International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
IJISAE
ISSN:2147-6799 www.ijisae.org Original Research Paper

Temperature Effects Adaptation to Akbaba Model for V-I Characteristic Determination of PV Panels

Nurettin Gökşenli[1], Mehmet Tümay[2], Enes Bektaş*[3], Ethar Sulaiman Yaseen Yaseen[4], Taha Etem[5]

Submitted:12/03/2024 **Revised**: 27/04/2024 **Accepted**: 04/05/2024

Abstract: This study enhances the Akbaba Model by integrating temperature effects on PV panels to improve accuracy and efficiency in photovoltaic system modelling and performance. This paper presents and analyzes the temperature impacts on PV panels within the Akbaba Model, which is used to derive the V-I properties of PV panels. Traditional diode equations have notable disadvantages: they are very complex, lack analytical solutions, and require repetitive and time-consuming operations necessitating a computer. Due to these disadvantages, the Akbaba Model, which provides an easier and more analytical solution, has been proposed and investigated in detail to easily obtain the V-I electrical characteristics of photovoltaic generators (PVG). Incorporating temperature influences helps the Akbaba Model in PV systems to improve accuracy by presenting fresh equations that account for temperature effects. A comparative study of the original and upgraded Akbaba Models shows that the temperature-adapted model performs better. Most importantly, for developing and maintaining more effective renewable energy systems, the upgraded model provides a more consistent instrument to enhance PV system efficiency. The study also indicates potential applications and model enhancements, directing further research. These improve PV installation reliability and performance and deepen the knowledge of PV system modelling. Most importantly, experimental application has been conducted to investigate the performance of the Akbaba Model under different temperatures for the first time in the literature.

Keywords: *Akbaba model, MPPT, Photovoltaics, Power electronics, Temperature effect*

Nomenclature

Symbol	Quantity	Symbol	Quantity
I_{max}	PVG current (at Pmax)	PV	photovoltaic
I_{sc}	short circuit current	PVG	photovoltaic generator
I_{out}	output current	T_a	ambient temperature
γ	system efficiency	T_{cell}	cell temperature
I_p	panel current	V_p	panel voltage
G	percent solar current	$V_{max,st}$	Standard PVG voltage (at Pmax)
P_{max}	maximum power	V_{out}	output voltage
P_{out}	output load power	V_{oc}	open circuit voltage of PVG
P_p	panel power	V_{max}	PVG voltage (at Pmax)

[1] *Çankırı Karatekin University, Dept. of Electronics and Automation, Vocational School, Çankırı, Türkiye, ORCID ID : 0000-0002-0858-4448*
[2] *Çankırı Karatekin University, Dept. of Electronics and Automation, Vocational School, Çankırı, Türkiye, ORCID ID : 0000-0003-2938-8005*
[3] *Çankırı Karatekin University, Dept. of Electrical Electronics Engineering, Engineering Faculty, Çankırı, Türkiye ORCID ID : 0000-0002-8380-4519*
[4] *Çankırı Karatekin University, Dept. of Electrical Electronics Engineering, Engineering Faculty, Çankırı, Türkiye ORCID ID : 0000-0002-5259-378X*
[5] *Çankırı Karatekin University, Dept. of Computer Engineering, Engineering Faculty, Çankırı, Türkiye ORCID ID : 0000-0003-1419-5008*
* *Corresponding Author Email: enesbektas@karatekin.edu.tr*

1. Introduction

The interest in clean and renewable energy sources has made photovoltaic (PV) systems a vital part of the worldwide energy change. Optimizing PV system performance and efficiency becomes even more critical as the market for renewable energy rises. Maximum Power Point Tracking (MPPT) approaches to guarantee that PV systems run at their maximum power output under different climatic circumstances, so this optimization mainly relies on their application.

Over the years, MPPT methods have been investigated and refined. Focusing on their energy efficiency and operational features, Dolara et al. [1] performed a comparative study of seven MPPT strategies, offering a basic knowledge of the advantages and disadvantages of every approach. Reisi et al. [2] likewise examined many MPPT methods, classifying them according to their methodological approaches and analyzing their relative performance.

Additionally, innovative control methods are intended to improve PV system efficiency. Arif et al. [3] greatly increased the total energy production of PV systems by developing a microcontroller-based sun tracker control system for real-time solar tracking. Hasanah et al. [4] used a computer-based solar tracking system to show further how automation may maximize PV performance.

Another critical area of inquiry is PV panel characterization. Designed especially for PV panels, Zegrar et al. [5] created an I-V curve tracer for thorough performance assessment.

De Riso et al. [6] presented a wireless self-powered I-V curve tracer for online characterization, highlighting diagnostic power and monitoring capacity developments.

Furthermore, hybrid approaches and intelligent control strategies show encouraging outcomes. Reviewing hybrid, optimum, and traditional MPPT methods, Bollipo et al. [7] and Hohm et al. [8] highlighted combining artificial intelligence and meta-heuristic algorithms to increase tracking accuracy and efficiency under many circumstances. Investigating MPPT methods under uniform and non-uniform solar irradiation, Ali et al. [9] showed how well-improved algorithms might adapt to changing environmental circumstances.

Additionally, artificial neural networks (ANN) mixed with conventional MPPT methods have been investigated. Dkhichi et al. [10] combined ANN with the Perturb & Observe method to enhance the power production of PV systems, therefore attaining more efficiency and stability. Messalti et al. [11] showed enhanced performance via hardware implementation and simulation via a variable step-size ANN-MPPT controller.

Researchers have also concentrated on creating new MPPT techniques catered to particular circumstances. López-Lapeña et al. [12] presented a novel MPPT technique for low-power solar energy collecting to solve the particular difficulties of low-power applications. Setiawan et al. [13] investigated PV-inverter setup and solar panel performance for tropical environments, offering insightful analysis for optimizing PV systems in particular climatic situations.

Thorough assessments and classifications of MPPT procedures have been undertaken to provide a comprehensive view of the area. Karami et al. [14] presented a comparison table for simple categorization and a broad overview and classification of many MPPT approaches, guiding readers to choose the most appropriate method. Reviewing the most utilized MPPT systems, Motahhir et al. [15] discussed every technique's idea, advantages, and disadvantages and advised appropriate low-cost integrated boards for hardware deployment.

Additionally, advanced MPPT methods grounded on meta-heuristic algorithms are investigated for their efficiency under partial shade situations. Using four partial shade patterns, Rezk et al. [16] contrasted CS and PSO approaches with traditional incremental resistance (INR), assessing the tracking performances of MPPT algorithms using MATLAB simulation. Yang et al. [17] analyzed 62 methods divided into seven categories and thoroughly summarized MPPT techniques under partial shading situations.

Moreover, new MPPT controllers grounded on sophisticated algorithms have been suggested. Using the Ant Colony Optimization (ACO) method, Titri et al. [18] presented an MPPT controller with great accuracy and resilience against fast weather fluctuations. Using an upgraded particle swarm optimization (PSO) approach, Shankar and Saravana Kumar [19] established a model for lowering partial shading effects in PV array topologies, demonstrating better monitoring of maximum power peak performance.

Improving the dependability and efficiency of PV systems depends on ongoing research and improvement of MPPT methods [11] [14],[20]-[21]. Researchers and engineers may maximize the performance of PV systems by using cutting-edge monitoring systems, sophisticated algorithms, and advanced control techniques, thereby influencing the worldwide scene of renewable energy [22],[23].

In this study, we improve the Akbaba Model equations by adding recently obtained equations to include the temperature impact on PV panels. Incorporating temperature influences helps improve the Akbaba Model in PV systems. It presents fresh equations, including temperature influences on PV panels, therefore enhancing the correctness of the model. A comparison study of the original and improved Akbaba Models shows that the temperature-adapted model is better. Crucially for designing and running more efficient renewable power systems, the improved model offers a more dependable tool for improving PV system efficiency. Also, the study suggests possible uses and improvements to the model, guiding further studies. These efforts develop an understanding of PV system modelling and increase PV installation performance and dependability. The findings show that adding temperature significantly improves the Akbaba Model's effectiveness, as determined in [24]. This improvement not only raises the forecast accuracy of the model but also offers a more trustworthy instrument for maximizing PV panel efficiency under different environmental circumstances.

The rest of the paper delineates the mathematical formulation and theoretical justification of novel equations that account for temperature effects. The results section compares the original and enhanced Akbaba Models, emphasizing their performance metrics and evaluation criteria. The conclusion underscores the model's accuracy, highlighting its contributions to the field and future research directions. The main findings are summarized, with a particular emphasis on the impact of temperature adaptation.

2. Akbaba Model

The conventional V-I characteristics of PVs, which are employed in literature [24], are highly complicated, need more analytical solutions, and need to use a computer to carry out time-consuming, repetitive operations. Therefore, in contrast to traditional ones, the Akbaba Model, which has a more straightforward and analytical solution, is utilized to derive the V-I electrical characteristics of the PVG. The Akbaba Model equations are given in Equation (1) [24].

$$I = \frac{(V_{oc}-V)}{A+BV^2-CV}$$
(1)

Here, Akbaba Model parameters A, B, C, V_{oc} and I_{sc} are determined for many selected G value, solar radiation of PVG. A parameter can be defined as in Equation (1) and Equation (2) can be examined using detailed procedures [25].

$$A = \frac{V_{oc}}{I_{sc}}$$
(2)

where, V_{oc} and I_{sc} are the open circuit voltage and the short circuit current of the solar panel respectively. Output power of PVG is given as following Equation (3):

$$P = IV = \frac{V(V_{oc}-V)}{A+BV^2-CV}$$
(3)

PV panels operate best when they are very close to reaching their maximum power trajectory because installation costs are too expensive. The voltage Vmax needed for maximum power P_{max} can be calculated by setting the derivative of P, given in (3), with respect to V to zero, as $dP/dV = 0$. With presented mathematical equalities on obtaining maximum output power of PVG, formulation of Vmax can be derived as following:

$$V_{max} = \left(\frac{V_{oc}}{I_{sc}}(C - BV_{oc})\right)\left(\frac{1}{\sqrt{(1-(1-I_{sc}(C-BV_{oc})))}}\right) \quad (4)$$

Then, I_{max} and P_{max} can be written from (3) and (4) as:

$$I_{max} = \frac{(V_{oc}-V_{max})}{(A+BV_{max}^2-CV_{max})}$$
(5)

$$P_{max} = V_{max}I_{max}$$
(6)

By comparing the V-I characteristic produced using parameters A, B, and C with the conventional V-I characteristic provided in [25], the accuracy of the V-I characteristic is determined. Fig. 1 shows the changes of the calculated A, B, C, and parameters for the PV panels utilized in this study concerning the per cent solar radiation *G*.

3. Adaptation of Temperature Effect to Akbaba Model

To find the maximum power of the PV panel with the temperature effects, some mathematical operations are used as follows:

$$T_{cell} = T_a + \frac{(NOCT-20)G}{80}$$
(7)

where, *G* is percent solar radiation and *NOCT* is 48ºC. T_{cell} is obtained as:

$$T_{cell} = T_a + 0.35G$$
(8)

According to (7), cell temperature increases above ambient levels, with increasing solar irradiance for different module types [26]. T_a is the ambient temperature and e approximated as seasonal average for Çankırı-Türkiye. Seasonal average temperature stored in the microprocessor is given in Table 1.

Table 1. Seasonal average temperature of Çankırı

December - February	March-May	June-August	September -November
18 ºC	24 ºC	28 ºC	25 ºC

From data of (7), I_{max} is modeled, but not generalized for all PVGs as:

$$I_{max} = 0.0061G$$
(9)

Parameters *A*, *B*, and *C* are determined experimental data at a cell temperature controlled at 25ºC. Therefore, *A*, *B*, and *C* are named as standard parameters and V_{max} calculated with these is called as standard maximum power point voltage $V_{max,st}$. From (1), (10) can be obtained as following:

$$I_{max} = \frac{(V_{oc,st}-V_{max,st})}{(A+BV_{max,st}^2-CV_{max,st})}$$
(10)

$V_{oc,st}$ is given in terms of *G* as in (10), also $V_{max,st}$ is computed as:

$$V_{max,st} = \frac{Q^2-4Q_1Q_3}{2Q_1}$$
(11)

where; $Q_1 = BI_{max}$, $Q_2 = CI_{max} - 1$, $Q_3 = AI_{max} - V_{oc,st}$

Finally, V_{max} is calculated as in (12). Experimental results have shown that V_{max} decreases as 0.18% /º C. Therefore, with respect to $V_{max,st}$, V_{max} reduces with temperature as following:

$$V_{max} = V_{max,st} - 0.036T_{cell}$$
(12)

$$P_{max} = V_{max} - I_{max}$$
(13)

Then, from (9), (12), and (13) P_{max} can be derived as following:

$$P_{max} = 0.0061GV_{max,st} - 0.00022GT_a - 0.0000768G$$
(14)

4. Results

The graph's curves in Fig. 1 show that when solar radiation rises, parameters A and C decrease inversely. The graph's curves show that parameter B first rises as solar radiation increases, and that it then decreases despite the increase in solar radiation after around 50% of the radiation. The graph illustrates how the I_{sc} value rises in direct proportion to increase in solar radiation.

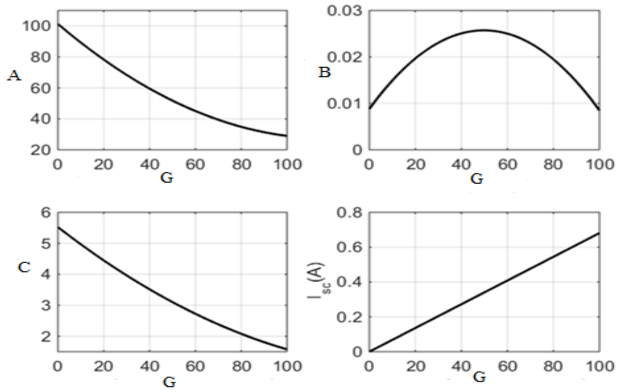

Fig. 1. Variations of A, B, C and I_{sc} with percent solar radiation G

In Fig. 2, V_{oc} and V_{max} values increase with increasing solar radiation, according to the curves in the graph. The P-V characteristics of the Solar Panel which is plotted using these measured values are shown in Fig. 3.

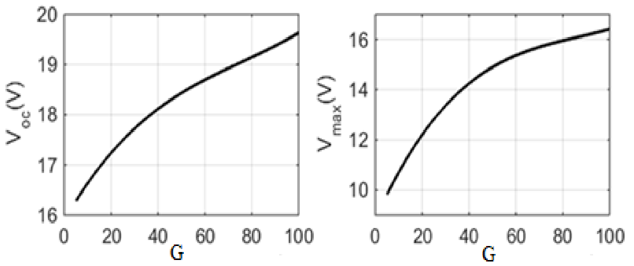

Fig. 2. Variations of V_{oc} and V_{max} with percent solar radiation G

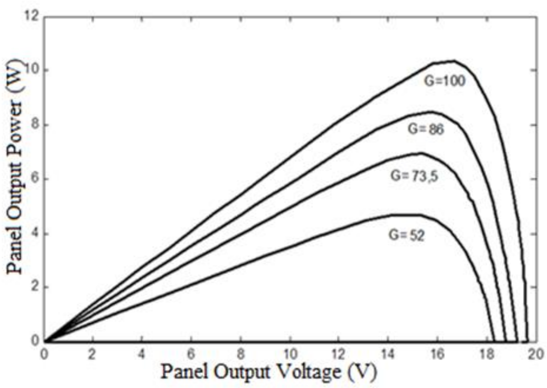

Fig. 3. P-V characteristics of used panel in several solar radiation

Fig. 3 the change curves of the panel output power in relation to the panel output voltage at varying solar radiation levels as the radiation increases. Plotting of the panel P-V characteristics at G = 100, maximum solar radiation, using the PVG power directly determined from the measured values and the panel P-V characteristics calculated using the Akbaba Model equation, is depicted in Fig. 4. It is seen that little differ from one another at all. This demonstrates the Akbaba Model's accuracy.

However, in Figs. 2-3, the effect of temperature is not taken into consideration. By considering the temperature effect, the accuracy of the Akbaba Model will be further enhanced. As mentioned above V_{oc} values calculated at 25°C panel temperature is used, as this value of panel temperature is for climate of city of Çankırı in Türkiye. For other locations another suitable average panel temperature could be used.

The V-I and P-I characteristics at various temperature of panel obtained by using Temperature Effect adapted Akbaba Model are shown Fig. 4 and Fig. 5 respectively.

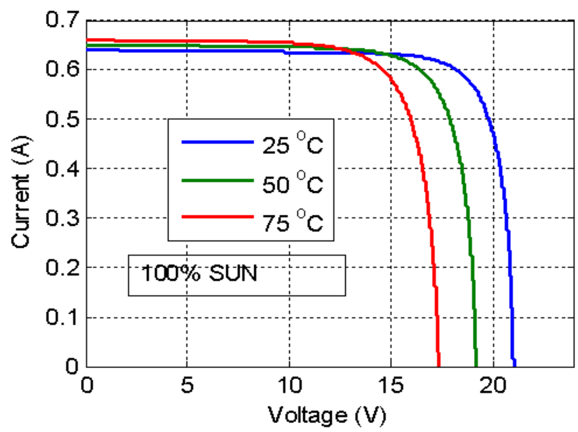

Fig. 4. V-I characteristic at various temperature

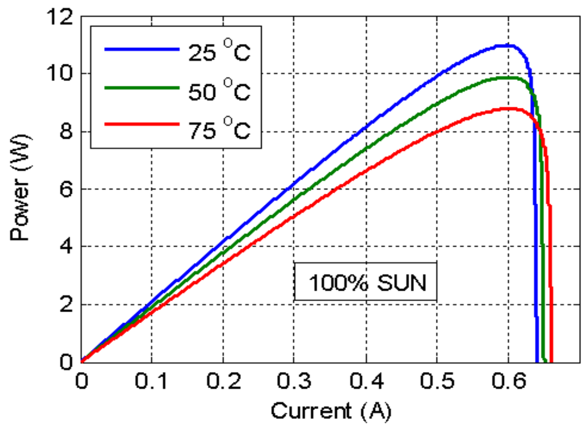

Fig. 5. P-I characteristic at various temperature

As can be expected from Fig. 4 and clearly seen from Fig. 5, current at maximum power, I_{max}, is almost independent of temperature, but maximum power decreases significantly with temperature. Decrease in power is due to the decrease in the voltage at maximum power, V_{max}, as temperature rises.

Since I_{max} is independent of cell temperature, it is measured and plotted according to the change of G which is percent solar radiation as given in Fig. 6.

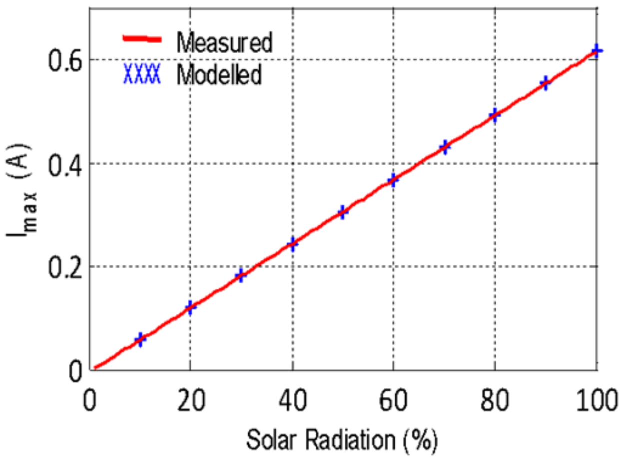

Fig. 6. I_{max} versus G

P_{max} values at different temperatures and different percent solar radiations have been calculated using (14) and the results are shown in Table 2.

Table 2. P_{max} values at different temperatures and different percent solar radiations

% G	T_{cell} at $T_a = 25$ °C	$V_{max,s}$ (V)	V_{max} (V)	P_{max} (W) at $T_a =$ 50 °C	P_{max} (W) at $T_a =$ 50 °C
52	16.56	16.56	15	4.76	4.47
73.5	17.43	17.43	15.6	6.99	6.59
80	17.81	17.81	15.9	7.76	7.32
100	18.56	18.56	16.4	10	9.45

In Table 2, it is seen that the P_{max} changes at different temperatures and different solar radiation. It is seen that P_{max} decreases with the increase in temperature for solar radiation of the same value. Thus, Pmax decreases inversely proportional to the increase in temperature.

5. Conclusion

In this study, we investigated the temperature effects of a newly designed microcontroller-based MPPT circuit [24]. The first application of the Akbaba Model to a PV array with temperature effects provides a more realistic and accurate system performance assessment. Conventional diode equations for the I-V characteristics of PVs [25] demonstrate that panel efficiency is temperature-dependent. Understanding the extent of this temperature influence is highly beneficial for PV panel designs. We improved the MPPT circuit's accuracy by including temperature effects; our investigation indicated that it is more cost-effective and more straightforward to operate than other systems in the literature. As a result, the system's efficiency was improved over previous work [24]. For instance, under 100 % solar radiation, the experimental output power in the previous study without temperature influence was 10 W. With temperature consideration in this study, the output power remained at 10W at Ta=25°C, indicating that the Akbaba Model equations produce consistent results at this ambient temperature. However, this study is critical as temperature variations impact outcomes in different environments.

Acknowledgements

Throughout the process of developing and completing our study, the guidance and support of Professor Dr. Mehmet AKBABA have been invaluable. His expertise and direction in Akbaba Model have significantly enhanced the quality of our work and contributed to its overall success. We are deeply grateful to him for his contributions and support.

Author contributions

Nurettin Gökşenli: Conceptualization, Methodology, Software, Field study

Mehmet Tümay: Data curation, Validation.

Enes Bektaş: Methodology, Visualization, Writing-Reviewing and Editing.

Ethar Sulaiman Yassen Yaseen: Introduction, Methodology, Writing-Reviewing

Taha Etem: Introduction, Writing-Reviewing

Conflicts of interest

The authors declare no conflicts of interest.

References

[1] Dolara, A., Faranda, R., & Leva, S. "Energy comparison of seven MPPT techniques for PV systems". *Journal of Electromagnetic Analysis and Applications*. (2009). DOI: 10.4236/jemaa.2009.13024

[2] Reisi, A. R., Moradi, M. H., & Jamasb, S. "Classification and comparison of maximum power point tracking techniques for photovoltaic system: A review". *Renewable and Sustainable Energy Reviews*, 19, 433-443. (2013). DOI: 10.1016/j.rser.2012.11.052

[3] Arif, E. M. H., Hossen, J., Murthy, G. R., Jesmeen, J. M. Z. H., & Raja, J. E. "An efficient microcontroller based sun tracker control for solar cell systems". *International Journal of Electrical and Computer Engineering (IJECE)*, 9(4), 2742-2750, (2019). DOI: 10.11591/ijece.v9i4.pp2742-2750

[4] Hasanah, R. N., Setyawan, A. B., Maulana, E., Nurwati, T., & Taufik. "Computer-based solar tracking system for PV energy yield improvement". *International Journal of Power Electronics and Drive System (IJPEDS)*, 11(2), 743-751. (2020). DOI: 10.11591/ijpeds.v11.i2.pp743-751

[5] Zegrar, M., Benmessaoud, M. T., & Zerhouni, F. Z. "Design and implementation of an IV curve tracer dedicated to characterize PV panels". *International Journal of Electrical and Computer Engineering*, 11(3), 2011-2018, (2021). DOI: 10.11591/ijece.v11i3.pp2011-2018

[6] De Riso, M., Matacena, I., Guerriero, P., & Daliento, S. "A Wireless Self-Powered I-V Curve Tracer for On-Line Characterization of Individual PV Panels". *IEEE Transactions on Industrial Electronics*, (2024). DOI: 10.1109/TIE.2023.3344843

[7] Bollipo, R. B., Mikkili, S., & Bonthagorla, P. K. "Hybrid, optimal, intelligent and classical PV MPPT techniques: A review." *CSEE Journal of Power and Energy Systems*, 7(1), 9-33. (2021). DOI: 10.17775/CSEEJPES.2019.02720

[8] Hohm, D. P., & Ropp, M. E. "Comparative Study of Maximum Power Point Tracking Algorithms". *Progress in Photovoltaics: Research and Applications*, 11, 47-62. (2003). DOI: 10.1002/pip.459

[9] Ali, A., Almutairi, K., Padmanaban, S., Tirth, V., Algarni, S., & Irshad, K. "Investigation of MPPT Techniques Under Uniform and Non-Uniform Solar Irradiation Condition–A Retrospection". *IEEE Access*, 8, 127368-127392. (2020). DOI: 10.1109/ACCESS.2020.3007710

[10] Dkhichi, F., Oukarfi, B., El Kouari, Y., Ouoba, D., Fakkar, A., & Sabiri, Z. "Performances of Artificial Neural Network combined with Perturb & Observe technique in maximizing the photovoltaic system power". In *2016 International Renewable and Sustainable Energy Conference (IRSEC)*. (2016). DOI: 10.1109/IRSEC.2016.7984023

[11] Messalti, S., Harrag, A., & Loukriz, A. "A new variable step size neural networks MPPT controller: Review, simulation and hardware implementation". *Renewable and Sustainable Energy Reviews*, 68, 221-233, (2017). DOI: 10.1016/j.rser.2016.09.131

[12] López-Lapeña, O., Penella, M. T., & Gasulla, M. "A New MPPT Method for Low-Power Solar Energy Harvesting". *IEEE Transactions on Industrial Electronics*, 57(9), 3129-3138, (2009). DOI: 10.1109/TIE.2009.2037653

[13] Setiawan, E. A., Setiawan, A., & Siregar, D. "Analysis on solar panel performance and PV-inverter configuration for tropical region". *Journal of Thermal Engineering*, 3(3), 1259-1270, (2017). DOI: 10.18186/journal-of-thermal-engineering.323392

[14] Karami, N., Moubayed, N., & Outbib, R. "General review and classification of different MPPT techniques". *Renewable and Sustainable Energy Reviews*, 68, 1-18, (2017). DOI: 10.1016/j.rser.2016.09.132

[15] Motahhir, S., El Hammoumi, A., & El Ghzizal, A. "The most used MPPT algorithms: Review and the suitable low-cost embedded board for each algorithm". *Journal of Cleaner Production*, 246, 118983, (2020). DOI: 10.1016/j.jclepro.2019.118983

[16] Rezk, H., Fathy, A., & Abdelaziz, A. Y. "A comparison of different global MPPT techniques based on meta-heuristic algorithms for photovoltaic system subjected to partial shading conditions". *Renewable and Sustainable Energy Reviews*, 74, 377-386, (2017). DOI: 10.1016/j.rser.2017.02.051

[17] Yang, B., Zhu, T., Wang, J., Shu, H., Yu, T., Zhang, X., Yao, W., & Sun, L. "Comprehensive overview of maximum power point tracking algorithms of PV systems under partial shading condition". *Journal of Cleaner Production*, 268, 121983. (2020). DOI: 10.1016/j.jclepro.2020.121983

[18] Titri, S., Larbes, C., Toumi, K. Y., & Benatchba, K. "A new MPPT controller based on the Ant colony optimization algorithm for Photovoltaic systems under partial shading conditions". *Applied Soft Computing*, 58, 465-479, (2017). DOI: 10.1016/j.asoc.2017.05.017

[19] Shankar, N., & SaravanaKumar, N. "Reduced partial shading effect in multiple PV array configuration model using MPPT based enhanced particle swarm optimization technique". *Microprocessors and Microsystems*, (2020). DOI: 10.1016/j.micpro.2020.103287

[20] Akbaba, M., "Matching three-phase AC loads to PVG for maximum power transfer using an enhanced version of the Akbaba Model and double step-up converter," Solar Energy, vol. 75, no. 1, pp. 17-25, (2003).

[21] Akbaba, M., "Optimum matching parameters of an MPPT unit used for a PVG- powered water pumping system for maximum power transfer," International Journal of Energy Research, vol. 30, pp. 395-409, (2006).

[22] Kumar , V. P. K., & Jijesh, J. J. "Comparative Analysis of Bio-Inspired Maximum Power Point Tracking Algorithms for Solar Photovoltaic Applications". International Journal of Intelligent Systems and Applications in Engineering IJISAE, 11(1), 100–110, (2021).

[23] Selvam, P. “Honey Badger Algorithm Using Partial Shading Condition MPPT Technique”. International Journal of Intelligent Systems and Applications in Engineering IJISAE, 12(19s), 558–567, (2024).

[24] Goksenli, N., Akbaba, M., “Development of a new microcontroller based MPPT method for photovoltaic generators using Akbaba model with implementation and simulation,” Solar Energy, vol.136, pp. 622-628, (2016).

[25] Akbaba, M., Alattawi, M. A. A., “A new model for I–V characteristic of solar cell generators and its applications,” Solar Energy Materials and Solar Cells, vol. 37, no. 2, pp. 123-132, (1995).

[26] Ross, R. G., “Flat-plate photovoltaic array design optimization,” in 14th IEEE Photovoltaic Specialists Conference, San Diego, CA, pp. 1126-1132, (1980).