

Sensorless control techniques are not only cost-effective but also reduces the internal complexity of the PV systems. Most of the researchers are used MATLAB/SIMULINK tool to analyze the overall PV systems. DC-DC converter is mainly used to improve the voltage profile and MPPT algorithms are used to harvest maximum power from PV arrays. For large-scale installations, the sensorless approach is one of the most rewarding options.

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AUTHORS PROFILE

R. Senthil obtained his B.E. (Mechanical Enginnering) and M.E. (Energy Engineering) from the University of Madras (1997) and Anna University (2000) respectively. He received Ph.D. (Solar Energy) from SRM Institute of Science and Technology (SRMIST), Chennai (2017). He has two decades of experience in teaching and research. He is working as Associate Professor at SRMIST, Chennai since 2005. Major research area is solar energy conversion and storage. He is a member of ASME, ISES, SESI and ISTE. He published more than 45 articles in the indexed journals. He received teaching and scientific excellence awards in 2018 from Marina Labs, Chennai. He is the reviewer in reputed journals like ASME Journal of Solar Energy, Solar Energy, Energy Efficiency, Thermal Science etc.