Maximum power point tracking of photovoltaic array using fuzzy logic control

Djaafar Toumi[1], Djilani Benattous[1], Ahmed Ibrahim[2], Bedida Tarek[3], Messaoud Zobeidi[4], Khelaifa Fethi[5], Hicham Serhoud[4], Yacine Labbi[1], Raef Aboelsaud[2], Sergey Obukhov[2], Mohamed Tayeb Boussabeur[6]
[1]VTRS-Research Laboratory, University of El-Qued, El-Qued, Algeria
[2]National Research Tomsk Polytechnic University, Tomsk, Russia
[3]Laboratoire d'Energie, Environnement et Système d'Information (LEESI), Université Ahmed Draia, Adrar, Algeria
[4]Department of Electrical Engineering, University of EL-Oued, Algeria
[5]Laboratory of Electronics and New Technologies (LENT), Larbi Ben M'hidi University, Oum El Bouaghi, Algeria
[6]LEVRS-Research Laboratory, University of El-Qued, El-Qued, Algeria

Article Info

Article history:

Received Jul 2, 2022
Revised Aug 25, 2022
Accepted Sep 12, 2022

Keywords:

Fuzzy logic control
MATLAB/Simulink
Maximum power point tracking
Perturb and observe
Photovoltaic array

ABSTRACT

This research introduces the simulation of photovoltaic (PV) array to track the peak point (MPPT) using fuzzy logic control. Therefore, real time simulation is performed in MATLAB/Simulink based on a PV model, boost converter and fuzzy logic-based tracker. A comparative study is carried out against perturb and observe (P&O) controller. The fuzzy logic technique based tracker can successfully track the maximum power point very fast and has precise control when compared to the P&O algorithm. The overall we conclude that the MPPT using the fuzzy logic technique takes a fast response and can improve the performance of the PV system.

This is an open access article under the CC BY-SA license.

Corresponding Author:

Ahmed Ibrahim
National Research Tomsk Polytechnic University, Tomsk 634050, Russia
Email: ibragim@tpu.ru

1. INTRODUCTION

One of the most important reasons that pushed them to pay attention to renewable energy sources is its environmentally friendly work and its great availability all over the world [1]. One of the most important energies is photovoltaic energy that is one of the most prominent and most promising energies because it has a clean and inexhaustible source (sustainable) [2]. The photovoltaic energy system converts sunlight into continuous electrical energy by means of solar cells made of semiconducting materials, where the work and efficiency of solar cells depends mainly on two factors; the temperature and solar radiation [3]. These cells have a non-linear characteristic that is evident through a curve output versus voltage [4], from the non-linear relationships of photovoltaic, we notice a unique point in certain conditions of illumination and temperature in which the value of the energy produced is the maximum energy [5]. This point referred to the maximum power point (MPPT) [6]. The decrease in the efficiency of cells is mainly caused by atmospheric differences (change of radiation and temperature) and to improve the efficiency of these cells, there are many MPPT technologies, among them the most prominent and most widespread is perturb and observe technique (P&O). However, this technology has limitations due to the nonlinearity of photovoltaic cells [7]. Incremental conductance techniques are many used in the literature which is relative simplicity of implementation [8].

In recent years, new technologies called artificial intelligence techniques have emerged. Among the most prominent of these techniques is the fuzzy logic technique. This technique is more effective and more accurate in tracking the maximum power point MPPT, as it achieves good and more stable results compared to using perturb and observe (P&O) technique [9]. This paper focuses on the maximum solar energy used fuzzy logical algorithm.

2. MODELLING AND SIMULATION OF 50 W PHOTOVOLTAIC (PV) ARRAY

The PV module is a sunlight-to-electricity conversion technology. In other words, it produces direct current without any noise or environmental effect when a PV module is exposed to solar irradiation. In this paper, we designed a 50 watt PV matrix. The primary building block of photovoltaic (PV) array is the solar cell, which is essentially the p-n semiconductor junction, as described in Figure 1 [10]. The following equations describing the PV model under studied:

$$I_{ph} = \frac{G}{G_{ref}}\left(I_{ph,ref} + \mu_{sc} * \Delta T\right) \quad (1)$$

$$I_{0,ref} = I_{sc,ref}\ exp\left(\frac{-V_{oc,ref} * q}{N_s * A * k * T_c}\right) \quad (2)$$

$$I_0 = DT_c^3 exp\left(\frac{-q * \varepsilon_G}{A * K}\right) \quad (3)$$

$$I_d = I_0\left[exp\left(\frac{V + I * R_s}{q}\right) - 1\right] \quad (4)$$

$$I_P = \frac{V + I * R_s}{R_P} \quad (5)$$

$$I = \boldsymbol{I_{ph}} - \boldsymbol{I_d} - \boldsymbol{I_P} \quad (6)$$

Where
I: The PV current,
I_d: The diode current current,
I_p : The shunt current,
I_0: The reverse saturation current,
$I_{sc,ref}$: the current at short circuit,
ε_G: the band gap energy of semiconductor
A: diode ideality factor,
q: The electron charge,
K: The Boltzmann constant,
T_c: The actual cell temperature (K),
V: the thermal voltage,
$V_{oc,ref}$: the voltage at open circuit
N_s: The number of PV cells connected in series,
N_P: The number of PV cells connected in parallel,
V: The output terminal voltage,
R_P: The parallel resistances of solar,
R_S: The series resistances of solar,
G: Irradiance (W/m^2),
G_{ref} : Irradiance at STC= 1000 W/m^2, ΔT= $T_c - T_{c,ref}$: (Kelvin),
μ_{sc}: Coefficient temperature of short circuit current (A/K),
$I_{ph,ref}$: Photocurrent (A) at STC.

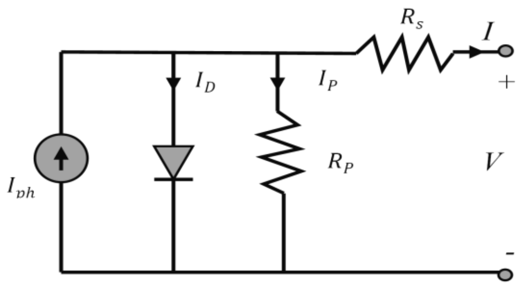

Figure 1. Mathematical modeling of PV cell

Through the photoelectric properties shown in Figure 2 [11]. This point is called the maximum power point (MPP) that we track using the MPPT technique [12]. The 50M (36) module connected in server having a maximum power is 50 W under standard conditions with $G = 1000\ W/m^2$ and $T = 25$ °C (298 °K), A = 1.3, N_s=36, N_P =1; T_{ref} = 298 °K(25 °C), E_g = 1.12eV, R_{sh} = 1000 Ω, R_s = 0.1 Ω. Electrical Characteristics of 50 M (36) PV module are shown in Table 1.

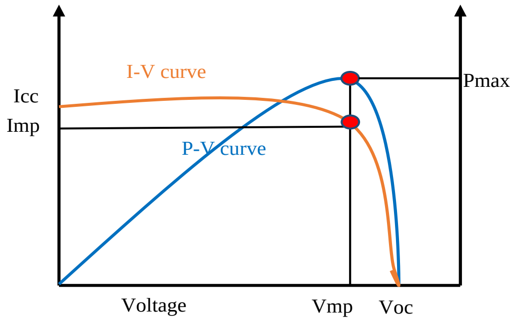

Figure 2. I-V and PV characteristics of a PV module

Table 1. Electrical characteristics 50 M (36) PV module

Parameters	Value
Maximum power	50 W
V_{max}	17.98 V
I_{max}	2.78 A
I_{sc}	3.04 A
V_{oc}	21.87 V
K_i	(0.065±0.15) A/°C

3. MODELING OF BOOST CONVERTER

The modelling of the boost converter is presented in this article before beginning our research on the modeling of MPPT controls. This causes the output voltage of *V*s to be increased compared to the input voltage of *V*pv. The circuit diagram modelling the converter is shown in Figure 3, whereas Table 2 summarizes the values of the elements used to make this converter [13].

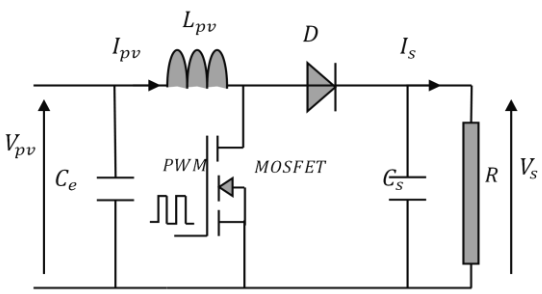

Figure 3. The boost converter scheme

Table 2. Component values of DC/DC converter

Parameters	Value
Bobbin L_{pv}	18 mH
Intput capacitorC_e	2200 µF
Output capacitor C_s	2200 µF
Switching frequency of the MOSFT f	1 KHz
Load R	22 Ohm

The (7) and (8) show the process of the boosting of the voltage of the PV system:

$$V_{pv} = L_{pv}\frac{di_{L_{pv}}}{dt} + (1 - a_{pv})V_s \quad (7)$$

$$C_S \frac{dV_s}{dt} + \frac{V_s}{R} = (1 - a_{pv}) i_{L_{pv}} \quad (8)$$

4. MAXIMUM POWER POINT TRACKING (MPPT)

4.1. P&O based MPPT tracking

In this paper, the P&O algorithm MPPT technique is applied to find MPP in 50 W modelled PV array. The P&O technique is selected in this research due to its simplicity and fast tracking of the maximum point operation of solar system. The flow scheme of P&O controller is shown in Figure 4.

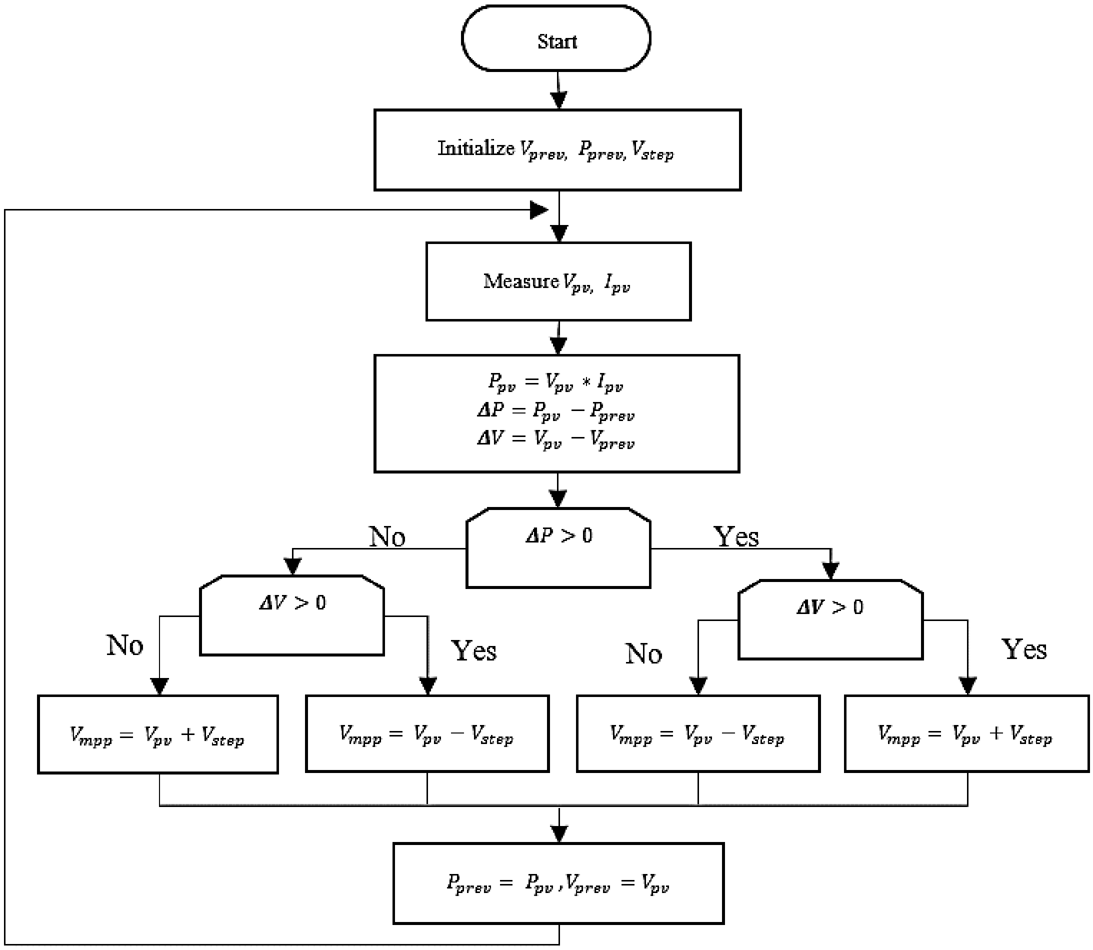

Figure 4. Chart of the implemented P&O

4.2. MPPT by using fuzzy logic

Fuzzy logic is used to extract the MPPT of PV module [14]. The implementation of the fuzzy algorithm, with its controlled rules, is simple and independent of solar characteristics. The rules of the controlled mechanism are shown in Table 3, which contains 49 rules of fuzzy controller.

Table 3. The rules implemented in the fuzzy logic controller

CE E	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NM	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PB	PB	NS
PM	NS	ZE	PS	PM	PB	PB	ZE
PB	PB	ZE	PS	PM	PB	PB	PB

4.2.1. Fuzzification

Controls are selected depending on the satisfaction of two control variables in the proposed input; they are the E error and the change in CE error in the k-test. We display the E and CE variants in the following form:

$$E(k) = \frac{P(k)-P(k-1)}{V(k)-V(k-1)} \quad (9)$$

$$CE(k) = E(k) - E(k-1) \quad (10)$$

4.2.2. Inference method

A rule is applied to fuzzy input by the inference engine to determine the fuzzy output. Therefore, the real input value must be fuzzified, before the rule can be evaluated to obtain an appropriate linguistic value [15]–[28]. The rapid changes in the consumption of PV power can be determined by applying minimum perturbation in the output of photovoltaic voltage.

4.2.3. Defuzzification

Defuzzification is the process of obtaining a single number from the output with can, defined by two algorithms; the max criterion method (MCM) and center of area (COA). The block diagram of the operation mechanism of the fuzzy logic technique is explained in Figure 5.

$$\Delta D = \frac{\sum_{j=1}^{n} \mu(\Delta D_j).\Delta D_j}{\sum_{j=1}^{n} \mu(\Delta D_j)} \quad (11)$$

the actual duty cycle ratio D is calculated as follows:

$$D(k) = D(k-1) + S_{\Delta D}\Delta D(k) \quad (12)$$

The presentation of the error, variation of the error and the change in duty cycle is shown in Figure 6.

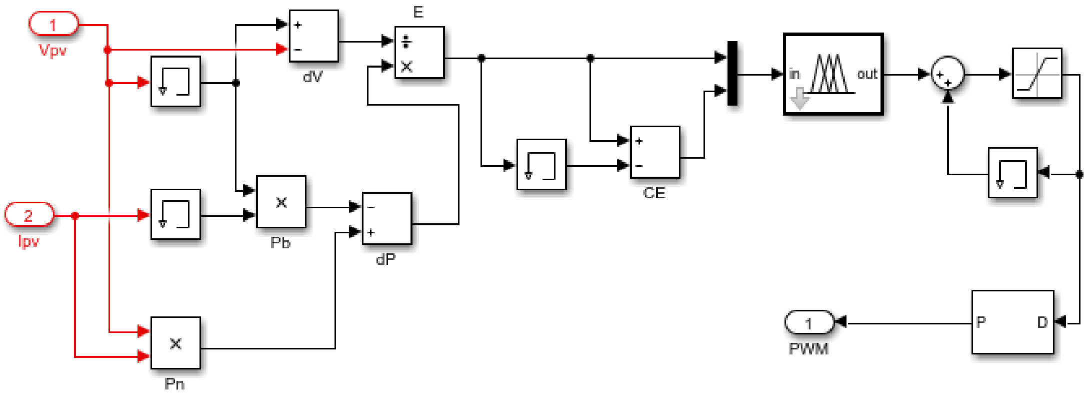

Figure 5. Block diagram of fuzzy MPPT algorithm

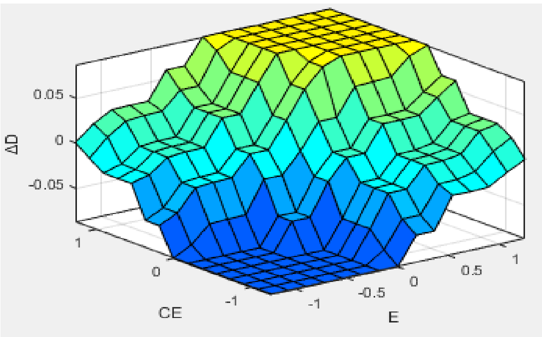

Figure 6. 3D presentation of the error, variation of the error and the change in duty cycle

5. SIMULATION RESULTS

Figures 7 to 12. Shows the different output results of the photovoltaic generator simulated using P&O and FL under (G=1000 W/m² and T=25 °C). Figure 7 shown the Output power of the PV generator for the different simulated algorithms. Where it takes 0.042 s for the traditional Perturb and Observe (P&O) algorithm to obey the MPP with a major power swing of (50.41-52.39 W). Whilst for the fuzzy logic controller method it takes 0.035 s just and without power oscillation at standard conditions (E=1000 W/m² and T=25 °C)

Figure 10 shows the simulation were presented for many solar irradiance values (800 W/m², 900 W/m² and 1000 W/m²) at fixed temperature of 25 °C. Figure 10 shows the results of the PV generator for many solar irradiance values (800 W/m²,900 W/m² and 1000 W/m²) at fixed temperature of 25 °C. To examine the system. Where we observe the fuzzy logic controller has better response time, much more accurate tracking and less oscillation at each step compared to the classical P&O controller.

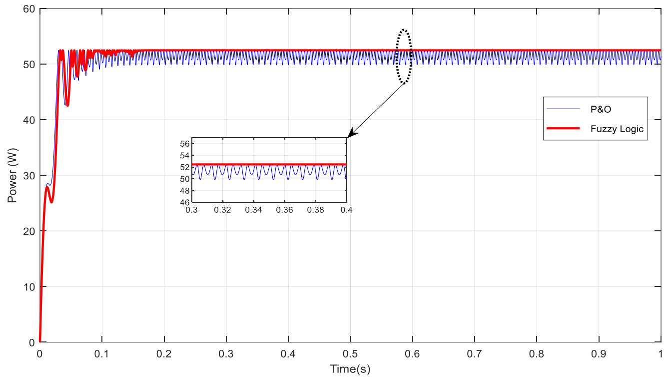

Figure 7. Output power of fuzzy logic control (FLC) and conventional P&O controller

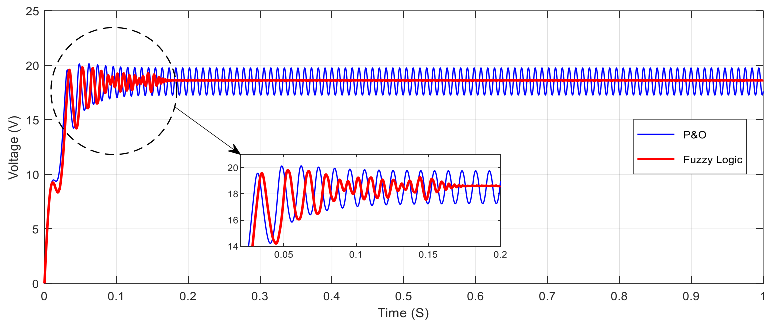

Figure 8. Output current of FLC

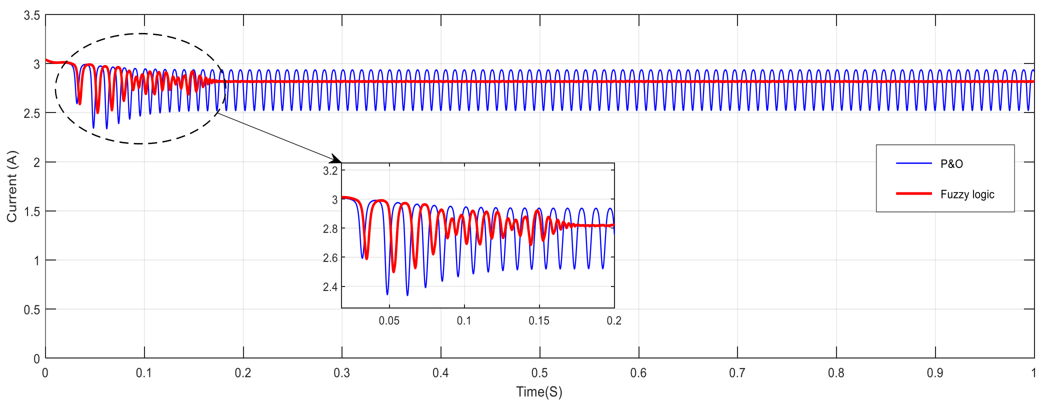

Figure 9. Output voltage of the controlled techniques

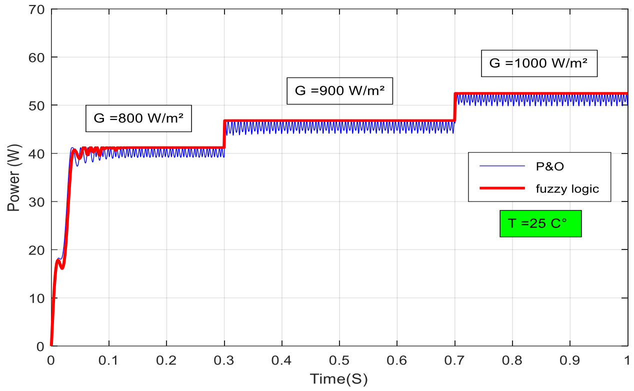

Figure 10. Output power of the tested model

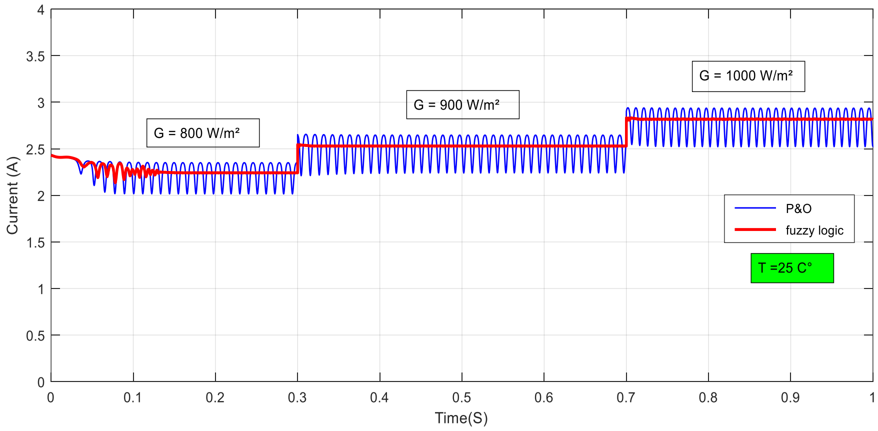

Figure 11. Output current of the simulations of the PV panels

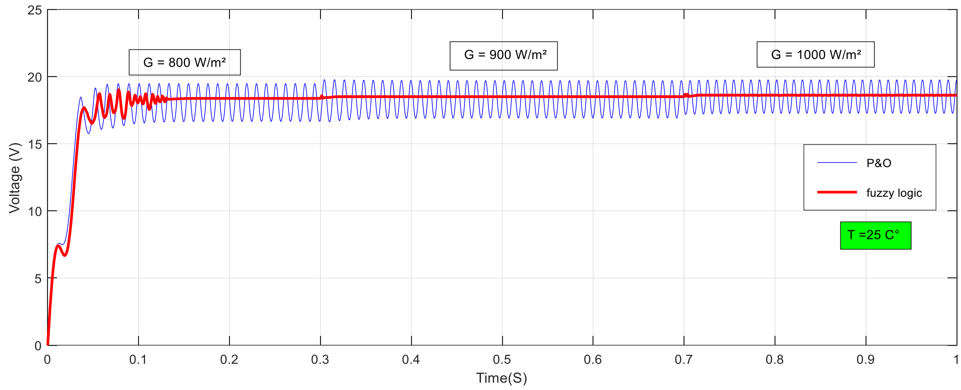

Figure 12. Voltages at different environmental

6. CONCLUSIONS

In this research, FL control is developed for maximation of PV array. We study the MPPT technology based on P&O and comparted to FLC. The controller of the fuzzy logic showed fast response and successfully control of tracking the maximum power point (MPPT) considering the effect of atmospheric changes. more than, the MPPT technology based on fuzzy logic control achieves good and more accurate results, more flexibility and eliminates the fluctuations in the power compared to MPPT technology based on P&O.

REFERENCES

[1] M. Elyaqouti, S. Hakim, S. Farhat, L. Bouhouch, and A. Ihlal, "Implementation in Arduino of MPPT using variable step size P&O algorithm in PV installations," *International Journal of Power Electronics and Drive Systems (IJPEDS),* vol. 8, no. 1 , pp. 434–443, 2017, doi: 10.11591/ijpeds.v8.i1.pp434-443.

[2] B. Kheira, S. Saad, and F. Zaamouche, "Simulation and experimentation of voltage source inverter (VSI) for a photovoltaic system," *Electrotehnica, Electronica, Automatica,* vol. 64, no. 3, 2016.

[3] M. Hebchi, A. Kouzou, and A. Choucha, "Improved perturb and observe algorithm for maximum power point tracking in photovoltaic system," *Electrotehnica, Electronica, Automatica*, vol. 66, no. 4, 2018.

[4] A. Saidi, "Comparative study of different load under P&O MPPT algorithm for PV systems," *Electrotehnica, Electronica,* Automatica, vol. 64, no. 4, 2016.

[5] A. S. Samosir, and H. Gusmedi, "Modeling and simulation of fuzzy logic based maximum power point tracking (MPPT) for PV application," *International Journal of Electrical and Computer Engineering (IJECE),* vol. 8, no. 3, 2018, doi: 10.11591/ijece.v8i3.pp1315-1323.

[6] V. K. Viswambaran, A. Bati, and E. Zhou, "Review of AI based maximum power point tracking techniques & performance evaluation of artificial neural network based MPPT controller for photovoltaic systems," *International Journal of Advance Science and Technology,* vol. 29, no. 10s, pp. 8159–8171, 2020.

[7] K. Loukil H. Abbes, H. Abid, M. Abid, and A. Toumi, "Design and implementation of reconfigurable MPPT fuzzy controller for photovoltaic systems," *Ain Shams Engineering Journal,* vol. 11, no. 2, pp. 319–328, October 2019, doi: 10.1016/j.asej.2019.10.002.

[8] A. Hafaifa, I. Kaid, M. Guemana and A. Salam, "Maximum power point tracking of photovoltaic system based on fuzzy control to increase the solar energy efficiency," in *Serrhini, M., Silva, C., Aljahdali, S. (eds) Innovation in Information Systems and Technologies to Support Learning Research. EMENA-ISTL 2019. Learning and Analytics in Intelligent Systems,* vol 7. Springer, 2019, doi: 10.1007/978-3-030-36778-7_62.

[9] A. Mahammedi, A. Kouzou, A. Hafaifa, and B. Talbi, "A new technique for photovoltaic system efficiency under fast changing solar irradiation," *Electrotehnica, Electronica, Automatica (EEA),* vol. 67, no. 67, pp. 12–19, 2019.

[10] I. Kaid, A. Hafaifa, M. Guemana, N. Hadroug, A. Kouzou and L. Mazouz, "Photovoltaic system failure diagnosis based on adaptive neuro fuzzy inference approach: South Algeria solar power plant," *Journal of Cleaner Production,* vol. 204, pp. 169–182, 2018, doi: 10.1016/j.jclepro.2018.09.023.

[11] X. Li, Z. Wang, M. Yang, and G. Yuan, "Dynamic simulation of a novel solar polygeneration system for heat, power and fresh water production based on solar thermal power tower plant," J*ournal of Thermal Science,* vol. 29, pp. 378–392, 2020, doi: 10.1007/s11630-020-1163-z.

[12] A. Messai, A. Mellit, A. M. Pavan, A. Guessoum, and H. Mekki, "FPGA-based implementation of a fuzzy controller (MPPT) for photovoltaic module," *Energy Convers. Manage*., vol. 52, no. 7, pp. 2695–2704, 2011, doi: 10.1016/j.enconman.2011.01.021.

[13] V. V. R. Scarpa, S. Buso, and G. Spiazzi, "Low-complexity MPPT technique exploiting the PV module MPP locus characterization," *IEEE Trans. Ind. Electron,* vol. 56, no. 5, pp. 1531–1538, May 2009, doi: 10.1109/TIE.2008.2009618.

[14] J. Lee and Y. Kim, "Sensorless fuzzy-logic-based maximum power point tracking control for a small-scale wind power generation systems with a switched-mode rectifier," *IET Renew. Power Gener.,* vol. 10, no. 2, pp. 194–202, 2016, doi: 10.1049/iet-rpg.2015.0250.

[15] P. P. Biswas, P. N. Suganthan, G. Wu and G. A. J. Amaratunga, "Parameter estimation of solar cells using datasheet information with the application of an adaptive differential evolution algorithm," *Renewable Energy,* vol. 132, pp. 425–438, 2019, doi: 10.1016/j.renene.2018.07.152.

[16] J. M. Blanes, F. J. Toledo, S. Montero, and A. Garrigs, "In-site real-time photovoltaic I–V curves and maximum power point estimator," *IEEE Trans. Power Electron.,* vol. 28, no. 3, pp. 1234–1240, Mar. 2013, doi: 10.1109/TPEL.2012.2206830.

[17] M. Killi and S. Samanta, "Modified perturb and observe MPPT algorithm for drift avoidance in photovoltaic systems," *IEEE Trans. Ind. Electron,* vol. 62, no. 9, pp. 5549–5559, Sep. 2015, doi: 10.1109/TIE.2015.2407854.

[18] I. Houssamo, F. Locment, and M. Sechilariu, "Experimental analysis of impact of MPPT methods on energy efficiency for photovoltaic power systems," *Int. J. Elect. Po wer,* vol. 46, pp. 98–107, 2013, doi: 10.1016/j.ijepes.2012.10.048.

[19] S. K. Kollimalla and M. K. Mishra, "Variable perturbation size adaptive P&O MPPT algorithm for sudden changes in irradiance," *IEEE Transactions on Sustainable Energy,* vol. 5, no. 3, pp. 718-728, 2014, doi: 10.1109/TSTE.2014.2300162.

[20] X. Li, Q. Wang, H. Wen, and W. Xiao, "Comprehensive studies on operational principles for maximum power point tracking in photovoltaic systems*," IEEE Access,* vol. 7, pp. 121407–121420, 2019, doi: 10.1109/ACCESS.2019.2937100.

[21] T. Haripriya, M. Alivelu, and U.M. Rao, „Performance evaluation of DC grid connected solar PV system for hybrid control of DC–DC boost converter," in *10th international conference on intelligent systems and control (ISCO),* 7–8 Jan 2016, pp. 1–6, doi: 10.1109/ISCO.2016.7726883.

[22] A. A. Nabulsi, and R. Dhaouadi, "Effiency optimization of a DSP-Based standalone PV system using fuzy logic and Dual-MPPT control," IEEE Trans. Indus. Inform., vol. 8, no. 3, pp. 573–584, 2012, doi: *10.1109/TII.2012.2192282.*

[23] E. M. Ahmed, and M. Shoyama, "Stability study of variable step size incremental conductane/impedance MPPT for PV systems," *Proceedings of 8th International Conference on Power Electronics (iCPE 201i) - ECCE Asia, May-Jun. 201I, TuB2-3, 2011.05,* doi: 10.1109/ICPE.2011.5944555.

[24] J. I. Corcau and L. Dinca, "Modeling and analysis of a fuzzy type MPPT algorithm," *2019 International Conference on Electrical Drives & Power Electronics (EDPE), The High Tatras, Slovakia, 2019,* pp. 230–234, doi: 10.1109/EDPE.2019.8883925.

[25] J. Li, and H. Wang, "Maximum power point tracking of photovoltaic generation based on the fuzzy control method," *in Proc. International Conference on Sustainable Power Generation and Supply, 2009,* pp. 1–6, doi: 10.1109/SUPERGEN.2009.5348168.

[26] A. Al-Gizi, A. H. Miry, and M. A. Shehab, "Optimization of fuzzy photovoltaic maximum power point tracking controller using chimp algorithm," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 12, no. 5, pp. 4549–4558, October 2022, doi: 10.11591/ijece.v12i5.pp4549-4558

[27] J. de la Cruz-Alejo, H. B. Cuellar, and I. C. A. Guillermo, "Control of the humidity percentage of a bioreactor using a fuzzy controller to grow bonsai," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 12, no. 3, pp. 2465–2476, June 2022, doi: 10.11591/ijece.v12i3.pp2465-2476.

[28] M. Ali *et al*., "The comparison of dual axis photovoltaic tracking system using artificial intelligence techniques," *IAES International Journal of Artificial Intelligence (IJ-AI)*, vol. 10, no. 4, pp. 901–909, December 2021, doi: 10.11591/ijai.v10.i4.pp901-909.

BIOGRAPHIES OF AUTHORS

Djaafar Toumi was born on 5 Feb 1993 in Eloued, Algeria. He received a master degree in electrical engineering from University of El Oued in 2018. He is Currently working toward his PhD thesis in electrical energy at University of El Oued. His fields of interest are control technology of photovoltaic system and intelligent control. He can be contacted at email: toumi-djaafar@univ-eloued.dz.

Djilani Benattous was born on May 24, 1959 in El Oued Algeria. He received his Engineer degree in Electrical Engineering from Polytechnic National Institute Algiers Algeria in 1984. He got Msc degree in Power Systems from UMIST England in 1987. In 2000, he received his doctorat d'état (PHD from Batna University Algeria). He is currently associate professor at El Oued university Algeria in Electrical Engineering. His research interests in Planning and Economic of Electric Energy System, Optimization Theory and its applications and he also investigated questions related with Electrical Drives and Process Control. He can be contacted at email: dbenattous@yahoo.com.

Ahmed Ibrahim was born in EL-Sharkia, Egypt, in 1987. He received the B.Sc. and M.Sc.degrees from the Faculty of Engineering, Zagazig University, Egypt, in 2009 and 2013, respectively. In 2021, he received Ph.D at Tomsk Polytechnic University., Tomsk, Russia He is currently a lecturer at National Research Tomsk Polytechnic University, Tomsk. He is working in the fields of optimization techniques, control systems, electric Power grids and renewable energy systems. He has more than 33 research articles and papers that are published in high-impacted journals and conferences. He can be contacted at email: ibragim@tpu.ru.

Bedida Tarek was born on 5 Feb 1993 in eloued, Algeria. He received a master degree in electrical engineering from University of El Oued in 2014. He is Currently working toward his PhD thesis in electrical energy at University of El Oued. His fields of interest are control technology of photovoltaic system and intelligent control, and Economic of Electric Energy System. He can be contacted at email: tarekbedida9@gmail.com.

Messaoud Zobeidi was born in El-oued (Algeria), on august 14, 1991. He received the Master degree in electrical engineering from the University of Djillali Liabes of Sidi Bel-Abbes, Algeria, in 2021, he received the PhD in electrical power system in the same university. His research interest's concern: using new methods for optimal location of FACTs devices based on sensitivity analysis to achieve power system security. He can be contacted at email: messoud91@yahoo.fr.

Khelaifa Fethi was born in El-oued (Algeria), on august 10, 1992. He received the Master degree in electrical engineering from the University of Djillali Liabes of Sidi Bel-Abbes, Algeria, in 2021. He is Currently working toward his PhD thesis in electrical energy at University Larbi Ben M'hidi Oum El Bouaghi, Algeria. His fields of interest are control technology of photovoltaic system, new methods for optimal location of FACTs devices based on sensitivity analysis to achieve power system and intelligent control. He can be contacted at email: fethi.khe01@gmail.com.

Hicham Serhoud as born on Mar. 30,1983 in El Oued Algeria. He received Master's degree in electrical engineering from Batna University, Algeria, in 2009. He received the PhD degree in electrical engineering from Mohamed Kheider University of Biskra (Algeria), in 2015. He is currently associate professor at El Oued university Algeria in Electrical Engineering. His fields of interest are control of Brushless doubly fed induction machines and double fed induction machines, modelling and control of wind turbines, sensorless control of electrical machine and the control technology of photovoltaic system. He can be contacted at email: serhoud-hicham@univ-eloued.dz.

Yacine Labbi as born in ElOued, Algeria in 1984, He received the B. Sc degree in Electrical Engineering from Biskra University Algeria in 2006, his MSc degree from Biskra University in 2009. He received the PhD degree in electrical engineering from Mohamed Kheider University of Biskra (Algeria), in 2015 He is currently associate professor at El Oued university Algeria and his areas of interest are optimal power flow, renewable energy, FACTS Modeling, application of Artificial Intelligence techniques, control and optimize electric power systems. He can be contacted at email: yacinelabbi@gmail.com.

Raef Aboelsaud was born in Zagazig, Egypt, in 1987. He received the B.Sc. degree (with honors) and the M.Sc. degree in electrical engineering from Zagazig University, Zagazig, Egypt, in 2009 and 2013, respectively. He is currently working toward the Ph.D. Degree in electrical engineering at Tomsk Polytechnic University, Tomsk, Russia. His current research interests include power electronic converters and control systems applied to renewable energy conversion and energy storage. He can be contacted at email: rsahmed@eng.zu.edu.eg.

Sergey Obukhov was born in Tomsk, Russia in 1963. In 1989, he received PhD degree from National Research Tomsk Polytechnic University, Tomsk, Russia and continued his career at the department in the position of senior researcher. Now he is a professor at National Research Tomsk Polytechnic University, Tomsk, Russia. And has 100 scientific publications in electric power engineering and electrical engineering. The research interest covers different types of renewable energy. He can be contacted at email: serob99@mail.ru

Mohamed Tayeb Boussabeur was born in Biskra, Algeria in 1993, He received the B. Sc degree in Electrical Engineering from Biskra University Algeria in 2016, his MSc degree from Biskra University in 2018. He is Currently working toward his PhD thesis in electrical energy at University of El Oued. His fields of interest are control technology of photovoltaic system and intelligent control, and Economic of Electric Energy System, He can be contacted at email: boussabeur-mtayeb@univ-eloued.dz.