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ORIGINAL RESEARCH ARTICLE

A novel Prairie Dog Optimization Algorithm (PDOA) based MPPT controlling mechanism for grid-PV systems

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ABSTRACT

Recently, the solar photovoltaic (PV) systems are increasingly used in many application systems, due to their efficiency and cost-effectiveness. Still, extracting the maximum energy from PV panels under varying climatic conditions is one of the most significant problems. For this purpose, various optimization based MPPT controlling mechanisms are developed in the conventional works for obtaining the maximum energy yield. However, it suffers with the major problems of low convergence, computational burden, high time consumption to reach the optimal solution, and lack of efficiency. Therefore, this research work objects to implement a novel and recently developed optimization technique, named as, Prairie Dog Optimization Algorithm (PDOA) for MPPT controlling. With superior tracking efficiency and enhanced speed, it helps to extract the greatest power from the PV panels. In order to manage the output of PV with less switching stress and loss, a high gain interleaved SEPIC DC-DC converter is also used. A better power quality is ensured by using the voltage source inverter to lower harmonic distortion levels. The significance of the proposed study is to develop a novel optimization based MPPT controlling technique to obtain the maximum energy yield form the PV panels. The PDOA technique is not previously used for power extraction and MPP tracking, due to its intelligent best optimum solutions with high convergence, the proposed work uses the PDOA technique to optimally identify MPP. Also, the voltage boosting and conversion is performed with the use of high gain interleaved SEPIC converter with increased efficiency. Performance study evaluates and compares the simulation outcomes and the efficacy of the suggested regulating topology using a variety of metrics, including IV & PV characteristics, output voltage, output power, THD, grid output, peak time, settling time, and others.

Keyword: solar photovoltaic (PV); renewable energy sources (RES); Prairie Dog Optimization Algorithm (PDOA); maximum power point tracking (MPPT); high-gain interleaved SEPIC DC-DC converter; power quality; grid systems

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1. Introduction

Electrical energy consumption has substantially increased as a result of the tremendous rise in world population[1,2]. By utilizing and implementing renewable energy can help to solve one of the issues that the global community is dealing with. This concept coupled with the rapid development of renewable sources has steered power electronics makers and producers towards the design, implementation, and maximum utilization of renewable energy sources (RES)[3,4]. Given that the usage of fossil fuels is no longer sufficient, solar energy has the greatest potential of all the renewable energy sources. Regulations that support photovoltaic (PV), which harnesses the energy of the sun to create light and power, as well as a recent, dramatic drop in price, are causing its use to expand quickly. Almost all parts of the world have tremendous long-term growth potential for this trustworthy, commercially available technology[5]. However, because of the non-linear nature of solar irradiation and periodic weather variations, solar power generation varies greatly, requiring the usage of a combination of both primary sources and batteries[6–8]. A crucial element in the fluctuation and losses of PV power generation is the low correlation of solar irradiance between nearby places over short time scales.

Additionally, PV has several substantial disadvantages, such as a high initial installation cost and insufficient energy production—only 12% to 25% of solar radiation is transformed into electricity—as well as other disadvantages. Researchers have looked at methods like using maximum power point tracking (MPPT)[9–11] sensors or printed thin solar cells to boost the overall amount of electric energy produced. One of the most important components of a PV system[12] is the MPPT controller, which maximizes power production and, as a result, the overall efficiency of the PV module. The output efficiency of a PV system is typically impacted by a number of internal and external factors, such as solar radiation, the surface and inner temperatures of PV arrays, shadow, dirt, and others. The aforementioned internal and external circumstances necessitate an effective MPPT[13–15], which can improve both the output efficiency of the power converter and the MPPT tracking speed.

Solar irradiance and temperature levels[16–18] are utilized to determine the PV module power output and voltage in order to maximize the power from the PV system utilizing MPPT techniques.

According to the literature, solar cells' non-linear properties reduce their conversion efficiency. Therefore, it is necessary to use all of the PV module's available power. Additionally, a PV module does not constantly provide power due to numerous factors including temperature, irradiance, geographic conditions, and other factors. The global maximum power point (GMPP), which fluctuates with temperature and solar irradiation, is the best point on the P-V curve of any solar module. At that point, the PV module generates the most power. MPPT procedures are used to verify that the PV module is always running at GMPP. Any solar controller that uses MPPT techniques will combine power electronics hardware with software to implement these algorithms. These algorithms help to guarantee that the solar array's output is always at its highest level. In order to find the best operational power point from a solar array, MPPT approaches carry out this analysis using an uninterrupted power tracking method[19]. Tracking this power is essential for optimum solar energy utilization because the maximum power of a solar array changes depending on numerous climatic factors. The MPPT system's objective is to sample the PV array's output and apply the appropriate resistance to produce the greatest amount of electricity under any given environmental conditions. By changing the duty cycle of the DC-DC converter, these approaches act as an impedance matching device between the PV panel and demand. The advantages of using the optimized MPPT controlling are given below:

- Greater capacity to optimize the variations in voltage.
- It works best for larger systems where the solar panel output significantly surpasses the battery voltage.
- It increases the system's output and thus its capacity.

The selection of a particular MPPT strategy is still up for discussion. As a result, there is an urgent need to continually research and evaluate the techniques that have been created, as doing so will enable the appropriate technique to be chosen depending on the situation[20]. This article reviews and compares various traditional and AI-based meta-heuristic MPPT algorithms based on a range of variables like monitor time, complexity, fluctuations around GMPP, installation cost, and more. Moreover, a DC/DC converter[21–24] and an embedded electrical system with a control algorithm make up an MPPT device. In order to harvest the most energy possible under all conceivable climatic and operational conditions, it is integrated into all PV installations. To get the most energy out of the solar panels, several optimization-based MPPT controlling techniques have been devised in the published studies[25–29]. However, it has problems with poor power production, high power loss, increased harmonic distortions, and bad power quality[30–33]. In order to get the most energy out of the PV panels, the proposed work aims to provide a unique optimization-based MPPT regulating algorithm. The major objectives of this work are as follows:

- A new Prairie Dog Optimization Algorithm (PDOA)-MPPT technique is used to maximize energy yield from PV under various irradiance and temperature circumstances.
- An innovative high-gain interleaved SEPIC DC-DC converter is used to manage the output voltage of PV panels based on the regulating signals produced by PDOA.
- The voltage source inverter has been utilized to enhance the quality of electricity with lower total harmonic distortions provided to the grid system.
- For performance evaluation, a thorough simulation study is conducted in order to validate the power tracking performance and effectiveness of the suggested PDOA based MPPT regulating technique.

Furthermore, this research is innovative in the following ways:

- Better representation: It incorporates the characteristics of a novel intelligent optimization algorithm for power tracking.
- Low computational burden: The mathematical computations performed in this study are not complex.
- Optimized performance: It effectively optimizes the grid load with an advanced electrical component.

The remaining sections of this manuscript are divided into the following groups: Section 2 provides a full review of the MPPT controlling techniques now employed in grid-PV systems, along with a discussion of their advantages and disadvantages. In Section 3, a detailed explanation of the suggested technique is given along with a schematic illustration. The simulation results and comparative evaluation of the proposed PDOA-MPPT technique are presented in Section 4. Section 5 includes an evaluation of the results and the future direction of the research.

2. Literature review

To attain most energy from solar panels, the current MPPT regulating techniques based on optimization are covered in-depth in this part. Additionally, based on the tracking effectiveness and energy production of each controlling mechanism, it examines the advantages and disadvantages of each.

Ali, et al.[19] conducted a thorough analysis to confirm the effectiveness of several MPPT controlling mechanisms across a range of solar irradiation circumstances. It includes many techniques such as ripple correlation, slide control, and hill climbing from Perturb and Observe (P&O), Incremental Conductance (INC). Awan, et al.[34] intended to get the most power out of the solar PV systems by using an Optimized Ten Check Algorithm (OTCA)-based MPPT regulating algorithm. Here, the PV panel output voltage has been raised in this case with the help of a boost DC-DC converter. The major goal of this work is to create a highly effective MPPT controlling model that is based on optimization and has a low computational and structural complexity. However, it is extremely difficult to deploy and has a longer settling time as its main issues.

Yap, et al.[35] presented a thorough overview of the various MPPT approaches based on Artificial Intelligence (AI) that are utilized to extract power from solar PV installations. When compared to conventional MPPT techniques, the AI-based MPPT algorithms all have quick convergence times, minimal steady-state oscillation, and excellent efficiency. Hai, et al.[36] utilized a farmland fertility optimization algorithm for improving the maximum power extraction of grid-PV systems. Here, the output power efficiency of PV systems was also improved using fuzzy logic control logic. Additionally, the recommended regulating technique's dependability and power tracking capability were evaluated in terms of tracking time, accuracy, and voltage oscillations. Ebrahim, et al.[37] developed a whale inspired optimization technique for tuning the gain parameters of fractional order Proportional Integral (PI) controller. In this work, the performance of the P&O, INC, PI, and Fractional Order Proportional Integral (FOPI) regulating approaches was compared based on the steady state response, settling time, rising time, and overshoot characteristics. According to this study, the FOPI controlling technique performs better than other controllers with a lower time and error rate. Padmanaban, et al.[38] employed a modified sine-cosine optimization algorithm for enhancing the power tracking rate of MPPT. Here, the primary factors of using the sine-cosine algorithm are easy deployment, high convergence, and less burden. Additionally, the output voltage of PV panels can be increased using the Zeta-DC-DC converter. The non-linearity control was then minimized using an adaptive fuzzy based sliding mode control. The main benefit of this method is its ability to measure maximum power under changing environmental circumstances. It was important to lower the error rate in order to guarantee a greater performance rate. Tchaya, et al.[39] deployed an improved P&O MPPT controlling technique incorporated with parallel active filter for improving the power tracking performance of grid-PV systems. Its oscillations occur around the MPP; small amplitude variations decrease the oscillation but result in a somewhat slower MPPT. The reference voltage is set to a portion of the open-circuit voltage to periodically verify the variation of solar irradiance because the open-circuit voltage is impacted by variations in temperature and irradiance. Moreover, it used a seven-level inverter for effectively reducing the THD with reduced number of switches. Still, it required to minimize the complexity, time and error rate by implementing an advanced optimization technique.

Guo, et al.[40] used a dependable second order sliding model regulating technique to improve the MPPT's tracking accuracy and efficiency. Using the standard Particle Swarm Optimization (PSO) method, the optimal parameters for the LC filtering circuit are derived in this case. The key benefits of this controlling method are its low cost and improved efficiency. Kim, et al.[41] deployed an optimization based fuzzy controlling technique for tracking the maximum possible solar energy from the PV panels under different operating conditions. Here, the controlling performance of the MPPT technique is determined according to the rule base of fuzzy logic. In order to track the energy from PV panels, Ge et al.[42] presented a BAT integrated fuzzy approach for determining the best MPPT settings. The goal of this effort is to extract the most power possible under various partial shade scenarios. Sibtain, et al.[43] used an Ant Colony Optimization (ACO) integrated P&O algorithm to increase the output of power from freestanding grid-PV installations. The objective of this study was to increase the controller's resilience and stability. Here, the optimal ACO algorithm solution is used to construct the PID controller's ideal parameters. The P&O MPPT method is then used to draw the most electrical energy feasible from the PV panels. Consequently, the voltage gain was improved by utilizing the boost DC-DC converter. Kerid, et al.[44] intended to improve grid-PV system power tracking efficiency, an IC MPPT regulating approach based on Extended Kalman Filtering (EKF). The key benefits of this controlling method are its ease of development, robustness, and improved system performance. Additionally, this controlling method's output voltage, current, and capacitor voltage were verified. Nevertheless, it has unique problems such poor convergence, an inability to operate in a variety of operating settings, and inefficiency. **Table 1** contrasts the conventional MPPT approaches using criteria for monitoring speed, accuracy, and efficiency.

This review of the literature reveals that the current studies strongly emphasize developing integrated MPPT optimization controlling approaches for improving the grid-PV systems' performance at power tracking. Typically, the AI optimization based MPPT techniques help to overcome the following problems:

- Absence of resilient, dynamic, and self-learning abilities.
- High steady-state error.
- High oscillation in power extraction.
- Delayed transient response.

As a result, the proposed work aims to design a unique MPPT regulating technique for grid-PV systems based on optimization.

Table 1. Comparative analysis among the existing MPPT techniques.

Techniques	Tracking speed	Tracking accuracy	Efficiency
P&O–GA	Very fast	Very high	High
P&O–PSO	Very fast	Very high	High
INC–PSO	Very fast	High	Very high
Hybrid GWO-FLC	Very fast	Very high	High
ANFIS–hill climbing	Fast	High	High
Modified HC-FLC	Fast	High	High
ANN–PSO	Very fast	Very high	Very high
Fractional short circuit current measurement-P&O	Very fast	Very high	High
Modified fractional open circuit voltage	Very fast	Very high	High
INC-simply moving voltage average	Very fast	Very high	Very high

3. Proposed methodology

The unique optimization-based MPPT controlling technique that is proposed and applied in grid-PV systems is explained in great length in this section. The primary accomplishment of this work is the creation of a novel Prairie Dog Optimization Algorithm (PDOA)-based MPPT regulating technique for maximizing PV panel output under diverse irradiance and temperature circumstances. The suggested model's main schematic is depicted in **Figure 1**, and it includes the following functional modules:

- PV panel design.
- PDOA-MPPT controlling.
- Voltage conversion using high gain interleaved DC-DC converter.
- Voltage Source Inverter (VSI).

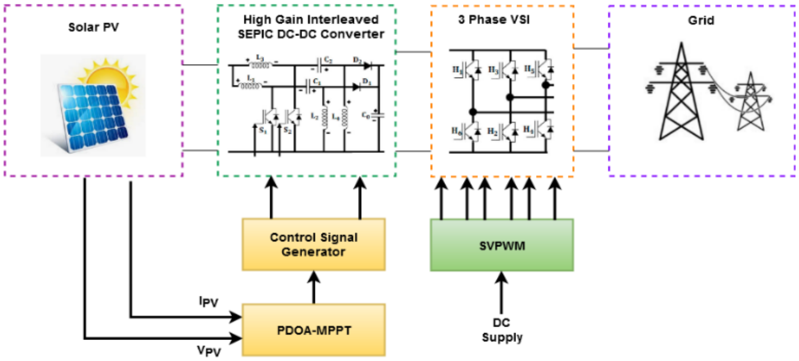


Figure 1. Schematic illustration of the proposed framework.

As shown in **Figure 1**, the solar PV is used as the main energy source, where the maximum peak point is estimated by using the PDOA-MPPT controlling technique. It helps to gain increased electrical energy from the PV panels. After that, the output voltage of PV is improved with proper regulation and boosting operation by using the high gain interleaved SEPIC converter. Then, the DC-AC conversion is performed with the use of three phase voltage source inverter, where the switches are actuated according to the switching pulses generated by the Support Vector Pulse Width Modulation (SVPWM) controlling technique. It also helps to improve the power quality output with reduced harmonics, and the final output is fed to the grid systems. In the previous optimization + MPPT controlling techniques, the GMPP is estimated for power tracking with complex mathematical operations, high time consumption, and error outputs. But, in the proposed model the PDOA could effectively resolve the problems with better performance results in terms of high output power, reduced THD, increased efficiency, and lower time consumption.

3.1. PV system modeling

The PV system modelling is carried out inside this framework, and the following model is used to estimate the current flow of the circuit I:

$$I = I_{pv} - I_s \left[\exp\left(\frac{eR_T}{akT} \right) - 1 \right] \tag{1}$$

Where, I_{pv} stands for photovoltaic current, I_s for leakage current through a series resistance, e for electron charge, T for diode temperature, R_T for thermal resistance, and k for Boltzmann constant. Similar to that, the cell's PV current flow is predicted using the following model:

$$I = I_{pv} - I_d - I_{sh} \tag{2}$$

Where, I_{sh} denotes the shunt current, and I_d represents the diode current. The operational point of PV is determined based on the total current generation of PV cells in accordance with the design parameters. Here, the operating and reference temperatures can be used to derive the reserved saturation current I_{rs}, which is adjusted in relation to temperature as calculated below:

$$I_s = I_{rs} \left(\frac{T_{op}}{T_{ref}} \right)^3 e^{\left[\frac{q}{nk} \left(\frac{1}{T_{op}} - \frac{1}{T_{ref}} \right) \right]} \tag{3}$$

Where, T_{ref} stands for the reference temperature at the rated value and T_{op} for the temperature at the operational point. **Figure 2** depicts the PV cell's equivalent circuit model, where power generation is done in relation to the amount of solar radiation[45].

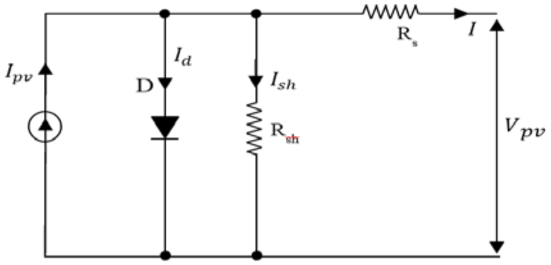


Figure 2. Equivalent circuit model of PV system.

3.2. PDOA-MPPT

An innovative and recently developed optimization technique called PDOA[46] is used after modelling the PV system to discover the highest power point as efficiently as possible and maximize the energy yield from the PV panels. In order to get the most energy out of solar systems, optimization-based MPPT regulating techniques are now frequently used in PV application systems. Various optimization methods, including Firefly (FF), Swarm Intelligence (SI), Bee Colony (BC), Jelly Fish (JF), and other meta-heuristics, are currently in use. However, the majority of optimization approaches suffer from significant computational burden, complexity, low convergence rates, slow processing speeds, long search times for the best solutions, and high iteration costs. As a result, the suggested method opposes the use of a novel, recently developed PDOA for MPPT controlling. Generally speaking, it is a type of meta-heuristic optimization algorithm that takes its cues from nature and mimics the behavior of prairie dogs. Finding the optimal solution to the given problem within the parameters and objectives specified is the goal of optimization. The characteristics of optimization problems that cannot be solved in a way that minimizes time or accuracy difficulty using conventional classical methods include unknown search areas, quasi parameter sets, large dimensions, and many other properties.

The recommended method carries out optimization by simulating the motions of four prairie dogs. The prairie dog's feeding and burrow-building habits are utilized to research the field of optimization problems. The prairie dogs build their burrows out of a plentiful food source. As the current food source runs out, the colony or troubled region is searched for new food or remedies. They create new tunnels around each new food source they come across. In this case, the goal is achieved by comparing the responses of the prairie dogs to two distinct alert or communication noises. The sounds or signals that prairie dogs make or release depend on whether a predator is nearby or whether there is food available. Prairie dogs' exceptional communication skills enable them to achieve their nutritional requirements and defend themselves from predators.

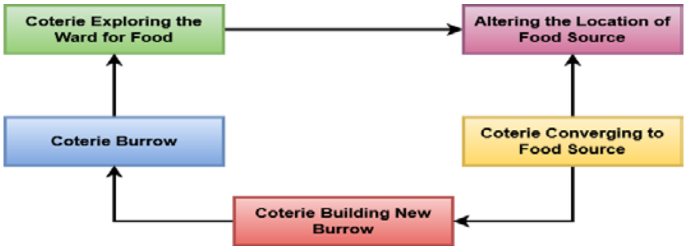


Figure 3. Exploration phase of PDOA.

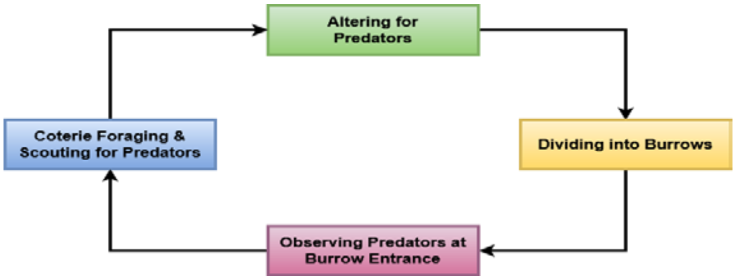


Figure 4. Exploitation phase of PDOA.

These two different tendencies cause the prairie dogs to congregate at a specific location or a promising site. The individual components go from one food source to another to start the optimization process. However, the prairie dogs do occasionally eat plants and insects. Additionally, they move around during the seasons, often eating grasses, small grains, and specific insects while searching for issues. Like other population-based algorithms, the PDOA uses a random initialization for the position of the prairie dogs. Using a vector in d-dimensional space to characterize each prairie dog's location, the populations of these mammal's act as search agents. Additionally, **Figure 3** provides a graphic illustration of this algorithm's exploration and exploitation skills. The parameter initialization, fitness assessment, exploration, exploitation, and selection of the best possible solution are the operational phases of the PDOA.

Algorithm I PDOA-MPPT controlling

```
Input:     Solar irradiance, temperature, and duty cycle;
Output:    Optimal solution for MPP;
Step 1:    Parameter initialization;
             1)  Optimization parameters such as $x, y, \delta, \beta$;
             2)  Initialize global best and current best solution $G_B$ and $C_B$ as $\emptyset$ respectively;
             3)  Initialize the candidate solutions of all coteries and prairie dogs as $P$ & $Q$;
Step 2:    While $it < Mx_{it}$ do
             For $(i = 1\ to\ y)$ do
                 For $(j = 1\ to\ x)$ do
Step 3:    Find the best fitness values of the prairie dogs;
Step 4:    Update the global best function $G_B$;
Step 5:    Update the randomized cumulative effect $CE_{i,j}$ based on the following model:
           $CE_{i,j} = \frac{G_{Bi,j} - r\alpha_{i,j}}{G_{Bi,j} + \Delta}$          (4)
Where, $r$ is the random number, $\alpha_{i,j}$ represents the i^th prairie dog at j^th dimension;
Step 6:    The digging strength of coterie is estimated according to the quality of food source and random value.
Step 7:    $\alpha_{i+1,j+1} = G_{Bi,j} \times \varepsilon \times rnd \forall 3\frac{Mx_{it}}{4} \le it \le Mx_{it}$          (5)
Where, $\varepsilon$ indicates the effect of predator, and $rnd$ is the random number.
Step 8:    if $\left(it < \frac{Mx_{it}}{4}\right)$ then //foraging activities
           $\alpha_{i+1,j+1} = G_{Bi,j} - eC_{Bi,j} \times \omega - CE_{i,j} \times Levy\ (y)$;          (6)
Where, $\omega$ indicates the specialized food source;
Step 9:    Else if $\left(\frac{Mx_{it}}{4} \le it < \frac{Mx_{it}}{2}\right)$ then //Burrowing activities;
           $\alpha_{i+1,j+1} = G_{Bi,j} \times eC_{Bi,j} \times Q \times Levy\ (y)$;          (7)
Where, $Q$ indicates the digging strength;
Step 10:   Else if $\left(\frac{Mx_{it}}{2} \le it < 3\frac{Mx_{it}}{4}\right)$ then //Food Alarm;
           $\alpha_{i+1,j+1} = G_{Bi,j} \times eC_{Bi,j} \times \sigma - CE_{i,j} \times rnd$;          (8)
Where, $\sigma$ indicates the
Step 11:   Else //Anti-predation alarm
           $\alpha_{i+1,j+1} = G_{Bi,j} \times P \times rnd$;          (9)
       End if;
                 End for;
             End for;
Step 12:   $it = it + 1$;
Step 13:   End while;
Step 14:   Return best solution $G_B$;
Step 15:   End;
```

By using the best solution, the maximum peak point is identified for obtaining the maximum possible energy from the PV panels. The flow of the PDOA technique is shown in **Figure 5**.

3.3. High gain interleaved SEPIC DC-DC converter

The high gain interleaved SEPIC DC-DC converter is used to control the output voltage of PV after the power is extracted using the PDOA-MPPT approach. Different DC-DC converter types, including flyback, boost, and zeta, have been utilized in traditional grid-PV systems to regulate voltage. However, it significantly limits with the major problems of high voltage stress, low conversion efficiency, and complex switching control. As a result, the proposed study aims to enhance grid-PV system performance by utilizing an enhanced high gain interleaved SEPIC converter. Additionally, it has the crucial advantages of low conduction loss, low voltage stress, and simple operation. The equivalent circuit model and generated switching pulses of the converter are depicted in **Figure 5** and **Figure 6** respectively.

Figure 5. Flow of PDOA.

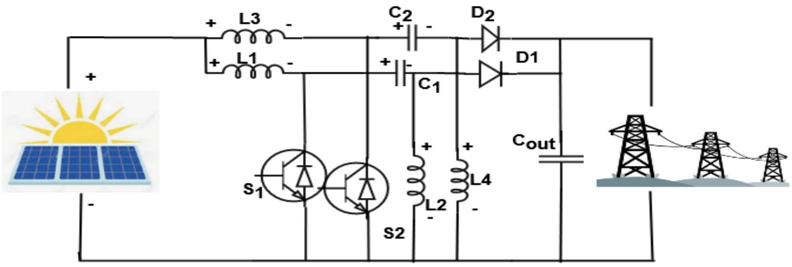


Figure 5. Equivalent circuit model of high gain interleaved SEPIC DC-DC converter.

Furthermore, depending on the PWM duty cycle, this converter can run in both buck and boost modes. The following model is used to define the converter’s final output voltage:

$$V_{DC} = \frac{D\times V_{DC}}{1-D} \qquad (10)$$

Where, V_{DC} indicates the output DC voltage, and D is the duty cycle. In this model, the ripple current is reduced to the maximum with the use of inductor and is defined as shown in below:

$$\Delta I_L = I_O \times \frac{(V_O \times 40\%)}{V_{PV}(min)} \qquad (11)$$

Consequently, the RMS value of current is computed based on the following model:

$$I_{CO}(RMS) = I_O\sqrt{\frac{V_{DC}+V_D}{V_{PC(min)}}} \qquad (12)$$

Moreover, the output capacitance of the converter is estimated as shown in below:

$$I_{Cin}(RMS) = \Delta I_L/\sqrt{2} \qquad (13)$$

By using this converter, the output voltage is highly increased with reduced switching loss.

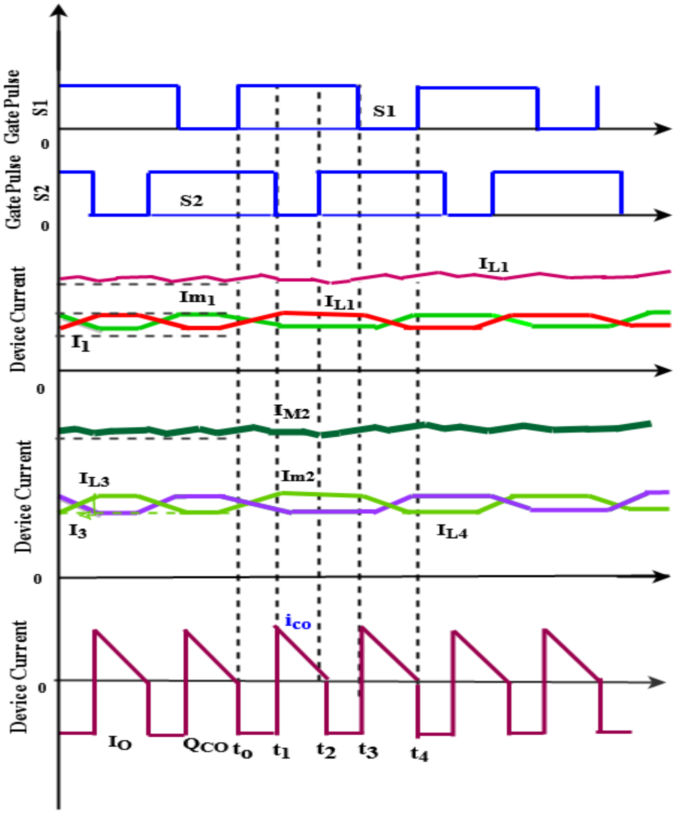


Figure 6. Switching pulses of converter.

3.4. Inverter

While the inverter is running, the grid system receives AC power from the batteries and additional PV sources. This controller controls the six transistors in this circuit. This method gives a wider range of pulse production in terms of phasor angle estimate and phase difference measurement. The circuit diagram for this inverter design, which also results in increased efficiency and decreased harmonic distortion, is shown in **Figure 7**.

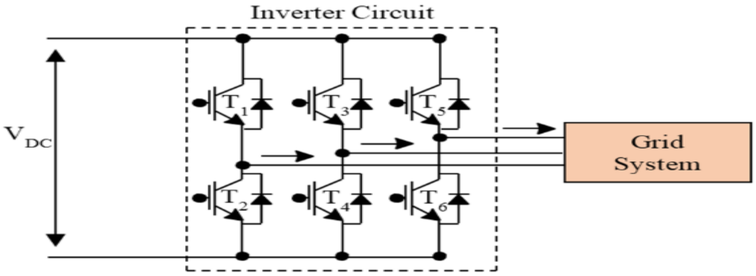


Figure 7. Schematic representation of VSI.

The grid system receives the inverter's output, which has a lower THD and better power quality. The performance of the suggested grid-PV system based on PDOA-MPPT is then evaluated using a variety of performance criteria.

4. Results and discussion

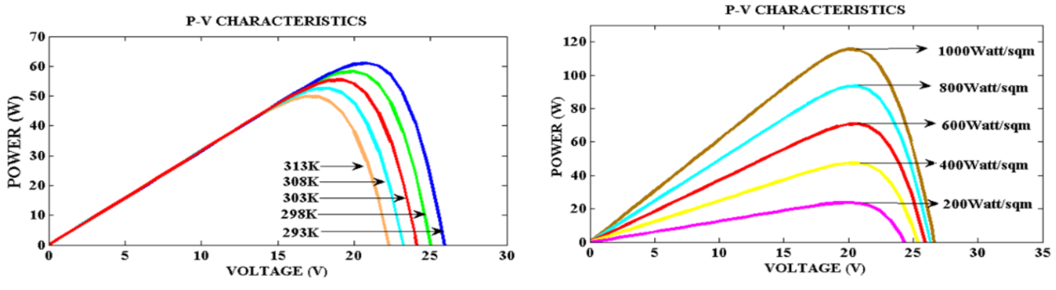
The proposed grid-PV system based on PDOA-MPPT's findings and analysis are presented in this part utilizing a variety of performance measures. The PDOA-MPPT regulating technique is employed in the suggested work to extract the most electrical energy possible from the solar PV panels. Here, the converter's controlling signals are produced in order to employ a PI controller to control the voltage output. The SVPWM controller has been employed to generate the controlling pulses for the switching components of the inverter, which is how the voltage source inverter is used to enhance power quality with low harmonic contents. **Table 2** contains the PV simulation configure oration parameters.

Table 2. PV panel specifications.

Parameters	**Specifications**
Solar panel	100 W
Maximum voltage V	20 V
Maximum current I	5.5 A
Open circuit voltage	21.6 V
Short circuit voltage	5.8 A

4.1. IV and PV characteristics

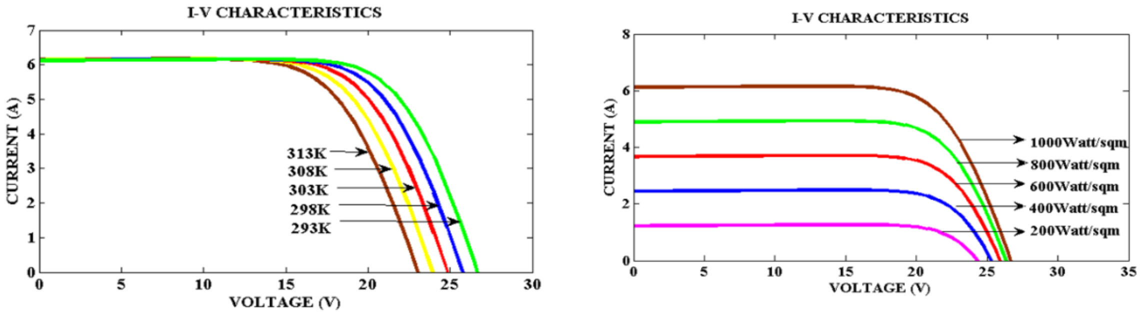
For assessing the performance of PDOA-MPPT controlling, the IV and PV characteristics are evaluated at first. **Figure 8** shows the voltage and power characteristics and 9 shows the voltage and current characteristics of the PDOA-MPPT controller. Based on this analysis, the accurate operating point of PV array is estimated at varying temperature and irradiation conditions. The PDOA-MPPT calculates the maximum peak point in both the global and local features of curves based on these IV and PV parameters. The switching pulses of the converter are controlled based on the peak value, and this provided the grid system with regulated DC power.



a

b

Figure 8. (a) PV characteristics with respect to different temperature; **(b)** PV characteristics with respect to different irradiation.



(a)

(b)

Figure 9. (a) IV characteristics with respect to different temperature; **(b)** IV characteristics with respect to different irradiation.

4.2. Fitness evaluation

Additionally, **Figure 10** depicts the fitness curve of the PDOA approach in relation to various iteration counts. Usually, the fitness plot is used to evaluate the optimization technique's overall performance. Since the optimum solution can be found with fewer iterations and a higher fitness value, a suitable optimization mechanism. It is seen that the PDOA-MPPT approaches locate the ideal solution with a smaller number of iterations, as indicated by the predicted curve. The suggested PDOA-MPPT technique has a significantly enhanced fitness estimation because to its improved exploration and exploitation capacity.

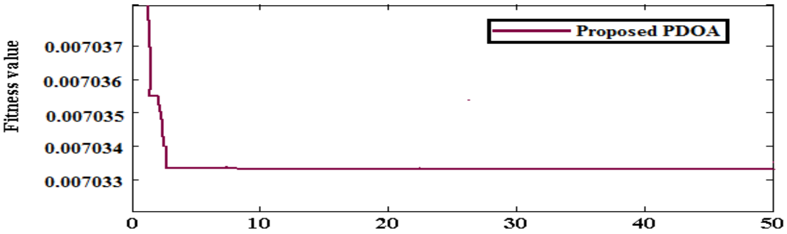


Figure 10. Fitness curve of PDOA.

4.3. Comparative analysis among the optimization based MPPT controllers

Comparing various optimization-based MPPT controllers now in use with recently developed PDOA techniques based on panel power response at various operating points is shown in **Figure 11a–d**. The analysis demonstrates that, with increased panel power (W), the suggested PDOA-based MPPT technique outperforms the competition.

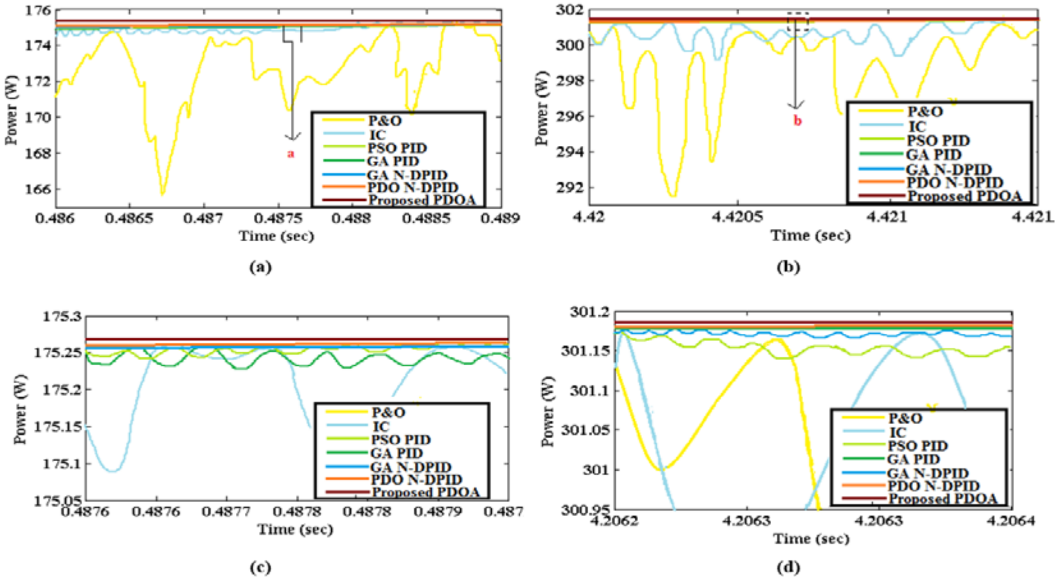


Figure 11. Comparative analysis based on panel power at different operating points.

4.4. Voltage and current

Figure 12 displays the output voltage and current curves for the high gain interleaved SEPIC converter with respect to variable time. The converter's performance and conversion efficiency are typically assessed using its output voltage and current parameters. The analysis reveals that throughout various time periods, the output voltage and current have greatly improved. The correct management of switching components has greatly enhanced the converter performance of the proposed grid-PV system.

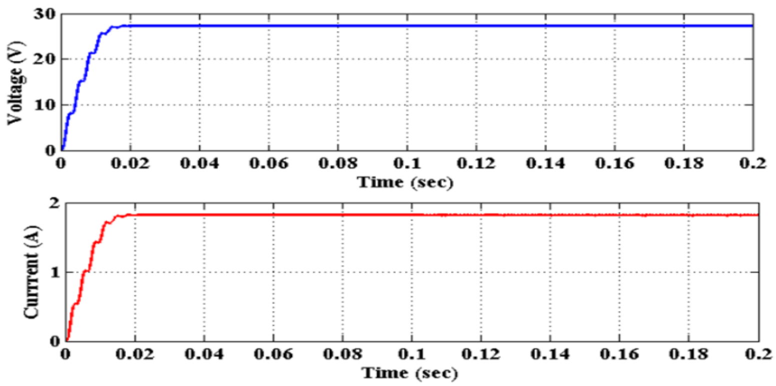


Figure 12. Output voltage and current of converter.

4.5. Grid voltage and current

As illustrated in **Figure 13**, the output grid voltage and current of the proposed system are also assessed in connection to various time occurrences (s). Overall, the results indicate that the proposed grid-PV system performs much better when PDOA and a high gain interleaved SEPIC converter are used. Since the optimization algorithm completely determines how well a controller performs. The suggested framework improves the performance of both optimization and MPPT controlling by increasing convergence and the optimal fitness value.

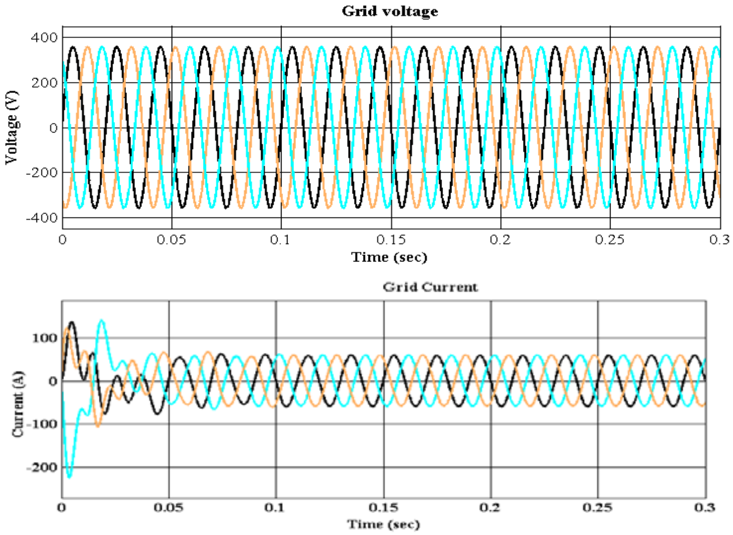


Figure 13. Grid voltage and current.

4.6. THD analysis

The proposed framework’s Total Harmonics Distortion (THD) with respect to varying frequency is depicted in **Figure 14** in terms of kHz. The noise/harmonics present in the output provided to the grid system are effectively reduced by the VSI utilized in the proposed circuit. As a result, the THD in the suggested grid-PV system is effectively decreased to 1.40%.

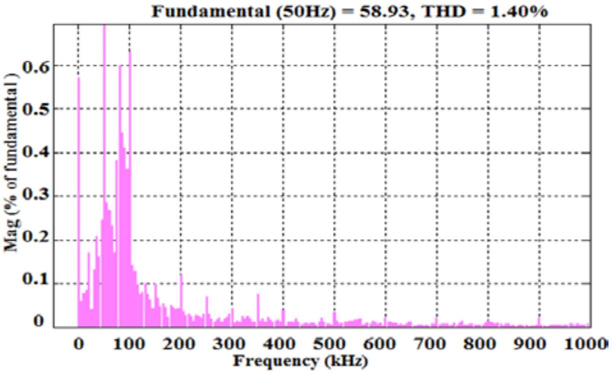


Figure 14. THD analysis.

4.7. Comparative analysis

Tables 3 and **4** validate the efficacy and settling times of suggested and currently available[47] optimization-based MPPT regulating techniques. Additionally, this research includes examples of the various DC-DC converter kinds that can be found in conventional works. The overall improved performance of the grid-PV system is assessed using the maximum efficiency value. The results show that the recommended PDOA-based MPPT performs better and more efficiently than the existing regulating strategies. The settling time, which is calculated as shown in **Table 4** and **Figure 15**, is one of the most crucial parameters used to evaluate the effectiveness of the regulating strategy. Based on the comparison analysis, it is clear that, when compared to the controlling strategies, the PDOA + MPPT greatly reduces the settling time (s).

Table 3. Efficiency analysis.

Converter	MPPT controller	Efficiency
SEPIC	PI + P&O	87
	PI + Fuzzy	89
	PI + GWO	93
	PI + WO	94.6
Luo	PI + P&O	92
	PI + Fuzzy	94
	PI + GWO	95.8
	PI + WO	96.2
Interleaved Luo	PI + P&O	95.4
	PI + Fuzzy	96.7
	PI + GWO	97.5
	PI + WO	98.3
Proposed high gain interleaved SEPIC	PDOA MPPT	99.2

Table 4. Settling time.

MPPT controller	SEPIC (s)	Luo (s)	Interleaved Luo (s)
PI	0.30	0.25	0.20
P&O	0.25	0.20	0.10
Fuzzy	0.20	0.16	0.10
GWO	0.15	0.13	0.09
WO	0.10	0.12	0.08
Proposed PDOA	0.08	0.10	0.06

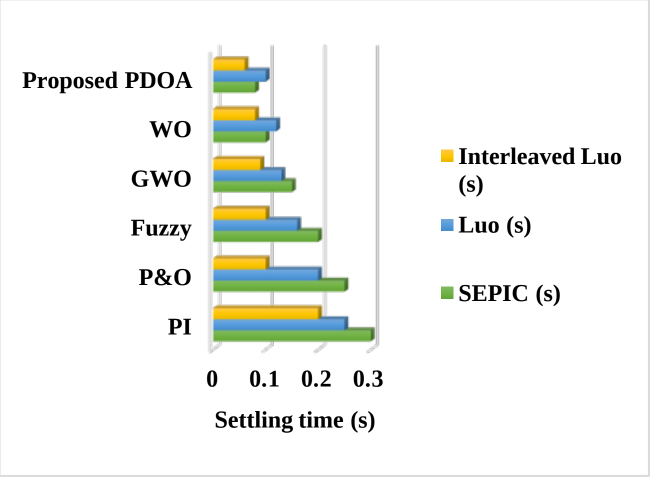


Figure 15. Settling time of various MPPT controlling techniques.

4. Conclusion

To maximize the output of the PV systems, this work employs the recently created PDOA-MPPT optimization-based controlling technique. The goal of this article is to maximize the energy output of solar panels in order to satisfy the energy requirements of the grid system using cutting-edge converters and management techniques. Additionally, it aims to enhance power quality through decreased THD, decreased switching loss, and boosted efficiency. The PV panels can now produce the most power under a variety of irradiance and temperature circumstances thanks to the use of the PDOA-MPPT controlling mechanism. The parameter initialization, fitness assessment, exploration, exploitation, and selection of the best possible solution are the operational phases of the PDOA. The main benefits of utilizing this method are quick convergence, lower computational load, and quicker arrival at the best possible solution in the search space. A high gain interleaved SEPIC DC-DC converter, which has a lower switching stress and loss value, is then used to regulate the output of PV. The harmonic content of the output transmitted to the grid system is also reduced using the VSI. Performance and results of the proposed PDOA-MPPT method are evaluated in terms of IV & PV characteristics, power response, efficiency, settling time, and others. The outcomes demonstrate that the suggested system's efficiency level is increased to 99.2% by including PDOA. The results of the comparisons demonstrate that the proposed technique performs better than the alternatives, yielding better performance outcomes.

In future, the present work can be enhanced by developing a hybrid PDOA technique for MPPT controlling in grid-PV systems.

Author contributions

Conceptualization, SM; methodology, SM; software, SM; validation, SM and SDSJ; formal analysis, SM; investigation, SM; resources, SM; data curation, SM; writing—original draft preparation, SM; writing—review and editing, SM; visualization, SM; supervision, SDSJ; project administration, SM; funding acquisition, NA. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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