Journal of Information Systems Engineering and Management
2025, 10 (39s)
e-ISSN: 2468-4376
https://jisem-journal.com/

Research Article

Enhanced Performance of Single-Phase Transformer less Inverter for Grid-Connected Photovoltaic Systems with Leakage Current Reduction

Mohammed Imran [1*], Manjula Mane[2]
[1*]*Research Scholar, Electrical Engineering Department, OUCE, Osmania University, Hyderabad, India*
[1*]*Email: imranmohammedphd@gmail.com*
[2]*Professor, Electrical Engineering Department, OUCE, Osmania University, Hyderabad, India*

ARTICLE INFO

Received: 22 Dec 2024

Revised: 17 Feb 2025

Accepted: 26 Feb 2025

ABSTRACT

Single-phase transformer less inverters is increasingly popular for small-scale grid-linked photovoltaic systems because of their higher effectiveness, low cost, and higher power density. Nevertheless, leakage current remains a significant concern in these inverters. To overcome these challenge, this paper presents a Lotus effect optimization algorithm (LEA) for enhanced performance of single-phase transformer less inverter for grid-linked photovoltaic systems with leakage current reduction .The major goal of the proposed method is to minimize ground leakage current, reduce THD, and enhance overall system performance and efficiency.The LEA is used to optimize the control signal of the inverter. The proposed technique is executed on the MATLAB platform and compared with existing techniques like the Manta Ray Foraging Optimization (MRFO), Chimp Optimization Algorithm (ChOA), and Improved Crayfish Optimization Algorithm (ICOA) to evaluate its performance. In contrast, existing methods demonstrate lower efficiency, with MRFO at approximately 96%, ChOA at approximately 91%, and COA at approximately 89%. This notable increase in efficiency underscores the superior performance and effectiveness of the proposed method, achieving approximately 99.5%, highlighting its enhanced capabilities compared to traditional approaches.

Keywords: Photovoltaic, Transformer less inverter, Common-mode voltage, Efficiency, Total Harmonic Distortion,High-Efficiency Rear-Contact.

Introduction

Energy from renewable sources, particularly PV schemes, has achieved significant attention because of the maximizing global demand for energy and the depletion of traditional resources [1]. Solar energy, as an inexhaustible and environmentally friendly power source, offers a promise alternative to conventional energy generation methods [2]. The incorporation of photovoltaic energy into power grids is gaining popularity, with ongoing efforts aimed at increasing the share of PV energy in the grid [3]. However, the widespread adoption of PV systems is hindered by the high cost of conversion schemes, particularly because of exclusive multi-winding transformers and filters in grid-linked inverter circuits [4]. PV inverter topologies can be categorized into transformer-based and transformer less inverters. While transformers offer galvanic separation to eliminate leakage current, they contribute to additional losses and increase both the cost as well as size of the inverter [5]. To address this, research has focused on designing transformer less inverters that reduce system cost and size but also introduce challenges, such as leakage currents caused by non-isolation [6]. High leakage currents are generated by stray capacitance with switch junction capacitance, charging as well as discharging due to fluctuating common-mode voltage (CMV) [7]. Various topologies, including oH5, H5, H6, HERIC, and HBZVR, have been proposed to address this issue, using common-mode clamping approach and freewheeling brushwood [8].These techniques aim to generate constant CMV and decouple the photovoltaic array from the grid during freewheeling periods [9]. Alternating Current bypass topologies have low transmission losses analyzed to Direct Current bypass ones, but some topologies, such as HBZVR, still face challenges in completely eliminating leakage current [10].

Literature review

In the literature, several research studies focus on reducing leakage current in photovoltaic (PV) systems at the distribution level using different techniques and approaches. Some of these studies are reviewed below:

Copyright © 2024 by Author/s and Licensed by JISEM. This is an open access article distributed under the Creative Commons Attribution License which permitsunrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Journal of Information Systems Engineering and Management
2025, 10 (39s)
e-ISSN: 2468-4376
https://jisem-journal.com/ **Research Article**

Kamalesh Chandra Rout[11]have presented rooftop solar power systems were a good substitute for land-based arrays since they use PV panels on building rooftops. This was addressed by proposing a Manta Ray Foraging Optimization (MRFO) approach to improve system performance and minimize power loss. C Yang *et al.* [12] have presented Single-diode, dual-diode, and three-diode solar cell methods can all have their parameters effectively estimated using ChOA. In terms of durability, global search capability, and convergence rate, ChOA was demonstrated to perform better than current algorithms. L Chaib*et al.*[13] have presented to improve the local and global search in estimating photovoltaic (PV) parameters, an enhanced ICOA was paired with fractional-order chaos maps (FC-maps) with a dimension learning-hunting (DLH) search strategy.

Xin Li*et al.*[14] have presented the link between electromagnetic interference (EMI) and leakage current in transformerless solar inverter systems using the common-mode (CM) circuit methods of current-source inverters. It identifies the variables influencing CM EMI and leakage current and offers techniques for precisely forecasting them with less computational complexity. L Jiang*et al.*[15] have presented a nine-switch inverter based on an AP-H9 to lower leakage current in transformerless 3-phase inverters for grid-tied PV systems. Reverse parallel diodes and a DC auxiliary circuit was added to the H8 inverter to efficiently minimize leakage current by limiting the CMV to two thirds of the DC voltage.

Despite significant advancements in single-phase transformer-less inverters for grid-linked photovoltaic schemes, leakage current remains a critical challenge, impacting both system efficiency and safety. Various optimization algorithms, such as MRFO, ChOA, and ICOA, have been explored to mitigate this issue; however, each has inherent limitations that hinder their effectiveness. MRFO, while useful in certain aspects, struggles with fine-tuning system parameters for optimal leakage current reduction, leading to suboptimal performance. ChOA, despite its strong global search capability, suffers from slow convergence and inefficient local search optimization, making it less effective in addressing leakage current in transformer-less inverters. Similarly, ICOA, though an improvement over COA, faces computational complexity and slower convergence, limiting its suitability for multi-objective optimization in PV systems. Additionally, existing transformer-less inverter topologies, such as H6 and HERIC, present their own drawbacks. The H6 topology, though effective in reducing leakage current, suffers from higher transmission losses due to the increased count of switches in the current path. On the other hand, the HERIC topology excels in minimizing switching losses but struggles with leakage current suppression due to variations in CMV. These limitations highlight the pressing need for an optimized inverter topology that not only reduces leakage current effectively but also enhances overall efficiency and performance, motivating the need for innovative solutions.

In this paper, the existing challenge of leakage current reduction and system inefficiencies in grid-linked PV schemes is addressed by integrating the LEA with transformer less inverters. While conventional methods struggle with optimizing leakage current reduction and overall system performance, the proposed approach leverages LEA's unique ability to enhance energy efficiency inspired by the lotus effect, offering a promising solution to existing optimization techniques like MRFO, ChOA, and ICOA. By combining the LEA's optimization capabilities with the dynamic needs of transformer less inverters, the proposed method ensures reduced leakage current, improved efficiency, and enhanced THD reduction. The proposed method can be applied in various fields, including residential and commercial solar energy systems, energy-efficient buildings, smart grids, and other renewable energy applications where minimizing leakage current and maximizing system performance are essential.

The contribution of this paper is described as follows:

This study proposes a novel single-phase transformer-less (TL) PV inverter with freewheeling and CM voltage clamping branches to eliminate leakage current and reduce conduction losses, improving system efficiency. The inverter utilizes MOSFET switches, ensuring enhanced efficiency and performance.
A **single-phase TL inverter topology** is used, incorporating **an additional switch (S7) and clamping diodes**, ensuring **constant CMV and nullified ground leakage current**.
The proposed LEA demonstrates its enhanced ability to optimize energy transfer, resulting in significant gains in both efficiency and system stability compared to conventional methods.

Copyright © 2024 by Author/s and Licensed by JISEM. This is an open access article distributed under the Creative Commons Attribution License which permitsunrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Journal of Information Systems Engineering and Management
2025, 10 (39s)
e-ISSN: 2468-4376
https://jisem-journal.com/
Research Article

A MATLAB-based simulation of the proposed single-phase TL photovoltaic inverter system is carried out, with results compared to existing methods like MRFO, ChOA, and ICOA, showcasing significant improvements in leakage current reduction and efficiency.

The system description is presented in Segment 2, detailing the configuration of leakage current reduction and efficiency optimization in transformer less PV inverters. Segment 3 covers optimizing the PV systems connected to the grid using LEA. Segment 4 presents the experimental outcomes and provides a comprehensive discussion. Segment 5 presents the conclusion, which is the last segment of this paper.

2. Configuration of Leakage Current Reduction and Efficiency Optimization in Transformer less PV Inverters

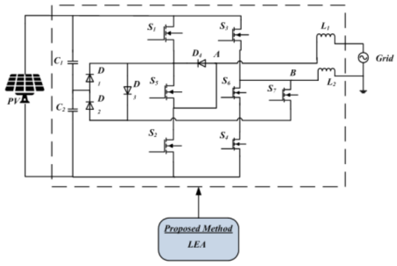

Fig 1: Circuit layout for single-phase transformer-less inverters MOSFET Architecture

The Fig 1 diagram illustrates a system consists of structure of single phase TL inverter circuits MOSFET topology a PV source that generates DC power, connected to the DC side of the inverter. A capacitor divider, formed by capacitors C1 and C2, stabilizes the DC voltage and assists in clamping the CMV. The core of the inverter includes multiple MOSFET switches (S1-S8) that convert DC power to AC through a controlled switching sequence. S1-S4 forms the main inverter bridge, while S5-S8 serves as the freewheeling branches to reduce conduction losses and develop effectiveness. The clamping branch, consisting of S5 and S6 along with the capacitor divider, helps eliminate leakage current. Diodes D1, D2, and D3 prevent reverse current flow and provide alternate paths for current. Inductors L1 and L2 act as filters, smoothing the AC current before it is send to the utility grid.The proposed method is employed to optimize the dynamic procedure of the PV system linked to the grid, ensuring better energy transfer and improving overall system efficiency. By enhancing the inverter's operation, the method reduces leakage current and conduction losses, resultant in a additional stable and effectual power conversion process. Finally, the grid connection allows the converted AC power to be supplied to the grid efficiently.

2.1. PV System Modeling

The output Direct Current power of the Photovoltaic panel $P_{PV}(t)$ based on solar radiant intensity, amalgamation capacity, panel area, with cell temperature [16]

$$P_{PV}(t) = \frac{G_t(t)}{1000} \times P_{PV-rated} \times \eta_{PV} \times \left[1 - \beta_T \left(T_C - T_{C,STC}\right)\right] \quad (1)$$

where $G_t(t)$ (w/m^2), the incident radiant power perpendicular to the array's surface, $P_{PV-rated}$ is the nominal power of the panel under standard test conditions (STC), η_{PV} signifies power reduction factor of photovoltaic panels (%)

Copyright © 2024 by Author/s and Licensed by JISEM. This is an open access article distributed under the Creative Commons Attribution License which permitsunrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Journal of Information Systems Engineering and Management
2025, 10 (39s)
e-ISSN: 2468-4376
https://jisem-journal.com/

Research Article

2.2. Operation of Single Phase Transformer Less Inverter

2.2.1. Mode 1

While $S2$, $S3$, $S6$ and clamping branch switch $S7$ are OFF switches, $S1$ and $S4$ are ON [16]. The current flows through $S1$, $L1$, grid, $L2$ and $S4$.

$$V_{CM} = \frac{V_{AO} + V_{BO}}{2} = \frac{(V_{PV} + 0)}{2} = \frac{V_{PV}}{2} = 0.5V_{PV} \tag{2}$$

$$V_{DM} = V_{AO} - V_{BO} = V_{PV} - 0 = V_{PV} \tag{3}$$

2.2.2. Mode 2

The switches, $S5$, $S6$ and $S7$ are ON and $S1$ and $S4$ are OFF and. Freewheeling current flows through $L1$, grid, $L2$, anti-parallel diode $D6$ and switch $S5$ [16].

$$V_{CM} = \frac{V_{AO} + V_{BO}}{2} = \frac{(V_{PV}/2 + V_{PV}/2)}{2} = \frac{V_{PV}}{2} = 0.5V_{PV} \tag{4}$$

$$V_{DM} = V_{AO} - V_{BO} = V_{PV}/2 - V_{PV}/2 = 0 \tag{5}$$

2.2.3. Mode 3

Current flows freely from the anti parallel diode $D4$ of switches $L2$, $S4$, grid, $L1$, and the anti-parallel $D1$ diode of switch $S1$ in this negative power area.[16].

$$V_{CM} = \frac{V_{AO} + V_{BO}}{2} = \frac{(0 + V_{PV})}{2} = \frac{V_{PV}}{2} = 0.5V_{PV} \tag{6}$$

$$V_{DM} = V_{AO} = V_{AO} - V_{BO} = 0 - V_{PV} = -V_{PV} \tag{7}$$

2.2.4. Mode 4

The switches $S1$ to $S4$ are OFF, whereas $S5$, $S6$ and $S7$ are ON. Non-interventionist current flow through $L2$ grid $L1$, anti-parallel diode $D5$ and $S6$ [16].

$$V_{CM} = \frac{V_{AO} + V_{BO}}{2} = \frac{(V_{PV}/2 + V_{PV}/2)}{2} = \frac{V_{PV}}{2} = 0.5V_{PV} \tag{8}$$

$$V_{DM} = V_{AO} - V_{BO} = V_{PV}/2 - V_{PV}/2 = 0 \tag{9}$$

2.3. Objective Function

The efficiency has been calculated using

$$\eta = \left(\frac{P_o}{P_i}\right) * 100 \tag{10}$$

where η is the rated output effectiveness, P_o output power (kW), P_i denotes input power at the rated output (kW). The THD can be distinct as

Copyright © 2024 by Author/s and Licensed by JISEM. This is an open access article distributed under the Creative Commons Attribution License which permitsunrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

$$THD = \sqrt{\frac{\sum_{n=2}^{\alpha} I_n^2}{I_2}} \quad (11)$$

here I_1 =RMS value of essential current, I_n =RMS value of nth order harmonic

3. Optimizing the PV Systems Connected to the Grid UsingLEA

In this section, LEA [17] is discussed. The LEAused to optimize the active process of the PV system linked to the grid. It is a nature-inspired evolutionary algorithm that combines the exploration aspects of the dragonfly algorithm with the self-cleaning properties of lotus leaves (the lotus effect) for extraction in optimization problems.The main advantage of the LEA is its ability to effectively balance exploration and exploitation, leading to superior optimization performance in complex systems. It enhances the inverter topology is its ability to leakage current elimination, leading to superior performance in transformer less grid-linked PV schmes. In Fig 2, the flowchart detailing the operation of the LEA is presented. The given details are provided below.

Step 1: Initialization

Initialize the input factors, including irradiance, temperature, voltage as well as current.

Step 2: Random Generation

A matrix can be used to represent the whole LEA population, including all different types of addax and it is given as the equation

$$X = \begin{bmatrix} X_{1,1} & X_{1,2} & \cdots & X_{1,d} \\ X_{2,1} & X_{2,2} & \cdots & X_{2,d} \\ \cdots & \cdots & \cdots & \cdots \\ X_{n,1} & X_{n,2} & \cdots & X_{n,d} \end{bmatrix} \quad (12)$$

were, m denotes populace matrix of LEA, n denotes count of addax in the populace, d is the count of decision variables.

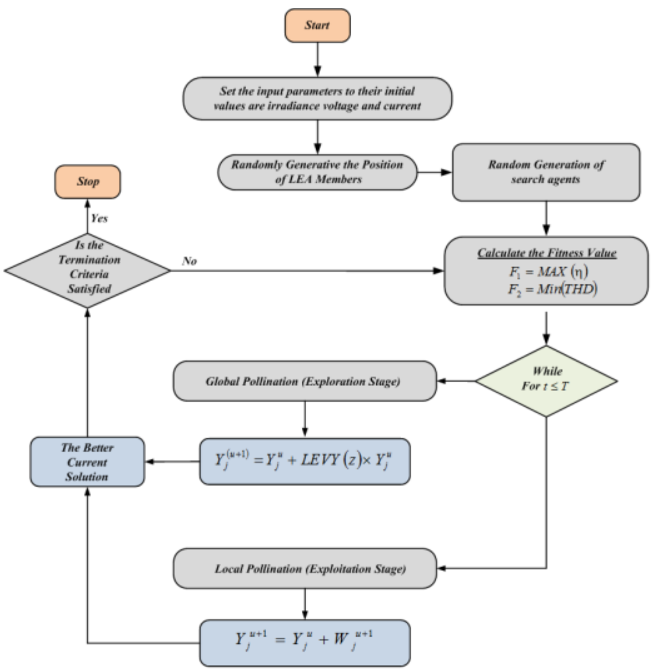

Fig 2: Flow chart of LEA

Copyright © 2024 by Author/s and Licensed by JISEM. This is an open access article distributed under the Creative Commons Attribution License which permitsunrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Journal of Information Systems Engineering and Management
2025, 10 (39s)
e-ISSN: 2468-4376
https://jisem-journal.com/ **Research Article**

Step 3: Fitness Function

The system's fitness is strong-minded by the objective function. To establish the fitness function are

$$F_1 = MAX\left(\eta\right) \tag{13}$$

$$F_2 = Min\left(THD\right) \tag{14}$$

In this step, F the fitness function is used to minimize leakage current, η enhancing overall system efficiency and reduce the THD performance in the single-phase transformer less PV inverter.

Step 4: Global Pollination (Exploration Stage)

The LEAis dragonfly behavior during pollination, focusing on two core strategies: escaping enemies and searching for food. These strategies help the algorithm move away from inferior solutions and toward better ones, with dragonfly positions continuously updated to refine the search for optimal solutions.

$$\Delta Y_j^{u+1} = \left(tT_j^u + hH_j^u + gG_j^u + qQ_j^u\right) + x\Delta Y_j^u \tag{15}$$

Here the term t is the coefficient value. The separation degree is indicated by T_j^u . The alignment coefficient is noted by b . The individual alignment is noted by H_j^u . The term i is the cohesion coefficient. The individual cohesion is indicated by G_j^u . The food sources are indicated by g , and the enemy is noted by q .

$$Y_j^{(u+1)} = Y_j^u + LEVY\left(z\right)\times Y_j^u \tag{16}$$

Step 5:Local Pollination (Exploitation Stage)

The pollination activity takes place during this phase, also referred to as the extraction stage. A coefficient determines the dimension of every flower's growth region neighboring the optimal-discovered flower in this pollination process.

Here, the term M is the iteration count. The term S is utilized to balance the exploitation and exploration phases. The capacity is measured as

$$W_j^{u+1} = r \times W_j^u \tag{17}$$

The position of moving drops is measured using

$$Y_j^{u+1} = Y_j^u + W_j^{u+1} \tag{18}$$

Here the term Y_{DEp}^u is the present location and the term W_j^u is the present velocity.

Step 6: Update Best Solution

In this stage, the proposed single-phase transformerless PV inverter undergoes performance evaluation, focusing on leakage current reduction and overall efficiency. The system's dynamic behavior is analyzed under different grid conditions, utilizing MOSFET switches in the single-phase transformer-less inverter to enhance efficiency, reduce switching losses, and minimize leakage current.

Step 7: Termination Criteria

Check the termination criteria; if the best answer is found, the procedure is over; if not, it is repeated. In this step, the proposed LEA is utilized to optimize the control signal of the inverter to enhance the performance of the

Copyright © 2024 by Author/s and Licensed by JISEM. This is an open access article distributed under the Creative Commons Attribution License which permitsunrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Journal of Information Systems Engineering and Management
2025, 10 (39s)
e-ISSN: 2468-4376
https://jisem-journal.com/ **Research Article**

MOSFET-based transformer-less photovoltaic inverter, minimize leakage current, and enhance overall system efficiency by reducing conduction losses.

4. Result and Discussion

In this section, the proposed LEA is introduced to enhance the performance of single-phase transformer less inverters for grid-linked PV systems. The method incorporates a new inverter topology that uses freewheeling and CMV clamping branches with MOSFETs and a capacitor divider, effectively reducing leakage current and conduction losses. The efficacy of the proposed system is optimized through a comparative analysis with existing methods such as MRFO, ChOA, and ICOA, demonstrating significant improvements in efficiency and a reduction in leakage current. The experimental outcomes of the proposed LEA for the single-phase transformer lesser PV inverter are presented below, showcasing its superior performance.

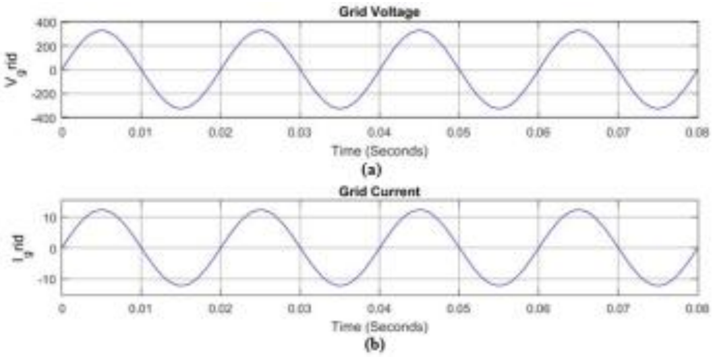

Fig 3: Analysis of inverter (a) grid voltage (b) grid current

In Fig 3, the evaluation of the inverter is shown (a) grid voltage (b) grid current. In the Fig 3(a) show analysis of grid voltage in the inverter the positive as well as negative peak voltages are approximately ±325V, resulting in a peak-to-peak voltage of around 650V. The waveform completes one cycle in approximately 0.02sec, corresponding to a frequency of 50 Hz, which aligns with the standard grid frequency. In the Fig 3(b) show analysis of grid currentin the inverter. The positive and negative peak currents are approximately ±12A, resulting in a peak-to-peak current of around 24A. The waveform completes one cycle in about 0.02sec, corresponding to a frequency of 50 Hz, which is standard for many grid systems.

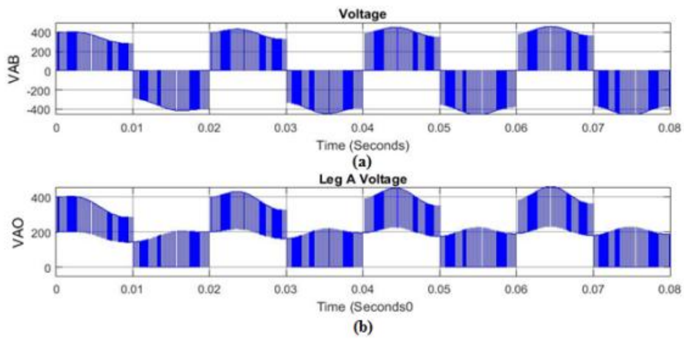

Fig 4: Evaluation of voltages in the inverter (a) Line -Line voltage (VAB) (b) Leg A voltage (VA)

In Fig 4, the evaluation of the inverter is shown (a) Line - Line voltage (b) Leg A voltage (VA).In Fig 4(a), the analysis of the line-to-line voltage (VAB) in the inverter is shown.The waveform alternates between positive and negative voltage levels, with peak voltages of approximately ±400V, resulting in a peak-to-peak voltage of around 800V. The fundamental waveform completes one cycle in about 0.02sec, corresponding to a frequency of 50 Hz, which aligns with standard grid requirements. In the Fig 4(b) show analysis of leg a voltage (V_A) in the inverter to generate Alternating Current voltage at Leg A, with high-frequency switching. The waveform alternates between different voltage levels, with a peak voltage of approximately 400V, a minimum voltage of 0V, and a mid-level around 200V. The voltage transitions occur smoothly over a short period, characteristic of PWM operation. The

Copyright © 2024 by Author/s and Licensed by JISEM. This is an open access article distributed under the Creative Commons Attribution License which permitsunrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

fundamental waveform repeats every 0.02sec, resulting in a frequency of 50 Hz, which meets standard grid requirements.

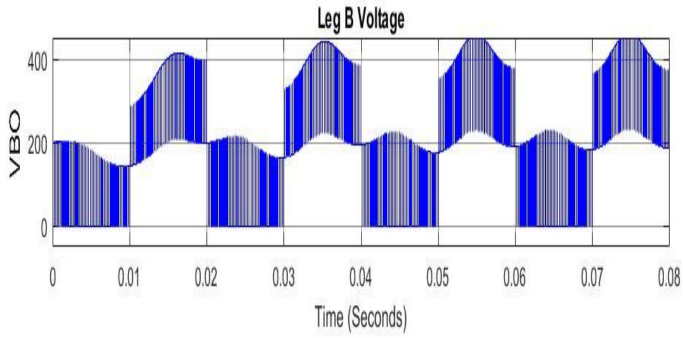

Fig 5: Evaluation of Leg B voltage (V_B) in the inverter

In the Fig 5 show evaluation of Leg B voltage (V_B) in the inverter voltage at Leg B, with high-frequency switching represented by the blue areas. The waveform alternates between multiple voltage levels, with a peak voltage of approximately 400V, a minimum voltage of 0V, and a mid-level around 200V. The voltage transitions occur gradually, reflecting typical PWM behavior. The fundamental waveform repeats every 0.02sec, resulting in a frequency of 50 Hz, aligning with standard grid requirements.

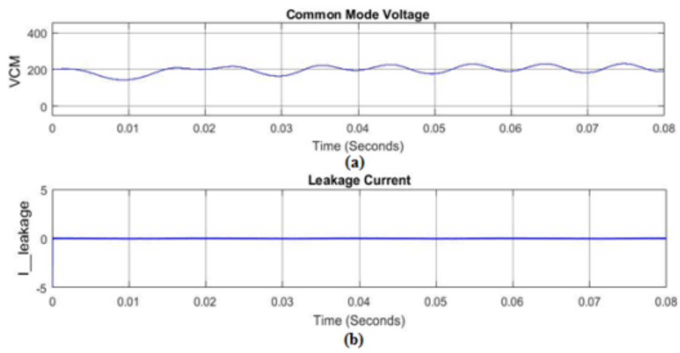

Fig 6: Analysis of inverter voltages and currents (a) VCM in the inverter (b) Ground leakage current in the inverter

In Fig 6, the analysis of inverter voltages and currents is shown (a) VCM in the inverter and (b) ground leakage current in the inverter. In the Fig 6(a) showanalysis of VCM in the inverter the inverter's average common-mode voltage is around 200 Volts, with a peak-to-peak ripple of approximately 50 Volts and a ripple frequency of 50 Hz. These values highlight the inverter's switching operation. In the Fig 6(b) show analysis of ground Leakage current in the inverter an average leakage current close to 0 Amperes, with fluctuations of less than ±0.1 Amperes. This indicates excellent performance in minimizing ground leakage current.

Table 1: Comparison of THD and Efficiency with Existing Methods

Method	THD%	Efficiency%
proposed	2.5	99.5
MRFO	3.8	96
ChOA	4.2	91
ICOA	4.4	89

Copyright © 2024 by Author/s and Licensed by JISEM. This is an open access article distributed under the Creative Commons Attribution License which permitsunrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Journal of Information Systems Engineering and Management
2025, 10 (39s)
e-ISSN: 2468-4376
https://jisem-journal.com/

Research Article

The Table 1 compares the efficacy of the proposed inverter with existing optimization techniques based on THD % and Efficiency %. It shows that the proposed inverter offers better results in both reducing harmonic distortion and improving efficiency compared to methods like MRFO, ChOA, and ICOA, indicating its superior overall performance.

5. Conclusion

This work presents a new single-phase transformer-less photovoltaic inverter topology that ensures constant CMV across all operational modes, effectively eliminating leakage current. The integration of freewheeling and CMV clamping branches enhances inverter performance, while the LEA method optimize the control signal of the inverter. The proposed inverter, utilizing MOSFET switches, significantly improves efficiency, reduces conduction losses, and minimizes ground leakage current. Simulation results show an impressive 99.5% efficiency, with minimal leakage current fluctuations of less than ±0.1 Amperes. Furthermore, the THD is reduced to 2.5%, showcasing a marked improvement in system performance. The results indicate that the LEA effectively enhances inverter operation by minimizing leakage current and conduction losses, ensuring superior power quality. This work provides a significant advancement in the design of single-phase transformer less PV inverters, contributing to the optimization of energy transfer and overall system stability.

Data Availability Statement

Data sharing does not apply to this article as no new data has been created or analyzed in this study.

Funding Information

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors

Reference

[1] Ponrekha A, S., Subathra, M. S. P., Bharatiraja, C., Manoj Kumar, N., &HaesAlhelou, H. (2025). A topology review and comparative analysis on transformerless grid-connected photovoltaic inverters and leakage current reduction techniques. *IET Renewable Power Generation*, *19*(1), e12655.

[2] Kibria, M. F., Mekhilef, S., Mubin, M., Tey, K. S., Elsanabary, A., Seyedmahmoudian, M., &Jerbi, H. (2025). A Hybrid Single-Phase Transformerless Solar Photovoltaic Grid-Connected Inverter with Reactive Power Capability and Reduced Leakage Current. *IEEE Access*.

[3] Hassan, A., AbouHouran, M., Chen, W., Yang, X., Ali, A. I. M., & Abu-Zaher, M. (2024). Robust PWM control scheme for switched-capacitor MLI with leakage current suppression in grid-connected renewable energy application.Heliyon, 10(11).

[4] de Carvalho, C. C., da Silva, P. R., Araújo, J. M., &Pomilio, J. A. (2025). Leakage Current Mitigation in On-Grid Photovoltaic Systems Using a Flexible Multi-Level Inverter Topology. *Eletrônica de Potência*, *30*, e202527-e202527.

[5] Bodele, N., &Kulkarni, P. S. (2024). A Zero-Leakage-Current Single-Stage PV-Battery Integrated Inverter with Active Power Decoupling. *IEEE Transactions on Circuits and Systems II: Express Briefs*.

[6] Shrestha, S., Subedi, R., Sharma, S., Phuyal, S., &Tamrakar, I. (2025). A Comparative Analysis of Transformer-less Inverter Topologies for Grid-Connected PV Systems: Minimizing Leakage Current and THD. arXiv preprint arXiv:2501.08103.

[7] Zou, Y., Zhang, L., Xing, Y., Zhuge, H., Shen, X., Zhang, Y., & Lu, Y. (2024). An optimized DPWM with reduced leakage current for three-phase three-level inverters with unbalanced neutral-point voltage.IEEE Transactions on Power Electronics.

[8] Mondal, S., Biswas, S. P., Islam, M. S. B., Islam, M. R., & Shah, R. (2024). A hybrid PWM technique for SMES integrated solar PV based grid-tied transformerless inverters. IEEE Transactions on Applied Superconductivity.

[9] Cedieu, S., Grigoletto, F. B., Lee, S. S., Barzegarkhoo, R., &Siwakoti, Y. P. (2024). A five-level common-ground inverter with reduced switch count for transformerless grid-tied pv applications. IEEE Transactions on Industry Applications.

Copyright © 2024 by Author/s and Licensed by JISEM. This is an open access article distributed under the Creative Commons Attribution License which permitsunrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

[10] Mondal, S., Rashid, M. O., Biswas, S. P., & Islam, M. R. (2025, February). An Optimized Switching Scheme to Reduce the Leakage Current and Power Loss of Transformerless Inverter.In 2025 IEEE International Conference on Mechatronics (ICM) (pp. 1-6).IEEE.

[11] using optimization algorithms. *Solar Energy*, *263*, 111832.

[12] Yang, C., Su, C., Hu, H., Habibi, M., Safarpour, H., &Khadimallah, M. A. (2023). Performance optimization of photovoltaic and solar cells via a hybrid and efficient chimp algorithm. *Solar Energy*, *253*, 343-359.

[13] Chaib, L., Tadj, M., Choucha, A., Khemili, F. Z., & EL-Fergany, A. (2024). Improved crayfish optimization algorithm for parameters estimation of photovoltaic models. *Energy Conversion and Management*, *313*, 118627.

[14] Li, X., Sun, Y., Jiang, L., Wang, H., Liu, Y., & Su, M. (2023). Common-mode circuit analysis of current-source photovoltaic inverter for leakage current and EMI. *IEEE Transactions on Power Electronics*, *38*(6), 7156-7165.

[15] Jiang, L., Chen, Y., Dai, F., Liu, K., Chen, X., & He, X. (2023). A nine-switch inverter with reduced leakage current for PV grid-tied systems using model-free predictive current control. *Energy Reports*, *9*, 396-405.

[16] Ahmad, Z., & Singh, S. N. (2017). An improved single phase transformerless inverter topology for grid connected PV system with reduce leakage current and reactive power capability. *Solar Energy*, *157*, 133-146.

[17] Dalirinia, E., Jalali, M., Yaghoobi, M., &Tabatabaee, H. (2024). Lotus effect optimization algorithm (LEA): a lotus nature-inspired algorithm for engineering design optimization. *The Journal of Supercomputing*, *80*(1), 761-799.

Copyright © 2024 by Author/s and Licensed by JISEM. This is an open access article distributed under the Creative Commons Attribution License which permitsunrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.