Zaria Journal of Electrical Engineering Technology, Department of Electrical Engineering, Ahmadu Bello University, Zaria – Nigeria. Vol. 13 No. 1 & 2, September 2024.

Development of Optimized Maximum PowerPoint Tracking Scheme for A Partially Shaded Photovoltaic System

M. Aderinola[1], A. S. Abubaka[2], A. B. Kunya[3]
[1](Department of Electrical and Electronics Engineering, Hussaini Adamu Federal Polytechnic, Kazaure – Nigeria).
[2] (Department of Electrical Engineering, Ahmadu Bello University, Zaria–Nigeria)
[3](Department of Electrical and Telecommunication and Computer Engieering, Kampala International University, Kampala-Uganda).
[1]*mushafahu@yahoo.cm, [2] abubakaras@abu.edu.ng, [3]abkunya@kiu.ac.ug

Keywords: –
Maximum Power point Tracking, Improved Grey Wolf Optimization, Perturb and Observe, Particle and Swamp Optimization and Matlab Software.
.

Article History: –
Received: **Dec. 22, 2023**
Reviewed: **Feb. 8, 2024**
Accepted: **Feb. 15, 2024**
Published: **Mar. 19, 2024**

ABSTRACT

Solar energy harnessed through photovoltaic (PV) technology plays a pivotal role in generating electrical energy. Maximizing the power output of solar modules requires optimal solar radiation. However challenges arise due to obstacles such as stationary objects, building, tree leaves and winds, which can result in the presence of multiple points of maximum power on the PV curve. This problem necessitates the use of maximum power point tracking (MPPT) tracking algorithms, especially in unstable climatic conditions and partial shading scenario. To this effect, five MPPT Algorithms were employed namely perturb and observe (P&O), particle swarm optimization (PSO), flower pollination algorithm (FPA), grey wolf optimization (GWO) and Improved grey wolf optimization (IGWO), taking into consideration, tracking time, efficiency and global maximum power point. The best performance that was observed was Improved Grey Wolf Optimization (IGWO) algorithm, which tracked the Global Maximum Power Point (GMPP) at 975.50 W from an input power of 977.06 W within a very short tracking time of 0.0052 seconds and an efficiency of 99.84%. This shows that IGWO algorithm has improved efficiency by 5.79%, 6.06%, 4.98%, and 3.91% compared to P&O, PSO, FPA, and the baseline (GWO). Similarly, their corresponding tracking times are 0.2918 seconds, 0.7928 seconds, 0.9108 seconds, and 0.7998 seconds more than the IGWO.

1. INTRODUCION

There is an urgent need for electrical energy due to the rising energy demand across sectors and businesses. Nonetheless the use of fossil fuels like coal and oil contributes to environmental deterioration and global warming. Consequently, there is an increasing need for renewable energy sources [1].

Technical and Vocational Educational Training (TVET) being one of the training sectors in Nigeria clamouring for the use of clean energy, which solar energy is inclusive. From many renewable natural resources available, solar energy is a leading contributor to usage in different sector on which people depends [2].

Photovoltaic (PV) cells represent the cutting edge of energy technology. But one of the inherent difficulties in using solar energy is the possibility of blocking sunlight, which can make it more difficult to effectively use the solar energy that is being received. This impediment can appear as shadows thrown on the PV cell surface by clouds, trees, buildings, or tree leaves. This results into partial shading covering some parts or all parts solar panel, which hinder the output power as well as maximum efficiency PV system. To this effect maximum power point need to be tracked using algorithms.

The maximum power point tracking (MPPT) in a PV power generating system is a distinct point in the power voltage characteristics curve at a certain solar or irradiance and ambient temperature conditions that varies with environmental conditions [2]

The peak power comprises both the local and global maximum power points, (LMPP) and (GMPP). Maintaining and restricting the GMPP is necessary to provide the best possible energy conversion from the PV module, particularly when there are many LMPPs present. The use of technology known as MPPT becomes required to overcome this challenge.

The real time, the MPPT system continuously and dynamically calculates the PV module's GMPPT while adjusting for varying weather and other environmental parameters.

By cleverly modifying the PV module's operating point, the MPPT system maximizes its output power and make sure it always work at or close to the GMPP. In order to maximize solar energy harvest and improve system efficiency as a whole, this optimization is essential. Through the use of MPPT technology, solar PV system can efficiently counteract the fluctuating nature of solar radiation and shadows, improving their efficiency and increasing their dependency as sources of sustainable and clean energy [3]

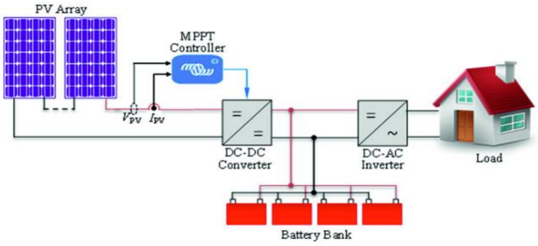

Fig. 1. Standalone pv system [4]

2.0 Literature Review

The literature present the impact of different algorithms on partial shading conditions taking into consideration maximum power output, efficiency, tracking time, accuracy etc.

According to [2], global maximum power point (GMPP) was tracked using modified invasive weed optimization integrated with perturb and observe (MIWO-P&O) algorithm. They claim that the result obtained allows for faster convergence and better search for the GMPP.

[5] carried out comparison among the following algorithm:, constant current step-Grey wolf Optimization (CCS-GWO), Grey wolf Optimization (GWO) and Genetic Algorithm (GA). It was observed from the simulation result that CCS-GWO perform better in term of tracking efficiency and accuracy.
Flying squirrel search optimization (FSSO) with Harris hawk optimizer (HHO) was integrated to locate the global maximum under partial shading condition (PSC). There exist better performance in term of tracking efficiency and tracking time when compared with other techniques like P&O and MIWO [6].

Using white shark optimization (WSO), [7] took into consideration 4 distinct patterns; short wide (SW), long wide (LW), short narrow (SN) and long narrow (LN). WSO performs better in global maximum power output throughout the four patterns examined when compared to HHO and FPA, with improvements of 26.22%

18.51%, 10.95% and 10% for SW, LW, SN and LN.

Under various partial shading circumstances, the MPP from the PV system was tracked using an altered version of the modified multi-stepped constant current –grey wolf optimization (MMSCC-GWO) algorithms. When the result were contrasted with Salp Swarm Optimization or SSA, it was discovered that the MMSCC-GWO performed well in terms of efficiency, tracking time and accuracy [8]

Other algorithms used for MPPT are improved whale optimization integrated with P&O [9]-[10], modified grey wolf optimization (MGWO) [11]-[12]. The former give better output in term of tracing efficiency while the later gives better output in term accuracy, tracking speed and output power.

2.1 PV Cell Model

A PV cell can be simplified and represented by a single diode equivalent circuit with load current (I_{PV}), voltage (V_{PV}) and other parameters as shown in Fig 2. This equivalent diode model is useful for analyzing and simulating the performance of PV cells and solar panels [11].

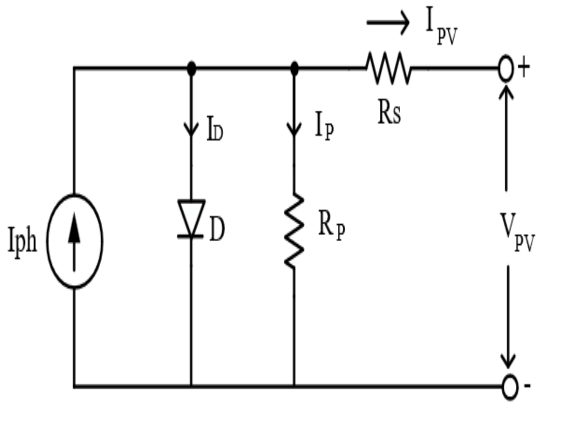

Fig. 2. Single diode equivalent circuit of a PV system

Mathematically,

$$I_{PV} = I_{ph} - I_D - I_p \quad (1)$$

From Eq. 1, the diode current I_D and current through the shunt resistance I_p are given by Eqs. 2 and 3 respectively.

$$I_D = I_o\left[\exp\left(\frac{V_{PV}+I_{PV}R_s}{AV_t}\right) - 1\right] \quad (2)$$

$$I_p = \frac{V_{PV}+I_{PV}R_s}{R_p} \quad (3)$$

Substituting Eqs. 2 and 3 into 1 gives the I-V characteristics of a PV module as presented in Eq. 4.

$$I_{PV} = I_{ph} - I_o\left[\exp\left(\frac{V_{PV}+I_{PV}R_s}{AV_t}\right) - 1\right] - \frac{V_{PV}+I_{PV}R_s}{R_p} \quad (4)$$

Where I_{PV} and V_{PV} are the current and voltage generated by the cell when exposed to light, I_o is the current that flows through the diode when it's in reverse bias, while R_s and R_p are series and shunt resistances respectively. $V_t$is the junction or diode thermal voltage which is defined as given in Eq. 5 and the factor A is the diode-modified quality factor which is usually assumed to be unity.

$$V_t = \frac{N_s nkT}{q} \quad (5)$$

3.0 Methodology

The method employed in this research work was introduction of partial shading by covering some part of cells, while leaving some part uncovered. This was achieved using MATLAB/Simulink software as can be seen in fig 3.

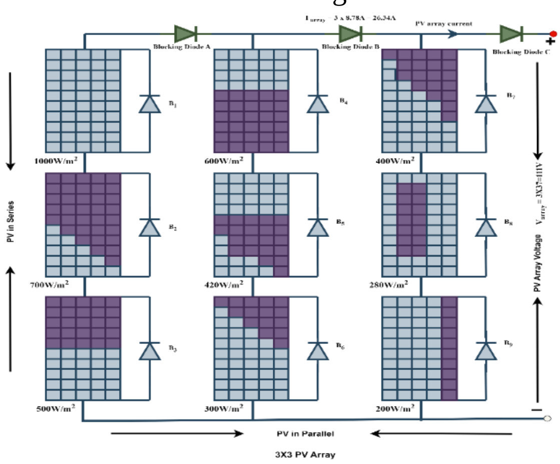

Fig 3: PV array configuration under partial shading

Fig 3 shows 3x3 configurations of partial shading conditions on a solar PV array. This configuration is connected in series-parallel with varying irradiance values to each PV module. In case1, under a non-uniform pattern, the non-uniform irradiance received by the three PV panels is set at 1000 W/m², 700 W/m², and 500 W/m². 600 W/m², 420 W/m²and 300 W/m² for case 2 and 400 W/m², 280 W/m² and 200 W/m² for case3 respectively. To model partial shading, the pattern, used involves a reduction of 0%, 30%, and 50% from the reference irradiance for case 1-3

Table 1: Parameters of Canadian Solar CS6X–325P PV array at STC

Parameter	PV module	PV array
Nominal maximum power (P_{mp})	325 W	2,925 W
Maximum voltage (V_{mp})	37 V	111 V
Maximum current (I_{mp})	8.78 A	26.34 A
Open circuit voltage (V_{oc})	45.5 V	136.5 V
Short circuit current (I_{sc})	9.34 A	28.02 A

3.1 DC-DC Boost Converter Modelling

Among the various DC-DC converters utilized in Photovoltaic (PV) systems, three prominent types are the buck, boost, and buck-boost converters. Notably, the boost converter stands out due to its superior stability and efficiency compared to its counterparts. Consequently, this study has opted to employ the boost converter, leveraging its advantageous characteristics to enhance the overall performance of the PV system. The voltage across a PV array changes from zero open circuit voltage depending on the irradiance level and temperature of the PV modules. Hence, the input and output voltages of the modules are not constant. To trap maximum power, the value of the duty cycle keeps changing. Consider a PV array shown in Figure 3 with nine PV modules, where three are connected in series and parallel.

Under partial shading, the change in irradiance affects the values of the current more than the voltage of the PV array. PV array voltage only changes by about 10% under partial shading.

4.0 Result of simulation

The simulation of result for case 1-3 for pv and i-v characteristics are presented here. Also the tracking processes of the algorithms used as well as time required to reach their maximum value were presented as well.

In scenarios where non-uniform irradiance affects the photovoltaic (PV) array, as observed in cases 1-3, the power-voltage (P-V) curve exhibits multiple local maximum power points (LMPPs) in addition to the global maximum power point (GMPP). This phenomenon is illustrated in Fig 4 Specifically, in case 1, two LMPPs are identified and one GMPP at 34.60 V and 76.05 V, and 118.44V corresponding to the lower (V_{LMPP1}), upper voltage (V_{LMPP2}) and global voltage ranges, respectively. The GMPP which corresponds to a maximum power output of 537.701W. Case 2 and 3 exhibit maximum power outputs of 320.86W and 211.42W when the voltage approaches approximately 117 V.

Similarly, case two and three has 34.40V and 34.91 as their lower (V_{LMPP1}), and 74.62V and 74.44V as upper voltage (V_{LMPP2}).

Although the voltage values at the GMPP are similar, significant variations in power output are observed.

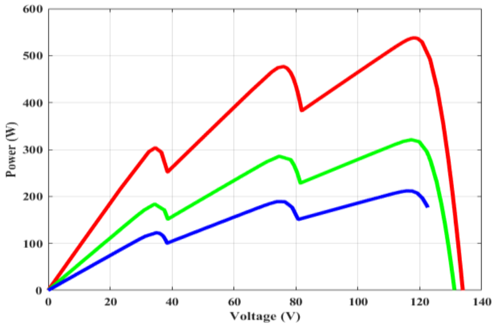

Fig.4. P-V characteristics curve for cases 1-3 under partial shading pattern

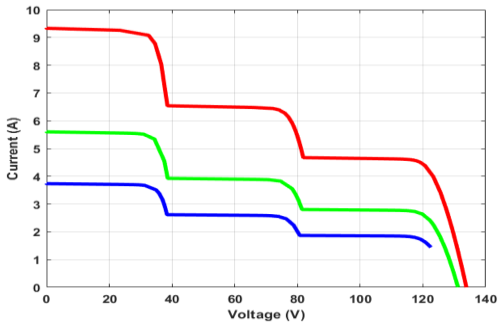

Fig. 5. I-V characteristics curve for cases 1-3 under partial shading pattern

In scenarios where non-uniform irradiance affects the photovoltaic (PV) array, as observed in cases 1-3, the comparative performance of various MPPT techniques under partial irradiance conditions is presented. The Perturb and Observe (P&O) algorithm, shown in fig 5 with an input power of 1449 W, tracked the Maximum Power Point (MPP) at 1376 W, resulting in an efficiency of 94.05%. The convergence of this algorithm was observed after 0.297 seconds

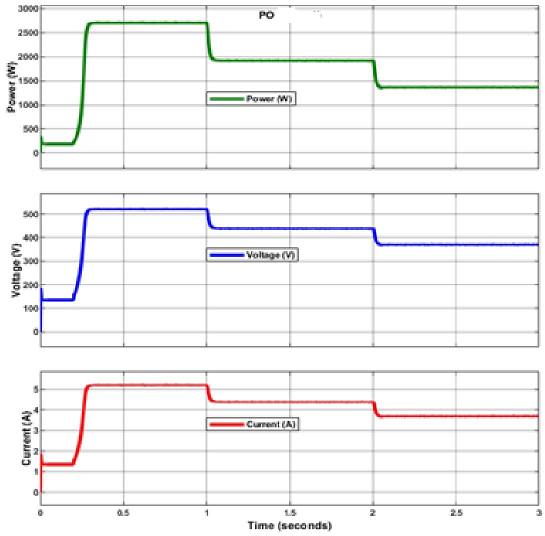

Fig. 6: GMPP tracking process of P&O under non uniform irradiance

Fig. 8: GMPP tracking process of FPA under non uniform irradiance

From fig. 7 - fig. 10, shows the behavior of each algorithm used for comparison. The Particle Swarm Optimization (PSO) algorithm tracked the MPP at 719.85 W in 0.798 seconds from an input power of 767.60 W, resulting in an efficiency of 93.78%. Unlike P&O and PSO, the Flower Pollination Algorithm (FPA) demonstrated a slightly improved efficiency of 94.86% from an input power of 1100.54 W, tracked at an MPP of 1044 W. However, it exhibited a higher tracking time of 0.916 seconds, 0.619 seconds and 0.118 seconds more than both P&O and PSO.

Based on Grey Wolf Optimization (GWO), the baseline algorithm tracked the MPP at 846.33 W after 0.805 seconds from an input power of 882.21 W, resulting in an efficiency of 95.93%. The performance of the baseline algorithm was better than those of the P&O, PSO, and FPA in terms of efficiency and convergence speed.

However, the best performance was observed that Improved Grey Wolf Optimization (IGWO) algorithm, which tracked the Global Maximum

Power Point (GMPP) at 975.50 W from an input power of 977.06 W within a very short tracking time of 0.0052 seconds and an efficiency of 99.84%. In this scenario, IGWO algorithm has improved efficiency by 5.79%, 6.06%, 4.98%, and 3.91% compared to P&O, PSO, FPA, and the baseline (GWO). Similarly, their corresponding tracking times are 0.2918 seconds, 0.7928 seconds, 0.9108 seconds, and 0.7998 seconds more than the IGWO.

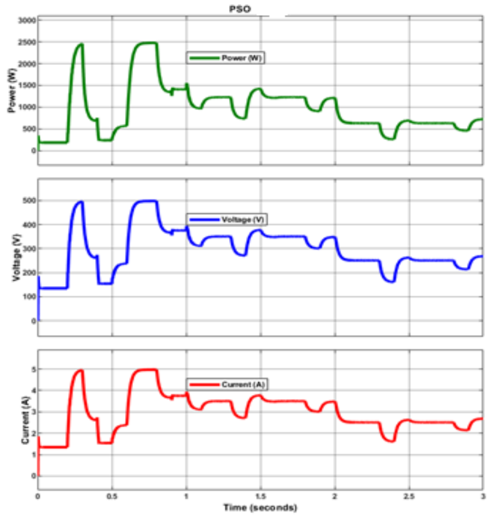

Fig. 7: GMPP tracking process of PSO under non uniform irradiance

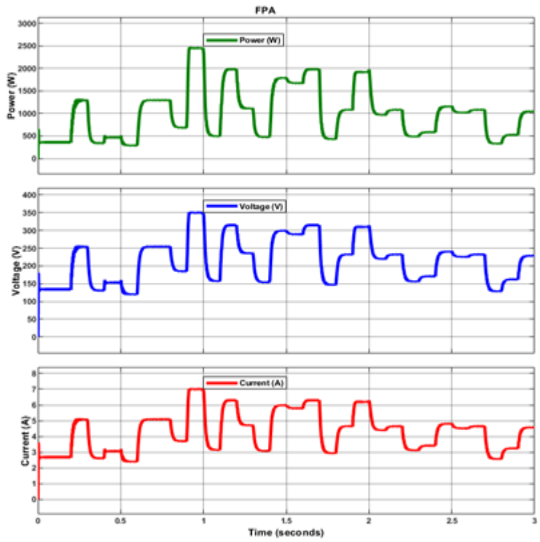

Fig. 8: GMPP tracking process of FPA under non uniform irradiance

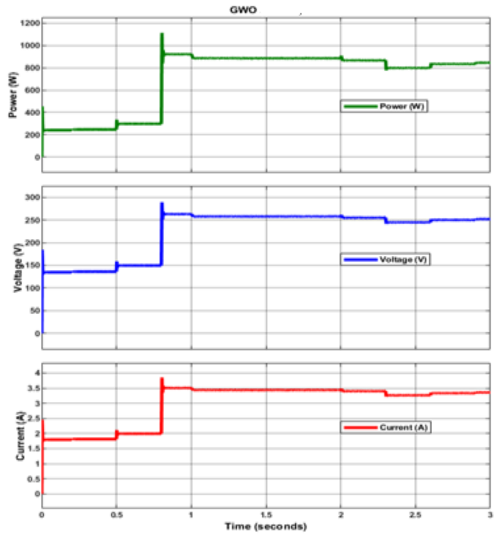

Fig. 9: GMPP tracking process of GWO under non uniform irradiance

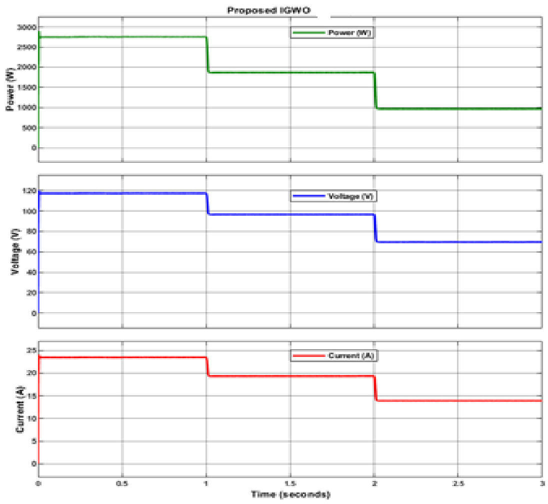

Fig. 10 GMPPT under GMPP tracking process of P&O under non uniform irradiance

This research as contributed to the field of knowledge in the following area

1. Fast tracking time
2. Less power loss

5.0 Conclusion

This study provides an in-depth analysis of the Improved Grey Wolf Optimization (IGWO) algorithm for locating the Global Maximum Power Point (GMPP) in Photovoltaic (PV) arrays. The IGWO algorithm outperforms four other methods: P&O, PSO, FPA, and GWO. It successfully identified the GMPP at 975.50 W from an input power of 977.06 W with an impressive tracking time of just 0.0052 seconds and an efficiency of 99.84%. Compared to P&O, PSO, FPA, and GWO, the IGWO algorithm shows improvements in efficiency of 5.79%, 6.06%, 4.98%, and 3.91%, respectively. Additionally, the tracking times for these other methods are significantly longer, at 0.2918 seconds, 0.7928 seconds, 0.9108 seconds, and 0.7998 seconds, respectively, when compared to the IGWO.

ACKNOWLEDGEMENT

I wish to express my sincere gratitude to God almighty for His love, faithfulness and guidance during this research work. I return all the glory to Him.

I want to express my profound gratitude to my supervisor Dr. A.S. Abubakar, Dr. A.B Kunya, for their efforts, valuable instructions and constant supervision towards the successful achievement of this research work.

I also want to show my sincere appreciation to the Head of Department, Prof. B. Jimoh, and all other staff of the department both teaching and non-teaching staff. I thank you all

REFERENCES

F. Berttahar, S. Abdeddaim, A. Betka, C. Omar S. M. Abdelkadir & D. J. Morrow. "A Comparative Study of PSO, GWO, and HOA Algorithms for MPPT in Partially Shaded PV System Model Predictive Load Frequency Control of Multi-Area Interconnected Power System", *Journal of Power Electronics and Drives. 9(44),* 86-104, 2024

M. K. Senapati, C.R. Pradhan, R. k. Calay, "A Computational Intelligence Based MPPT for PV Power Generation System with Small Signals Analysis", *Department of Electrical Engineering, Indian Institute of Technology, Dhaband, India.* 1(1), 1 –25, 2020.

Chauhan U., Rani A., Kumar B., and Singh V. "A Multi Verse Optimization Based MPPT Controller for Drift Avoidance in Solar System",*Intelligent and Fuzzy System*, 36(3), 2175-2184, 2019.

M. K. Senapati, M. Senapatti, P. k. Panigrehi. "Efficient MPPT Algorithms for PV System under PSCs Hybrid FSSO-HHO Approachwithhardware-In-loop Validation", *Research Square.* 5(10), 1-25 2023.

I. Dagal, B. Akin, Y.D. Darl. "A Modified Multi-Stepped Constant Current Based on Gray Wolf Algorithm for Photovoltaics Applications", *Springer Nature, Germany*, 46(2), 8441-8460, 2024.

C.H. Basha, M. Palati, C. Damajayulu, S.M. Muyeen, P. Venkatareddy. "A Novel on Design and Implementation of Hybrid MPPT Controller for Solar PV under Various PSCs", *Scientific Research Report*,1(5), 1-10, 2024

J. Zhong, L. Zhang, L. Qin. "Research on the MPPT of PV power Generation Based on Improved WOA and P&O under PSCs", *Energy Engineering,* 23(7), 3571-3582, 2023.

N.A. Khadim, A.A. Obed, A.J. Abid, H. Kotb and A. Emara. "Optimal PV Reconfiguration Based on White Shark Optimization", *Research Article,* 12(1), 27385- 27396, 2024.

Obukhov, S., Ibrahim, A., ZakiDiab, A. A., Al-Sumaiti, A.S., and Aboelsaud R. "Optimal Performance of Particle Swarm Optimization Based on maximum Power Tracker for Stand

Alone PV System under Partial Shading Conditions", *IEEE Access*, 8(6), 20770-20785, 2020.

H. Belmadini, R. Bradini, A. Kheldoun, K. Mohammed, S. Mikhlef, Y. Blikheir, A. Oublaid. "A New Fast Efficient MPPT Algorithm for PS PV System using Hyperbolic Slime Mould Algorithm", *International Journal of Energy Research*, 7(3), 55825-55835, 2024

A. El-GhajGhaj, H. Karmouni, N. El-Ounalji, M.O. Jamil, H. Ojida, and M. Sayyouri. "Comparative Analysis of Classical and Meta-heuristic MPPT Algorithms in PV", *Springer Nature Switzerland*, 7(5), 29- 37, 2023.

Ramanchandra N., Natarajan R., "Productivity Enhancement of Total-Cross-Tied PV Array under Static Shading Conditions", *IEEE Transaction of Power Electronics*, 38(3), 4053-4060, 2023.