High Performance Adaptive PSO MPPT Technique for PV Based Micro Grid for a Rural Area

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Abstract: As the world is switching over to renewable energy with solar energy as the most vital form of it, so it is essential to operate it in a manner that we can extract maximum efficiency from the photovoltaic panels. But due to some uncalled for scenarios when the PV panels are subjected to partial shading conditions its efficiency is greatly impacted. The MPPT here comes for its rescue. When PSC occurs the PV trajectories will be distinct and very complex due to various peaks available. The traditional MPPT techniques will fail to reach the Global Maximum Power Point and it usually stays at the Local Maximum Peak Point which surely would decline the performance and ability of the PV module. This research focuses on comparing the Particle Swarm Optimization approach and Perturb and Observe technique of MPPT for tracking peak power to identify the GMPP so as to attain the Maximum Power from the PV system. A rural area is selected as the demography of the location suits the proposed study. The load for the location is calculated and then both the algorithms are applied and their performance is analyzed in the study. The performance characteristics of the boost converter can be studied by varying its duty cycle with the two algorithms. This approach provides a high reliability robustness and proficiency towards MPP. The authenticity of this proposed algorithm was established using MATLAB/Simulink.

Index Terms: Partial Shading Conditions, Photovoltaic, Maximum Power Point MPP, Maximum Power Point Tracking MPPT, Global Power Point GMP, Particle Swarm Optimization (PSO), DC-DC Boost Converter, P&O MPP.
1. Introduction

The global increase in energy demand causing huge environmental pollution has inspired researcher and the technological growth in the field of renewable energy resources. In between these renewable sources the solar energy is playing a vital role for providing a clean power electrical source as it offers easy installation to the users in most of the frontages of buildings and roofs of residence. Therefore it becomes a necessity to improve its efficiency and performance of PV plants. A PV module is an arrangement of many solar cells connected in series and parallel combination and the PV models are then connected both in series and parallel so as to generate the necessary voltage or current for a particular application. But the previous output reduces when the current voltage curves of the PV cells are not identical due to uneven irradiation, cell deterioration, soiling, clouds and partially shading conditions [1]. Numerous MPPT techniques have been reported the most common algorithm being the per tube and observation method (P&O). In this method External circuit perturbs the array voltage and simultaneously measures the changes of the resulting output power. Though P&O is relatively easy and economical algorithm, it forces the system to fluctuate around the maximum power point rather than tracking it continuously, this makes the algorithm inefficient in steady-state conditions. Moreover the P&O algorithm does not work well if it is subjected to changing environmental condition as it is unable to distinguish if the change in power is because of the varying environmental conditions or is it the due to the perturbation that is within the algorithm. In IC (Incremental Conductance) method the derivation of the array power with respect to the voltage of the array is zero at MPP, to the right of MPP it is negative and to the left of MPP it is positive. The incremental conductance method has good performance under varying environmental conditions but due to the complex hardware and software requirements of this method the response time increases. Another method called fractional open circuit voltage (FOCV) method takes into account the relationships between VM the array voltage at which maximum power is obtained, VOC, the open circuit voltage so as to track the MPP. Like P&O, FOCV algorithm is inexpensive and less complex to implement. However the FOCV method tracks MPP based on the assume relationship between VOC and VM which is not appropriate. Hence it is not a true MPP tracker method. The undesirable complexities of fuzzy logic and neural network based algorithm makes it less preferred even though they have high performance and easy convergence for different environmental conditions [2]. A transient oscillations in the output voltage is generated by MPPT algorithm due to the rapidly changing nature of duty cycle for tracking MPP. Therefore the ideal MPPT algorithm would show minimal oscillations and would converge faster to track MPP. For producing constant output voltage from the converters PSO particle swarm optimization technique is used in solar PV systems. For PSC also it greatly improves the efficiency and performance of MPPT so as to improve output power[3-5]. PV system power generation reduces because of the mismatch in partial shading and panel design grading causing the adverse effects on the efficiency [6]. The proposed technique was simulated in MATLAB environment by subjecting the PV systems to varying irradiation. For different irradiations the Maximum output power is extracted using P&O and PSO Techniques. As PSO is a more advanced technique the power output with it is much better extracted than with P&O Model Under Partial Shading Condition.
2. Stand Alone PV System

Off grid solar installations are more in number in our country as in the rural area frequently faces power cuts where the power generation required is usually small and off grid solar installation helps meet the demand[7-8].

2.1. Calculation of load for the office:

Table 1 shows the load calculation.

So our load is approximately 8 KW. We are receiving electricity bill for one month if the bill is of 1200 units then for daily average requirement 1200/30=40KWh(Units)

2.2. Size of PV system

Our requirement is 40 kilowatt hours per day solar intensity is normally on an average available for minimum 5 hours. So the PV system requirement is 40/5=8KW.

Usually battery has losses during charging let us assume it to be 15 to 30% so the required system approximately is of 11 KW

2.3. Panel size and number of panels.

Panel size available between250 to 350 W. We can use 250 W, 44 panels
So 250*44=11000 W.

2.4. Area required for 11 kilowatt system normally area required for a 1 kilowatt system is 12 square feet. So for 11 kilowatt 132 square feet.

2.5. Size of Battery Backup:

Here required daily load 8KW. Battery is available in voltage range of 12 and 24 V.WH is to be converted into AH to determine the Battery Bank size. Here needed battery backup is 8 hours approximately=8KW*8hrs=64000Wh

If battery size is 300 ampere hour and 24 volts=64000Wh/24=2666.66Ah.
Approximately for 8 kilowatt load 2800 Ah of total battery bank is required for 8hrs of loading conditions .So 14 battery of 200 ampere hours and 24 volts will be needed . Required Voltage for charging is minimum 8 to 10% higher than the required voltage (14*24=336) due to losses. Approximately we can say required voltage is 370 V.
Charging current required for Lead Acid Battery should be around 10% to 15% of its ampere hour so here it would be around 20 to 25 amperes for 200 ampere hour. Thing to note is that it should never be greater than 25% of ampere hour to prevent battery expiration and thermal runaway.

### Table 1. LOAD CALCULATION

| S No | Appliances          | Wattage | Quantity | No of Hours | Load Calculation |
|------|---------------------|---------|----------|-------------|------------------|
| 1    | Ceiling fan         | 75      | 1        | 5           | 375              |
| 2    | Table fan           | 50      | 1        | 5           | 250              |
| 3    | Cooler              | 250     | 1        | 5           | 1250             |
| 4    | Laptop              | 100     | 1        | 2           | 200              |
| 5    | Tube light          | 40      | 1        | 1           | 40               |
| 6    | Tube light          | 20      | 1        | 1           | 20               |
| 7    | LED bulb            | 9       | 1        | 1           | 9                |
| 8    | LED bulb            | 5       | 1        | 1           | 5                |
| 9    | Light Bulb Incandescent | 40  | 1    | 1          | 40               |
| 10   | Air Conditioner (1 Ton,3star) | 1200 | 1 | 5 | 6000 |

**TOTAL LOAD(W)**

**8189W**

### 3. PV System Formulation

The PV panels consist of PN junction made of thin wafers or layers of semiconductors. At night or in dark the output characteristic i.e ,the I-V characteristics of the solar cell are similar to that of a diode that is they are exponential. The PV panels when they are exposed to sunlight the sun's Photon which is having a greater energy than that of the semiconductors band gaps are absorbed this creates the electron hole pair ,these Carriers under the influence of the electric fields are swept apart in a PN junction creating a current proportional to the radiation incident on [9-13]. This current is circulated externally when short circuited by intrinsic PN junction diode and is circulated internally by intrinsic
PN junction diode. The cells are made of crystalline silica materials the proportionate model of PV cell presented in Figure 1.

![Figure 1. Single Photovoltaic Cell Equivalent Circuit Diagram](image)

From Kirchhoff’s current law we write the load current as equation 1

\[ I = I_{sc} - IR \left[ e^{\frac{q(I\cdot R_s + V)}{A \cdot K \cdot T}} - 1 \right] - \left[ e^{\frac{I\cdot R_s + V}{R_p}} \right] \]  

(1)

Where

- \( I \): The output current from cell (A)
- \( V \): The output voltage from cell (V)
- \( P \): power of cell (W)
- \( I_{sc} \): The short circuit current for the cell (A)
- \( I_R \): reverse saturation current (A)
- \( q \): electron charge C
- \( K \): Boltzmann constant (1.38 * 10^-23 J/K)
- \( T \): temperature of module (K)
- \( A \): diode identity factor (1.3)

The bypass current \( I_P \) is close to zero and the resistance in parallel \( R_p \) is small amount the equation 1 for the output current is rewritten as

\[ I = I_{sc} - IR \left[ e^{\frac{q(I\cdot R_s + V)}{A \cdot K \cdot T}} - 1 \right] \]  

(2)

Single PV cell unit is not enough to extract sufficient power for satisfying for fulfilling the different demands. Many PV cells are stacked in parallel and series combination to obtain the maximum energy for utilization. This architecture of cells is called PV module, they have the capability to produce power as per the demand. Let’s assume \( N_p \) is the quantity of cells arranged in parallel while \( N_s \) is the cells in series equation(2) is transformed into equation(3)

\[ I = N_p \cdot I_{sc} - N_p \cdot IR \left[ e^{\frac{q(N_p\cdot I\cdot R_s + V)}{A \cdot K \cdot T \cdot N_s}} - 1 \right] \]  

(3)

4. Bypass diodes for PV system

When the models are installed some of the portion of the modules might get covered by clouds tall buildings Shadow of other PV Panels one over another, shadows from trees, etc. This might cause
less current supplied by the PV cell which are covered than those which are non covered [14]. Contrary to this solar cells must have same current for all branches of PV models. If the output of the cell is close to zero or zero this will cause the cell to work in negative region of voltage. Consequently the voltage of the entire outlet will reduce. This will cause a hotspot as the cells now start absorbing power and will heat up. Figure 2 shows partial shading conditions due to non uniform radiation intensity on PV systems due to clouds. Result of this is lot of power will be consumed and most of the power of shaded PV array will be condensed with significant amount. To reduce these self-heating effects of the modulus bypass diodes are connected crosswise with the array. The PV trajectory establishes many maxima or peak and displays the difference of maximum power point in the models. Figure 3 the first peak shows the maximum power point with bypass diodes while the second peak demonstrates the NPP without presence of bypass diodes.

![Figure 2](image)

**Figure 2.** PSC caused by the clouds on PV System
5. Different Parameters Used In Standalone PV Module

The Tata power solar system TP 250 MBZ PV module is used, the electrical characteristics are
\( N_p=4, \) 
\( T_{ref}=25 \) °C, \( V_{oc}=36.8 \) Volt \( I_{sc}=8.83 \) amps, 
\( K =1.380658e^{-23}, q=1.6*10^{-19} \) \( E_g=1.1, \) \( I_{r}=[1000 \ 900 \ 600] \)

6. Influence of PSC on PV system

The PSC has two impacts on solar modules, first the hotspot phenomena due to partial shading causes damage which causes the output power of the system to be reduced, secondly the local peaks in the PV trajectory causes conventional techniques like INC and P&O to fail as they cannot distinguish between LMPP and GMPP and it will remain in LMPP which will result in lot of loss in the power[15-18]. During partial shading the PV trajectory of module has various peaks as shown in Figure 3. The INC algorithm will track LMPP if it is positioned near it and will cause lot of power loss so it is compulsory to implement GMP tracking algorithms which can ignore all LMP in PV systems. This paper proposes the dynamic PSO approach for tracking of GM PP.
In P&O algorithm we perturb the PV panels operating voltage with small increments, if the change in $\Delta P$, is positive we are going in the direction of MPP so we keep on perturbing in that same direction[19] and if $\Delta P$, becomes negative it means we are going away from MPP and therefore the sign of perturbation needs to be changed. Figure 6 is the graph between PV panels voltage and the output power for a given irradiation. The point marked MPPT will be the maximum power point of the theoretical Maxima of PV. Consider two points A and B point. The point A is shown on the left side of MPP which means by providing a positive perturbation to the voltage we can move towards maximum power point on the other hand the point B which lies on the right hand side of the MPP here if we give a positive perturbation the value of $\Delta P$ becomes negative therefore it is imperative to change the direction of perturbation for reaching MPP. Here we use only one sensor for sensing the voltage of the PV array which reduces the cost of this algorithm and hence makes it easier to implement[20]. Even though the time complexity for this algorithm is less but on reaching near to MPP this does not stops and keeps on pertubing in both the direction. Here when the algorithm has come closer to MPP we can set error limits appropriately or we can use updated functions but this would
increase the algorithms time complexities even though P&O method has simplicity but its performance depends majorly on the trade off between the tracking speed and the oscillation that occurs around MPP. A small perturbation will increase the tracking speed but at the same time increases oscillations another disadvantage of P and O algorithm is under rapid fluctuations of irradiance the algorithm is likely to lose its direction of tracking MPP, this happens because under partial shading condition the PV curves are characterized by multiple peaks. Since P&O algorithm is unable to discern the MPP correctly it's efficiency and performance is very poor under such conditions.

![Figure 6. Solar Panel Characteristics showing MPP and its operating points A and B](image)

### 8. PSO algorithm for tracking GMPP

PSO is simple intelligent meta heuristic optimization approach it was proposed by Ebehard and Kennedy in 1995 [21]. PSO is an evolutionary algorithm search optimization technique. The idea is inspired by attitude of birds in a group to solve difficulties involved during a search process or in optimization. In PSO each particle of the swarm will evaluate at various positions in a search space of n dimension and will travel with the velocity depending on its personal best position i.e (Pbest) and the best position among the group that is Global best (Gbest)[22]. Each particle in a specified group exchanges the information in its process of search, that is each group will try to reach close to the optimum solution. The velocity and position of each particle is expressed as equation [4 ] and [5]

\[
v_i(k + 1) = wg \cdot v_i^{(k)} + c_1r_1 \left( p_{bi}^{(k)} - S_i^{(k)} \right) + c_2r_2 \cdot (G_b^{(k)} - S_i^{(k)}) \quad (4)
\]

\[
s_{i}^{(k+1)} = s_{i}^{(k)} + v_i^{(k+1)} \quad (5)
\]

Where -

- I: The number of particles
- wg: The weighting function
- vi: The particle I velocity at iteration k
cj: Time bearing social and cognitive factor
ri: The random variable is distributed uniformly (0 to 1)
Sj: The current position of agent I at iteration k
Pbi: The best position of agent I
Gb: The best position in the group

The value of inertia weight should be kept low so that the careful optimization can be made and this will make the algorithm tracking capacity strong enough to achieve the precise solution. Its value usually ranges from 0.4 to 0.9.

\[ w(k) = w_H - \frac{k}{k_H} \cdot (w_H - w_L) \quad (6) \]

In equation (6) \( w_H \) and \( w_L \) are the higher and lower values of \( w \) and \( k_H \) is the highest number of iteration.

\[ c_1(k) = C_1 \cdot H - \frac{k}{k_H} \cdot (C_1 \cdot H - C_1 L) \quad (7) \]

\[ c_2(k) = C_2 \cdot L - \frac{k}{k_L} \cdot (C_2 \cdot H - C_2 L) \quad (8) \]
In question 3 c1 and c2 can distribute the tracking capabilities of PSO they do so by influencing the directions of different particles. Usually c1 and c2 range from 0 to 2. The algorithm described above of the PSO will be utilized to preserve the GM PP tracking techniques during PSC for PV system. The PV trajectory will become very complex and more distinct due to the availability of various peaks. To solve this issue the PSO must be changed to encounter the applied observations regarding PV system. The elaborated flowchart of the PSO algorithm is presented in Fig. 7. The important constraints used in the PSO is listed in Table 2. The proposed PSU approach is very efficient, independent of the systems and can be executed by means of controller. The fitness function of PSO algorithm for tracking GMPP is express as equation 9.

\[
\text{fitness}(V_p, I_p) = V_p \cdot I_{sc} - V_p \cdot I_{R} \left[ e^{q(V_p + I_p \cdot R_s) / kT} - 1 \right] \tag{9}
\]

| Parameters                | Symbol | Value |
|---------------------------|--------|-------|
| No of Particles           | u      | 4     |
| Weight of Inertia         | w      | 0.4   |
| Cognitive Coefficient     | c1     | 1.2   |
| Social Coefficient        | c2     | 2     |

Steps involved in PSO algorithm for extracting GMPP are as follows:
1. Initially random particles in the search space originated in PSO. the velocity of these particles are also randomly chosen.
2. Provide the solution of candidates to fitness function for evaluation and obtaining the fitness values among the particles.
3. Find out the particles global best and personal best among the entire particles.
4. Evaluate and update the velocities and position of each particles using eq (4) and (5)
5. If convergence is achieved stop the search process if condition is not fulfilled raise the iteration count and once again start the evaluation of fitness process.

9. Simulation Results and Analysis

To evaluate the efficiency and reliability off the suggested method MATLAB/Simulink is used. The modeling of PSO algorithms dc-dc converter solar module and P&O algorithms dc-dc converter solar module is designed in MATLAB environment for irradiance of 1000, 900 and 600W/m² which shows the PSC conditions which the PV system is subjected to. The algorithms dynamic codes are developed in S function builder. The constraints of solar module are recorded in Table 3 while the parameters of dc-dc boost converter circuit in Table 4 respectively [23]

Figure (8) and (9) show the Simulink Model of the MPPT_PV_SYSTEM Using P&O and PSO Algorithm.
Figure (10) and (11) show the Results of Voltage, Current and Power of the PV System Under Partial Shading Condition for PSO and P&O Algorithm.

Figure (12) shows the Comparative analysis of the Duty Cycle By PSO and P&O Algorithm.

In the PSO algorithm the GMPP is traced around 112 W and the output from P&O algorithm is 56.01W. So it is clear that the PSO Algorithm outperformance than the P&O Algorithm for extracting Maximum Power From PV System. From this we can conclude PSO algorithm is robust under PSC conditions and also during sudden changes in weather. Table (3) shows the Details of the PV Array used. Table (4) and (5) shows the Parameter of DC-DC Boost Converter Obtained by PSO Algorithm.

**Table 3. Details Of a single PV Array**

| Parameter             | Value |
|-----------------------|-------|
| Maximum Power         | 249W  |
| Open Circuit Volatge  | 36.8V |
| Short Circuit Current | 8.83A |
| Maximum Voltage       | 30V   |
| Maximum Current       | 8.3A  |

**Table 4. Parameter and Output of DC-DC Boost Converter Obtained With PSO Algorithm**

| Parameter            | Value |
|----------------------|-------|
| Output Power         | 112W  |
| Output Voltage       | 105.9V|
| Output Current       | 1.059A|
| Boost Capacitor      | 2e-3F |
| Boost Inductor       | .5e-3H|
| Switching Frequency  | 10KHz |
Table 5. Parameter and Output of DC-DC Boost Converter Obtained with P&O Algorithm

| Parameter               | Value     |
|-------------------------|-----------|
| Output Power            | 56.01W    |
| Output Voltage          | 74.84V    |
| Output Current          | .7484A    |
| Boost Capacitor         | 2e-3F     |
| Boost Inductor          | .5e-3H    |
| Switching Frequency     | 10KHz     |

Figure 8. Simulink Model of the MPPT_PV_SYSTEM Using P&O Algorithm
Figure 9. Simulink Model of the MPPT_PV_SYSTEM Using PSO Algorithm

Figure 10. Results of Voltage, Current and Power of the PV System Under Partial Shading Condition for P&O Algorithm
Figure 11. Results of Voltage, Current and Power of the PV System Under Partial Shading Condition for PSO Algorithm
10. Conclusion

We have evaluated and compared the conventional P&O algorithm with PSO algorithm. The P&O cannot detect maximum power point when it is subjected to changing irradiations and partial shading conditions therefore this algorithm cannot be employed for extracting maximum power of a PV system. For improving tracking speed PSO method was used which initializes the particles so as to search the new MPP which resulted in a better and dynamic response as can be seen from the result output. The result indicate PSO algorithm outperforms giving various advantages (i) it has zero oscillations at MPP (ii) The tracking speed is fast (iii) it can locate MPP under varying environmental conditions such as partial shading and large fluctuations (iv) implementation of this algorithm is easy to develop. In this paper calculation of boost converter parameters for PV system was done. Also MPPT tracking was obtained using PSO. The main objective of this paper is to present PSO algorithm for tracking the MPPT of the PV by tracking GMPP for the PV system. The proposed PSO algorithm could be performed appropriately during partial shading conditions. The partial shading condition generated
multiple peaks and all other algorithm failed to differentiate between GMPP and LM PP and gave power output near LMP. Only PSO algorithm was efficient to discriminate between LMPP and GMPP. It also had a high convergence rate which makes it a remarkable match to any conventional algorithms [24].

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