Analysis and Implementation of Improved MPPT for Partial Shading Condition

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***Abstract* - The Power Converter with MPPT controller is a heart of any solar PV system. The basic MPPT controller is capable to learn non-linear I-V characteristic of PV system and search an optimal point where power output is maximum, known as Maximum Power Point. In case of Partial shading, I-V curve is highly non-linear with multiple power points and simple MPPT is not capable to trace out MPP point. The various improved MPPT methods are developed for tracking MPP under partial shading condition. In this paper, improved MPPT method is discussed and implemented. The simulation-based analysis is carried out for performance analysis.**

***Index Terms* - Solar Photovoltaic System, Maximum Power Point, Maximum Power Point Tracker, Partial Shading, Solar Controller.**

I.INTRODUCTION

The utilization of renewable energy source in total power generation is increased significantly due to latest technology development and concern to save conventional energy source. The various development agencies and governments come actively to utilize more and more renewable energy. The Solar, Wind, Hydro and Tidal are the some of the well-established renewable energy source. The solar photovoltaic system is one of the best promising fields and widely adapted by many nations due to develop technology and reduced material cost [1].

The solar energy is a main source of energy for the planet earth and all other form of energy is depended upon this basic source of energy. It is inexhaustible and readily available. The countries near the equator receive abundant amount of solar energy with plenty number of clear shiny day. In these places, the solar plant based upon thermal, and PV is a good option to generate electrical energy. Further, Solar Photovoltaic Grid System is preferred all over the world due to less complicated system and highly reduced installation cost.

The main research for system efficiency improvement is still going on and it is in very advance stage of development. At present, the photovoltaic panel conversion efficiency is in the range of 11-28% [2]. This achieved efficiency is further reduced due to panel degradation and highly unexpected environment conditions. In this direction, it is very essential to use high efficiency power electronic circuit with MPPT capability for maximum possible energy extraction.

The efficiency of simple MPPT is highly compromised if the radiation at different PV panels is not equal. The partial shading is a most appropriate term for this condition and the I-V curve of Solar PV panels is unexpected with multiple local MPP. The simple MPPTs are not able to find out the global maximum power point [3]. The various improved MPPT algorithms are suggested in literature [5-6]. These improved MPPTs are able to track global MPP and it further increase the system efficiency. In this paper, review of various improved MPPTs is presented in more elaborative way.

The MPPT technique analysis under shading situations is performed and presented in better way. This paperwork can be used as guidelines for researcher and practitioners working in the field of solar MPPT.

This paper is structured in five sections. The brief detail of PV model and MPPT concept are presented in section 2. The improved MPPT is descripted in section 3. The section 4 descripts mathematical analysis of improved MPPT simulation. The brief concluding remarks are mentioned in conclusions section.

II. SOLAR PV SYSTEM AND MPPT CONCEPT

The Photovoltaic system is a concept to directly convert solar radiation energy into electricity by using a semiconductor panel. This panel is working upon a principle of photovoltaic effect. One PV panel is a connected group of many PV cells which is a basic unit of PV system. It is a P-N semiconductor which works to utilize radiation energy for movement of holes and electron and it is a cause of ultimate voltage generation at terminal. This phenomenon is known as photovoltaic and if it is connected across some passive load than generated charge start flowing in a circuit [1]. The typical current and voltage rating of PV cell is very low and it is connected in series and parallel fashion for increase of voltage and current respectively. In mathematical term, it is a radiation control current source with parallel diode and loss resistance. A mathematical model which is highly recommended by research scholar and developer is shown in Fig. 1. A generalize mathematical equation is derived from a single diode model and given below by (1)

$$I = I_{PV} - I_o\left(\exp\left(\frac{q(V + R_s I)}{aN_s kT}\right) - 1\right) - \frac{V + R_s I}{R_{ph}} \dots\dots\dots (1)$$

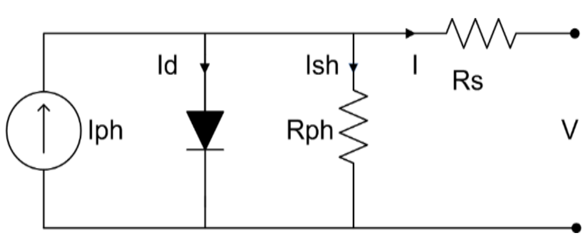

Fig-1 A single diode mathematical model of solar PV panel

where I_{PV} = photovoltaic current, Io = diode saturation current, q = electron charge, T = absolute temperature, k = Boltzmann constant (1.38*10-23 J/K), a = diode ideality factor, Rph = shunt resistance and, Rs = series resistance.

The open circuit voltage, short circuit current, I-V curve, Fill Factor and optimal power point are the important technical parameters for any PV panel. The open circuit voltage is a voltage across the panel terminal when no load is connected. Similarly short circuit current is maximum current drawn by PV panel when both terminals are directly shorted. The I-V curve of PV panel is non-linear and point of actual operation is totally unknown and depends upon the external load [6]. It is observed after analysis that power output from panel is totally depends upon the point of actual operation and there is only one point where power is maximum and known Maximum Power Point. The I-V curve of PV panel is shown in Fig. 2 for better visualization of actual concept. So, it is very clear that maximum power output from PV panel is depends upon actual solar radiation, internal system losses and load point selection. The solar radiation and internal system losses are not controllable and there is only one option to optimize PV panel output by selecting a suitable output load.

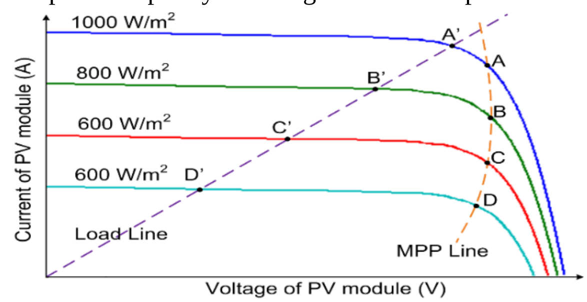

Fig-2 I-V curve of PV panel with MPP demonstration

As shown in Fig. 2, the I-V curve is non-linear. If the fixed load is connected to PV panel then system try to work at A', B', C' and D' and this is not an optimal power points. The optimal power point is shown by A, B, C and D point. The manual load adjustment is not a practical option. For this purpose, DC-DC / DC-AC switch mode converter is used which has an option to regulate input terminal voltage by changing a pulse signal modulation. This converter is controlled by Maximum Power Point Tracker controller which perturbs the location of operation by continuously monitoring of I & V. The P&O, INC, Fuzzy logic MPPT are some of the basic MPPT techniques. But above basic controller is not good enough for partial shading case where different panel receive different amount of radiation.

The partial shading condition is arises due to many factor like nearby obstruction (i.e. building, tower, trees etc.), environment condition, faulty panel and dust etc. In this condition, I-V curve is not as simple as shown in Fig. 2. The new I-V curve due to partial shading has a multiple local optimal point (local maximum power point). For this condition, he maximum current in a string is decided by minimum current generating panel [7]. The mismatch loss is increased under partial shading and it has a capability to damage panel permanently. The bypass diode across the PV panel is used to save internal cell of panel. For study and further exploration of improved MPPT for partial shading condition, 10 x 5 PV array with defined partial shading pattern is shown in Fig. 4. Similarly, The I-V and P-V curve for this shading pattern is displayed in Fig. 5. The Fig. 5 is self-explanatory where I-V curve has a multiple MPP point and simple MPPT is struck at any of the local MPP point without any consideration. So, it is very essential to do further modification in controller to track real MPPT point.

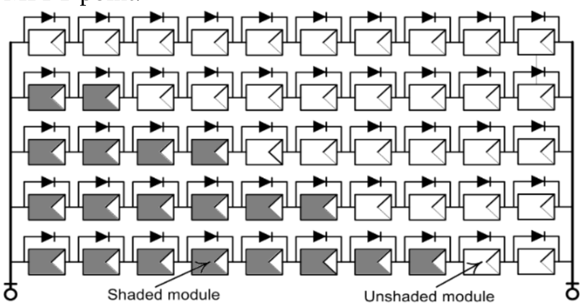

Fig-3 10 x 5 PV array with partial shading pattern for testing

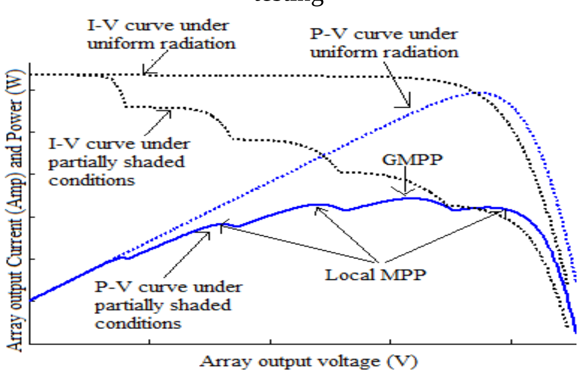

Fig-4 I-V and P-V curve for solar PV array under partial shading condition.

III. IMPROPED MPPT ALGORITHM

The various research for MPPT controller design improvement is already in picture. The various research were performed to reduce tracking time, reduce oscillation and simplified control strategies. These studies are a basic step to develop an improved MPPT with partial shading tracking capability. Generally improved MPPT is a concept where one or two techniques clubbed in one place with slight modification in algorithm.

Some of the improved MPPT techniques are identified in literature. A power curve scanning technique is one of the effective methods mentioned in [8-9]. In this technique, the whole I-V curve is scanned and then GMPPT is identified. After detecting actual MPPT point, simple P&O MPPT starts it work to operate system at that point. The scanning is performed at regular interval and the chance of actual MPP point is very rare. The huge fluctuation in output power during scanning is a major drawback of this simple technique. A load line matching MPPT method is another smart way to identify global MPP point. It is observed that universal MPP point is near to load line point and in this way it can be identify easily. But for some of the partial shading pattern, it can be able to identify nearby vicinity and gives wrong result. Apart from this, Fibonacci search technique, Partial Swarm Optimization technique, Distributed MPPT and Structure Reconfiguration method are some of the tested and active research area for development of sophisticated and improved MPPT.

In this paper, a modified curve scanning method is explored for better result and refined output. In this method, curve is scanned at fixed interval and slope of (dP/dV) is also measured at that point. If the curve is scan from high voltage end to low voltage end than change in slope sign can give a clue of local MPP (if slope sign is change from negative to positive than there is a local MPP in between two scan point). As the scanning is limited to fixed number of point, the scan time is reduced considerably. As this method involve power slope analysis, it is also known as power slope detection method. The Fig. 5 demonstrates the concept of slope detection method and self-explanatory.

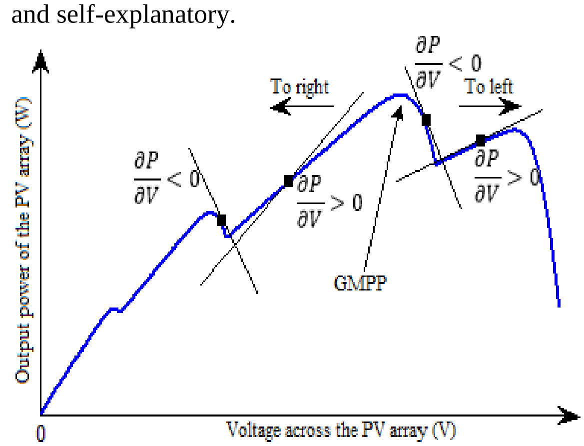

Fig-5 Change in slope (dP/dV) sign at local MPP point

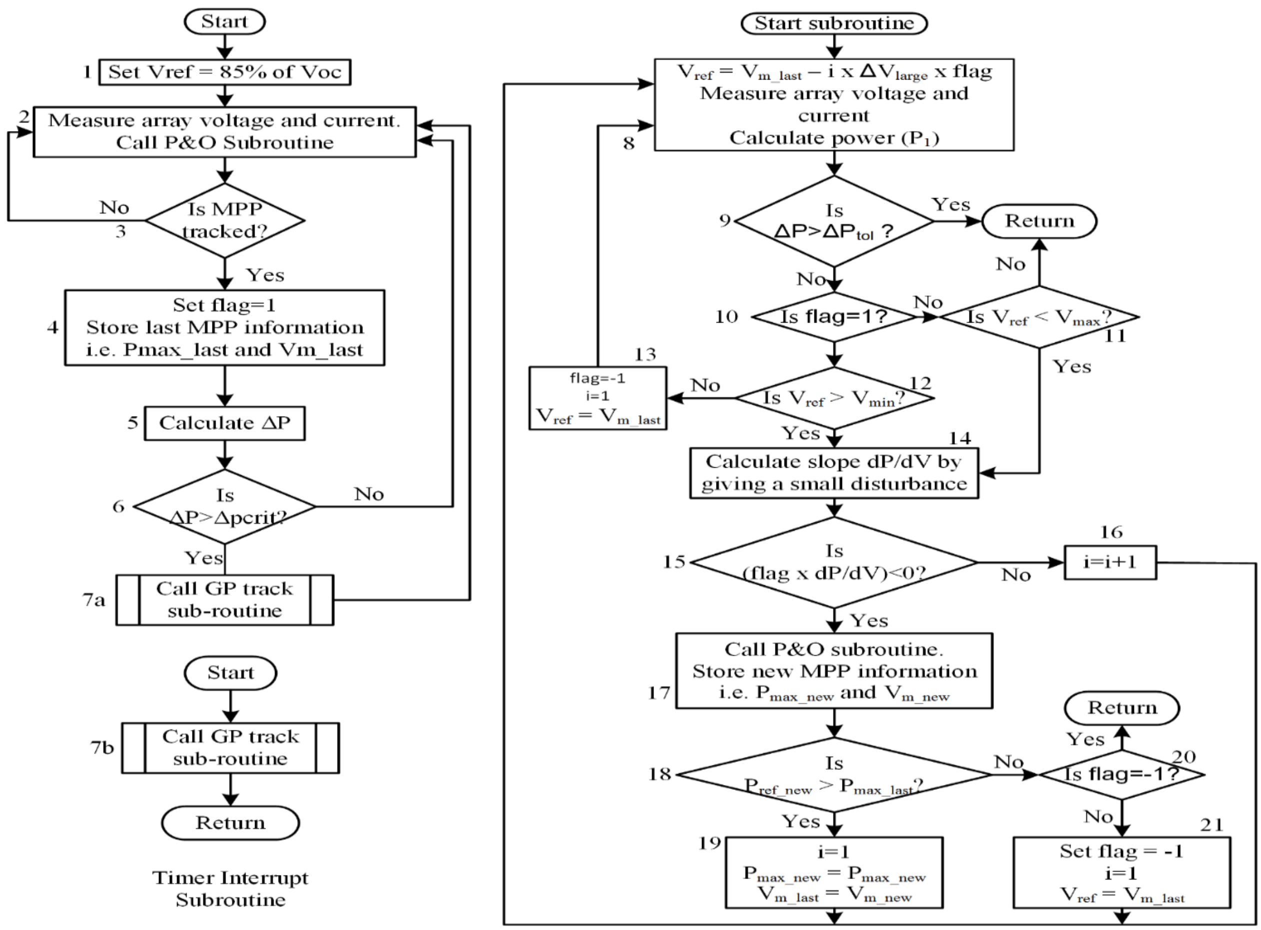

Fig-6 Power Slope Scanning technique algorithm for MPP tracking

In this method, any of the simple MPPT like P&O is used to track local MPP point. After fixed interval time, a global tracking cycle starts with curve scanning. First, left side of LMPP is scanned using slope (dP/dV) sign. If next local MPP power output is less than previous MPP then scanning is terminated at that direction (Left side scanning), otherwise MPP point is updated. After completing left side scanning, right side scanning is also performed for checking any local MPP point. After completing the scanning, the global MPP is detected and system is activated with new MPP point. In this case, scan length is reduced and at the same time, time of scanning is also reduced due to limited point scanning. The interrupt timer setting ans step size of scan are the important parameter of this improved MPPT technique and the accuracy is depends upon above parameters. The algorithm for power slope scanning technique is shown in Fig. 6. As all of the MPP is recide below a reference voltage (Vref) value which is equal to 85% of Voc (block 1). The main block contains P&O technique for monitoring and updating MPP (block 2 to 6). When any disturbance in power output occur or timer interrupt then main program is able to sense the condition and call sub loop (power slope algorithm) for correction in MPP point (block 7a). The subroutine can be called periodically by little modification in algorithm. It is also possible to initiate user interrupted subroutine. In this method, assume that Global point is reached and suddenly isolation changes. In this case, the MPP is shifted to nearby vicinity without carrying of global MPP. This MPP is traced by P&O method (block 2). Whether MPP is reached or not, is checked by determining the sign of the power in two consecutive perturbations (block 3). When the first local peak (point A) is tracked, the algorithm stores the current information about PV array’s output power and output voltage as Pmax_last and Vm_last respectively. The subroutine then set the flag (flag==1) for the checking of GP on the left side of point A. The sudden change in insolation level (ΔG) or shading leads to a variation in power (ΔP). If the ΔP is greater than a certain critical power variable (ΔPcrit), then GP tracking starts (block 5 and 6). It is reported that a sudden variation in ΔG is smaller than 0.027 kW/m^2 and occurs within 1 second. Based on this, ΔPcrit can be fine-tuned for the set of PV system and environment conditions. A flag is equal to one after initiation of subroutine and other power peak scanning starts. This is carried out by changing ΔVlarge value. It should be less than the minimum displacement between two consecutive peaks (block 8). To insure that no peak is missed, ΔV_{large} with value 30% of Voc is considered.

IV. SIMULATION RESULT AND ANALYSIS

For performance study of proposed improved MPPT, power curve scanning technique is also simulated in Matlab Simulink environment. The algorithm of power curve scanning technique is written in state Space method. The simulation is carried out with partial shading condition of Fig. 3. The tracking speed and power output performances are considered as base platform for analysis of proposed MPPT. The analysis of Power Curve Scanning GMPPT is performed for shading pattern of Fig. 3. The power and voltage variation curve for Power Curve Scanning Technique are shown in Fig. 7 and Fig. 8 respectively. The Fig. 7 shows that the timer interuppt is used to initiate stepwise scanning after fixed interval. The method simply scan the P-V curve and point out three local MPP points. At the end, it restores system by selecting optimal local MPP point. As shown in Fig. 7, it is clear that output power is fluctuate significantly. Again time to track full cycle is also more due to full curve scanning.The total calculated time for actual MPP point tracking under the set partial shading condition is approximately 1.79 sec. The Power Curve Scanning method can be explained by observing the Fig. 7 and Fig. 8.

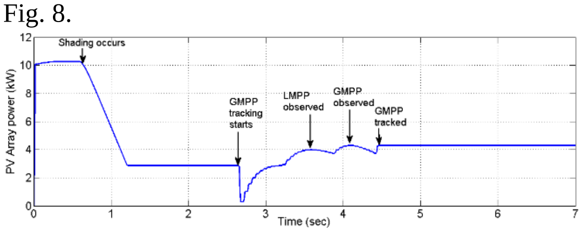

Fig-7 Power output pattern for power scanning MPPT controller under specific shading pattern

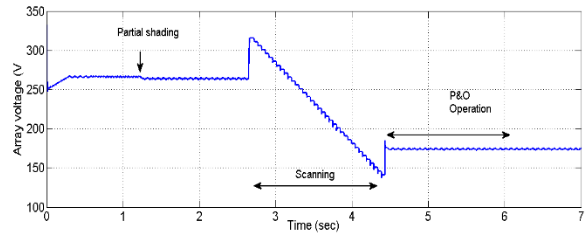

Fig-8 Array voltage output with respect to time for power scanning method

For doing analysis of proposed MPPT, PV array (10 x 5) with initial constant radiation of 1000W/m^2 is used. Suddenly at time=1.2 sec, partial shading with pattern in Fig. 3 is occured. For analysis, controller is designed with time interrupt scanning, so scanning is start only after completion of interuppt time slot. So, controller still work in main block with P&O MPPT. After interrupt cycle completion, sub-routine program is activated and then power slope scanning is performed to identify two local MPP. The sub-routine programe is start at 1.6 sec. After completion of sub-routine condition, the operating voltage point is shifted from 230 V to 185 V, which is clearly shown in Fig. 9 and Fig. 10. The time period for sub-routine program completion is 1.29 sec. Also it is clear from Fig. 9 and Fig. 10 that the power and voltage is not fluctuating in nature and it is a very important improvement in MPPT controller design. Again time to track global MPP point is reduced in comparison to power curve scanning method (1.79 sec). The response of current output at PV arraya terminal is shown in Fig. 11.

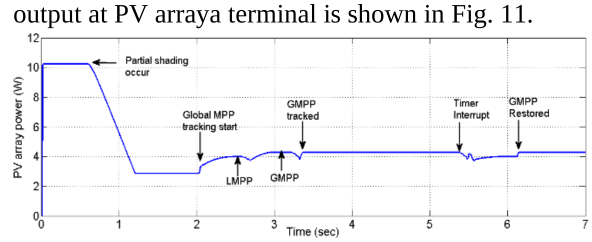

Fig-9 Output power for improved MPPT algorithm

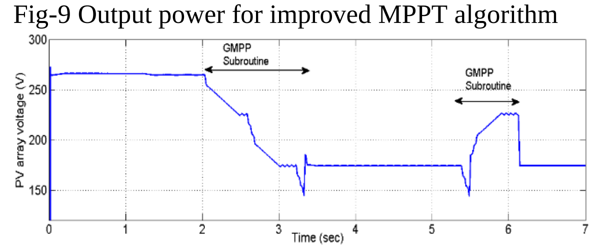

Fig-10 Output voltage for improved MPPT algorithm

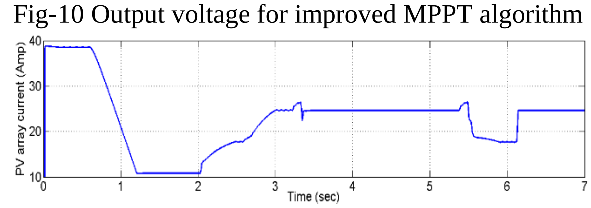

Fig-11 Output current for improved MPPT algorithm

V. CONCLUSIONS

The current and voltage relation for photovoltaic is non-linear and highly depends upon many factors like solar radiation, output load, temperature and partial shading conditions etc. The control of some external factor is not in a hand of user and must be accepted as available. In this scenario, MPPT controller is one the basic and important component of solar PV system. In this paper, improved MPPT controller with capability to work perfectly in partial shading condition is presented. The develop algorithm is used to make Simulink model in Matlab environment. The analysis is also performed and presented for its suitability in term of performance.

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