DOI: https://doi.org/10.24113/ijoscience.v4i4.129

MPSO-MPPT based Single Phase Grid PV System for Power Enhancement

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Abstract: **The solar power became a challenging area among other renewable energy sources (RESs) since the photovoltaic (PV) systems have the benefits of not inflicting pollution, having low maintenance, and durable operation life. Besides these benefits, a PV system has many drawbacks like significantly higher installation cost comparing some other RESs, and limited potency ranges between 9–18%. The feasibility analyses have a good role so as to work out the foremost appropriate plant site before installation. On the other hand, the operating analyses and enhancements supported maximum power point tracking (MPPT) are quite necessary to extend the harvested total energy. To maximize the performance of solar photovoltaics (PV) under dynamic climatic conditions, MPPT (Maximum Power Point Tracking) controllers are integrated into photovoltaic systems. This research presents a modified PSO algorithm based on the method of tracking the maximum global power point used for photovoltaic systems with variable co-efficient. The modified PSO (MPSO) algorithm is able to trace the maximum global power point faster. This improves the effectiveness of follow-up. Simulation results show that MPSO coordination control methods have better tracking accuracy as compared to P&O as well as PSO MPPT Technique. This also improves the energy efficiency of the photovoltaic system.**

Keywords *:*PV System, DC-DC Converter, PWM, Voltage & Current Control, MPPT Technique, PSO, P&O, Power Efficiency

1. INTRODUCTION

Solar energy is one of the fastest growing fields of renewable energy [1–3]. The main advantages of photovoltaics include its applicability in most regions of the world, both in industrial and household applications. In order to achieve an optimum efficiency of photovoltaic modules, it is necessary to use the MPPT control algorithm of the inverter circuit connected to the panel. The maximum power point tracking (MPPT) is an algorithm that's related to dc-dc power converters and inverters to trace maximum power point during energy conversion method [3]. Thus, the generated energy is maximized in this approach. Although there are many strategies planned to implement an MPPT system, there are two algorithms referred to as "perturb and observe" (P&O) and therefore the "incremental conductance" strategies are widely used since they're commercially preferred. The recent researches on MPPT algorithms exhibited that a lot of sophisticated algorithms yield higher outputs examination to widely known basic methods [4]. Therefore, a large kind of numerical strategies as well as fuzzy logic, neural networks and different computational strategies are planned. Though these recent algorithms need enhanced quality, they simply compete with malfunctions of previous methods in terms of partial shading, misdirection during tracking, power fluctuations around MPP, and inadequate performance at low irradiance.

1.1 Photovoltaic Energy Conversion

A PV energy conversion system consists of a PV module, a dc-dc device, an electrical converter, and ideally an energy storage system (ESS). The PV module is established by PV cells that are series and parallel connected to generate the specified rated power. The cells are made in monocrystalline or polycrystalline structure relying to the purity of semiconductor [5–7]. The polycrystalline cells that give limited potency around 13–14% are less economical comparing to the monocrystalline that the efficiency will increase up to 20. This circuit shown in Fig 1 includes a photocurrent source, a diode, and serial and shunt resistors that are referred to as one-diode or five-parameter model [8]. The calculations of the one-diode model are depended to the output current:

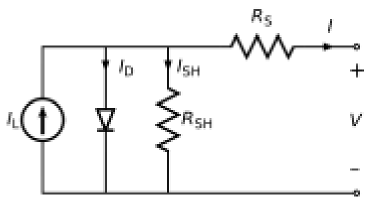

Fig.1. Single-diode electrical equivalent of a mono or polycrystalline PV cell

$$I_o = I_{PV} - I_D(V) - I_{SH}(V) \quad (1)$$

Where (V) shows the dependency of diode current and resistor current to the terminal voltage whereas they're independent from irradiation value.

I_D is current of the diode.

A PV module consists of variety of series cells NS whereas the cells are connected in series and parallel in PV arrays as shown in Fig. 2 wherever the arrangement defines the maximum output voltage V_M and maximum output current I_M.

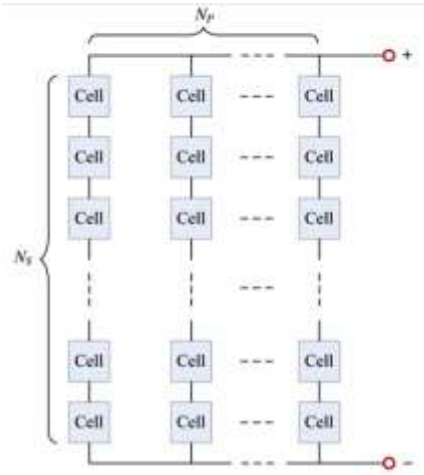

Fig.2. Electrical Connection Diagram of a PV Array

2. SOLAR POWER CONVERSION AND MPPT

The solar energy generation systems have attracted in depth attention in many application areas like agricultural, residential, and even industrial sites. Moreover, the sensations associated with greenhouse emissions and carbon footprints are key factors to promote the use of solar energy systems. Nowadays, the installation costs are reduced and overall potency of a PV system is increased comparing to a few decades ago [8-12].

The complete diagram of a solar power generation system with grid-connection is represented in Fig. 3. The solar panel may be a combination of PV modules serial and parallel to get the desired power in various voltage and current ratings. The power conversion stage consists of dc power interface and its ac conversion pairs. The dc-dc converters are wont to stabilize the intermittent characteristic of solar array that's significantly depended to solar irradiation and ambient temperature [13]. the ability conversion structure are often in single-stage or double-stage interface wherever the single-stage includes simply a dc-ac inverter whereas the double-stage consists of dc-dc converter and dc-ac electrical converter as seen in Fig 3.

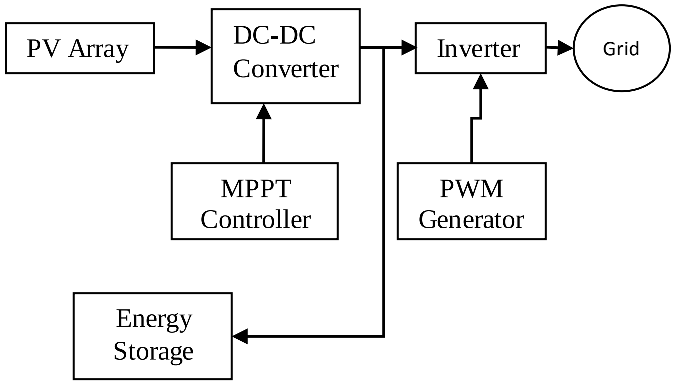

Fig.3. Block Diagram of a Solar Power Generation System

The single-stage interface lacks in the stabilizing the dc bus voltage against speedily variable dc output of solar panel. However, the electrical converter needs operative an algorithm to trace the utmost power point so as to match dc bus voltage of solar panel. However, it's impractical to sustain optimum matching at all radiation levels since the utmost power point rapidly fluctuates relying to the radiation and temperature. This operation will be performed in large-scale solar plants wherever the generated dc bus voltage excesses the specified offer voltage of inverter [11]. A dc-dc convertor is connected between solar panel and electrical converter to match the specified dc bus voltage within the double-stage power conversion system. The dc-dc convertor handles the MPPT operation and therefore the dc bus voltage is matched at this first stage. The MPPT algorithm of converter will increase or decreases the dc bus voltage in keeping with varied atmospheric condition and maintains the match between dc supply limits of inverter. The MPPT algorithm controls the duty cycle of dc-dc converter wherever it changes the regenerate dc voltage level by adjusting the operation amount of semiconductor switch within the topology. Thus, the maximum power is extracted from solar panel by suitably matching I-V balance of solar modules. The widely used dc-dc converter topologies are Buck-Boost and Cuk besides classical buck or boost topologies in solar energy generation systems. The second interface employed in double-stage is electrical converter that converts the dc bus voltage to ac power wherever the converted ac power is either provided to the standalone loads or is injected to the utility grid [12-15]. The electrical converter topology to be employed in this interface depends to the power level wherever two-level or multilevel topologies are often chosen. The MPPT operation of the PV panels is performed centrally at the dc-ac electrical converter. the main benefits of this scheme are reduced cost of electrical converter and decreased shift losses due to distinctive converter structure [16]. However, the central converter usage causes to a main disadvantage in nonheritable energy state since it's controlled by one MPPT wherever the individual MPPT support isn't obtainable for every PV strings. Thus, the acquired maximum power level is limited below shading, thermal variations, aging or disorientation of PV strings [17].

3. PROPOSED SYSTEM ARCHITECTURE

The complete scheme of the single-phase grid-tied PV system is shown in Fig. 4, which includes the PV array, Boost Converter, the single-phase H-bridge inverter, the PLL system, PSO-based MPPT algorithms, and the DC-bus voltage and AC-current regulator.

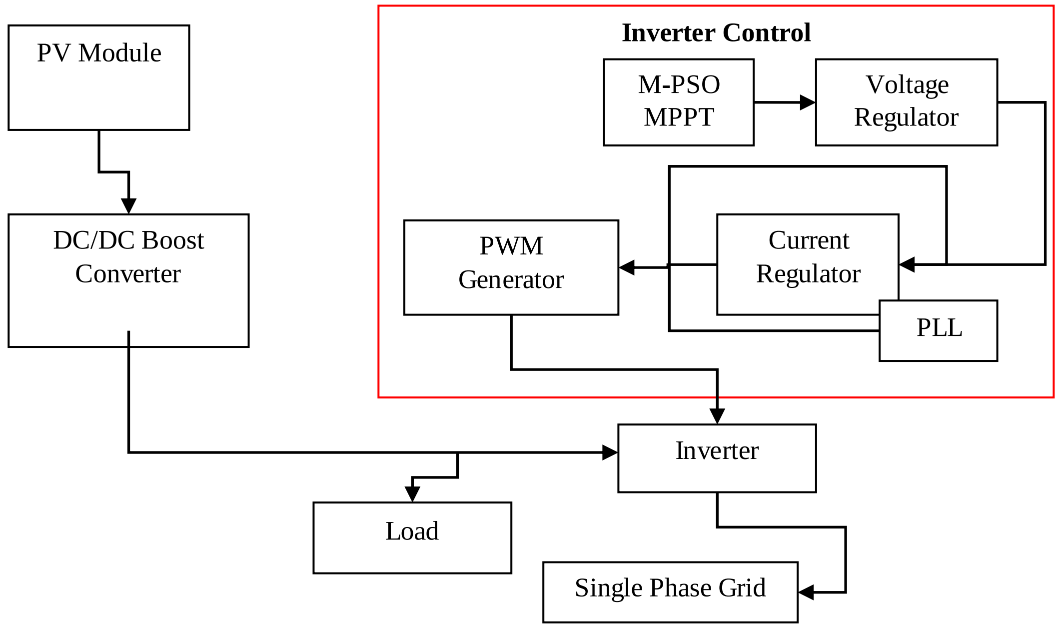

Fig.4. M-PSO based Single Phase PV Grid System

PV Array

The solar cell equivalent electrical circuit is considered as a current source where the PV cell output current are given in equation 3.1.

$$I_{pv} = I_{ph} - I_r \left[e^{q\left(\frac{V + i_{pv} R_S}{\eta k T}\right)} - 1 \right] - \frac{V + i_{pv} R_S}{R_p} \qquad (2)$$

Where, I_{ph} is the photocurrent, Ir is the reverse saturation current, Rs are the series and shunt resistance, q is the electron charge; η is the ideality factor of the junction p-n; k is the Boltzmann constant; T represents the ambient temperature, in Kelvin.

Boost Converter

A boost converter is a DC-to-DC power converter that steps up voltage from its input supply to its load. It is a class of switched-mode power supply (SMPS) containing a diode and a transistor and at least one energy storage element i.e. a capacitor or inductor.

MPPT Controller

The Maximum Power Point Tracking (MPPT) controller is based on the 'Perturb and Observe' technique and Particle Swarm Optimization (PSO) technique. This MPPT system automatically varies the V_{dc} reference signal of the inverter V_{dc} regulator in order to obtain a DC voltage which will extract maximum power from the PV string [18-20].

Since the photovoltaic system works by injecting power into the grid and simultaneously to the APF, the intermediate circuit voltage must be controlled so that the intermediate circuit voltage (V_{dcmin}) ensures correct operation of the connected inverter. to the network. In other words, the DC bus voltage must be controlled based on the amount of energy available in the PV array. When the power generated by the photovoltaic generator is sufficient, considering the favorable environmental conditions (solar radiation and temperature), the voltage reference of the DC Vdc bus is always defined by the MPPT algorithm so that V_{dc} = VMPP is greater than V_{dcmin}. In this case, the energy generated by the photovoltaic generator is completely introduced into the network. On the other hand, in adverse environmental conditions where the voltage at the maximum output power conditions (VMPP) is insufficient to maintain the intermediate circuit voltage, the algorithm sets the voltage reference of the intermediate circuit to a constant value (V_{dc}). = VMPP).

PI Controller

The system also uses a PI controller. The task of the MPPT algorithm is simply to calculate the reference voltage V_{ref} at which the operating voltage PV must move to obtain the maximum power. This process is repeated periodically at a slower pace. The external control circuit is the PI controller which controls the input voltage of the converter. In this simulation, we assume that KP is 0.15 and KI is 6.5. A relatively high KI value ensures that the system stabilizes at a higher speed. The PI controller works to minimize the error between V_{ref} and the measured voltage by varying the duty cycle through the switch.

V_{dc} Regulator

It determines the required active current reference for the current regulator.

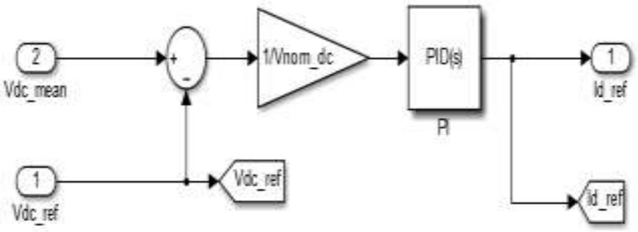

Fig 5. V_{dc} Regulator

Current Regulator

Based on the current references (reactive current), the regulator determines the required reference voltages for the inverter.

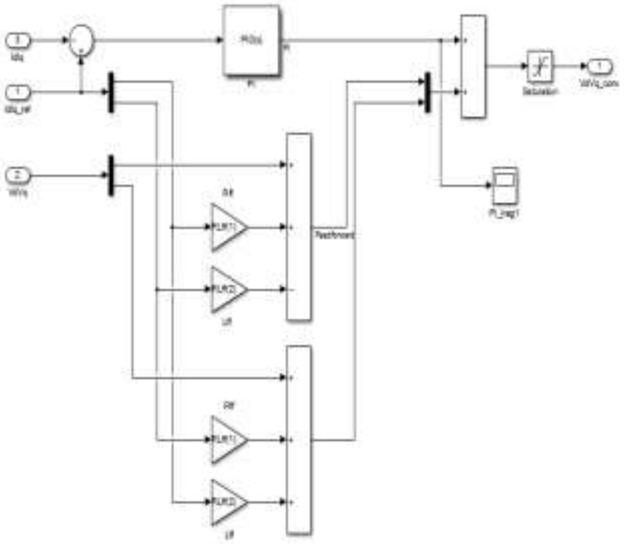

Fig 6. Current Regulator

PLL & Measurements

Required for synchronization and voltage/current measurements. The PLL system estimates the utility phase-angle that is used to generate the coordinates (sin(θ), cos(θ)) of the unit vector employed in the SRF-based algorithm, as well as to generate the sinusoidal current (i_{pv}) that composes part of the total PV reference current.

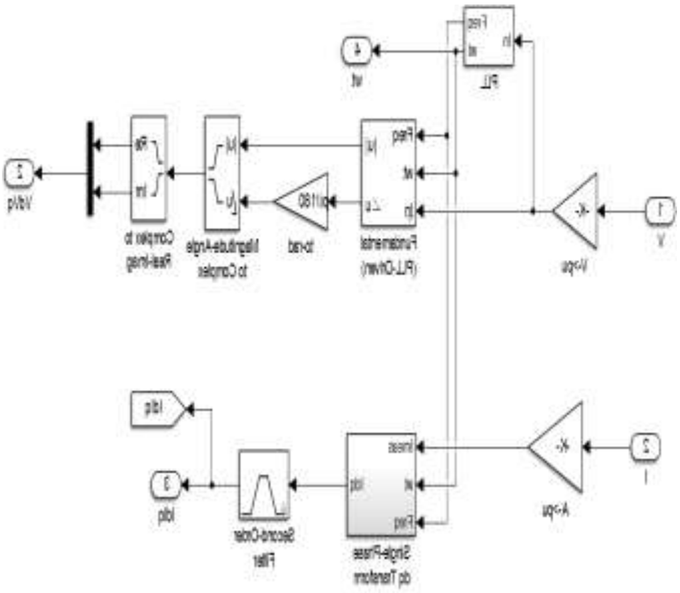

Fig 7. PLL & Measurements

PWM Generator

Use the PWM bipolar modulation method to generate firing signals to the IGBTs

Inverter Controlling

In this research, the photovoltaic system realized consists of a single conversion stage in which the photovoltaic generator is connected directly to the inverter connected to the grid. The algorithm used to execute MPPT is based on the PSO method. In other words, the proposed modified MPPT MPO technique is used to trace the global maximum power point (GMPP) of the photovoltaic array. Unlike MPPT techniques based on the Local Maximum Power Point (LMPP), such as P & O [14] and PSO, they improve the overall performance of the photovoltaic system.

In this section the descriptions of MPPT techniques based on PSO and P&O methods are presented.

Modified PSO MPPT Technique

Particle swarm optimization PSO is a novel swarm optimization algorithm that is firstly proposed by Kennedy as an evolutionary algorithm based on behavior of birds. PSO uses a set of particles that each one suggests a solution to the optimization problem [13]. It is based on the success of all particles that emulates a population where the position of each particle depends to the agent position to detect the best solution P_{best} by using current particles in the population G. The position of any particle xi is adjusted by

$$x_i^{k=1} = x_i^k + v_i \quad (3)$$

where the velocity component vi represents the step size and is calculated by:

$$v_i^k = wv_i^k + c_1 r_1 (P_{best_i} - x_i^k) + c_2 r_2 (G - x_i^k) \quad (4)$$

where x is the inertial weight, c_1 and c_2 are the acceleration coefficients, r_1 and r_2 are random values that belong to the interval of [0, 1], P_{best_i} is the best position of particle i, and G is the best position in the entire population.

A typical MPPT method should be used to integrate PSO algorithm to controller.

The most common integration is based on the Hill-Climbing algorithm or P & O for PSO. The flow diagram of an MPPT PSO algorithm is shown in Figure 8. The operation shown in the flowchart can be analyzed in five steps: initialization, fitness evaluation, updating of the best individual and overall value, updating of the speed and position of each particle and determination of convergence. In the first phase, the particles are randomly initialized in the distribution space or initialized on the described grid nodes that cover the search space [14].

Likewise, the initial velocity values are randomly defined. The fitness value of each particle is evaluated in the second step in which the suitability assessment is performed to provide a candidate solution for the objective function. The best individual and general fitness values are determined in the third phase

where pbest_i and gbest are determined. Thus, the positions will be updated and replaced with the best fitness values if they are found. The speed and position of each particle are updated in the fourth step. The last step in the flowchart examines the convergence criterion. If the criterion is satisfied, the process is complete. Otherwise, the iteration number is incremented and the procedure returns to step 2.

The application of PSO MPPT in a photovoltaic system depends on the coherent definitions of the two systems. The positions of the particles are used to define the working cycle of the DC converter and the function of evaluating the physical fitness value represents the output power of the PV generator. The algorithm's success is achieved by increasing the number of particles that provides a more accurate MPP tracking operation, even for shading problems. On the other hand, a larger number of particles lead to greater complexity. The range of particles is generally chosen because the number of cells connected in series in a PV array is such as to obtain the most precise operating time.

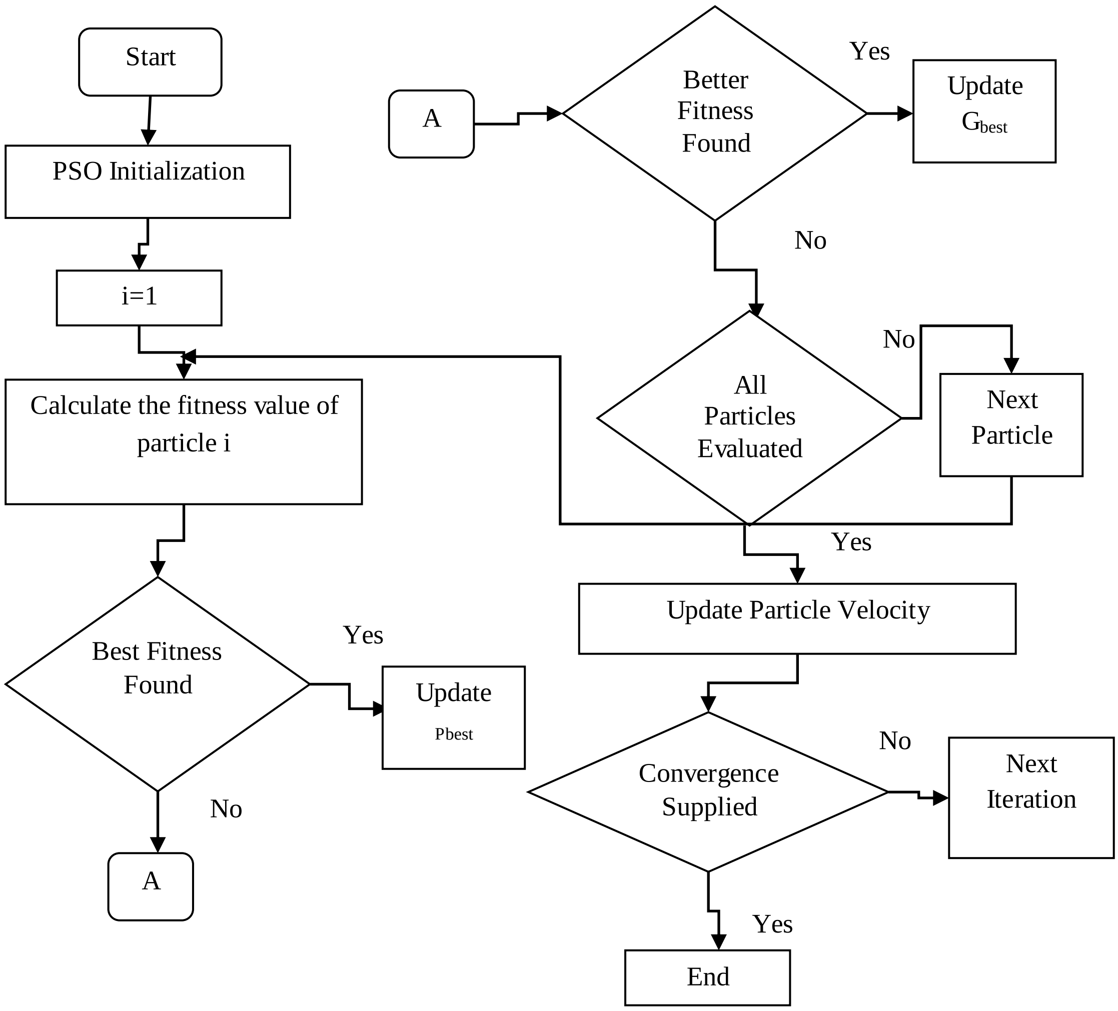

Fig 8. PSO-MPPT Technique

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The algorithm updates the swarm as following :

For each particle
Initialize particle
Do
For each particle
Calculate fitness value
If the fitness value is better than the best fitness value (p_{best}) in history set current value as the new p_{best}
End
Choose the particle with the best fitness value of all the particles as the g_{best}
For each particle
Calculate particle velocity
Update particle position
End
While maximum iterations or minimum error criteria is not attained.

Calculation of fitness function

Each Particle's fitness function is calculated using p_{best} as well as g_{best} which is best position among entire group of particles.

In each generation velocity and position of each particle is updated using following equation

$$v = w*v + c_1 * r_1 * (p_{best} - present\_position) + c_2 * r_2 * (g_{best} - present\_position)$$

$$present\_position = present\_position + v$$

Where, v is the particle velocity
present_position is the current particle (solution)
p_{best} and g_{best} are defined as stated before.
r_1 and r_2 is a random number between (0,1).
c_1, c_2 are learning factors which is calculated using acceleration coefficients (ϕ_1 and ϕ_2).
C_1=1+rand();
C_2=ϕ-rand();
Where $\phi = \phi_1 + \phi_2$
w=inertia weight which is calculated as:
w= K_i*rand()
where K_i=1/N, N is number of particles
rand() is a random parameter uniformly distributed in [0,1].

In the proposed strategy every particle uses a different inertia weight to provide exploitation capability to the particles. The two learning factors, C_1 and C_2 are other two important parameters deciding the performances of a MPSO.

4. RESULT ANALYSIS

The proposed system presents power control strategies for a single phase solar power grid system with a versatile power transmission. This system allows the maximum use of freely available renewable energy sources such as solar. An P&O, PSO and MPSO MPPT algorithm is used with the system to control the power generation. The inverter converts DC power from an traditional power supply to an AC power supply that can be used for the connected load.

The application of PSO MPPT in a PV system is depended to the matching definitions of both systems. The particle positions are used to define the duty cycle of dc converter, and the fitness value evaluation function stands for the output power of PV array. The inverter converts DC power from an traditional power supply to an AC power supply that can be used for the connected load. This solar PV system operates under variable irradiance condition. The presented PSO-based MPPT technique is used for tracking the global maximum power point (GMPP) of the PV array. Different from the MPPT techniques based on the local maximum power point (LMPP), such as the P&O technique, improving the overall PV system performance.

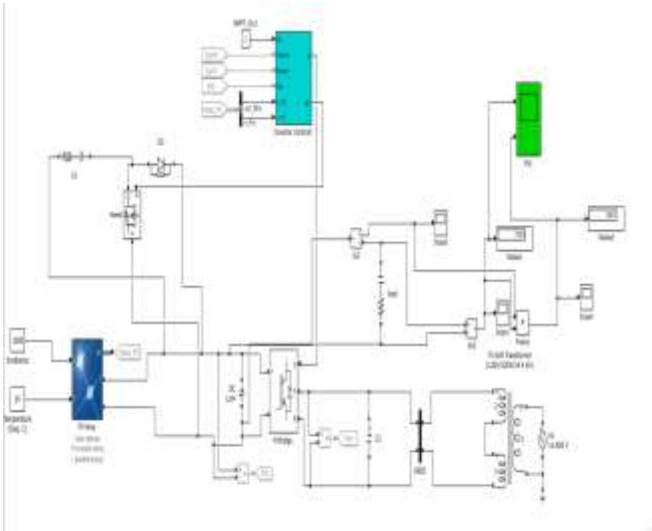

Fig 9. Single Phase Grid Connected PV System based on MPSO-MPPT

Figure 9 illustrates the single-phase grid connected PV System based on MPSO MPPT technique. The system is designed by using solar PV array along with boost converter and h-bridge MPSO MPPT controlled inverter which is connected to the single-phase grid system.

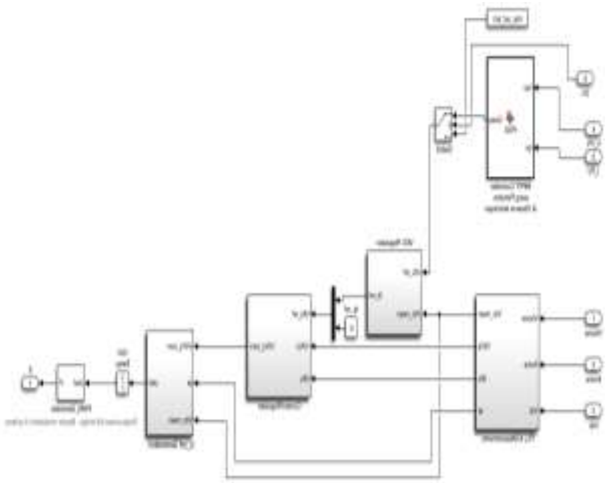

Fig 10. Inverter Control of PV System based on MPSO MPPT

Figure 10 illustrates the inverter control single-phase grid connected PV System based on MPSO MPPT technique. The inverter is modeled using a PWM-controlled single-phase full-bridge IGBT module (H-bridge).

The system parameters used in PSO and MPSO scenario are as shown in Table I as well as result obtained of both algorithm are illustrated in Figure 11-18.

Table 1: System Parameters for PSO and MPSO

S. No.	System Parameters	PSO	MPSO
1	Maximum PV power	245W	245W
2	Maximum power point voltage	30.8 V	30.8 V
3	Maximum power point current	7.96A	7.96A
4	Open circuit voltage	37.5V	37.5V
5	Short-circuit current	8.49A	8.49A
6	Nominal utility frequency	60 Hz	60 Hz
7	DC-bus capacitor	2115 µF	4000 µF
8	PWM (K_P)	0.15	0.15
9	PWM (K_I)	6.6	6.5
10	Inductive Filter Resistance	0.48 ohm	0.4 ohm
11	Inductive Filter Resistance	1.5 mH	2 mH
12	PSO acceleration Co-efficient	1.5 and 1.2	1.5 and 1.2
13	PSO inertia weights	$W_{initial}$ =0.02, W_{final}=0.9	$W_{initial}$=random in range between 0,1
14	Load Capacitance	940 µF	940 µF
15	Load Resistance	100	100

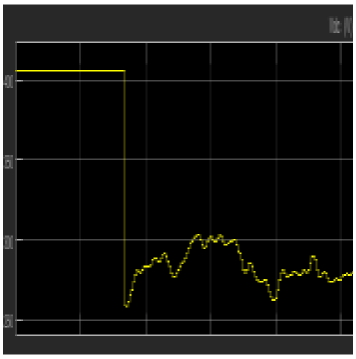

Fig 11. V_{dc} (mean) for PSO MPPT

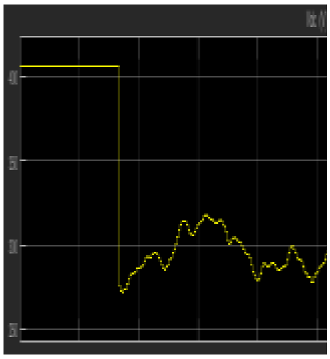

Fig 15. V_{dc} (mean) for MPSO MPPT

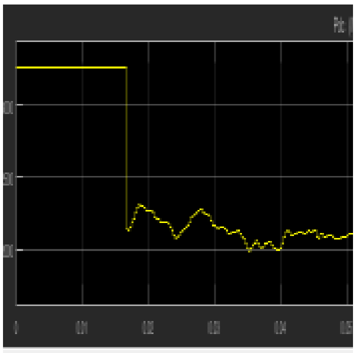

Fig 12. P_{dc} (mean) for PSO MPPT

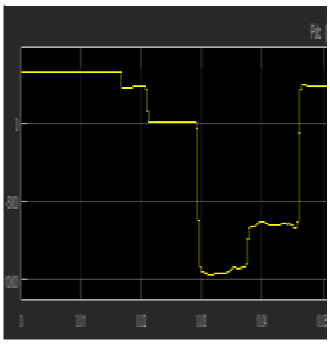

Fig 16. P_{dc} (mean) for MPSO MPPT

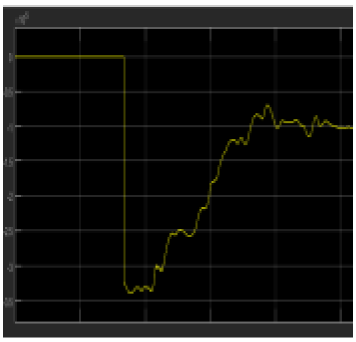

Fig 13. Active Power of Grid System for PSO MPPT

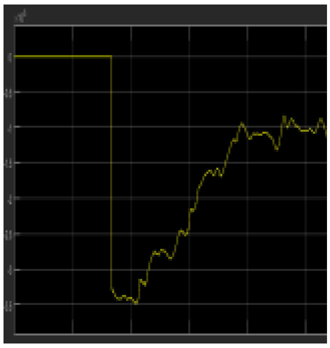

Fig 17. Active Power of Grid System for MPSO MPPT

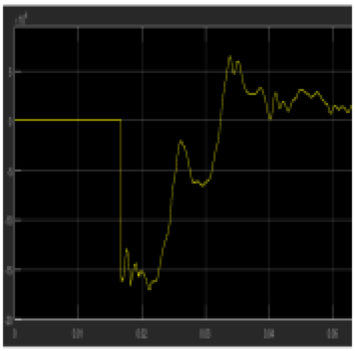

Fig 14. Reactive Power of Grid System for PSO MPPT

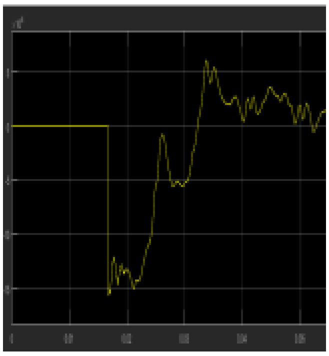

Fig 18. Reactive Power of Grid System for MPSO MPPT

The comparison analysis between the MPPT-based on PSO and MPSO are based on the PV array is illustrated below. The PSO and MPSO MPPT algorithms are evaluated considering solar radiation intensity where the quantities of voltage and power involved in the PV system operation are shown in below figures. As can be observed, both the MPSO and PSO MPPT algorithms are able to search the GMPP available in the PV array.

Table II: Comparative Analysis of PSO and MPSO MPPT Techniques

Parameters	Values (Simulation for 0.1 sec)	
	PSO MPPT	MPSO-MPPT
Voltage	222.8V	310V
Power	87.23W	392W

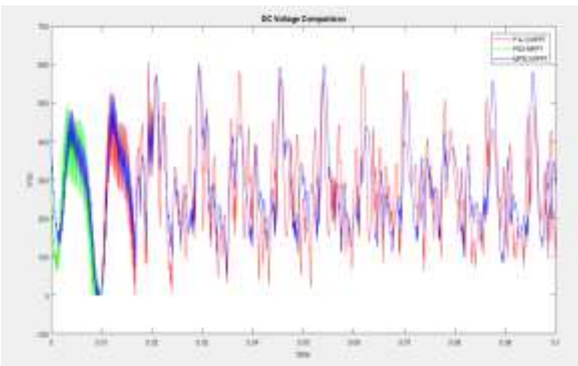

Fig 19. Comparative Analysis of Mean DC Voltage

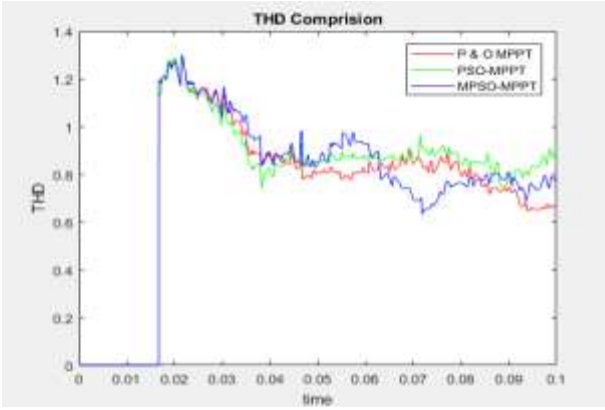

Fig 20. Comparative Analysis of THD

By means of the simulation results, it can be observed that both MPPT algorithms reach the GMPP when the PV array is submitted to irregular solar radiation. Although the P&O algorithm reaches the MPP faster than the PSO-based MPPT, it can be observed that higher oscillations appear in steady state.

Total harmonic distortion, or THD is a common measurement of the level of harmonic distortion present in the systems. THD can be related to either current harmonics or voltage harmonics, and it is defined as the ratio of total harmonics to the value at fundamental frequency. From figure 20 it has been concluded that MPSO MPPT technique has lower harmonic distortion as compared to PSO-MPPT Technique.

5. CONCLUSION

Maximum Power Point Tracking (MPPT) techniques are used in photovoltaic systems (PV) to maximize the output of the photovoltaic generator by continuously monitoring the maximum power point (MPP), which depends on temperature and irradiation conditions. The problem of the MPPT has been addressed in several ways in the literature, but especially for low-cost implementations, the algorithm of detection of the maximum power point Perturb and Observation (P & O) is the most used method because its ease of implementation. A disadvantage of P & O is that the operating point of the steady state oscillates around the MPP, resulting in a waste of a certain amount of available energy; moreover, it is known that the P & O algorithm can be confused during these time intervals characterized by rapidly changing atmospheric conditions. The basic P & O algorithm is easy to implement, but it is difficult to get the exact MPP due to the oscillation. There is therefore a need to modify the basic P & O algorithm: the voltage and current are the parameters measured in the P & O algorithm.

The results of the experimental measurements are in accordance with the predictions of the P & O algorithm theoretical analysis. To maximize the performance of solar photovoltaics (PV) under dynamic climatic conditions, MPPT (Maximum Power Point Tracking) controllers are integrated into photovoltaic systems. This research presents a modified PSO algorithm based on the method of tracking the maximum global power point used for photovoltaic systems with variable co-efficients. The PSO algorithm is able to trace the maximum global power point faster. This improves the effectiveness of follow-up. Simulation results show that PSO coordination control methods have better tracking accuracy. This also improves the energy efficiency of the photovoltaic system.

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