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Maximum Power Point Tracking of PV System under Partial Shading Condition

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Abstract:

The performance of the photovoltaic panel depends on atmospheric conditions such as temperature, irradiance etc. The conventional maximum power point tracking (MPPT) algorithms like Hill climbing, Perturb and Observe (P&O), Incremental Conductance (INC) are simple and efficient techniques to track MPP during uniform irradiance condition. However, under partially shaded conditions (PSC), these conventional algorithms fail to recognize global maximum power point (GMPP) and gets trapped in one of the local maximum power point (LMPP). To effectively track global maximum power point (GMPP) under partially shaded conditions heuristic algorithms like Ant Colony Optimization (ACO) can be used instead of conventional Maximum Power Point Tracking (MPPT) algorithms. This paperproposes a simpler fast-converging maximum power point tracking technique (MPP) for Photovoltaic (PV) system under partially shaded condition (PSC) using ACO.

Keywords **— Ant-colony optimization (ACO), photovoltaic (PV) systems,maximum power point tracking (MPPT), perturb and observe (P&O).**

I. INTRODUCTION

Renewable energy sources are of ever increasing economic and environmental importance in all countries. Now a days renewable energy sources are important because of the increased oil prices, depletion of fossil fuel reservoirs, and global warming. The renewable energy sources available are of wind, solar, tidal, hydro, geo-thermal and biomass. Among that, photovoltaic (PV) or solar energy has several advantages, namely it is ecofriendly,omnipresent, absence of rotating of parts. As a consequence, the total installed photovoltaic capacity in severalrural areas has increased. Farther, the development of smart grid concepts has accelerated the usage of solar energyandPhoto Voltaic systems is anticipated to play a livelypart in distributed generation (DG) systems. The photo voltaic systems have several challenges such as high installation cost and low power conversion efficiency. The maximum power output of the PV system largely depends onatmospheric condition. The PV system has a point in the power voltage curve where the out power reaches maximum that point is called maximum power point and as the environmental conditions changes the MPP also changes [1]. The efficiency of the PV system can be maximized by incorporating a maximum power point tracking (MPPT) technique with the system now a day which is an indispensablepart in PV systems.

Since the nature of power-voltage and current-voltage curves is nonlinear the maximum power point tracking in the PV power generation system is a major challenge. Two major factorsthat depending the characteristic curve are irradiance and temperature. There for depending on these two factors the tracking of the maximum power point is a complicated task. If in a power generation system thePV array receives uniform irradiance then the system exhibits a PV curve with a single maximum power point (MPP). The maximum power points tracking for such a system is done using conventional tracking schemes such as incremental conductance (IC), hill climbing (HC) and perturb and observe (P&O) methods.The conventional tracking schemes can only use under uniform irradiance condition. Under non uniform irradiance condition they will track in a wrong direction [1].

The basic components of the PV system are a PV cell. The PV cells are connected to form PV modules these PV modules connected in series or parallel to form PV system. Because of thetrees, buildings and moving clouds etc. neighboring to the PV system some of the PV arrays are partially shaded. The PV curve becomes more complex under partially shaded condition (PSC) and the PV curve exhibits multiple peaks. Among the multiple peaks the point with maximum power is called global maximum power point (GMPP) and all others are called local maximum power points (LMPPs) [2]. The conventional tracking methods used for uniform irradiance cannot be used under partially shaded condition since conventional methods fails to recognize global maximum power point (GMPP) and gets trapped into one of the local maximum power points (LMPP). Some heuristic algorithmssuitable for tracking maximum power point of PV system under partially shaded conditions are recently available [11].

This work proposes animprovedmaximum power point tracking (MPPT) scheme using ant colony optimization (ACO) method. Instead of starting from one point in hill climbing, ant colony optimization algorithm will select number of points, and perturbation is done in each point. After each perturbation check the position of the point, and find out the point which is at maximum power among them. The next perturbation is based on the position of that point. By repeating these steps we can converges all points to the global maximum power point (GMPP).

II. MAXIMUM POWER POINT TRACKING

For certain irradiance every single solar panel has a point where the output power reaches its peak value, referred to as Maximum Power Point (MPP). In Order to maximize the efficiency of PV system, a Maximum power point tracking (MPPT) technique is combined with the system. There are varieties of methods to track MPP. Traditional methods are Perturb and Observe (P&O),Hill Climbing (HC), Incremental Conductance (IC) etc. [2]. To Overcome the defects of traditional methods heuristic algorithms can be utilized such as Ant Colony Optimization (ACO) [14], Gray Wolf Optimization (GWO) algorithms [6] etc.

Among all the existing approaches the most widely used conventional algorithms are perturb and observe (P&O)andhill climbing methods.The main difference between hill climbing and perturb and observe method is that in hill climbing duty ratio of power converter is perturbed but in perturb and observe method operating voltage of PV array is perturbed. The perturbation in duty ratio of power converter perturbs the voltage and current of the PV array attached to that [3]. Hill climbing and P&O methods are alternative ways to envision the same fundamental method. Fig 1 shows the PV curve, here when we are increasing the voltage if the power is increasing then the system is operating at the left of the maximum power point and if the power is decreasing then the system is operating at the right of the maximum power point.Therefore, the next perturbation should be kept same to reach MPP if the power is increasing otherwise the perturbation should be reversed. Repeat the process until the MPP is reached.There is a chance of oscillation nearer to MPP, by reducing the perturbation step size the oscillation can be minimized [2].

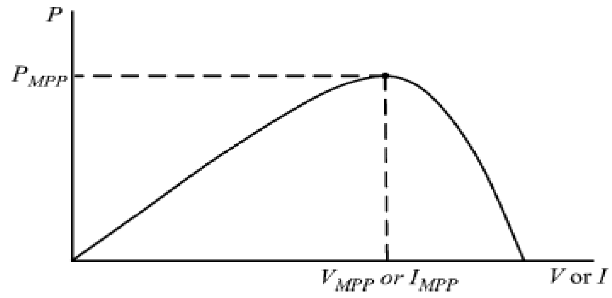

Fig. 1 Characteristic PV array power curve.

The PV array connected in series or parallel to form PV system. Because of the trees, buildings and moving clouds etc. neighboring to the PV system some of the PV arrays are partially shaded. The PV curve becomes more complex under partially shaded condition (PSC) and the PV curve exhibits multiple peaks. Among the multiple peaks the point with maximum power is called global maximum power point (GMPP) and all others are called local maximum power points (LMPPs) [2]. The conventional tracking methods used for uniform irradiance cannot be used under partially shaded condition since conventional methods fails to recognize global maximum power point (GMPP) and gets trapped into one of the local maximum power points (LMPP).

Instead of starting from one point in hill climbing, ant colony optimization algorithm will pick out number of points, and perturbation is done in every single point. After each perturbationcheck the position of the point, and find out the point which is at peak power among them. The next perturbation is based on the position of that point. By repeating these steps we can converges all points to the Global Maximum Power Point (GMPP). The basic blocks of maximum power point tracking system are solar cell, dc-dc converter, MPPT scheme and a load as in Fig. 2.

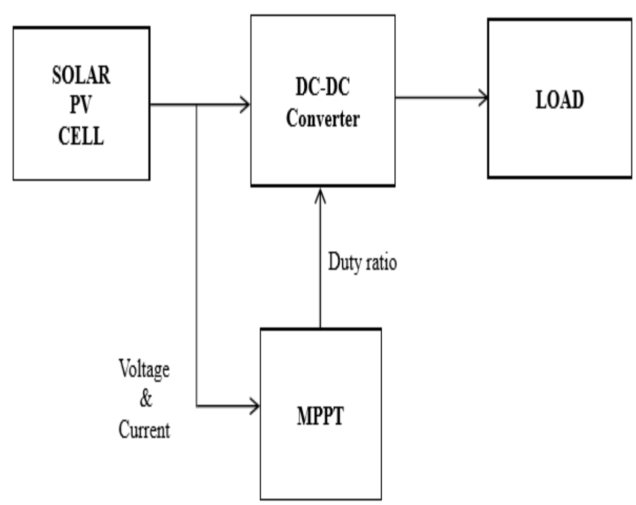

Fig. 2Block diagram of PV system.

A solar cell converts light in to electric current using the photo electric or photovoltaic effect. The output power of PV system is very low we need to boost up that for which we use DC-DC converter. The DC-DC converter is a boost converter. Boost converter act as a switching converter. The operation of the boost converter is controlled by an electronic switch which is opening and closing periodically [9]. For a particular irradiance each solar panel has a point where the output power reaches its peak value, Called Maximum Power Point (MPP). In order to maximize the efficiency of PV system, we have to track the operating point to maximum power point. A Maximum Power Point Tracking (MPPT) technique is integrated together withthe system to track the operating point to maximum power point.

III. PV ARRAY UNDER PARTIAL SHADING

The PV arrays are connected in series or parallel to form PV system. PV arrays can be partially shaded due to neighboring buildings, trees, poles, and moving clouds. PV array under partial shading is shown in Fig. 3. The insolation level is proportional to the short circuit current of the PV cell hence the photo current of shaded PV cell reduces as the effect of partial shading while the unshaded cells continue to function without any decrease in photo current.The string current over all the series connected cells must be equal, so that to carry large current of the unshaded cells the shaded cells operate in a reverse bias region. Due to the reverse voltage polarity the shaded cells consumes power.

Therefore, PV array's maximum extractable power decreases. There is a chance of avalanche break down as the bias voltage increases.Thiscauses thermal breakdown of the PV cell and hence create a hot spot. The cells getting burn out if the excessive heating is untreated and an open circuit is created in the shaded string. Bypass diode can be used to avoid this hot spot.The reverse voltage in the cells is limited by connecting these bypass diodes parallel to the cells and hence power loss in the shaded cells are limited.These diodes are connected parallel to the cells to limit the reverse voltage and, hence, the power loss in the shaded cells. For example, in a module with 24 series cells, one diode may be connected across each set of 12 series cells. The bypass diode restricts the reverse voltage to less than the breakdown voltage of the PV cells if the reverse voltage across the shaded cell increases.

The cells of a module no longer carry the same current when partially shaded because of an alternate current path provided by the bypass diodes. Therefore, the power–voltage curve become more complex and develops multiple maxima as shown in Fig. 4. Among all the peaks the point with maximum power is called Global Maximum Power Point (GMPP)and all others are called Local Maximum Power Point (LMPP). The most commonly used uniform irradiance schemes such as perturb and observe cannot be used here. Under partially shaded condition the conventional algorithms fails to recognize Global Maximum Power Point (GMPP) and gets trapped into one of the local maximum power point (LMPP).

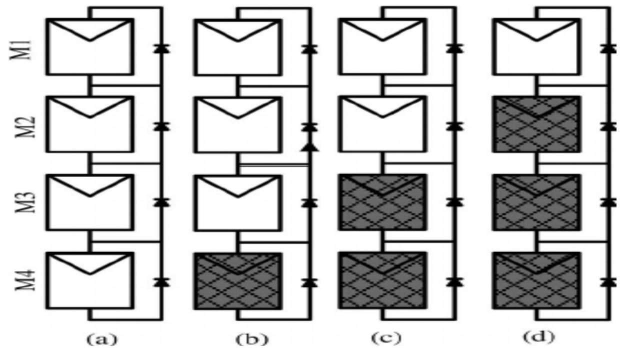

Fig. 3PV array under PSC

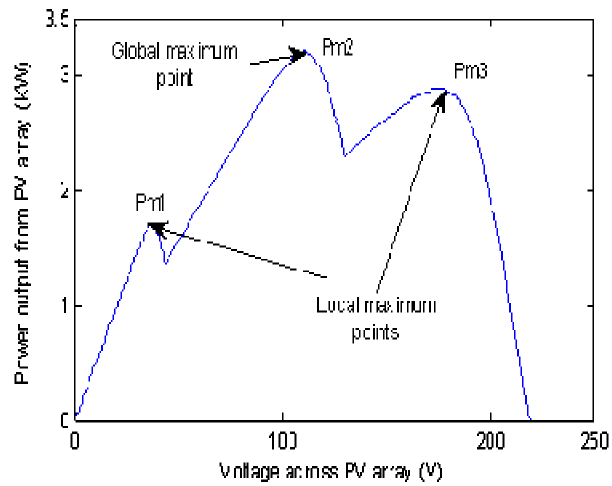

Fig. 4PV curve under PSC.

To effectively track global maximum power point under partially shaded condition heuristic algorithm can be used instead of conventional MPPT algorithms [4]. Such algorithms are Ant Colony Optimization algorithm (ACO), Gray Wolf Optimization algorithm (GWO)[6], Particle Swarm Optimization algorithm (PSO) etc.

IV. ANT COLONY OPTIMIZATION

Ant Colony Optimization algorithm for maximum power point tracking is based on the behavior of ants searching for food. The first ant colony optimization algorithmproposed in the early nineties is known as Ant System. Number of other ACO algorithms has been proposed after that. It was introduced to solve difficult combinational optimization problem.

Instead of taking one point in Perturb and Observe based algorithm, Ant Colony Optimization based algorithm selects number of points and the points are represented by duty ratio and corresponding PV output power is measured [1]. Find the point where the power is maximum and find the corresponding duty ratio. At the next step all duty ratio positions are perturbed based on the location of the maximum power point and again measure the PV output Power corresponding to the perturbed position and corresponding duty ratio. Repeating these steps will converge all the points to global maxima.

ACO selects number of points instead of starting from one point in hill climbing. Let that be d_{01}, d_{02}, d_{03}, d_{04}, d_{05}&d_{06} as in Fig. 5[1].

Find the output power corresponding to each duty ratio. Find out the point with maximum power and find the corresponding duty ratio. From this graph the position with maximum power is a_4 with power 40.68 and the corresponding duty ratio is d_{04}.

At the next step all duty ratio positions are perturbed based on the position of the maximum power point and update the duty ratio using the below equations (1).

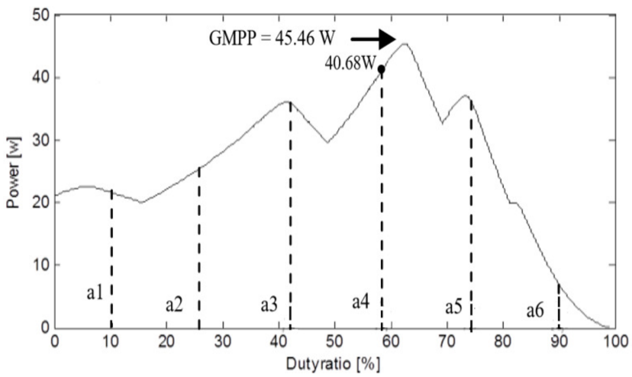

Fig. 5Illustration of ACO based MPPT scheme.

$$d_i^{k+1}=d_i^k+\delta_1(k)\Delta d_i \quad (1)$$

Where $\delta_1(k)$ step size of ant movement. For the k^{th} iteration, we have,

$$\delta_1(k)=\delta_0 e^{-k}, \text{ where } \delta_0 \text{ is taken as 15.}$$

$$\Delta d_i=d_{max}-d_i$$

Where, d_{max} is the duty ratio corresponding to the current maximum power point. Repeat these steps until all points will converges to Global Maximum Power Point (GMPP).

V. FLOW CHART OF ACO

The flow chart for Ant Colony Optimization based algorithm is shown in Fig. 6.

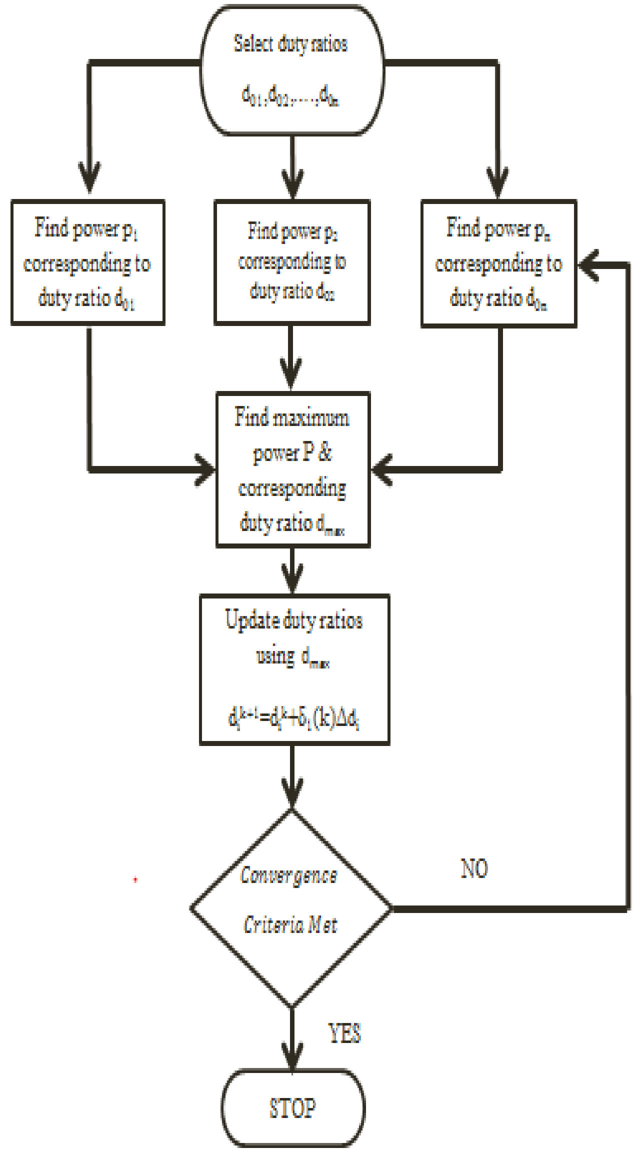

Fig. 6Flow chart for ACO algorithm.

VI. SIMULATION PARAMETERS

The boost converterdesignparameters are given in table. 1

Table. 1Design Parameters

Inductor	438μH
Capacitor	5μF
Resistor	60Ω

VII. SIMULATION DIAGRAMS

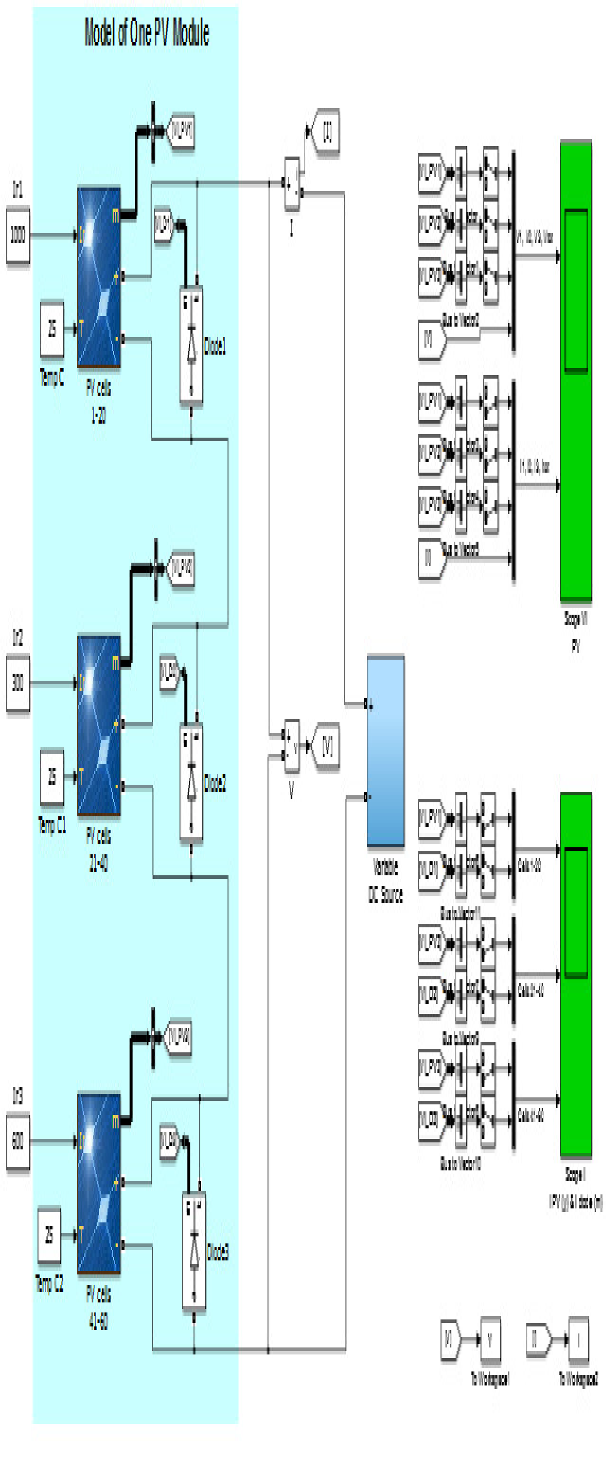

Fig. 7Simulation of partial shading.

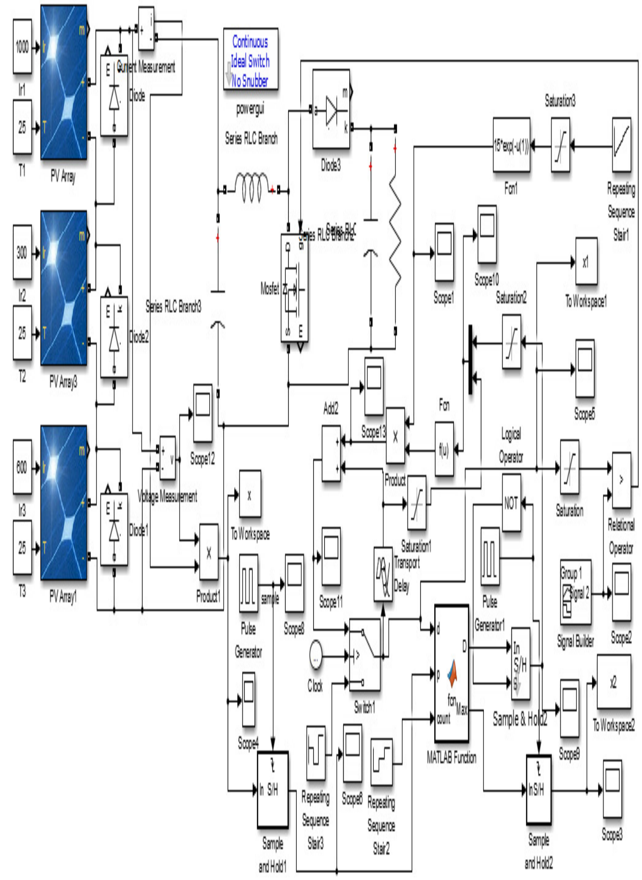

Fig. 8Simulation of ACO algorithm.

VIII. SIMULATION RESULTS

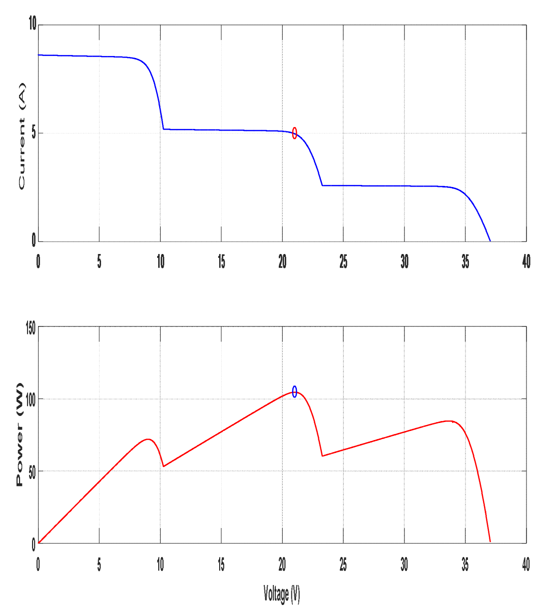

Fig. 9Current voltage curve and PV curve under partial shading.

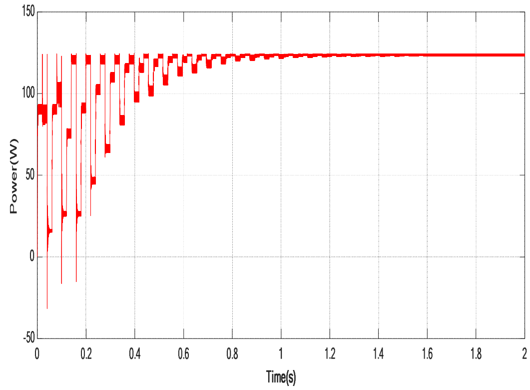

Fig. 10Output power during ACO under intensity of (1000,1000,1000W/m^2)

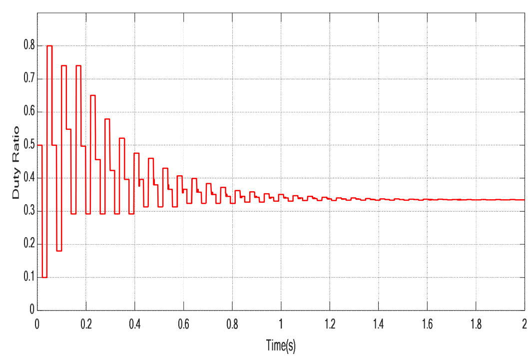

Fig. 11Duty ratio waveform during ACO under intensity of (1000,1000,1000 W/m^2)

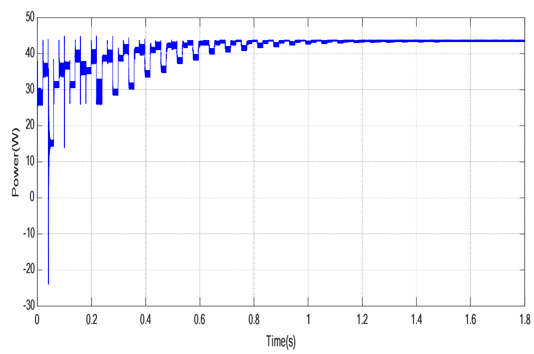

Fig. 12Output power during ACO under intensity of(1000,500,100W/m^2)

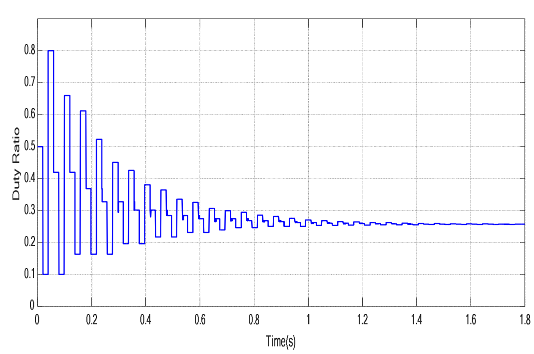

Fig. 13Duty ratio waveform during ACO under intensity of(1000,500,100W/m^2)

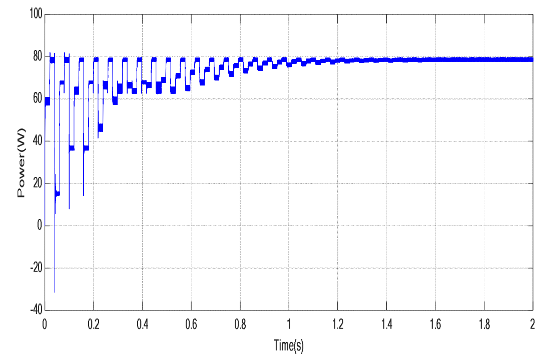

Fig. 14Output power during ACO under intensity of(1000,800,600W/m^2)

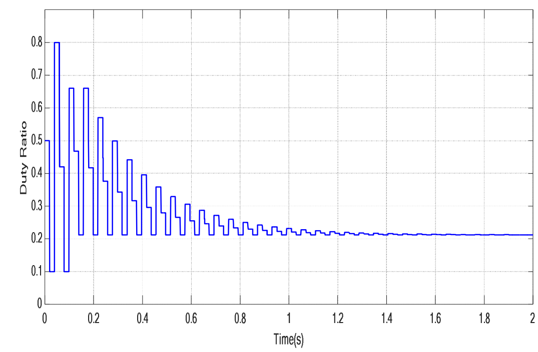

Fig. 15Duty ratio waveform during ACO under intensity of(1000,800,600W/m^2)

SIMULATION RESULT ANALYSIS

It is seen from simulation results that, the improved Ant Colony Optimization (ACO) algorithm based method over comes the drawback of conventional algorithms based method under Partially Shaded Condition (PSC). That is the Ant Colony Optimization (ACO) algorithm based method converges to Global Maximum Power Point (GMPP) instead of tracking in to local maximum power points (LMMP) in conventional algorithms based method. Output power tracked using ACO algorithm for different intensity of light are given in Fig. 9 to 15.

The analysis of simulation and results at various conditions are tabulated in tableIII and IV. Table III gives the convergence time of the different shading patterns using different multiplication constants. The results are analyzed for 3 different multiplication constants 5,10 and 15. By analyzing the table it is clear that convergence time decreases as the multiplication constant increases. The smallest convergence time is for 15, hence which extracts more energy from the Photo Voltaic system. The theoretical maximum value of each shading pattern is also given in the table II.

Table III gives the convergence time and the maximum power tracked for different shading patterns using different number of duty ratios. The different shading patterns are tested using different number of duty ratios. The number of duty ratios selected varies from 3 to 6. As the number of duty ratios increases the convergence time also increases but the power will tracked in to a value which is closer to the theoretical value of the maximum power. The tracking efficiency increases as the number of duty ratio increases.

Table.II Convergence time for different multiplication constants

Shading Pattern (Irradiance)	Multiplication constant			Theoretical Maximum Power
	5	10	15	
1000,500,100	5.4	2.7	1.8	43.6
1000,800,600	4.6	1.6	1.4	81.7
1000,400,700	5	2	1.7	60.5
600,900,300	4.4	1.7	0.9	51.9
500,200,700	5	2.7	1.7	42.2
1000,300,600	5.5	2.6	1.9	52.1

Table.IIIConvergence time (T)and maximum power (P) for different number of duty ratios.

Shading Pattern (Irradiance)	Number of duty ratios selected							
	3		4		5		6	
	T	P	T	P	T	P	T	P
1000,500,100	1.8	39.7	2.5	42.6	3	43.2	3.5	43.7
1000,800,600	1.4	79.6	2.4	80.2	2.9	80.6	3.6	81.9
1000,400,700	1.7	58.7	2.4	59.4	3.1	59.9	3.4	60.1
1000,300,600	1.9	51.5	2.1	51.6	2.8	51.8	3.6	52.2

CONCLUSIONS

This paper proposes an improved ACO algorithm based maximum power point tracking method (MPPT) in PV systems under Partially Shaded Conditions (PSC). In this the convergence time decreased by increasing the multiplication constant in the ACO equation and the tracking efficiency is increased by increasing the number of duty ratios selected. From the obtained resultsit is clear that this new MPPT exhibits superior performance compared to traditional MPPTs.

The new method effectively tracks the Global Maximum Power Point (GMPP) under partially shaded condition instead of getting trapped in to Local Maximum Power Point (LMPP), with minimum tracking time and hence which extracts more energy from the Photo Voltaic system. The superiority of the new MPPT is demonstrated by presenting the obtained results.

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