SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V11I9P103

Volume 11 Issue 9, 28-38, September 2024

Original Article

A Multi-Objective Grey Wolf Optimization Technique for Minimizing the Current Harmonics in a Grid Connected 5-level Packed U Cell Based PV DSTATCOM

K. Soujanya[1], J. Upendar[2]

[1]*Department of Electrical Engineering, University College of Engineering, Osmania University, Telangana, India.*
[1]*CMR College of Engineering & Technology, Hyderabad, Telangana, India.*
[2]*Department of Engineering, University College of Engineering, Osmania University, Telangana, India.*

[1]*Corresponding Author : itssoujis@gmail.com*

Received: 02 July 2024 Revised: 03 August 2024 Accepted: 02 September 2024 Published: 28 September 2024

Abstract *- In today's electrical system, the integration of Solar Photo Voltaic (PV) into the grid is actively promoted to address the rising demand for electrical power and mitigate environmental concerns associated with fossil fuel consumption. Power Quality (PQ) emerges as a crucial concern that impacts both utilities and consumers. The onset of PQ issues in the contemporary electric power system stems from the interconnection of PV, the adoption of grid technologies, the widespread utilization of power electronics equipment and the utilization of advanced optimization techniques to obtain maximum power from PV. This paper proposes a MOGWO controller-based PV DSTATCOM employing a PUC5 inverter to address the PQ problems, which are to obtain the maximum power from the three solar panels and minimum Total Harmonic Distortion. The voltage-source inverter's control signals are derived through the PQ control scheme. The effectiveness of the suggested system is validated through MATLAB outcomes. The results underscore the significance of the proposed MOGWO-based MPPT algorithm in enhancing performance and notable enhancements achieved in the performance of the PV-DSTATCOM, leading to simultaneous improvements in current Total Harmonic Distortion (THD), which is obtained around 3.29%.*

Keywords *- Multi Objective Grey Wolf Algorithm (MOGWO), Photovoltaic Distribution Static Compensator (PV-STATCOM), PQ control, MPPT, MLI.*

1. Introduction

Photovoltaic (PV) power generation represents a promising solution in our pursuit of sustainable energy. Harnessing the boundless energy of the sun, PV technology PV technology showcases human creativity and advancement; from its modest origins, PV has burgeoned into a thriving and rapidly growing industry worldwide.

At its core, PV power generation epitomizes the fusion of cutting-edge semiconductor [1] materials and the awe-inspiring photovoltaic effect, seamlessly transforming sunlight into a potent source of direct current energy. Since the inception of solar cells, relentless advancements in materials science and technological prowess have catalyzed a remarkable evolution, propelling PV systems into the realm of affordability. Moreover, the landscape of renewable energy policy has portrayed an instrumental task in fostering the proliferation of PV technology on a worldwide scale. Initiatives such as feed-in tariffs and mandates for renewable energy integration have provided fertile ground for the flourishing adoption of PV solutions across diverse nations and regions [2]. Given the inherent variability of PV power generation due to meteorological factors, managing its intermittent and stochastic nature becomes paramount for grid stability and reliability. One innovative solution that has emerged to address this challenge is the Static synchronous Compensator (STATCOM) [3].

STATCOM represents a paradigm shift in shunt reactive power compensation technology. Leveraging converter technology, STATCOM functions akin to a source of variable voltage and current, offering precise control over the amplitude and phase of the delivered voltage/current. This control capability enables STATCOM to dynamically modulate the penetration of reactive power into the grid, effectively mitigating voltage fluctuations and enhancing grid stability. In the realm of distribution networks, a specialized variant known as D-STATCOM assumes prominence.

Tailored for the intricacies of distribution systems, D-STATCOM fulfils a vital role in bolstering voltage regulation and power quality, thereby fortifying the resilience of the grid in the face of fluctuating PV power output. As the adoption of PV technology continues to surge, the integration of grid-connected PV systems with reactive power compensation assumes pivotal importance in alleviating grid stress and enhancing power quality compensation of reactive power [4] by integrating DSTATCOM with a grid to improve the power quality of the system Utilization of enhanced control methods to achieve Maximum Power Point Tracking (MPPT), thereby yields maximum energy from the PV array.

The quest for efficient MPPT algorithms in the realm of photovoltaic systems has been a subject of extensive inquiry, as highlighted in the literature [5]. An ideal MPPT algorithm should exhibit characteristics such as smooth and steady tracking behavior, ensuring optimal power extraction while mitigating the impact of transient phenomena. Moreover, adaptability emerges as a crucial attribute, enabling the algorithm to adjust dynamically in response to fluctuations in environmental conditions and system parameters, thereby maximizing energy yield and safeguarding the longevity of PV components. Several MPPT methods have been discussed to improve the competence of Photovoltaic (PV) systems. Notable among these are Hill Climbing (HC), Perturb and Observe (P&O), and Incremental Conductance (IC).

The HC [6] method involves perturbing the power converter duty ratio, while P&O [6-8] perturbs the PV system operating voltage. However, these both suffer from oscillations around the Maximum Power Point (MPP) due to continuous perturbations aimed at maintaining MPP, resulting in power loss. The P&O algorithm's performance is influenced by parameters such as perturbation rate and size.

In response to these limitations, the IC [9] method was introduced to reduce oscillations and improve module efficiency. Although it mitigates oscillations compared to P&O, it may not eliminate them. Additionally, both P&O and IC techniques combat difficulties when dealing with fluctuating weather conditions [10, 11]. These findings underscore the ongoing efforts to develop MPPT algorithms that offer robust performance under dynamic environmental conditions. Researchers are constantly investigating innovative methods to reduce oscillations, improve efficiency, and guarantee adaptability, with the goal of maximizing power extraction from Photovoltaic (PV) systems under different operating conditions.

In addition to the conventional Incremental Conductance (IC) algorithms, several improved versions have been proposed to increase the Maximum Power Point Tracking (MPPT) capability, particularly in scenarios involving fast-changing irradiance levels and load conditions [12, 13]. Notably, these advancements aim to achieve a rapid response in tracking the MPP under dynamic operating conditions. One notable approach involves the introduction of trigonometric rules, as outlined in [13], to build a connection between the PV system's I-V curve and load line, the load line and the I-V curve of the PV system. This method facilitates faster MPP tracking by leveraging simple mathematical principles to optimize power extraction, especially in situations where irradiance levels and load characteristics fluctuate rapidly.

Additionally, a specialized MPPT controller is suggested for photovoltaic systems that function in environments with rapidly changing sunlight intensity and partial shading [14]. This innovative controller employs a scanning technique to systematically explore the operating conditions and ascertain the highest power-delivery capability of the PV panel in real-time. By dynamically adapting to changing environmental considerations, like insolation levels and partial shading effects, this controller ensures efficient MPP tracking and maximizes power output under dynamic operating scenarios.

Metaheuristic optimization methodologies, including Particle Swarm Optimization (PSO) [15] and Firefly algorithms [16], have been widely utilized in engineering applications. Mirjalili et al. introduced Grey Wolf Optimization (GWO) [17], which motivated grey wolves to hunt. GWO provides a strong and swift convergence in contrast to alternative optimization methods. It necessitates fewer parameters for adjustment and fewer operators, which gives it an edge in expeditious design procedures.

While GWO has gained considerable attention in the research community, its application in designing MPPT algorithms remains relatively unexplored. Therefore, this study aims to leverage GWO to design an efficient MPPT algorithm tailored to address the challenges by harnessing its unique capabilities. The proposed MPPT algorithm seeks to achieve superior tracking performance, ensuring optimal power extraction from PV systems.

The DSTATCOM can be realized by using various MLI technologies. There are a number of Multilevel inverter technologies for DSTATCOM in the literature [18-22]. These inverters have certain disadvantages as the level of the inverter is increased, like an increased number of capacitors in flying capacitor MLI, increased number of DC sources in H bridge MLI and increased number of clamping diodes in NPC MLI with increase of levels of inverter.

In this article, a comprehensive grid-connected PV simulation system featuring D-STATCOM is meticulously elucidated. Furthermore, an in-depth analysis of the structure and functionalities of D-STATCOM is provided, emphasizing its pivotal role in coordinating power flow, stabilizing voltage, and enhancing power quality within the grid. The effectiveness of the suggested control method is rigorously authenticated through extensive simulation studies, which corroborate its ability to mitigate current harmonics, improve power quality and ensure smooth PV integration into the grid.

Even though there is much literature available on the maximization of solar power and the reduced power quality issues using evolutionary algorithms, there are still gaps in improving the power quality because of the low convergence rate, oscillation at the point of maximum power and estimation of local and global MPP. In view of this, this article utilizes a PUC 5 inverter to realize the DSTATCOM and a Multi Objective GWO to reduce the current harmonics in the grid connected PVDSTATCOM. The structure of this article is as follows:

Section 2: This section explains the grid-connected PV DSTATCOM with a PUC-5 multi-level inverter, which is controlled using the PQ Reference frame theory.

Section 3: Here, the Maximum Power Point Tracking (MPPT) algorithm based on Multi Objective Grey Wolf Optimization (MOGWO) is detailed. This section elaborates on the methodology employed to track the efficient MPPT.

Section 4: This section depicts the proposed multi-objective GWO and the simulation outcomes obtained through the implementation of the MOGWO-based MPPT algorithm. It offers insights into the suggested algorithm's performance, validating its efficacy in view of Current THD.

Section 5: Ultimately, the paper ends by summarizing the key findings and implications drawn from the study. It underscores the significance of the projected MPPT based on the GWO algorithm in enhancing the performance and reliability of PV Systems.

2. Grid Connected PV DSTATCOM with 5 Level PUC 5 Inverter

The illustrated comprehensive setup in Figure 1 includes an Alternating Current (AC) grid supplying power to the connected load, and it also integrates solar Photovoltaics (PV) through a Voltage Source Inverter (VSI) control that includes a PV-DSTATCOM, (PV-DSTATCOM) connected to the AC grid's Point of Common Coupling (PCC). The interfacing inductance (Lf) connects the PV-DSTATCOM to the AC network. Additionally, the RC ripple filters (rrf and crf) are used to reduce ripples caused by switching.

The paper employs a 5 level Packed U-cell (PUC5) inverter topology [23], delving into various design considerations such as switching approaches, DC capacitor voltage balancing, and the determination of switch voltage ratings, which is illustrated in Figure 2.

The switching table for operating the switches of the 5-level packed U cell Inverter is detailed in Table 1.

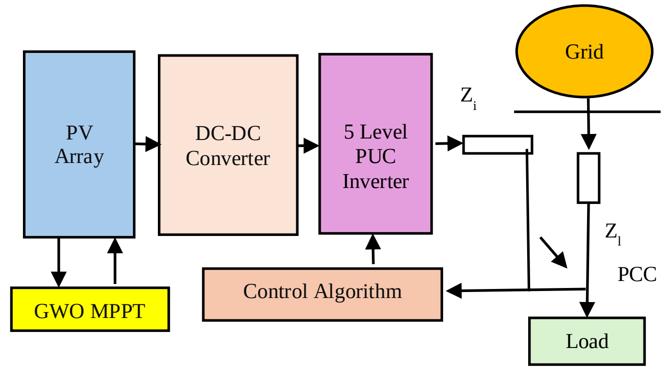

Fig. 1 Schematic representation of the overall proposed system

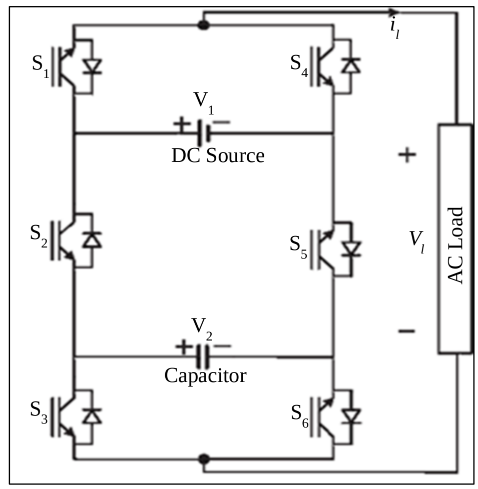

Fig. 2 5 level packed U-cell inverter

Table 1. Switching states of packed U cell 5

State	S1	S2	S3	S4	S5	S6	Output Voltage	Va
1	1	0	0	0	1	1	V1	Vdc
2	1	0	1	0	1	0	V1-V2	Vdc/2
3	1	1	0	0	0	1	V2	Vdc/2
4	1	1	1	0	0	0	0	0
5	0	0	0	1	1	1	0	0
6	0	0	1	1	1	0	0	-Vdc/2
7	0	1	0	1	0	1	V2-V1	-Vdc/2
8	0	1	1	1	0	0	0	-Vdc

In this paper, the control of the Voltage Source Inverter (VSI) is facilitated through the generation of triggering pulses coordinated by the PQ Reference Frame control strategy [24], as depicted in the comprehensive control approach illustrated in Figure 3. This holistic control methodology encompasses aspects of both AC and DC voltage regulation.

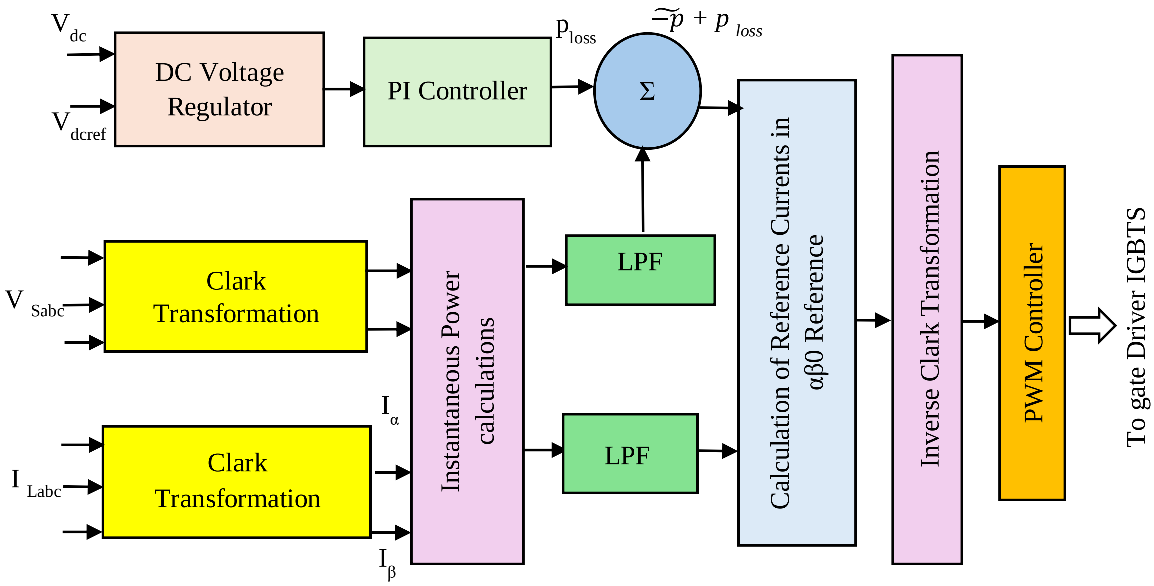

Fig. 3 Block diagram of instantaneous reactive power theory

3. Application of Grey Wolf Algorithm

An optimization method based on metaheuristics called the Grey Wolf Optimization (GWO) algorithm takes its cues from the social interactions and hunting strategies of grey wolves. Grey wolves usually will be in packs of about 6 to 12, and the social hierarchy for living or hunting consists of four levels as follows.

Introduced by Mirjalili et al., GWO has gained prominence in the field of optimization due to its simplicity, robustness, and fast convergence. One notable advantage of GWO is its capability to efficiently handle nonlinear objective functions, making it well-suited for a wide range of optimization problems. GWO possesses a remarkable benefit in its capacity to effectively manage nonlinear objective functions, rendering it highly suitable for a diverse array of optimization problems.

From the perspective of Tracking MPP design for Photovoltaic (PV) systems, GWO offers a promising alternative to traditional optimization techniques. By leveraging the collective intelligence and collaborative hunting behavior of grey wolves, GWO-based MPPT algorithms aim to dynamically adjust the operating parameters of PV systems to trace the Global Peak (GP) amidst changing environmental situations.

The application of GWO in MPPT design involves formulating an optimization problem to raise the power output of the PV system while considering constraints such as system limitations and environmental factors. GWO iteratively explores the solution space, simulating the predatory habits of grey wolves to converge towards the optimal operating point. The GWO algorithm incorporates a communal order shown in Figure 4 motivated by the behavior of grey wolves, consisting of 4 distinct types: α, β, δ, and ω. This hierarchy is mathematically modelled to emulate the leadership structure observed in wolf packs during hunting. The best answer in this hierarchy is called alpha (α), and the next two top solutions are called beta (β) and delta (δ), respectively. The remaining possible solutions belong to the omega (ω) class.

Grey wolves' hunting habits serve as an inspiration for the GWO algorithm, which incorporates crucial phases, including tracking, surrounding, and striking prey to speed up optimization tasks.

During the hunting process, grey wolves exhibit a coordinated strategy of encircling their prey before launching an attack. This encircling behavior is crucial for effectively trapping and capturing prey [25]. Figure 5 illustrates steps of the GWO algorithm: hunting and chasing.

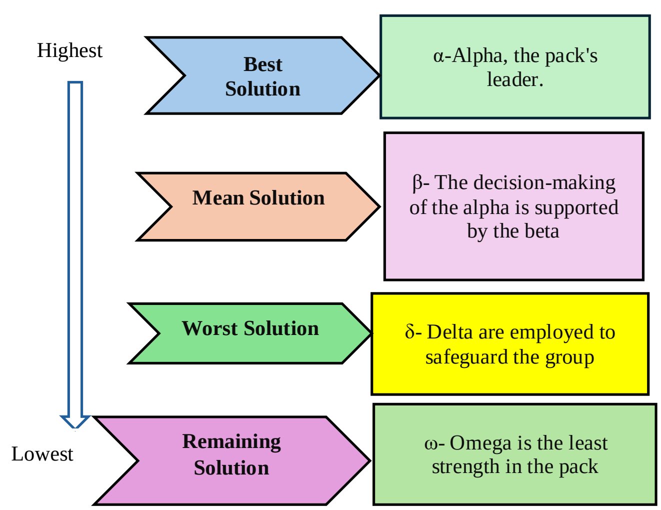

Fig. 4 Social hierarchical levels of grey wolves

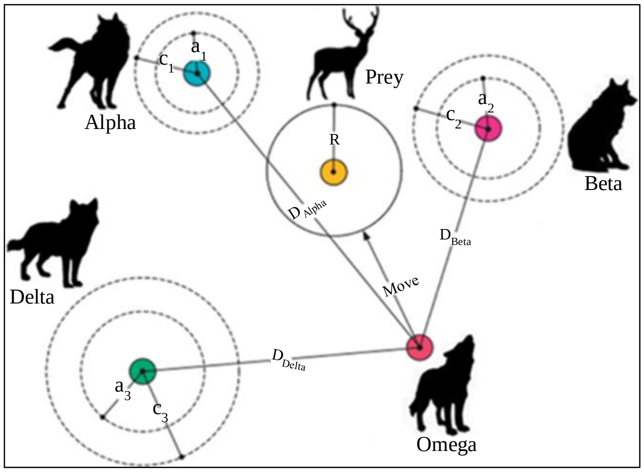

Fig. 5 Hunting nature of grey wolves: chasing and tracking prey

3.1. Mathematical Modelling of GWO

Mathematically, the encircling behavior observed in the GWO algorithm can be modelled using specific equations, which guide the optimization process towards converging on the optimal solution. These equations encapsulate the coordinated movement and strategic positioning of the grey wolves as they surround their target, ensuring a systematic and efficient approach to optimization.

The mathematical equations of chasing, attacking, encircling and attacking the prey are given below.

$$\vec{D} = \left|\vec{C}.\overrightarrow{X_p}(t) - \vec{X}(t)\right| \quad (1)$$

$$\overrightarrow{X_p}(t+1) = \overrightarrow{X_p}(t) - \vec{A}.\vec{D} \quad (2)$$

where the present iteration is denoted by t, coefficient vectors A and C are utilized, with Xp representing the position vector of the prey and X representing the position vector of a grey wolf. The vectors A and C are determined in the following manner:

$$\vec{A} = 2\vec{a}.\overrightarrow{r_1} - \vec{a} \quad (3)$$

$$\vec{C} = 2.\overrightarrow{r_2} \quad (4)$$

Where the elements of vector a are gradually reduced linearly from 2 to 0 throughout the iterations, while r1 and r2 represent random vectors within the range of 0 to 1

3.2. Pseudo Code of GWO

Begin
Initial a population of n grey wolf x_i = (i= 1, 2 ,...,n);
Initialize $\overrightarrow{A}$, $\overrightarrow{a}$ *and* $\overrightarrow{C}$
Calculate the fitness of each search agent;
Xα = best search agent;
Xβ = second best search agent;
Xγ= third best search agent;
while (t< MaxGeneration) or (stop criterion);
for each search agent
Update the position of the current search agent
End for
Update $\overrightarrow{A}$, $\overrightarrow{a}$ *and* $\overrightarrow{C}$
Calculate the fitness of all search agents;
Update Xα, Xβ and Xγ
t = t + 1
End while
Return Xα,
End

4. Proposed Multi-Objective Grey Wolf Optimization Method

4.1. Problem Formulation

To ensure maximum power from the three solar panels and minimum harmonics in the grid-connected system, this paper asserts a multi-objective optimization technique employing GWO. The stated grid-connected system with PUC 5 PV DSTATCOM and MOGWO is shown in Figure 6.

4.2. Objective Function

The objective of MO-GWO Optimization is the maximization of the power from solar panels and minimization of harmonics in the current as given by Equation (5).

$$Of = THD + \frac{1}{\frac{(P1+P2+P3)}{3}} \quad (5)$$

Where P1, P2 and P3 are the power output of the three solar panels of the three phase PUC5 inverter, and THD is the total harmonics distortion in current on the source side.

The expression 1/(P1+P2+P3)/3) represents the reciprocal of the average power output of three power measurements, P1, P2 and P3. The use of this term in a fitness function balances the solution's performance by emphasizing higher power outputs. In the context of an optimization problem where lower fitness values are better, minimizing this reciprocal term encourages solutions with higher average power outputs.

The algorithm is incentivized to find solutions that not only have low Total Harmonic Distortion (THD) but also maximize power output, striking a balance between power quality and quantity. Since power is maximum and THD is minimum, the inverse of per unit of power is taken, which will be minimum, so ultimately, the tuning is done for minimum values.

4.3. Implemented Research Methodology

In this paper, an active harmonic filter is used to reduce current harmonic distribution levels. This is called Photo Voltaic based Distributed Static Var Compensation (PV D-

STATCOM) and is used to mitigate current harmonic produced by the Non-Linear Diode Rectifier Load connected to enhance the quality of power of the system which is connected in the grid system. An inverter is an important part of any renewable energy power conversion for DC to AC. In this article, a recently developed packed U-cell (PUC5) inverter configuration is utilized in considering the design conditions, the number of components, the switching method, balancing of the voltage of DC capacitor and switches voltages ratings in comparation with the traditional multilevel inverter and is used to realize the PV DSTATCOM in the grid-connected system. The instantaneous reactive current control technique is used as the control strategy for PV STATCOM with hysteresis current control to generate the reference signals for the PUC 5-based DSTATCOM to mitigate the current harmonics. The system is simulated and analyzed to achieve the objective function using MOGWO, which tunes the Kp and Ki to sustain the DC voltage to the inverter to get the extreme power from the solar panels and to reduce the total harmonic distortion in source currents, which results due to the nonlinear diode rectifier connected to the system. The details of the grid system are given in Table 2.

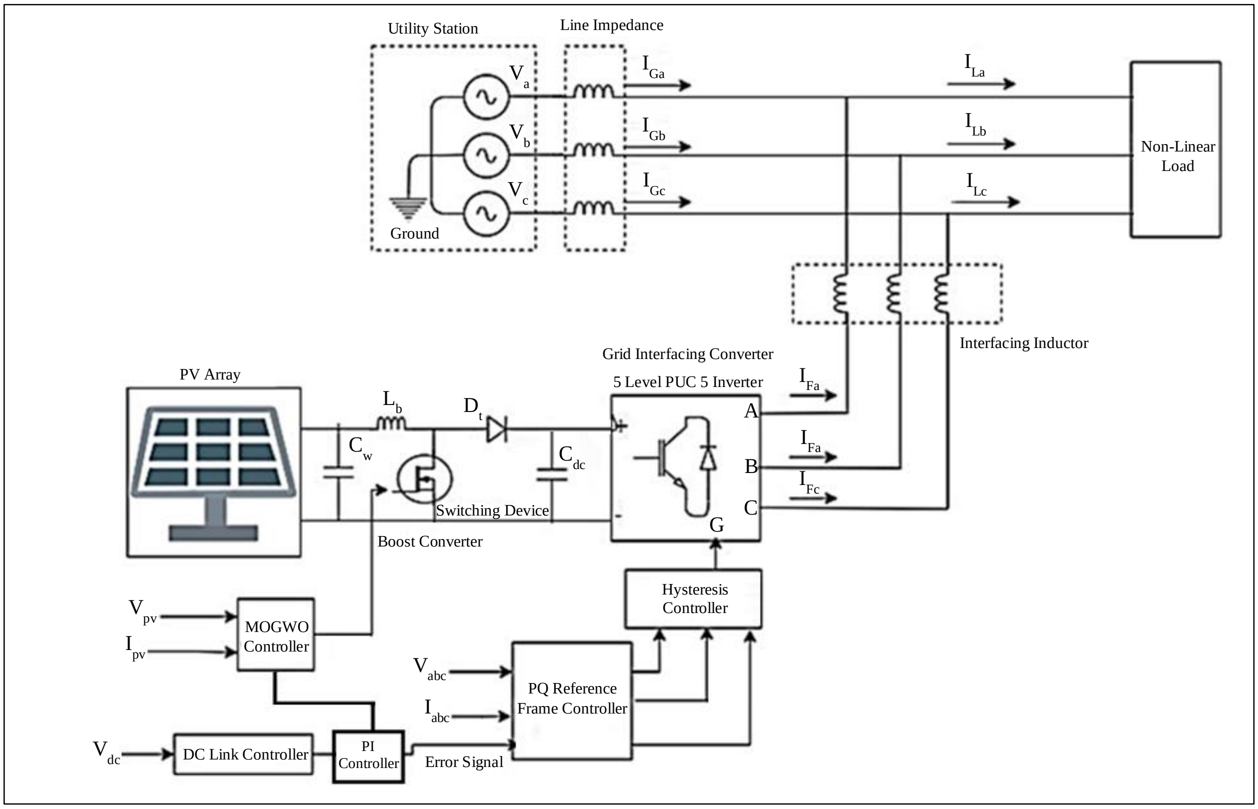

Fig. 6 Block diagram of grid-connected system MOGWO algorithm

Table 2. Specifications of grid and PV system

	Parameter	Value
Source voltage	Vph -Vph	400V(RMS)
	Frequency	50Hz
Line Impedance	Line Impedance	Rs=1Ω, Ls=0.1mH
Non-Linear Load	Three Phase Diode Bridge Rectifier with RL load	8Ω,0.4mH
Filter Capacitance	Filter Capacitance	0.01µ F
Solar PV	Temperature	25^0 C
	Irradiance	1000W/m^2
	Open Circuit Voltage	22.2 Volts
	Short Circuit Current	5A
DC-DC Boost Chopper	Inductance	1µ H
	Capacitance	2m F

4.4. Tuning of Gains of PI Controller

The MOGWO technique fine-tunes the parameters, which includes,

- Determining the optimal voltages for three PV panels to get the extreme power output from the PV.
- Tuning the values of Kp and Ki of the PI controller to generate a voltage error signal.

The objective function of Multi-objective GWO Optimization is,

- Maximization of the power output of 3 solar panels.
- Minimization of THD.

In the context of tuning the Kp and Ki values of a Proportional-Integral (PI) controller, GWO operates as follows.

1. Initialization: The algorithm initializes a population of grey wolves. In the context of tuning Kp and Ki, each wolf corresponds to a possible solution, where the positions of the wolves correspond to different combinations of Kp and Ki values.
2. Objective Function Evaluation: The performance criteria of the control system define the objective
3. function. For tuning Kp and Ki, the objective function typically measures how well the controller performs in terms of minimizing the error between the desired and actual outputs.
4. Searching for Optimal Solutions: The grey wolves collaborate in the search for the optimal solution (i.e., optimal Kp and Ki values). They employ three main hunting techniques.
5. Searching: Wolves search for prey in their territory. In the context of optimization, this corresponds to exploring the solution space by adjusting Kp and Ki values.
6. Chasing: Dominant wolves lead the hunting pack and chase prey. Similarly, in optimization, the dominant solutions guide the search towards promising regions in the solution space where the objective function is minimized.
7. Attacking: Wolves coordinate their attacks on prey. In optimization, this involves converging towards the best solution found so far.
8. Updating the Positions: Based on the hunting behavior, each wolf updates its position in the solution space. This is done iteratively, with wolves adjusting their positions based on their exploration and the influence of other wolves in the pack.
9. Selection of Optimal Solution: After a certain number of repetitions or when a termination criterion is met, the algorithm chooses the optimal solution found so far. In the context of tuning Kp and Ki, this corresponds to selecting the combination of Kp and Ki values that yield the minimal value of the objective function.

4.5. Parameter Selection

The various parameters are selected, and the algorithm is executed multiple times. The best results for which the algorithm converged are tabulated in Table 3.

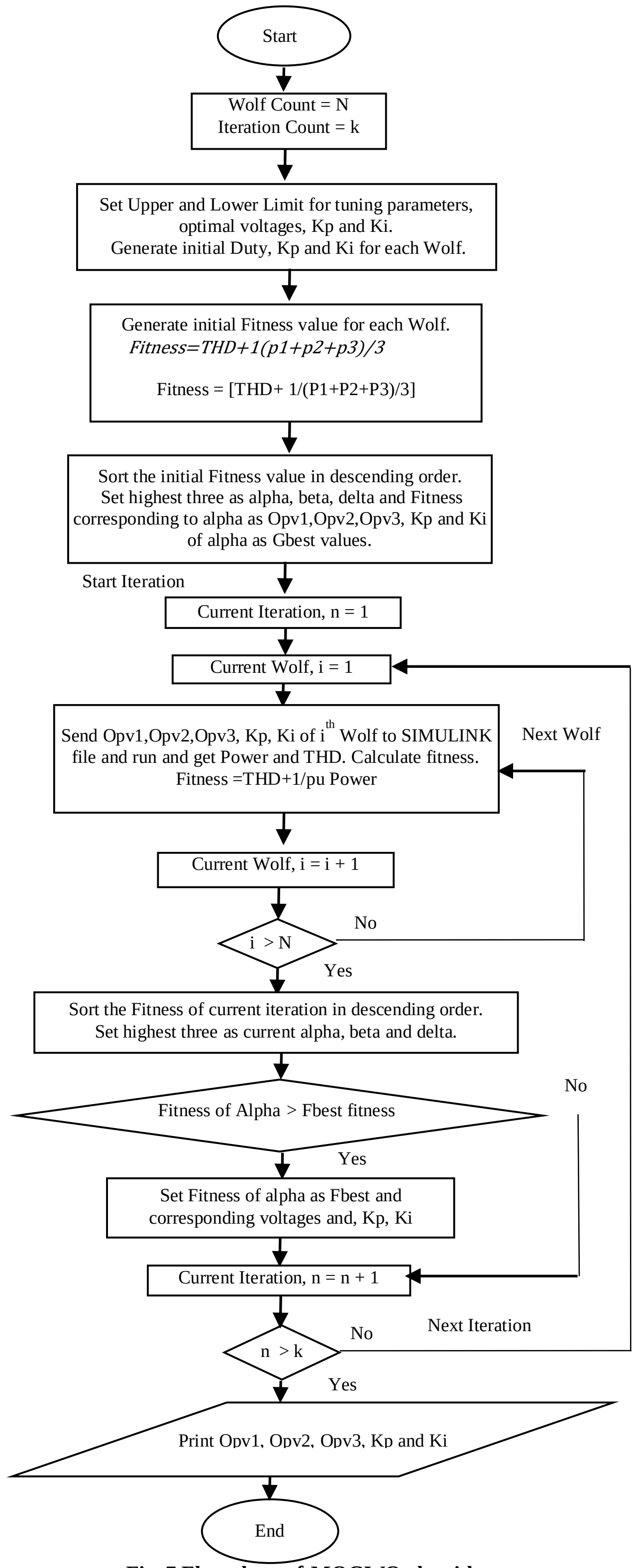

Fig. 7 Flow chart of MOGWO algorithm

By iteratively applying these steps, MOGWO explores the solution space to determine the best values of Kp and Ki that reduce the error and improve the performance of the PI controller in regulating the system. The flow chart of MOGWO for the proposed system to achieve the objective function is shown in Figure 7.

Table 3. Parameters selection for MOGWO

Parameter	Value
'N' Population Size	20
Iterations Count	20
Decision variables (Voltages to the three PV Panels, Kp and Ki)	5
a_{max}	0.2 (Initial value 1.8)
a_{min}	0 (Final Value 0)
K_{pmin} (Max value of proportional gain)	0.0001
K_{pmax} (Min value of proportional gain)	0.001
K_{imin} (Max value of integral gain)	0.01
K_{imax} (Min value of integral gain)	0.1
Optimum Voltage of three PV panels (Minimum)	70V
Optimum Voltage of three PV panels (Maximum)	100V

5. Results and Discussion

The MOGWO-based solar PV fed DSTATCOM is simulated in MATLAB, and the best values of proportional and integral gains obtained by Simulating are tabulated in Table 4, which results in an optimum value of DC voltage to the PV panels reducing the current THD to 3.29%.

Table 4. Gain values of PI controller

MPPT Optimization Technique	Proportional Gain (K_P)	Integral Gain (K_I)
Sliding Mode Control	0.006	0.08
MOGWO	0.0091	0.0987

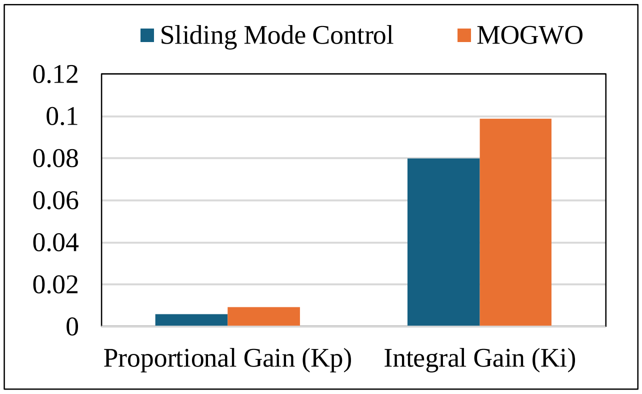

Fig. 8 Kp and Ki gains of PI Controller

It offers insights into the performance of the suggested algorithm, validating its efficacy in view of Current THD in comparison to the PV DSTATCOM (PUC 5) with Sliding Mode Control. The FFT analysis of the harmonic spectrum of source current of the grid-connected PV DSTATCOM (PUC 5) with sliding mode control and MOGWO technique are shown in Figure 9(a, b), and the THD is tabulated in Table 5.

Table 5. Comparison table of THD of Grid side source current

Optimization Method	Grid Side Source Current
PV-DSTATCOM (PUC 5) with Sliding Mode Control	4.9%
PV DSTATCOM (PUC 5) with MOGWO Control (proposed)	3.29%

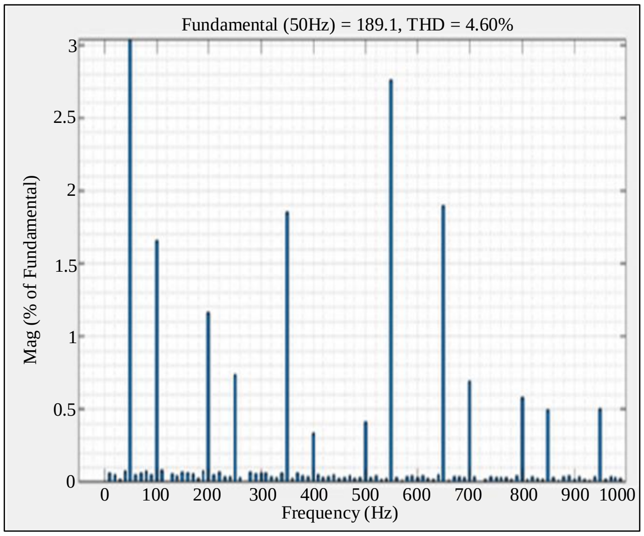

Fig. 9(a) Harmonic spectrum with sliding mode control

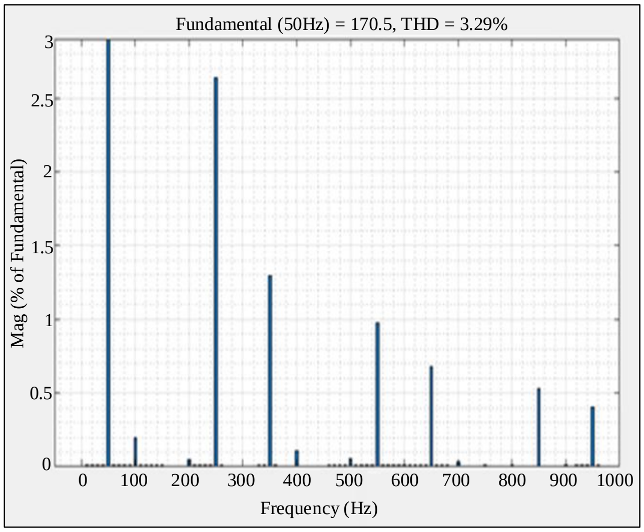

Fig. 9(b) Harmonic spectrum with MOGWO Control

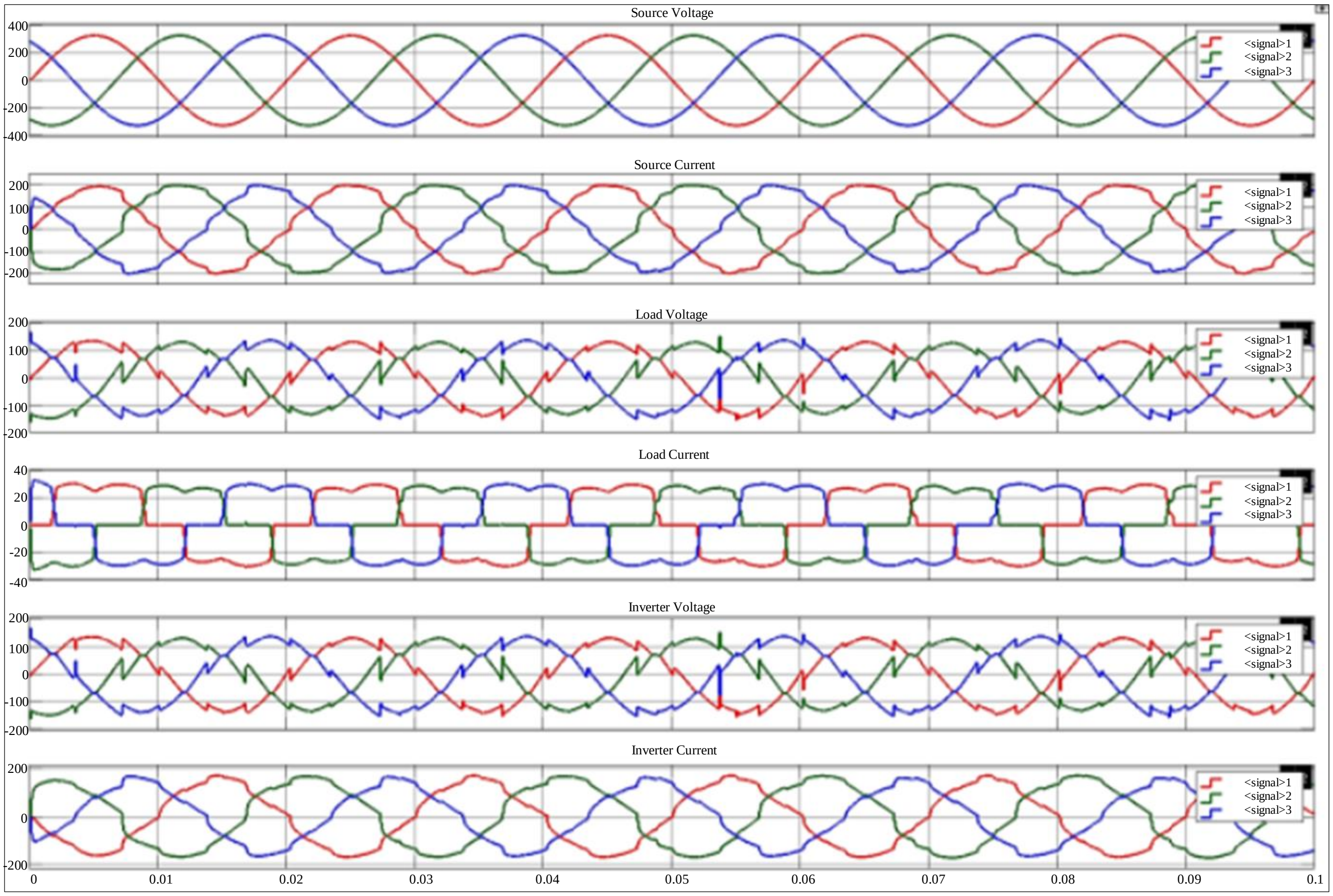

Fig. 10 Source voltage and current, voltage and current of load, voltage and current inverter waveforms with MOGWO control

Table 6. Best values of the fitness function of MOGWO

Parameter	Value
Optimum Voltage of Panel 1	94.4417 V
Optimum Voltage of Panel 2	94.4417 V
Optimum Voltage of Panel 3	94.4417 V
Kp of PI controller	0.0091
Ki of PI Controller	0.0987

Table 7 Optimum powers of PV panels

Parameter	Value
Optimum Power of Panel 1	4743 W
Optimum Power of Panel 2	7283 W
Optimum Power of Panel 3	6262 W

The operation PV-DSTATCOM representing grid voltages (vgabc), grid currents (igabc), load voltage (vlabc), load currents (iLabc), and PVD voltage (vpvabc), currents (iPVDabc) simulated with PUC5 inverter and MOGWO technique are shown in Figure 10. The best values obtained by MOGWO are tabulated in Table 6. The optimized value of PV power of the three solar panels obtained through the simulation of MOGWO is tabulated in Table 7.

6. Conclusion

This paper introduces an advanced operational framework for the unified PV DSTATCOM, offering a comprehensive explanation of its operation concerning Power Quality (PQ) enhancement by reducing the current harmonics. The study utilizes the proposed MOGWO algorithm, seeks to achieve superior tracking performance, improves the tracking efficiency, converges at a faster rate and reaches the maximum power point, ensuring optimal power extraction from PV systems by adjusting the gain values of the PI controller, as well as to determine the optimal voltages for the three PV panels of the three-phase inverter.

It can also eliminate the harmonic components of the load current. It provides a chance to maximize the power output of the three PV panels while minimizing the THD in the source current because it keeps the source voltage and current in phase and supports the reactive power requirement for the solar panel and load at PCC in the grid system. The tuning of the gains of the PI controller is done using the MOGWO, which plays a vital role in reducing the error in the DC voltage reference so that appropriate control signals are released to the PVDSTATCOM inverter to mitigate the current harmonics injected into the source side due to nonlinear load connected. The effectiveness of the proposed system has been confirmed through simulation results. The article extensively evaluates the system's performance, demonstrating a significant improvement in the tuning of Kp and Ki and reducing current THD. Specifically, the achieved Kp value of 0.0091 and Ki value of 0.0987 are favorable in minimizing the objective function, i.e. the current THD value to 3.29%, which is significantly less in comparison with the higher current THD of 4.9% observed in the PV DSTATCOM with sliding mode control and with the THD obtained by PQ control in [26] which signifies the efficacy of MOGWO optimization.

References

[1] GAO Xibin, and LI Jiannin, "The Research and Development of Key Technology of PV Power Generation," *Journal of Shanghai Electric Technology*, vol. 6, no. 3, 2013.

[2] Ma Ning, "Overview and Development Prospects on Solar Photovoltaic," *Electrical Technology of Intelligent Buildings*, vol. 5, no. 2, pp. 25-28, 2011. [Google Scholar]

[3] D.J. Hanson et al., "STATCOM: A New Era of Reactive Compensation," *Power Engineering Journal*, vol. 16, no. 3, pp. 151-160, 2002. [CrossRef] [Google Scholar] [Publisher Link]

[4] S. Rajalingam et al., "Power Quality Improvement in the Distribution System by Interconnecting PV Using Hybrid DSTATCOM," *International Journal of Advanced Technology and Engineering Exploration*, vol. 9, no. 88, pp. 310-325, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[5] Hiren Patel, and Vivek Agarwal, "Maximum Power Point Tracking Scheme for PV Systems Operating under Partially Shaded Conditions," *IEEE Transactions on Industrial Electronics*, vol. 55, no. 4, pp. 1689-1698, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[6] Bidyadhar Subudhi, and Raseswari 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, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[7] Mohammed A. Elgendy, Bashar Zahawi, and David J. Atkinson, "Assessment of Perturb and Observe MPPT Algorithm Implementation Techniques for PV Pumping Applications," *IEEE Transactions on Sustainable Energy*, vol. 3, no. 1, pp. 21-31, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[8] Mohammed A. Elgendy, Bashar Zahawi, and David J. Atkinson, "Operating Characteristics of the P&O Algorithm at High Perturbation Frequencies for Standalone PV Systems," *IEEE Transactions on Energy Conversion*, vol. 30, no. 1, pp. 189-198, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[9] Mohammed A. Elgendy, Bashar Zahawi, and David J. Atkinson, "Assessment of the Incremental Conductance Maximum Power Point Tracking Algorithm," *IEEE Transactions on Sustainable Energy*, vol. 4, no. 1, pp. 108-117, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[10] Moacyr Aureliano Gomes de Brito et al., "Evaluation of the Main MPPT Techniques for Photovoltaic Applications," *IEEE Transactions on Industrial Electronics*, vol. 60, no. 3, pp. 1156-1167, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[11] N. Femia et al., "Optimization of Perturb and Observe Maximum Power Point Tracking Method," *IEEE Transactions on Power Electronics*, vol. 20, no. 4, pp. 963-973, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[12] Kok Soon Tey, and Saad Mekhilef, "Modified Incremental Conductance Algorithm Fr Photovoltaic System under Partial Shading Conditions and Load Variation," *IEEE Transactions on Industrial Electronics*, vol. 61, no. 10, pp. 5384-5392, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[13] Tey Kok Soon, and Saad Mekhilef, "A Fast Converging MPPT Technique for Photovoltaic System under Fast Varying Solar Irradiation and Load Resistance," *IEEE Transactions on Industrial Informatics*, vol. 11, no. 1, pp. 176-186, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[14] R. Kotti, and W. Shireen, "Efficient MPPT Control for PV Systems Adaptive to Fast Changing Irradiation and Partial Shading Conditions," *Solar Energy*, vol. 114, pp. 397-407, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[15] Kashif Ishaque et al., "An Improved Particle Swarm Optimization (PSO)-Based MPPT for PV with Reduced Steady-State Oscillation," *IEEE Transactions on Power Electronics*, vol. 27, no. 8, pp. 3627-3638, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[16] Kinattingal Sundareswaran, Sankar Peddapati, and Sankaran Palani, "MPPT of PV Systems under Partial Shading Conditions through a Colony of Flashing Fireflies," *IEEE Transactions on Energy Conversion*, vol. 29, no. 2, pp. 463-472, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[17] Seyedali Mirjalili, Seyed Mohammad Mirjalili, and Andrew Lewis, "Grey Wolf Optimizer," *Advances in Engineering Software*, vol. 69, pp. 46-61, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[18] Natarajan Prabaharan, and Kaliannan Palanisamy, “A Comprehensive Review on Reduced Switch Multilevel Inverter Topologies, Modulation Techniques and Applications,” *Renewable and Sustainable Energy Reviews*, vol. 76, pp. 1248-1282, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[19] C.W. Winil, and V. Aishwarya, “Comparative Study of Reduced Switch Multilevel Inverter Topologies,” *Intelligent Solutions for Smart Grids and Smart Cities*, pp. 461-477, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[20] Clark Hochgraf et al., “Comparison of Multilevel Inverters for Static Var Compensation,” *Proceedings of 1994 IEEE Industry Applications Society Annual Meeting*, Denver, CO, USA, vol. 2, pp. 921-928, 1994. [CrossRef] [Google Scholar] [Publisher Link]

[21] Marif Daula Siddique et al., “A New Multilevel Inverter Topology with Reduce Switch Count,” *IEEE Access*, vol. 7, pp. 58584-58594, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[22] Afshin Balal et al., “A Review on Multilevel Inverter Topologies,” *Emerging Science Journal*, vol. 6, no. 1, pp. 185-200, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[23] Hani Vahedi, and Kamal Al-Haddad, “PUC5 Inverter - A Promising Topology for Single-Phase and Three-Phase Applications,” *IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society*, Florence, Italy, pp. 6522-6527, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[24] Agrani Sharma, and Anil S. Thosar, “Distribution System Power Quality Improvement Using D-STATCOM,” *Journal of Advanced Research in Power Electronics & Power Systems*, vol. 5, no. 3&4, pp. 14-20, 2018. [Google Scholar] [Publisher Link]

[25] Satyajit Mohanty, Bidyadhar Subudhi, and Pravat Kumar Ray, “A New MPPT Design Using Grey Wolf Optimization Technique for Photovoltaic System under Partial Shading Conditions,” *IEEE Transactions on Sustainable Energy*, vol. 7, no. 1, pp. 181-188, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[26] Amit Kumar, Mukul Anand, and Pradeep Kumar, “Integration of PV Array in DSTATCOM with Comparative Analysis of Different Control Mechanisms,” *International Journal of Applied Engineering Research*, vol. 14, no. 2, pp. 169-176, 2019. [Google Scholar] [Publisher Link]