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Research article

A novel mine blast optimization algorithm (MBOA) based MPPT controlling for grid-PV systems

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Abstract: One of the most important areas in today's world is meeting the energy needs of various resources provided by nature. The advantages of renewable energy sources for many application sectors have attracted a lot of attention. The majority of grid-based enterprises use solar photovoltaic (PV) systems to collect sunlight as a reliable energy source. Due to solar PV's simple accessibility and efficient panel design, it is widely used in a variety of application scenarios. By employing the Maximum Power Point Tracking (MPPT) technique, the PV modules can typically operate at their best rate and draw the most power possible from the solar system. Some hybrid control mechanisms are utilized in solar PV systems in traditional works, which has limitations on the problems of increased time consumption, decreased efficiency, and increased THD. Thus, a new Mine Blast Optimization Algorithm (MBOA) based MPPT controlling model is developed to maximize the electrical energy produced by the PV panels under a different climatic situations. Also, an interleaved Luo DC-DC converter is used to significantly improve the output voltage of a PV system with a lower switching frequency. A sophisticated converter and regulating models are being created to effectively meet the energy demand of grid systems. The voltage source inverter is used to lower the level of harmonics and ensure the grid systems' power quality. Various performance indicators are applied to assess the simulation and comparative results of the proposed MBOA-MPPT controlling technique integrated with an interleaved Luo converter.

Keywords: solar photovoltaic (PV) systems; renewable energy sources (RES); maximum power point tracking (MPPT); mine blast optimization algorithm (MBOA); interleaved luo dc-dc converter; grid systems

1. Introduction

Due to the enormous rise in global population, electrical energy consumption has increased dramatically [1,2]. One of the issues facing the international community is addressed by the use and deployment of renewable energy [3,4]. Among all renewable energy sources, solar energy has the best future because fossil fuel use is no longer adequate. Especially photovoltaic (PV) [5], which harnesses the solar energy to produce electricity and electrical, is increasing quickly as a result of government policies that are encouraging of it as well as a recent, sudden decline in price. Nevertheless, PV has some significant drawbacks [6,7], including a high initial installation cost and mediocre energy production; only 15% to 25% of solar radiation is converted into electricity. In order to increase the overall amount of electric energy produced, researchers have looked for strategies such as using maximum power point tracking (MPPT) devices [8]. A key component of a PV system, MPPT controllers maximize power production and, as a result, the overall efficiency of the PV module. A DC/DC converter and an embedded electrical system with a control algorithm make up an MPPT device [9,10]. It is built in each PV installation to take the most energy possible in real time under all conceivable operating and environmental situations. Perturb and Observation (P&O), Incremental Conductance (InC), constant current, and constant voltage are the most widely used MPPT control algorithms in PV systems [11]. They have the advantage of being relatively simple to use and performing exceptionally well in uniform radiation and temperature environments. However, as every technique has drawbacks, they are unable to react to ongoing environmental changes and fail to identify the Maximum Power Point (MPP) [12].

These allow for the optimization of the MPP computation in a number of ways, such as by detecting the area under the MPP curve using the derivative value and scaling factor and by employing the variable step approach. But, problems were also found in locating the MPP at various radiation levels. Other Artificial Intelligence (AI) based algorithms [13–15], including those using Neural Network (NN), Support Vector Machines (SVM), Fuzzy Logic (FL), and etc are used to improve the performance of MPPT. The fact that FL algorithms are built on knowledge of the PV system and its surroundings is a benefit. Their performance is heavily reliant on expertise in establishing rules and membership duties, which is a negative aspect. Other drawbacks mentioned by include the difficulty to react rapidly when solar irradiance is changing. System performance may suffer from the array's varied PV panels and the presence of one or more hot spots. Meta-heuristic algorithms, which are primarily designed to handle complex problems with multiple variables and produce the best values, have been taken into consideration recently. For example, Firefly (FF), Ant Colony (AC), Bee Colony (BC), Jelly Fish (JF), Particle Swarm (PS), Spider Monkey (SM), and etc are the most commonly meta-heuristic models for developing MPPT controllers [16–18]. These were put forth because, by combining potential solutions or employing random variables, they can identify the global MPP. These algorithms use a number of particles during each iteration to search for a potential solution. The precision or speed may be improved with a large number of particles. However, it can also result in tracking with less energy. Additionally, random variables used in the combination and selection of the solution cause undesirable energy fluctuation [19,20]. The main objective of this paper is to implement a novel and smart optimization technique for developing the MPPT controlling model.

Research Gap & Contribution:

There have been numerous research ideas on MPPT for PV systems introduced in the last ten years. There have been some MPPT methods that are based on uniform irradiances, while others are partial shade circumstances. As each technique has its own set of advantages and disadvantages, however selecting MPPT for certain PV system designs and circumstances could be a challenging task. To assist researchers and field engineers in selecting the best MPPT for a specific PV system, many reviews on the topic have been presented in the earlier works. Moreover, some of the standard MPPT controlling techniques such as P&O, ripple correlation control, hill climbing and etc for maximum power extraction from RES. However, partial shading, or when panels in an array get unequal illumination, renders these strategies completely useless. These techniques also show poor convergence, inadequate traceability speed, and too many steady-state oscillations. Because of this, it is necessary to combine conventional techniques with new ones in order to track MPP under varying climatic conditions. The improvements made before have enhanced their performance, but they are still insufficient for all operating scenarios. To overwhelm these problems, this research work aims to develop a new optimization based MPPT controlling technique for extracting the maximum solar energy from the PV panels. Table 1 presents the comparative analysis of the existing techniques used for power extraction, where the pros and cons of each technique are discussed.

Table 1. Study on the previous works.

References	Controlling technique	Advantages	Drawbacks
[21]	Standard P&O	It requires very few sensors, simple to implement, and requires low cost.	Low performance, oscillations around MPP, and inaccurate MPP tracking.
[22]	Hill Climbing	Simple deployment, and easy to understand.	It is not more suitable to accurately track MPP under changing climatic conditions, and ineffective tracking.
[23]	Standard PSO-MPPT	Fast processing, highly robust, and no steady state oscillations.	It is highly difficult to identify the optimal parameters.
[24]	Fuzzy logic controller	Simple design, and it does not require any prior knowledge.	Increased computational error, and complexity in rule generation.
[25]	Genetic Algorithm – MPPT	It has the better ability to reach global optimum with low oscillations, and better speed of tracking.	Non-deterministic in nature, and time dependent.
[26]	Artificial Neural Network (ANN) – MPPT	Better tracking efficiency, and good performance.	It requires the periodical training for assuring an accurate peak point.

This section provides the complete literature review of the existing models related to maximum power extraction from solar PV systems. Moreover, it investigates some of the recent converter and controlling topologies used in the grid-PV systems with its problems and benefits.

In some of the existing literature works, methods for analyzing MPPT are employed in order to attain the maximum operating point without the use of machine learning algorithms, which present numerous challenges because of the dynamic changes in irradiation circumstances. However, some other investigations used machine learning methods to track MPPT in PV systems. The Least Square Support Vector Machine (LSSVM) with Incremental Conductance (INC) and P&O approaches are taken into consideration for analysis in the paper's thorough investigation of several ML-based MPPT algorithms in PV systems. Similar to this, the maximum peak point is reached in PV power plants by using the Bayesian optimization technique. Most of the papers concentrated on the implementation of optimal forecasting approaches for increasing the performance of controllers. In order to anticipate short-term PV power, Vandeventer et al [27] adopted an ensemble-based hybrid Genetic Algorithm Support Vector Machine (GASVM) mechanism, in which the SVM is used to categorize past meteorological data in order to achieve the desired output power. The best parameters for use in prediction are chosen after the GA is employed to create the uniform weight matrix. Sobri et al [28] compared ensemble and time series methods, two AI techniques for effective forecasting. According to this study, ensemble approaches combine the features of both linear and non-linear techniques to boost prediction accuracy. As a result, the ensemble process based on Bayesian theory [29] is used to reliably forecast solar irradiation in PV power plants. Here, the baseline is created with the use of ensemble methods, and the clustering is initialized to create various subsets by grouping the original data. A flying capacitor transformer-less inverter was employed by Siwakoti and Blaabjerg [30] to improve the efficiency of single stage PV systems. It also used a Pulse Width Modulation (PWM) approach to lessen harmonics, switching loss, and ripples in the output current. Three different modes of operation, including zero state, positive cycle, and negative cycle, have been used here. The absence of leakage current and improved compensatory capacity were this technique's main advantages. An improved controlling method was created by Beena et al [31] to improve grid interactive inverter power quality. Reduced overall harmonic distortions, DC current injection, power factor, and voltage variations were the main factors that were taken into account in this work. Additionally, the non-linear load was linked in parallel to the grid system as part of this work's use of a transformer-less inverter architecture. However, this approach neglected to focus on energy conservation as a means of enhancing the power system's dependability.

Yadeo, et al [32] built a new converter called a transistor clamped dual active bridge DC-DC to reduce current stress and improve voltage regulation. This paper's main contribution was to increase system effectiveness with lesser loads and different conversion ratios. Additionally, a distinct power flow equation was developed using the converter's suggested modelling. Lakshmi, et al [33] developed a single stage DC to DC converter to control the DC voltage using MPPT Here, it was indicated that a considerable need for inverter current existed in order to support reactive power. The LCL filtering approach was then used in conjunction with the controlling strategy to ensure that the required levels of power quality were met. Both the active and reactive power adjustments were computed under a constant load state throughout the simulation analysis. Prasad, et al [34] used a Synchronous Reference Frame (SRF) technique and an adaptive hysteresis current management scheme to increase the grid-PV systems' ability to sustain reactive power.

The P&O MPPT algorithm was also used to maximize the power generated by solar PV installations. The output voltage of the PV system has been increased in this case using the boost DC-DC converter topology. In real-time application systems, the SRF has the capacity to function in both stable and dynamic states. The advantages of this strategy were straightforward calculations and significant voltage gain. However, it does not solve the main issue of higher harmonic contents in output power brought on by nonlinear load. Somaling and Santha [35] intended to improve the effectiveness of power systems with the use of a bidirectional DC to DC converter without magnetic coupling. Here, the step up and step down operations were utilized in this design. The necessary number of components, voltage stress, current stress, and voltage gain have all been computed in order to assess the performance of this converter. Rahmani, et al [36] presented an Advanced Universal Power Quality Conditioning System (AUPQS) to address the harmonics and distortion issues in power grid systems. Utilizing a series active filtering approach, the output voltages in this case were produced under unbalanced load conditions. The use of MPPT, which raises the overall efficiency of the grid systems, may also help PV systems function more effectively. The Perturbation Observer based Functional Order Sliding Mode Controller (POFO-SMC) was developed by Yang et al [37] to harvest solar energy from PV systems under various climatic conditions. In this case, the control gain matrix was created to guarantee the accuracy of the input and output linearization. Increased robustness, decreased un-modeled dynamics, external disturbances, and stochastic fluctuations were benefits of this regulating method.

Based on the survey, it is determined that the converter and controller topologies now in use have both advantages and disadvantages. In many works, the standard MPPT controllers are developed for identifying the peak point to track power. Yet, the loss of power is caused by these algorithms' quick fluctuations around the MPP. Moreover, failing to account for the effects of partial shade circumstances results in these traditional solutions failing to follow the real MPP. Intelligent or optimum MPPTs are combined with traditional MPPTs to create hybrid based MPPT approaches. The most effective fusion of intelligence and optimization is also present in some hybrid strategies. The MPP is estimated in the first stage of the tracking approach for these combined MPPT and then fine-tuned in the second stage using cutting-edge methodologies. Hence, an intelligent controller is developed, which incorporates the functions of meta-heuristic optimization algorithms and machine learning models for finding the solution to track energy. The loss of power is caused by the fact that these algorithms oscillate quickly around the MPP. Moreover, failing to account for the effects of partial shade circumstances results in these traditional solutions failing to follow the real MPP. However, it mostly falls short when it comes to problems with increasing voltage sag, oscillation, and response time. The proposed study aims to create a new controller with MPPT and a DC to DC converter topology to address these issues.

The core contributions of this work are as follows:

- To obtain the maximum electrical energy from the PV panels with the use of Mine Blast Optimization (MBO) based MPPT controlling algorithm under different climatic conditions.
- To highly boost the output voltage of PV system with reduced switching frequency, an interleaved Luo DC-DC converter is used.
- To efficiently satisfy the energy demand of grid systems, an advanced converter and controlling models are developed.
- To reduce the level of harmonics for ensuring the power quality of grid systems, the voltage source inverter is used.
- To analyze the simulation and comparative results of the proposed MBO-MPPT controlling technique incorporated with an interleaved Luo converter, various performance measures are used.

The article is organized as follows: Section 1 provides background information, an introduction to the subject, as well as the goal this article seeks to accomplish. The thorough literature assessment on MPPT controlling and power quality enhancement in grid-PV systems is also presented in this section. The suggested framework is clearly explained in Section 2 along with an illustration of how it would work. The suggested MBOA-MPPT technique's simulation and comparison results are validated in Section 3 using a variety of metrics. Section 4 concludes by outlining this article's conclusions and suggestions for further research.

2. Materials and methods

This section provides the clear explanation for the proposed Mine Blast Optimization Algorithm (MBOA) based MPPT controlling technique for harvesting the maximum power from the PV panels. The main objective of this work is satisfy the energy demand of grid systems by extracting more energy from the solar panels. For this purpose, a recently developed MBOA is utilized in this work, which is to optimally identify the MPP for obtaining the maximum energy yield under different climatic conditions. The work flow model of the proposed MBOA-MPPT controlling model is shown in Figure 1, which includes the following major operations:

- PV panel modeling
- MFOA-MPPT power extraction
- Interleaved Luo converter
- Inverter for harmonics reduction
- Output to grid systems

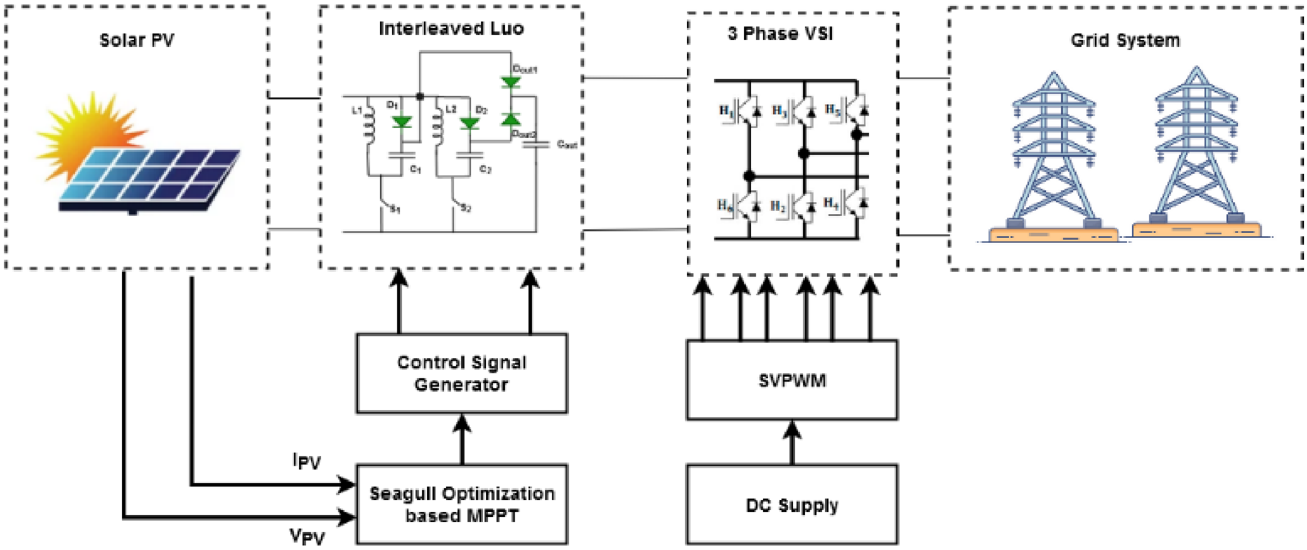


Figure 1. Workflow of the proposed system.

This research suggests a hybrid technique for solar PV generating systems to maximize and maintain the power to load. The suggested hybrid technique is the joint execution of MBOA-MPPT, which seeks to continuously track the MPP and maintain the system's power flow in order to maximize the output power of the PV module. Based on the voltage and current characteristics, it optimizes the precise duty cycles of the DC-DC converter under changing climatic conditions. The proposed technique regulates and preserves the power to the load in an ideal manner using this proper management. Using this control method, load demands are optimally addressed while external disturbances and fluctuations in system parameters are minimized. The suggested MBOA technique have a superior searching performance in terms of providing greater dynamic response, quicker convergence, better tracking speed, and robustness against with the existence of load uncertainties. Initially, the PV panel is modeled, and the MFOA-MPPT technique is used to obtain the peak point for tracking the maximum electrical energy from the PV panels. After that, an interleaved Luo DC-DC converter is used to boost the output of PV with reduced switching frequency and loss. Consequently, the 3 phase voltage source inverter is used to enhance the output power quality of grid systems with reduced total harmonics distortions. Table 2 describes the problems and benefits correlated to the proposed optimization integrated MPPT controlling technique.

Table 2. Pros and cons of the proposed optimization + MPPT controlling techniques.

Advantages	Limitations
Reduced cost	Quality of solution is highly depends on the nature of problem
Global optimum	Computational complexity also depends on the problem
Fast convergence	
Reaches optimal solution in the early iterations	
Better exploration and exploitation capabilities	

2.1. PV system model

Based on the parameters utilized for the solar cell arrangement and the irradiance factor, PV systems are created. The solar cells are gathered with a current generator to transform the solar energy into electrical power depending on the amount of power being extracted. As shown in Figure 2, the PV panel is modeled at first to harvest energy from the solar PV system, and the current is produced as follows:

$$I = I_{PV} - I_d - I_{sh} \tag{1}$$

where, I indicates the output current, I_{PV} indicates the PV current, I_d represents the diode current, and I_{sh} defines the shunt current. Moreover, the PV current is generated according to the following model:

$$I_{PV} = \frac{G}{G_{Rf}}\left(I_{sh,Rf} + \mu_{sh} \,.\, \Delta T\right) \tag{2}$$

where, $I_{sc},_{Rf}$ represents the reference short circuit and reference current, G denotes the solar irradiation in terms of W/m^2, G_{Rf} indicates the irradiation at STC, μ_{sh} indicates the temperature coefficient (A/k), and the value ΔT is estimated by using the following equation:

$$\Delta T \;=\; T - T_{Rf} \tag{3}$$

where, T is the temperature in terms of kelvin and T_{Rf} indicates the temperature at STC. The current flow through the diode (I_d) is computed by using the following model:

$$I_D = I_0\left[exp^{\left(\frac{V+IRs}{p}\right)}\right] \tag{4}$$

$$I = I_{ph} - I_0\left[exp^{\frac{V+IR_S}{a}}\right] - \left(\frac{V+IR_S}{R_P}\right) \tag{5}$$

where, I_0 is the reverse saturation current of the diode, R_s represents the series resistance, R_p indicates the parallel resistance, and p is the modified ideality factor.

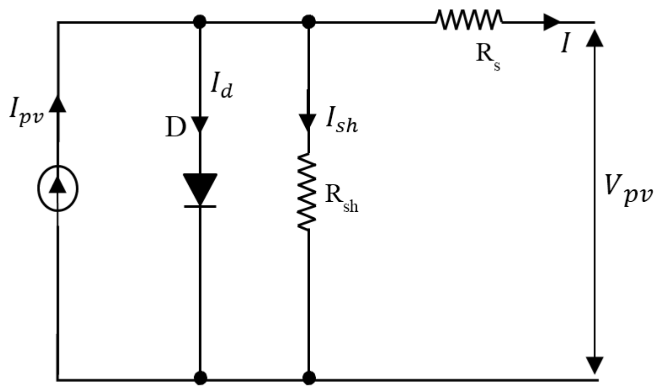


Figure 2. PV panel schematic representation.

2.2. Mine Blast Optimization Algorithm (MBOA) based MPPT

Typically, optimization is one of the most widely used meta-heuristic model for solving the complex problems. Specifically, the different types of optimization techniques are used in the grid-PV systems for modeling the MPPT controllers. In the existing works, some of the well-known approaches like FF, AC, BC, JF, and etc are used to find out the maximum peak point for tracking the electrical energy from the solar panels. However, it still has some problems like reduced convergence rate, slow in process, lack of reliability, and high time consumption to find the global MPP. For this purpose, the proposed work intends to implement a newly developed optimization technique, called as, MBOA [38,39] for MPPT. The proposed algorithm is based on the observation of a mine bomb blast, in which shrapnel fragments are launched and impact with additional mine bombs nearby, causing them to explode. Consider a minefield where clearing the mines is the goal in order to comprehend the scenario. Consequently, the objective is to detect the mines, with the one that can cause the most casualties having the most explosive effect and being in the best location being the most crucial. Mine bombs of various shapes, sizes, and explosive strengths are buried. The casualties caused by each piece of shrapnel that is spread out when a mine bomb explodes are calculated. The presence of more mines with potentially higher explosive potential may be indicated by a high value for injuries per piece of shrapnel in a given area. Each piece of shrapnel has certain trajectories and separations to crash with other mine bombs, which may cause additional mines to explode as a result of the contact. We may find the most explosive mine by watching for shrapnel bits to collide with other mines. The number of casualties brought on by a mine bomb explosion is taken into account while determining whether the mine bomb's location serves its objective purpose.

One mine bomb may be placed in each square of an endless grid that is the domain (mine field) solution. In this technique, the upper bound and lower bound values are estimated at first to initialize the maximum number of iterations and the size of the search space:

$$S = \{S_k\}, k = 1,2,3, \dots, G_d \tag{6}$$

$$S_0 = lwb + C * (upb - lwb) \tag{7}$$

where, G_d is the search space dimension that is equal to the number of independent variables, S_0 is the initial variable, lwb denotes the lower bound, and upb is the upper bound. The locations and separations of the shrapnel fragments are determined if the exploration component is satisfied; if not, the convergence condition is validated for halting the requirements.

As a result, the following model is used to determine the direction of the shrapnel:

$$Z_{n+1}^{m} = \frac{Q_{y+1}^{x} - Q_{y}^{x}}{S_{y+1}^{x} - S_{y}^{x}} \tag{8}$$

where, Z_{y+1}^{x} indicates the direction of shrapnel pieces, Q_{y}^{x} & O_{y+1}^{x} are the objective function values at y and $(y+1)^{th}$ iterations. The shrapnel fragments are then produced using the revised positions, as follows:

$$S_{y+1}^{x} = S_{Z(y+1)}^{x} + \exp\left(-\sqrt{\frac{Z_{y+1}^{x}}{d_{y+1}^{x}}}\right) S_{y}^{x} \tag{9}$$

Additionally, the constraints are checked once to see if shrapnel is produced or not, and the best shrapnel pieces are then thought of as the best temporary fix. The shrapnel piece's position was then updated in order to determine the best temporal solution. The following models are used to calculate the placement and separation of the shrapnel bits:

$$S_{Z(y+1)}^{x} = d_{y}^{x} * rnd * \cos(\varphi) \tag{10}$$

$$d_{y+1}^{x} = \sqrt{\left(S_{y+1}^{x} - S_{y}^{x}\right)^{2} + \left(Q_{y+1}^{x} - Q_{y}^{x}\right)^{2}} \tag{11}$$

Additionally, based on the following model, the shrapnel's distance is adaptively reduced:

$$d_{y}^{x} = \frac{d_{y-1}^{x}}{\exp\,(i/\delta)} \tag{12}$$

where, δ and i are the reduction constants and iteration number index respectively. The algorithm can be terminated after the convergence criterion has been verified and the stopping condition has been satisfied as shown in Figure 3. At each repetition of the time samples, this fitness plot shows an improving controlling efficiency. The controller's gain parameters are carefully chosen to deliver the right pulses to the switching devices. Here, each iteration represents a snapshot in time, and the fitness number represents how much ideal power is flowing through the circuit.

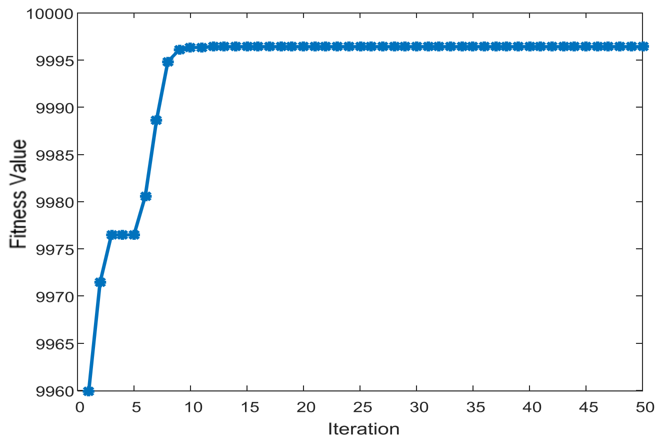


Figure 3. Fitness curve of MBOA.

2.3. Interleaved Luo DC-DC converter

After obtaining the maximum energy yield, the interleaved Luo DC-DC converter [40,41] is used to boost the output voltage of PV with reduced switching loss and frequency. Traditionally, different types of converter topologies like buck, boost, bi-directional, flyback, and etc are used in the grid-PV systems for maximizing the output voltage. Since, it has the problems like increased number of switching components, high switching frequency, and high ripple current. Therefore, the proposed work aims to use an interleaved Luo converter for effectively regulating the voltage of grid-PV systems. The circuitry representation and its operating modes of the interleaved Luo converter are shown in Figure 4 and Figure 5 respectively. Here, the converter's output voltage is given as follows:

$$V_{out} = 3\frac{2-D_c}{1-D_c}V_{PV} \tag{13}$$

where, V_{out} denotes the converter's output voltage, D_c is the duty cycle, and V_{PV} denotes the PV array's output voltage. With the aid of an inductor and this converter topology, the output ripple current can be decreased as shown below:

$$\Delta OuI_L = OI_L \times 40\% = I_o \frac{(V_o \times 40\%)}{V_{PV}(min)} \tag{14}$$

The calculated values of inductances L1 and L2 are displayed below:

$$L_1, L_2 = \frac{V_{PV}(min)}{\Delta OI_L \times fsw}.D_{max} \tag{15}$$

where, D_{max} denotes the pulse's maximum duty cycle when applied to the converter. Next, the current's input's Root Mean Square (RMS) I_{ip} is determined as follows:

$$I_{ip}(rms) = \frac{\Delta OuI_L}{\sqrt{12}} \tag{16}$$

The inductor is electrified when the switch is in the ON position, and the output current is then transferred to the output capacitor I_{OC}. It is estimated as shown in below:

$$I_{OC}(rms) = I_o\sqrt{\frac{V_{Dc}+V_{Dr}}{V_{Pv}(\min)}} \tag{17}$$

where, V_{Dc} stands for the converter's output voltage and V_{Dr} for the voltage drop across diodes D1 and D2, the capacitance that results is approximated as follows:

$$C_o = \frac{I_o \times d_p}{V_{ri}S_{0.5}S_{SF}} \tag{18}$$

where, $S_{0.5}$ and S_{SF} are the impedance at 50% of the duty cycle and the switching frequency, respectively, and d_p is the duty cycle of the control signal generator.

The inverter stage is where the grid system receives its AC power supply from the battery and PV power sources. The proposed controller is used to regulate the six transistors in this circuit. With regard to phasor angle estimation and phase difference measurement, this technique offers an expanded spectrum of pulse generation. Additionally, this inverter design achieves higher efficiency with lower harmonic distortion. Finally, the quality improved output is fed to the grid system with reduced harmonic contents.

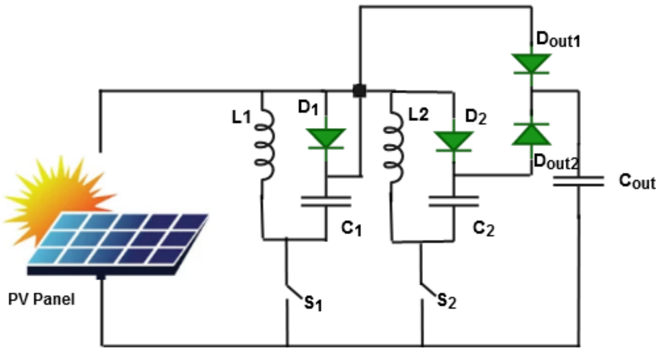
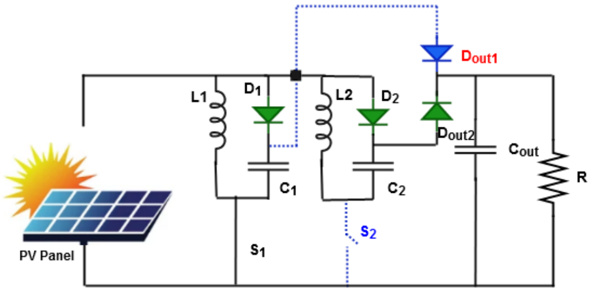
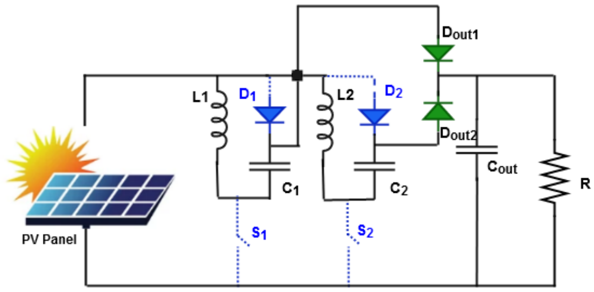


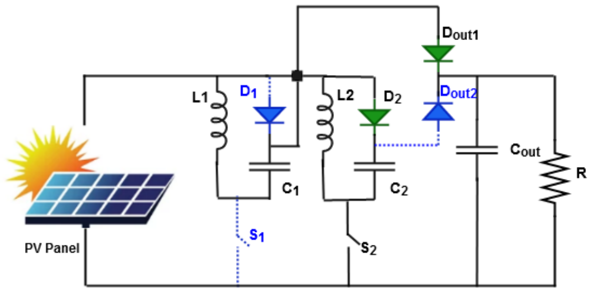
Figure 4. Schematic representation of interleaved Luo converter.



(a) Mode 1



(b) Mode 2



(c) Mode 3

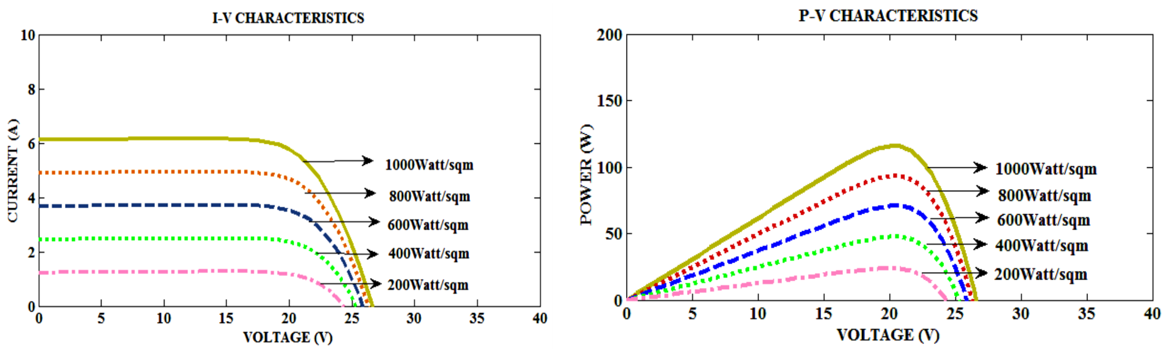
Figure 5. Mode of operations.

3. Results and discussion

The proposed MBOA-MPPT controlling mechanism's simulation analysis is validated in this section by using different parameters. Here, the embedded function of the MATLAB/SIMULINK tool is used to extract the simulation results. Table 3 presents the simulation parameters of the proposed power extraction framework. The suggested controller design's current voltage (IV) and power voltage (PV) characteristics for various irradiance and temperature conditions are shown in Figures 6 and 7 respectively. The IV characteristics are often examined and tracked primarily to calculate the actual power generated by the PV modules under precise operating conditions. The current-voltage characteristics at various irradiances of 200 W/m^2, 400 W/m^2, 600 W/m^2, 800 W/m^2, and 1000 W/m^2 in 25℃ are shown in Figure 6a. Solar voltage and current vary as a result of variations in sun irradiation. The production capacity of solar cells is determined by the intensity of light, as shown in Figure 6b. The only energy point that can be maintained while maintaining the same solar cell temperature is the same light output. These features allow for an estimation of the controlling technique's ability to extract the maximum amount of power. According to the evaluation, the proposed controller design offers a quick and dynamic reaction with an identical replication of the features of IV and PV. By using the MBOA, the performance of MPPT is highly improved with better IV and PV characteristics. Moreover, the generated switching pulses of the MPPT controller are shown in Figure 8.

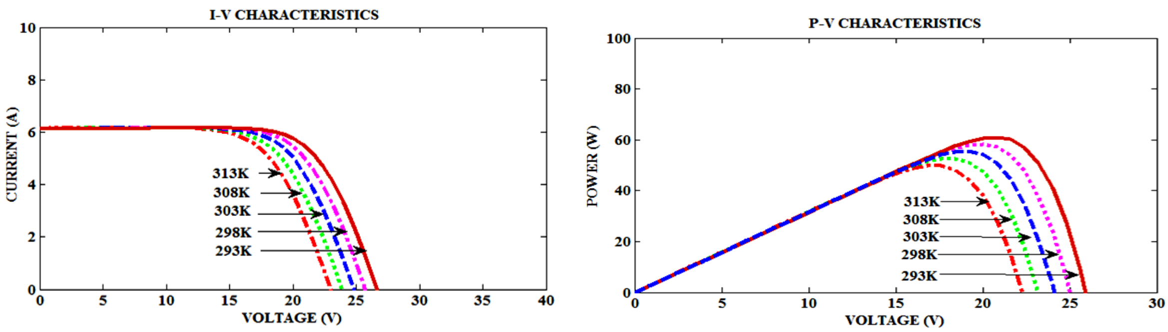
Table 3. Solar PV Panel specifications.

Parameters	Specification
Solar Panel	100 W
Open circuit voltage V_{oc}	26.6 V
Short circuit current I_{sc}	6.2 A
Temperature T	298 K
Peak current	6.1 A
Maximum Power	100.15 W



(a) (b)

Figure 6. (a) IV characteristics based on changing irradiation, (b) PV characteristics based on changing irradiation.



(a) (b)

Figure 7. (a) IV characteristics based on changing temperature conditions, (b) PV characteristics based on changing temperature conditions.

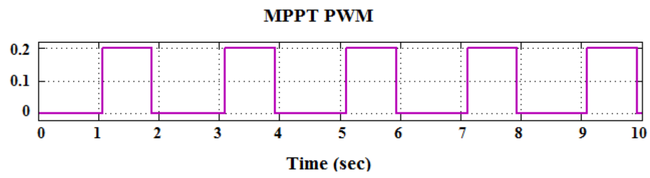


Figure 8. Switching pulses for MPPT.

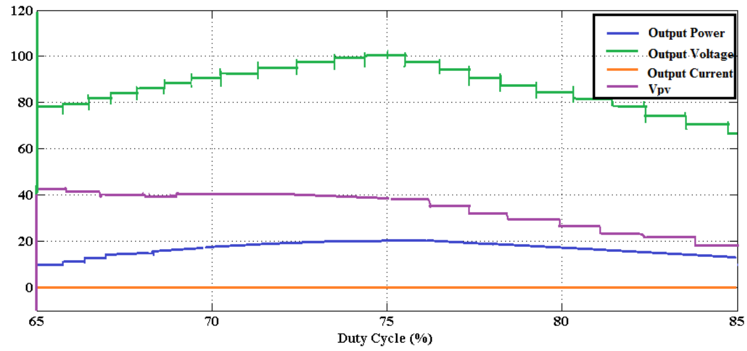


Figure 9. Duty cycle.

In this analysis, the duty cycle linearly changed in order to verify that the PV system was operating at its maximum power point as shown in Figure 9. By gradually reducing or increasing the duty cycle of the converter employed as the interface between the load and the PV panel, the MPPT algorithms are able to increase the output power of PV panels. The obtained results indicated that the optimal duty cycle can be reached more rapidly and with fewer steady-state oscillations using the proposed method. Moreover, the reference current generated from the MPPT controller is shown in Figure 10.

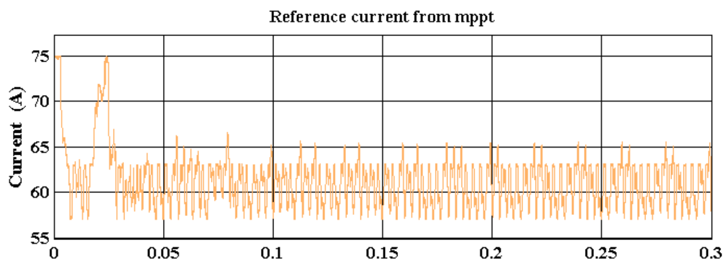


Figure 10. Reference current from MPPT.

Figures 11 and 12 validates the output inverter voltage and current of the proposed grid-PV systems with respect to varying time instances (s) respectively. The performance of the inverter used in the grid-PV circuit model is determined according to its output voltage and current parameters.

Similarly, the performance of an interleaved Luo converter used in the proposed circuit model is assessed based on the parameters of voltage gain, output voltage and current. In which, the voltage gain is one of the most essential parameter used to validate the regulation efficiency and voltage boosting level of the converter. Figure 13 compares the voltage gain of existing buck-boost and proposed interleaved Luo converter with respect to varying duty cycle. The results indicate that the proposed converter provides an increased voltage gain, when compared to the other existing converter. As shown in Figure 14, the output voltage and current of converter is validated with respect to varying time (s).

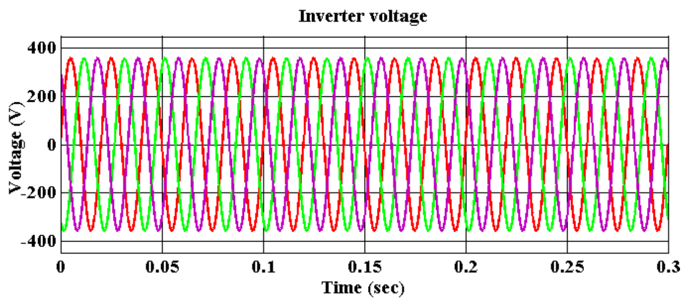


Figure 11. Inverter voltage.

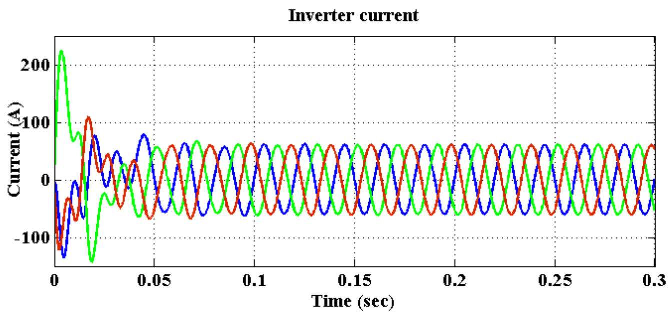


Figure 12. Inverter current.

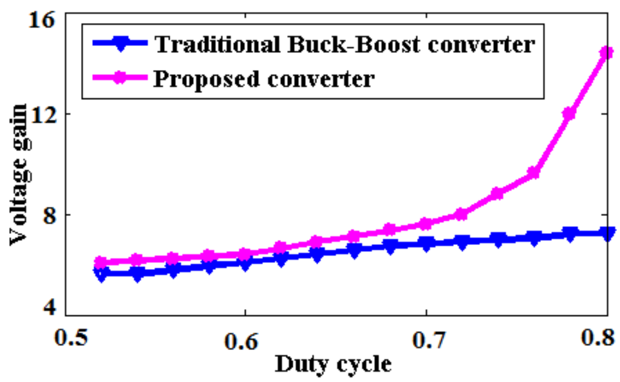


Figure 13. Comparative analysis among the existing and proposed converters based on voltage gain.

The performance of grid system is assessed based on the parameters of grid current and voltage as shown in Figure 15. Since, its performance is entirely depends on the power tracking efficiency and voltage regulation of the converter and controlling models. Moreover, the Total Harmonics Distortion (THD) of the existing and proposed circuit models are validated and compared as shown in Figure 16 and Figure 17 respectively. The increased level of harmonic contents can degrade the performance of entire grid-PV system, hence it must be effectively reduced for assuring the better system efficiency and performance. The obtained results state that the proposed controlling model could effectively reduce the THD to 1.16% by improving the power quality of grid system.

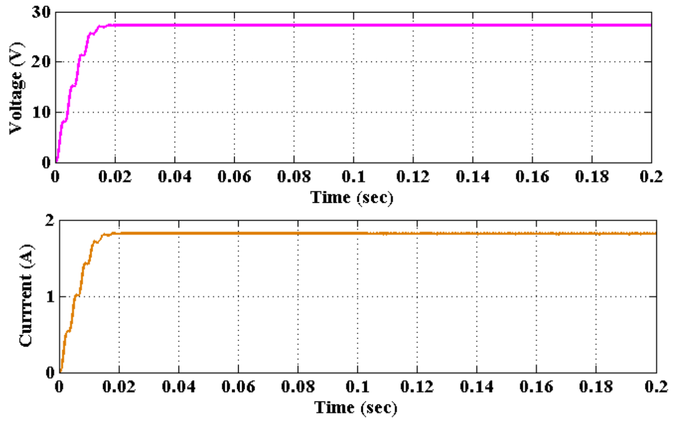


Figure 14. Output voltage and current of DC-DC converter.

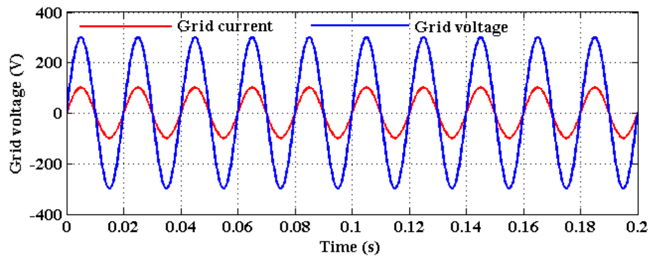
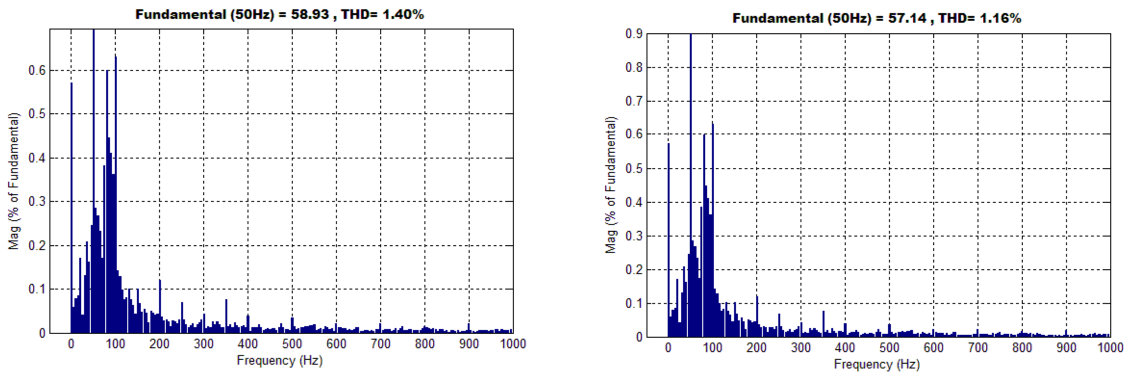


Figure 15. Grid output voltage and current.



(a) **(b)**

Figure 16. (a) THD analysis of existing MPPT controller, (b) THD analysis of proposed MPPT controller.

Table 4 presents the comparative analysis among the existing and proposed MPPT controlling techniques based on the parameters of settling time (s), rise time (s) and peak overshoot (W). These parameters are mainly used to validate the overall improved performance of the MPPT controlling techniques, and it must be reduced for ensuring the better system efficacy. Moreover, the power tracking efficiency of the existing [42] and proposed MPPT controllers are validated and compared as shown in Table 5. Based on the results, it is observed that the proposed MBOA-MPPT technique outperforms the other controllers with reduced settling time, rise time, peak overshoot, and increased efficiency.

Table 4. Comparative analysis among the MPPT techniques.

Performance Measure	MVO-MPPT	GWO-MPPT	PSO-MPPT	P&O MPPT	MBOA-MPPT
Settling time (s)	0.0078	0.0082	0.0082	0.1939	0.0069
Rise time (s)	0.0016	0.0017	0.0018	0.0028	0.0012
Peak overshoot (W)	0.3481	0.4986	0.5308	0.6328	0.2891

Table 5. Comparative analysis among the MPPT techniques based on efficiency (%).

Irradiance W/m^2	MVO-MPPT	GWO-MPPT	PSO-MPPT	P&O MPPT	MBOA-MPPT
400	97.93	96.89	95.67	86.66	98.2
600	98.89	98.29	97.78	92.97	99.2
800	99.28	99.12	98.10	91	99.45
1000	99.40	99.30	98.40	87.96	99.6

Table 6 compares various existing and proposed hybrid MPPT controlling techniques based on the parameters of tracking efficiency (%) and speed (s). The results state that the proposed MBOA-MPPT technique outperforms the other algorithms with high power tracking efficiency and speed due to the identification of best optimal solution with accurate MPP tracking. Similarly, Table 7 also compares the convergence time to reach global MPP (s), power oscillations under steady state (%), and power extracted at MPP (kW). For this analysis, the GWO based MPPT techniques are utilized for comparison, and the results stated that the proposed MBOA-MPPT technique outperforms other controllers with better performance. Moreover, Figure 17 presents the comparison of various MPPT controlling techniques such as Bat-FLC, fuzzy logic, IC, P&O and proposed MBOA-MPPT based on the parameters of tracking efficiency (%), oscillations around MPP (W) and response time (s). Overall, the estimated results indicate that the proposed MBOA-MPPT technique overwhelms the existing models with highly improved MPPT performance results.

Figure 18 shows the SWOT analysis of the proposed solar PV based grid applications, which helps to analyze the major strengths, weakness, opportunities and threats of using PV systems in current and future application systems.

Table 6. Power tracking efficiency and speed.

Methods	Tracking efficiency (%)	Speed (s)
P&O	85.2	0.54
HC	84.6	0.61
PSO	88	0.58
HHO	89.4	0.12
GWO	91.5	0.43
FA	90.7	0.52
ABC	90.3	0.39
ANN	94.7	0.132
FLC	92.9	0.72
GA	89.6	0.69
Proposed	99.5	0.065

Table 7. Comparative analysis.

MPPT Techniques	Convergence time to global MPP (s)	Power oscillations (%)	Power Extracted at MPP (kW)
GWO	0.14	0	2.37
GWO-Beta	0.142	0	2.37
GWO-IC	0.178	1.34	2.37
GWO-P&O	0.18	3	2.34
Proposed	0.9	0	2.46

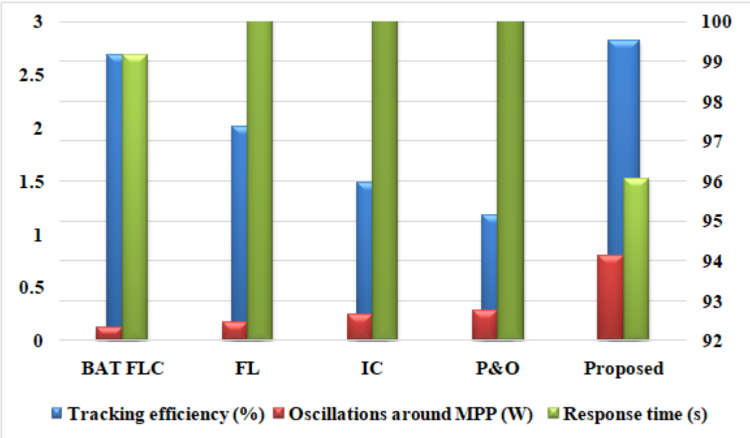


Figure 17. Analyzing among various MPPT controlling techniques.

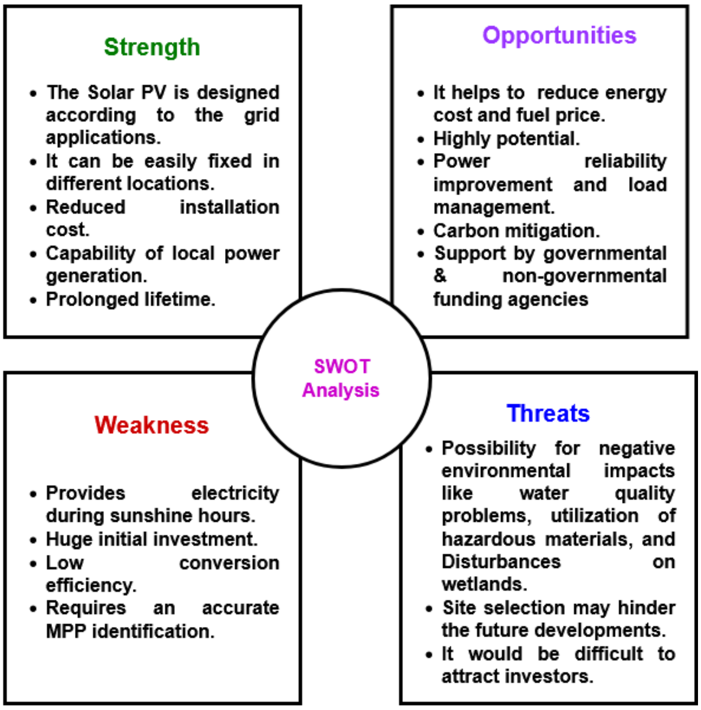


Figure 18. SWOT analysis.

4. Conclusions

This paper presents a new optimization based MPPT controlling technique, named as, MBOA-MPPT for grid-PV systems. In this research, an effective MBOA-MPPT technique has been put forth to enhance the system MPPT and power flow control of solar PV generating systems. This work objects to implement a new controlling strategy for satisfying the energy demand of grid-PV systems. Also, an interleaved Luo DC-DC converter is used to regulate the output of PV with reduced switching loss and switching frequency. The PV panel is first modelled, and the peak point is then obtained using the MFOA-MPPT technique in order to track the highest electrical energy produced by the PV panels. The output of PV is then increased with less switching frequency and loss using an interleaved Luo DC-DC converter. As a result, grid systems with lower total harmonic distortions use the 3-phase voltage source inverter to improve the output power quality. The key benefits of the proposed MBOA-MPPT controlling technique are increased convergence rate, reduced time consumption, reduced THD, and high power tracking efficiency. Moreover, an extensive simulation analysis is carried out to validate the performance and power tracking efficacy of the proposed MBOA-MPPT technique by using the parameters of IV & PV characteristics, voltage gain, duty cycle, and etc. Also, the settling time, overshoot, rise time, and efficiency of the existing and proposed MPPT controlling approaches are compared. The estimated results state that the proposed controlling model could effectively reduce the THD to 1.16% by improving the power quality of grid system. The rise time is reduced to 0.0012 s, settling time is reduced to 0.0069 s, and peak overshoot is reduced to 0.2891. Overall, the obtained results indicate that the MBOA-MPPT technique provides an improved performance, when compared to the other approaches.

Conflict of interest

The authors declare that they have no conflict of interest.

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