Journal of Engineering and Technology for Industrial Applications

ISSN ONLINE: 2447-0228

ITEGAM-JETIA

Manaus, v.11 n.51, p. 151-156. January/February., 2025.
DOI: https://doi.org/10.5935/jetia.v11i51.1334

RESEARCH ARTICLE OPEN ACCESS

PERFORMANCE ASSESSMENT OF A MULTI-VERSE OPTIMIZER BASED SOLAR-PV INVERTER FOR GRID CONNECTED APPLICATIONS

Venkata Anjani Kumar G[1], M. Damodar Reddy[2], Chilakapati Lenin Babu[3] and Palepu Suresh Babu[4].

[1] Assistant Professor,Department of EEE, Rajiv Gandhi University of Knowledge Technologies- Ongole, Ongole,Andhra Pradesh, India.
[2] Professor,Department of EEE, S V U College of Engineering, Sri Venkateswara University - Tirupati, Andhra Pradesh, India.
[3] Assistant Professor,Department of EEE, RSR Engineering College - Kadanuthala, Nellore, Andhra Pradesh. India.
[4]Assistant Professor,Department of EEE, Annamacharya University – Rajampet, Andhra Pradesh, India.

[1]http://orcid.org/0009-0004-3111-0525, [2]http://orcid.org/0000-0002-7113-5805,
[3]http://orcid.org/0000-0001-9749-979X, [4]http://orcid.org/0000-0001-5786-1395.

E-mail: anjishelectrical@gmail.com, mdreddy999@rediffmail.com, ch.leninbabusvu@gmail.com, sureshram48@gmail.com.

ARTICLE INFO

Article History
Received: October 14, 2024
Revised: November 20, 2024
Accepted: December 01, 2024
Published: February 28, 2025

Keywords:
Ant Lion Optimization,
Grid Current and Voltage,
Multi-Verse Optimization,
PV Inverter Control,
Total Harmonic Distortion.

ABSTRACT

As the need for renewable energy has increased over the preceding decade or so, grid connected Photovoltaic (PV) systems have grown in prominence. Effective control strategies have become vital role in ensuring the optimal performance of these systems, particularly in the sense of Power Quality (PQ), efficiency, and grid synchronization. Hence, this paper proposes a Multi-Verse Optimizer (MVO) based inverter controlling stratage for enhancing the concert of a grid connected PV system. The MVO algorithm is employed to determine optimal gain values for both the current and voltage controllers of the PV inverter. The anticipated MVO-based controller is rigorously evaluated through MATLAB/ Simulink, considering key performance indicators such as grid current total harmonic distortion (THD), grid's voltage and current, and PV's voltage and current. With the aim of demonstrating the effectiveness of the suggested technique, a comparative study is carried out using a 3.5 kW grid connected PV system test case, benchmarking the MVO-based controller in contradiction to an Ant Lion Optimizer (ALO) based controller. The simulation outcomes conclusively validate the superior demonstration of the proposed technique as compared to ALO controller across all evaluated cases, highlighting its capability to achieve notable improvements in grid-connected PV system performance.

I. INTRODUCTION

Growing global energy demand and heightened environmental concerns have catalyzed a significant surge in the integration of energy from renewable sources, especially photovoltaic solar systems, into the existing power grid [1]. Grid-connected PV systems offer a multitude of advantages, such as improved energy sustainability, decreased carbon emissions, and less dependence on fossil fuels [2]. However, the efficient operation of these systems necessitates the implementation of sophisticated control strategies to ensure optimal power transfer, maintain grid stability, and meet the stringent grid interconnection standards [3],[4].

Inverters are essential to the operation of PV systems that are associated to the grid. These inverters feed alternating current (AC) that may be provided into the grid from the direct current (DC) electricity obtained by the PV panels [5]. The performance of the inverter directly impacts the overall efficiency, power quality, and stability of the PV system connected to grid [6-8]. Therefore, designing and implementing effective control strategies for PV inverters is of paramount importance. Proper control techniques are essential to ensure that the PV inverter operates at its optimal efficiency, injects high-quality power into the grid, and maintains grid synchronization and stability [9-11].

Recent advancements in the field of optimization algorithms have opened up new avenues for enhancing the performance of PV inverter control systems. In the literature, numerous control techniques have been suggested to enhance the grid-connected PV inverter's performance, including conventional linear controllers, such as Proportional-Integral (PI) and Proportional-Resonant (PR) controllers, as well as cutting-edge governing strategies proceeding on Fuzzy Logic (FL), Neural Networks (NN), and Optimization Algorithms (OA) [12], [13]. Among these, optimization algorithms have gained substantial attention owing to their facility to handle non-linear system dynamics, uncertainties, and disturbances effectively [14].

An innovative approach in controlling grid-connected PV inverter using the Multi--Verse Optimizer (MVO) technique is introduced in this paper. The MVO algorithm is a fairly recent metaheuristic optimization method that lures inspiration as of Cosmological notions such as Worm Holes, Black Holes, and White Holes [15]. Due to its efficient exploration and exploitation capabilities, fast convergence speed, and overall robustness, the MVO algorithm has demonstrated promising results in solving various optimization problems across a widespread range of applications. The employment of the MVO-based control strategy in this work aims in order to improve the grid-connected PV inverter's performance by adhering to significant features like power quality, efficiency, and grid synchronization.

II. MATERIALS AND METHODS

II.1 MULTI-VERSE OPTIMIZER (MVO) ALGORITHM

A stochastic optimization technique called the Multi-Verse Optimizer was motivated by the fascinating ideas of wormholes, black holes, and white holes in Cosmology, introduced by Seyedali Mirjalili in 2016. The MVO algorithm simulates the dynamic interactions between these cosmic entities to effectively explore the search space and ultimately identify optimal solutions for complex optimization problems [16-18]. The core principles underlying the MVO algorithm are presented in Figure 1.

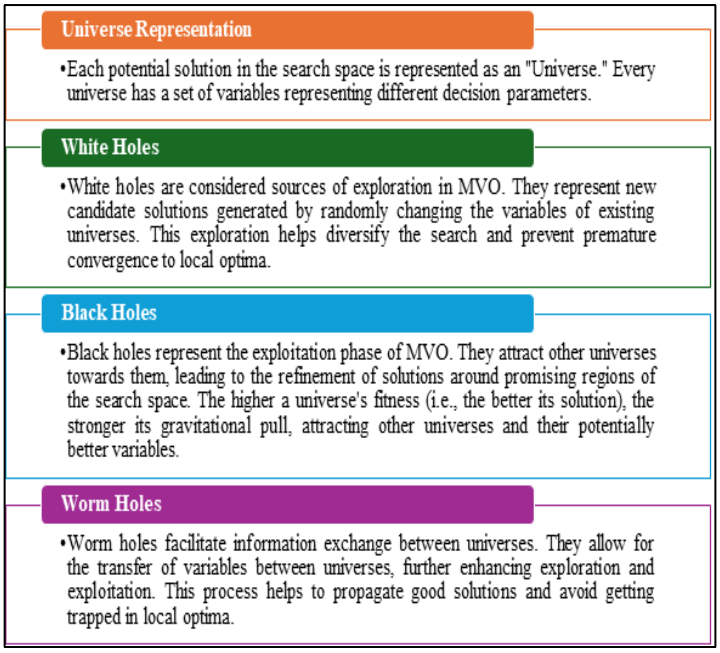

Figure 1: Core Principles of MVO Algorithm.
Source: Authors, (2025).

The MVO algorithm iteratively updates the positions and characteristics of universes constructed using the principles of Worm Holes, Black Holes, and White Holes. Over time, the universes converge towards the areas where the search could yield the best results, ultimately leading to the identification of optimal or near-optimal solutions. MVO has several advantages that make it suitable for optimizing complex problems such as Global Search Capability, Fast Convergence, Parameter Sensitivities etc. Due to these advantages, Feature selection, image processing, and other optimization problems and engineering design have all found successful applications of MVO. In the context of this paper, MVO is utilized to optimize the gain values of the voltage and current controllers of a grid coupled PV inverter, marking to enhance its overall performance.

II.2 OPTIMUM PV INVERTER CONTROL

PI controllers are widely used in grid-connected PV inverters for regulating current and voltage as a result of their easiness and effectiveness. However, the performance of a PI controller heavily relies on the proper selection value of its proportional gain and integral gain. Manually tuning of these gains can be a time-consuming and challenging task, as it often requires extensive experimentation and may not result in optimal performance, especially under varying operating conditions such as changing load, environmental factors, or grid disturbances. The manual tuning process can be further complicated by the PV system's complexity, non-linear dynamics and its interaction with the grid, making it difficult to achieve the desired functionality in various operational environments [19], [20].

The Multi-Verse Optimizer algorithm proves to be highly beneficial in this application, as it may effectively be constructed using the principles of Worm Holes, Black Holes, and White Holes to search for the optimal combination of proportional and integral gain values for the PI controller, to obtain this Integral Time Absolute Error (ITAE) which desires to be optimized. The ITAE of PI controller is specified as follows

$$\mathrm{ITAE} = \int_0^t t|e(t)|dt \qquad (1)$$

By optimizing these gain values, the MVO algorithm can minimize a predefined objective function that reflects the desired performance criteria, such as minimizing the grid current total harmonic distortion, dipping the steady-state error (ESS), and improving the dynamic response of the grid-connected PV inverter. This optimization process helps to overcome the challenges associated with manually tuning the PI controller gains, which can be a time-consuming and complex task, especially given the non-linear PV system's dynamics and its interface with the grid. The Figure 2 shows the MVO flowchart used to adjust the PI controller of a grid-connected PV inverter.

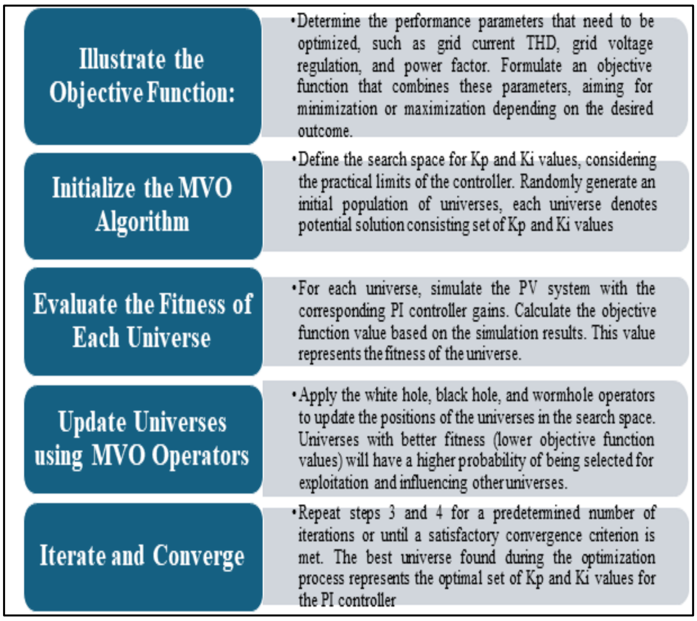

Figure 2: Flow Chart of MVO Algorithm.
Source: Authors, (2025).

The grid integrated PV inverter can operate more efficiently, reliably, and with better power quality if the PI controller is tuned using the MVO algorithm. This algorithm may cope with intricate, non-linear systems makes it well-suited for optimizing the dynamic behavior of the inverter under various operating conditions.

III. TEST CASE

This work proposes and implements a methodology for tuning PI controllers using Multi-Verse Optimizers. The system in consideration is a grid coupled PV system with a power output of 3.5 kW. The following are the initialization parameters of the MVO algorithm:

Population Size (N): 100
Number of Iterations (Max Iter): 500
White Hole Probability (W_H): 0.7
Black Hole Probability (B_H): 0.1
Fitness Function: ITAE

- **Procedure for optimal tuning of PI control using MVO algorithm:**

Step 1: Initialization:

$$X_{ij} = LB_j + rand(0,1) * (UB_j - LB_j) \quad (2)$$

Step 2: Fitness function: (X_i)

Step 3: White Hole: $X_{ij}(t+1) = X_{ij}(t)$ (3)

Step 4: Black Hole:

$$X_{ij}(t+1) = X_{ij}(t) + B_H + (Best_j - X_{ij}(t) \quad (4)$$

Step 5: WEP:

$$WEP(t) = WEP_{min} + \left(\frac{WEP_{max} - WEP_{min}}{Maxiter}\right) * t \quad (5)$$

Step 6: Worm hole Adjustment:

$$X_{ij}(t+1) = \begin{cases} X_{ij}(t) + TDR * (UB_j - LB_j) * rand; & \text{if } rand < WEP(t) \\ X_{ij}(t) - TDR * (UB_j - LB_j) * rand; & \text{otherwise} \end{cases} \quad (6)$$

IV. RESULTS AND DISCUSSIONS

To validate the efficacy of the proposed Multi-Verse Optimizer based PI controller tuning methodology, a series of simulations were conducted on a test case of 3.5 kW, PV system integrated to grid. The illustration of the MVO-tuned PI controller was rigorously correlated against a controller tuned using the ALO algorithm. This comparative analysis focused on critical performance indicators, including grid current and voltage, PV current and voltage, Total Harmonic Distortion under the following scenarios:

- Performance Evaluation of ALO Based PV Inverter
- Performance Evaluation of MVO Based PV Inverter

IV.1 PERFORMANCE EVALUATION OF ANT LION OPTIMZER BASED PV-INVERTER

In this case, Ant Lion Optimizer based Inverter is implemented on a grid associated PV system. The Figure 3 depicts the performance evaluation parameters including grid current and voltage, PV current and voltage, and Total Harmonic Distortion. These parameters are tested under different conditions of solar irradiance and ambient temperature.

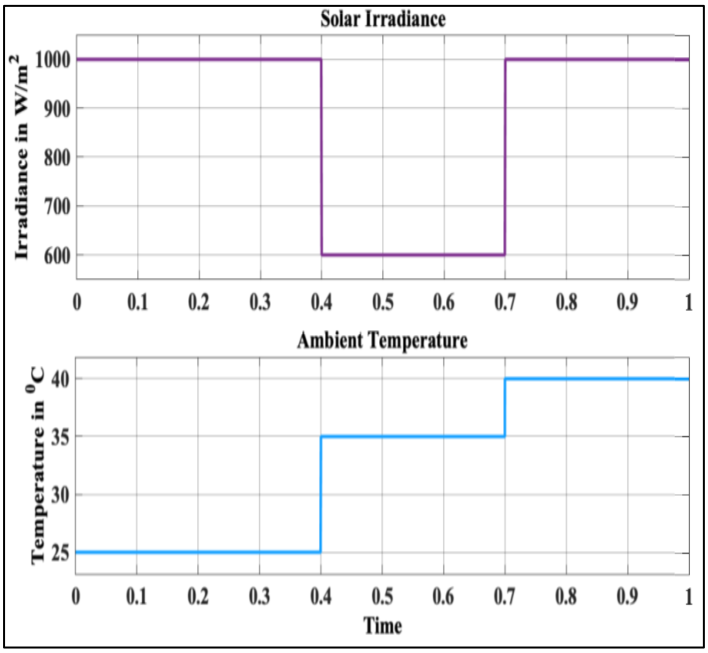

Figure 3: Solar Irradiation as well as Ambient Temperature.
Source: Authors, (2025).

The performance evaluation curves, including PV current and voltage, are as illustrated in Figure 4 below w.r.t solar irradiance and temperature.

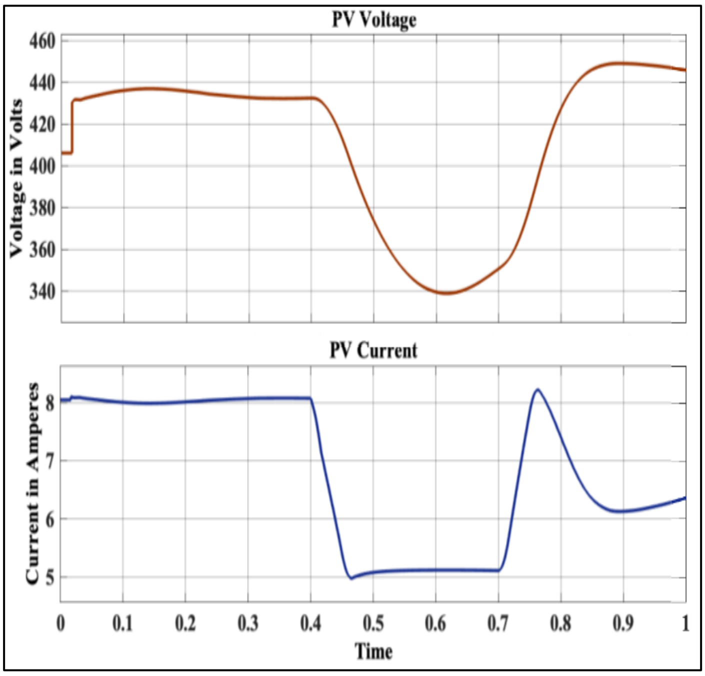

Figure 4: Photovoltaic Voltage and Current using ALO Algorithm.
Source: Authors, (2025).

The performance curves of the grid's current and voltage with ALO algorithm are depicted in Figure 5 below. These curves are met w.r.t grid integrated PV inverter control topology for variance in solar irradiations and temperatures.

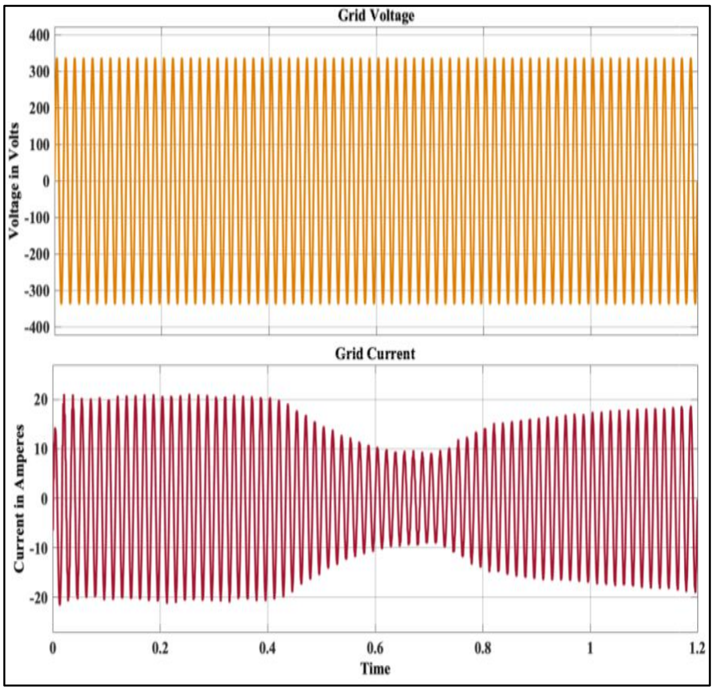

Figure 5: Grid's Voltage and Current using ALO Algorithm.
Source: Authors, (2025).

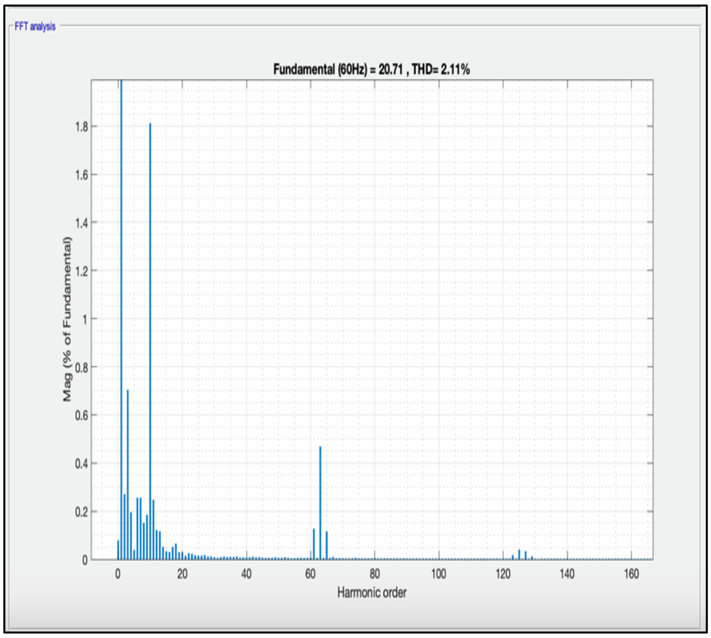

Figure 6: %THD Spectrum using ALO Algorithm.
Source: Authors, (2025).

The Figure 6 shows that the %THD spectrum obtained using an ALO-based PV inverter is 2.11%. The %THD analysis further is investigated by MVO technique for the superior performance of PV inverter.

IV.2 PERFORMANCE EVALUATION OF META-VERSE OPTIMIZER BASED PV-INVERTER

In this case Multi-Verse Optimizer based Inverter is implemented on a grid linked PV system. Figure 7 shows the performance evaluation parameters including grid current and voltage, PV current and voltage, and Total Harmonic Distortion. These parameters are tested under different conditions of solar irradiance and ambient temperature.

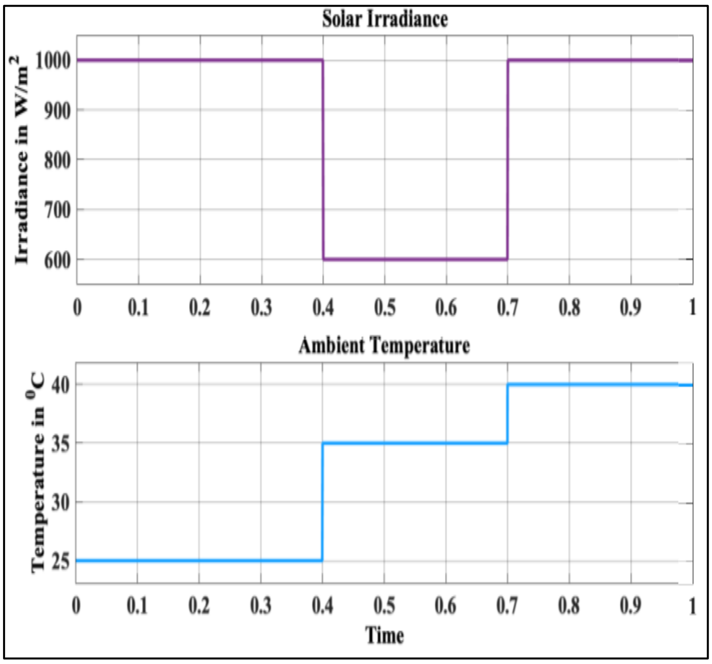

Figure 7: Solar Irradiation as well as Ambient Temperature.
Source: Authors, (2025).

The performance evaluation parameters including PV's current and voltage, are as illustrated in Figure 8 w.r.t solar irradiations and temperature obtained in Figure 7. The inverter output is obtained accordingly and it can be shown that MVO algorithm-based PV inverter gives enhanced results when compared to ALO algorithm.

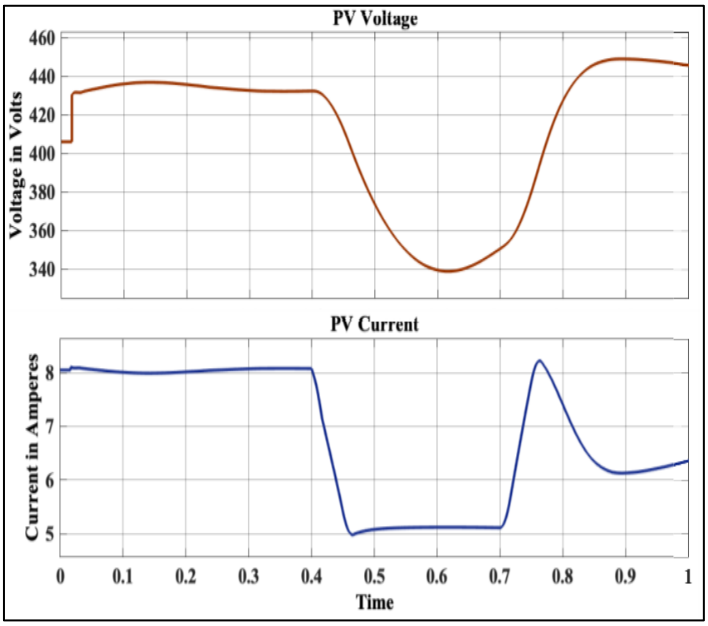

Figure 8: Photovoltaic Voltage and Current utilizing MVO Algorithm.
Source: Authors, (2025).

The evaluating performance parameters like the current and voltage of the grid are depicted in Figure 9, according to PV inverter output.

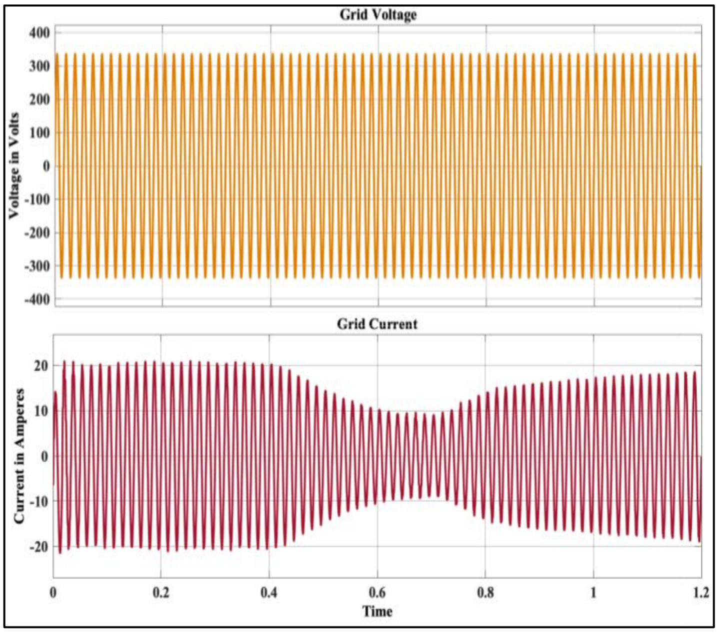

Figure 9: Grid's Voltage and Current using MVO Algorithm.
Source: Authors, (2025).

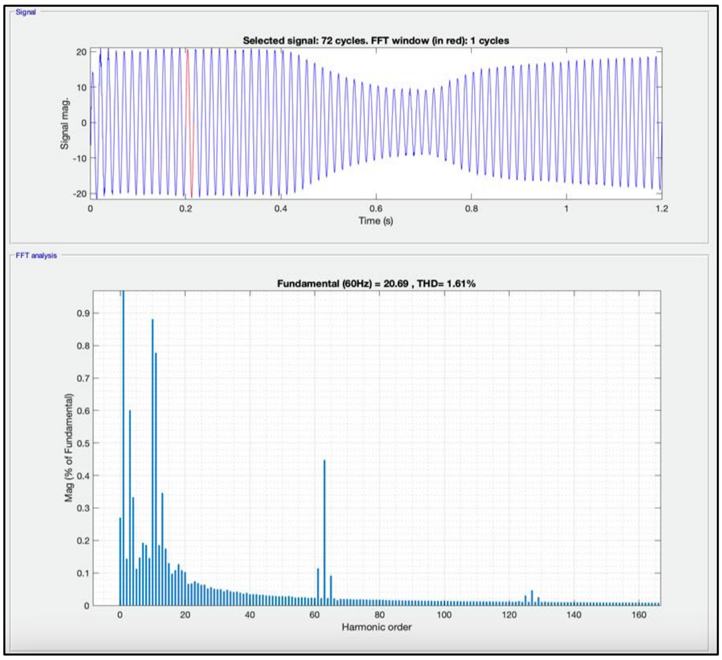

Figure 10: %THD window using MVO Algorithm
Source: Authors, (2025).

The Figure 10 shows that THD analysis using an MVO-based PV inverter is 1.61% and thus enhanced output results have obtained. According to the test case considered, the simulation results show that the proposed MVO-based PV inverter performs better than the ALO algorithm, with a reduction in THD of 2.11% to 1.61% and enhanced inverter output associated to grid connection w.r.t solar irradiations and temperatures considered. The comparisons of inverter control topologies of the test case is shown in Table 1.

Table 1: Comparison of PV Inverter Control Strategies.

Type of PV-Inverter Control	**%THD**
Ant Lion Optimization	**2.11%**
Meta-Verse Optimization	**1.61%**

Source: Authors, (2025).

V. CONCLUSIONS

This study investigated the efficacy of employing the Multi-Verse Optimizer (MVO) algorithm for tuning the PI controller of a grid-connected PV inverter. The performance of the MVO-tuned controller was rigorously evaluated through extensive simulations and compared against a benchmark controller tuned using the Ant Lion Optimizer (ALO) algorithm. The results unequivocally demonstrate the superiority of the MVO-based PI controller across all evaluated metrics.

The MVO algorithm effectively minimized grid current THD, ensuring compliance with stringent power quality standards. Additionally, it significantly enhanced grid current and voltage regulation, even under fluctuating solar irradiance and varying load conditions, highlighting its robustness. Furthermore, the MVO-tuned controller facilitated improved power extraction from the PV panels, leading to enhanced overall system efficiency. The THD is decreased from 2.11 % to 1.61 % as compared to ALO algorithm.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Venkata Anjani Kumar G,M.Damodar Reddy,
Methodology: Venkata Anjani Kumar G.
Investigation: Venkata Anjani Kumar G, Palepu Suresh.
Discussion of results: Venkata Anjani Kumar G, Chilakapati Lenin Babu.
Writing – Original Draft: Venkata Anjani Kumar G, Chilakapati Lenin Babu.
Writing – Review and Editing: Venkata Anjani Kumar G, Chilakapati Lenin Babu.
Resources: Venkata Anjani Kumar G and Palepu Suresh.
Supervision: M.Damodar Reddy.
Approval of the final text: Venkata Anjani Kumar G, Chilakapati Lenin Babu, Palepu Suresh.

VII. REFERENCES

[1] B. Aldbaiat, M. Nour, E. Radwan, and E. Awada, "Grid-Connected PV System with Reactive Power Management and an Optimized SRF-PLL Using Genetic Algorithm," Energies, vol. 15, no. 6, p. 2177, Mar. 2022, doi: 10.3390/en15062177.

[2] T. Eswara Rao and S. Elango, "Implementation of FPGA Based MPPT Techniques for Grid-Connected PV System," Intelligent Automation & Soft Computing, vol. 35, no. 2, pp. 1783–1798, 2023, doi: 10.32604/iasc.2023.028835.

[3] M. Hajji, Z. Yahyaoui, M. Mansouri, H. Nounou, and M. Nounou, "Fault detection and diagnosis in grid-connected PV systems under irradiance variations," Energy Reports, vol. 9, pp. 4005–4017, Dec. 2023, doi: 10.1016/j.egyr.2023.03.033.

[4] M. Ikić and J. Mikulović, "Experimental Evaluation of Distortion Effect for Grid-Connected PV Systems with Reference to Different Types of Electric Power Quantities," Energies, vol. 15, no. 2, p. 416, Jan. 2022, doi: 10.3390/en15020416.

[5]C. Buzzio, Y. S. Poloni, G. G. Oggier, and G. O. García, "A current-source DC-AC converter and control strategy for grid-connected PV applications," International Journal of Electrical Power & Energy Systems, vol. 154, p. 109399, Dec. 2023, doi: 10.1016/j.ijepes.2023.109399.

[6] M. Morey, N. Gupta, M. M. Garg, and A. Kumar, "A comprehensive review of grid-connected solar photovoltaic system: Architecture, control, and ancillary services," Renewable Energy Focus, vol. 45, pp. 307–330, Jun. 2023, doi: 10.1016/j.ref.2023.04.009.

[7] V. Boscaino et al., "Grid-connected photovoltaic inverters: Grid codes, topologies and control techniques," Renewable and Sustainable Energy Reviews, vol. 189, p. 113903, Jan. 2024, doi: 10.1016/j.rser.2023.113903.

[8] K. Li, Z. Chen, Y. Wang, X. Wu, and T. Wang, "Development of Highly Adaptable Inverter with Power Quality Control Ability," in 2023 IEEE 5th International Conference on Civil Aviation Safety and Information Technology

(ICCASIT), Dali, China: IEEE, Oct. 2023, pp. 1345–1349. doi:10.1109/ICCASIT58768.2023.10351649.

[9] J. Girona-Badia, V. A. Lacerda, E. Prieto-Araujo, and O. Gomis-Bellmunt, "Enhancing the AC network stability with a grid-forming control for single-stage PV inverter," Electric Power Systems Research, vol. 235, p. 110666, Oct. 2024, doi: 10.1016/j.epsr.2024.110666.

[10] Venkata Anjani Kumar G and M. Damodar Reddy, "Mitigation of grid current harmonics by ABC-ANN based shunt active power filter," ARASET, vol. 33, no. 1, pp. 285–298, Oct. 2023, doi: 10.37934/araset.33.1.285298.

[11] L. B. Chilakapati and T. G. Manohar, "Power Quality Enhancement in a Grid-Integrated Solar-PV System with a Hybrid UPQC Control Strategy," JSESD, vol. 13, no. 2, pp. 120–137, Aug. 2024, doi: 10.51646/jsesd.v13i2.220.

[12] C. Lenin Babu and T. Gowri Manohar, "Control Strategies for Mitigating Power Quality Issues in Renewable Energy Coordinated Microgrid—A Comprehensive Review," in Proceedings from the International Conference on Hydro and Renewable Energy, vol. 391, B.-M. Hodge and S. K. Prajapati, Eds., Singapore: Springer Nature Singapore, 2024, pp. 417–428. doi: 10.1007/978-981-99-6616-5_47.

[13] W. V. Jahnavi and J. N. C. Sekhar, "A comprehensive review on application of AI algorithms for Grid connected Solar Photovoltaic Systems," ITEGAM, vol. 10, no. 49, 2024, doi: 10.5935/jetia.v10i49.1248.

[14] V. A. K. G., and M. D. Reddy, "PSO Trained Feed Forward Neural Network Based SAPF for Power Quality Enhancement in Distribution Networks," ijeetc, pp. 279–287, 2023, doi: 10.18178/ijeetc.12.4.279-287.

[15] Das Biswas, Sangita, Bikram Das, and Champa Nandi. "A comprehensive review of optimization techniques for power quality improvement using multilevel inverters." In AIP Conference Proceedings, vol. 3242, no. 1. AIP Publishing, 2024. doi: 10.1063/5.0234302.

[16] I. Aljarah, M. Mafarja, A. A. Heidari, H. Faris, and S. Mirjalili, "Multi-verse Optimizer: Theory, Literature Review, and Application in Data Clustering," in Nature-Inspired Optimizers, vol. 811, S. Mirjalili, J. Song Dong, and A. Lewis, Eds., Cham: Springer International Publishing, 2020, pp. 123–141. doi: 10.1007/978-3-030-12127-3_8.

[17] O. Ceylan, M. Neshat, and S. Mirjalili, "Optimization of Multilevel Inverters Using Novelty-driven Multi-verse Optimization Algorithm," in 2021 56th International Universities Power Engineering Conference (UPEC), Middlesbrough, United Kingdom: IEEE, Aug. 2021, pp. 1–6. doi: 10.1109/UPEC50034.2021.9548192.

[18] E. Hosseini, K. Z. Ghafoor, A. Emrouznejad, A. S. Sadiq, and D. B. Rawat, "Novel metaheuristic based on multiverse theory for optimization problems in emerging systems," Appl Intell, vol. 51, no. 6, pp. 3275–3292, Jun. 2021, doi: 10.1007/s10489-020-01920-z.

[19] V. A. K. G and M. D. Reddy, "Fuzzy and PSO tuned PI controller based SAPF for Harmonic Mitigation," IJEER, vol. 11, no. 1, pp. 119–125, Mar. 2023, doi: 10.37391/ijeer.110116.

[20] V. A. K. G and D. R. M, "Optimized PI tuning of DG-Integrated Shunt Active Power Filter Using Biogeography-Based Optimization Algorithm," JESA, vol. 56, no. 6, pp. 907–916, Dec. 2023, doi: 10.18280/jesa.560602.