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Ant Colony Optimization based Maximum Power Point Tracking (MPPT) for Partially Shaded Standalone PV System

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ABSTRACT

Maximum Power Point Tracking (MPPT) is a prime technology to improve power utilization of photo Voltaic (PV) system as the output power depends on the incident insolation and ambient temperature. The conventional MPPT techniques function efficiently when the panel is exposed to uniform irradiance distribution. But when the PV panel is shaded by a fraction (partially shaded) the output power curve exhibit multiple peaks points (MPPs). The conventional MPPT algorithm fails by getting stuck with local maxima where as a global search algorithm would prevail over conventional MPPT techniques. Therefore in this work an Ant Colony Optimization (ACO) technique is proposed which successfully tracks the global peak and thereby improving the performance of PV array .The suggested work is realized in MATLAB/Simulink and simulation results of ACO MPPT is compared with a conventional Perturb and Observe (P&O) MMPT .The results reveal that ACO is versatile for various shading pattern and has an clear edge over the mundane MPPT technique.

Keywords: Photo Voltaic (PV) system, Partial shading, Buck converter, Maximum Power Point Tracking (MPPT), Ant Colony (ACO) algorithm, Insolation(irradiation), Global Maximum Power Point (GMPP).

1. INTRODUCTION

In recent past, renewable energies have been experiencing incredible growth due to the booming awareness of the depletion of fossil fuels and prevailing power crisis scenario. Among all renewable energy resources, PV drags special attention not only due to its inherent advantages such as non-depleting, available free of cost, pollution free etc but also its compatible structure with off-grid and on-grid solutions (Luque and Hegedus, 2003; Tyagi et al., 2013). The output power of a PV cell varies nonlinear with respect to operating voltage and it has one maximum peak point (MPP) relevant to a particular value of voltage (V_{mpp}). There is a definite need for a track mechanism called maximum power point tracking (MPPT) to make the PV system to operate at its maximum power. A plenty of MPPT algorithms have been developed by researchers (Hussein et al., 1995; Dolara et al., 2009; Esram and Chapman, 2007). Among all MPPT techniques Perturb &Observe and, Incremental Conductance techniques are more advantageous and most prevalently used (Fangrui et al., 2008; LI and Wang, 2009; Femia et al., 2005). The power voltage characteristic curve of PV panel gets further complex when the panel is shaded (Hiren and Vivek, 2008; Anuradha and Asim, 2009) as it exhibits power curves multi summit curves. The multi summit power curves essentially have a global peak and as many as local peaks.

There are enough number research papers archived regarding employing a global search algorithm such as Particle Swarm Optimization (PSO) and

Differential Evolution (DE). The particle swarm optimization was the strong contender among all the soft computing techniques contributing in MPPT schemes (Cheng et al., 2010; Liu et al., 2012). The quest

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Nomenclature:

I_{pv}	-	Photocurrent	I_s	-	diode reverse saturation current
q	-	Electron charge	V	-	Voltage across the diode
$\hat{a}$	-	Solar irradiance in W/m^2	K	-	Boltzmann's constant
T	-	Junction temperature	n	-	Ideality factor of the diode
R_s	-	Series resistance of the cell	R_{sh}	-	shunt resistance of the cell
N_s	-	no. of cells connected in series	N_p	-	no. of cells connected in parallel
T_{no}	-	Nominal temperature	E_g	-	band gap energy of the semiconductor
V_t	-	thermal voltage			

on improving the performance of PSO aided global search were also interesting and yielded feasible results (Ishaque et al., 2012; Phimmasone et al., 2011). DE algorithm was the second prominent meta heuristic technique which rendered its global search hand in grasping MPP (Sheraz and Abido, 2012; Kashifishaque and Zainal, 2011). Till date the scout on using new algorithm did not dwindled as Jubaer and Zainal (2014) proposed a new cuckoo search algorithm. Though an ACO MPPT is not new to research arena, but for (LianLianjiang et al., 2013) ACO was not dealt felicitously.

This paper has its own distinct way of employing ACO MPPT and here the control algorithm is built by using the irradiation and temperature parameters. A detail PV array modeling during partially shaded condition is realized in MATLAB/Simulink environment and the ACO is employed to successfully track the global power peak.

2. PV MODELING

2.1. PV Modeling during uniform insolation

A solar cell is the fundamental component in a solar module. The equivalent circuit of the PV cell is given in Fig. 1.

The PV array can be mathematically modelled using its functional equations.

Now the current to the load is given by

$$I = N_p I_{pv} - N_p I_s \left[\exp\left[\frac{q(V + R_s I)}{nN_s KT} - 1\right]\right] - \frac{V + R_s I}{R_{sh}} \tag{1}$$

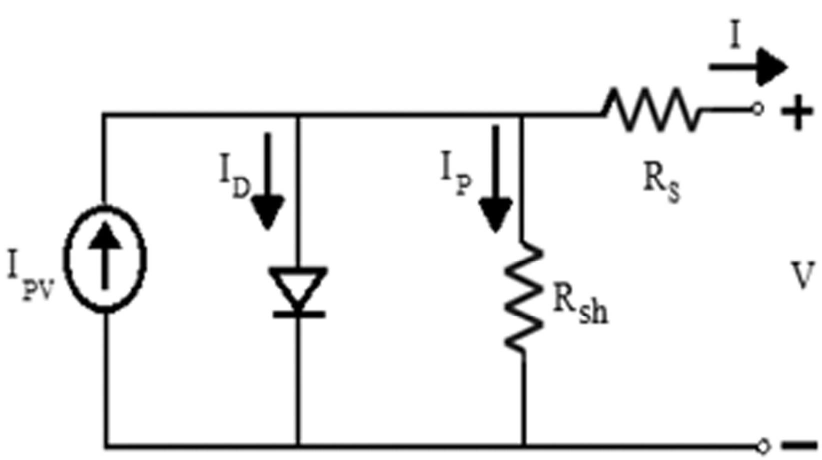

Figure 1: Equivalent circuit of the practical PV cell

In this equation, I_{pv} is the photocurrent, I_s is the reverse saturation current of the diode, q is the electron charge, V is the voltage across the diode, K is the Boltzmann's constant, T is the junction temperature, n is the ideality factor of the diode, and R_s and R_{sh} are the series and shunt resistors of the cell, respectively. N_s and N_p are the number of cells connected in series and parallel respectively. As mentioned earlier PV current is a function of temperature and solar irradiation

$$I_{pv} = \left[I_{sc} + K_i \left(T - 298 \right) \right] \frac{\beta}{1000} \tag{2}$$

Where K_i = 0.0017 A/°C is the cell's short circuit current temperature coefficient and β is the solar radiation (W/m2).

The diode reverse saturation current varies as a cubic function of the temperature and it can be expressed as

$$I_s \left(T \right) = I_s \left[\frac{T}{T_{nom}} \right]^3 \exp \left[\left[\frac{T}{T_{nom}} - 1 \right] \frac{E_g}{nV_t} \right] \tag{3}$$

Where I_s is the diode reverse saturation current, T_{nom} is the nominal temperature, E_g is the band gap energy of the semiconductor and V_t is the thermal voltage.

Fig. 2 shows the relation between power output and operating voltage of the PV panel. While modeling the equations one could assess that the power output is proportional to the irradiation level where as it has a inverse effect to temperature. As any semiconductor material the increase in excess temperature would reduce the performance of PV cell. The inference from Fig. 2 is as there is a dip in irradiation the power output decreases gradually also when temperature increases the open circuit voltage decreases thereby reducing the effective power delivery.

2.2. Partially Shaded Module

When PV system's exposure to sunlight is meddled by environmental hindrances and if it is exposed unevenly then it is meant that PV system is partially shaded. PV arrays of three parallel connected panels are shown in Fig 2.

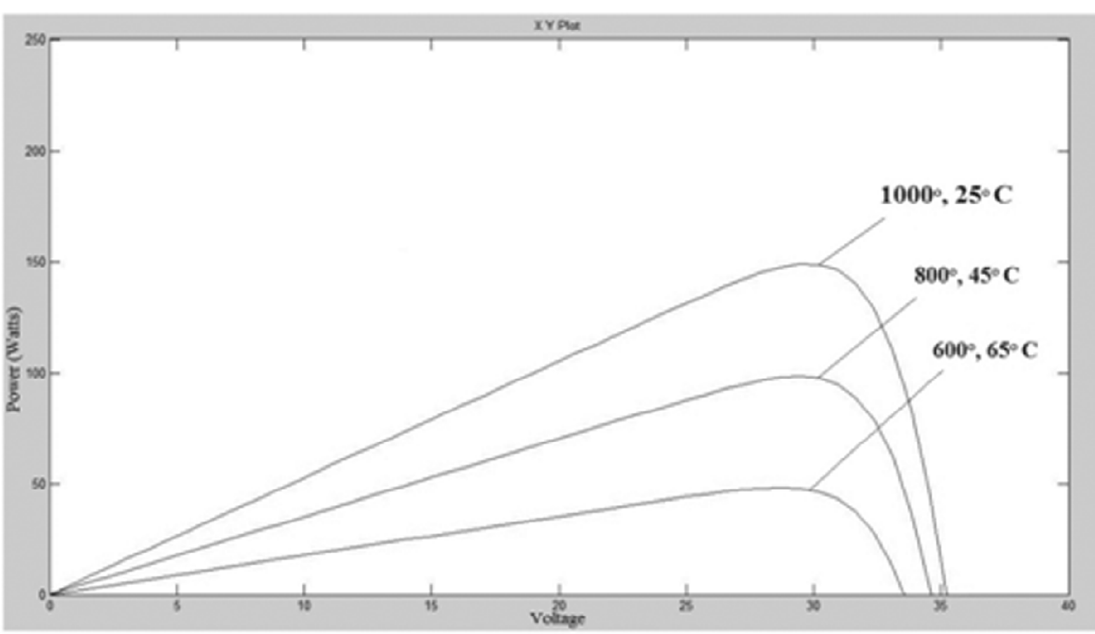

Figure 2: Partially shaded array.

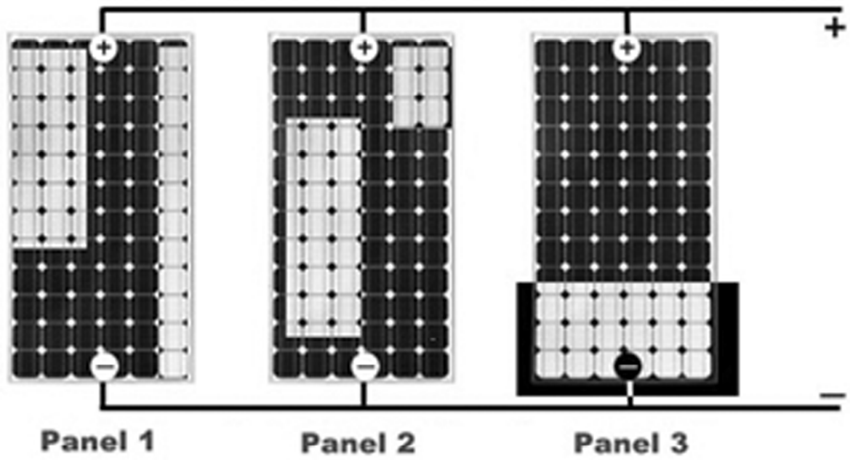

Figure 3: PV panels connected in parallel with shading effects.

When partially shading occurs the PV curves pattern would be having multi power peaks as shown in Fig 3. Table 1 shows the details of short circuit current ($I_{sc)}$ and open circuit voltage $V_{(oc).}$ The resultant short circuit of three panels is addition of the three panel's current since the panels are connected parallel and interestingly the open circuit voltage will be the maximum among the three panel's $V_{(oc).}$ The most important analysis done for a shaded array is its power profile, as it is quite imperative that the resultant power curve will have multi peaks as each individual power gets hindered by in-homogenous irradiation.

Table 1
Shaded Panels Description

No. Panels	*Short Circuit current (Amperes)*	*Open Circuit Voltage (Volts)*	*Power Output (Watts)*
Panel 1	5.0.	10.1	30.0
Panel 2	2.9	15.0	30.0
Panel 3	1.3	18.0	17.0
Resultant	9.2	8.0	61.25(G_{max}) 43(L_{max}) 17(L_{max})

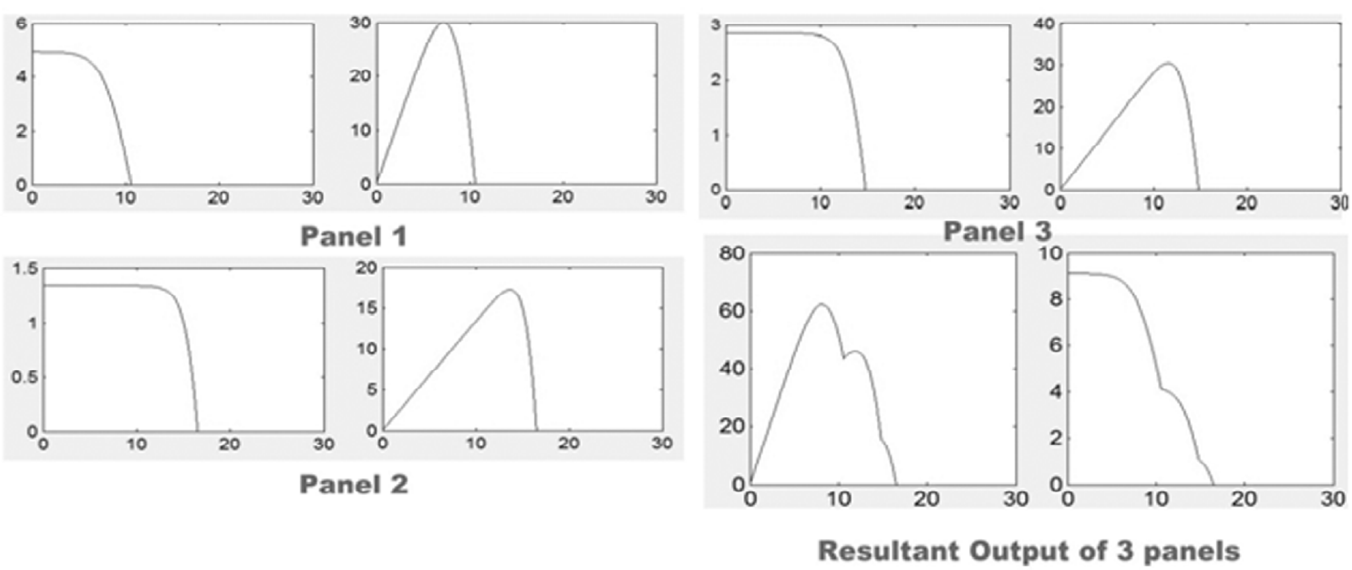

Figure 4: PV characteristics of array under study in partially shaded condition

Fig. 4 shows the output (I-V& P-V) curves of the partially shaded PV system. The last pane shows the array characteristics exhibiting multiple power peaks, say 17Watt, 42Watt, 62.2 Watt. The characteristic curves are simulated in MATLAB/Simulink GUI environment and the inference is the global maxima occurring at 61.2 W at an operating voltage of 8.1 volt.

3. ANT COLONY MPPT

The block diagram representation of the proposed approach is shown in Fig. 5.The system necessarily consists of cascaded PV source, a digital signal controller where the Ant Colony coding is employed, dc-dc converter and a load. The dc-dc converter may refer to a boost converter or a buck converter. The choice between boost and buck converter depends on the load being employed. The load being a standalone load of low rating that has to be fed continuously even during off shine period then the converter should be a buck converter which matches the battery voltage appropriately for charging. In this work a standalone system is considered therefore buck converter in employed.

3.1. Ant colony Algorithm

Ant colony algorithm came into existence by mimicking the social behavior of ants. When ants search their food it would follow a shortest path between their nest and food. They have an inherent capacity to emit a chemical called pheromone which drags response within members of the same species .When ants wander for search of food it would emit pheromone trail on their way. The search may be random initially. Ants may also follow the same path while returning to the nest as it would trace the pheromone trail. Therefore the pheromone trail becomes even thicker and rigid and will be the shortest path. If the pheromone path is not the shortest then it would evaporate and vanish off its own.

Ant colony MPPT is implemented by making most out of the ant’s behavior .The process starts with randomly initializing the ants. The objective function is framed by including each panel’s exposure to irradiation and temperature. The pheromone concentration is given by the formula

$$T_{ij} = \rho T_{ij}(t-1) + \Delta T_{ij}; \qquad t = 1,2,3...T \tag{4}$$

where

T_{ij} - Revised concentration of pheromone

ΔT_{ij} - Change in Pheromone concentration

ρ - Pheromone concentration rate (0-1)

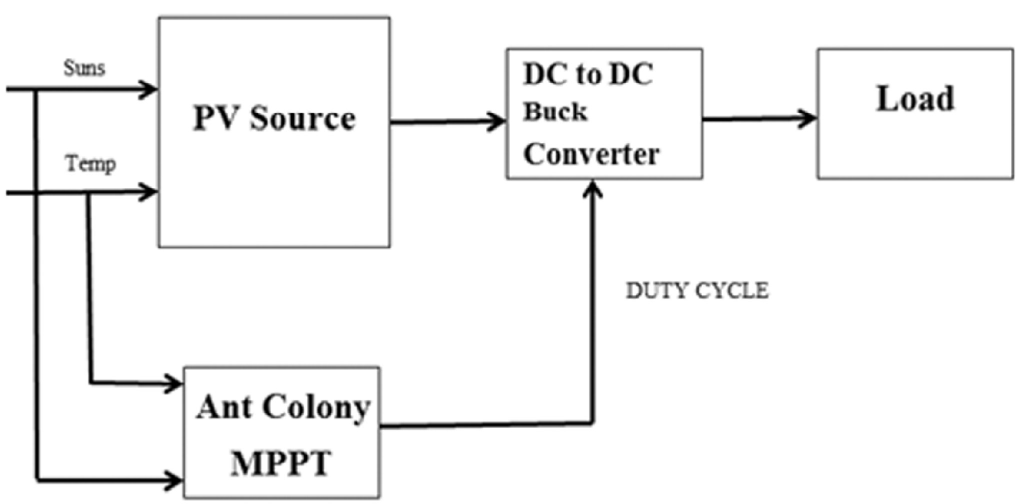

Figure 5: Block diagram of the proposed system

The pheromone rate ‘ρ’ plays a crucial role as absurd values. Concentration rate would wrongly direct the convergence to happen at local maximum.

Pheromone concentration ΔT_{ij} is given by

$$\Delta T_{ij} = \begin{cases} R / fitness_k \quad I_{ij} \quad is \ chosen \ by \ ant \ k \\ 0 \quad otherwise \end{cases} \tag{5}$$

3.2. Algorithm for Ant colony

The functional equation of Ant colony algorithm Initialize the pheromone trails and parameters;

Step 1: Create population of ‘m’ ants (solutions);

Step 2: For every individual ant, evaluate ûtness (k);

Step 3: Determine the best position for each ant;

Step 4: Find the ant with global best position;

Step 5: Update the pheromone trail;

Step 6: Check if convergence is satisfied;

The objective function for ACO is to find the operating voltage at which global power peak exists. By deducing the voltage and by varying the duty cycle of the DC-DC converter, the PV panel can be made to operate at its peak power for the given time.

$$\text{Fitness function} = \text{Panel } 1(V_1{}^* (I_1 (S_1, T1) + \text{Panel } 2 (V_2{}^*(I2 (S_2, T2) + \text{Panel } 3 (V_3{}^*(I_3, S_3, T3) \tag{7}$$

Where V represents panel voltage;

I represents panel current;

S represents panel irradiation;

T represents panel temperature; suffixes 1, 2, 3 represents respective panels in an array.

Equation (7) shows the fitness equation has interdependence between voltage, current, and temperature and irradiation. The power curve with multi power peaks is formed by the cumulative product of voltage and current where current or voltage is a function of irradiation and temperature.

3.3. DC-DC Buck Converter

Since the output from Solar panels is a DC voltage, DC/DC converter is used to provide the flexibility to amend the DC voltage or current at any point in the circuit. The buck converter is designed to step down a fluctuating solar panel voltage to a lower constant DC voltage. It uses voltage feedback to keep the output voltage constant. These are often preferred as they are smaller, light weight, provide a high quality output, and more efficient than the traditional linear power regulators and more compatible with battery loads. The fundamental equation of buck converter is given

$$\frac{V_{out}}{V_{in}} = D; \; I_{out} = \frac{I_{in}}{D} \tag{6}$$

$$R_0 = \frac{R_{in}}{\left(1 - D^2\right)} \tag{7}$$

Where

V_{out} - Output voltage of the converter; R_0 the output resistance.

V_{in} - Input voltage of the converter; R_{in} the input resistance.

D - Duty cycle of the switch

4. RESULTS AND DISCUSSION

Ant colony algorithm is a combination of positive feed back mechanism and greedy search algorithm.The positive feed back mechanism aids in early detection of global optimised point. The Fig. 6(a) shows the random distribution of ants in search space (random initialisation) and its convergence towards global peak power is realised in Fig. 6(b). Fig. 6(c) depicts the final convergence at global power peak, say 62 Watts. The last panel Fig. 6(d) shows a plot between peak power attained with respect to iteration. The simualtion results are tabulated in Table 2 and results clearly reveal that the proposed technique has an clear edge over its conventional counterpart. Fig. 7 depicts the peak power tracked and its relevant operating voltage is shown in Fig. 8.

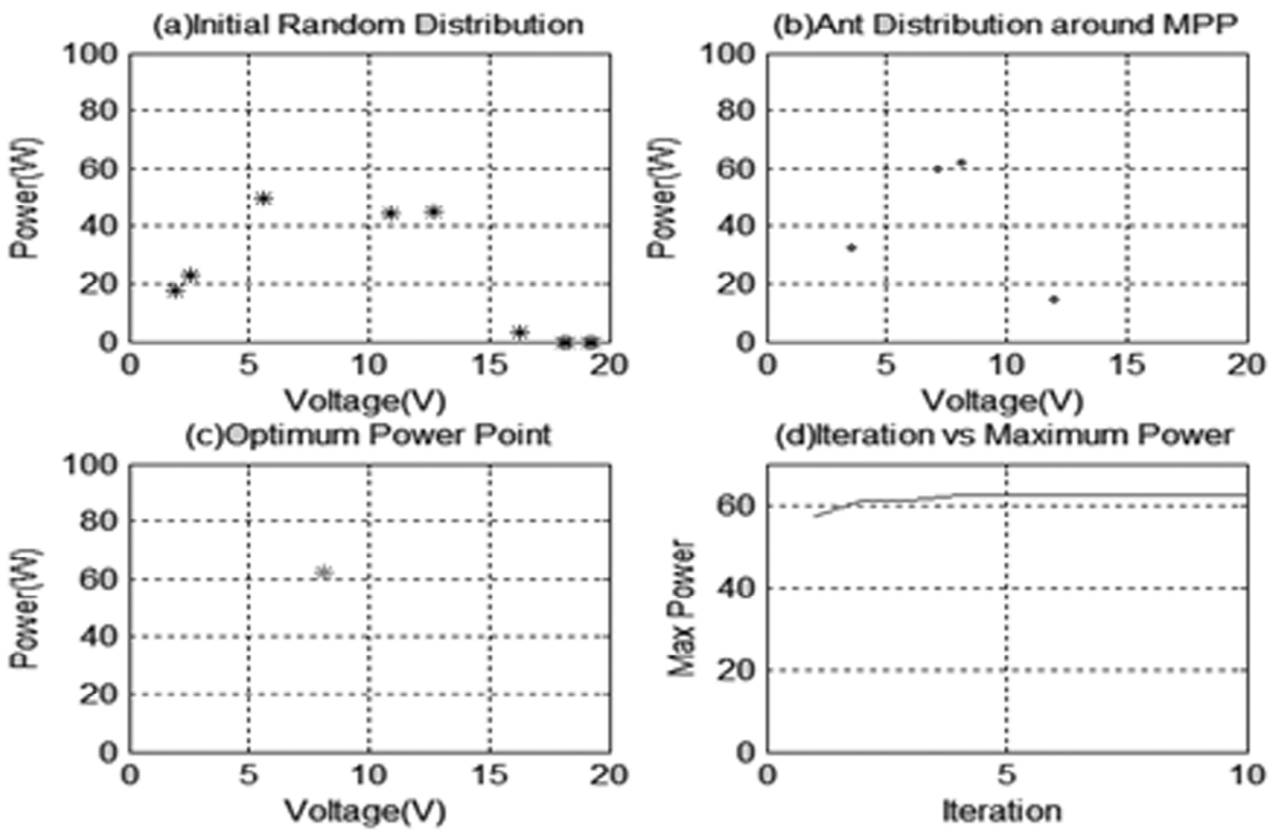

Figure 6: Convergence outputs of Ant Colony algorithm

Table 2
Simulation Result Comparisons

Scheme	*Power delivered*	*Operating Voltage*	*Time taken to reach MPP*	*Iteration*
Without MPPT	12.05 W	16.5	NA	NA
With P&O MPPT	17.0 W	15.1	0.02s	NA
Ant Colony	61.4W	8.13	0.076s	15-20

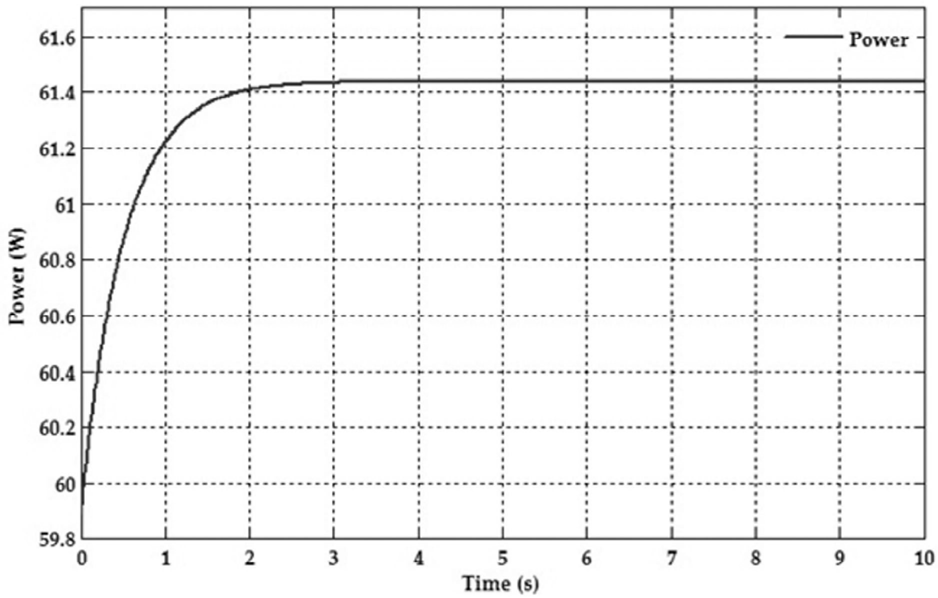

Figure 7: Power Tracked by Ant Colony algorithm

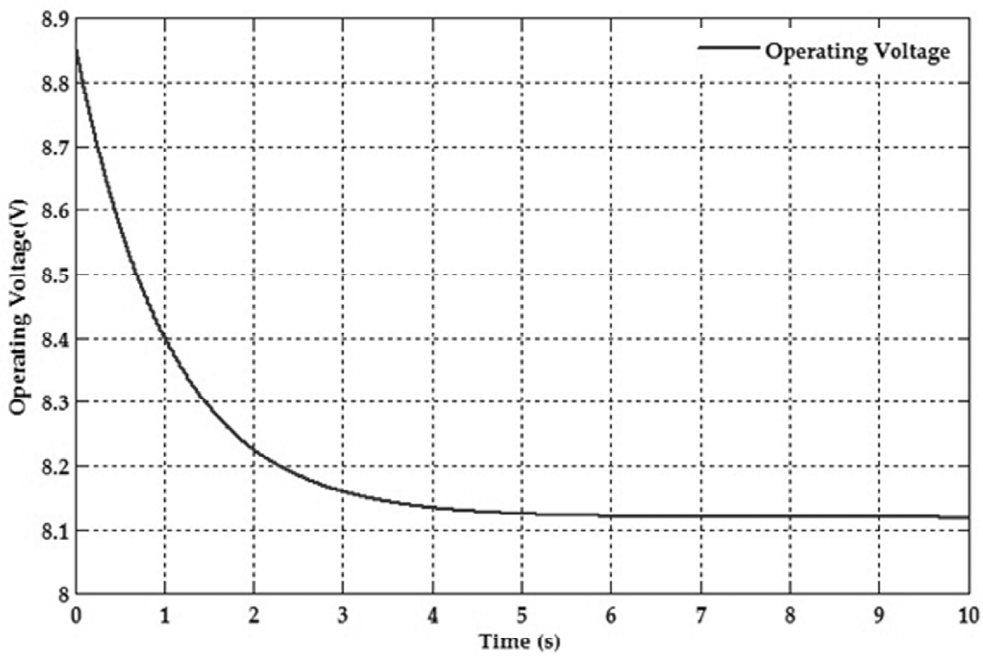

Figure 8: Operating voltage at MPP

5. CONCLUSION

Solar photovoltaic (PV) based electricity generation costs are declining and expected to become economically attractive as technologies improve and the cost of electricity generated by fossil fuels rises. This paper discussed the modeling and simulation of PV array and also the implementation of an extended MPPT algorithm. The simulation results show the voltage and current characteristics (V-I), and power and voltage (P-V) characteristics of the modeled PV array in partially shaded condition. Maximum power tracking in PV array which is partially shaded is achieved by ant colony algorithm cuddled MPPT. This method is superior to conventional MPPT algorithms in particular when partial shading is considered. The result of the simulation shows that ACO aided MPPT achieves 61.42W where as the conventional MPPTs will stick to 15.1W.

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