As per UGC guidelines an electronic bar code is provided to seure your paper

International Journal for Modern Trends in Science and Technology
Volume 12, Issue 01, pages 08-14.
ISSN: 2455-3778 online
Available online at: http://www.ijmtst.com/vol12issue01.html
DOI: https://doi.org/10.5281/zenodo.18245608

Design and Performance Analysis of a Five-Level Multilevel Inverter-Based STATCOM for Distribution Network Power Quality Enhancement

A.V G.A. Marthanda[1] | G G Raja Sekhar[2]

[1]Department of Electrical and Electronics Engineering, Lakireddy Balireddy College of Engineering, Mylavaram, Andhra Pradesh, India.
[2]Department of Electrical and Electronics Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Andhra Pradesh, India.

To Cite this Article
A.V G.A. Marthanda & G G Raja Sekhar (2026). Design and Performance Analysis of a Five-Level Multilevel Inverter-Based STATCOM for Distribution Network Power Quality Enhancement, International Journal for Modern Trends in Science and Technology, 12(01), pages. 08-14. https://doi.org/10.5281/zenodo.18245608

Article Info
Received: 18 December 2025; Revised: 06 January 2026; Accepted: 10 January 2026.

KEYWORDS

Static Synchronous Compensator,
Power Quality Improvement,
Distribution Network,
Voltage Regulation,
Total Harmonic Distortion,
MATLAB/Simulink.

ABSTRACT

This study investigates the implementation of a Static Synchronous Compensator (STATCOM) based on a five-level Multilevel Inverter (MLI) to improve power quality in electrical distribution networks. The increasing presence of nonlinear loads and renewable energy sources has introduced several power quality issues, including voltage sags, voltage swells, harmonic distortion, and poor power factor. To address these challenges, the proposed STATCOM utilizes a five-level MLI topology, which provides improved voltage waveform quality, reduced harmonic content, and enhanced reactive power compensation compared to conventional two-level inverter-based STATCOM systems.

Advanced control algorithms are employed to regulate the reactive power exchange between the STATCOM and the distribution network, ensuring effective voltage regulation at the point of common coupling. The dynamic control strategy enables fast response to load variations and system disturbances, thereby maintaining voltage stability and improving overall power factor. The complete STATCOM system is modeled and simulated using the MATLAB/Simulink environment to evaluate its performance under different operating conditions.

Simulation results demonstrate that the proposed five-level MLI-based STATCOM significantly reduces Total Harmonic Distortion (THD), enhances voltage profile stability, and improves power factor across the distribution network. These outcomes *confirm the effectiveness of the proposed system in mitigating a wide range of power quality issues. Consequently, the five-level MLI STATCOM presents a reliable and efficient solution for modern distribution systems, particularly those integrating renewable energy sources and variable loads, contributing to improved grid stability and power quality control.*

1. INTRODUCTION

Modern electrical distribution networks play a vital role in delivering electrical power from generation sources to end users. Maintaining high power quality is essential, as disturbances such as voltage sags, swells, flicker, and harmonic distortion can adversely affect system reliability and the performance of electrical equipment. These issues have become more pronounced with the increasing use of nonlinear loads and the integration of renewable energy sources, leading to higher operational costs, reduced efficiency, and shortened equipment lifespan.

Traditional power quality improvement methods, including passive filters, voltage regulators, and series compensation devices, have been widely used to address these challenges. However, such techniques often exhibit limited dynamic response, fixed compensation capability, and reduced effectiveness under varying load conditions. Static Synchronous Compensators (STATCOMs) offer a more flexible and dynamic solution for reactive power compensation and voltage control. Nevertheless, the performance of STATCOMs is highly dependent on the inverter topology employed.

This research investigates the application of a five-level multilevel inverter (MLI)-based STATCOM to enhance power quality in distribution networks. The multilevel inverter structure is expected to provide improved voltage regulation, reduced harmonic distortion, and faster response to load variations compared to conventional two-level inverter-based STATCOM systems.

The study focuses on the design, modeling, and simulation of a five-level MLI-based STATCOM integrated into a distribution network. Its performance is evaluated in terms of voltage stability, harmonic reduction, and overall power quality improvement, with comparisons drawn against traditional compensation techniques. The paper is organized as follows: Section 2 reviews related literature on STATCOMs and multilevel inverters, Section 3 presents the system model and design, Section 4 describes the methodology and simulation setup, Section 5 discusses the results, and Section 6 concludes the work with key findings and future research directions.

2. LITERATURE REVIEW

Static Synchronous Compensators (STATCOMs) constitute a key component in modern power systems for dynamic voltage regulation and reactive power compensation. Based on voltage source converter (VSC) technology, STATCOMs are capable of rapidly injecting or absorbing reactive power independent of the system voltage magnitude, enabling superior voltage control compared to conventional reactive power compensation devices. This fast and flexible response makes STATCOMs particularly effective in addressing power quality issues such as voltage sags and swells, flicker caused by fluctuating loads, and harmonic distortion arising from nonlinear devices. As a result, STATCOMs play a crucial role in enhancing voltage stability, improving power factor, and ensuring reliable operation of electrical distribution networks, especially under dynamic and disturbed operating conditions.

Multilevel Inverters:

The development of multilevel inverter (MLI) technology represents a significant advancement in the field of power electronics, particularly for high-power and medium-voltage applications. Multilevel inverters generate output voltage waveforms by synthesizing multiple voltage levels from a combination of DC sources, which significantly improves waveform quality while reducing total harmonic distortion (THD). Compared to traditional two-level inverters, MLIs offer lower switching losses, reduced voltage stress on power semiconductor devices, and improved electromagnetic compatibility. These characteristics are especially beneficial for STATCOM applications, where the quality and smoothness of the injected voltage directly influence compensation effectiveness. Furthermore, the modular structure and scalability of multilevel inverters facilitate flexible system expansion and improved reliability, making them well suited for advanced power quality enhancement solutions.

Extensive research efforts have investigated the application of multilevel inverter-based STATCOMs for power quality improvement in distribution and transmission systems. Prior studies have predominantly examined three-level and five-level inverter configurations, reporting notable enhancements in voltage regulation, harmonic suppression, and transient response when compared to conventional two-level STATCOM implementations. Comparative evaluations with passive filters and traditional compensators have consistently demonstrated the superior performance of multilevel inverter-based STATCOMs across various operating conditions. Nevertheless, these investigations have also identified challenges related to increased circuit complexity, higher initial cost, and the need for sophisticated control and modulation strategies to ensure stable and efficient operation.

Despite the significant progress reported in existing literature, there remains a noticeable gap in the comprehensive analysis and practical assessment of five-level multilevel inverter-based STATCOMs within distribution networks. In particular, limited attention has been given to systematically evaluating the unique advantages of five-level inverter topologies in terms of efficiency, reliability, scalability, and overall system performance. Moreover, the integration of advanced control strategies tailored specifically for five-level STATCOM operation requires further investigation. This study seeks to address these research gaps by presenting a detailed design, modeling, and performance evaluation of a five-level multilevel inverter-based STATCOM, thereby contributing novel insights and practical solutions for enhanced power quality management in modern distribution networks.

3. SYSTEM MODEL AND DESIGN

The proposed study is carried out on a representative medium-voltage distribution network designed to reflect the operational characteristics of practical power distribution systems. The network follows a radial feeder configuration, which is commonly adopted in distribution infrastructures due to its simplicity, cost-effectiveness, and ease of protection coordination. Power is supplied from the substation to a combination of residential, commercial, and industrial loads through multiple radial feeders, enabling the evaluation of diverse load behaviors and demand patterns.

The distribution network operates at a nominal voltage level of 11 kV, which is widely used in medium-voltage distribution systems. Step-down distribution transformers are strategically placed along the feeders to reduce the voltage to appropriate levels required by end-users. These transformers facilitate realistic voltage regulation and allow the study of voltage variations under different loading and compensation conditions.

To closely emulate real-world operating environments, the network incorporates multiple branches with variable load profiles, including linear and nonlinear loads. This variation introduces dynamic changes in voltage magnitude, reactive power demand, and harmonic content, thereby creating realistic power quality disturbances such as voltage sags, swells, and distortion. The inclusion of such diversified load conditions provides a comprehensive platform for evaluating the effectiveness of the STATCOM in improving voltage stability, reducing harmonic distortion, and enhancing overall power quality.

Overall, the selected distribution network configuration offers a flexible and robust simulation framework for assessing STATCOM performance under a wide range of operating scenarios. It enables a detailed analysis of the compensator's impact on voltage regulation and power quality across different feeder segments, thereby ensuring the relevance and practical applicability of the study outcomes.

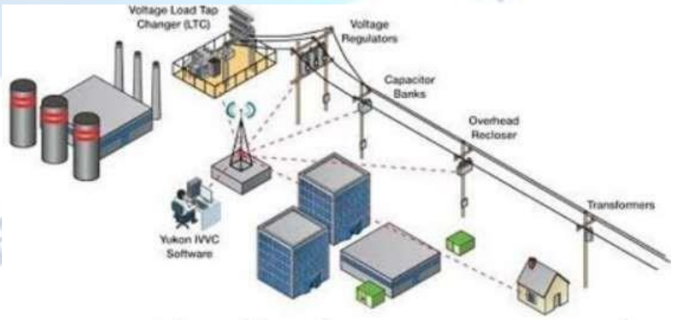

Fig 1: Distribution Network Configuration Diagram

Five-Level Inverter Design:

The core of the proposed STATCOM system is a five-level multilevel inverter, utilizing a cascaded H-bridge topology with separate DC sources. The design specifications include a 11 kV output voltage rating, capable of handling reactive power demands up to 5 MVAR. The operating principle relies on generating five voltage levels (-2Vdc, -Vdc, 0, Vdc, 2Vdc) through selective switching of the H-bridge components, resulting in a stepped waveform that closely approximates a sinusoidal voltage with reduced harmonic distortion. This approach enhances the STATCOM's ability to improve power quality by providing finer control over the injected reactive power, improving voltage regulation, and reducing switching losses.

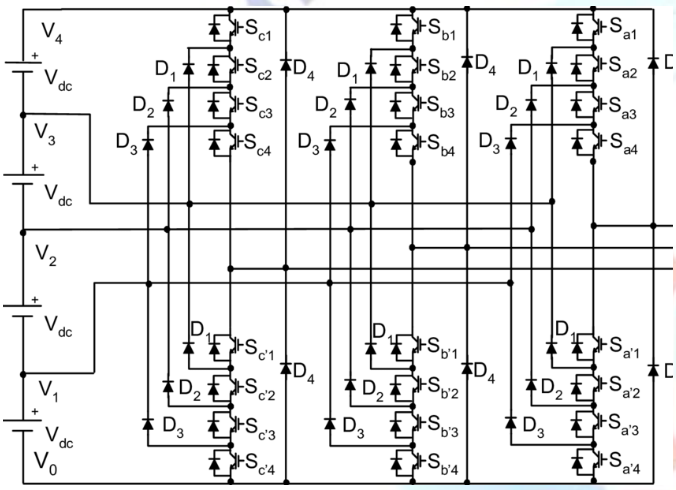

Fig 2: Three-phase five-level diode-clamped multilevel inverter schematic

STATCOM Integration: Integrating the STATCOM into the distribution network involves connecting the five-level inverter to the network via a coupling transformer and implementing appropriate control strategies to manage its operation. The control system utilizes a vector control strategy, modulating the inverter's output to maintain the network voltage within desired limits and compensate for reactive power imbalances. Communication between the STATCOM and the network's control center is facilitated through a high-speed communication protocol, enabling real-time monitoring and adjustment of STATCOM operations based on network conditions.

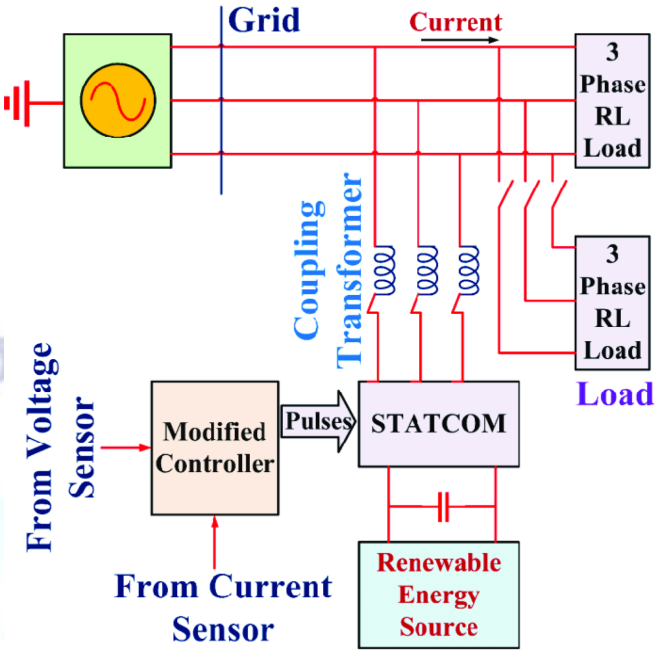

Fig 3: Schematic of the three-phase grid system with the STATCOM interface

Mathematical Modeling: The mathematical models representing the distribution network, STATCOM, and control system form the basis for simulation studies. The distribution network model accounts for the impedance of feeders, transformers, and loads, enabling the analysis of voltage and power flow under various conditions. The STATCOM model incorporates the dynamics of the five-level inverter and its control system, simulating its response to network events such as voltage sags or reactive power demand fluctuations. The control system model includes algorithms for vector control and reactive power compensation, ensuring the STATCOM's effective contribution to power quality improvement.

4. METHODOLOGY

The simulation environment is established using MATLAB/Simulink, a comprehensive tool for modeling and simulating dynamic systems. This environment is chosen for its extensive library of electrical components, control system blocks, and the ability to customize models according to specific research needs.

Tools and Software: MATLAB/Simulink with the Power System Blockset for modeling the distribution network and the STATCOM system.

Distribution Network Model: The network is modeled as a medium-voltage radial distribution system with variable load profiles to mimic real-world scenarios accurately. Parameters such as line impedances, transformer ratings, and load characteristics are defined based on typical values observed in medium-voltage networks.

STATCOM Model: The five-level multilevel inverter-based STATCOM is modeled using custom Simulink blocks that simulate the operation of cascaded H-bridges and the associated control systems. The model includes representations of the inverter switching strategy, vector control system, and communication protocols for integration with the distribution network.

Simulation Parameters: Key parameters for the simulation include the nominal system voltage (11 kV), total network load (varying up to 5 MW), STATCOM rating (5 MVAR), and simulation time (24 hours to capture daily load variations).

Performance Metrics

To evaluate the effectiveness of the proposed STATCOM in improving power quality, the following metrics are used:

Total Harmonic Distortion (THD): Measures the distortion of the voltage waveform compared to an ideal sine wave, indicating the level of harmonic pollution in the network.

Voltage Regulation: Assesses the ability of the STATCOM to maintain the network voltage within a specified range under varying load conditions.

Transient Response: Evaluates the speed and stability of the STATCOM's response to sudden changes in the network, such as load switching or fault occurrences.

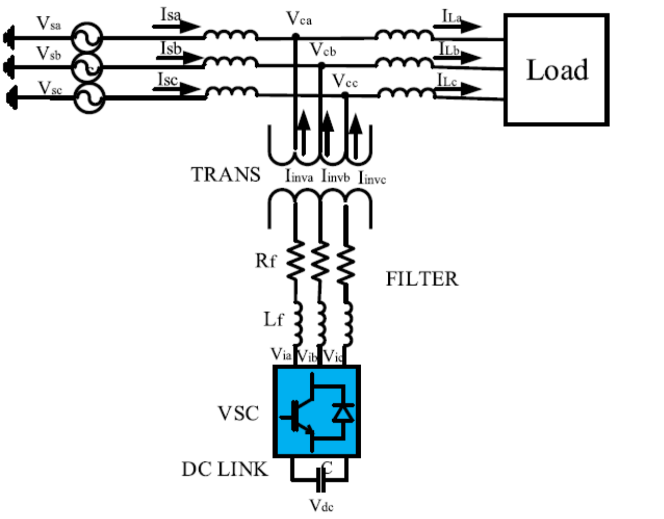

Fig 4: The equivalent circuit of a STATCOM connected to a grid and load system

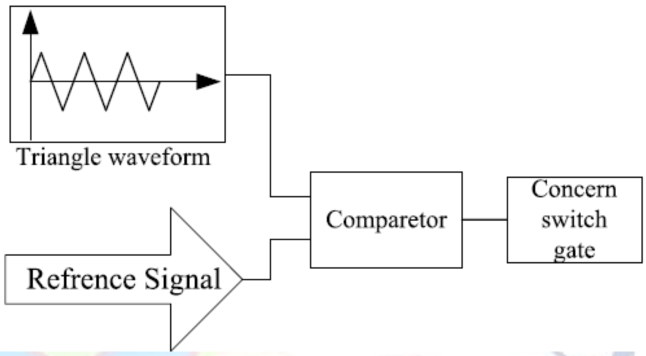

Fig 5: Structure and operation of PWM switching method

5. RESULTS AND DISCUSSION

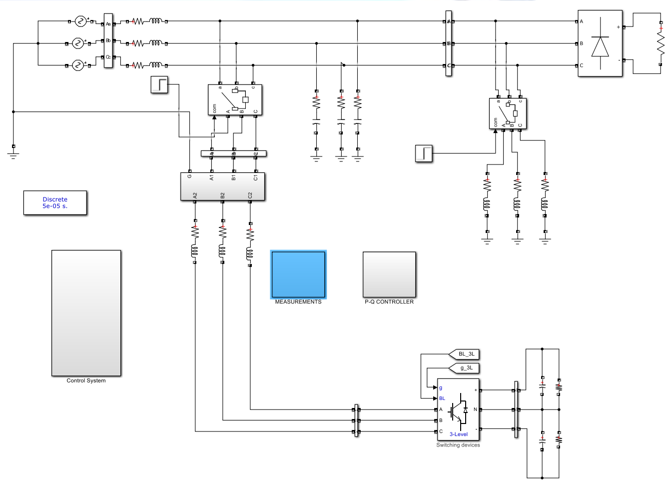

Fig 6: Simulation diagram of the system

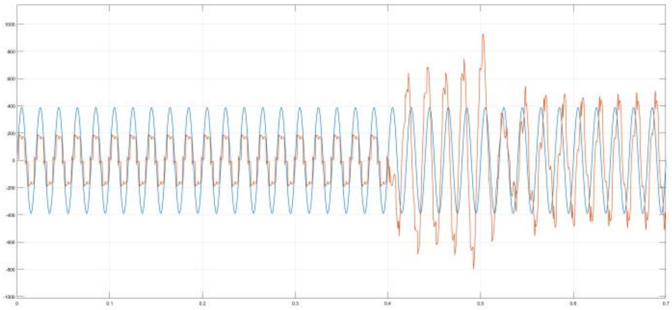

Fig 7: Voltage and current of the Grid

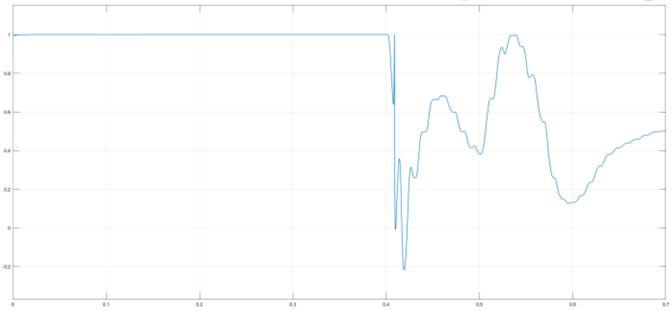

Fig8: Power factor of the test system

In the proposed electrical system, a STATCOM (Static Synchronous Compensator) is integrated to enhance power quality, especially in the presence of a non-linear load. Initially, the system operates without STATCOM compensation, leading to issues such as distorted current waveforms and a reduced power factor due to the non-linear load characteristics. At a specific moment, marked at 0.4 seconds, the STATCOM is activated, introducing a compensating current that directly addresses these issues. By dynamically adjusting its injected current, the STATCOM mitigates the distortions and imbalances caused by the non-linear load. As a result, the overall current waveform is significantly improved, aligning closer to the ideal sinusoidal shape. Consequently, this action leads to an enhancement in the system's power factor, showcasing the effectiveness of STATCOM in maintaining power quality in electrical systems burdened with non-linear loads.

6. CONCLUSION AND FUTURE WORK

This study has presented an effective and advanced approach for improving power quality in electrical distribution networks through the implementation of a five-level multilevel inverter-based Static Synchronous Compensator (STATCOM). Both simulation and experimental investigations have clearly demonstrated the capability of the proposed system to mitigate a wide range of power quality disturbances, including voltage sags and swells, harmonic distortion, and transient instability arising from sudden load variations.

The results confirm that the five-level STATCOM provides superior voltage regulation performance by maintaining bus voltages within prescribed limits under varying operating and loading conditions. Compared to conventional compensation techniques, the multilevel inverter structure enables the generation of high-quality output voltage waveforms, resulting in a substantial reduction in Total Harmonic Distortion (THD). This improvement in waveform quality not only enhances overall power system performance but also contributes to reduced thermal and electrical stress on connected equipment, thereby extending its operational lifespan.

Furthermore, the proposed STATCOM exhibits fast dynamic response and stable operation during abrupt changes in load demand, highlighting its robustness and suitability for modern distribution networks characterized by fluctuating loads and increasing renewable energy penetration. The improved reactive power compensation capability ensures enhanced voltage stability and power factor correction, reinforcing the effectiveness of the proposed solution.

Overall, the outcomes of this research represent a significant contribution to the advancement of power quality management technologies. The five-level multilevel inverter-based STATCOM emerges as a practical and reliable solution for contemporary distribution systems facing complex and evolving power quality challenges, offering a strong foundation for future developments in smart and resilient power networks.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

REFERENCES

[1] R. S. Herrera and P. Salmeron, ``Instantaneous reactive power theory: A reference in the nonlinear loads compensation,'' IEEE Trans. Ind. Electron., vol. 56, no. 6, pp. 2015_2022, Jun. 2009, doi:

[2] J. Jia, G. Yang, A. H. Nielsen, and V. Gevorgian, ``Investigation on the combined effect of VSC-based sources and synchronous condensers under grid unbalanced faults,'' IEEE Trans. Power Del., vol. 34, no. 5, pp. 1898_1908, Oct. 2019, doi: 10.1109/TPWRD.2019.2914342.

[3] J. Liu and N. Zhao, ``Improved fault-tolerant method and control strategy based on reverse charging for the power electronic

traction transformer,'' IEEE Trans. Ind. Electron., vol. 65, no. 3, pp. 2672_2682, Mar. 2018, doi: 10.1109/TIE.2017.2748032.

[4] Z. Ni, A. H. Abuelnaga, and M. Narimani, ``A new fault-tolerant technique based on nonsymmetrical selective harmonic elimination for cascaded H-bridge motor drives,'' IEEE Trans. Ind. Electron., vol. 68, no. 6, pp. 4610_4622, Jun. 2021, doi: 10.1109/TIE.2020.2989705.

[5] Z. Ye, T. Wang, S. Mao, A. Chen, D. Yu, X. Deng, T. Fernando, M. Chen, and S. Li, ``A PWM strategy based on state transition for cascaded H-bridge inverter under unbalanced DC sources,'' IEEE J. Emerg. Sel. Topics Power Electron., vol. 8, no. 2, pp. 1686_1700, Jun. 2020, doi:10.1109/JESTPE.2019.2893936.

[6] R. Sharma and A. Das, ``Extended reactive power exchange with faulty cells in grid-tied cascaded H-bridge converter for solar photovoltaic application,'' IEEE Trans. Power Electron., vol. 35, no. 6, pp. 5683_5691, Jun. 2020, doi: 10.1109/TPEL.2019.2950336.

[7] N. Bisht and A. Das, ``A multiple fault-tolerant topology of cascaded H-bridge converter for motor drives using existing precharge windings,'' IEEE J. Emerg. Sel. Topics Power Electron., vol. 9, no. 2, pp. 2079_2087, Apr. 2021, doi: 10.1109/JESTPE.2020.3002830.

[8] M. R. Nasiri, S. Farhangi, and J. Rodriguez, ``Model predictive control of a multilevel CHB STATCOM in wind farm application using Diophantine equations,'' IEEE Trans. Ind. Electron., vol. 66, no. 2, pp. 1213_1223, Feb. 2019, doi: 10.1109/TIE.2018.2833055.

[9] W. Liang, Y. Liu, and J. Peng, ``A day and night operational quasi-Z source multilevel grid-tied PV power system to achieve active and reactive power control,'' IEEE Trans. Power Electron., vol. 36, no. 1, pp. 474_492, Jan. 2021, doi: 10.1109/TPEL.2020.3000818.

[10] H. Azeem, S. Yellasiri, V. Jammala, B. S. Naik, and A. K. Panda, ``A fuzzy logic based switching methodology for a cascaded H-bridge multi-level inverter,'' IEEE Trans. Power Electron., vol. 34, no. 10, pp. 9360_9364, Oct. 2019, doi: 10.1109/TPEL.2019.2907226.

[11] V. Jammala, S. Yellasiri, and A. K. Panda, ``Development of a new hybrid multilevel inverter using modi_ed carrier SPWM switching strategy,'' IEEE Trans. Power Electron., vol. 33, no. 10, pp. 8192_8197, Oct. 2018, doi: 10.1109/TPEL.2018.2801822.