Enhancing the output power of solar cell system using artificial intelligence algorithms

Ahmed H. Ali[1], Raafat A. El-Kammar[2], Hesham F. A. Hamed[1,3], Adel A. Elbaset[3,4], Aya Hossam[2]
[1]Department of Telecommunication Engineering, Faculty of Engineering, Egyptian Russian University, Cairo, Egypt
[2]Department of Electrical Engineering, Faculty of Engineering (Shoubra), Benha University, Benha, Egypt
[3]Department of Electrical Engineering, Faculty of Engineering, Minia University, Minia, Egypt
[4]Department of Electromechanics Engineering, Faculty of Engineering, Heliopolis University, Cairo, Egypt

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ABSTRACT

The main objective of research in the field of solar cell systems is to obtain the maximum output power. In this respect, artificial intelligence (AI) is considered the current icon. Hence, in the present paper; perturbation & observation (P&O) and particle swarm optimization (PSO) algorithms were used to achieve the maximum power. Solar irradiance at three different regions of Egypt was measured using a new technique based on Arduino microcontroller. The obtained experimental results of the solar irradiance were inlaid to the MATLAB simulation program to study the performance of the proposed algorithms. Many improvements were carried out in P&O and PSO algorithms to harvest maximum power for long hours daily by a continuous modulation of the duty cycle. The output maximum power and the reaching time of both improved P&O and PSO are better than the traditional one and PV array, which indicates their efficiency in harvesting the maximum power and enhancing the performance of solar cell systems. The reinforcing of the PV system by P&O improved its efficiency by 98.733%, while PSO improved its efficiency by 99.968%.

Corresponding Author:

Ahmed H. Ali
Department of Telecommunication Engineering, Faculty of Engineering, Egyptian Russian University
Badr City, Cairo-Suez Road, Postal Code 11829, Egypt
Email: ahmed_hamdy0064@yahoo.com

1. INTRODUCTION

One of the main obstacles to the spread of solar cells systems is the loss of output solar energy, which results due to environmental changes. Accordingly, in order to overcome this problem, various artificial intelligence algorithms such as perturbation & observation (P&O), particle swarm optimization (PSO), artificial immune system (AIS), artificial bee colony (ABC), and artificial fish swarm algorithm (AFSA) play a pivotal role to get the maximum power point MPP [1]–[6]. In solar energy, artificial intelligence is extensively applied in predicting, controlling, and hence improving the performance of solar cell systems [7], [8]. Simplicity, flexibility, and high performance have made the PSO algorithm a nerve for many applications. Additionally, PSO has been considered as an effective tool to perform multi-objective functions. It also provides a valuable high-accuracy solution and fast convergence speed to optimization problems [6]–[9]. On the other hand, the P&O algorithm is one of the most common artificial intelligence (AI) techniques that provide better tracking under uniform solar conditions. It is classified as the simplest and easiest AI algorithm [10], [11]. A DC-DC converter is an effective tool for controlling the PV output voltage to get the desired value, even though the photovoltaic (PV) voltage changes with solar irradiance. The DC-DC converter continually adjusts the energy amount absorbed from the source and injected into the load, which achieves the desired output voltage regulation, i.e., controlling the relative periods of energy absorption and injection [12], [13]. In 2017, Kermadi and Berkouk [14] studied the possibility of getting maximum power using different AI algorithms, fuzzy logic, artificial neural network, genetic algorithm, PSO, and proportional integral derivative under the same conditions. The authors conducted a comparison between the used algorithms to evaluate their efficiency and cost [14]. Priyadarshi *et al*. [15] used particle swarm optimization linked by the internet of things (PSO-IoT) to get maximum power point tracking. The authors showed that the PV system performance improved through using PSO-IoT technique. They also compared the efficiency of the proposed PSO-IoT algorithm with other algorithms, P&O, ant colony optimization, and artificial bee colony [15]. Qasim and Vladimir in studied the role of the changes in the pulse width modulation (PWM) of a DC/DC converter for wind and solar energy hybrid system. The authors used incremental conductance and P&O maximum power point tracking algorithms. The authors obtained a regulated AC output voltage to obtain a constant RMS voltage at different loads [16].

From the aforementioned above, P&O and PSO algorithms were used to get the maximum power point of a solar cell system. Improvements in P&O and PSO through the changing in duty cycle to control the pulse width were conducted to obtain a highly maximum power point. The used solar irradiance was measured using a new highly efficient technique based on Arduino microcontroller in three different solar profiles cities at Egypt; Cairo, Luxor, and El- Beheira as shown in Figure 1 [17]. The chosen of the three regions was intended to obtain different solar irradiance because they are characterized by different climatic conditions, which enhances the validity of the results of the maximum power that will be obtained from the P&O and PSO algorithms [17], [18].

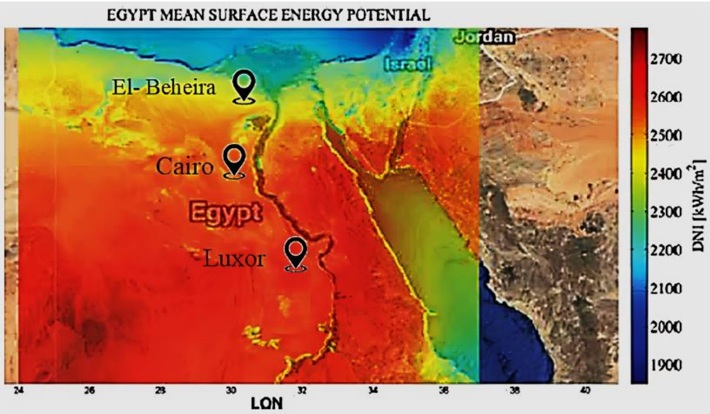


Figure 1. The solar atlas of Egypt

2. PRACTICAL PROCEDURES AND METHODOLOGY

The built proposed system, which contains solar irradiance tracer, PV array, DC-DC converter, and maximum power point tracking system (MPPT), is shown in Figure 2. A commercial 1 Soltech 1STH-215P 213.15w linked by a DC-DC converter was used. The output PV voltage and current are sensed by the maximum power point tracking algorithm, P&O and PSO. The controller algorithms adjust the duty ratio producing PWM to the DC-DC converter.

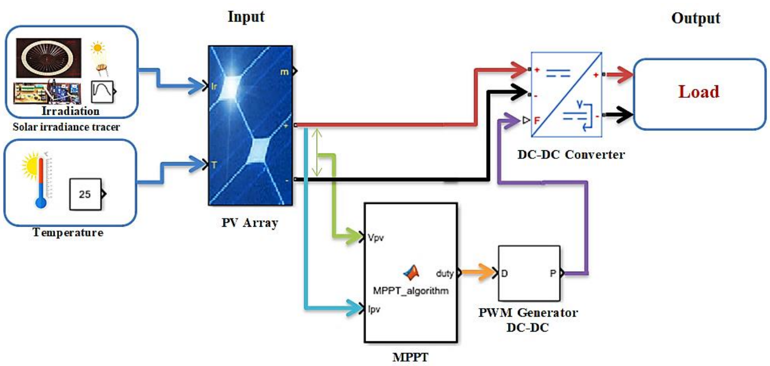


Figure 2. The block diagram of the proposed system

2.1. Solar irradiance tracer

A new technique based on the Arduino microcontroller was implemented to measure solar irradiance as shown in Figure 3. The solar irradiance in three different regions in Egypt which are Cairo, Luxor, and El-Beheira was measured. The chosen of the three regions is based on their sunshine and weather. Luxor is an Upper Egypt city distinguished by a high solar irradiance, El-Beheira coastal city has low irradiance, and Cairo is categorized as a fair weather. The solar power radiation has been obtained through converting the measured solar irradiance (lux) to solar power radiation W/m^2 as in the following relation [19]:

$$1\ \mathrm{kW/m^2} = 683\ \mathrm{klux}\ ,\mathrm{i.e.}\ 1\ \mathrm{lux} = \ 1/683\ \ \mathrm{W}/m^2$$

Figure 3. Solar irradiance tracer control system: 1) LDR starter, 2) 9 V from adaptor, 3) operational amplifier, 4) transistor BC547BP, 5) relay 9 V, 6) 9 V to Arduino, 7) 5 V from Arduino, 8) 7 jumpers from LDRs, 9) switch from 7 jumpers from LDRs to analog pins of Arduino, 10) Arduino uno, 11) RTC module, and 12) SD memory card

2.2. PV array model

A PV panel with the characteristics listed in Table 1 was used as a power source for the system. Three series PV modules in one string have been connected to build the used MATLAB/Simulink PV array model. Two inputs, solar irradiance in W/m^2 and cell temperature in °C are fed into the PV array as shown in Figure 4 because they are the main influences on the electrical behavior of solar cells.

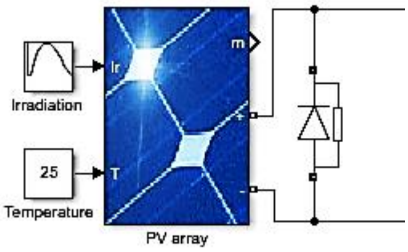


Figure 4. PV array model of the present study

Table 1. The used PV panels characteristics

Array data	Parallel strings			1	Series-connected modules per string			3
Module data (1Soltech 1STH-215-P)	Maximum Power (W)	213.15	Voltage at maximum power point Vmp (V)	29	Cells per module (Ncell)	60	Current at maximum power point Imp (A)	7.35
	Open circuit voltage Voc (V)	36.3	Temperature coefficient of Voc (%/ºC)	-0.36099	Short-circuit current Isc (A)	7.84	Temperature coefficient of Isc (%/ºC)	0.102

2.3. DC-DC converter

In order to track the maximum power point generated from the PV, a duty cycle is controlled, which in turn controls the DC-DC converter. The MATLAB/Simulink simulated DC-DC converter topology diagram is shown in Figure 5. PV array source, Boost converter, and load connection are conducted. Boost inductor, load resistor, capacitor, diode, and MOSFET as a switch are the fundamentals constituents of the DC-DC boost converter.

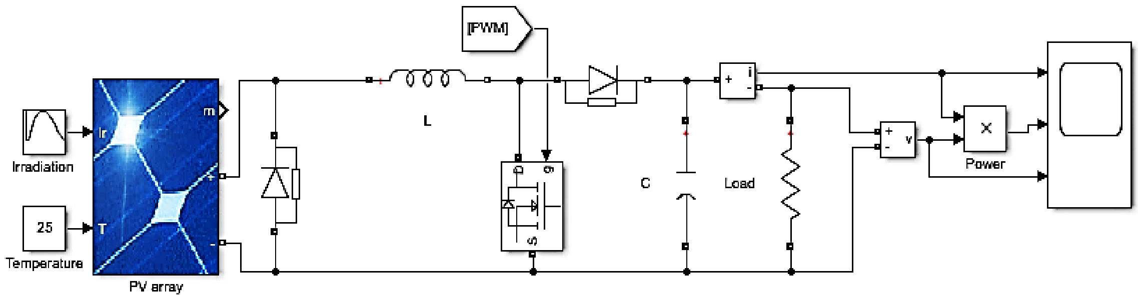


Figure 5. The PV source linked with DC-DC boost converter

2.4. MPPT algorithms

The P&O and PSO algorithms were used as an MPPT controller to supply the DC-DC converter by PWM. The conventional P&O and PSO were used and many improved were conducted to enhance the output power of the PV system. The details of the conventional and improved P&O and PSO are discussed in below.

2.4.1. Conventional P&O

Voltage pulses perturbation, increasing and decreasing, around its initial value is the basis of the P&O MPPT controller. The perturbation is the main factor affecting the duty cycle of PWM, which controls the DC-DC converter output [19]–[22]. The MPP is reached using P&O through achievement the condition.

$$\Delta P_{pv}\Delta V_{pv} = 0 \quad (1)$$

The Simulink block diagram model of the conventional P&O MPPT controller algorithm is shown in Figure 6.

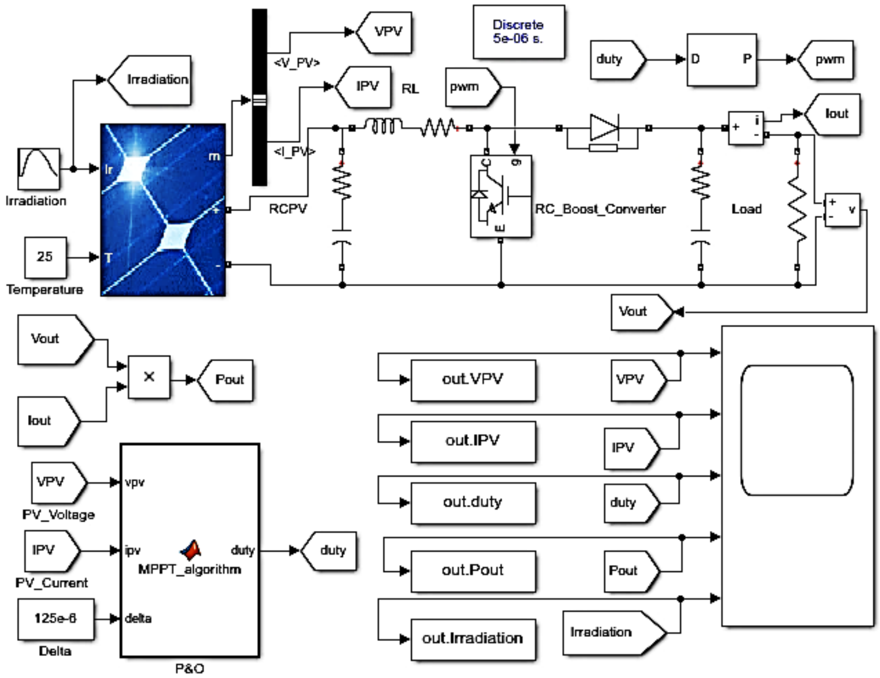


Figure 6. The block diagram of P&O MPPT controller

2.4.2. Conventional PSO

Using the concepts of movement & intelligence of swarm and social interaction to solve problems in PSO controller has made it a robust optimization technique. In order to reach the optimized solution, this technique uses a number of agents or particles in a specific region, each of which traces specific best conditions reached by the particle itself. So, each particle reaches the optimal solution or gets as close to it as possible. The position and velocity of the conventional PSO are defined as [23]–[25].

$$v_i(n+1) = wv_i(n) + c_1 r_1 \left(p_{best,i} - x_i(n)\right) + c_2 r_2 \left(g_{best} - x_i(n)\right) \tag{2}$$

$$x_i(n+1) = x_i(n) + v_i(n+1), i = 1, 2, 3, ... \tag{3}$$

Where, v_i, x_i, n, w, r_1, r_2, c_1, c_2, are the velocity of particle i, the position of particle i; n the iteration number, w is the inertia weight, r_1 & r_2 random variables uniformly distributed within [0,1], and c_1 & c_2 the cognitive and social coefficient, respectively. The best position that found by the ith particle stored in $p_{best,i}$, while that for all the particles stored in g_{best}.

Tracking the MPP and adjusting the duty cycle of the DC-DC converter to get the maximum power is the main goal of the PSO algorithm. The PSO algorithm is centered on the particle iteration, duty cycle ranges, and the weights. The PSO algorithm calculates the required duty cycle for the initial particle for supplying the DC-DC converter to obtain the output volts, current, and power. This procedure will be repeated for all particles until the maximum value of the generated power is reached. In conventional PSO, the duty cycle remains fixed for all conditions even if the shading condition changed because the particles not reinitialize. The Simulink block diagram of the conventional PSO MPPT controller algorithm is shown in Figure 7.

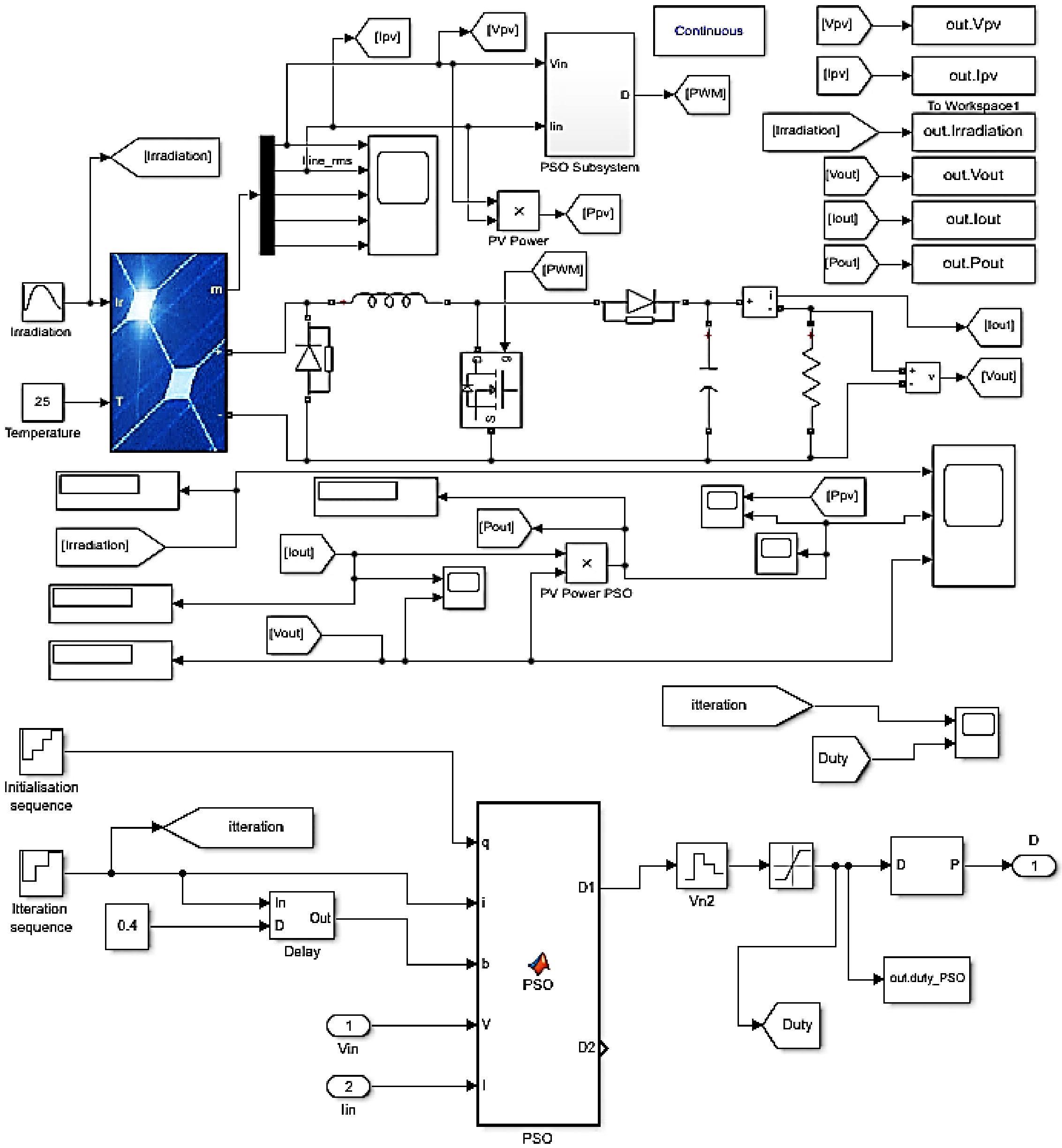


Figure 7. The block diagram of PSO MPPT controller and the subsystem of PSO algorithm

2.4.3. Improved P&O

The improved P&O based on tune the variable value of the perturbation is shown in Figure 8(a). The tune of the output voltage was conducting by the changing in the duty cycle D through the factor ΔD. The fluctuation of the output value around MPP was controlled and minimized using reducing the step size. Step size makes a large change in the duty cycle if the operating point is far from MPP and reduces the change when the operating point is close to MPP.

2.4.4. Improved PSO

Enhancement was carried out on the PSO algorithm by controlling the adjustment of the duty cycle and then obtaining a higher power than the traditional algorithm. In the conventional PSO, the three parameters $w, c_1,$ and c_2 are constant. In the present article, the improved PSO achieved through variation $w, c_1,$ and c_2 to accelerate the convergence. Hence, in (2) must be rewrite as (4).

$$v_i(n+1) = w(n)v_i(n) + c_1(n)r_1\left(p_{best,i} - x_i(n)\right) + c_2(n)r_2\left(g_{best} - x_i(n)\right) \quad (4)$$

The $w(n)v_i(n)$ term is used to maintain the continuity of particle movement in the same direction as its original movement, leading to an increase in the efficiency of controlling the convergence of PSO. On the other hand, the appropriate selection of the inertia weight works to fade $v_i(n)$ during the implementation of the algorithm, leading to an acceleration of convergence.

The flowchart of the proposed PSO algorithm is shown in Figure 8(b). With any shadow, the steps of the operating principle return to the beginning to implement the new conditions. As a result, a modification in the duty cycle will be carried out. The employed proposed PSO parameters are listed in Table 2.

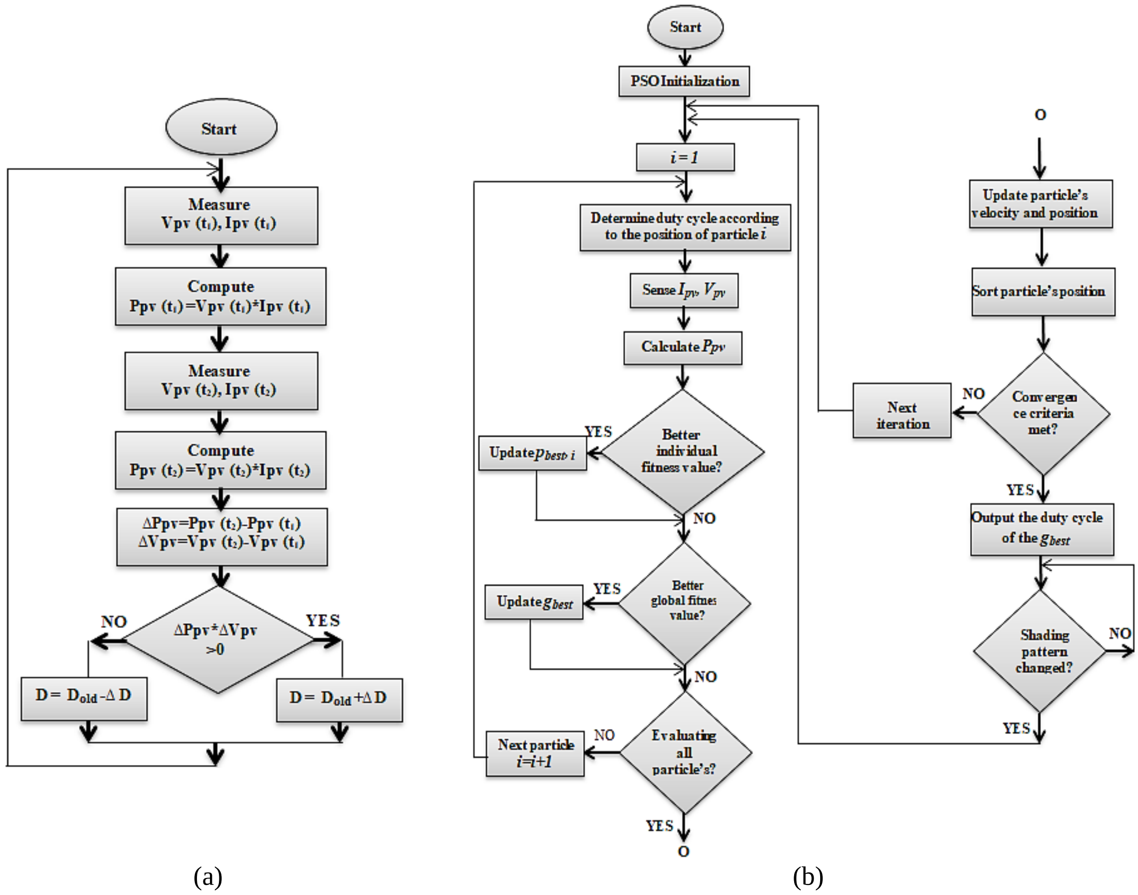


Figure 8. The improved flowchart (a) P&O and (b) PSO

Table 2. PSO simulation parameters

Parameter	w	c1	c2	r1	r2	Number of particles	Maximum iterations	Var_{min}	Var_{max}
Value	0.4	0.8	1.2	0.25	0.25	3	10	0.4	0.95

3. RESULTS AND DISCUSSION

3.1. Solar power radiation

Solar radiation measurements were conducted in the summer (June) and the built solar irradiance tracer system began detecting solar radiation from the sunrise (6 AM) to sunset (7 PM) as shown in Figure 9. Initially, all results of the measured solar power in the three selected regions throughout the day follow the standard behavior of the solar spectrum variation with time as shown in Figure 9. In other words, the solar power behavior shows an increase up to its maximum value at 11 am followed by a gradual decrease through the rest of the day. Luxor results showed slightly higher values than Cairo and both of them are higher than El-Beheira.

This was attributed to the clearness of the sky and the low humidity and mist in the Luxor and Cairo areas compared to the El-Beheira. On the other hand, the lower values of Cairo than Luxor are due to the dustiness of the surrounding factories and their relative raising of humidity compared to Luxor. MATLAB was fed by the measured solar power irradiance, Figure 9, to study the output power of PV and the role of P&O and PSO algorithms in improving the solar system's performance and obtaining the maximum power.

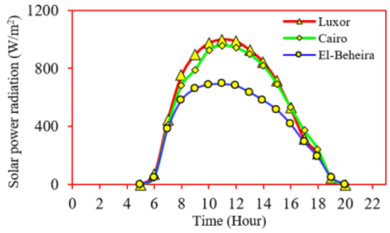


Figure 9. Measured solar power radiation in the three regions, Luxor, Cairo, and El-Beheira

3.2. MPPT algorithms

The simulation was conducted over a period of 14 seconds, each 1 second equivalent to an hour of the measured spectrum. The obtained simulation results of current, voltage, and maximum generated power waveforms of the studied PV array, the conventional P&O, conventional PSO, improved P&O, and improved PSO algorithm under different solar irradiance conditions are shown in Figures 10-13. First, it was found that both the current and voltage are dramatically influenced by irradiance changes for the PV, P&O, and PSO as shown in Figures 10(a)-10(b), 11(a)-11(b), 12(a)-12(b), and 13(a)-13(b) respectively. On the other hand, the output voltage of the improved P&O is the highest as shown in Figures 11(b), 12(b), and 13(b) due to the permanent control in the duty allowing tracking of the maximum power. Consequently, the output power of the system based on the improved P&O outperforms that of conventional P&O and PV [Figure 10(c)] array for each value of solar irradiance as shown in Figures 11(c), 12(c), and 13(c). The broadening of the output power full width at maximum height FWMH strongly reflected the effective role of the AI algorithm in the improvement of the system performance. This broadening means that P&O accelerates the reaching of the MPP for each value of solar irradiance and also the length of the harvest period of the highest power of the system. As shown in Figures 10-13 the FWMH of the improved P&O is wider than both the conventional P&O and PV array. The improved P&O has a bandwidth of 9.45, 10.04, and 9.24 hours for Luxor, Cairo, and El-Beheira respectively, while the conventional has 9.36, 9.42, and 9.09 hours, and PV array has 8.39, 8.51, and 7.54 hours. Hence, the system reinforced by the improved P&O is an efficient than both conventional P&O and PV array.

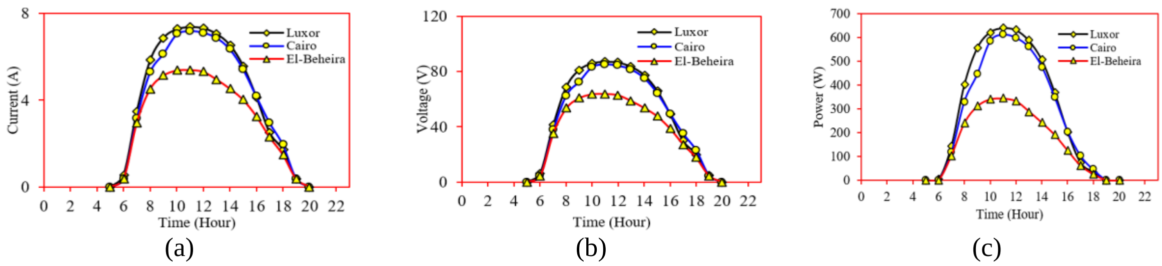
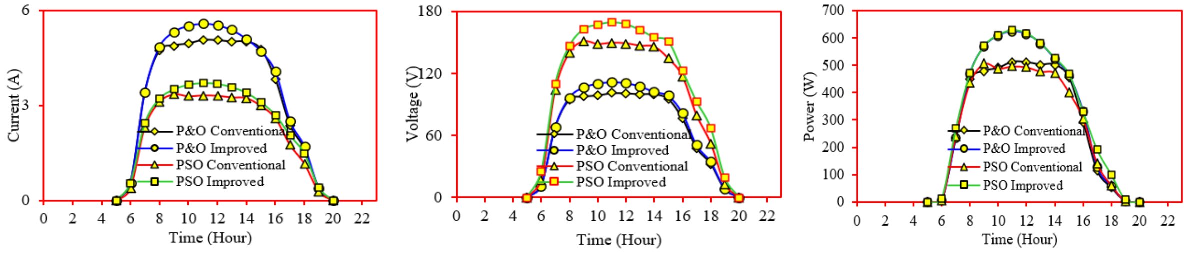


Figure 10. Comparing the simulation results of PV array for the three studied regions in (a) output current, (b) output voltage, and (c) output power

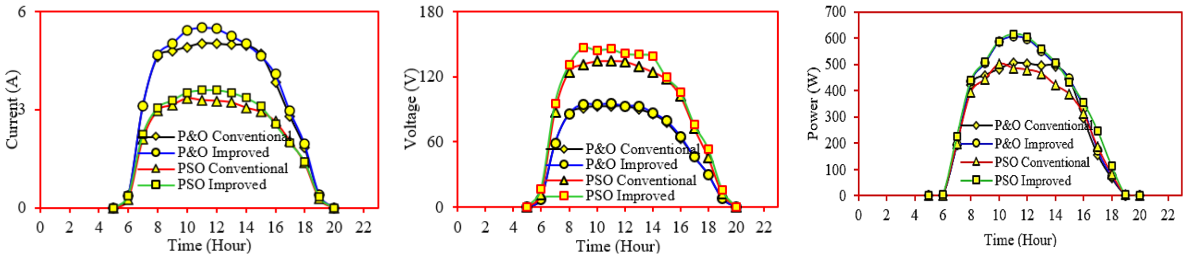


(a) (b) (c)

Figure 11. Comparing the obtained simulation results using conventional P&O, conventional PSO, improved P&O, and improved PSO for Luxor city in (a) output current, (b) output voltage, and (c) output power

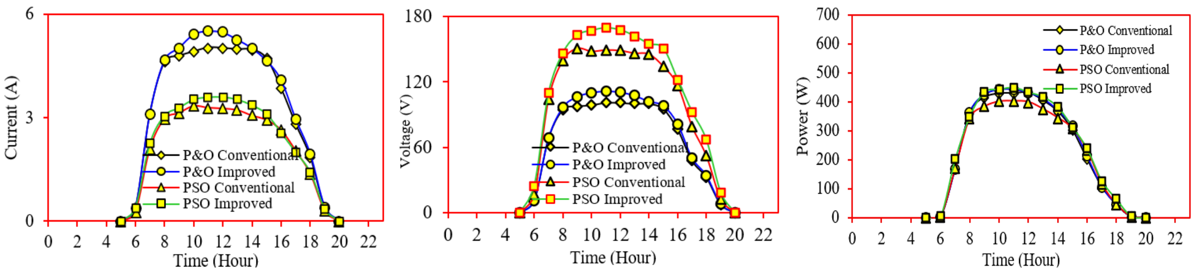
The comparison of FWMH of the improved P&O for the three studied regions showed that the bandwidth of Cairo is wider than that of Luxor, which was attributed to the long of the solar day period (the period between sunrise and sunset) for Cairo compared to Luxor. The sunrise in Cairo begins early and ends late compared to Luxor. Although the solar day of El-Beheira is longer than that of Cairo and Luxor its bandwidth is the least, which is attributed to the density of the mist in it that reduces the actual solar day for it, in addition to its high humidity compared to Cairo and Luxor. As a result of the inability of the conventional PSO algorithm to reinitialize the particles when a sudden shade occurs, the system always has a constant duty cycle for all values of solar irradiance conditions. But in the same regard, the multi-duty cycle of improved PSO during the system operation produces higher maximum generated power at each value of solar irradiance conditions as shown in Figures 11(c), 12(c), and 13(c). The FWMH of improved PSO is 10.24, 10.45, and 9.48 hours for Luxor, Cairo, and El-Beheria respectively, while of the conventional PSO are 9.54, 10.06, and 9.21 hours and for PV array 8.39, 8.51, and 7.54 hours. The wide broadening of FWMH of improved PSO compared to the conventional and PV array reflect the effectiveness of the designed improved PSO control.

$$Efficiency\ (\%) = \frac{MPPT\ algorithm\ extracted\ power}{PV\ maximum\ power} \times 100 \quad (5)$$



(a) (b) (c)

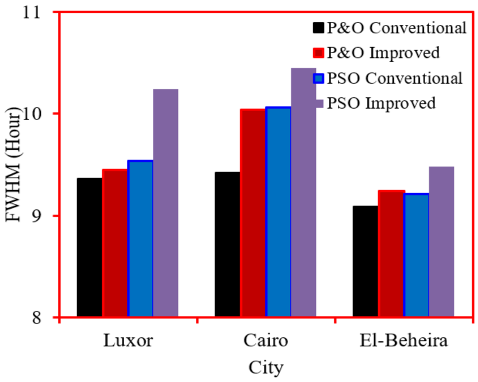
Figure 12. Comparing the obtained simulation results using conventional P&O, conventional PSO, improved P&O, and improved PSO for Cairo city in (a) output current, (b) output voltage, and (c) output power



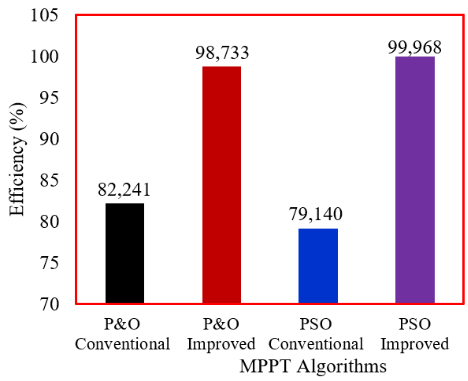
(a) (b) (c)

Figure 13. Comparing the obtained simulation results using conventional P&O, conventional PSO, improved P&O, and improved PSO for El-Beheira city in (a) output current, (b) output voltage, and (c) output power

As a comparison between the conventional P&O, conventional PSO, improved P&O and improved PSO, the FWMH of them are plotted in Figure 14(a). Both P&O and PSO achieve the maximum power for each solar irradiance value in a shorter time than PV array and cover a long time period at maximum power. On the other hand, PSO reaches in a slightly shorter time than the P&O. So, P&O and PSO are efficient in reaching the maximum power immediately and the PSO is slightly better than the P&O. Finally, the efficiency of the used conventional P&O and PSO and the implemented improved P&O and PSO was calculated using in (5) [15] and is displayed in Figure 14(b). As can be seen from Figure 14(b), the MPPT based on the improved P&O and PSO algorithms has much higher efficiency compared to the conventional.



(a)



(b)

Figure 14. Comparison between the conventional and improved of P&O and PSO (a) FWMH and (b) efficiency

4. CONCLUSION

The series of conducted studies in this paper to enhance the performance of solar cell systems using new improved P&O and PSO algorithms showed the extent of its efficiency in reaching the maximum power point MPP faster. Irradiance of three different regions, Luxor, Cairo, and El-Beheira, was experimentally measured using highly efficient technique to be used as a radiation source. Improved P&O and PSO have a faster-reaching speed to MPP and cover a longer period of time than conventional P&O and PSO and PV array. The bandwidth values confirmed the ability of both improved P&O and PSO systems to achieve maximum power faster and for a longer period of time. The improved P&O and PSO harvest maximum power for period 9.24, 9.45, and 10.04 hours and 9.48, 10.24, and 10.45 hours for El-Beheria, Luxor, and Cairo respectively compared to 7.54, 8.39, and 8.51 hours for the PV array. The comparison between improved P&O and PSO showed that PSO was achieved the maximum power slightly faster and for a longer period than P&O. The efficiency of the output power of the PV system was improved by 98.733% and 99.968% by using P&O and PSO algorithms, respectively. Hence, both P&O and PSO algorithms enriched the solar systems' ability to harvest maximum power faster and for a longer period.

REFERENCES

[1] D. Toumi *et al.*, “Maximum power point tracking of photovoltaic array using fuzzy logic control,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 13, no. 4, p. 2440, Dec. 2022, doi: 10.11591/ijpeds.v13.i4.pp2440-2449.

[2] H. Zeynal, Z. Zakaria, and B. Pourveis, “An efficient MPPT based photovoltaic control model considering environmental parameters,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 13, no. 4, p. 2432, Dec. 2022, doi: 10.11591/ijpeds.v13.i4.pp2432-2439.

[3] A. Youssef, M. El-Telbany, and A. Zekry, “The role of artificial intelligence in photo-voltaic systems design and control: A review,” *Renewable and Sustainable Energy Reviews*, vol. 78, pp. 72–79, Oct. 2017, doi: 10.1016/j.rser.2017.04.046.

[4] H. Hamdi, C. Ben Regaya, and A. Zaafouri, “Real-time study of a photovoltaic system with boost converter using the PSO-RBF neural network algorithms in a MyRio controller,” *Solar Energy*, vol. 183, pp. 1–16, May 2019, doi: 10.1016/j.solener.2019.02.064.

[5] H. Patel, R. Gajjar, and M. R. Pandya, “Artificial intelligence based MPPT techniques for solar PV system: a review,” *International Journal of Emerging Technologies and Innovative Research*, vol. 6, no. 5, pp. 212–218, 2019.

[6] O. Ben Belghith, L. Sbita, and F. Bettaher, “MPPT Design Using PSO Technique for Photovoltaic System Control Comparing to Fuzzy Logic and P&O Controllers,” *Energy and Power Engineering*, vol. 08, no. 11, pp. 349–366, 2016, doi: 10.4236/epe.2016.811031.

[7] Y.-H. Liu, S.-C. Huang, J.-W. Huang, and W.-C. Liang, “A Particle Swarm Optimization-Based Maximum Power Point Tracking Algorithm for PV Systems Operating Under Partially Shaded Conditions,” *IEEE Transactions on Energy Conversion*, vol. 27, no.

4, pp. 1027–1035, Dec. 2012, doi: 10.1109/TEC.2012.2219533.
[8] N. Priyadarshi, V. Ramachandaramurthy, S. Padmanaban, and F. Azam, “An Ant Colony Optimized MPPT for Standalone Hybrid PV-Wind Power System with Single Cuk Converter,” *Energies*, vol. 12, no. 1, p. 167, Jan. 2019, doi: 10.3390/en12010167.
[9] K. Ishaque, Z. Salam, and A. Shamsudin, “Application of particle swarm optimization for maximum power point tracking of PV system with direct control method,” in *IECON 2011 - 37th Annual Conference of the IEEE Industrial Electronics Society*, Nov. 2011, pp. 1214–1219, doi: 10.1109/IECON.2011.6119482.
[10] R. H. Mohammed, A. A. Abdulrazzaq, and W. K. Al-Azzawi, “Benefits of MPP tracking PV system using perturb and observe technique with boost converter,” *International Journal of Power Electronics and Drive Systems*, vol. 13, no. 4, pp. 2468–2477, 2022, doi: 10.11591/ijpeds.v13.i4.pp2468-2477.
[11] S. Padmanaban, N. Priyadarshi, M. Sagar Bhaskar, J. B. Holm-Nielsen, V. K. Ramachandaramurthy, and E. Hossain, “A Hybrid ANFIS-ABC Based MPPT Controller for PV System With Anti-Islanding Grid Protection: Experimental Realization,” *IEEE Access*, vol. 7, pp. 103377–103389, 2019, doi: 10.1109/ACCESS.2019.2931547.
[12] B. M. Hasaneen and A. A. Elbaset Mohammed, “Design and simulation of DC/DC boost converter,” in *2008 12th International Middle-East Power System Conference*, Mar. 2008, pp. 335–340, doi: 10.1109/MEPCON.2008.4562340.
[13] Kambli Omkar Vijay and P. Sriramalakshmi, “Comparison between Zeta Converter and Boost Converter using Sliding Mode Controller,” *International Journal of Engineering Research and*, vol. V5, no. 07, Jul. 2016, doi: 10.17577/IJERTV5IS070322.
[14] M. Kermadi and E. M. Berkouk, “Artificial intelligence-based maximum power point tracking controllers for Photovoltaic systems: Comparative study,” *Renewable and Sustainable Energy Reviews*, vol. 69, pp. 369–386, 2017, doi: 10.1016/j.rser.2016.11.125.
[15] N. Priyadarshi, S. Padmanaban, J. B. Holm-Nielsen, M. S. Bhaskar, and F. Azam, “Internet of things augmented a novel PSO-employed modified zeta converter-based photovoltaic maximum power tracking system: hardware realisation,” *IET Power Electronics*, vol. 13, no. 13, pp. 2775–2781, Oct. 2020, doi: 10.1049/iet-pel.2019.1121.
[16] M. A. Qasim and V. I. Velkin, “PWM effect on MPPT for hybrid PV solar and wind turbine generating systems at various loading conditions,” *Periodicals of Engineering and Natural Sciences*, vol. 9, no. 2, pp. 581–592, 2021, doi: 10.21533/pen.v9i2.1840.
[17] H. El-Askary, P. Kosmopoulos, and S. Kazadzis, *The Solar Atlas of Egypt*. 2018.
[18] A. H. Ali, A. S. Nada, and A. S. Shalaby, “Economical and efficient technique for a static localized maximum sun lux determination,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 10, no. 2, p. 777, Jun. 2019, doi: 10.11591/ijpeds.v10.i2.pp777-784.
[19] S. Manna *et al.*, “Design and implementation of a new adaptive MPPT controller for solar PV systems,” *Energy Reports*, vol. 9, pp. 1818–1829, Dec. 2023, doi: 10.1016/j.egyr.2022.12.152.
[20] A. I. M. Ali and H. R. A. Mohamed, “Improved P&O MPPT algorithm with efficient open-circuit voltage estimation for two-stage grid-integrated PV system under realistic solar radiation,” *International Journal of Electrical Power & Energy Systems*, vol. 137, p. 107805, May 2022, doi: 10.1016/j.ijepes.2021.107805.
[21] D. A. Jalindar and S. Tiwari, “A Modified Perturb & Observe Algorithm For Maximum Power Point Tracking With Zero Voltage Switching Buck Boost Converter in Photovoltaic System,” in *2018 2nd IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, Oct. 2018, pp. 337–342, doi: 10.1109/ICPEICES.2018.8897408.
[22] A. A. Elbaset, H. Ali, M. Abd-El Sattar, and M. Khaled, “Implementation of a modified perturb and observe maximum power point tracking algorithm for photovoltaic system using an embedded microcontroller,” *IET Renewable Power Generation*, vol. 10, no. 4, pp. 551–560, Apr. 2016, doi: 10.1049/iet-rpg.2015.0309.
[23] N. Wang, B. Li, Y. Duan, and S. Jia, “A multi-energy scheduling strategy for orderly charging and discharging of electric vehicles based on multi-objective particle swarm optimization,” *Sustainable Energy Technologies and Assessments*, vol. 44, p. 101037, Apr. 2021, doi: 10.1016/j.seta.2021.101037.
[24] Z. Xie and Z. Wu, “A flexible power point tracking algorithm for photovoltaic system under partial shading condition,” *Sustainable Energy Technologies and Assessments*, vol. 49, p. 101747, Feb. 2022, doi: 10.1016/j.seta.2021.101747.
[25] H. M. Seoudy, M. A. Saadeldin, and W. A. Mohamed, “Design and implementation of optimal controller for DFIG-WT using autonomous groups particle swarm optimization,” *International Journal of Power Electronics and Drive Systems*, vol. 13, no. 3, pp. 1813–1821, 2022, doi: 10.11591/ijpeds.v13.i3.pp1813-1821.

BIOGRAPHIES OF AUTHORS

Ahmed H. Ali is an assistant lecturer in Department of Telecommunication Engineering, Faculty of Engineering, Egyptian Russian University, Cairo, Egypt. He received his B.Eng. and M.Eng. degrees in Telecommunication Engineering and Electronics and Electrical Telecommunication Engineering from Egyptian Russian university and Al-Azhar University, Egypt, in 2012 and 2020 respectively. His research interests include the field of power electronics, embedded systems, control systems, smart systems, renewable energy sources, artificial intelligence, Internet of Things. He can be contacted at email: ahmed_hamdy0064@yahoo.com.

Raafat A. El-Kammar is a Professor in Computer Engineering Department, Faculty of Engineering (Shoubra), Benha University, Cairo, Egypt. He received the B.S., M.S., Ph.D. degrees in Electronics Engineering from Benha University, Cairo, Egypt. His research interests include the applications of Artificial Intelligence, sensor networks, neural network, Internet of Things. He can be contacted at email: rafat.alkmaar@feng.bu.edu.eg.

Hesham F. A. Hamed was born in Giza, Egypt, in 1966. He received the B.Sc. degree in electrical engineering, the M.Sc. and Ph.D. degrees in electronics and communications engineering from Minia University, EL-Minia, Egypt, in 1989, 1993, and 1997 respectively. He was the dean of faculty of engineering, Minia University. He was a Visiting Researcher at Ohio University, Athens, Ohio. From 1989 to 1993 he worked as a Teacher Assistant in the Electrical Engineering Department, Minia University. From 1993 to 1995 he was a visiting scholar at Cairo University, Cairo, Egypt. From 1995 to 1997 he was a visiting scholar at Texas A&M University, College Station, Texas (with the group of VLSI). From 1997 to 2003 he was an Assistant Professor in the Electrical Engineering Department, Minia University. From 2003 to 2005 he was Associate Professor in the same University. He is currently the dean of faculty of Artificial Intelligence, Russian University, Cairo. He has published more than 200 papers. His research interests include analog and mixed-mode circuit design, low voltage low power analog circuits, current mode circuits, nano- scale circuits design, FPGA, and applications of Artificial Intelligence. He can be contacted at email: hfah66@yahoo.com.

Adel A. Elbaset was born in Nag Hammadi, Qena, Egypt, in 1971. A. Elbaset is a Full Professor with the Faculty of Engineering at Minia University, Egypt. He received the B.S., M.Sc., and Ph.D. from Minia Universityin 1995, 2000, and 2006, respectively. Dr. A. Elbaset is also currently a Full Professor with the Faculty of Engineering at Heliopolis University where he also works as a Vice-Dean for Student Affairs and Head of the Department of Electromechanics. He has published over 120 technical papers with international journals and conferences and has supervised and examined more than 50 M.Sc. and Ph.D. theses at Minia and other Egyptian universities. His research interests are in the area of wind energy systems, photovoltaics, renewable energy systems, power electronics, power system protection and control, power quality and harmonics, and applications of neural networks and fuzzy systems. Dr. Adel has published 15 international books in the field of renewable energy. He can be contacted at email: adel.soliman@hu.edu.eg.

Aya Hossam is received the B.S., M.S., Ph.D. degrees in Electronics Engineering from Benha University, Cairo, Egypt in 2012, 2015 and 2019, respectively. She is currently an Assistant Professor with the Electrical Engineering Department, Benha University, Cairo, Egypt. Her research interests include IoT, signal processing, image processing, acoustic devices, sensor networks and AI. She received the Best Student award from the President, the Best Student award from the Minister of High Education, and the Best Engineer award from President of Egyptian Engineers Syndicate. She can be contacted at email: aya.ahmed@feng.bu.edu.eg.