Study of cuckoo search MPPT algorithm for standalone photovoltaic system

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ABSTRACT

The low operating and maintenance expenses of photovoltaic (PV) power generation make it a popular choice for rural power generation systems. Solar radiation, temperature, and load impedance are the major factors influencing the final output of solar PV. Consequently, the solar PV system experiences oscillations in its operation. These oscillations in the operating point pose a difficulty in transferring maximum power from the source to the load in an efficient way. A method called as "maximum power point tracking" is used to address this problem. This technique eliminates oscillations ensure that stability of operating point at the maximum power point. PV has several maximum power points (MPP) under partial shade situations, which is characterized by its non-linear features. As a result, it is challenging to find actual MPP. While tracking and collecting the maximum power from PV, the cuckoo search optimization (CSO) technique developed by biological intelligence is used in this article. The cuckoo search (CS) has several advantages, including a short tuning process that is efficient as well as fast convergence. The step-up converter steps up the voltage. In order to steady the converter, the counter variable is employed to provide delay. Resistive load is present.

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1. INTRODUCTION

Renewable energy is best source for producing power without affecting the environment, and it is a market trend that is expanding. Additionally, the market for solar energy expands in tandem with rising electricity consumption [1]. The biggest drawback of solar panels is their low efficiency when compared to other energy producing technologies. The majority of studies discovered that solar panels convert sunlight into electricity with an efficiency of about 30%. On the other hand, it may be expensive to add a different controller and device to increase that efficiency; therefore, we developed a maximum power point tracking (MPPT) technique that makes the most of the solar panel's potential [2]. The majority of cases demonstrate that the MPPT makes up for changes in the current and voltage properties of the solar board. More power can be supplied to the battery in the form of voltage and current thanks to MPPT. The amount of incoming solar energy and the cell's operating temperature has a significant impact on the photocurrent. The dc-dc step-up converter was recycled to adjust the duty cycle so as to modify the load and obtain the greatest power output from a photovoltaic (PV) module. Maximum power points (MPP) essentially search for the operational point in real time. The effectiveness of a photovoltaic solar system is increased by using the conventional MPPT methods under conditions of steady irradiation [3]. The primary weakness of these customary MPPT methods is their incapability to mitigate the oscillations of the operating point of photovoltaic system around “maximum power point” (MPP). The monitor depicts a shading phenomenon caused by the shadows cast by towering trees and tall buildings [4]. Urban areas witness an impact on performance, attributed to the solar PV's power generation dependence on solar irradiation and temperature. Furthermore, energy from highly irradiated PV panels disperses to those with lower irradiation levels, resulting in the conversion of electricity to heat. Consequently, the overall power output diminishes. This study employs a metaheuristic cuckoo search optimization (CSO) MPPT technique to tackle this issue [5].

The modeling of solar panels is briefly explored in section 2. Additionally, in sections 3, 4, and 5, respectively, the operation of the MPPT model followed by the “DC-DC converter” and the “MPPT controller” has been proposed in order to acquire the maximum power. In sections 6 and 7 detailed methodology of cuckoo Search MPPT techniques has been briefly presented. Section 6 contains a list of each method's experimental findings. Finally, the research for part 7 is complete.

2. MODELLING OF SOLAR PANEL

PV/solar cells are devices that directly convert solar light energy to electricity. Sunlight contains tiny energy particles called photons, which can be renewed into electrical energy. The photovoltaic effect is a term used to describe this occurrence [6]. When sunlight impacts a PV cell that is short-circuited, it generates charge carriers that initiate the flow of electric current. Series of parallel interconnection of multiple PV modules is used to form PV array. Each PV module comprises a collection of interconnected photovoltaic cells [7].

For modeling and control reasons, a photovoltaic panel model is essential. The producers of PV panels frequently do not provide all the information required regarding the panel. When a PV panel is operating at its “maximum power point” (MPP), it is most efficiently used. To do this, figuring out the MPP is crucial, which may be done using an appropriate tracking method like the MPPT algorithm. A buck or boost DC/DC converter frequently makes an MPPT's operation easier [8].

Employing a PV panel with a stable voltage and power reference, which in turn controls the duty cycle of the “DC/DC converter”, is an easy way to set up an MPPT. In order to maximize the solar electricity now accessible in settings that are continually changing, the MPPT of the photovoltaic system desires to be improved by a controller [9]. The analogous circuit of the photovoltaic cell is shown in Figure 1. PV panels have a response current of:

$$i_{pv} = I_{ph} - I_0\left[\exp\left(\frac{n_p v_{pv} + i_{pv} R_s}{n_s v_t}\right) - 1\right] - \frac{n_p v_{pv} + i_{pv} R_s}{R_{sh}} \tag{1}$$

The diode current equation is:

$$I_D = I_0\left[\exp\left(\frac{V_{pv} + i_{pv} R_s}{n_s v_t}\right) - 1\right] \tag{2}$$

The thermal generated voltage is $V_t = \frac{a k_b\, t}{q}$. R_s and R_{sh} stand for series and parallel resistance in the aforementioned equations; a represents diode-ideality factor; In a PV panel, n_s and n_p stand for the number of series and shunt cells, respectively; k_b represents Boltzmann’s constant and the charge of one electron is q.

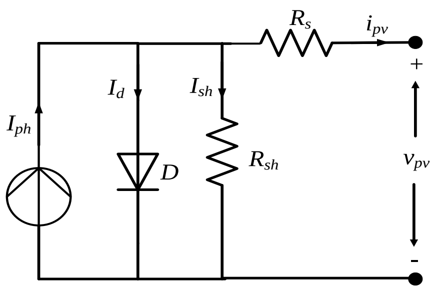

Figure 1. Schematic diagram of PV cell equivalents

3. DC-DC CONVERTER

Boost converters are DC-DC power converters that produce an output voltage boost. A step-up converter circuit using MOSFET switches is shown in Figure 2. Two operating modes are possible for it. When the boost inductor current ramps up, the transistor turns on, and the diode turns off, mode 1 is initiated [10].

The diode transmits the inductor's stored energy to the load. By altering the MOSFET's time for turning on or off, power flow can be managed. The i/p voltage and the o/p voltage are related by (3).

$$\frac{Vo}{Vi} = \frac{1}{1-D} \tag{3}$$

Here, Vi implies response voltage of the PV, Vo refers to the step-up converter's voltage, D indicates duty cycle, expressed by (4).

$$D = \frac{Ton}{T} \tag{4}$$

In this context, "Ton" refers to the duration during which the MOSFET is actively turned on, while "T" represents the total cycle period time. The transistor functions as a switch, being cycled on and off in accordance with a pulse width modulated (PWM) control signal [11]. PWM operates at a consistent frequency, with "T" remaining constant and "Ton" being subject to variation. Consequently, the duty cycle "D" can be adjusted anywhere between 0 and 1. Table 1 indicates the parameters of the DC-DC step-up converter.

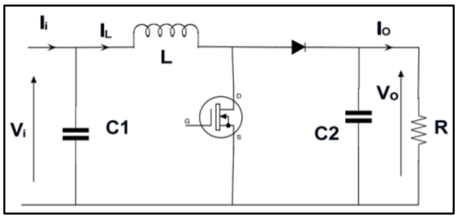

Figure 2. Boost converter circuit diagram

Table 1. Converter parameters

Parameter	value
Resistance "R"	50 Ω
Inductance "L"	120 µH
Capacitance "C"	330 µF
Capacitance "C1"	330 µF

4. MAXIMUM POWER POINT TRACKING

MPPT efficiently performs a real-time search for the operational position that generates the maximum quantity of electricity that can be collected from the solar array at any insolation grade. Discussion and simulation of five MPPT techniques will take place [12]. A comprehensive MPPT system is composed of four essential components: a controller, a pulse-width modulation generator, a comparator, and a DC/DC boost converter [13]. An MPPT system is formed by combining a DC-DC converter and an MPPT tracking algorithm. MPP tracking is the term assigned to this tracking procedure [9]. By adjusting the DC-DC converter's working point to the appropriate voltage and panel current at MPP, MPP can be monitored. MPP changes with the weather [14].

A "maximum power point tracking" mechanism is engaged in the middle of the photovoltaic panel and the load to optimize the produced PV power [15]. An MPPT system is conjured of a controller, a "DC-DC boost converter", a comparator, and a pulse-width modulation generator [16]. Due to the rapidly changing weather, it becomes necessary to alter the MPPT controller and algorithm [17] as shown in Figure 3.

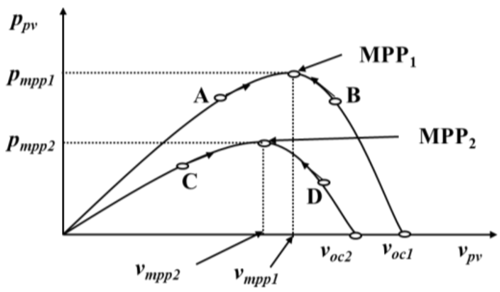

Figure 3. MPP differs with weather conditions

Figure 4 shows a DC-DC boost converter with a sliding mode MPPT controller. The MPPT controller tracks the maximum power point of the solar PV panel and provides a gate pulse to the PWM generator, which controls the duty cycle of the switch in the boost converter. The boost converter then increases the voltage from the solar panel to the desired output voltage.

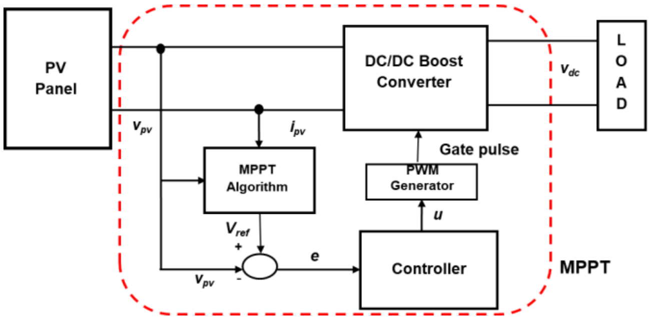

Figure 4. Block diagram of proposed model

5. CUCKOO SEARCH MPPT TRACKING

Due to ease of implementation, the cuckoo search optimization (CSO) exhibits numerous advantages. It efficiently handles nonlinear problems in real-time and operates with fewer tuning constraints, leading to rapid convergence [18]. Two cuckoo species, the Ani and Guira, utilize communal nests and occasionally introduce foreign eggs to enhance their hatching success [19]. Some cuckoo varieties engage in brood parasitism; for instance, the intelligent Tapera species imitates their host's appearance to maximize their reproductive success. The timing of egg-laying process of Tapera is truly remarkable. While host birds might be deceived into adopting foreign eggs, any identified alien eggs are either discarded or the whole nest is abandoned, prompting the host bird to establish a fresh nest elsewhere [20]. Brood parasitism can manifest in three forms: intraspecific, cooperative, and nest takeover. In this study, an approach involving MPPT utilizing the cuckoo search algorithm is familiarized [21]. The suggested method begins by initializing an initial solution for the PV panel's operating voltage, referred to as "Va," which is set to [0, 25, 0]. In the context of the CS process, "Va" represents the nest. Fitness value of the power is deliberated using the steps described in (5).

$$P_a = V_a \times I_a \tag{5}$$

The logic sequence of the cuckoo search algorithm is as follows:

- Step 1: Initiate population of n host nests, ß, k_{levy} , P_a , d^{min} , d^{max} and iter ^{max}. Taking i=1.
- Step 2: Measure the corresponding PV voltage and current after generating the duty cycle for the converter. Calculate PV power.
- Step 3: If i>n then Iter=1 proceed else take i=i+1 and goto step 2.
- Step 4: Specify dbset take i=1.
- Step 5: Update Levy flight and duty cycle.
- Step 6: If d_1 <d^{min} & d_1> d^{max} then continue else go to step 8.
- Step 7: Response the duty cycle di for converter and measure the corresponding PV voltage and current and find the PV power.
- Step 8: If i>n go to next step else i=i+1 go to step 5 and continue.
- Step 9: Find the worst next.
- Step 10: If rand >Pa abandon the worst nest and construct a new one using Levy fly at the new location then determine PV power.
- Step 11: If I_{ter}> $iter^{max}$ respond the duty cycle of d best else take iter=iter+1 and continue from step 4.
- Select a random nest, and then use a random walk to create a new solution after finding the best current.

$$V_i(t+1) = V_i(t) + \alpha \oplus L\acute{e}vy\ (\lambda) \tag{6}$$

A basic form of random movement is recycled, which is not as effective as levy flights. Moreover, to handle issues involving different scales, a step size vector is employed and is set at 0.05. After generating new solutions, the fitness values are re-evaluated, and the optimal choice is identified [22]. The MPPT algorithms, tracked by CS, compute a reference voltage termed "V_{ref}," which is created for each temperature and irradiation level [23]. The variance amongst Vref and the actual PV response voltage, known as "V_{pv}," is considered to yield the error voltage, Verror [24]. The proportional-integral-controller is chosen above the proportional or proportional-integral controller [25]. Though the trial-and-error approach is employed to tune the proportional-integral-derivative (PID) controller parameters, it doesn't guarantee precise calculation of controller coefficients.

6. SIMULINK MODEL

The entire system, as represented in Figure 5 is simulated using the MATLAB Simulink platform. To accurately trace the true maximum power point, the “cuckoo search (CS) algorithm” is employed, ensuring the optimal transfer of maximum power from the photovoltaic array to the load across diverse irradiation and shading scenarios. The graphical representation in Figures 6-11 illustrates the “current”, “voltage”, and “power” attributes of the photovoltaic module while applying the CS algorithm for maximum power point tracking (MPPT).

Table 2 outlines specifications for a photovoltaic module with 60 cells, having a maximum power output of 249 W. The module exhibits an open circuit voltage of 36.8 V, a voltage at the Maximum Power Point of 30 V, and a short circuit current of 8.83 A, providing key electrical parameters for understanding its performance in solar energy applications.

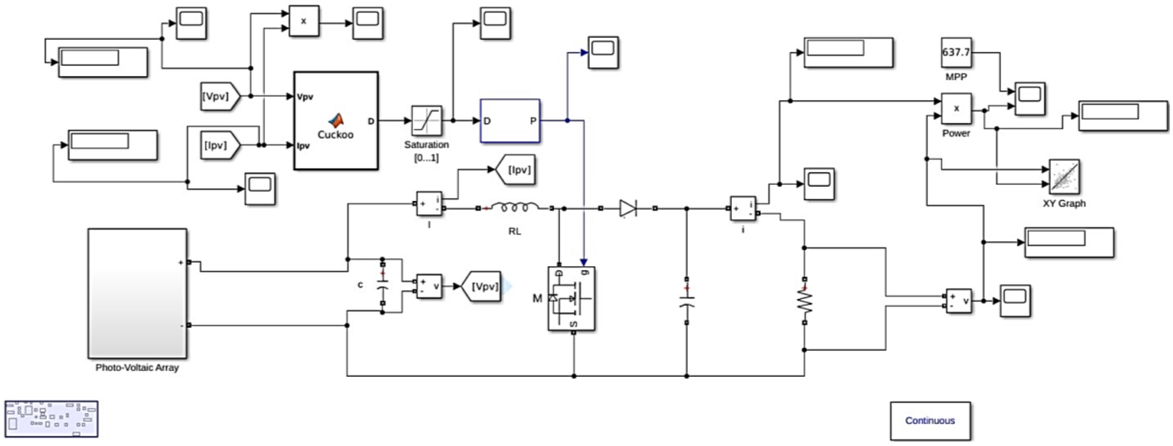

Figure 5. Simulink diagram of proposed model

Table 2. PV module specification

Parameter	Value	Parameter	Value
Cell per module	60	Voltage at MPP	30 V
Maximum power	249 W	Short circuit current	8.83 A
Open circuit voltage	36.8 V	Current at MPP	8.3 A

7. RESULTS

The figure below illustrates the input and output profiles of voltage, current, and power. The “current”, “voltage”, and “power” curve of a photovoltaic cell before a boost are seen in Figures 6-8. The “current”, “voltage”, and “power” curve of a photovoltaic cell following a boost converter are shown in Figures 9-11.

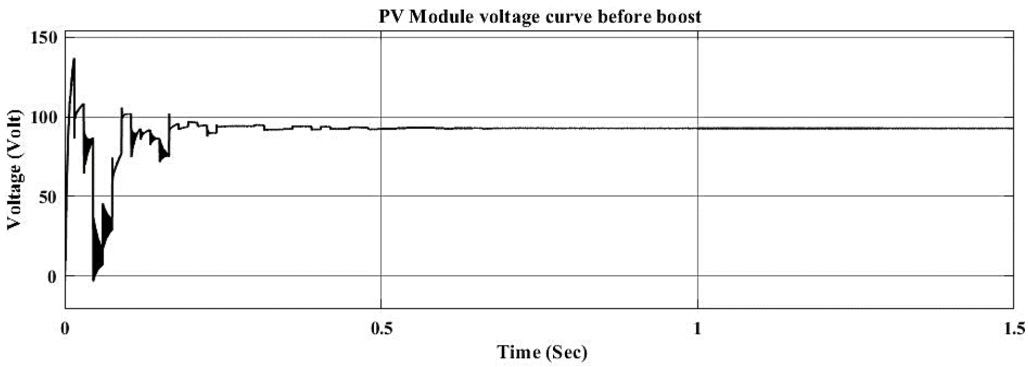

Figure 6. Input voltage v/s time characteristic

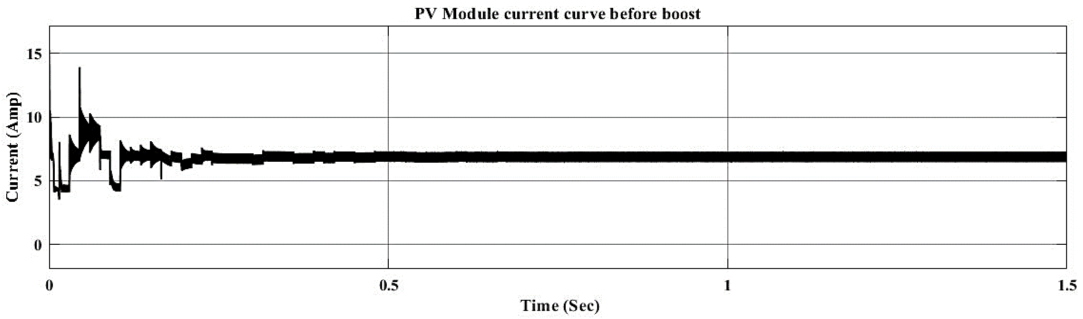

Figure 7. Input current v/s time characteristic

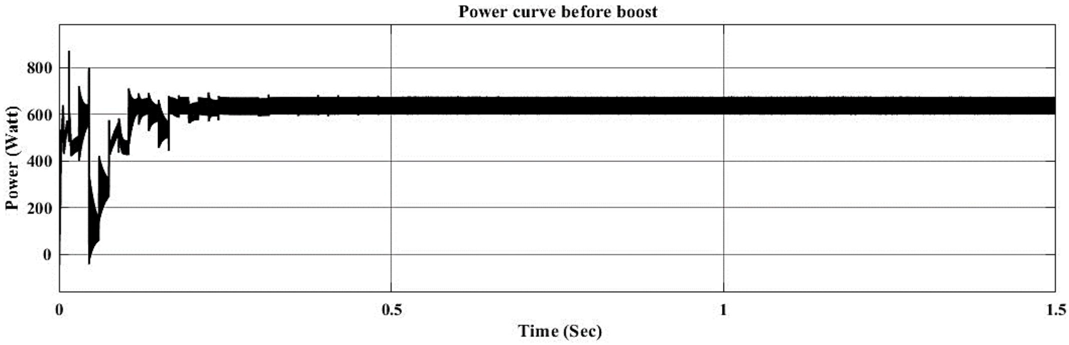

Figure 8. Input PV power - time characteristic

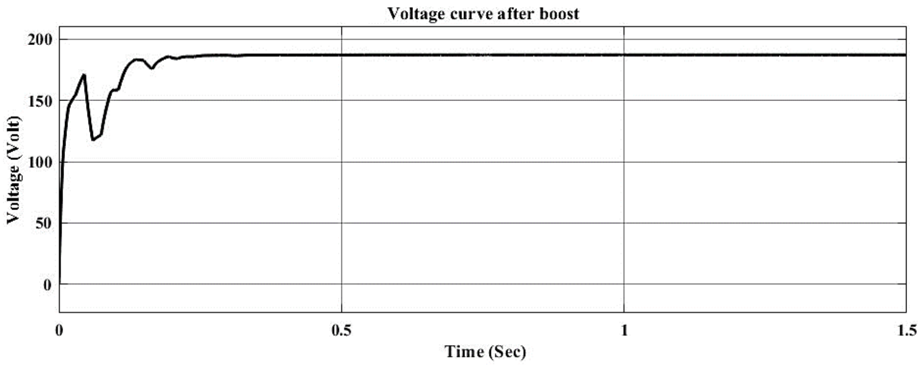

Figure 9. Output voltage v/s time characteristic

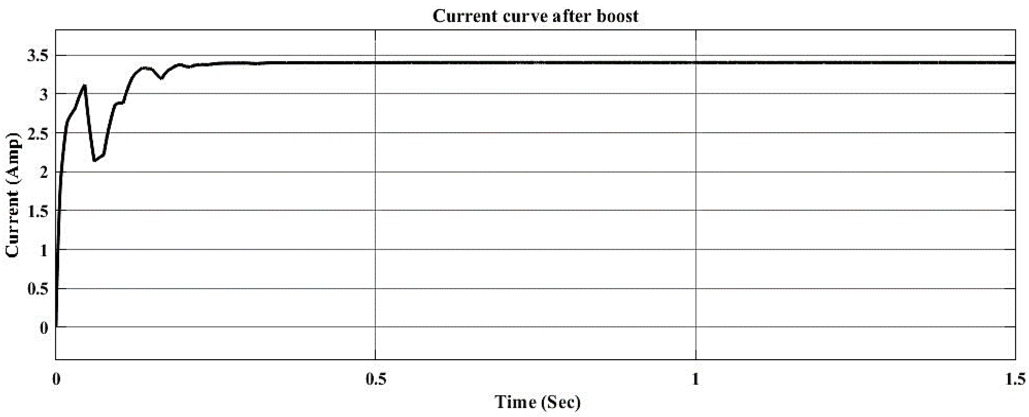

Figure 10. Response current - time characteristic

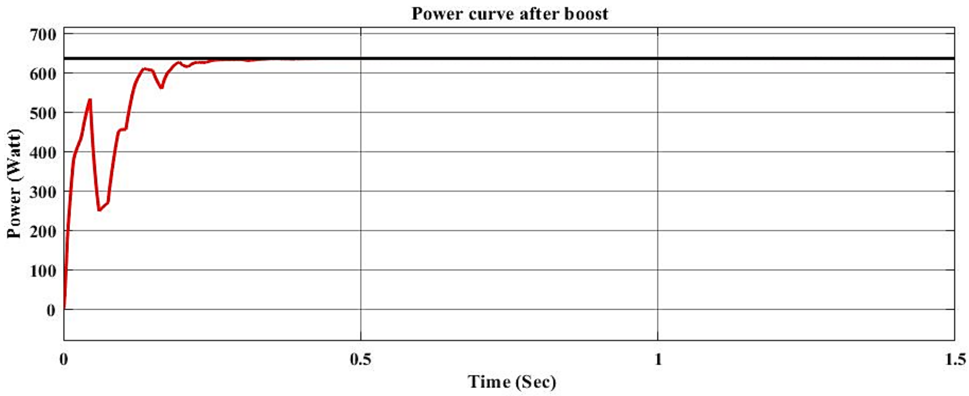

Figure 11. Response power - time characteristic

8. CONCLUSION

The MATLAB/Simulink software is utilized to simulate the cuckoo search (CS) optimization MPPT technique under partial shading conditions. The developed CS algorithm demonstrates remarkable efficiency in managing partial shading conditions (PSC) across various shading scenarios. On the other hand, the perturb and observe (P&O) algorithm demonstrates limitations when dealing with the impact of partial shading conditions on the solar panel. The outcomes further reveal that the CS-tracked power experiences minimal fluctuations in evaluation to the P&O algorithm, showcasing more consistent power output. Additionally, the progress of the CS algorithm is straightforward and exhibits reduced difficulty.

REFERENCES

[1] W. Xiao, M. G. J. Lind, W. G. Dunford, and A. Capel, "Real-time identification of optimal operating points in photovoltaic power systems," *IEEE Transactions on Industrial Electronics*, vol. 53, no. 4, pp. 1017–1026, Jun. 2006, doi: 10.1109/TIE.2006.878355.

[2] M. G. Villalva, J. R. Gazoli, and E. R. Filho, "Comprehensive approach to modeling and simulation of photovoltaic arrays," *IEEE Transactions on Power Electronics*, vol. 24, no. 5, pp. 1198–1208, May 2009, doi: 10.1109/TPEL.2009.2013862.

[3] A. F. Murtaza, H. A. Sher, F. Usman Khan, A. Nasir, and F. Spertino, "Efficient MPP tracking of photovoltaic (PV) array through modified boost converter with simple SMC voltage regulator," *IEEE Transactions on Sustainable Energy*, vol. 13, no. 3, pp. 1790–1801, Jul. 2022, doi: 10.1109/TSTE.2022.3172315.

[4] F. H. Aghdam and M. Abapour, "Reliability and cost analysis of multistage boost converters connected to PV panels," *IEEE Journal of Photovoltaics*, vol. 6, no. 4, pp. 981–989, Jul. 2016, doi: 10.1109/JPHOTOV.2016.2566885.

[5] V. K. Goyal and A. Shukla, "Isolated DC-DC boost converter for wide input voltage range and wide load range applications," *IEEE Transactions on Industrial Electronics*, vol. 68, no. 10, pp. 9527–9539, Oct. 2021, doi: 10.1109/TIE.2020.3029479.

[6] B. S. Revathi and M. Prabhakar, "Solar PV fed DC Microgrid: applications, converter selection, design and testing," *IEEE Access*, vol. 10, pp. 87227–87240, 2022, doi: 10.1109/ACCESS.2022.3199701.

[7] V. Salas, E. Olías, A. Barrado, and A. Lázaro, "Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems," *Solar Energy Materials and Solar Cells*, vol. 90, no. 11, pp. 1555–1578, Jul. 2006, doi: 10.1016/j.solmat.2005.10.023.

[8] B. Subudhi and R. Pradhan, "A comparative study on maximum power point tracking techniques for photovoltaic power systems," *IEEE Transactions on Sustainable Energy*, vol. 4, no. 1, pp. 89–98, Jan. 2013, doi: 10.1109/TSTE.2012.2202294.

[9] J. K. Sahu, B. Panda, J. P. Patra, and P. Sahoo, "Fuzzy logic based maximum power point tracking design," in *2022 4th International Conference on Smart Systems and Inventive Technology (ICSSIT)*, Jan. 2022, pp. 01–05, doi: 10.1109/icssit53264.2022.9716400.

[10] O. Trejo and A. Ortiz-Conde, "A simple algorithm for high-accuracy maximum power point calculation of photovoltaic systems," *IEEE Journal of Photovoltaics*, vol. 10, no. 6, pp. 1839–1845, Nov. 2020, doi: 10.1109/JPHOTOV.2020.3022668.

[11] J. K. Sahu, B. Panda, and J. P. Patra, "Artificial neural network for maximum power point tracking used in solar photovoltaic system," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 14, no. 3, pp. 1694–1701, Sep. 2023, doi: 10.11591/ijpeds.v14.i3.pp1694-1701.

[12] J. K. Sahu, B. Panda, S. Sahu, and J. P. Patra, "Harmonics estimation of a standalone PV system integrated with a modified SPWM inverter," in *Proceedings of the 3rd International Conference on Smart Systems and Inventive Technology, ICSSIT 2020*, Aug. 2020, pp. 654–656, doi: 10.1109/ICSSIT48917.2020.9214186.

[13] A. Costa De Souza, F. Cardoso Melo, T. Lima Oliveira, and C. Eduardo Tavares, "Performance analysis of the computational implementation of a simplified PV model and MPPT algorithm," *IEEE Latin America Transactions*, vol. 14, no. 2, pp. 792–798, Feb. 2016, doi: 10.1109/TLA.2016.7437224.

[14] M. Etezadinejad, B. Asaei, S. Farhangi, and A. Anvari-Moghaddam, "An improved and fast MPPT algorithm for PV systems under partially shaded conditions," *IEEE Transactions on Sustainable Energy*, vol. 13, no. 2, pp. 732–742, Apr. 2022, doi: 10.1109/TSTE.2021.3130827.

[15] S. K. Mishra, J. K. Sahu, and T. M. P. C. Reddy, "MPPT for a solar PV Array: ANN and P&O comparison," in *3rd IEEE International Conference on Technology, Engineering, Management for Societal Impact using Marketing, Entrepreneurship and Talent, TEMSMET 2023*, Feb. 2023, pp. 1–6, doi: 10.1109/TEMSMET56707.2023.10150165.

[16] K. Chen, S. Tian, Y. Cheng, and L. Bai, "An improved MPPT controller for photovoltaic system under partial shading condition," *IEEE Transactions on Sustainable Energy*, vol. 5, no. 3, pp. 978–985, Jul. 2014, doi: 10.1109/TSTE.2014.2315653.

[17] K. Y. Yap, C. R. Sarimuthu, and J. M. Y. Lim, "Grid integration of solar photovoltaic system using machine learning-based virtual inertia synthetization in synchronverter," *IEEE Access*, vol. 8, pp. 49961–49976, 2020, doi: 10.1109/ACCESS.2020.2980187.
[18] M. I. Mosaad, M. Osama abed el-Raouf, M. A. Al-Ahmar, and F. A. Banakher, "Maximum power point tracking of PV system based cuckoo search algorithm; review and comparison," *Energy Procedia*, vol. 162, pp. 117–126, Apr. 2019, doi: 10.1016/j.egypro.2019.04.013.
[19] C. Hussaian Basha, V. Bansal, C. Rani, R. M. Brisilla, and S. Odofin, "Development of Cuckoo Search MPPT Algorithm for Partially Shaded Solar PV SEPIC Converter," in *Advances in Intelligent Systems and Computing*, 2020, vol. 1048, pp. 727–736, doi: 10.1007/978-981-15-0035-0_59.
[20] A. Ibrahim, R. Aboelsaud, and S. Obukhov, "Maximum power point tracking of partially shading PV system using cuckoo search algorithm," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 10, no. 2, pp. 1081–1089, Jun. 2019, doi: 10.11591/ijpeds.v10.i2.pp1081-1089.
[21] Z. B. Hadj Salah *et al.*, "A New Efficient Cuckoo Search MPPT Algorithm Based on a Super-Twisting Sliding Mode Controller for Partially Shaded Standalone Photovoltaic System," *Sustainability*, vol. 15, no. 12, p. 9753, Jun. 2023, doi: 10.3390/su15129753.
[22] A. M. Eltamaly, "An improved cuckoo search algorithm for maximum power point tracking of photovoltaic systems under partial shading conditions," *Energies*, vol. 14, no. 4, 2021, doi: 10.3390/en14040953.
[23] E. M. Ali, A. K. Abdelsalam, K. H. Youssef, and A. A. Hossam-Eldin, "An enhanced cuckoo search algorithm fitting for photovoltaic systems' global maximum power point tracking under partial shading conditions," *Energies*, vol. 14, no. 21, p. 7210, Nov. 2021, doi: 10.3390/en14217210.
[24] M. Elzalik, T. A. Enany, M. Said, and A. Y. Hassan, "Comparison between Cuckoo Search algorithm and Grey Wolf Optimizer Algorithm on Photovoltaic Models Performance," in *2022 23rd International Middle East Power Systems Conference, MEPCON 2022*, Dec. 2022, pp. 01–05, doi: 10.1109/MEPCON55441.2022.10021814.
[25] I. A. Hasan, M. Jawad, and B. Abdullah, "Characteristics Performance Prediction of PV Panel Using Cuckoo Search Algorithm," *IOP Conference Series: Materials Science and Engineering*, vol. 518, no. 3, p. 032033, May 2019, doi: 10.1088/1757-899X/518/3/032033.

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