Zouhir Boumous*[1], Samira Boumous[2]

Electrical engineering Department, LEER Laboratory, Souk Ahras University, Algeria
ORCID: 1 0000-0003-4972-1805, 2 0000-0003-2213-6542

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Novel Intelligent control of photovoltaic system using ANFIS Gravitational Search for MPPT controller

***Abstract**. An MPPT (Maximum Power Point Tracking) controller is a crucial component in photovoltaic (PV) systems connected to the grid. It optimizes the power output of the PV panels by tracking the maximum power point (MPP) of the PV array and adjusting the operating conditions to extract the maximum available energy. ANFIS (Adaptive Neuro-Fuzzy Inference System) is a computational model that combines the principles of fuzzy logic and neural networks. It can be used as a control strategy for MPPT in photovoltaic systems. ANFIS-based MPPT controllers utilize the adaptive and learning capabilities of ANFIS to track the MPP of the PV array. In this regard, in this article, Investigation to MPPT controller of Microgrid using Gravitational Search Algorithm and ANFIS Controller.*

***Streszczenie.** Kontroler MPPT (Maximum Power Point Tracking) jest kluczowym elementem systemów fotowoltaicznych (PV) podłączonych do sieci. Optymalizuje on moc wyjściową paneli fotowoltaicznych poprzez śledzenie maksymalnego punktu mocy (MPP) macierzy fotowoltaicznej i dostosowywanie warunków pracy w celu uzyskania maksymalnej dostępnej energii. ANFIS (Adaptive Neuro-Fuzzy Inference System) to model obliczeniowy, który łączy w sobie zasady logiki rozmytej i sieci neuronowych. Może być stosowany jako strategia sterowania MPPT w systemach fotowoltaicznych. Kontrolery MPPT oparte na ANFIS wykorzystują zdolności adaptacyjne i uczenia się ANFIS do śledzenia MPP macierzy PV. W związku z tym w niniejszym artykule zbadano kontroler MPPT mikrosieci przy użyciu algorytmu wyszukiwania grawitacyjnego i kontrolera ANFIS. (**Nowatorskie inteligentne sterowanie systemem fotowoltaicznym z wykorzystaniem wyszukiwania grawitacyjnego ANFIS dla sterownika MPPT**)*

Keywords: MPPT algorithm, Photovoltaic system, ANFIS, Power system, Grid, Gravitational search algorithm .
Słowa kluczowe: Algorytm MPPT, system fotowoltaiczny, ANFIS, system zasilania, sieć, algorytm wyszukiwania grawitacyjnego.

Introduction

In recent years, the use of new energy sources especially wind and solar is highly recommended, which has encouraged researchers to focus on optimizing and controlling these systems [1-2]. The history of Maximum Power Point Tracking (MPPT) controllers can be traced back to the early development of solar power systems. The development of solar power systems began in the 1970s, and initially, simple charge controllers were used to regulate the charging of batteries from solar panels. These early charge controllers did not incorporate MPPT functionality and operated based on fixed voltage or current settings. In the 1980s, researchers started exploring the concept of MPPT to improve the efficiency of solar power systems. The concept involved dynamically adjusting the operating point of solar panels to maximize their power output, even under varying environmental conditions. The 1990s saw significant advancements in MPPT technology. Researchers and engineers began experimenting with various algorithms and control techniques to track the maximum power point. Perturb and Observe (P&O) and Incremental Conductance were among the popular algorithms developed during this period[3-4]. MPPT controllers started gaining wider commercial use in solar power systems during the early 2000s. These controllers utilized the MPPT algorithms to continuously track the maximum power point of the solar panel array, maximizing the energy harvested from the sun. Actually the MPPT controllers have become an essential component in modern solar power systems. [5]They are widely used in various applications, including residential, commercial, and utility-scale solar installations [6]. MPPT controllers have evolved to incorporate advanced algorithms, such as fractional open-circuit voltage and model predictive control, to improve the accuracy and speed of tracking the maximum power point.[7-8]

MPPT controller

The primary function of an MPPT controller is to match the impedance of the PV array with the load, allowing the panels to operate at their MPP voltage and current levels. This is necessary because the MPP of a PV panel can vary due to factors like temperature, shading, and variations in solar irradiance. By constantly tracking and adjusting the operating point, the MPPT controller ensures that the PV panels operate at their most efficient state and maximize the power output [9] .In a grid-connected PV system, the MPPT controller works in conjunction with other components, such as inverters and grid-tie equipment. The MPPT controller continuously samples the PV array voltage and current to determine the power at the MPP. It uses an algorithm to track changes in the operating conditions and adjust the load impedance accordingly. This process is typically performed digitally using a microcontroller or a dedicated MPPT control IC (Integrated Circuit).[10-11]

ANFIS

ANFIS-based MPPT controllers utilize the adaptive and learning capabilities of ANFIS to track the MPP of the PV array. The ANFIS controller takes input variables such as PV array voltage, PV array current, and possibly other factors like temperature and solar irradiance.[12] The ANFIS model uses fuzzy logic to define linguistic rules that describe the relationship between the input variables and the desired output, which is the optimal operating point or MPP. [13-14]The ANFIS controller uses a learning algorithm to train the neural network component of the model. The training process adjusts the parameters of the fuzzy inference system and neural network to minimize the error between the desired output and the actual output of the controller. Once the ANFIS model is trained, it can generate the optimal operating point or MPP based on the input variables. This output is used to adjust the load impedance or other control parameters to maximize the power output of the PV array.[15]

GSA algorithm

The GSA algorithm has also been applied to optimize photovoltaic (PV) systems, which are used to convert sunlight into electricity. [16]The goal of applying the GSA algorithm in the context of PV systems is typically to find the optimal design parameters or configurations that maximize the efficiency, power output, or other performance metrics of the PV system. By applying the GSA algorithm to optimize photovoltaic systems, researchers and engineers can effectively explore the design space and find configurations that lead to improved efficiency, power output, or other desired performance metrics. This can help in designing more efficient and cost-effective PV systems for various applications, including solar power plants, residential installations, and remote/off-grid systems.[17-19]. the new approach used in this work is the GSA-MPPT algorithm , which is a combination of the Gravitational Search Algorithm (GSA) and Maximum Power Point Tracking (MPPT) techniques for optimizing the performance of photovoltaic (PV) systems.

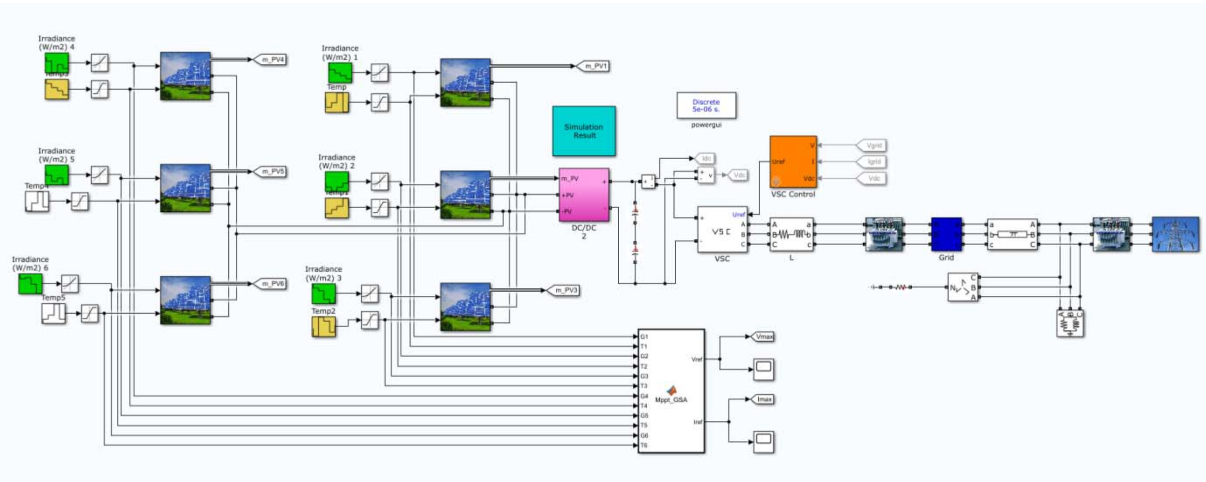

Fig.1. Block Simulation

Modelling of Photovoltaic panel

The modeling of PV (Photovoltaic) panels involves representing the electrical behavior of the panels under varying conditions. Photovoltaic cells are the building blocks of the PV system. Photovoltaic cells produce very low voltage and current. They are therefore configured, in series and in parallel, to obtain higher power as required [21]. For modeling of a solar PV module same methodology is adopted as described for a solar cell. The simplified circuit model of a solar panel is shown in figure 2.

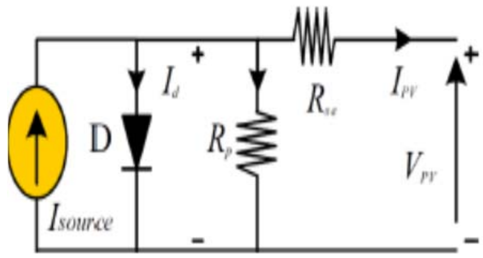

Fig .2. Single diode model of PV cell with Rs and Rsh

The model used has two resistors, one in series and the other in parallel. The series resistance (Rs) represents current losses due to metal contacts in the PV cells, and the parallel resistance (RSH) represents current leakage through the resistive path in parallel with the PV cells . current leakage through the resistive path in parallel with the intrinsic device intrinsic

The GSA-MPPT algorithm utilizes the GSA optimization algorithm to track and maintain the maximum power point (MPP) of a PV panel or array. MPPT is a control technique used in PV systems to extract the maximum power available from the solar panels by continuously adjusting the operating point to match the varying environmental conditions [20].

System Modeling

Figure 1 shows the simulink block diagram of the proposed microgrid. In this paper. The performance of a solar unit located at Souk Ahras city in North east of Algeria as shown in figure 1 is analyzed device [22-23]. Several solar cells must be connected to form a PV solar module. The output current equation is given by:

(1) $$I = I_{ph} - I_0\left(e^{\left(\frac{q(V+I*R_s)}{n\,k\,N_s T}\right)} - 1\right) - I_{sh}$$

where Iph is the photo-current; Io is the saturation current; q is the electron charge; V is the output voltage of the PV module; n is the ideality factor of the diode; K is the Boltzmann constant; Ns represents the number of solar cells connected in series; T is the solar cell temperature; and Ish is the current through the shunt resistor. The current generated from the incidence of radiation at a given temperature is expressed as:

(2) $$I_{ph} = (I_{sc} + K_i\ (T - 298) * (\tfrac{G}{1000})$$

Where: Isc represents the short circuit current; ki is the temperature coefficient of the Isc at standard test conditions (STCs); and G is the solar irradiance.

Reverse saturation current I_{rs} is :

(3) $$I_{rs} = I_{SCref}\left[\exp\left(\frac{qV_{OC}}{N_s kAT}\right) - 1\right]$$

The module saturation current I_D, which varies with cell temperature variation is:

(4) $$I_D = I_{rs}\left[\frac{T}{T_{ref}}\right]^3 \exp\left[\left(\frac{qC_g}{Ak}\right)\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right]$$

Then the output current characteristics of the PV module:

$$I_{PV} = N_P I_{SC} - N_S I_D\left\{\exp\left[\frac{q\left(V_{PV} + I_{PV}R_S\right)}{N_S kAT}\right] - 1\right\} - V_{PV} + \left(\frac{I_{PV}R_S}{R_P}\right)$$

Where: V_{PV} Output voltage of the PV module; N_P Number of parallel cells; N_S Number of series cells. R_P Shunt resistance in practical model of the PV module; R_S Series resistance in practical model of the PV module.

In this study, the Yingli Energy 'China' YL250-P-29b module is used. The parameters of the module at STC are given figure 3.

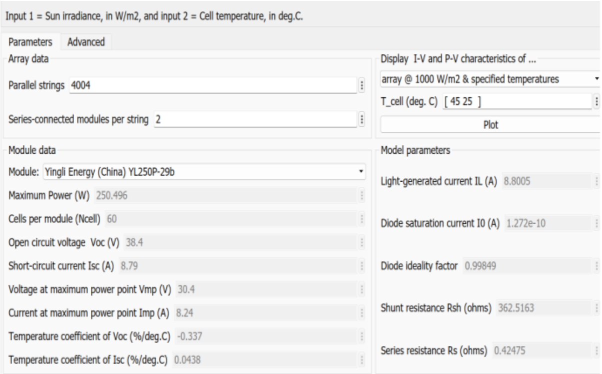

Fig .3. Specifications of the YL250-P-29b.

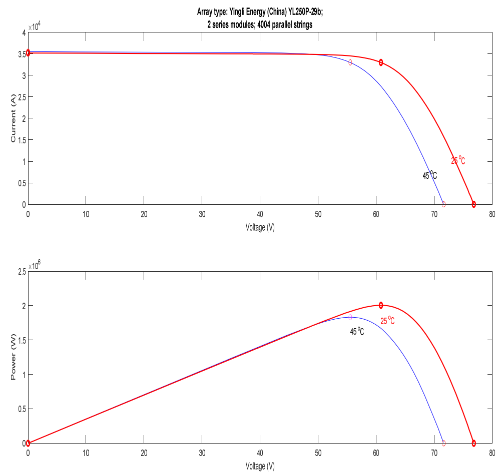

Fig .4. I-V and P-V curves.

MPPT controller

The literature review shows that, whenever metaheuristic algorithms are employed for maximum power tracking either in original form or hybrid form, the following areas need to be improved for better performance and are MPPT efficiency, tracking time, oscillations during tracking and the computational data [24-27]. The main objective of this study is to improve PV system performance based on a robust and reliable MPPT control algorithm [28-30] .For that purpose, the approach recommended by the authors of this paper is the MPPT control using GSA Algorithm and ANFIS approach. The problem of duty ratio perturbation in conventional method can be solved by an adaptive mechanism [31-33].

Adaptive neuro fuzzy inference system

The ANFIS reference model gives out the expected value of the maximum power output from the PV modules at a specific temperature and irradiance. The ANFIS structure has shown in Figure 5. It has five layer networks. Voltage and mean puissance are two inputs to the ANFIS controller. The membership functions for the ANFIS controller are shown in Figure 6. Five membership functions generate the 25 rules detail in figure 7. Based on these 25 rules standards the most extreme power is obtained. The fuzzy principles are set for the membership functions so that the overall system will be robust [34-35]. The Sugeno fuzzy model with two inputs and one output is given in Figure 5.

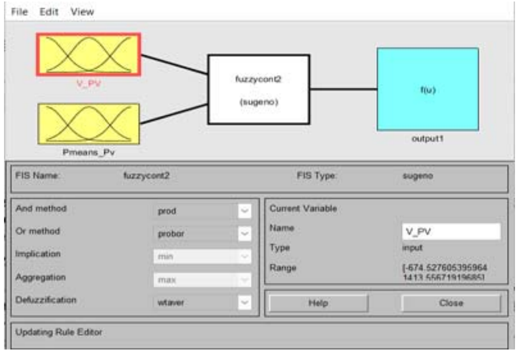

Fig .5. ANFIS structure.

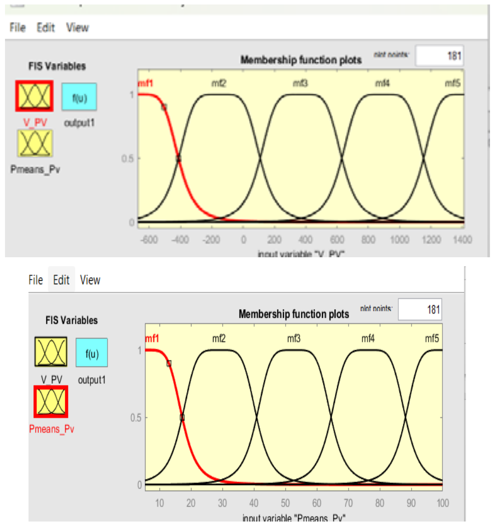

Fig .6. Membership function

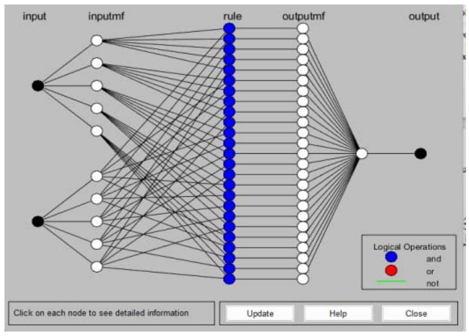

Fig. 7. ANFIS inputs and rules

Figure 8 represents the surface plot of the ANFIS controller. It shows the relationship between the inputs (V and Pmean) and the output (duty) of the proposed system.

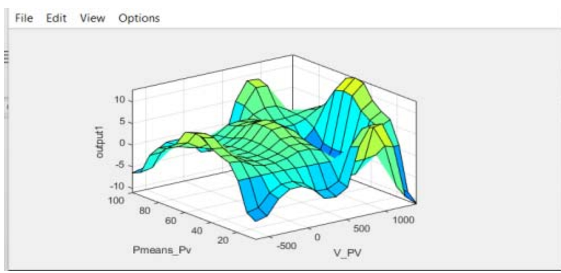

Fig.8. A 3D surface between input1 (V_PV) and input2 (Pmean_Pv) verse output (ΔD)

In present work, the number of epochs is 500 for the training of ANFIS controller and training error was observed for all epochs. It was observed that the training error was decreased with increase in the number of epochs and was found to be constant at 0.0412 when epochs are varied from 400 to 500. In figure 9, we present the variation of error vs. epochs.

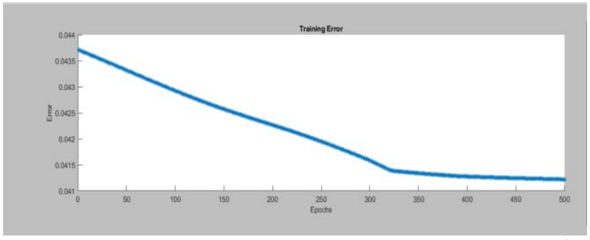

Fig.9 .Training performance of the proposed model

The output of the training are shown in Figure 10.

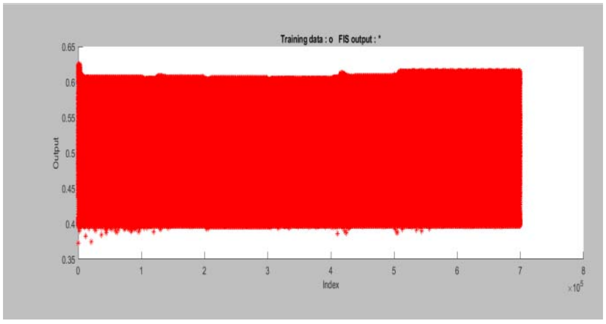

Fig.10. Training output.

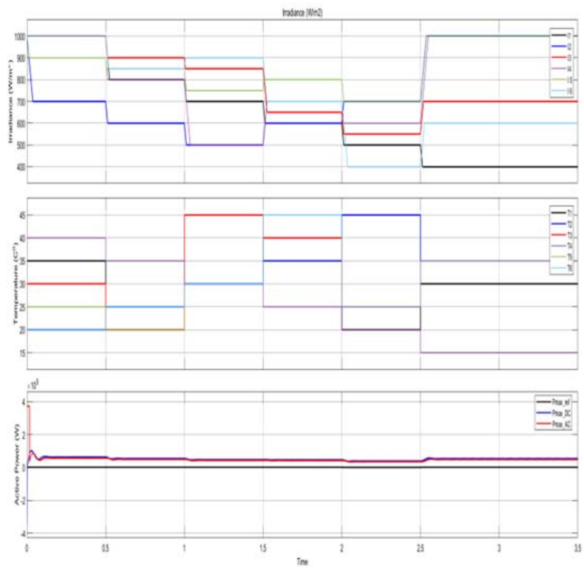

Fig.11. Evolution of Irradiance, Temperature and active power.

Conclusion

The investigation of using the Gravitational Search Algorithm (GSA) and Adaptive Neuro-Fuzzy Inference System (ANFIS) controller for Maximum Power Point The MPPT controller plays a crucial role in extracting the maximum available power from renewable energy sources, such as solar panels or wind turbines, in a microgrid system. GSA is used to optimize the parameters of the MPPT controller. The GSA algorithm can explore the parameter space of the controller, such as the gains, setpoints, or control rules, to find the optimal values that maximize the power extraction from the renewable energy sources. GSA's ability to balance exploration and exploitation can be leveraged to fine-tune the controller's parameters and improve its performance.

The ANFIS controller can be employed as the MPPT controller in the microgrid system. ANFIS combines the advantages of fuzzy logic and neural networks to create an intelligent control system capable of capturing and utilizing expert knowledge in the form of fuzzy rules. ANFIS can model the nonlinear characteristics and dynamics of the renewable energy sources and adjust its parameters based on the feedback signals to track the maximum power point.

The efficiency, stability and reliability of a photovoltaic energy are considered major factors for establishing this energy resource on the market. In this research, common maximum power point tracking techniques, using Gravitational Search Algorithm and ANFIS Controller. Adaptive neural fuzzy inference system and artificial neural network have been proposed for a grid-connected PV system to maximise the output power of a PV array. The aim has also been improving the stability and reliability of a PV power conversion, especially in the context of a rapid change in atmospheric conditions.

REFERENCE

[1] Shahin Azali, Mansour Sheikhan, "Intelligent control of photovoltaic system using BPSO-GSA-optimized neural network and fuzzy-based PID for maximum power point tracking", *Appl Intell (2016)* 44:88–110 DOI 10.1007/s10489-015-0686-6.

[2] Malinowski, M., Leon, J., and Abu-Rub, H., 2017, "Solar Photovoltaic and Thermal Energy Systems: Current Technology and Future Trends," *Proc. IEEE, 105(11)*, pp. 1–15. 10.1109/JPROC.2017.2690343.

[3] Kumar, A., Rizwan, M. And Nangia, U. (2021) 'Development of ANFIS-based algorithm for MPPT controller for standalone photovoltaic system', *Int. J. Advanced Intelligence Paradigms*, Vol. 18, No. 2, pp.247–264.

[4] Neeraj Priyadarshi , Mahajan Sagar Bhaskar, Sanjeevi kumar Padmanaban , Frede Blaabjerg , Farooque Azam, " New CUK–SEPIC converter based photovoltaic power system with hybrid GSA– PSO 108-112_algorithm employing MPPT for water pumping applications", *IET Power Electron*, 2020, Vol. 13 Iss. 13, pp. 2824-2830.

[5] Kamran, M., Mudassar, M., Fazal, M. R., Asghar, M. U., Bilal, M., and Asghar, R., 2018, "Implementation of Improved Perturb & Observe MPPT Technique With Confined Search Space for Standalone Photovoltaic System," *J. King Saud Univ.—Eng. Sci*, 32(1), pp. 432–441. 10.1016/j.jksues.2018.04.006.

[6] Nagy Osman a , Haris M. Khalid a , Tha'er O. Sweidan a , Mohammed I. Abuashour b , S.M. Muyeen, "A PV powered DC shunt motor: Study of dynamic analysis using maximum power Point-Based fuzzy logic controller", *Energy Conversion and Management*: X 15 (2022) 100253, doi.org/10.1016/j.ecmx.2022.100253 .

[7] P.Sindhuja,V.Usha reddy, "Enhancement Of Grid Connected Pv Inverter Using Optimal Maximum Power Point Tracking Algorithm With Estimation Of Climatic Parameter", *International Conference on Inventive Systems and Control* (ICISC-2017).

[8] Moyo R.T, Tabakov P.Y.Moyo S, "Comparative analysis of different computational intelligence techniques for maximum power point tracking of PV systems", *Journal of sustainable energy* vol. 13, no. 1, June, 2022.

[9] Motahhir, Saad & Abdelaziz, el ghzizal & Sebti, Souad & Derouich, Aziz. (2018). Modeling of Photovoltaic System with Modified Incremental Conductance Algorithm for Fast Changes of Irradiance. *International Journal of Photoenergy*. 2018. 1-13. 10.1155/2018/3286479.

[10] Ranganai T. Moyo, Pavel Y. Tabakov, Sibusiso Moyo, "Design and Modeling of the ANFIS-Based MPPT Controller for a Solar Photovoltaic System", *Journal of Solar Energy Engineering*, August 2021, Vol. 143.

[11] Dilovan Haji, Naci Genc, "Dynamic Behaviour Analysis of ANFIS Based MPPT Controller for Standalone Photovoltaic

Systems", International journal of renewable energy research, Vol.10, No.1, March, 2020.

[12] Noman, Abdullah & Addoweesh, Khaled & Alolah, Abdulrahman. (2017). Simulation and Practical Implementation of ANFIS-Based MPPT Method for PV Applications Using Isolated Ćuk Converter. *International Journal of Photoenergy*. 2017. 1-15. 10.1155/2017/3106734.

[13] A. S. Mahdi · A. K. Mahamad, S. Saon , T. Tuwoso, Hakkun Elmunsyah, S. W. Mudjanarko, " Maximum power point tracking using perturb and observe, fuzzy logic and ANFIS", *SN Applied Sciences* (2020) 2:89 | https://doi.org/10.1007/s42452-019.

[14] Hai Tao , Mehrdad Ghahremani , Faraedoon Waly Ahmed , Wang Jing , Muhammad Shahzad Nazir, Kentaro Ohshima," A novel MPPT controller in PV systems with hybrid whale optimization-PS algorithm based ANFIS under different conditions", *Control Engineering Practice* Volume 112, July 2021, 104809, https://doi.org/10.1016/j.conengprac.2021.104809.

[15] Mlakić, Dragan & Nikolovski, Srete. (2016). ANFIS as a Method for Determinating MPPT in the Photovoltaic System Simulated in Matlab/Simulink. 10.1109/*MIPRO.2016*.7522301.

[16] Kumar, Sanjeev & Agrawal, Richa. (2023). A hybrid C-GSA optimization routing algorithm for energy-efficient wireless sensor network. *Wireless Networks*. 1-14. 10.1007/s11276-023-03288-7.

[17] Salem Alkhalaf, Ziad M. Ali, Hitoshi Oikawa, "A novel hybrid gravitational and pattern search algorithm based MPPT controller with ANN and perturb and observe for photovoltaic system", *Soft Computing* (2022) 26:7293–7315 https://doi.org/10.1007/s00500-022-07139-z(0123456789().,-volv)(0123456789().,-volv).

[18] Zong, Tiancheng & Li, Junhong & Lu, Guoping. (2022). Identification of Hammerstein–Wiener Systems with State-Space Subsystems Based on the Improved PSO and GSA Algorithm. *Circuits, Systems, and Signal Processing*. 42. 10.1007/s00034-022-02268-0.

[19] Hasanien, Hany & Al-Durra, Ahmed & Muyeen, S M. (2016). Gravitational Search Algorithm-based Photovoltaic Array Reconfiguration for Partial Shading Losses Reduction. 56 (6 .)-56 (6 .). 10.1049/cp.2016.0577.

[20] Sundareswaran, K. & Vethanayagam, Vigneshkumar & Simon, Sishaj P & Nayak, P. (2016). Gravitational search algorithm combined with P&O method for MPPT in PV systems. 1-5. 10.1109/INDICON.2016.7838956.

[21] Vinod, Raj Kumar, S.K. Singh, Solar photovoltaic modeling and simulation: As a renewable energy solution, *Energy Reports*, Volume 4, 2018, Pages 701-712, ISSN 2352-4847, https://doi.org/10.1016/j.egyr.2018.09.008.

[22] Aldair, A. A., Obed, A. A., and Halihal, A. F., 2018, "Design and Implementation of ANFIS-Reference Model Controller .Based MPPT Using FPGA for Photovoltaic System," *Renew. Sustain. Energy Rev*, 82, pp. 2202–2217.

[23] Manisha, Prerna Gaur, " The Survey of MPPT under non-uniform atmospheric conditions for the Photovoltaic Generation Systems", *Int. J. Inf. Tecnol*. (April 2021) 13(2):767–776, https://doi.org/10.1007/s41870-020-00591-w.

[36] ed STATCOM for Reactive Power Compensator in Distribution Grid, PRZEGLĄD ELEKTROTECHNICZNY, ISSN 0033-2097, R. 98 NR 4/2022.

[24] V. Balaji, A. Peer Fathima, "Hybrid algorithm for MPPT tracking using a single current sensor for partially shaded PV systems", *Sustainable Energy Technologies and Assessments*, Volume 53, Part A, 2022, 102415, ISSN 2213-1388, https://doi.org/10.1016/j.seta.2022.102415.

[25] B. G. S. Dhas and S. N. Deepa, "A hybrid PSO and GSA-based maximum power point tracking algorithm for PV systems," *2013 IEEE International Conference on Computational Intelligence and Computing Research*, Enathi, India, 2013, pp. 1-4, doi: 10.1109/ICCIC.2013.6724181.

[26] M. Kermadi, Z. Salam, J. Ahmed and E. M. Berkouk, "An Effective Hybrid Maximum Power Point Tracker of Photovoltaic Arrays for Complex Partial Shading Conditions," in *IEEE Transactions on Industrial Electronics*, vol. 66, no. 9, pp. 6990-7000, Sept. 2019, doi: 10.1109/TIE.2018.2877202.

[27] S. Makhloufi and S. Mekhilef, "Logarithmic PSO-Based Global/Local Maximum Power Point Tracker for Partially Shaded Photovoltaic Systems," in *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 10, no. 1, pp. 375-386, Feb. 2022. Doi: 10.1109/JESTPE.2021.3073058.

[28] Duman, S., Yorukeren, N. & Altas, I.H. A novel MPPT algorithm based on optimized artificial neural network by using FPSOGSA for standalone photovoltaic energy systems. *Neural Comput & Applic* **29**, 257–278 (2018). Https://doi.org/10.1007/s00521-016-2447-9.

[29] Ncir, N., El Akchioui, N. An Intelligent Improvement Based on a Novel Configuration of Artificial Neural Network Model to Track the Maximum Power Point of a Photovoltaic Panel. *J Control Autom Electr Syst* **34**, 363–375 (2023). Https://doi.org/10.1007/s40313-022-00972-5.

[30] Ncir, N., El Akchioui, N. An advanced intelligent MPPT control strategy based on the imperialist competitive algorithm and artificial neural networks. *Evol. Intel*. (2023). Https://doi.org/10.1007/s12065-023-00838-y.

[31] Motahhir, S., El Hammoumi, A., & El Ghzizal, A. (2020). The most used MPPT algorithms: Review and the suitable low-cost embedded board for each algorithm. *Journal of cleaner production*, *246*, 118983.

[32] Woźniak, M., Sikora, A., Zielonka, A., Kaur, K., Hossain, M. S., & Shorfuzzaman, M. (2021). Heuristic optimization of multipulse rectifier for reduced energy consumption. *IEEE Transactions on Industrial Informatics*, *18*(8), 5515-5526.

[33] Khaled Osmani, Ahmad Haddad, Thierry Lemenand, Bruno Castanier, Mohamad Ramadan, An investigation on maximum power extraction algorithms from PV systems with corresponding DC-DC converters, *Energy*, Volume 224, 2021, 120092, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2021.120092.

[34] Shaik Ruksana Begam. Loveswara Rao Burthi3. Shobha Rani Depuru, "Adaptive Neuro-Fuzzy Sliding Mode Controller (ANF-SMC) to control speed, electromagnetic torque (EMT), Stator Current, and Back EMF using PMBL DC motor(PMBLDCM) in Electric Propulsion of Electric Vehicles", PRZEGLĄD ELEKTROTECHNICZNY, ISSN 0033-2097, R. 99 NR 8/2023.

[35] Mahmood T. Alkhayyat, , Mohammed Y. Suliman , Adaptive Neuro-Fuzzy Controller Bas