A new efficient MPPT for improving the performance of photovoltaic system using the arithmetic optimizer algorithm

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Article Info

Article history:

Received Jan 22, 2025
Revised Apr 11, 2025
Accepted May 31, 2025

Keywords:

Arithmetic optimization algorithm
Fractional order proportional integral
Maximum power point tracking
Optimization
Photovoltaic systems

ABSTRACT

Solar energy is well suited to combating global warming as a leading renewable energy supply. Solar systems in the form of photovoltaic (PV) generation are incredibly dependent on their operating circumstances regarding their techno-economic feasibility. The nonlinear control challenge is exacerbated by the partial shading (PS) environment, which results in significant power losses. High tracking and settling time, oscillations at global maxima (GM), and local maxima (LM) trapping under PS circumstances are all apparent shortcomings of metaheuristics-based maximum power point tracking (MPPT) control systems in the literature. This work provides a new meta-heuristic method called the arithmetic optimization algorithm (AOA) technique based on MPPT control of PV systems to address these issues. The suggested technique improves PV system performance by allowing faster and more accurate tracking and very low oscillations. The simulation results demonstrate the suggested AOA control technique stands out for its ease of implementation, robustness, and steady-state power tracking efficiency of up to 99.643%.

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1. INTRODUCTION

Photovoltaic (PV) systems and other renewable energy sources are in high demand right now because fossil fuels cause major environmental problems like global warming, environmental degradation, and water pollution [1], [2]. Solar energy is expected to be a significant renewable energy source in the present and future due to the sun's abundance and sustainability [3], [4]. Because of the nonlinear properties of the PV array, the maximum power point tracking (MPPT) method is utilized to ensure that the PV array is constantly producing the maximum power attainable [5], [6]. In the literature, many MPPT strategies have been described and discussed [3], [7]. They are divided into two categories: traditional MPPT methods and advanced MPPT methods. The traditional MPPT methods include perturb and observe (P&O) [8], [9], incremental conductance (INC) [10], [11], and incremental resistance (INR) [12]. They are the most often used strategies due to the fact that their structures are straightforward and they are easy to put into operation. In the steady state, however, their duty cycle oscillates [8], resulting in power losses. Besides, the ability to track the maximum power point (MPP) under uniform solar irradiation has been demonstrated using conventional MPPT techniques. Traditional approaches have failed to track the true MPP in fast-changing climates and partially shaded conditions. The advanced methods include fuzzy logic [13], artificial neural network (ANN) [14], and evolutionary computation [15], [16]. It is possible to get greater performance under uniform sun irradiation and partially shaded conditions [8].

This paper presents a new MPPT based on arithmetic optimization algorithm (AOA) with fractional order proportional integral controller (FOPI) to track MPP. The proposed MPPT was compared with conventional methods such as P&O, INC, and the classical MPPT based on a proportional integrative (PI) controller. The results demonstrated the AOA with FOPI has less fluctuation, less ripple and faster tracking of the maximum power point.

The structure of this article is as follows: section 2 explains the proposed system. In section 3, the arithmetic optimization method is illustrated. Section 4 represents the proposed MPPT based on AOA-FPI. Section 5 shows the results and discussion.

2. PROPOSED MAXIMUM POWER POINT TRACKING CONTROL BASED ON AOA-FPI

Figure 1 depicts the schematic diagram of the PV system investigated in this study. The topology comprises a PV array and a DC-DC quadratic boost converter (QBC).

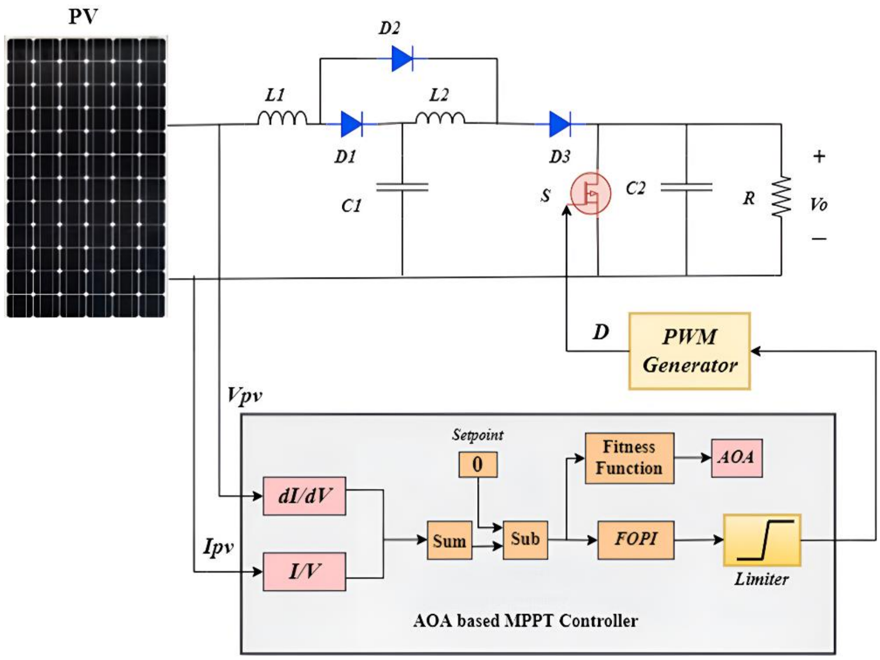

Figure 1. Proposed system

2.1. Modeling of photovoltaic array

There are just a few forms of equivalent circuit models for PV cells in the literature. Single diode types with shunt and series resistance are well known in the circuit design community. The current I_{ph} which is proportional to the quantity of solar irradiation and is used to express the amount of electrical energy produced by PVs. While the resistance of the shunt component reflects the leakage current, the resistance of the series component indicates the internal resistance [17]. Additional information and equations regarding the single-diode equivalent circuit of the PV cell may be found in [18], [19].

2.2. Design of quadratic boost converter

Several advantages to using a QBC include increasing efficiency and voltage gain without increasing the number of switches or the duty cycle used. Because this converter introduces less current ripple into the source, the efficiency and life span of the PV arrays can be increased in tandem with them [19]-[22]. The QBC depicted in Figure 2 has a single switch and contains two capacitors, three diodes, two inductors, and load resistance in addition to the switch [23]. The optimization procedure using the AOA is illustrated in Figure 3. Those converters that are cascaded combine converters back to back with the help of additional switches. The QBC is an example of a converter that performs a similar function but with only one switch, unlike other types. Its voltage conversion ratio is more significant than a traditional boost converter.

When combined with PV systems, wind energy systems, and microgrid applications, this converter becomes more suitable for a power system [20], [22]. In (1), the formula for the output voltage gain is provided:

$$V_O = \left[\frac{1}{(1-D)^2}\right] V_{in} \tag{1}$$

where $'D'$ is the duty cycle and $'V_{in}'$ is the input voltage.

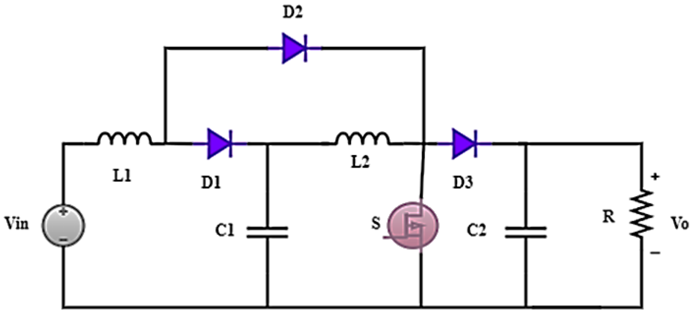

Figure 2. Electrical model of QBC [23]

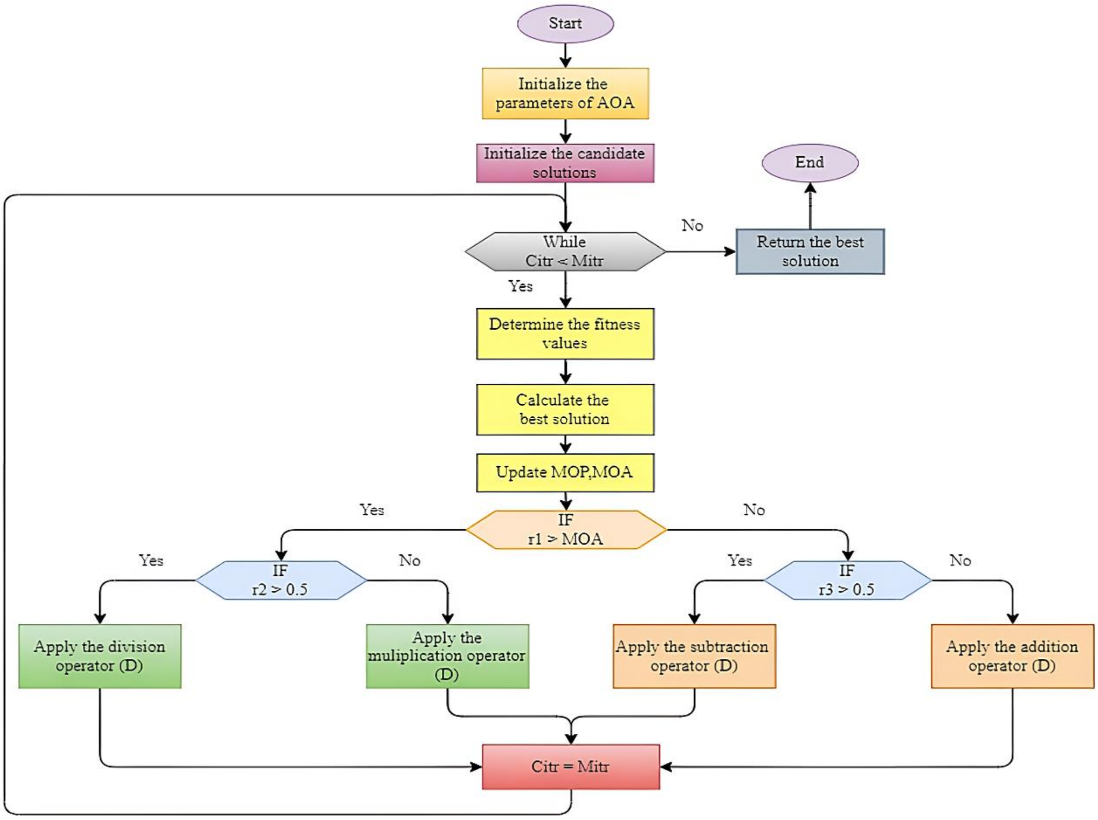

Figure 3. AOA flowchart

3. THE ARITHMETIC OPTIMIZATION ALGORITHM

The arithmetic optimization method is a recently discovered optimization technique based on the proven laws of arithmetic operations [24]. Geometry, algebra, and analysis are the three pillars on which numerical theory is built, and they constitute one of the most important components of contemporary mathematics. The core mathematical parameters for data analysis are arithmetic operators (division, addition, multiplication, and subtraction). There are two phases to the AOA method: exploration and exploitation.

3.1. Fractional order proportional-integral-derivative controller

Among the benefits of using a FOPID controller are the fact that it has no steady-state error, has gain and phase cross-over frequencies, in addition to the gain and phase margin, and provides robustness against variants in the phase crossover frequency and high-frequency noise. The FOPID controller can be expressed mathematically as (2):

$$u(t) = K_P e(t) + K_I \int_0^t e(t)dt + K_D\,[de(t)/dt] \tag{2}$$

following the application of the Laplace transform to the equation, we obtain the (3):

$$L_F(s) = (K_p) + (K_i/s^{\lambda}) + (K_d`s^{\mu}) \tag{3}$$

where:
K_P : represents the proportional constant
K_I : represents the integral constant
K_D : represents the derivative constant
λ , μ : indicates real numbers

The AOA is used to optimize the three parameters of the FOPID (K_P, K_I , and λ). Figure 3 shows the block diagram of FOPID [24]. Setting μ and λ equal to 1 creates a classical proportional integral differential (PID) controller. As a result, the traditional PID controller is really a particular instance of the FOPID controller. The FOPID schematic diagram show in Figure 4. This addition increases flexibility, reliability, and system performance. This increases the system's stability and robustness against rapid changes. Now, the designer must determine five variables instead of three, making performance more difficult [25].

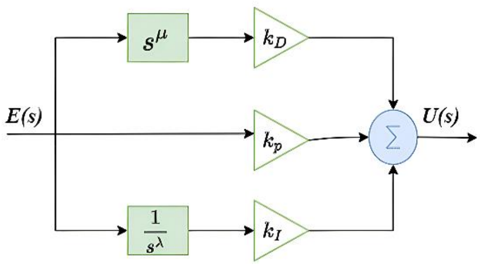

Figure 4. The FOPID schematic diagram [24]

4. PROPOSED MAXIMUM POWER POINT TRACKING

In contrast to traditional MPPT controllers, optimization controllers are resilient in the face of rapid climatic changes. The AOA with FPI controller is used in this section to optimize the MPPT controller. AOA is connected to the FOPI controller via fitness function; the performance index used in this study is integral time absolute error (ITAE) to reduce the error and overshoot, as depicted in Figure 5.

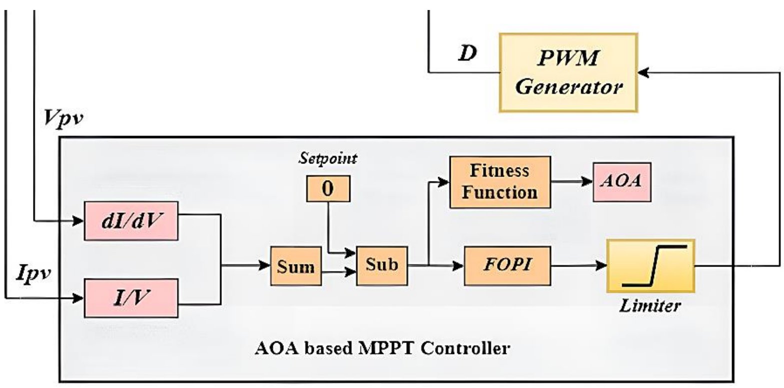

Figure 5. Proposed AOA MPPT strategy

$$I_{ITAE} = \int_0^T t\,|e(t)|\,dt \quad (4)$$

5. RESULTS OF SIMULATION

MATLAB/Simulink software is utilized to test a PV system's suggested design for MPPT. The P&O approach-based controller, IC algorithm-based controller, and traditional MPPT based on PI controller are compared with the AOA-FOPI-based controller. The PV module is connected to a DC-DC converter as illustrate in Figure 1. Table 1 contains the information that pertains to this PV panel. The suggested system is simulated in a variety of circumstances so that the proposed MPPT performance can be evaluated under a variety of environmental situations. In the first case, the temperature is constant at 25 ℃ and the solar radiation is variable. In the second case, the temperature is variable and the solar radiation is constant at 1000 W/m^2. In the third situation, both the temperature and the amount of sunlight change at the same time. The results show in each case that the proposed AOA-FPI shows better performance compared to the traditional methods, as the proposed system shows faster tracking of the maximum power point and less fluctuation.

Case 1: temperature remains constant while irradiance varies as shown in Figures 6-8.

Table 1. describes the data sheet of the PV panel used in this work

Model	Pmax (W)	Vmp (V)	Imp (A)	Voc (V)	Isc (A)
LR5-72HPH-535M	535	41.5	12.9	49.35	13.78

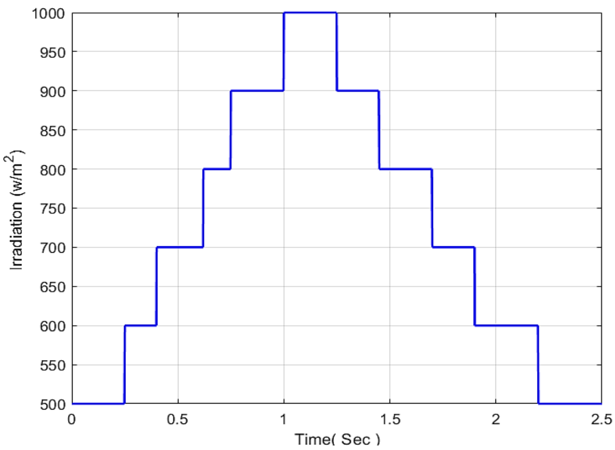

Figure 6. Step change of irradiance (W/m^2)

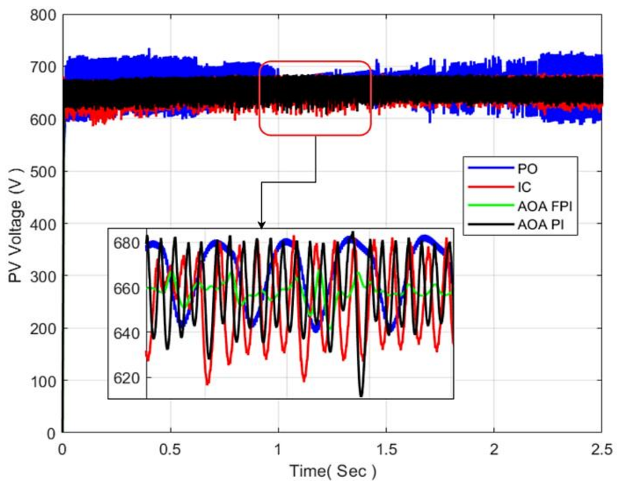

Figure 7. Response of voltage

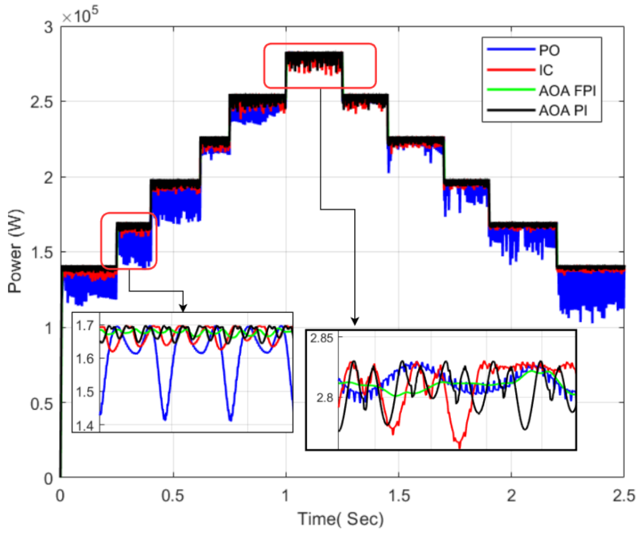

Figure 8. Dynamic response of PV power under variable irradiance

Case 2: irradiance remains constant while temperature varies as shown in Figures 9-11.

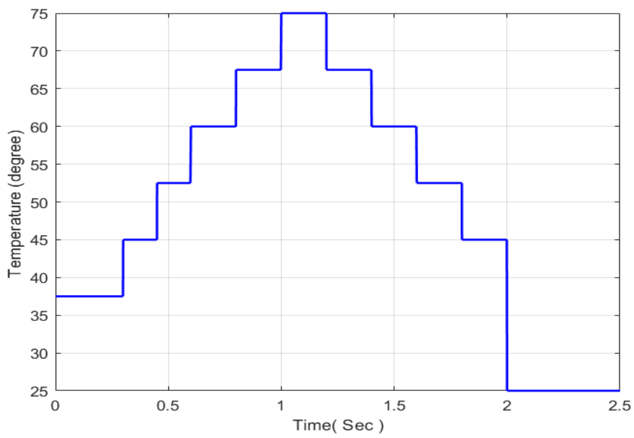

Figure 9. Step change of temperature

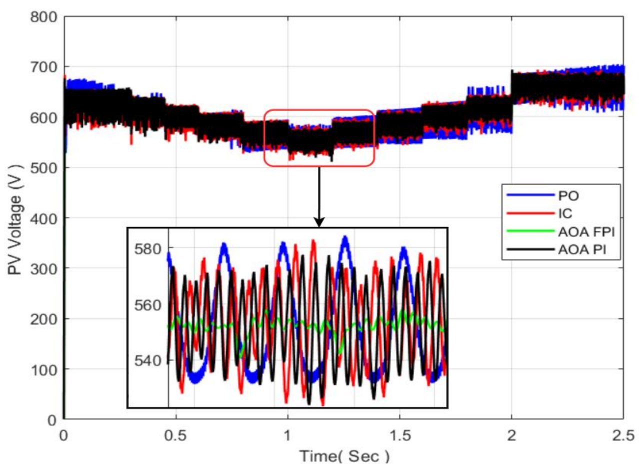

Figure 10. Dynamic response of voltage under variable temperature

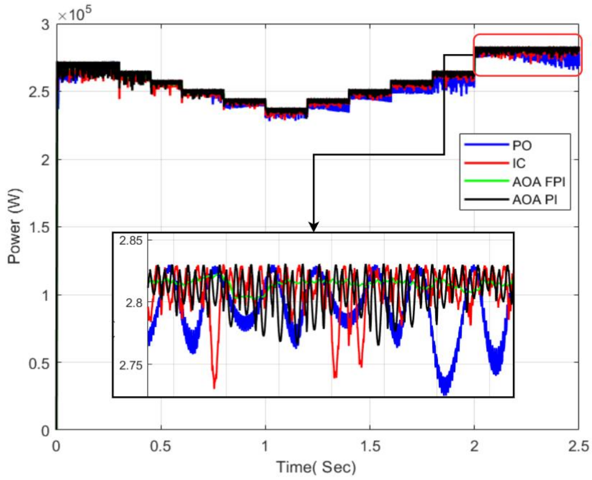

Figure 11. Dynamic response of PV power under variable temperature

Case 3: change in irradiance and temperature at the same time as shown in Figures 12-15.

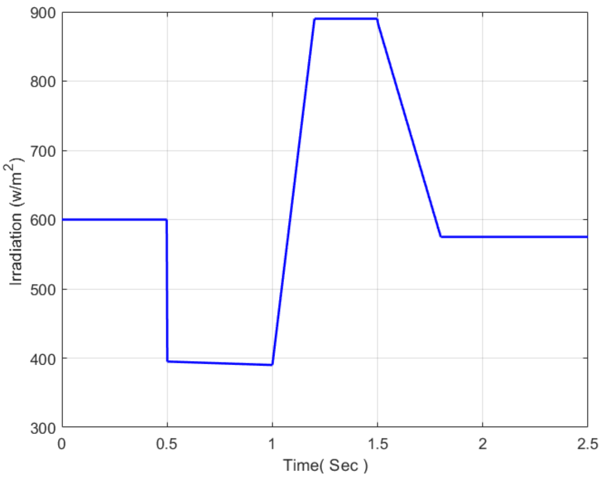

Figure 12. Step change of irradiance

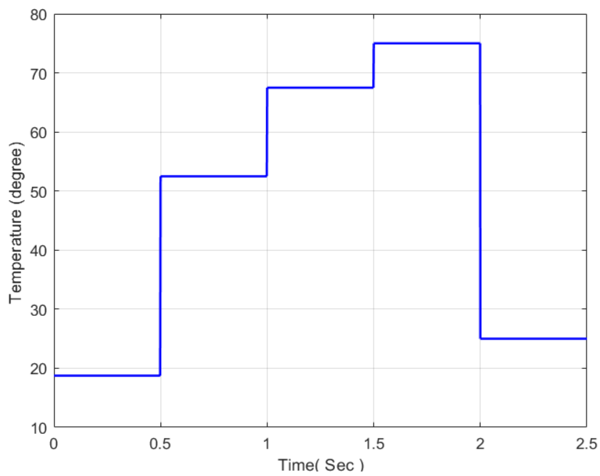

Figure 13. Step change of temperature

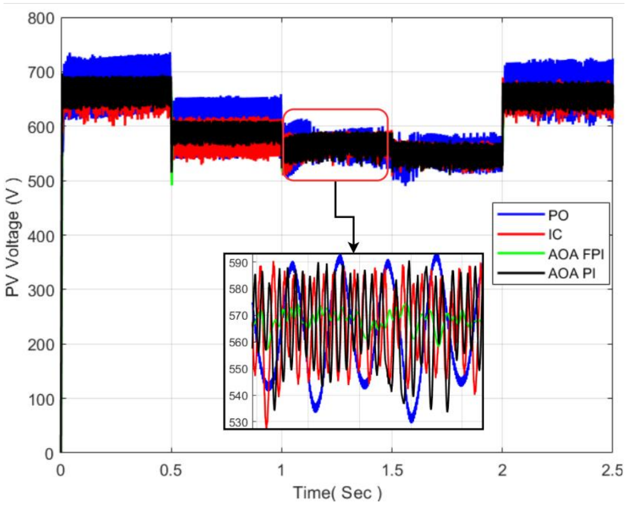

Figure 14. Dynamic response of voltage under variables irradiance and temperature

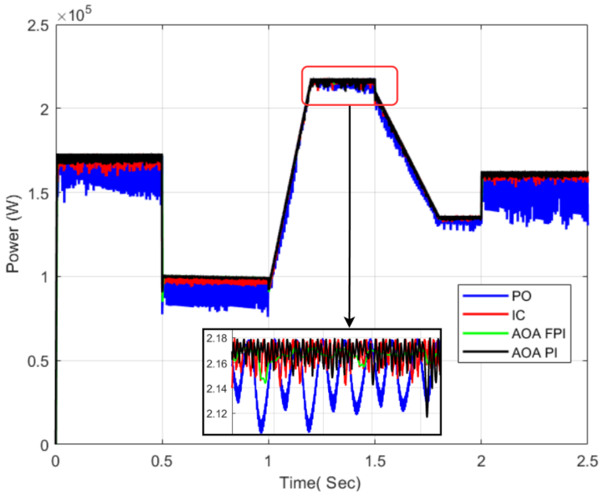

Figure 15. Dynamic response of PV power under variables irradiance and temperature

6. CONCLUSION

A new AOA for MPPT is proposed in this research. The suggested AOA-FOPI based on the MPPT controller has been tested with rapid irradiance and temperature variations to evaluate its performance. The outcomes of the simulations demonstrate that the suggested controller is superior to the P&O method-based controller, the IC method-based controller, and the traditional MPPT controller based on PI. Compared to other controllers, the suggested controller has a quicker response rate and higher precision. The suggested model's simulation results outperform those of the traditional methods, according to the results of the performance study.

ACKNOWLEDGEMENTS

The author would like to direct her gratitude for the support received from the Al-Furat Al-Awsat Technical University.

REFERENCES

[1] G. Boyle, *Renewable energy: Power for a sustainable future*, Oxford University Press, 2018.
[2] J. Payne, F. Gu, G. Razeghi, J. Brouwer, and S. Samuelsen, “Dynamics of high penetration photovoltaic systems in distribution circuits with legacy voltage regulation devices,” *International Journal of Electrical Power & Energy Systems*, vol. 124, Jan. 2021, doi: 10.1016/j.ijepes.2020.106388.
[3] Z. Salam, J. Ahmed, and B. S. Merugu, “The application of soft computing methods for MPPT of PV system: A technological and status review,” *Applied Energy*, vol. 107, pp. 135–148, Jul. 2013, doi: 10.1016/j.apenergy.2013.02.008.

[4] K. Ishaque, Z. Salam, H. Taheri, and Syafaruddin, “Modeling and simulation of photovoltaic (PV) system during partial shading based on a two-diode model,” *Simulation Modelling Practice and Theory*, vol. 19, no. 7, pp. 1613–1626, Aug. 2011, doi: 10.1016/j.simpat.2011.04.005.
[5] R. F. Coelho, F. Concer, and D. C. Martins, “A study of the basic DC-DC converters applied in maximum power point tracking,” in *2009 Brazilian Power Electronics Conference*, Sep. 2009, pp. 673–678, doi: 10.1109/COBEP.2009.5347723.
[6] Y-H. Ji, D-Y. Jung, J-G. Kim, J-H. Kim, T-W. Lee, and C-Y. Won, “A real maximum power point tracking method for mismatching compensation in PV array under partially shaded conditions,” *IEEE Transactions on Power Electronics*, vol. 26, no. 4, pp. 1001–1009, Apr. 2011, doi: 10.1109/TPEL.2010.2089537.
[7] M. Balato, L. Costanzo, P. Marino, G. Rubino, L. Rubino, and M. Vitelli, “Modified TEODI MPPT technique: Theoretical analysis and experimental validation in uniform and mismatching conditions,” *IEEE Journal of Photovoltaics*, vol. 7, no. 2, pp. 604–613, Mar. 2017, doi: 10.1109/JPHOTOV.2016.2634327.
[8] F. L. Tofoli, D. de C. Pereira, and W. J. de Paula, “Comparative study of maximum power point tracking techniques for photovoltaic systems,” *International Journal of Photoenergy*, vol. 2015, no. 1, pp. 1–10, Jan. 2015, doi: 10.1155/2015/812582.
[9] M. A. G. Brito, L. Galotto, L. P. Sampaio, G. A. Melo, and C. A. Canesin, “Evaluation of the Main MPPT Techniques for Photovoltaic Applications,” *IEEE Transactions on Industrial Electronics*, vol. 60, no. 3, pp. 1156–1167, Mar. 2013, doi: 10.1109/TIE.2012.2198036.
[10] S. Motahhir, A. E. Ghzizal, S. Sebti, and A. Derouich, “Modeling of photovoltaic system with modified incremental conductance algorithm for fast changes of irradiance,” *International Journal of Photoenergy*, vol. 2018, pp. 1–13, 2018, doi: 10.1155/2018/3286479.
[11] S. Motahhir, A. E. Hammoumi, and A. E. Ghzizal, “Photovoltaic system with quantitative comparative between an improved MPPT and existing INC and P&O methods under fast varying of solar irradiation,” *Energy Reports*, vol. 4, pp. 341–350, Nov. 2018, doi: 10.1016/j.egyr.2018.04.003.
[12] Q. Mei, M. Shan, L. Liu, and J. M. Guerrero, “A novel improved variable step-size incremental-resistance MPPT method for PV systems,” *IEEE Transactions on Industrial Electronics*, vol. 58, no. 6, pp. 2427–2434, Jun. 2011, doi: 10.1109/TIE.2010.2064275.
[13] A. Elkhateb, N. A. Rahim, J. Selvaraj, and M. N. Uddin, “Fuzzy-logic-controller-based SEPIC converter for maximum power point tracking,” *IEEE Transactions on Industry Applications*, vol. 50, no. 4, pp. 2349–2358, Jul. 2014, doi: 10.1109/TIA.2014.2298558.
[14] Y-H. Liu, C-L. Liu, J-W. Huang, and J.-H. Chen, “Neural-network-based maximum power point tracking methods for photovoltaic systems operating under fast changing environments,” *Solar Energy*, vol. 89, pp. 42–53, Mar. 2013, doi: 10.1016/j.solener.2012.11.017.
[15] M. F. N. Tajuddin, S. M. Ayob, Z. Salam, and M. S. Saad, “Evolutionary based maximum power point tracking technique using differential evolution algorithm,” *Energy and Buildings*, vol. 67, pp. 245–252, Dec. 2013, doi: 10.1016/j.enbuild.2013.07.085.
[16] M. Seyedmahmoudian *et al.*, “Maximum power point tracking for photovoltaic systems under partial shading conditions using bat algorithm,” *Sustainability*, vol. 10, no. 5, Apr. 2018, doi: 10.3390/su10051347.
[17] E. M. G. Rodrigues, R. Melício, V. M. F. Mendes, and J. P. S. Catalão, “Simulation of a solar cell considering single-diode equivalent circuit mode,” *Renewable Energy and Power Quality Journal*, vol. 1, no. 9, pp. 369–373, May 2011, doi: 10.24084/repqj09.339.
[18] M. Zolfaghari, S. H. Hosseinian, S. H. Fathi, M. Abedi, and G. B. Gharehpetian, “A new power management scheme for parallel-connected PV systems in microgrids,” *IEEE Transactions on Sustainable Energy*, vol. 9, no. 4, pp. 1605–1617, Oct. 2018, doi: 10.1109/TSTE.2018.2799972.
[19] R. Dhanasekaran and T. A. Prasath, “Performance comparison of solar power using quadratic boost converter with coupled inductor,” in *2014 IEEE International Conference on Advanced Communications, Control and Computing Technologie*, May 2014, pp. 376–380, doi: 10.1109/ICACCCT.2014.7019467.
[20] J. D. Navamani, M. L. Veena, A. Lavanya, and K. Vijayakumar, “Efficiency comparison of quadratic boost DC-DC converter in CCM and DCM,” in *2015 2nd International Conference on Electronics and Communication Systems (ICECS)*, Feb. 2015, pp. 1156–1161, doi: 10.1109/ECS.2015.7124765.
[21] S. Balci, N. Altin, H. Komurcugil, and I. Sefa, “Performance analysis of interleaved quadratic boost converter with coupled inductor for fuel cell applications,” in *IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society*, Oct. 2016, pp. 3541–3546, doi: 10.1109/IECON.2016.7794045.
[22] T. R. Choudhury and B. Nayak, “Comparison and analysis of cascaded and Quadratic Boost Converter,” in *2015 IEEE Power, Communication and Information Technology Conference (PCITC)*, Oct. 2015, pp. 78–83, doi: 10.1109/PCITC.2015.7438108.
[23] S. Angalaeswari *et al.*, “Design and execution of quadratic boost converter (QBC) in renewabe energy synergies,” *Turkish Journal of Computer and Mathematics Education (TURCOMAT)*, vol. 12, no. 9, pp. 2957–2968, 2021.
[24] M. Moradi, “A genetic-multivariable fractional order PID control to multi-input multi-output processes,” *Journal of Process Control*, vol. 24, no. 4, pp. 336–343, Apr. 2014, doi: 10.1016/j.jprocont.2014.02.006.
[25] A. Mohanty, M. Viswavandya, and S. Mohanty, “An optimised FOPID controller for dynamic voltage stability and reactive power management in a stand-alone micro grid,” *International Journal of Electrical Power & Energy Systems*, vol. 78, pp. 524–536, Jun. 2016, doi: 10.1016/j.ijepes.2015.12.008.