IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 3, July 2026
Impact Factor: 8.2

Advanced MPPT Control Techniques for Efficient Solar Photovoltaic (PV) System

Ajay Kumar[1] and Raj Kumar[2]
[1]M.Tech Scholar, Department of Electrical Engineering (Power System)
[2]Assistant professor, Department of Electrical Engineering (Power System)
Shri Phanishwar Nath Renu Engineering College, Araria, Bihar

Abstract: *This study evaluates centralized and distributed Particle Swarm Optimization (PSO)-based Maximum Power Point Tracking (MPPT) for photovoltaic (PV) systems under uniform and partial shading conditions, with comparison against the conventional Perturb and Observe (P&O) algorithm. Simulation results demonstrate that PSO provides superior maximum power point tracking, higher power extraction, reduced oscillations, and effective global MPP identification under changing irradiance. In the centralized configuration, PSO achieves 72.92 W at uniform irradiance and 69.57 W under partial shading, outperforming P&O. The distributed PSO-MPPT configuration further enhances performance by independently optimizing individual PV sub-modules, thereby reducing mismatch losses. It achieves a minimum settling time of 13 ms and power improvements of 4.43% under uniform irradiance and up to 20% under partial shading. Overall, the proposed PSO-based distributed MPPT approach offers an efficient, flexible, and reliable solution for high-performance photovoltaic energy conversion systems.*

Keywords: PSO-MPPT; Distributed MPPT; Partial Shading; Photovoltaic Systems; P&O Algorithm.

I. INTRODUCTION

The solar energy production is the fastest growing area in the renewable energy sector. India's installed solar capacity is 36.8 GW at the end of the first quarter of 2020 as reported by Aarushi Koundal (2020), world solar installations will continue with faster growth rates as forecasted by HIS Markit (2020). The world cumulative capacity has reached 583GWby 2019 and may approach a capacity of 750GWas forecasted by IRENA (2020).

Solar PV systems are mainly classified as standalone and grid connected systems. The standalone systems are designed to operate independently from the utility grid. It is also designed to supply isolated loads especially in domestic electrification with DC/AC power for a specific size. Battery is used for energy storage. The grid connected solar PV systems are designed to connect or operate in parallel with the electricity utility grid.

The big challenge which lies in PV power production is to tackle the nonlinear characteristics of solar PV source. The V-I characteristics of solar photovoltaic module depends on the irradiance and temperature associated with it. In a day solar photovoltaic module is subjected to different irradiance and temperature levels because of sun's orientation, weather/climatic conditions and partial shading such as passing clouds, neighbouring trees and buildings. If PV module is directly connected to the load impedance mismatch occurs between load and photovoltaic panel which leads to less energy harvesting. This type of power transfer may lead to oversizing of the PV array and hence the overall cost of a given application. Extract the maximum available power from the photovoltaic module by making it operate at the efficient voltage, a maximum power point tracker is provided in the solar photovoltaic system. It is an electronic subsystem, composed of maximum power point (MPP) tracking algorithm-based computation system along with a DC-DC power converter, which helps PV panel to operate at maximum power point (MPP). During load variation or the sunlight variation there is only one point at which the PV module exhibits MPP. At MPP, PV panel resistance (Rpv) is equal to load resistance (RL), which is known as optimum solar PV resistance Rpvopt. A DC-DC converter is used for the purpose of impedance matching between load and the PV source. When it is connected between the PV module and the load, the PV panel's operating voltage is decided by the load resistance (RL) and duty cycle (D*)*. Thus, under

DOI: 10.48175/568

ISSN 2581-9429 IJARSCT

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 3, July 2026
Impact Factor: 8.2

different loading and atmospheric conditions the duty cycle can be adjusted to change Rpv to match Rpvopt in order to extract maximum electric power from the PV panel.

The overall efficiency of a PV system is depending on the efficiency of the individual PV array, DC-DC converter and the implemented MPPT algorithm. The efficiencies of the PV panel and the converter are not easily improved because they depend on the type of hardware technology. But efficiency of MPP tracking can be increased easily by introducing a new control MPPT algorithm to track true maximum power point. This paper presented the investigation of particle swarm optimisation based MPPT technique in partially shaded solar PV system. Under the non-uniform solar insolation conditions, the photovoltaic power system exhibits a peculiar property of multimodal V-I and V-P characteristics because of the presence of multiple local maxima and a global maximum power point. The presence of such non ideal power characteristic makes the conventional MPPT algorithms not suitable to track the actual global maximum power point successfully. In normal maximum power point tracking methods, all the PV panels are connected to single maximum power point tracker to extract the maximum power. If any fault occurs in the PV panel or low irradiance in some part of the panel cause reduction of solar power generation. In order to address this issue, this research work proposes and investigates the application of Distributed Maximum Power Point Tracking technique (DMPPT) along with the Particle Swarm Optimisation (PSO) approach to capture the optimum global maximum power point effectively.

II. LITERATURE REVIEW

A detailed literature survey has been carried out in the area of solar PV standalone system implemented in domestic electrification

Mohamed Saleem Abdul Kareem & Manimaran Saravanan (2016) has presented a new method for accurate estimation of five parameters of PV panel and effective estimation of maximum power point under static and dynamically varying environmental conditions. This method uses Gauss-Seidel iterative method for solving nonlinear equations of solar PV panel and proposed two new equations to find the ideality factor and shunt resistance of PV panel model. The PV model proposed yields good results at STC and under varying environmental conditions.

Mohamed *et al.* (2018) have presented an algorithm for modelling and estimating maximum power point (MPP). This algorithm required only two information such as open circuit voltage (VOC) and short circuit current (ISC) of the PV module. Frequent sampling of panel operating voltage and current are used to estimate MPP via Newton-Raphson (NR) method. Determination of MPP enables the PV system to deliver maximum available power.

Joshi *et al.* (2018) have presented new boost converter in solar-powered electric vehicle application. The voltage regulation of the DC link using battery along with the MPPT is implemented by controlling the switching signals of the new boost converters. The power-sharing analysis between battery and PV array along with battery charging are carried out. Adopting new boost converter rises the benefits in solar powered vehicles.

Hussain, Zohaib & Babaei (2019) have presented the buck -boost converter based solar charge controller for battery charging application. The proposed model exhibited a less oscillation during switching of MOSFET. Effective charging is accomplished under the charismatic characteristics of PV array under various irradiance and temperature levels.

Shahdadi *et al.* (2019) have presented improved fast terminal slip sliding mode control (SMC) for maximum power point tracking. The availability and stability conditions of SMC had been investigated. This study presented the robustness of SMC to the uncertainty of parameters. The proposed technique is recommended for commercial choice for solar PV systems.

Sunar *et al.* (2017) have claimed that intelligent MPPT techniques such as fuzzy logic control MPPT and artificial neural network MPPT achieved good performances, fast tracking and no overshoot in grid connected PV system under all type of climatic conditions.

Allouche *et al.* (2018) have presented a sugeno fuzzy MPPT method. In this work maximum power voltage-based control and direct maximum power (DMP) are used to control the output PV voltage to the reference PV voltage.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 3, July 2026
Impact Factor: 8.2

Kapumpa *et al.* (2017) have presented fuzzy control MPPT for 1MW standalone PV plant. Generally, FLC MPPT algorithm considered the error e(t) and the change in error de(t)/dt as inputs. Differentiation of error not only increases the complexity of computation but also introduce error.

Khanam *et al.* (2018) have proposed the artificial neural network based MPPT to estimate the irradiance and temperature from array's voltage and current signals in order to determine the optimum peak operating point. This MPPT technique gives a good performance. But, the indirect estimation of solar irradiance and temperature introduced lagging in MPPT performance.

Koochaksaraei *et al.* (2019) have proposed an Adaptive Neuro-Fuzzy Inference System based MPPT controller. The proposed MPPT helps to transfer maximum power to the load. The duty cycle of the two-switch flyback inverter, which has been connected between the solar panel and the load, were generated with the aid of the proposed ANFIS method. Simulation results showed the accuracy and high efficiency of the proposed tracker.

Priyadarshi *et al.* (2020) have introduced an adaptive neuro-fuzzy inference system-particle swarm optimization (ANFIS-PSO)-based hybrid MPPT method to acquire rapid and maximal PV power with zero oscillation tracking. In this work the inverter control strategy was implemented by a space vector modulation hysteresis current controller to get quality inverter current by tracking accurate reference sine-shaped current.

III. PARTICLE SWARM OPTIMISATION (PSO) MPPT TECHNIQUE

In this research work particle swarm optimisation based MPPT technique is proposed to address partial shading issues. Perturbation is done based on the concept of particle swarm optimization. The flowchart of the proposed MPPT scheme is shown in the Figure. 6.5. 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 as discussed by Zheng Yibin *et al.* (2016).

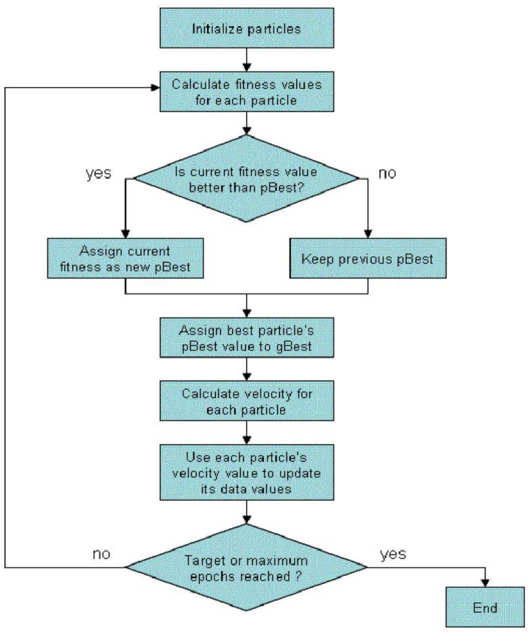

Figure 1 Flowchart of particle swarm optimisation MPPT technique

The following steps describe the working of PSO MPPT algorithm:

1. The figure shows that the perturbation in duty cycle is computed by two different terms: First, the difference between the previous duty cycle $d_i(k)$ and the local best particles *P*best. Second, the difference between the previous duty cycle

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 3, July 2026
Impact Factor: 8.2

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.

2. Once the particle reaches MPP, the velocity of particles is practically zero. Hence, at steady state there is no oscillations in MPP tracking. These steady-state oscillations are very critical because it is one of the major reasons for the reduced MPPT efficiency of conventional algorithms.

3. In the case of rapid fluctuations in the environmental conditions, the P&O method loses the direction of new MPP and tracking will be driven into a wrong direction. However, the proposed PSO method works with three duty cycles for proceeding MPP tracking in right direction. Since the operating power information is obtained from all three duty cycles, it never loses the direction of MPP in rapid fluctuations.

4. In the condition of partial shading, the V-P 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 still tracks the global peak correctly.

IV. PROPOSED MODEL

The simulation of centralised and distributed MPPT system is done in MATLAB/Simulink environment which are shown in Figures 2 and 3. The figure illustrates a MATLAB/Simulink PV system with MPPT control under unequal irradiance conditions of 1000 and 800 W/m². Two PV modules feed an MPPT DC–DC converter, while voltage, current, and power are measured using scopes, displays, and product blocks. The model evaluates PV performance and power extraction under partial shading.

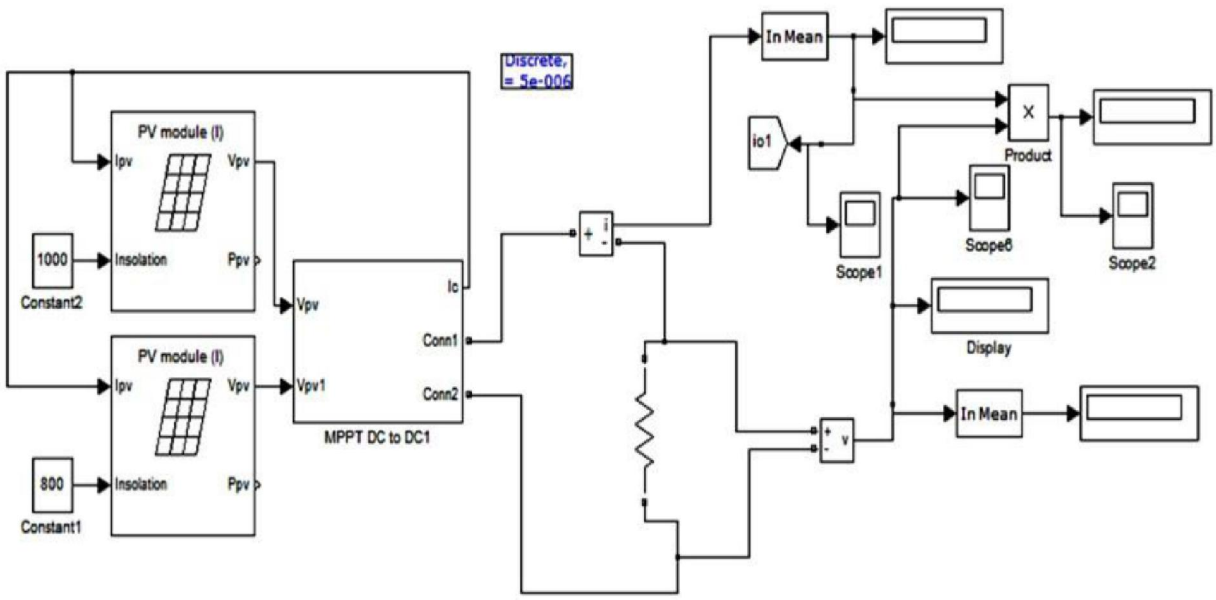

Figure 2 Simulation model of centralised PSO MPPT

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 3, July 2026
Impact Factor: 8.2

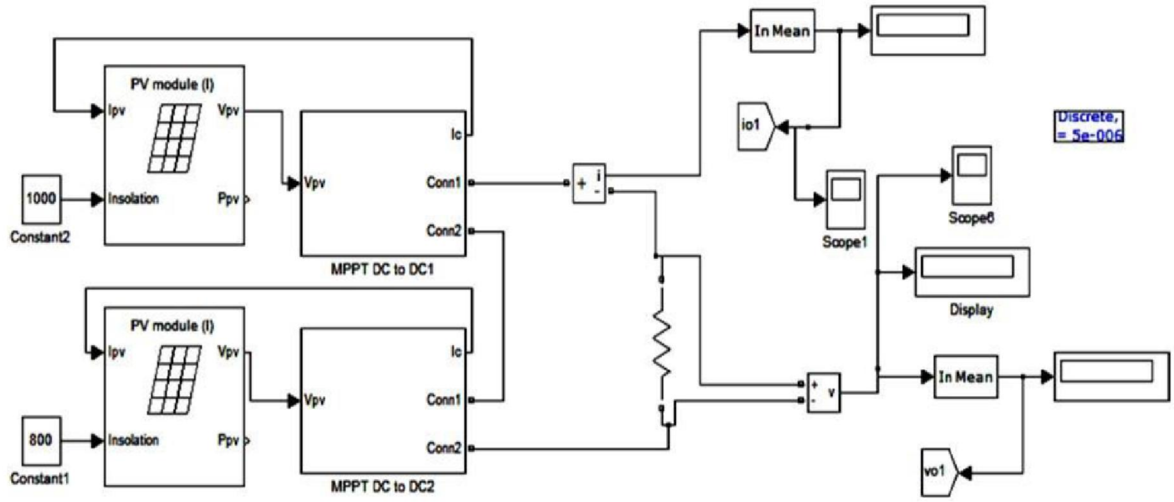

Figure 3 Simulation model of PSO based distributed MPPT

V. RESULT ANALYSIS & DISCUSION

The MATLAB m-file coding is done for PSO MPPT algorithm. The simulated wave forms of power and voltage of PV system are given in Figures 4 and 5. The comparative results of P&O and PSO MPPTs in CMPPT configuration is tabulated in Tables 1. and comparative result of P&O and PSO MPPTs in DMPPT configuration is tabulated in Table 2.

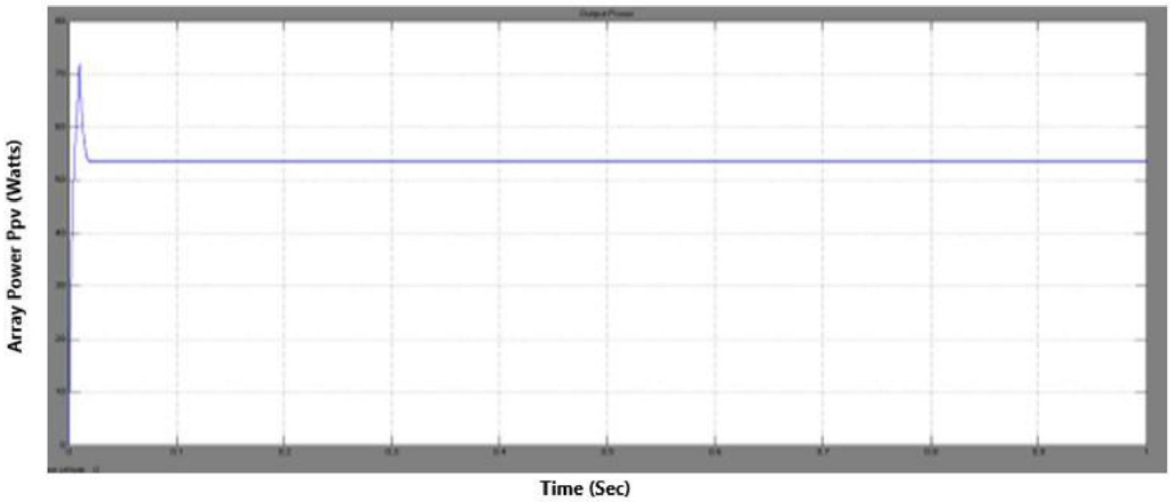

Figure 4 Simulated power output of centralised PSO MPPT

IJARSCT
ISSN: 2581-9429
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Volume 6, Issue 3, July 2026
Impact Factor: 8.2

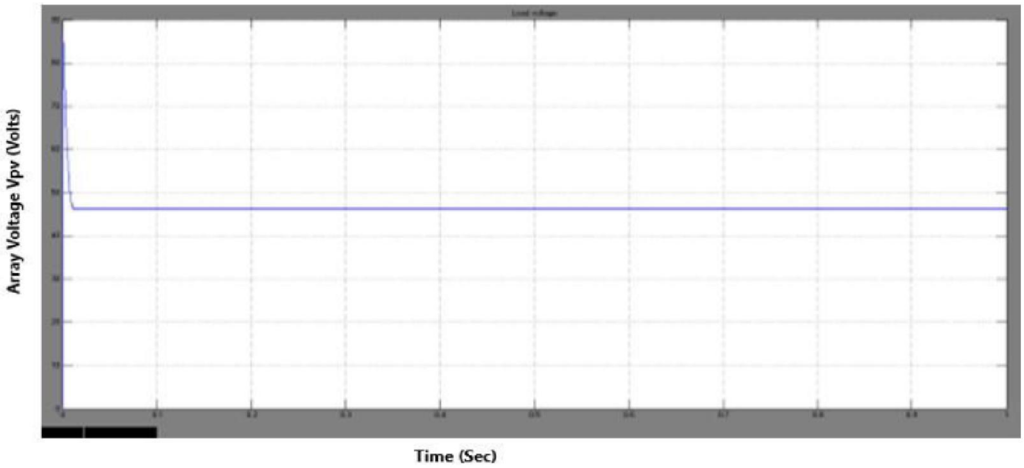

Figure 5 Simulated voltage output of centralised PSO MPPT

Table 1 Comparison of MPPT techniques in CMPPT configuration

Solar Panels Irradiance Level	**System Output Voltage (Volts)**		**System Output Power (Watts)**	
	P&O	**PSO**	**P&O**	**PSO**
Panel1:1000W/m^2 **Panel2:**1000W/m^2	52.4	53.6	70.5	72.92
Panel1:1000W/m^2 **Panel2:**700W/m^2	51.5	52.7	67.2	69.57

The output voltage waveforms of individual impedance matching boost converter are shown in Figures.6 and 7.

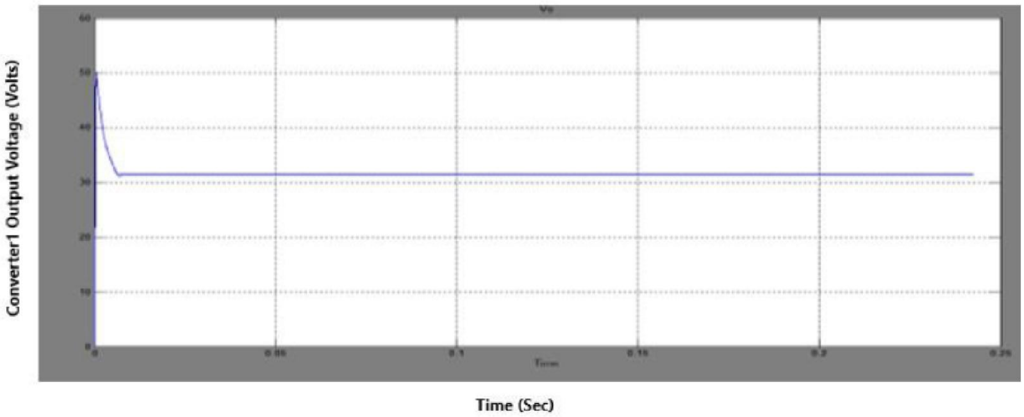

Figure 7 Simulated output voltage of boost converter 1

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 3, July 2026
Impact Factor: 8.2

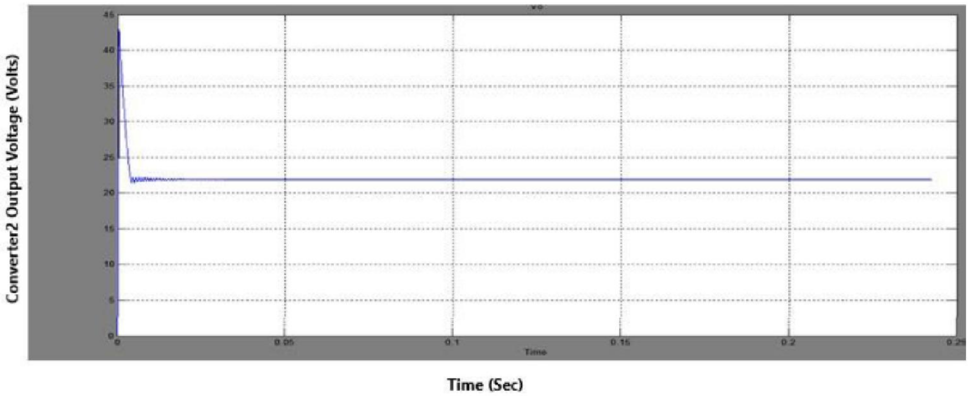

Figure 8 Simulated output voltage of boost converter 2

The overall output voltage waveform of PV system when the panels are connected in series is shown in Figure. 9.

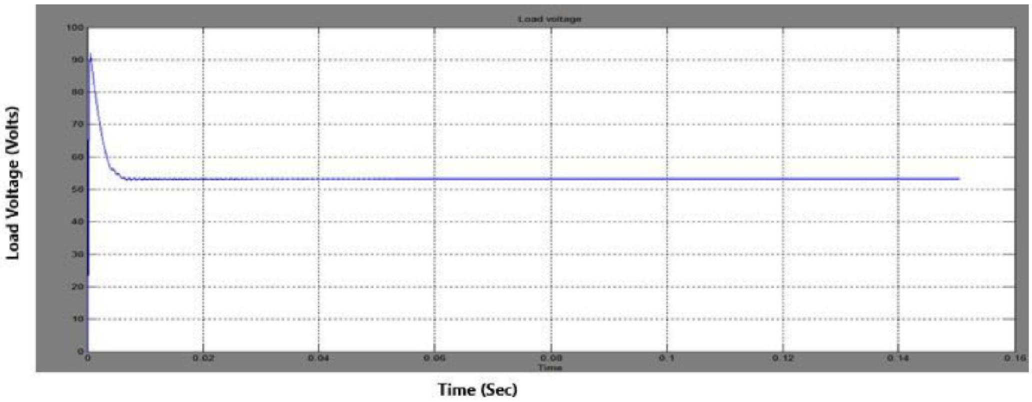

Figure 9 Simulated overall output voltage of partially shaded system

The output power obtained from PSO and P&O MPPT techniques are compared and shown in Figure. 10. The obtained voltage and power values for Distributed MPPT system in PSO MPPT technique are tabulated. Simulation results show that the proposed distributed PSO based MPPT lowest settling time to stabilize the power output at 13ms. The improvement of power extraction is 4.43% at uniform insolation and it is in the range 4.91% to 20% under partially shaded condition.

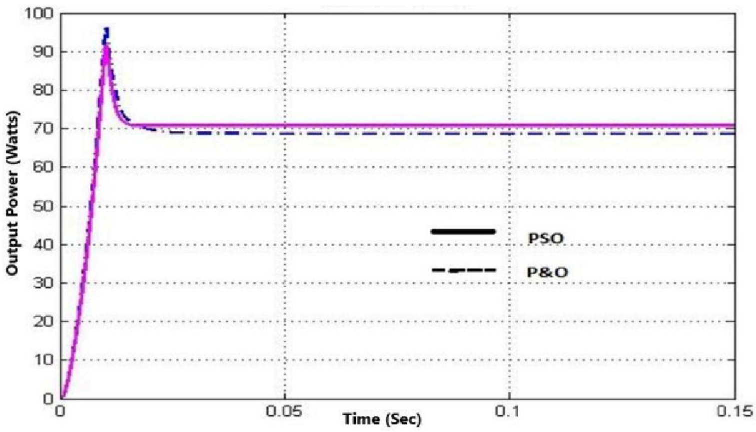

Figure 10 Simulated output power comparison of PSO and P&O MPPT techniques

The obtained voltage and power values for Distributed MPPT system in PSO MPPT technique are tabulated in Table 4.

Table 4 System output values in distributed PSO MPPT configuration

Solar Panels Irradiance Level	System Output Voltage(Volts)	System Output Power(Watts)
Panel1:1000W/m^2 Panel2:1000W/m^2	52.88	73.34
Panel1:1000W/m^2 Panel2:700W/m^2	51.64	71.13

VI. CONCLUSION

This paper investigated the performance of the PSO-based MPPT technique and compared it with the conventional P&O algorithm. The results demonstrated that PSO offers superior tracking performance, including faster MPP convergence, negligible oscillations at the operating point, and effective global maximum power point tracking under varying irradiance and partial shading conditions. The proposed distributed MPPT configuration enables independent operation of PV sub-modules at their optimum power levels, thereby reducing mismatch losses and improving system flexibility, scalability, and overall lifetime. The PSO algorithm required approximately 520 ms for initial MPP tracking and nearly 60 ms for retracking under changing conditions. These results confirm that PSO-based MPPT is a reliable and efficient solution for high-performance photovoltaic energy conversion systems.

REFERENCES

1. Aarushi Koundal 2020, ET Energy World, Renewable capacity statistics 2020, International Renewable Energy Agency (IRENA), Abu Dhabi.
2. Alan Mc Intosh & Jennifer Pontius 2017, 'Chapter 4 - Human impacts on the global landscape, science and the global environment', Case Studies Integrating Science Global Environment, Edition 1, pp. 361-470.
3. Allouche, M, Dahech, K & Chaabane, M 2018, 'Multi objective maximum power tracking control of photovoltaic systems: T-S fuzzy model-based approach', Soft Computing-Soft Computing: A Fusion of Foundations, Methodologies and Applications, vol. 22, pp. 2121-2132.
4. Almasri, A, Al Shabrawi, B, Sardar, A, Al Atifi, A, Al Harbi, A & Ammous, A 2020, 'Contribution to the realization of DC nano-grid including PV source,' Industrial & Systems Engineering Conference (ISEC), Makkah, Saudi Arabia, DOI: 10.1109/ISEC49495.2020.9230136, pp. 1-5.
5. Amara Karima, Arezki Fekik, D Hocine, Mohamed Lamine Bakir, El-Bay Bourennane, Toufik Ali Malek, Ali MalekAmara, K 2018, 'Improved performance of a PV solar panel with adaptive neuro fuzzy inference system ANFIS based MPPT', 7th International Conference on Renewable Energy Research and Applications (ICRERA), DOI:10.1109/ ICRERA.2018. 8566818, pp. 1098-1101.
6. Burmester, Daniel, Rayudu, Ramesh Seah, Winston Akinyele & Daniel 2017, 'A review of nano grid topologies and technologies', Renewable and Sustainable Energy Reviews, Elsevier, vol. 67, pp. 760-775.
7. Carlos Robles Algarín & John Taborda Giraldo 2017, 'Article fuzzy logic based MPPT controller for a PV system', Energies, vol. 10, P. 2036.
8. Chaibi, Y, Salhi, M & El-jouni, A 2019, 'Sliding mode controllers for standalone PV systems: Modeling and approach of control', Hindawi International Journal of Photoenergy, vol. 2019, pp. 1-12.

IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 6, Issue 3, July 2026

Impact Factor: 8.2

9. Chander Jagdish & Aeidapu Mahesh 2015, 'Effect of recombination of charge carriers on modeling of PV array', International Conference on Energy, Power and Environment: Towards Sustainable Growth (ICEPE), pp. 1-5, DOI: 10.1109/EPETSG.2015.7510076.
10. Das & Pratima 2016, 'Maximum power tracking based open circuit voltage method for PV system', Energy Procedia, vol. 90, pp. 2-13.
11. Dunlop, ED, Gracia Amillo, A, Salis, E, Sample, T & Taylor, N 2018, 'Standards for the assessment of the environmental performance of photovoltaic modules, power conversion equipment and photovoltaic systems', Publications Office of the European Union, Luxembourg, ISBN 978- 92-79-86608-1, DOI:10.2760/89830
12. Ebrahim EA, Maged, NA, Abdel-Rahim, N & Bendary, F 2019, 'Photovoltaic-based interconnected-modified DC-nano- grids within an open energy distribution system', 6th International Conference on Advanced Control Circuits and Systems (ACCS) & 2019 5th International Conference on New Paradigms in Electronics & information Technology (PEIT), Hurgada, Egypt, 2019, pp. 253-258, DOI: 10.1109/ACCSPEIT48329.2019.9062843.
13. Elangovan, S, Kamatchi Kannan, V, Senthil Raja, K & Bhuvaneswari, S 2018, 'Mathematical analysis for controlling chaos in positive luo converter using sliding mode control', International Journal of Pure and Applied Mathematics, vol. 119, pp. 2517-2528.
14. González Montoya, D, Ortiz Valencia, PA & Ramos-Paja, CA 2019, 'Fixed-frequency implementation of sliding-mode controllers for photovoltaic systems', International Journal of Energy Environmental Engineering, vol. 10, pp. 287-305.
15. Hadeed Ahmed Sher, Ali F Murtaza, Abdullah Noman, Khaled EAddoweesh & Marcello Chiaberge 2015, 'An intelligent control strategy of fractional short circuit current maximum power point tracking technique for photovoltaic applications', Journal of Renewable and Sustainable Energy, vol. 7, DOI: 10.1063/1.4906982.
16. Hussain, I, Zohaib, M & Babaei, E 2019, 'Modeling, simulation of buck boost converter with MPPT and control of battery charging application', 3rd International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT), DOI: 10.1109/ISMSIT.2019.8932883, pp. 1-5.
17. Joel, YS, Saikumar, HV & Rao Patange, SS 2016, 'Design & performance analysis of fuzzy based MPPT control using two-switch non inverting buck boost converter', International Conference on Electrical Power and Energy Systems (ICEPES), DOI: 10.1109/ICEPES.2016.7915967, pp. 414-419.
18. Joseph, SC, Ashok, S & Dhanesh, PR 2017, 'An effective method of power management in DC nanogrid for building application,' IEEE International Conference on Signal Processing, Informatics, Communication and Energy Systems (SPICES), Kollam, India, DOI: 10.1109/SPICES.2017.8091303, pp. 1-5.
19. Joshi, VV, Mishra, N & Malviya, D 2018, 'Solar energy integration with new boost converter for electric vehicle application', 8th IEEE India International Conference on Power Electronics (IICPE), DOI:10.1109/IICPE.2018.870 9611, pp. 1-6.
20. Kalam Azad, MG, Rasul, MMK, Khan, Subhash, C & Sharma 2019, 'Introduction to sustainable and alternative eco fuels', Advances in Eco-Fuels for a Sustainable Environment, Woodhead Publishing Series in Energy, Elsevier Science, pp. 1-14.