Effect of Partial Shading on a PV Array and Its Maximum Power Point Tracking Using Particle Swarm Optimization

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Abstract. The maximum power point (MPP) of a Solar Photovoltaic (SPV) array varies with temperature and irradiation. Shadow of various objects falling on a certain portion of the SPV array causes partial shading condition (PSC) which results in the formation of hot spot. Thus, reducing the power (output) by 33% on a single cell in addition to the occurrence of various peaks on a P-V curve. To detect global maxima among the multiple peaks is a challenge for researchers. Hence, different Maximum Power Point Tracking (MPPT) techniques are used to overcome this challenge. In this paper, the impact of partial shading on SPV array has been analysed and the Particle Swarm Optimization (PSO) based MPPT technique is used to obtain global maxima under partial shading conditions. The MPPT controller is incorporated with a converter (boost) to vary the input voltage as per the duty cycle of the switch generated by PSO algorithm-based controller.

Keywords. Maximum power point tracking (MPPT), Solar photovoltaic (SPV) array, hot spot, partial shading, Particle Swarm Optimization (PSO), Partial Shading (PS), Partial Shading Condition (PSC).

1. Introduction
The ever-expanding power demand is amongst the most significant issues in the power sector. Most of the sector uses conventional sources of electrical energy like natural gas, oil, coal, etc., that cause various kinds of pollutions including air pollution, acid rain, and the production of greenhouse gases giving rise to abnormal climatic changes. However, sustainable resources of energy like tidal, wind and solar are clean, free, and are abundantly available in nature and hence rivalling with conventional energy sources. Among these sustainable resources of energy, solar energy is utilised through Solar photovoltaic (SPV). Many researchers are working on SPV power system for the generation of electricity due to its advantages, which include high efficiency, cleanliness, less maintenance requirement, free operation, ecological inexhaustibility and energy sustainability [1]-[7]. The PV system has a noteworthy improvement over the past few decades but the main disadvantage is the high cost of installation. Therefore, the system should be employed at its Maximum Power Point (MPP) at given irradiance which is conceivable through the incorporation of the Maximum Power Point Tracking (MPPT) technique. The MPP of SPV array alters with temperature and irradiation. Under normal operating conditions, the output of SPV array has a single peak. However, the shadow of various objects falling on the SPV array causes partial shading condition (PSC). Due to partial shading...
(PS), hot spot is created in the SPV array, which reduces its power output and results in the formation of multiple peaks at the output. To detect global maxima among these peaks is a challenging task for researchers presently. Different MPPT techniques have been presented by the researchers for overcoming this challenge [8]-[34].

Sundareswaran and Palani [8] presented a combined Particle Swarm Optimisation (PSO) and Perturb and Observe (P&O) approach to detect MPP during PSC, PSO shows better efficiency when compared to P&O approach. Lian et al. [9] has presented MPPT approach based on P&O together with PSO, and here PSO shows better efficiency. Ishaque et al. [10] have given a detailed report on MPPT procedure with direct control for SPV system under PS with PSO. On an average, the suggested method is 99.5% efficient. Miyatake [11] has given a report on an interesting MPPT approach by employing PSO, to achieve control of SPV array with one pair of current and voltage source. On an account of the multi-dimensionality of the algorithm, it is employed to find global MPP even when the PSC is complex. Lodhi et al. [12] has given a report on PSO to achieve global MPP in SPV system under PSC. It presents MPPT technique based PSO approach for extraction of global MPP system. The suggested PSO technique when performed appropriately during PSC pointed the global MPP for achieving a better comparison with INC method during PSC. Diana and Sudah [13] presented a paper on MPPT of PV system by PSO. The paper gives a brief concept of PSO. In this paper by using a DC-DC converter one can observe both the boosted voltage and the required power (output). The SPV panel acts as the voltage source to the boost converter and its pulses are given by the pulse generator which reduces the complexity and improves efficiency of the circuit. Wei et al. [14] reported on an improved PSO based strategy for SPV arrangement. The specified method tracks MPP with greater speed accompanied by the fluctuations.

Algarin et al. [15] presented the tracking of MPP using fuzzy Logic MPPT controller for SPV arrangement. In this paper, all the components of PV system were modelled in MATLAB /Simulink environment. The fuzzy controller shows better performance during sudden change in temperature in comparison to the P&O controller, which is subjected to considerable power loss. Alajmi et al. [16] presented MPPT based on FLC considering three stages of operation. In first step the P-V curve is examined, under uniform and partial shading. In second step position of local peak are stored, and in third P&O is used for detecting the global peak. Input changes in power, current and change in maximum power are fed to fuzzy controllers. The membership function is applied to each input and then if-then rule is applied. In every step the output duty cycle is updated. Masoum and Sarvi [17] have presented a report on a new Fuzzy based MPPT for photo voltaic application. The proposed fuzzy tracker is naturally robust to atmospheric alterations. Considerable increase in solar power output (350%) is achieved. The fuzzy tracker has high accuracy under different operating conditions, performs online adaptive search of solar panel maximum power, does not require any external sensor or a dummy solar panel for detecting temperature and solar intensity.

Selvan et al. [18] presented a report on simulation of Fuzzy Logic Control (FLC) based MPPT approach for SPV system and concluded that SPV system becomes more efficient if MPPT controller with Fuzzy Logic is incorporated in the SPV system. Eltamaly [19] presented modelling of Fuzzy logic controller (FLC) for SPV MPPT. Detecting the MPP by employing the FLC provides an accurate mechanism for detecting MPP surprisingly in altering climatic conditions. Raziya et al. [20] presented MPPT procedure based on P&O approach for SPV system under PSC. MPP detecting efficiency was realized to be 84.90%. Fazal et al. [21] presented revised P & O MPPT approach for PSC. The proposed MPPT algorithm reduces the tracking time and minimize the oscillation at the maximum power point. Batineh [22] presented an article on an intelligent MPP using FLC under severe weather condition. The efficiency of detecting global maxima was realized to be 96% with FLC. Hashim et al. [23] has given a report on the achieving fast and accurate MMPT approach by designing dc-dc boost converter in standalone SPV arrangement. The method was successful in acquiring the specified approach. Chao et al. [24] presented a multi core PSO operation for MPPT of a distributed SPV arrangement under PSC. The PSC is identified by using one-diode and multiple-peak power (output) condition similar to SPV array is observed while simulating the characteristics. The time to detect global MPP was observed to be almost 1.3 seconds.
Reddy et al. [25] has given a report on analysis of P&O MPPT approach under uniform and PSC. The simulation shows that the suggested P & O procedure is easy to execute with boost converter system and the better detecting capability is achieved even under the varied and unvaried irradiation conditions are employed. Because of this simplicity of implementation and fast response, the P & O algorithm with Boost converter system combination can be extended in the grid-connected PV system applications. Khaled et al. [26] presented a PSO based technique for PS detection for PV system. The result shows the effectiveness of the proposed technique. Hajighorbni et al. [27] presented an evolution of Fuzzy logic subset effect on MPPT for photovoltaic system. The work compares different fuzzy subsets to detect the most efficient subset used for FLC. The second subset was observed to be the best fuzzy subset which detected MPP in minimum time with high efficiency. Ramaprabh et al. [28] detected MPP during PSC of SPV system using Fibonacci search methodology with FLC. The introduced approach was able to detect global peak for all condition. Safumi et al. [29] presented PSO approach to track maximum power point during shading condition with a voltage and current sensor connected in the load side to measure converter losses and the generated power by SPV arrangement. The introduced scheme is capable of detecting the global MPP under PSC (complex) also. The time taken by the approach to detect the global MPP was observed to be 1 to 2 s.

Alonso et al. [30] presented MPPT method consisting of a traditional P & O approach but with second stage able to detect aberrations on the SPV generator curve for global MPP tracking. The approach was able to find the real MPP with high speed and accuracy under any circumstance. Patel and Agarwal [31] presented MPPT approach for SPV arrangement under PSC. The approach works along with dc-dc converter to detect GP and feedforward control scheme is used to increase the GP detecting speed. The MPP detecting time with this controller is about one-tenth of the time taken by the conventional controller. Kim and Kim [32] presented an MPPT approach to detect the global point under PSC. The introduced scheme includes enhancement of profile searching and hence improving tracking performance. Murtaza et al. [33] has presented a report on activation of bypass diode (BD) in MPPT technique for SPV arrays during PSC. The advantages of this technique are the new voltage can be limited and voltage steps can be intelligently calibrated. The method shows better results as compared to the past introduced MPPTs. Simulations reveal that the method ensures convergence to the global maxima. It is observed that the efficiency of the building integrated SPV plant is over 96.6% with this approach. Ahmed and Masafumi [34] presented an interesting MPPT approach for PV application under PS insolation condition. The introduced technique enables wide-range search to detect global MPP and extraction of more power from SPV array under PSC as compared to the other methods. The method ensures fast and accurate response.

In the paper, the impact of PS on SPV array is observed in MATLAB/Simulink. Under different shading patterns, SPV array characteristics are modelled in the form of I-V graphs. By analysing the graph, it leads to various important observations which are summed up in the following statements. In order to prevent hotspot formation during PS, bypass diodes are used across each module. The hot spots occur as the voltage (reverse) across the shaded module increases. The shaded module gets completely damaged if the power dissipation exceeds the maximum power capability resulting in an open circuit [4]. It is observed that a considerable amount of power loss occurs due to the PS and formation of multiple peaks at the output. Various MPPT algorithm techniques such as P&O, Fibonacci Search Method, PSO, Artificial Neural Network (ANN), FLC, etc. are used to obtain global maxima from multiple peaks under PSC. Here, PSO approach is used to achieve the global maxima. This paper is segregated into six sections. Section 2 defines the characteristics of SPV arrangement under PSC and normal condition. Section 3 describes the design of a SPV system. Section 4 presents the MPPT technique using PSO algorithm. Section 5 shows the analysis and discussion of the SPV system under PSCs. Finally, section 6 concludes the presented work.

2. SPV System Characteristics
The SPV system operates under two conditions i.e. normal condition and PSC (PSC). These conditions are explained below:

2.1. Normal Condition
Figure 1 represents a circuitry for the SPV system having a diode, a current source, and two resistors, which are directly influenced by solar irradiance and temperature. The operation of SPV system varies with open-circuit voltage ($V_{oc}$) and short circuit current ($I_{sc}$). These values are provided by the manufacturer of the cell. Normally, the voltage (output) of a cell lies between 0.5 V - 0.9 V, thus the power (output) of a solar cell is quite low, which is not sufficient for practical applications. Therefore, the cells are connected in series to form a module. These modules connected in series is called a string, which increases the voltage. The strings connected in parallel is called an array, which increases the current. The output of the module is given in Eq. (1):

$$I_{pv} = I_{ph} - I_{01} \left[ e^{\frac{V_{pv}+I_{pv}R_s}{N_sAqRT}} - 1 \right] - \frac{V_{pv}+I_{pv}R_s}{R_p} = 0$$

Where, $V_{pv}$ & $I_{pv}$ are (output) voltage and current, respectively. $I_{ph}$ is photocurrent and $I_{01}$ is diode current (saturation). $A$ refers to ideality factor of diode; $q$ is electron’s charge ($q = 1.602*10^{-19}$ C) and $K$ signifies the Boltzmann constant. In Eq. (1), usually $R_p$ has a high value to reduce the high-power losses in a solar module during low generated current. The value of $R_s$ is usually taken small, as high value reduces the short circuit current. Figure 2 shows the output characteristic (I-V characteristics and P-V (characteristics) of SPV module with different solar irradiation levels. From Figure 2, it is clear when the solar irradiation levels are high the current and thus power output of the SPV module is large.

Figure 2. Characteristics (I-V and P-V) of SPV system under normal condition.
2.2. Partial Shading Condition

The phenomenon partial shading (PS) happens when a shadow of various objects falls on a definite portion of the module within an array of the SPV system. Hence, the array receives diverse irradiance level. The $I_{sc}$ of the array is related to degree of irradiance, due to which shaded module starts generating less current whereas the un-shaded module keeps on working at a higher photocurrent. As the modules are series connected, the current through it must be equal but due to PS, the shaded module acts as a load with the reverse voltage across it, therefore, maximum output power from the array reduces. If reverse voltage across shaded module swells it leads to avalanche breakdown resulting in a hot spot. To overcome the above disadvantage, bypass diodes (BD) are connected across each module. The BD turns on when the reverse voltage across it exceeds barrier potential, thereby provides an additional path for the flow of current. Because of the initiation of bypass diode, the current through the string is not the same one as during PSC. Now the string carries the current produced by the un-shaded cell or module only. This results in formation of various local maxima at the output of SPV array. These various local maxima of the P-V curve under PS depends on the $N_s$ (no. of series connected modules) and activation of the bypass diode. Figure 3 shows a string having four modules in series. The modules are operated at constant temperature (25°C) and different solar irradiation (500, 800, 1000, 1000), respectively. The no. of cells in series (in a module) are 72 with the open-circuit voltage (of a module) equivalent to 50.93V and the short circuit current of 6.2A.

![PV String Partial Shading Model](image1)

**Figure 3.** SPV string under partial shading effect.

![XY Plot](image2)

**Figure 4.** Characteristics (I-V) of a single string undergoing PS phenomenon.
Figure 5. Characteristics (P-V) of a single string undergoing PS phenomenon.

Figure(s) 4 and 5 shows I-V and P-V curves of the SPV string, respectively. In Figure 4, starting from $4V_{oc}$ to $3V_{oc}$, the current in the string equals the shaded current generated by module 4. At $3V_{oc}$, the bypass diode of module 4 operates and now current in string equals the shaded current of module 3. At $2V_{oc}$, the bypass diode of module 3 operates, and the current start raising which equals the current generated by module 2. The string now behaves as module 2 in series. At $V_{oc}$ bypass diode of module 2 operate and now the current in string is equivalent to the non-shaded current produced by module 1. Accordingly, the power variation curve of SPV string is presented in Figure 5.

3. Design of a SPV System

In this section, the design of various components has been discussed.

3.1. Design of Boost Converter

The Boost converter is controlled by the MPPT controller (using PSO algorithm) in order to detect MPP. It also increases the output voltage in addition to power. The converter consists of a switch (which operates at high frequency), an inductor, a capacitor and a diode. The MPPT controller changes the duty cycle of the converter switch so as to deliver maximum power to load at voltage higher than input terminal voltage.

3.1.1. Modes of Operation

Boost converter operates in both modes (charging and discharging).

3.1.1.1. Mode-I (Charging)

In this mode, switch is closed and current from the source flows to the inductor, thus increasing inductor current. The diode operates in reverse bias condition and the necessary load demand is sufficed by discharging of the capacitor.

3.1.1.2. Mode-II (Discharging)

In this mode of operation, diode operates in forward bias condition and the switch remains open. As the inductor starts discharging, it along with the source supplies power to the capacitor to satisfy or meet the demands of the load. The voltage gain of the converter is:

$$\frac{V_o}{V_{in}} = \frac{1}{1-D} \quad (2)$$
Where, \( D \) represents the duty cycle.

From above expression one obtains,

\[
V_{in} = V_0 (1-D) \quad (3)
\]

\[
I_{in} = \frac{I_0}{1-D} \quad (4)
\]

### 3.2. Design of a Resistor

\[
R_{in} = R_0 (1-D)^2 \quad (5)
\]

The Eq. (5) shows the correlation between the load resistance and the internal resistance of array where \( D \) is the converter duty cycle. To obtain the maximum power from array, the resistance of load should be greater or equal to the internal resistance of the SPV array. Because the value of duty cycle varies from 0 to 1, the internal resistance of array is given by:

\[
R_{in} = \frac{V_{in}}{I_{in}} = \frac{V_0 (1-D)}{I_0/(1-D)} = \frac{V_0}{I_0} (1 - D)^2 \quad (6)
\]

It gives,

\[
R_{in} = R_0 (1-D)^2 \quad (7)
\]

The maximum power tracking will fail if the condition \((R_0 \geq R_{in})\) is not fulfilled.

### 3.3. Design of an Inductor

The purpose of designing an inductor is to maintain volt-second balance of converter and to reduce ripple in the output current. A large value of inductor results in the low ripple output current, but here a lower inductor value is preferred due to its high cost. Inappropriate use of inductor results in ripple at the output. To operate the converter in continuous conduction mode, \( I_{min} \) ought to be greater than zero. Also, the calculation of inductor current is done at a maximum value of power under uniform irradiation i.e. 1000W/m²

\[
I_{min} > 0 \quad (8)
\]

\[
L > D(1-D)^2 RT/2 \quad (9)
\]

Substituting \( T=1/f \), one obtains

\[
L > D(1-D)^2 R/2f \quad (10)
\]

From Eq. (10) it is clear that high switching frequency means low inductor value. Here, the value of \( R \) is between \( R_{min} \) and \( R_{max} \) i.e. \( R_{min} < R < R_{max} \). Also, for variable output and duty cycle, it is required to have maximum value of \( D \) i.e. \( D_{max} \).

### 3.4. Design of a Capacitor

The expression for required capacitance is given by:

\[
C > D/Rf (\Delta V_{out}/\Delta V_{out, max}) \quad (11)
\]

Where, \( \Delta V_{out} \) is the ripple present in the output voltage.
4. **MPPT using PSO**

Owing to the low efficiency of the SPV systems, various methods are practiced to increase the efficiency while balancing the generation with the load demand properly. To obtain maximum possible power from a varying source of generation, MPPT is used with its controlling technique. The MPPT controller is incorporated with boost converter to achieve the maximum power from the array which is delivered to load. Various methods for controlling MPPT are P&O, PSO, FLC, Fibonacci line search, etc. In the paper, MPPT control is done using PSO technique.

4.1. **PSO Algorithm**

The PSO was first presented by James Kennedy and Russell Eberhart in 1995. It is population based stochastic approach and was influenced by social behaviour of birds flocking or fish schooling. Due to its rapid convergence, simple structure, fast convergence ability and ease of implementation, PSO technique has been studied by several researches for MPPT application. This method starts with initialization of a group of random particles (solutions) and search for optima by updating generation. In every iteration particle are updated by following two best values. The first one is the \( P_{\text{best}} \) i.e. personal best position achieved by each particle and it is updated in each iteration, and the second one is \( G_{\text{best}} \) i.e. global best obtained by any particle in the group. When the two best values are found, the particle updates its position and velocity with Eq(s). 12 and 13.

\[
V_i^{k+1} = w \times V_i^k + c_1 \times r_1 [P_{\text{best}} - x_i^k] + c_2 \times r_2 [G_{\text{best}} - x_i^k] \tag{12}
\]

\[
x_i^{k+1} = x_i^k + V_i^{k+1} \tag{13}
\]

Where, the \( V_i \) (velocity) indicates the step size, \( w \) is inertia weight, \( c_1 \) and \( c_2 \) are called learning factors, \( r_1 \) and \( r_2 \) are random values that lie within 0 to 1 and \( x_i \) represent position of particles. In the above equations, position can be replaced with duty cycle and the velocity act as a step size to D. The flowchart of PSO is shown in Figure 6.

![Figure 6. PSO Algorithm Flowchart.](image-url)
5. Analysis and Discussion

The analysis of the developed SPV system is done in this section and the obtained results are discussed.

The Figure 7 represents the developed SPV system executed in MATLAB/Simulink, composed of a single string having three modules, boost converter and the PSO controller. The code for PSO algorithm is created in S-function builder. The frequency (switching) of converter is 50KHz. Value of converter parameters is $c_1=10^{-6}$, $c_2=0.4676e^{-3}$, $L=1.1478e^{-3}$. Figure(s) 8 and 9 shows the P-V and I-V characteristic during different irradiance level, respectively.

![Simulation layout of SPV system.](image)

**Figure 7.** Simulation layout of SPV system.

![Characteristics(P-V) under PSC](image)

**Figure 8.** Characteristics(P-V) under PSC
Figure 9. Characteristics (I-V) under PSC

From Figure 9, evidently, that the power (output) at the SPV string has three peaks, among which two are local maxima and one is global maxima. Hence, the PSO algorithm should detect the global maxima. The output power, voltage & current of the SPV system is shown in Figure(s) 10, 11 and 12, respectively.

Figure 10. Power of SPV system using PSO.

Figure 11. Voltage of PV system using PSO.
Figure 12. Current of SPV system using PSO.

Figure 13. Power Output from boost converter.

Figure 14. Voltage output of boost converter.
Figure 15. Current Output of boost converter.

From Figure 10, it is clear that the maximum power achieved by PSO algorithm during PSC is 637.4W at a voltage of 148V (Figure 11). From Figure 11, it is evident that the output voltage is boost up to 179.3V. The power, voltage and current output of the boost converter are presented in Figures(s) 13, 14 and 15, respectively.

From Figure13, it is evident that at t = 0.3s, the output power of the boost converter is almost equal to the MPP. Expectedly, the output voltage (Figure 14) and current (Figure 15) of the boost converter are high at that instant. Moreover, the boost converter continuously tracks the MPP using PSO algorithm. Thus, the MPP during PSC is successfully tracked by using PSO algorithm in the MPPT for developed SPV system.

6. Conclusions
The paper focuses on the maximum power point tracking (MPPT) of a solar photo voltaic (SPV) system under PSCs. Under PSC, multiple peaks are developed at the output of P-V curve. To detect global maxima among the multiple peaks is quite difficult. For this, Particle Swarm Optimization (PSO) based MPPT controller is developed. The SPV system including PSO based MPPT controller is modelled in MATLAB/Simulink. The MPPT controller is incorporated with boost converter to vary the input voltage as per the duty cycle of the switch in order to track the MPP. The result shows that the developed PSO based MPPT controller successfully detects the MPP of the SPV system under PSCs.

References
[1] R. Ahmad, A. F. Murtaza, H. A. Sher, U. T. Shami and S. Olalekan, “An analytical approach to study PS effect on PV array,” Renewable and Sustainable Energy Reviews, vol. 74, pp. 721-73, July 2017.
[2] A. Sarwar, M. S. J. Asghar, F. I. Bakhsh, “Microcontroller Based Novel Dc-to-Ac Grid Connected Inverter Topology,” Int. J. on Electrical and Power Engineering, vol. 02, no. 03, pp. 14-18, Nov 2011.
[3] Jena D, & Ramana V V, “Modelling of PV system for uniform and non-uniform irradiance”, Renewable and Sustainable Energy, vol. 52, pp. 400-417. July 2015.
[4] S. Silvestre, A. Boronat, A. Chouder, “A study of bypass diode configuration on PV module”, Applied Energy, vol. 86, pp. 1632-1640.September 2009.
[5] Seyedmahmoudian, M, Horan. B, Soon. T. K, Rahmani. R, Oo. A. M. Than, “State of the art artificial intelligence- based MPPT techniques for mitigating partial shading effects on PV system”, Renewable and Sustainable Energy Reviews, vol. 64, pp. 435-455.June 2016.
[6] Jubaer Ahmad, & Zainal Salam, “A critical evaluation on MPPT methods for PS in PV system”, Renewable and Sustainable Energy, vol. 47, pp. 933-53. April 2015.

[7] N. Sharma, F. I. Bakhsh, S. Mehta, “Efficiency Enhancement of a Solar Power Plant Using Maximum Power Point Tracking Techniques” IEEE International Conference on Computational and Characterization Techniques in Engineering & Sciences (CCTES-18), Integral University, Lucknow, India, 14-15 September, 2018.

[8] Sundareswaran K, & Palani S, “Application of a combined PSO and P&O method for MPPT in PV system under PSC”, Renewable Energy, vol. 75, pp. 308-317. September 2014.

[9] Lian, K. L., Jhang, J. H., & Tian, I. S. (2014). MPPT method based on P&O combined with PSO. IEEE Journal of Photovoltaics, vol. 4, pp. 626-633, March 2014.

[10] Ishaque K, Salam Z., Shamsudin A., & Amjad M. “ A direct control based MPPT method for PV system under PSC using PSO algorithm”, Applied Energy, vol.99, pp. 414-422, November 2012.
[26] Khaled. A, Aboubakeur. H & Abdelhamid, R. “A PSO-based Technique for PS Detection for PV systems”. *Journal of electrical systems and materials*, vol.1, pp. 10-20, March 2019

[27] Hajighorbani, M.A Radzi, M.Z Kadir, S. Shafie, Khanaki, R., & Maghami, M. R. “Evaluation of Fuzzy Logic Subsets Effects on MPPT for PVSystem”. *International Journal of Photoenergy*, vol. 2014, pp. 13, September 2014.

[28] Ramaprabha, R., Balaji, M., & Mathur, B. L. “MPPT of partial (incomplete)ly shaded solar PV system using modified Fibonacci search method with fuzzy controller”. *Journal of electrical power and energy systems*, vol. 43, pp. 754-765, July 2012.

[29] Masafumi M., Mummadi V., F, Toriumi., N, F., & H, K. “MPPT of multiple photo voltaic arrays with a PSO approach”. *IEEE Transactions on Aerospace and Electronic systems*, vol. 47, pp.367-80. August 2009.

[30] R, Alonso, Ibaez P., Marteniz V., Roman E., & Sanz A. “An Innovative perturb, observe and check algorithm for partially shaded PV system”. *13th European Conference on 2009 Power Electronics and Applications*, pp.1-8, October 2009

[31] Patel H., & Agarwal V. “MPPT Scheme for PV systems operating under PSC”. *IEEE Trans Ind Electron*, vol.55, pp. 1689-1698, May 2008

[32] Kim R.Y, & Kim J.H. “An improved global MPPT scheme under partial shading condition”. *International conference on Electrical Machines and Systems*, vol. 2, pp. 65-68, 2013

[33] A. Murtaza, M. ChiabERGE, F. SpERTINO, D. BoERO, M. De Giuseppe, “A MPPT Technique based on bypass diode mechanism for PV arrays under PS”. *Energy Build*, vol. 73, pp. 13-25, January 2014.

[34] Nabil A. Ahmed, Masafumi M. “A novel MPPT for PV application under partial (incomplete)ly shaded insolation conditions”. *Electric Power System Research*, vol. 78, pp. 777-784, September 2008.