Middle-East Journal of Scientific Research 24 (3): 927-936, 2016
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2016.24.03.23095

Distributed MPPT System for non Uniform Solar Irradiation

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Abstract: Under the non-uniform solar insolation conditions, the photovoltaic (PV) power system exhibits a peculiar property of multimodal i-v or v-p characteristic and results in obtaining multiple local maxima and a global maximum power point (MPP). Due to the presence of such non ideal power characteristic, the conventional maximum power point tracking (MPPT) algorithms cannot track the actual global MPP successfully. In normal MPPT controlling methods, all the PV panels are connected to single MPPT to produce the maximum output. If any fault occurs in the PV panel or less irradiance in some part of the panel also leads to reduction of power generation. Hence this paper investigates and discusses the application of Distributed MPPT technique(DMPPT) along with the Particle Swarm Optimisation approach in order to capture the optimum global MPP effectively. In this method each panel is connected separately to separate MPPT. Each MPPT is connected to the Boost converter and finally all the MPPTs are connected in series to increase the voltage. Here voltage and power of DMPPT system is observed using MATLAB/simulink modelling.

Key words: Photovoltaic system · DMPPT technique · PSO algorithm · Boost converter

INTRODUCTION

Energy saving is biggest issue now a days, renewable energy is playing a big role in producing electricity, among them wind and solar are popular renewable energy sources. Solar Energy is a good choice for electric power generation. Fast tracking of global maximum power point (MPP) is a challenge, many research is going on this direction. Although there are several benefits in solar energy, there are some challenges that obstruct its growth. The two main challenges are low conversion efficiency and its erratic nature of power output.

A Solar Photovoltaic (PV) Cell converts the solar radiation into electrical energy. This is the most popular method of power generation in recent days. To track the maximum power of the PV panel the maximum power point technique is used in the solar system [1]. To improve the conversion efficiency of the PV System many MPPT techniques have been introduced and implemented.The different MPPT techniques are used in Solar like Perturb & Observe, Incremental conductance etc. Conventional MPPT technique is inefficient during the mismatches in the irradiance at the PV panel. This mismatch occurs due to the partially shaded condition which happens because of shadows of trees, clouds, overhead lines, buildings, etc [2, 3]. This partially shaded condition will result in the reduction of power production. If the PV panels are connected in series during the partially shaded condition the output power of the whole PV system will be affected. This leads to more losses which reduces the efficiency of the system [5, 6]. Distributed Maximum Power Point Tracking (DMPPT) scheme is used in which each PV module is operated at its own Maximum Power Point. This scheme will tend to increase the output power of the different PV panels which is connected under partially shaded conditions [4]. Moreover, the maximum power of a string of PV modules operating in mismatching conditions is lower than the sum of the powers which could be extracted by the PV modules if, each one of them, could operate in its MPP. Distributed Maximum Power Point Tracking (DMPPT) architectures allow to overcome the drawbacks associated to mismatching phenomena [4].

The most common algorithm is perturb and observe (P&O) method. While P&O is inexpensive and relatively simple, the algorithm is inefficient in the steady state because it forces the system to oscillate around the MPP instead of continually tracking it [7]. It causes a reduction in the PV module output power [8]. In addition it cannot operate the module at its maximum output power in rapidly

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changing of weather conditions [9]. Particle swarm optimization (PSO) is an intelligence optimization theory to overcome the problems associated with search and optimisation [10].

The purpose of this paper is to develop PSO based Distributed MPPT scheme for solar photovoltaic system with varying static and dynamic conditions. The complete system is simulated using MATLAB environment.

Solar PV Array Modelling: From the physical behaviour and mechanism of a solar cell an equivalent electrical circuit is derived, worldwide two different circuits are accepted as equivalent electrical circuit of solar cell, the first one is a simplified model of a single solar cell that exhibits an approximate characteristic of a solar cell and second one having two diodes combination one for reflecting diffusion and other for carrier. The equivalent circuit is shown in Fg. 1 below.

The photovoltaic cell output voltage is basically a function of the photocurrent which is mainly determined by load current depending on the solar irradiation level during the operation.

Applying nodal equations to Fig. 1, where I_{PH} and diodes, R_{SE} and R_{SH} are meeting together.

$$I_{PH} = I_D + I_{SH} + I \quad (1)$$

$$I = I_{PH} - I_D - I_{SE} \quad (2)$$

$$I = I_{PH} - I_{sat1}\left(e^{\frac{q(V+I*R_{SE})}{KT}} - 1\right) - I_{sat2}\left(e^{\frac{q(V+I*R_{SE})}{2KT}} - 1\right) - \left[\frac{V+I*R_{SE}}{R_{SH}}\right] \quad (3)$$

when both diodes are combined together then the equation becomes,

$$I = I_{PH} - I_{sat}\left(e^{\frac{q(V+I*R_{SE})}{AKT}} - 1\right) - \left[\frac{V+I*R_{SE}}{R_{SH}}\right] \quad (4)$$

The symbols used are:

V: cell output voltage, V.
T: reference cell operating temperature (25°C).
R_{SE}: series resistance of cell (0.001 Ω).
I_{PH}: photocurrent, function of irradiation level and junction temperature (5 A).
I_{sat}: reverse saturation current of the diode ($2*10^{-4}$ A).
I: cell output current, A.
K: Boltzmann constant (1.38×10^{-23} J/K).

Table 1: Solar Panel Specifications

Parameter	Specification
Rated Maximum power	40W
Open Circuit Voltage	21.90V
Short Circuit Current	2.45A
Rated Voltage	17.40V
Rated Current	2.30A

The Solar panel is designed with the specifications given in the Table 1.

Fig. 2. shows the simulation of two PV panels with varying insolation. The insolations are as 700W/m^2 and 1000W/m^2. Fig. 3 and Fig. 4 shows the P-V and I-V characteristics for varying insolation levels.

DC/DC Boost Converter: A step-up converter is used in this paper to connect a PV panel with a load in order to adjust the operating voltage and current of the PV panel at optimal values. The boost converter contains an MOSFET and a diode which are represented as a dual ideal switch U in order to simplify the circuit analysis. If U is a state of 0, the diode is ON and the MOSFET is OFF and vice versa if U is a state of 1. The boost converter contains also passive components an inductor L, an capacitor C and a resistance R. The operation principle of the boost converter can be demonstrated for each switching period under the continuous conduction mode (CCM) into two modes, the first mode is an ON mode in the duration 0 ≤ ◎◎ ≤ ◎◎◎◎◎◎ and its state equations can be represented as follows.

$$v_s = L\frac{i_2 - i_1}{t_1} \quad (5)$$

$$t_1 = L\frac{i_2 - i_1}{V_s} \quad (6)$$

The second mode is an OFF mode in the duration ◎◎◎◎◎◎ ≤ ◎◎ ≤ ◎◎◎◎ and its state equations can be represented as the following:

$$v_L = v_S - v_o \quad (7)$$

$$L\frac{i_2 - i_1}{t_2} = v_S - v_O \quad (8)$$

$$t_2 = L\frac{i_2 - i_1}{V_S - V_O} \quad (9)$$

From equations (6) and (8),

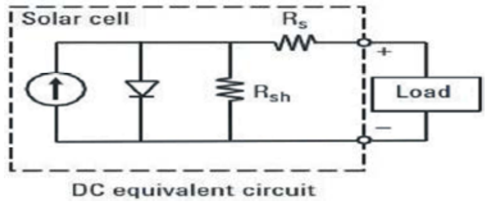

Fig. 1: Simplified circuit diagram of Solar cell

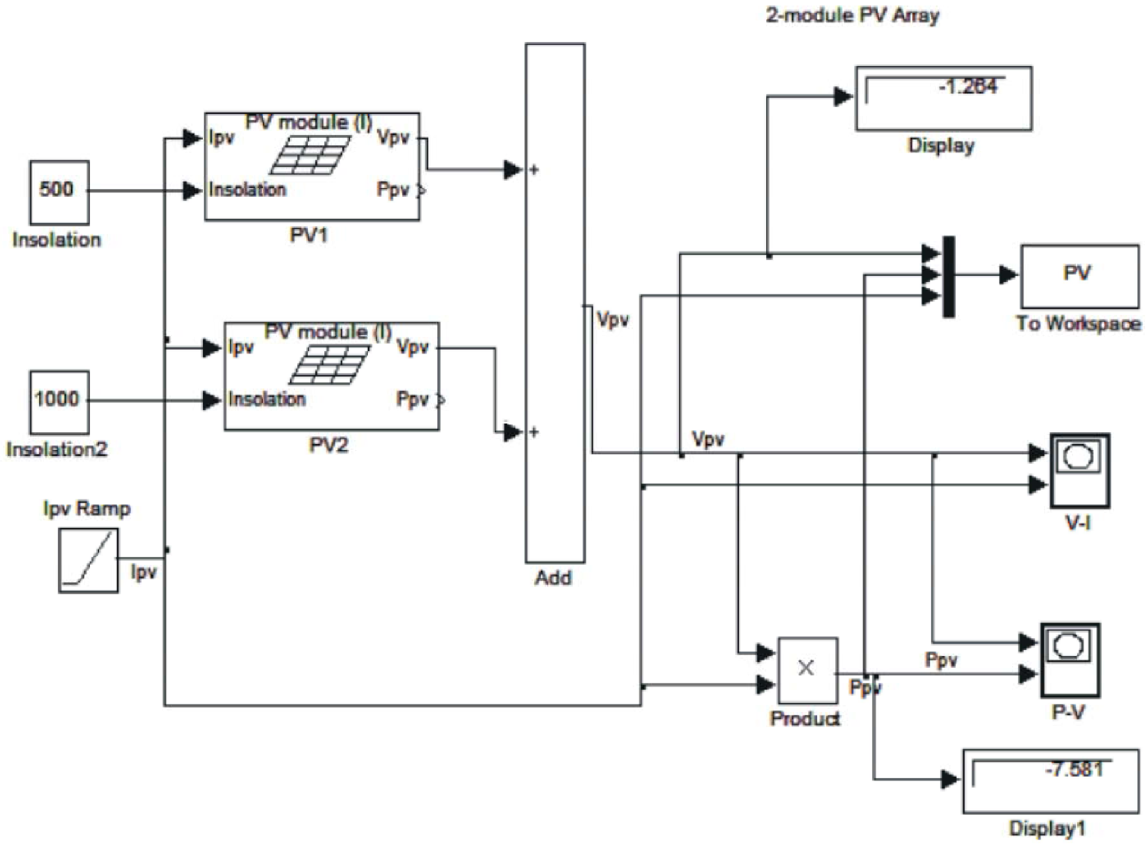

Fig. 2: Simulation of two PV panels with varying insolation

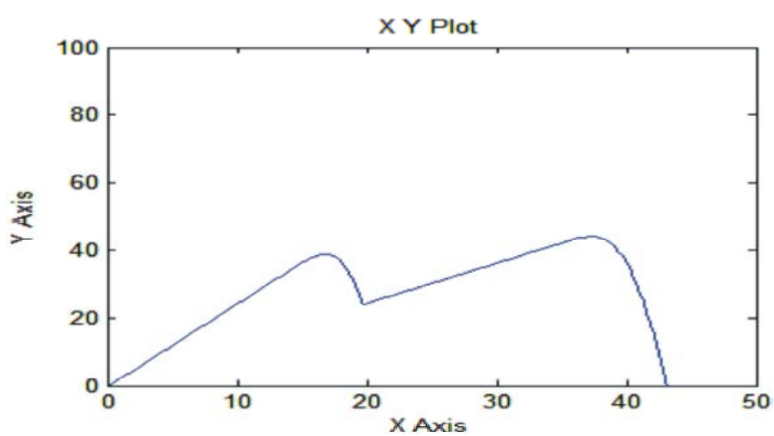

Fig. 3: P-V characteristics for varying insolation levels

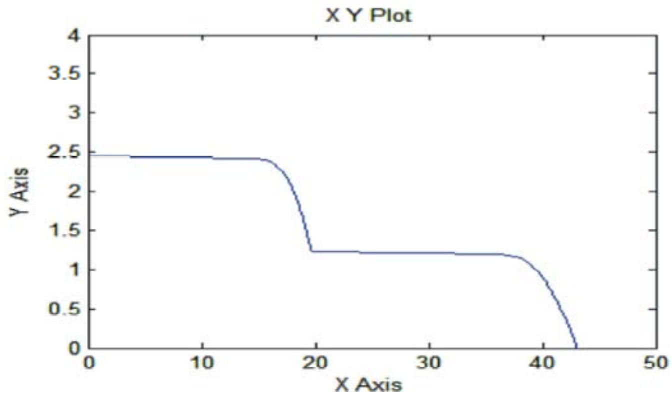

Fig. 4: I-V characteristics for varying insolation levels

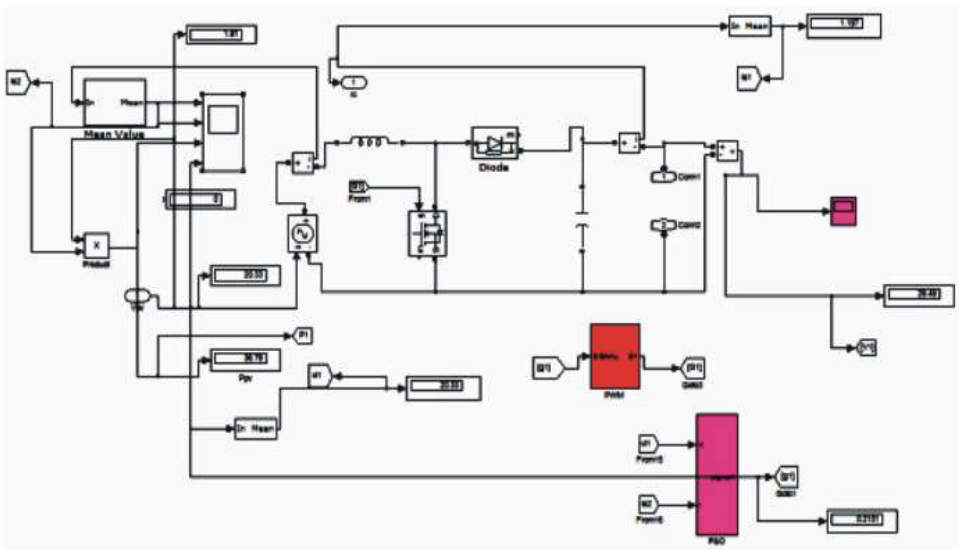

Fig. 5: Simulation Model of Boost Converter

Table 2: Boost Converter Specifications

Parameters	Specifications
Inductor	$2.5e^{-3}$H
Capacitor	$960e^{-6}$F
Switching Frequency	10kHz
Resistive Load	48ohm

$$L(i_2 - i_1) = (v - v_o)t_2 = vt_1 \quad (10)$$

$$T = t_1 + t_2 \quad (11)$$

From equation (10)

$$v = \frac{1}{1-D} v_S \quad (12)$$

where,

$$D = \frac{t_1}{T} \quad (13)$$

The input and output voltages of the boost converter are varied with the solar irradiances and load variations. The Boost converter is designed with the following specifications.

MPPT Algorithms: Based on the approach used for generation of the control signal as well as the PV system behaviour around the steady state conditions, they are usually classified into the many methods.

Perturb and Observe Algorithm: Perturb & Observe (P&O) is the simplest method. This is the most widely used MPPT scheme. The method involves moving operating voltage by one step and then examining the change in generated power. If the power increases, the operating point moves in the same direction. This process goes on until it reaches MPP.

Particle Swarm Optimisation Based MPPT: The P&O method is eliminated due to its slow convergence speed. Perturbation is done based on the concept of particle swarm optimization. The flowchart of the proposed MPPT scheme is shown in the Fig. 8. In this scheme Particle Swarm Optimization with MPPT Controller is used to find out the maximum power point.

PSO was introduced by James Kennedy and Russell C Eberhart in the year 1995. PSO is a stochastic, population-based EA search method, modelled after the behaviour of bird flocks. The PSO algorithm maintains a swarm of individuals (called particles), where each particle represents a candidate solution. Particles follow a simple behaviour: emulate the success of neighbouring particles and its own achieved successes. The position of a particle is, therefore, influenced by the best particle in a neighbourhood *P* best as well as the best solution found by all the particles in the entire population *G* best.

The particle position x_i is adjusted using;

$$X_{si}^{k+1} = X_i^K + \varnothing_i^{k+1} \tag{14}$$

where the velocity component □$_i$ *represents* the step size. The velocity is calculated by;

$$\varnothing_i^{k+1} = w\varnothing_i^k + c_1 r_1\{R_{best} - x_i^k\} + c_2 r_2\{G_{best} - x_i^k\} \tag{15}$$

where w is the inertia weight, *c*1 and *c*2 are the acceleration coefficients, *r*1, *r*2 *ε U*(0, 1), *P*best is the personal best position of particle *i* and *G*best is the best position of the particles in the entire population.

If position is defined as the actual duty cycle while velocity shows the perturbation in the present duty cycle, then equation can be rewritten as;

$$d_i^{k+1} = d_i^k + \varnothing_i^{k+1} \tag{16}$$

However, for the case of PSO, resulting perturbation in the present duty cycle depends on P_{best} and G_{best}. If the present duty cycle is far from these two duty cycles, the resulting change in the duty cycle will also be large and vice versa. In the latter, the perturbation in the duty cycle is always fixed but in PSO it varies according to the position of the particles. With proper choice of control parameters, a suitable MPPT controller using PSO can be easily designed.

The Fig. 6 illustrates the flowchart of the PSO method:

- Equation (16) shows that the perturbation in duty cycle is computed by two difference terms: the difference between the previous duty cycle *di*(*k*) and the local best particles *P*best and the difference between the previous duty cycle *di*(*k*) and the global best particle G_{best}. Thus, the power converter tracks the two best P_{best} and G_{best} at the same time. As a result, the tracking spaces are searched to obtain an optimal solution with a faster speed.
- Once the particle reaches MPP, the velocity of particles is practically zero. Hence, at steady state no oscillations will be seen. These steady-state oscillations are very critical because it is one of the major reasons for the reduced MPPT efficiency.
- In the case of rapid fluctuations in the environmental conditions, the P&O method can lose the direction of new MPP and tracking could be driven into a wrong direction. However, the proposed method works on three duty cycles. Since the operating power information is obtained from all three duty cycles, it never loses the direction of MPP in rapid fluctuations.
- In the condition of partial shading, the *P-V* characteristic curve is characterized by multiple peaks.

As a result, the P&O method is most likely to trap at local maxima. On the other hand, the PSO method works based on a searching scheme. Hence, it can still track the global peak correctly.

Distributed MPPT: With the increasing deployment of PV generation and the constant need to reduce the cost of PV generated electricity, mismatch losses can no longer be tolerated. This gave rise to a new group of PV architectures, called Distributed Maximum Power Point Tracking (DMPPT). DMPPT facilitates the extraction of maximum power from each individual module, thus eliminating the mismatch losses.

The advantages of distributed MPPT over the conventional MPPT are high-lighted during partial shading and other mismatch issues. The DMPPT realizes the local MPPT of each module unlike the conventional string MPPT. This leads to a increase in system efficiency. The DMPPT renders more flexibility. The overall lifetime of the system increases with the implementation of DMPPT and makes the system easily replicable. This entire system enables the sub-modules to operate independently at their optimum power output level irrespective of the changes in the irradiance in each module. This effectively decouples the PV sub-modules from the rest of the system and eliminates mismatch losses.

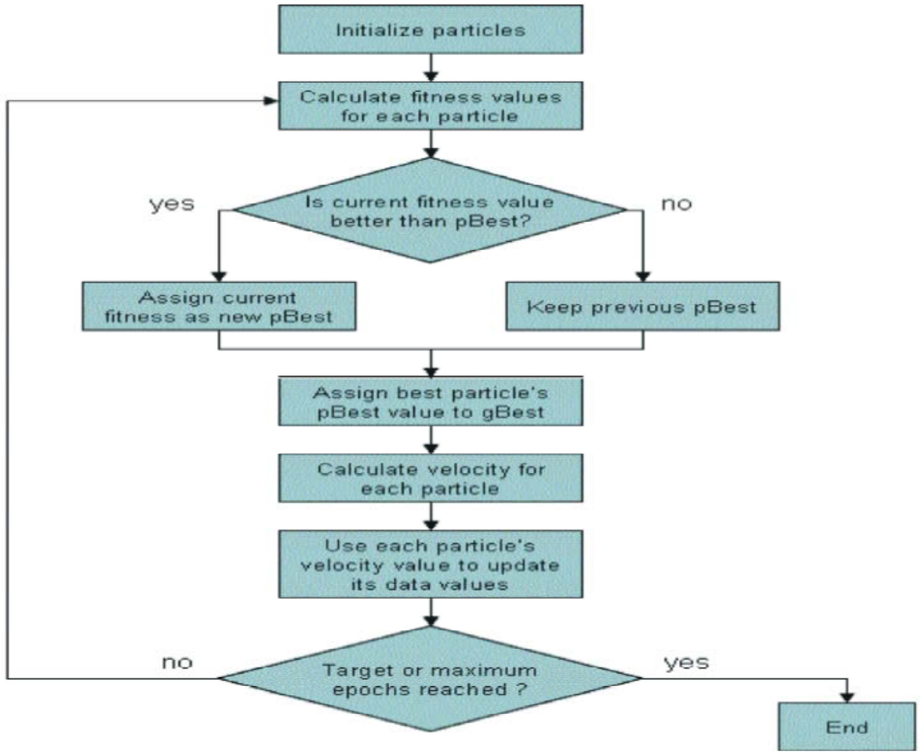

Fig. 6: Flowchart of the Particle Swarm Optimisation

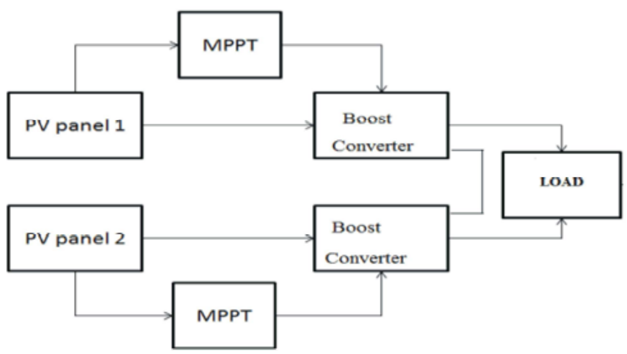

Fig. 7: Distributed MPPT Structure

Table 3: Comparison of MPPT techniques in Centralised system

	Output Voltage		Output Power	
	P&O	PSO	P&O	PSO
Panel 1: 1000W/m^2 Panel 2: 1000W/m^2	52.4V	53.6V	70.5W	72.92W
Panel 1: 1000W/m^2 Panel 2: 700W/m^2	51.5V	52.7V	67.2W	69.57W

Table 4: Obtained values for Distributed MPPT system using PSO

	Output Voltage	Output Power
Panel 1: 1000W/m^2 Panel 2: 1000W/m^2	52.88V	73.34W
Panel 1: 1000W/m^2 Panel 2: 700W/m^2	51.64V	71.13W

Simulation and Results: The Simulation of centralised and distributed MPPT system was done in MATLAB and the comparison results are discussed below.

The comparison of PSO and P&O MPPT techniques for centralised system under same and varying insolation condition is tabulated in Table 3. The Output power and voltage by using PSO based centralised system is shown in Fig. 9 and Fig. 10 respectively.

The Output Voltage waveforms for separate boost converter is shown in Fig. 12 and Fig. 13.

The overall output voltage waveform when the panels are connected in series is shown in Fig. 14.

The Output power obtained by using PSO and P&O MPPT technique is compared and is shown in Fig. 15.

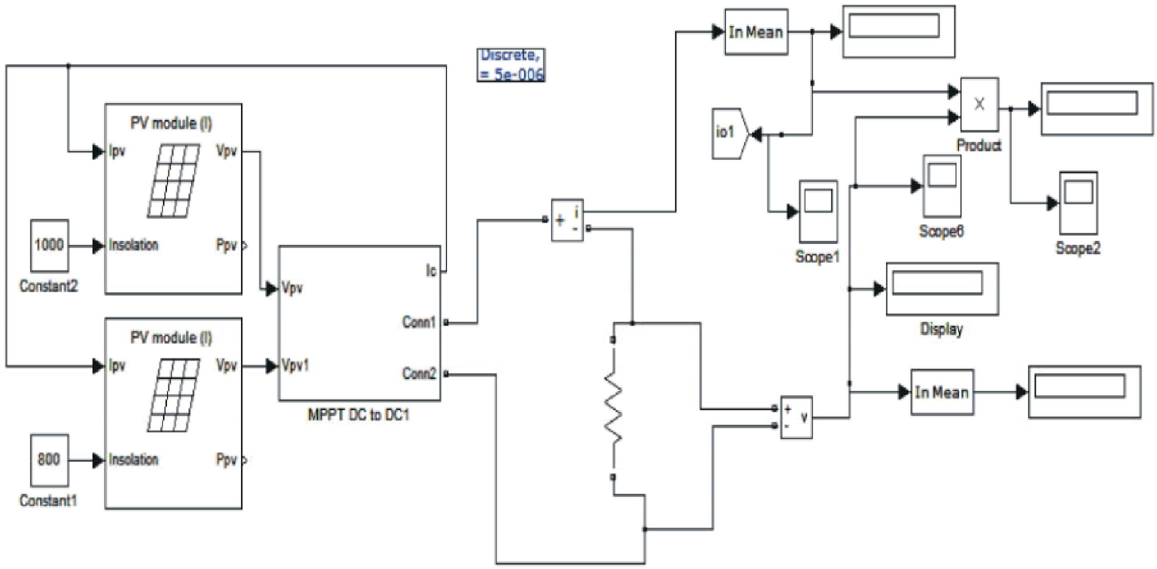

Fig. 8: Simulation Model of Centralised MPPT System

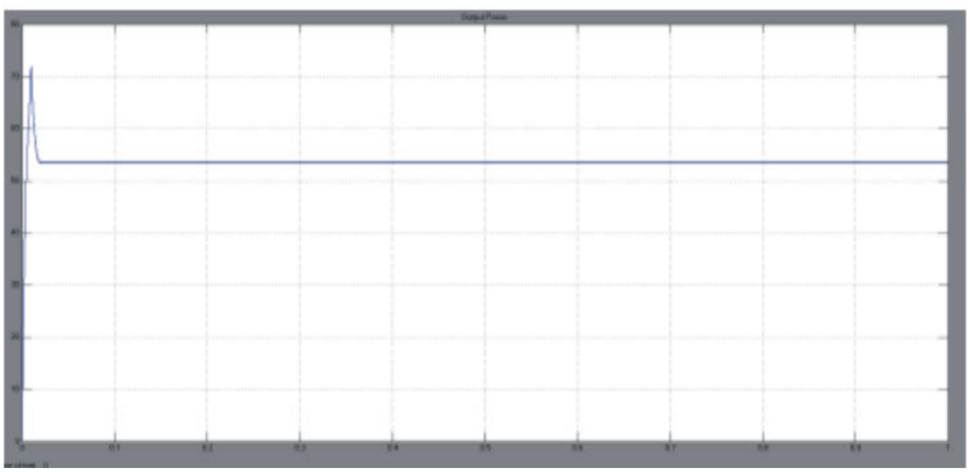

Fig. 9: Simulated Power Waveform for Centralised system

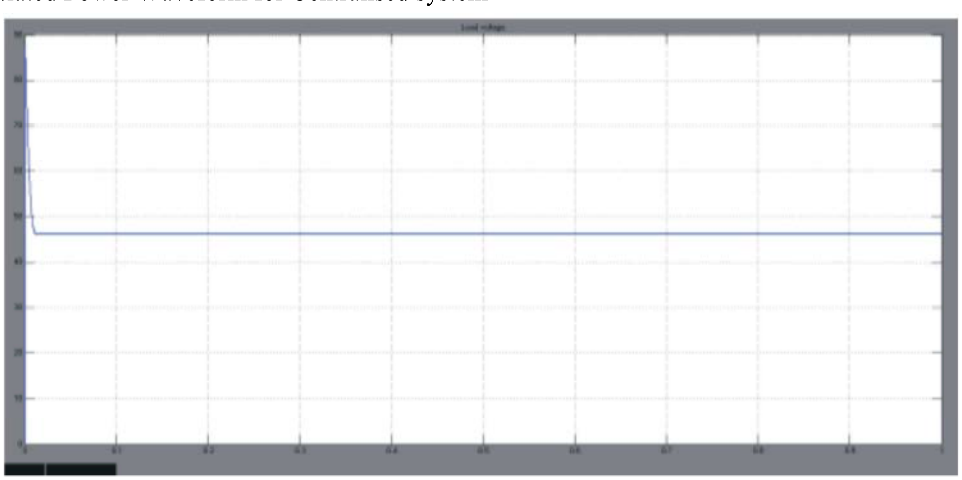

Fig. 10: Simulated Voltage Waveform for Centralised system

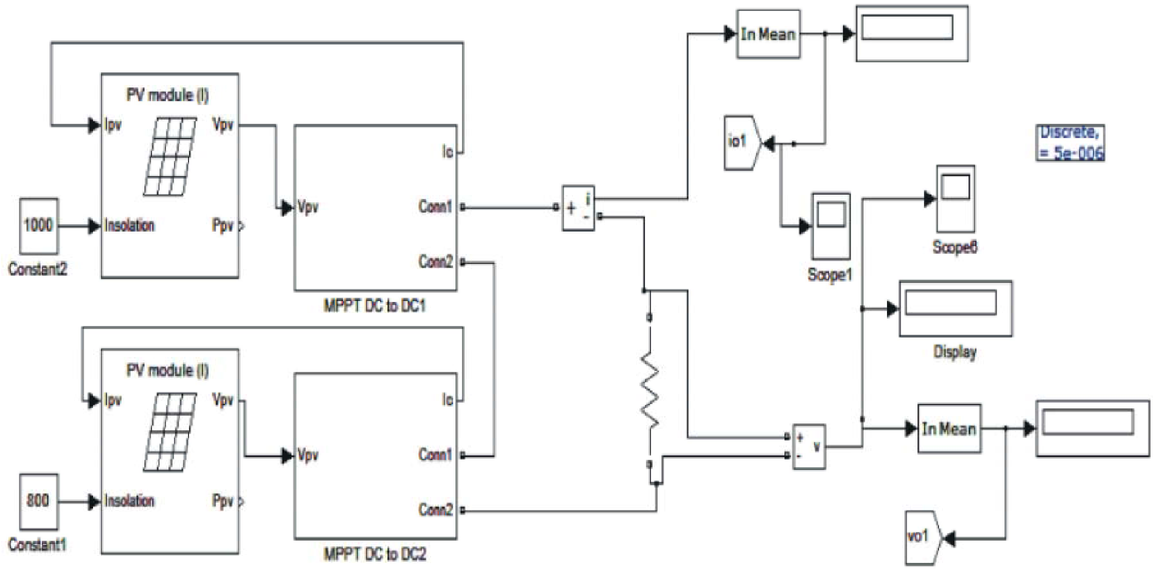

Fig. 11: Simulation Model of PSO based Distributed MPPT system

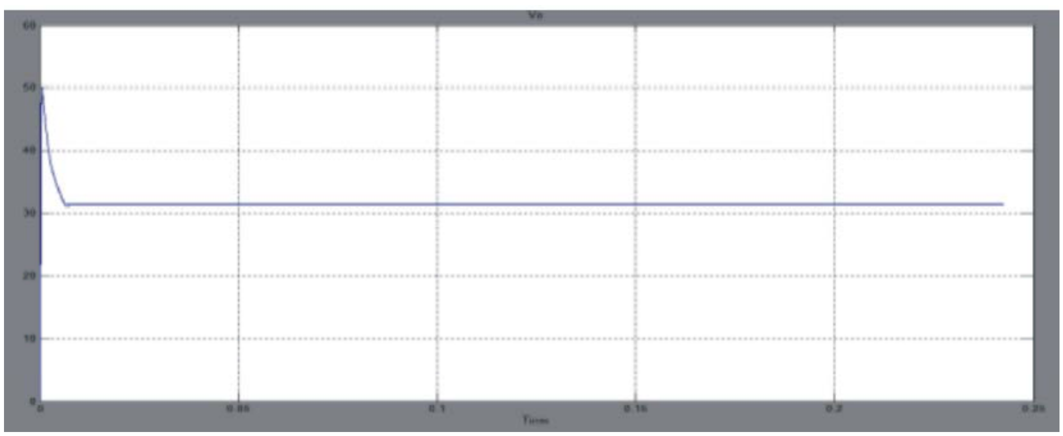

Fig. 12: Output voltage waveform of Boost converter 1

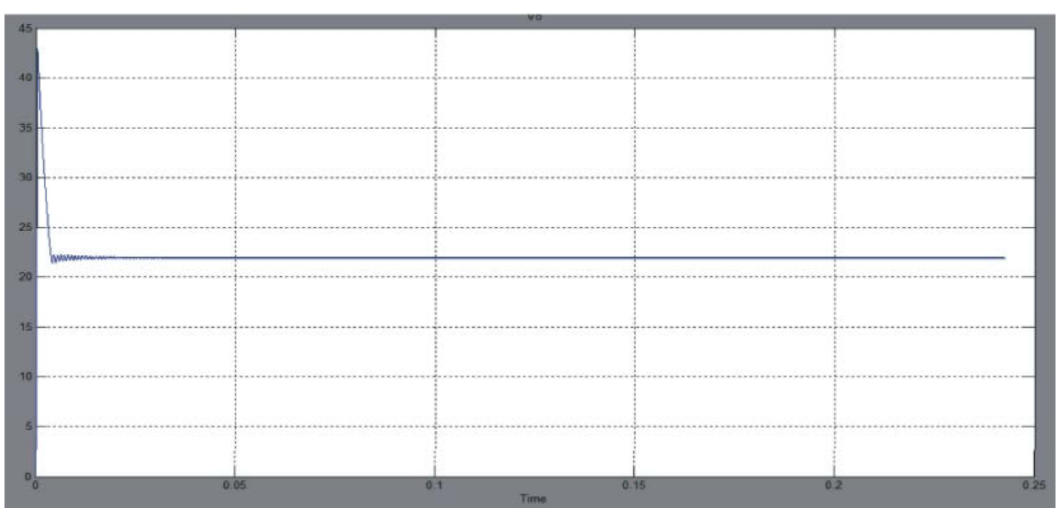

Fig. 13: Output voltage waveform of Boost converter 2

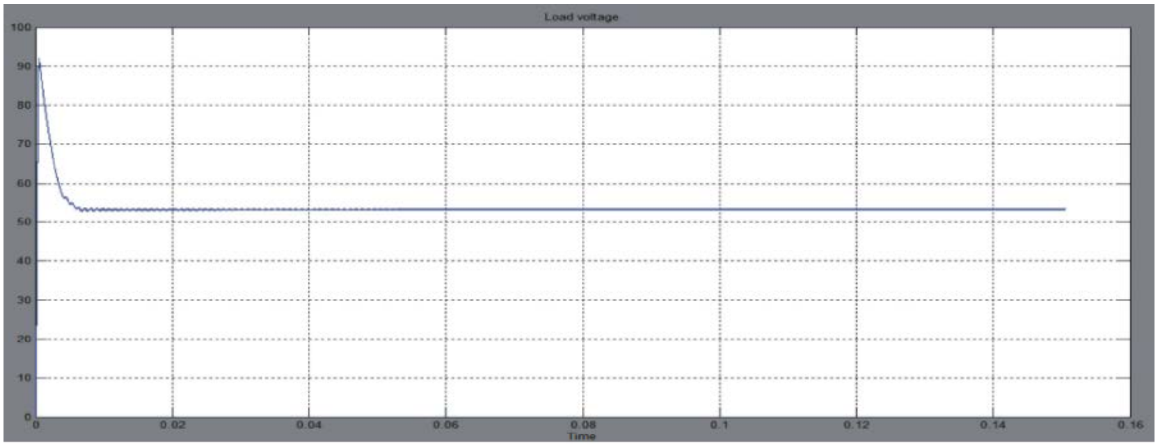

Fig. 14: Overall Output voltage waveform

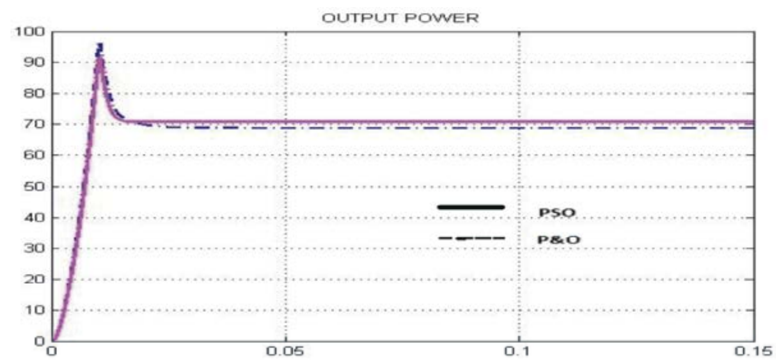

Fig. 15: Output Power Comparison of PSO and P&O under varying insolation condition

The obtained voltage and power values for Distributed MPPT system by using PSO method is tabulated in Table 4.

CONCLUSION

The Distributed Maximum Power Point Tracking (DMPPT) technique used in this project gives more power than the Centralised MPPT method. The usage of Centralised MPPT technique will not result in the extraction of maximum power during partially shaded condition. But the implementation of DMPPT technique yields the extraction of maximum power. This project evaluates and compares the PSO method with the conventional P&O algorithm based MPPT. To improve the tracking speed, a simple and efficient PSO method is used to reinitialize the particles to search for the new MPP, resulting in superior dynamic response. The results indicate that the proposed PSO gives a number of advantages it has a faster tracking speed, it exhibits zero oscillations at the MPP, it could locate the MPP for any environmental variations including partial shading condition and large fluctuations of insolation.

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