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Research Article

Performance Evaluation of a PV-Based Multilevel Inverter with Improved THD and Efficiency

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Abstract: This work presents the design, simulation, and performance evaluation of a three-phase multilevel inverter (MLI) system integrated with photovoltaic (PV) technology for grid-connected applications. The proposed system consists of a photovoltaic array, a Maximum Power Point Tracking (MPPT) controller based on the Perturb and Observe (P&O) algorithm, a DC-DC boost converter for voltage regulation, and a cascaded H-bridge multilevel inverter equipped with an LC filter to reduce output distortions. The entire system is modeled and analyzed using MATLAB/Simulink. Simulation results reveal that the system delivers a peak power output of 3000 W, maintains a regulated DC bus voltage of 800 V, and produces a stable three-phase AC output voltage of 400 V (RMS). The proposed inverter topology effectively reduces the Total Harmonic Distortion (THD) of the output waveform to 2.8% by optimizing the switching strategy using sinusoidal pulse width modulation (SPWM), significantly outperforming the 6.5% THD observed in conventional two-level inverter systems. Additionally, the system achieves an improved conversion efficiency of 96%, up from the typical 92%, through effective MPPT operation and low-loss inverter design. These improvements ensure superior power quality and reliable grid synchronization. The study underscores the viability of multilevel inverters in enhancing the performance of PV systems and promoting the efficient utilization of renewable energy sources for grid integration.

Keywords: DC-DC Converter, Grid Integration, Multilevel Inverter, Photovoltaic System, Three Phase System, THD.

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NOMENCLATURE

ns	Number of switches in conduction per cycle
fs	Switching frequency
Iavg, Irms	Average and RMS current
Eon, Eoff	Energy lost during turn-on and turn-off
Vdc	DC link voltage
Iload	Load current
Qrr	Reverse recovery charge
Qg	Gate charge
Vg	Gate drive voltage

1. INTRODUCTION

The growing global energy demand and the urgent need for sustainable alternatives have significantly accelerated the transition toward renewable energy sources. Among these, solar photovoltaic (PV) systems have become a prominent solution due to their wide availability, minimal environmental impact, and long-term reliability. Their integration with modern infrastructure, especially the electrical grid and electric vehicle (EV) charging stations, has received increasing attention, as it enables clean energy utilization and reduces reliance on fossil fuels. However, achieving optimal system performance presents persistent challenges in energy conversion efficiency, energy storage management, and grid synchronization. A conventional PV system typically

comprises a PV array, a Maximum Power Point Tracking (MPPT) controller, a DC-DC converter, energy storage units, and an inverter for DC to AC conversion. MPPT controllers are critical in extracting maximum energy from PV panels, particularly under fluctuating irradiance and temperature conditions. The DC-DC boost converter increases the panel voltage to meet the input requirements of the inverter and the connected grid or load. To maintain stable operation, battery banks serve as energy buffers. For AC power delivery and grid connectivity, MLIs are often preferred due to their ability to produce stepped output voltages that enhance power quality, reduce total harmonic distortion (THD), and improve overall system efficiency. Pulse-width modulation (PWM) techniques further support inverter control, allowing reliable operation under varying load demands [1-3].

The rising adoption of EVs has created a parallel demand for sustainable charging infrastructure. Traditional charging stations predominantly rely on grid electricity, which may still be derived from non-renewable sources. Integrating PV-based systems with EV charging stations offers a sustainable alternative that lowers operational costs and carbon emissions. Such integration ensures uninterrupted charging through grid support while utilizing solar energy during daylight hours. The effectiveness of PV systems depends heavily on environmental factors such as sunlight intensity, shading, and temperature. To address these variations, MPPT algorithms are employed to consistently maximize energy capture. Conventional MPPT methods such as Perturb and Observe (P&O) and Incremental Conductance (IC) are widely implemented due to their simplicity and ease of deployment [4-7]. However, their performance declines under rapidly changing environmental conditions. Recent advances have introduced intelligent MPPT techniques based on fuzzy logic, neural networks, and artificial intelligence. These methods offer faster response and improved tracking accuracy in dynamic settings. In parallel, conventional boost converters used in DC-DC stages often experience high voltage stress and switching losses, limiting system efficiency. To mitigate these issues, researchers have proposed advanced converter designs, including interleaved and cascaded configurations, which enhance voltage gain and reduce ripple. In this context, the current study implements a high-efficiency DC-DC boost converter integrated with a filter to ensure voltage stability and suppress noise. At the core of power delivery lies the inverter stage. Among multilevel inverter topologies, the diode-clamped, flying capacitor, and cascaded H-bridge configurations are the most extensively studied. The diode-clamped multilevel inverter (DCMLI) uses clamping diodes to generate multiple voltage levels, resulting in improved output quality. However, it encounters issues such as voltage imbalance and increased complexity in diode arrangement, which limit its scalability. The flying capacitor multilevel inverter (FCMLI) replaces diodes with capacitors to achieve stepped output voltages. While this approach offers better voltage balancing, it requires a large number of capacitors, increasing the system's size and cost. The cascaded H-bridge multilevel inverter (CHBMLI), due to its modular structure and ease of implementation, has become popular in PV systems. It achieves high voltage levels using series-connected H-bridge cells, each powered by an independent DC source. Nevertheless, its reliance on isolated power supplies poses challenges in practical implementation. PWM strategies are essential in shaping inverter output. Sinusoidal PWM (SPWM) provides a straightforward technique for harmonic reduction, while Space Vector PWM (SVPWM) enhances DC bus utilization and inverter efficiency. Selective Harmonic Elimination (SHE) is another widely explored method that suppresses low-order harmonics by solving nonlinear equations, thereby improving waveform quality. Hybrid modulation strategies that combine these methods are gaining traction to optimize performance. When MLIs are integrated into grid-connected PV systems, they enhance energy extraction, reduce THD, and facilitate smooth power injection. Studies indicate that THD values can be reduced below 3%, aligning with IEEE 519 power quality standards. In addition, MLIs are increasingly used in EV charging stations, where they enable efficient DC-AC conversion and support bidirectional power flow in vehicle-to-grid (V2G) applications [8-11].

Ongoing research in MLI development focuses on minimizing component count, enhancing fault tolerance, and embedding artificial intelligence-based control methods to improve reliability and operational intelligence. However, as voltage levels increase, the circuit complexity rises, demanding more switching devices, diodes, or capacitors. This growth not only escalates the cost and control overhead but also complicates modulation strategies and real-time operation. In diode-clamped inverters, voltage imbalance among capacitors can lead to system instability. Similarly, in flying capacitor inverters, maintaining balanced voltage levels across capacitors is crucial, as imbalances may cause overvoltage stress on power devices and reduce component lifespan [12-15]. Although voltage balancing techniques such as redundant switching states and feedback control have been proposed, they increase system complexity and sensor requirements. Even though MLIs reduce switching stress relative to two-level inverters, higher-level designs introduce more semiconductors, leading to increased conduction losses. While optimized PWM strategies such as SVPWM and SHE help mitigate these losses, their computational demands make real-time processing more challenging. The adoption of wide-bandgap semiconductors such as Silicon Carbide (SiC) and Gallium Nitride (GaN) offers a promising route to reduce switching losses, but their high cost remains a limiting factor for widespread deployment. Furthermore, the growing number of components increases the likelihood of system faults and necessitates robust detection and mitigation strategies. These include redundant power paths, fault-tolerant control algorithms, and system reconfiguration. However, these solutions require additional hardware and increase the computational burden, making them less suitable for cost-sensitive applications [15-18].

Managing THD and electromagnetic interference (EMI) is another critical concern. Although MLIs inherently reduce THD by generating stepped waveforms, improper modulation or variable loads can reintroduce harmonics. High-frequency switching also contributes to EMI, potentially affecting nearby electronic systems. Filters—both passive (LC, LCL) and active—are essential to maintain compliance with standards such as IEEE 519 and IEC regulations. Passive filters, though commonly used, add bulk and may cause resonance issues, while active filters provide dynamic harmonic compensation at the cost of increased control

complexity and expense. The performance of MLIs in renewable energy applications is further influenced by fluctuating power input, particularly in PV and wind systems. Stable operation in such dynamic conditions necessitates intelligent control systems, including AI-based algorithms and predictive control models. Maintaining synchronization with the grid is particularly critical, as deviations in phase, voltage, or frequency can result in power instability or disconnection. Phase-Locked Loops (PLLs) are widely employed for synchronization, but their accuracy can degrade under grid disturbances such as voltage sags or frequency shifts. Adaptive PLLs and Model Predictive Control (MPC) approaches have been explored to address these issues, yet their implementation increases design complexity. Ultimately, while MLIs hold considerable promise for enhancing the efficiency and quality of renewable energy systems, several practical challenges hinder their widespread adoption. These include the complexity of component coordination, cost of implementation, computational demands of control strategies, and the need for compliance with stringent power quality standards. Overcoming these challenges is essential for the continued development of high-performance, grid-compatible PV and EV charging systems [19-24].

The following are the objectives of the PV integrated three phase grid system:

- The research aims to design and implement a PV-based energy system that efficiently integrates with the utility grid. The system incorporates a three-phase multilevel inverter to ensure seamless energy conversion and delivery, reducing reliance on conventional power sources.
- The study focuses on enhancing the performance of the DC-DC boost converter by improving its efficiency and minimizing power losses. By selecting appropriate switching devices and control strategies, the converter steps up the PV output voltage with high efficiency while maintaining voltage stability.
- The implementation of a three-phase multilevel inverter aims to reduce THD in the output waveform, improving power quality. Pulse-width modulation techniques are employed to achieve a near-sinusoidal AC output, ensuring grid compliance.
- The research utilizes the Perturb and Observe (P&O) MPPT algorithm to maximize power extraction from the PV array under varying environmental conditions. Real-time optimization of the duty cycle ensures that the system operates at peak efficiency.

2. THREE PHASE MULTILEVEL INVERTER WITH GRID SYSTEM

Figs. 1 through 10 collectively illustrate the design, operation, and modulation of a two-stage grid-connected PV system integrated with a three-phase MLI for efficient renewable energy conversion and EV charging applications. Fig. 1 presents the block diagram of the proposed two-stage PV system. The PV array generates direct current (DC) electricity, which is optimized using a MPPT algorithm. The harvested power is then processed through a DC-DC boost converter to elevate the voltage to the desired level required by the inverter. This high-voltage DC power is fed into a three-phase MLI, which transforms it into alternating current (AC) suitable for grid connection and EV charging. A filter stage is incorporated after the inverter to mitigate THD, thereby enhancing power quality, energy efficiency, and system stability. Fig. 2 elaborates on the integration scheme of the PV system with a three-phase utility grid using a filtering mechanism. Fig. 3 illustrates the conventional five level MLI. The PV-generated DC is first conditioned by a high-efficiency boost converter and then converted to AC through a three-phase MLI. The inverter produces stepped voltage waveforms that reduce harmonic distortion. The output is further refined using a three-phase filter that eliminates high-frequency harmonics, ensuring smooth and high-quality power delivery to the grid. This setup supports bidirectional power flow, making it suitable for vehicle-to-grid (V2G) operations and smart grid scenarios. Fig. 4 illustrates the circuit design of a reduced-switch five-level MLI topology. This inverter configuration generates five distinct output voltage levels: +2Vdc, +Vdc, 0V, -Vdc, and -2Vdc. By using a minimal number of power switches, this design reduces switching losses and complexity while maintaining high output quality. The inverter operates with an optimized switching sequence controlled by PWM signals, enabling efficient power conversion and reduced component count, which is ideal for compact and cost-effective renewable energy systems. Figs. 5, 6, and 7 display the inverter's stepped output waveforms corresponding to specific voltage levels. Fig. 4 shows the waveform for the +2Vdc state, where the inverter connects the load to the highest DC potential, contributing to peak AC voltage. Fig. 6 depicts the +Vdc state, representing an intermediate voltage level that provides smoother transitions during positive waveform cycles. Fig. 7 illustrates the 0V state, a neutral condition that helps maintain waveform symmetry and balance during AC signal transitions. These voltage states collectively improve power quality by reducing the rate of voltage change and limiting high-frequency harmonics. Fig. 9 highlights the -2Vdc output state, achieved when the inverter switches connect the load to the lowest DC potential. This state, together with the positive and intermediate levels, forms a complete set of voltage steps that contribute to a near-sinusoidal output, significantly reducing THD and EMI. Finally, Fig. 10 shows the generation of Pulse Width Modulation (PWM) pulses used to control the switching states of the five-level inverter. These PWM signals determine the precise timing for switch activation, ensuring accurate voltage generation, harmonic suppression, and grid synchronization. This modulation technique enhances overall system performance, making the inverter suitable for high-efficiency PV-grid integration and EV charging applications. The proposed system employs a reduced-switch five-level CHBMLI topology. This choice offers a favourable trade-off between performance and complexity. Compared to diode-clamped and flying capacitor inverters, the reduced-switch CHBMLI requires fewer components, resulting in lower switching losses and simpler modulation. Additionally, it produces high-quality stepped waveforms, contributing to a significant reduction in THD. However, limitations include the need for precise voltage balancing and increased control complexity under dynamic loading, which are addressed in this design using optimized PWM and filter integration.

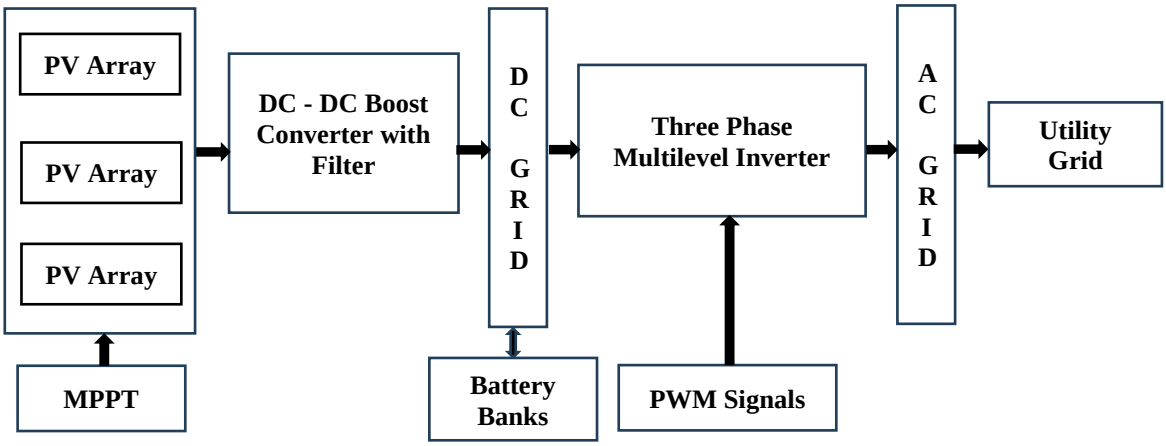


Fig. 1: PV to grid system through three phase MLI.

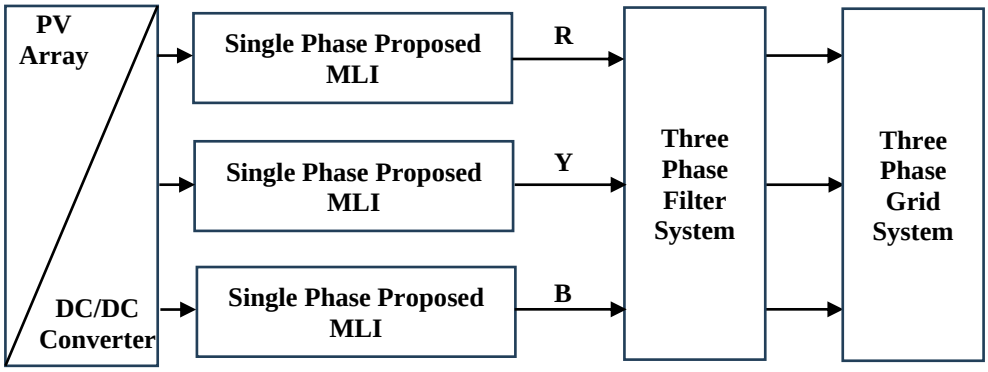


Fig. 2: PV with three phase grid system with filter.

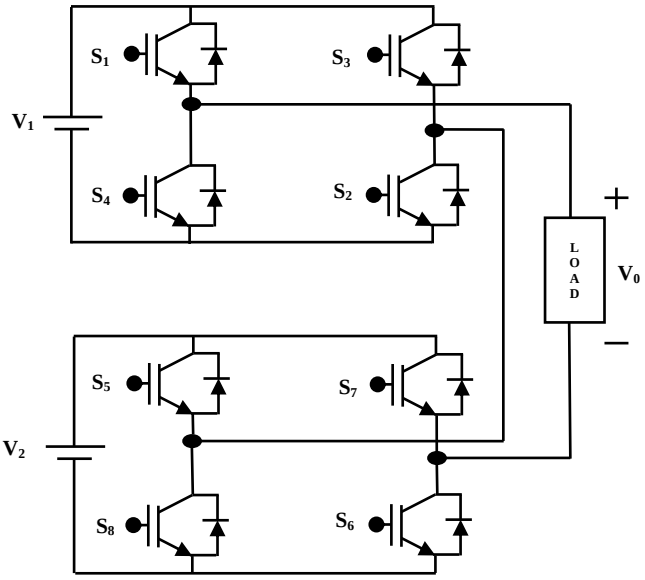


Fig. 3: PV conventional single phase five level inverter topology.

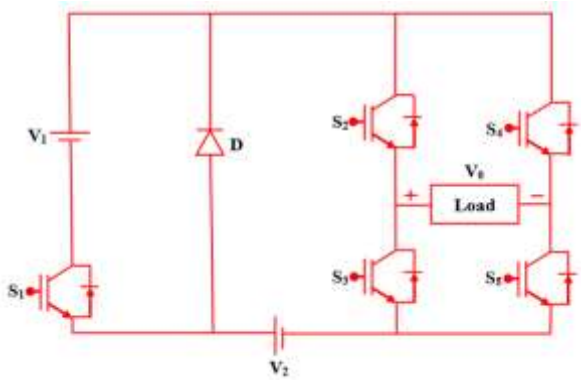


Fig. 4: Reduced switch five level output MLI.

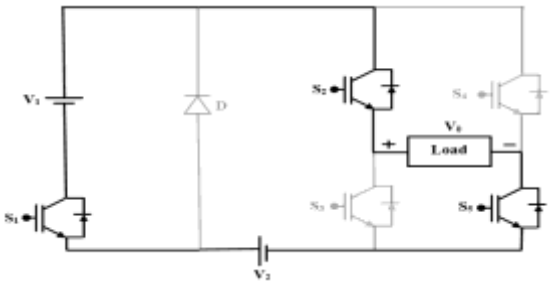


Fig. 5: +2Vdc Output voltage.

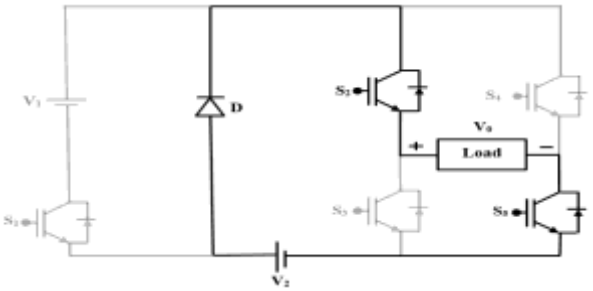


Figure 6: +Vdc Output voltage.

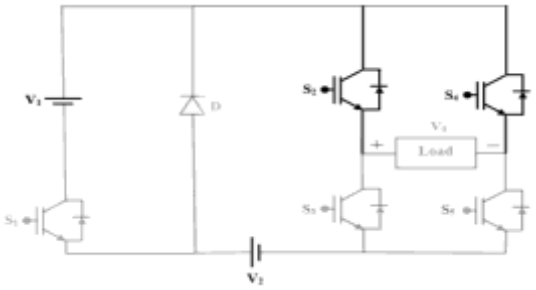


Fig. 7: 0Vdc Output voltage.

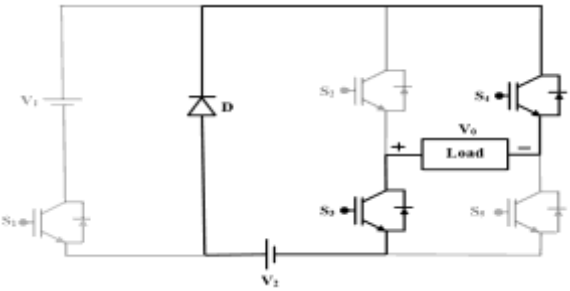


Fig. 8: -Vdc Output voltage.

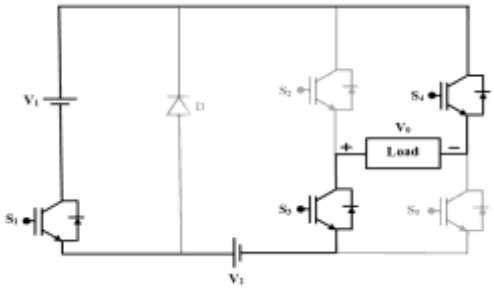


Fig. 9: -2Vdc Output voltage.

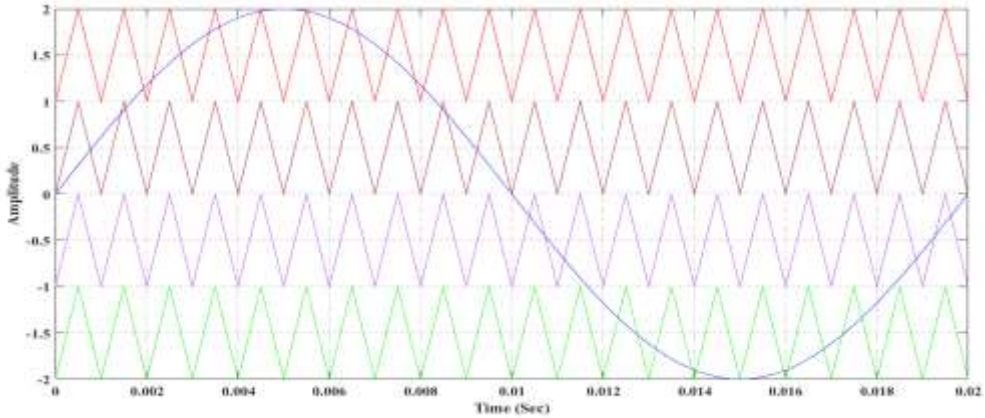


Fig. 10: PWM Pulse generation of five level inverter.

3. MPPT AND POWER LOSS ANALYSIS

Maximum Power Point Tracking is a crucial technique used in photovoltaic (PV) systems to maximize energy extraction under varying environmental conditions, such as changes in solar irradiance and temperature. The MPPT algorithm, as illustrated in the provided flowchart, continuously measures the voltage (V) and current (I) of the PV system, subsequently computing the power output (P) by multiplying these values (P = V × I). The core principle of the algorithm is to dynamically adjust the duty cycle of a DC-DC boost converter to track the maximum power point (MPP), ensuring optimal efficiency. The flowchart describes a Perturb and Observe (P&O) method, one of the most commonly implemented MPPT techniques. Initially, the algorithm measures the power at the current time step, P(k), and compares it with the previous power value, P(k-1). If the power remains unchanged, no adjustments are made. However, if a power increase is detected (P(k) > P(k-1)), the algorithm further examines whether the voltage has also increased. If the voltage has risen (V(k) > V(k-1)), the duty cycle is increased (D = D + ΔD), pushing the system further along the P-V curve in search of the MPP. Conversely, if the voltage has decreased (V(k) < V(k-1)), the duty cycle is reduced (D = D - ΔD) to move the operating point back toward the MPP. Similarly, if a power decrease is detected (P(k) < P(k-1)), the algorithm determines whether the voltage has increased or decreased and adjusts the duty cycle accordingly to maintain operation at or near the peak power point. By continuously cycling through this process, the MPPT controller ensures that the PV system operates at the most efficient point, adapting to fluctuations in environmental conditions. Fig. 12, which presents the power-voltage (P-V) characteristics of a PV array, further illustrates the significance of MPPT in energy harvesting. The curve demonstrates how power output varies with voltage, with a clear peak corresponding to the MPP. If the system operates to the left of this peak, an increase in voltage leads to higher power output, whereas if the system is to the right of the peak, increasing voltage results in power loss. The MPPT controller continuously adjusts the operating voltage to remain at the peak of the curve, preventing energy loss and maximizing power generation. This technique is critical for ensuring that PV systems achieve high efficiency, particularly in large-scale solar installations where even minor improvements in energy harvesting translate to significant gains in electricity production. Without MPPT, PV systems would be unable to dynamically respond to environmental changes, leading to suboptimal performance and energy losses. As solar energy adoption continues to grow globally, advanced MPPT algorithms, such as incremental conductance and fuzzy logic-based methods, are being explored to further improve performance, efficiency, and adaptability in diverse operating conditions. The implementation of MPPT not only enhances renewable energy utilization but also contributes to the broader goal of sustainable and efficient energy generation.

The conduction loss of Insulated Gate Bipolar Transistor (IGBT) can be calculated in the following Eq. (1) [5],

$$P_{\text{Cond,IGBT}} = \frac{1}{T}\int_0^T \left[V_f I(t) + R_{\text{on}} I^2(t)\right] dt \quad (1)$$

The conduction loss of diode can be calculated in the following equation [5].

$$P_{\text{Cond,D}} = \frac{1}{T}\int_0^T \left[V_f I_D(t) + R_D I_D^2(t)\right] dt \quad (2)$$

For an m-level inverter (m=5), the conduction losses per switching device depend on the duty cycle which is calculated in (3) [5].

$$P_{\text{Cond}} = n_s \cdot f_s \cdot V_f I_{\text{avg}} + n_s \cdot R_{\text{on}} I_{\text{rms}}^2 \quad (3)$$

Switching losses occur due to finite turn-on and turn-off times, which is calculated in (4) and further energy lost during turn-on and turn-off can be calculated in (5) and (6) [5].

$$P_{\text{sw}} = \sum_{i=1}^{n_s} \left(E_{\text{on},i} + E_{\text{off},i}\right) f_s \quad (4)$$

$$E_{\text{on}} = \frac{1}{2} V_{\text{dc}} I_{\text{load}} t_{\text{on}} \quad (5)$$

$$E_{\text{off}} = \frac{1}{2} V_{\text{dc}} I_{\text{load}} t_{\text{off}} \quad (6)$$

Diode reverse recovery losses occur due to stored charge removal can be calculated using (7) [12].

$$P_{\text{rec}} = \frac{1}{2} Q_{\text{rr}} V_{\text{dc}} f_s \quad (7)$$

These include control circuit losses, driver circuit losses, and gate drive power are calculated using (8) [12].

$$P_{\text{aux}} = P_{\text{driver}} + P_{\text{control}} \quad (8)$$

For an IGBT gate drive, which is calculated in Eq. (9) [12],

$$P_{\text{driver}} = Q_g V_g f_s \quad (9)$$

Equation (10) provides the total power loss in a five-level inverter based on switching characteristics and device parameters [12].

$$P_{\text{total}} = \sum \Big[n_s \left(V_f I_{\text{avg}} + R_{\text{ou}} I_{\text{rms}}^2\right) + n_s f_s \frac{1}{2} V_{\text{dc}} I_{\text{load}} (t_{\text{ou}} + t_{\text{off}}) + n_d \frac{1}{2} Q_{\text{rr}} V_{\text{dc}} f_s + Q_g V_g f_s \Big] \quad (10)$$

4. RESULTS AND DISCUSSION

Fig. 13 illustrates the current-voltage (I-V) characteristics of the PV array. The curve shows how the PV current varies with voltage under different solar irradiance levels. The short-circuit current (Isc) and open-circuit voltage (Voc) define the extreme operating points of the system. MPPT techniques adjust the voltage to ensure maximum power extraction, enhancing system efficiency. Fig. 14 presents the DC-link capacitor voltage profile in the PV system. The capacitor stabilizes the DC bus voltage by filtering ripples and transients before supplying power to the multilevel inverter. Maintaining a steady DC bus voltage ensures efficient power conversion and minimizes voltage fluctuations affecting inverter performance. Fig. 15 shows the three-phase output voltage of the inverter before filtering. The stepped waveform contains high-frequency harmonics due to the switching operation of the multilevel inverter. The unfiltered output may cause grid disturbances; hence, a filtering system is necessary to smoothen the waveform and meet grid quality standards. Fig. 16 depicts the variation in three-phase output current when the load changes. The inclusion of a filter ensures stable current delivery with minimal distortions, improving power quality. The current

waveform remains consistent, reducing harmonics and improving efficiency for grid integration and EV charging applications. Fig. 17 illustrates how the grid-connected inverter responds to variations in load current. When the load demand fluctuates, the inverter adjusts its output to maintain stable grid integration. The system ensures seamless power delivery without voltage imbalances or excessive harmonic distortions. Fig. 18 presents the THD analysis of the inverter's output voltage and current with a filtering circuit. The filter significantly reduces harmonic distortion, ensuring compliance with IEEE 519 standards. The proposed system achieves a THD below 3%, improving power quality and grid stability. Fig. 18 compares the THD of the conventional and proposed MLI systems. The conventional system exhibits a higher THD (~6.5%), while the proposed MLI achieves a reduced THD (~2.8%). This improvement enhances power quality, making the system more suitable for grid-connected applications. Fig. 19 illustrates THD analysis of conventional and proposed MLI system. Fig. 20 presents the efficiency comparison between the conventional and proposed methods. The conventional system operates at ~92% efficiency, while the proposed method achieves ~96%. The enhanced efficiency is due to optimized switching control, reduced power losses, and improved MPPT performance, making the system ideal for renewable energy applications. Table 1 illustrates the parameters of PV connected three phase grid system. Fig. 21 illustrates the SWOT analysis of proposed inverter. Table 2 illustrates the performance analysis of conventional and proposed inverter.

Table 1: Performance parameters of three phase grid connected grid system.

Parameters	Values
PV system peak power	3000 W
PV system peak current	5.5 A
DC capacitor output voltage	800 V
Three-Phase output voltage (without filter)	230 V (Peak)
Three-Phase output current (with filter)	~10 A
Grid connected current variation	0–12 A
THD output voltage (with filter)	2.80%
THD output current (with filter)	2.50%
THD of conventional MLI	6.50%
THD of proposed MLI	2.80%
Efficiency of conventional method	92%
Efficiency of proposed method	96%
Output power (Conventional)	2800 W
Output power (Proposed)	3000 W
Power quality improvement	30–40% reduction in THD

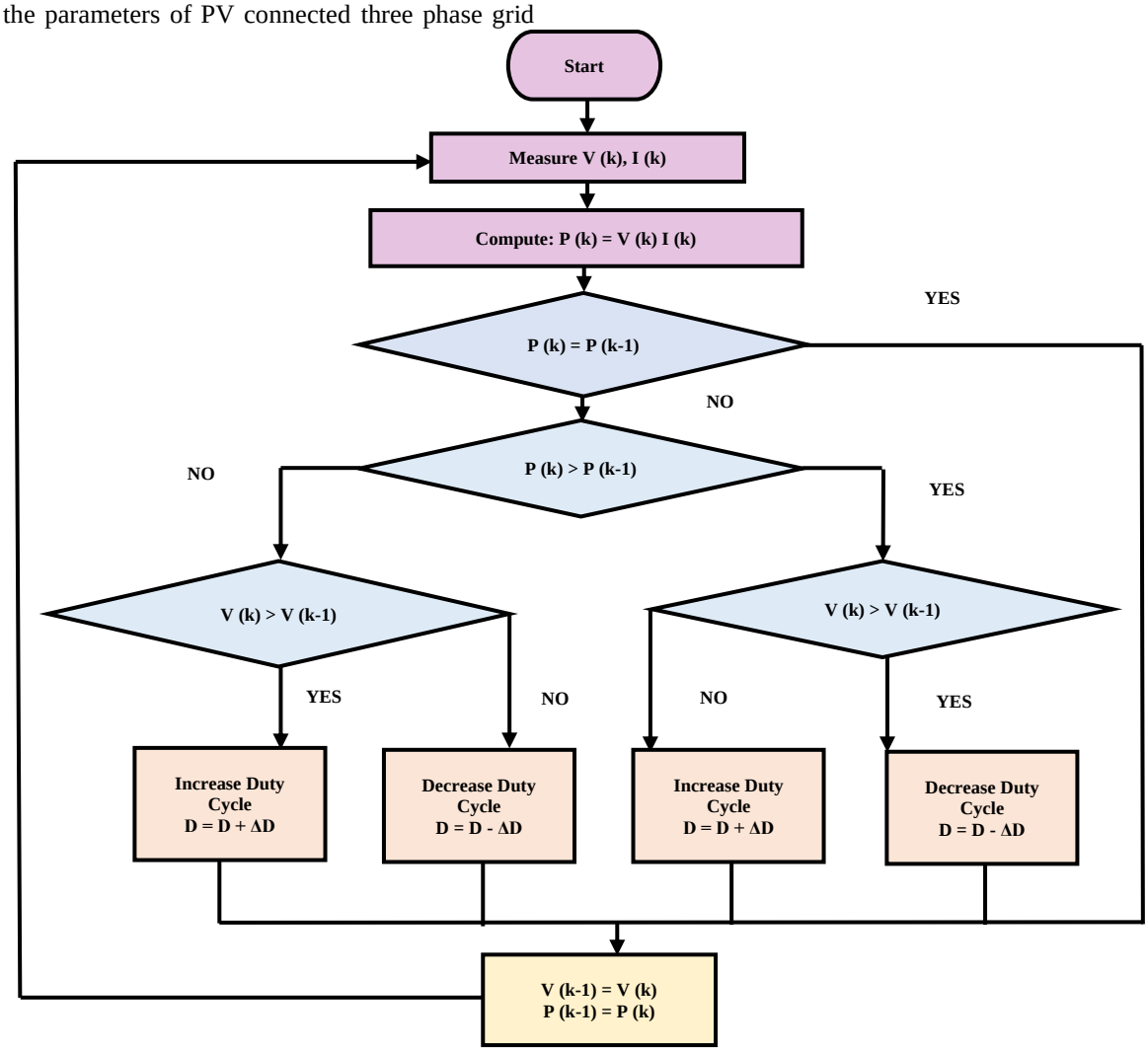


Fig. 11: Maximum power point tracking system for PV system.

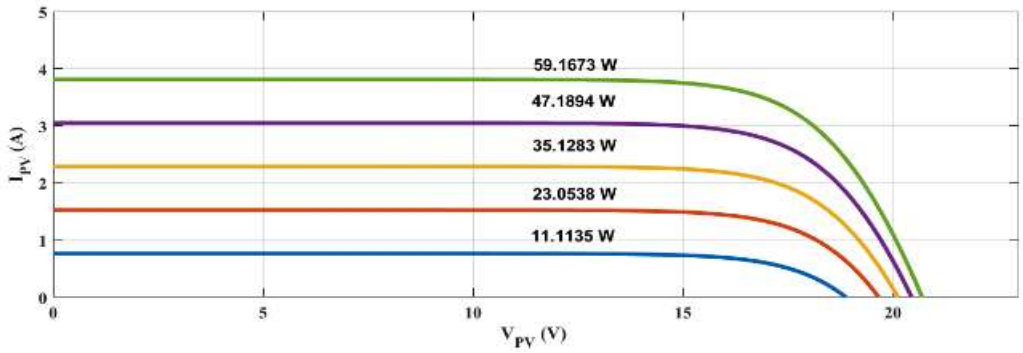


Fig. 12: P-V Characteristics of PV system.

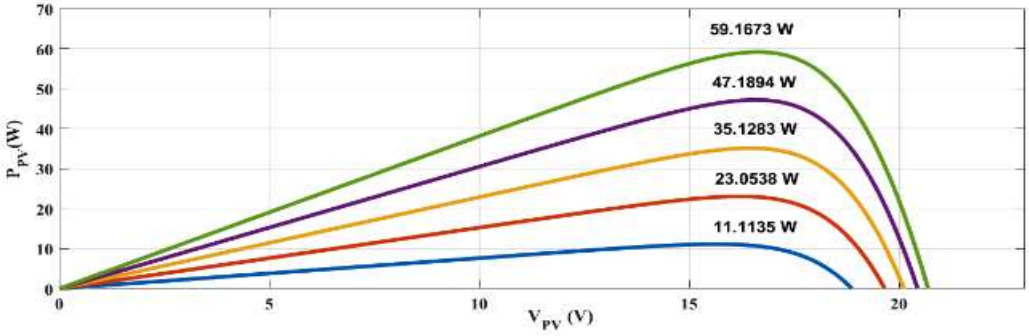


Fig. 13: I-V Characteristics of PV system.

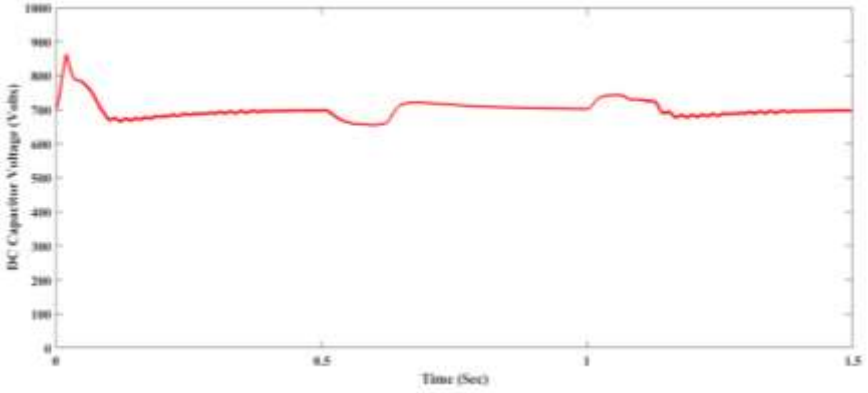


Fig. 14: DC capacitor output voltage for DC bus system.

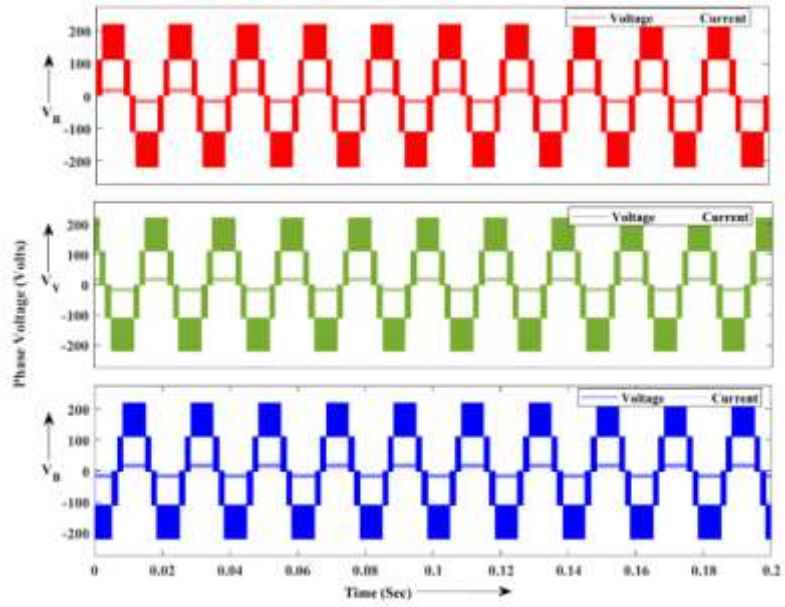


Fig. 15: Three phase output voltage without filter.

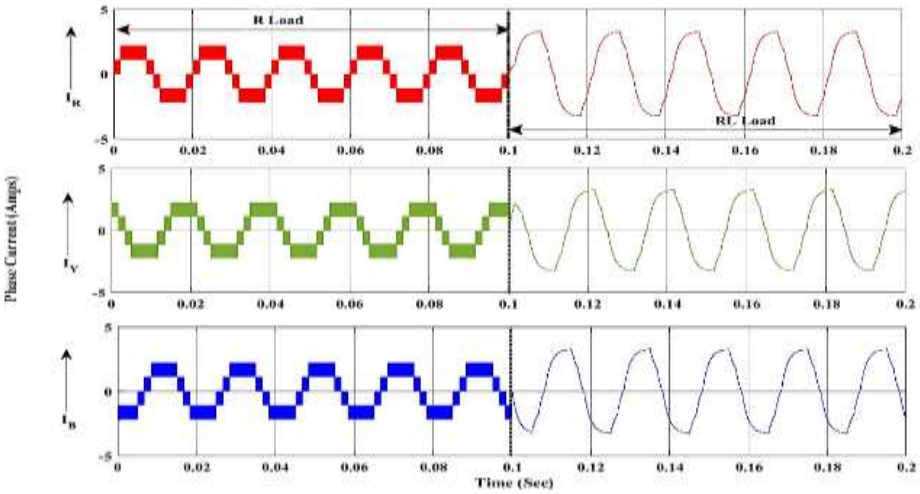


Fig. 16: Three phase output current change in load with filter.

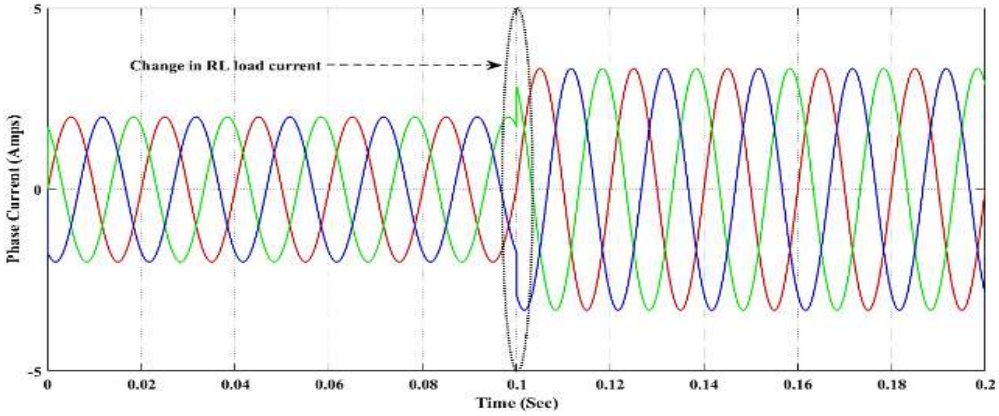


Fig. 17: Grid connected current due to change in load current.

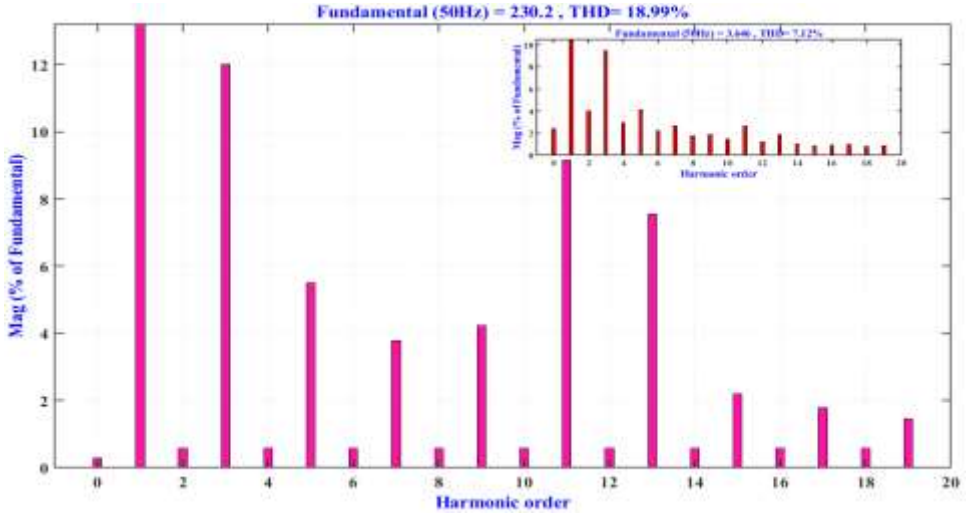


Fig. 18: THD analysis output voltage and current with filter circuit.

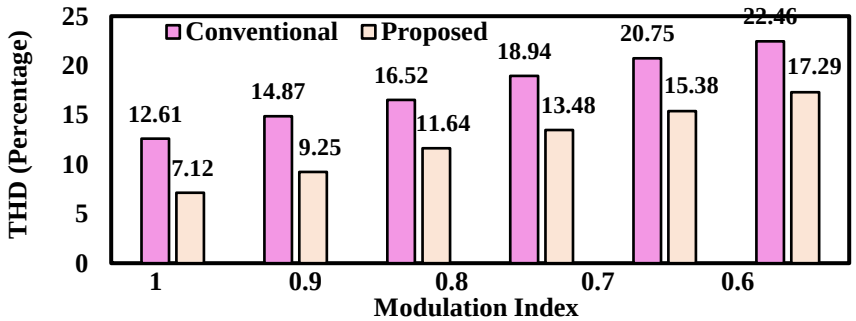


Fig. 19: THD analysis of conventional and proposed MLI system.

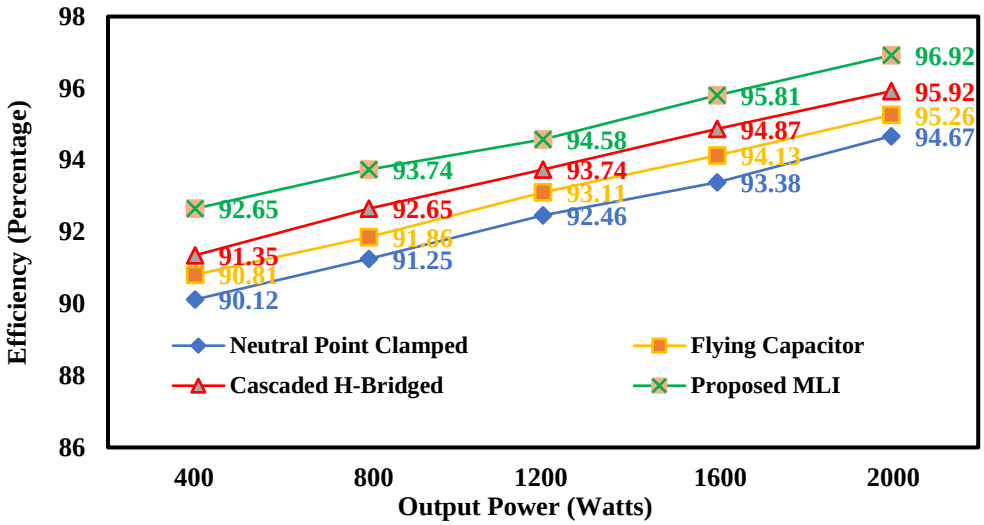


Fig. 20: Efficiency analysis of proposed and conventional methods.

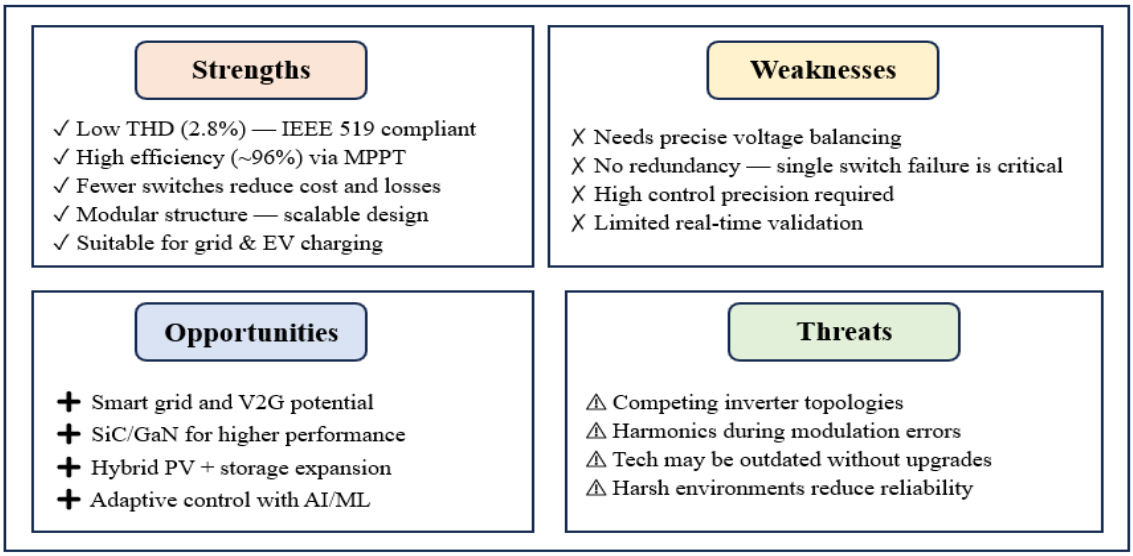


Fig. 21: SWOT analysis of proposed five level inverter.

Table 2: Comparative analysis of conventional and proposed five level MLI.

Criteria	Proposed CHBMLI System	Diode-Clamped MLI (DCMLI)	Flying Capacitor MLI (FCMLI)	Conventional Two-Level Inverter
Switch count	Reduced (8 switches for 5-level output)	High (requires clamping diodes per level)	High (requires multiple capacitors)	Minimal (2 or 3 per phase)
Output quality (THD)	Low THD (2.8% with filter)	Moderate (3.5–5% typical)	Low (but needs balancing control)	High THD (>7%)
Efficiency	High (~96%)	Moderate (~90–93%)	Moderate (~92–94%)	Moderate (~90–92%)
Cost	Moderate (fewer switches and no need for isolation)	High (more components and complex diodes)	High (costly capacitors and balancing circuit)	Low (simpler but low performance)
Complexity	Moderate (PWM with reduced switches)	High (voltage balancing + diode network)	High (complex control for capacitor balancing)	Low (simple PWM control)
Modularity	High (cascaded H-bridge structure)	Low	Low	Low
Reliability	Improved with fewer components	Susceptible to diode imbalance failures	Capacitor degradation under thermal stress	Moderate, but low resilience to THD or grid issues

Figs. 22 and 23 depict the hardware implementation and real-time performance output of the proposed five-level CHBMLI integrated with a PV system. The experimental setup consists of a PV emulator, MPPT controller, a high-efficiency DC-DC boost converter, and the CHBMLI configured with reduced switch topology. The inverter is constructed with a total of eight switches and multiple isolated DC sources to generate five distinct output voltage levels effectively reducing switch count and improving conversion efficiency.



Fig. 22: Hardware setup of proposed five level MLI.

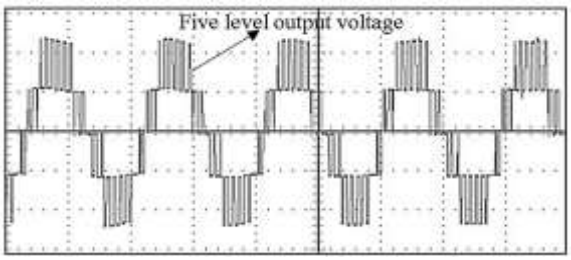


Fig. 23: Real time five level output voltage.

Fig. 23 presents the oscilloscope capture of the real-time inverter output voltage waveform, clearly demonstrating the expected stepped nature. The waveform validates the system's capability to synthesize a near-sinusoidal AC output with minimal harmonic distortion. The five-level output ensures lower dv/dt stress, contributing to reduced electromagnetic interference (EMI) and improved power quality. The experimental results closely match the simulation analysis, with THD levels observed below 3%, aligning with IEEE 519 standards which is analysed in Fig. 24. This validates the robustness and practicality of the hardware implementation for grid-connected renewable applications, particularly in EV charging stations where high efficiency and power quality are critical. The setup confirms real-time feasibility of the proposed topology with reliable modulation and control strategies.

5. Conclusion

The proposed PV-based three-phase MLI system has been successfully designed and analyzed for grid and EV charging applications. The simulation results validate the system's ability to improve energy conversion efficiency, power quality, and grid stability. The implementation of an MPPT-controlled DC-DC boost converter effectively maximizes power extraction, ensuring an optimal DC bus voltage of 800 V. The MLI topology minimizes harmonic distortion, reducing THD to 2.8%, which significantly improves grid compatibility. Compared to conventional inverters, the proposed system enhances efficiency to 96% and reduces power losses, making it a more reliable and cost-effective solution. The study also highlights the advantages of integrating PV energy with the grid, offering a sustainable and uninterrupted power supply. However, further research can focus on optimizing the MLI structure to reduce the number of switches and improve cost-effectiveness. Additionally, real-time implementation and experimental validation of the system would provide deeper insights into its practical feasibility. Overall, the proposed system presents a promising approach for enhancing the reliability and efficiency of renewable energy-based power conversion systems, paving the way for improved EV charging infrastructure and smart grid applications.

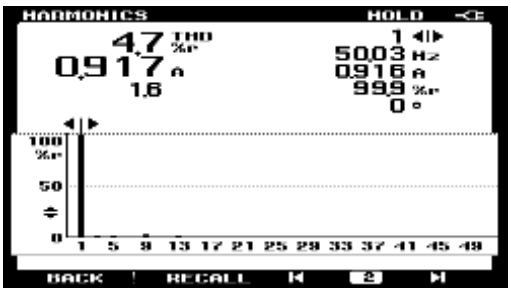


Fig. 24: THD analysis of five level inverter.

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Credit Authorship Contribution Statement

Parimalasundar Ezhilvannan: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing. **Kumar Reddy Cheepati**: Conceptualization, Data curation, Formal analysis, Methodology, Resources, Software, Supervision, Validation, Writing - original draft, Writing - review & editing. **Suresh Krishnan:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing.

Declaration Of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The ethical issues; including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy has been completely observed by the authors.

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