**Journal of Information Systems Engineering and Management**
2024, 9(4)
e-ISSN: 2468-4376
https://jisem-journal.com/

**Research Article**

# Solar Photovoltaic–Integrated Cascaded H-Bridge Multilevel Inverter with Fuzzy Logic–Based Adaptive Harmonic Mitigation for Grid-Connected Applications

[1]N.Vanajakshi, [2]Dr .M .Uma Vani , [3]Dr .R .Srinivas Rao
*[1] Research Scholar, [23]Professor*
*[123]EEE Department*
*[2] Lakireddy Bali Reddy College of Engineering, Mylavaram, Vijayawada, Krishna.*
*[1,3]University College of Engineering, JNT University, Kakinada-533003*
*1vanajakshina@gmail.com,2 marreddy.umavani@gmail.com,3 srinivas jntueee@gmail.com*

**ARTICLE INFO**

Received: 01 Sept 2024

Revised: 20 Oct 2024

Accepted: 28 Oct 2024

**ABSTRACT**

The rapid integration of solar photovoltaic (PV) systems into modern power grids demands advanced power electronic converters capable of delivering high-quality voltage under fluctuating operating conditions. Cascaded H-bridge multilevel inverters (CHB-MLIs) are well suited for solar PV applications due to their modularity, scalability, and ability to interface multiple isolated DC sources; however, variations in solar irradiance, DC-link voltage imbalance, and load disturbances significantly degrade harmonic performance when conventional control methods are employed. This paper proposes a solar PV–integrated performance-enhanced CHB multilevel inverter using a hybrid control strategy that combines selective harmonic mitigation (SHM) with a fuzzy logic controller (FLC) for adaptive harmonic suppression. Optimal switching angles derived through SHM ensure low steady-state harmonic distortion, while the fuzzy logic controller dynamically adjusts the modulation index based on voltage error and harmonic feedback to compensate real-time disturbances caused by PV intermittency. Simulation results on a seven-level CHB inverter demonstrate a substantial reduction in low-order harmonics, improved transient response, enhanced DC-link voltage balancing, and nearly 50% reduction in total harmonic distortion compared to conventional SHE and PI-based controllers. The proposed control framework is therefore highly suitable for grid-connected solar PV systems, renewable energy interfaces, and medium-voltage power conversion applications requiring stringent power-quality compliance and robust dynamic performance.

**Keywords:** Solar photovoltaic system, cascaded H-bridge multilevel inverter, fuzzy logic controller, selective harmonic mitigation, harmonic suppression, grid-connected PV, total harmonic distortion.

## I.INTRODUCTION

Grid-connected solar photovoltaic (PV) generation has expanded rapidly over the last decade, pushing power-electronic interfaces to meet stricter grid codes on harmonic injection, power factor, and dynamic support under wide irradiance and temperature variations [12]. In this context, multilevel inverters have become a preferred solution for medium- and high-power renewable interfaces because they can synthesize staircase voltage waveforms with lower dv/dt stress, reduced filter requirements, and improved power quality compared with conventional two-level converters [7], [12]. Among multilevel topologies, the cascaded H-bridge (CHB) inverter is especially attractive for PV systems because of its modular structure and its natural compatibility with multiple isolated DC sources (e.g., PV strings), enabling scalability and redundancy in large installations [1], [7].

Early grid-connected CHB PV systems demonstrated that independent regulation of cell DC-link voltages and coordinated control can improve operating range and allow stable operation even under unbalanced PV conditions (e.g., mismatch among strings) [1]. Similarly, modular CHB PV converters have been explored with added functionalities such as nonactive power compensation to support the grid while extracting PV power, highlighting the broader role of PV inverters beyond real-power conversion [2]. Despite these advantages, CHB PV inverters face persistent challenges related to harmonics, DC-link voltage balancing, and control robustness when PV sources fluctuate, partial shading occurs, or the load/grid conditions change quickly [4], [7], [8]. These issues directly impact total harmonic distortion (THD), converter losses, thermal stress, and ultimately compliance with power-quality standards [12].

Harmonic mitigation in CHB and other multilevel inverters is commonly addressed through modulation strategies such as carrier-based PWM and selective harmonic elimination/pulse-width modulation (SHEPWM), where switching angles are chosen to cancel specific low-order harmonics while maintaining the desired fundamental component [3], [10]. However, classical SHEPWM requires solving nonlinear transcendental equations that can exhibit multiple solutions and sensitivity to operating points, making real-time implementation difficult across a wide modulation range [3], [10]. To improve feasibility and harmonic performance, researchers have proposed optimization-driven SHE methods that compute switching angles more reliably and achieve lower THD over broader operating conditions [11], [14]. A comprehensive review of SHEPWM formulations and solution strategies also emphasizes the importance of robust solvers and practical implementation considerations for multilevel converters deployed in real power systems [10].

For CHB PV systems specifically, a major practical bottleneck is maintaining balanced DC-link voltages among cascaded cells, especially during PV mismatch and dynamic irradiance changes [4], [7]. Improved balancing strategies for CHB converters have been reported to extend controllability and prevent individual cell overvoltage/undervoltage conditions that can distort the output waveform and degrade harmonic performance [4]. In parallel, PV-focused CHB control and modulation studies have explored methods to reduce DC voltage fluctuation and stabilize operation under changing solar input, since DC-side ripple and imbalance propagate into AC-side distortion and current quality issues [8]. Quasi-Z-source CHB configurations have also been investigated for PV integration, combining buck–boost capability with multilevel conversion to better tolerate PV voltage variation while supporting grid injection requirements [5].

Beyond modulation and balancing, intelligent and hybrid control methods have gained attention for handling the nonlinear, time-varying behavior of PV-fed multilevel inverters. In PV applications, fuzzy logic has been applied not only to inverter-side control but also to maximum power point tracking (MPPT), demonstrating robustness under nonlinearities and parameter uncertainties when compared with purely classical approaches [9]. More broadly, hybrid frameworks that combine offline harmonic-optimized switching patterns with online adaptive control are increasingly motivated by the need to sustain low THD and good dynamic response under real operating disturbances (irradiance steps, load transients, and grid perturbations) [7], [8], [12]. Recent literature on metaheuristics-based SHE further reinforces that optimization algorithms can effectively enhance harmonic elimination performance, particularly when operating points vary and conventional solvers struggle [14]. Complementary PV inverter reviews also underline that converter selection, modulation choice, and control architecture jointly determine efficiency, reliability, and grid compliance, especially for multilevel grid-connected PV systems [12].

Accordingly, current research trends point toward PV-aware CHB inverter control that jointly addresses (i) harmonic suppression (low THD and targeted low-order harmonic reduction), (ii) DC-link balancing and stability during PV mismatch, and (iii) fast transient performance without excessive switching loss penalties [7], [8], [10], [12]. Within this scope, combining selective harmonic mitigation (via optimized switching angles) with intelligent/adaptive controllers provides a practical pathway to achieve both steady-state power quality and robust dynamic behavior, which is essential for modern grid-connected PV interfaces [8], [10], [14], [15].

## II.LITERATURE REVIEW

Recent research on cascaded H-bridge multilevel inverters (CHB-MLIs) has increasingly focused on improving harmonic performance and robustness under practical operating conditions, particularly for renewable-energy-fed systems. Several studies emphasize the limitations of classical selective harmonic elimination (SHE) when applied to multilevel inverters with varying DC-link voltages and load disturbances. Advanced numerical and hybrid analytical approaches have been introduced to improve convergence reliability and harmonic suppression over wide modulation ranges [16], [17]. These works demonstrate that while SHE remains effective for steady-state harmonic reduction, its performance deteriorates under nonideal conditions, motivating the integration of adaptive and intelligent control strategies.

Metaheuristic optimization techniques have emerged as powerful tools for computing optimal switching angles in multilevel inverters. Algorithms such as particle swarm optimization (PSO), genetic algorithms (GA), quantum-behaved PSO (QPSO), and differential evolution have been successfully applied to SHE problems to eliminate dominant low-order harmonics and minimize total harmonic distortion (THD) [18], [19]. Comparative studies show that metaheuristic-based SHE methods outperform classical solvers in terms of global convergence and robustness, especially for higher-level inverters and unequal DC-source conditions common in photovoltaic (PV) systems [20]. However, these methods are typically implemented offline or via lookup tables, limiting their ability to respond to fast dynamic changes.

To address real-time performance degradation, intelligent controllers such as fuzzy logic controllers (FLCs) and neural-network-based schemes have been proposed for harmonic mitigation and voltage regulation in CHB inverters. FLC-based approaches offer superior transient response and robustness against parameter variations compared to conventional PI controllers, particularly in systems with nonlinear dynamics and uncertain operating conditions [21], [22]. These studies report notable reductions in THD and improved stability during load and source disturbances, although fuzzy controllers alone may not achieve the same steady-state harmonic minimization as optimized SHE techniques.

More recent literature highlights the effectiveness of hybrid control frameworks that combine optimized switching-angle computation with intelligent online compensation. By merging metaheuristic-based SHE or SHM methods with fuzzy or adaptive controllers, researchers have achieved both low steady-state THD and enhanced dynamic performance [23], [24]. Such hybrid strategies are especially relevant for grid-connected renewable energy applications, where DC-source intermittency and grid disturbances are unavoidable. Survey and review papers further recommend hybrid intelligent–optimization approaches as a promising direction for next-generation multilevel inverter control [25].

Overall, existing studies confirm that while optimization-based SHE methods and fuzzy logic control independently improve inverter performance, their integration provides a more comprehensive solution. However, limited work has systematically addressed the combined impact of fuzzy logic–based adaptive control and selective harmonic mitigation in solar PV–fed CHB inverters, particularly with emphasis on DC-link balancing and real-time harmonic feedback. This gap forms the primary motivation for the proposed work.

**Journal of Information Systems Engineering and Management**
2024, 9(4)
e-ISSN: 2468-4376
https://jisem-journal.com/

**Research Article**

## III.PROPOSED SYSTEM MODELLING

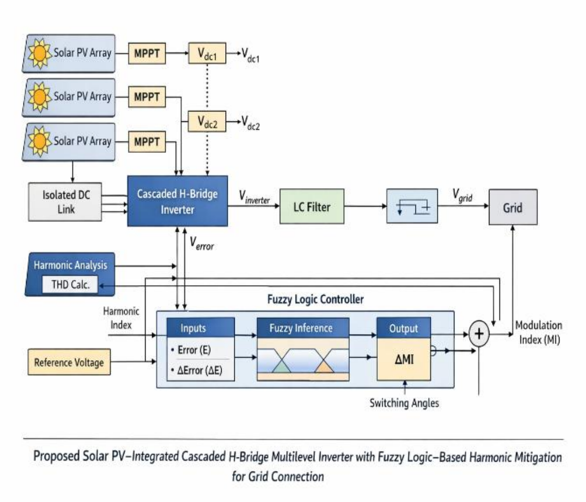


Figure1 : MATLAB/Simulink Block Diagram of Solar PV–Integrated Cascaded H-Bridge Multilevel Inverter With Hybrid Fuzzy Logic–Selective Harmonic Elimination (FLC–SHE) Control for Grid Connection

### 1. Solar PV Integration

The proposed system integrates multiple solar photovoltaic (PV) sources with a cascaded H-bridge multilevel inverter (CHB-MLI) to form a modular and scalable grid-connected power conversion architecture. Each PV string is connected to an individual H-bridge cell through an isolated DC-link, enabling independent maximum power extraction and improved fault tolerance. Due to variations in solar irradiance, temperature, and partial shading, the PV output voltage exhibits nonlinear and time-varying characteristics, which directly affect DC-link stability and inverter output quality. To address these challenges, the system employs a hybrid control strategy in which optimal switching angles derived offline ensure low steady-state harmonic distortion, while an online fuzzy logic controller dynamically compensates for PV-induced disturbances. This integration allows efficient utilization of solar energy while maintaining grid-compliant voltage and current waveforms under fluctuating operating conditions.

### 2. CHB Inverter Topology

The cascaded H-bridge inverter topology used in this work consists of three single-phase H-bridge cells connected in series**,** resulting in **a** seven-level output voltage waveform. Each H-bridge is supplied by an isolated DC source derived from a solar PV string, enabling the inverter to synthesize stepped voltage levels of –3Vdc, –2Vdc, –Vdc, 0, +Vdc, +2Vdc, and +3Vdc. This modular structure significantly reduces voltage stress on individual switches, lowers dv/dt, and improves output waveform quality compared with conventional two-level inverters. The harmonic content of the output voltage is primarily governed by the switching angles within each quarter cycle, which are selected to eliminate dominant low-order harmonics. However, unequal DC-link voltages and dynamic PV conditions can distort the synthesized waveform, necessitating adaptive control to preserve harmonic performance and voltage balance across the cascaded cells.

Journal of Information Systems Engineering and Management
2024, 9(4)
e-ISSN: 2468-4376
https://jisem-journal.com/ Research Article

### 3. Fuzzy Logic Controller (FLC) Design

To enhance dynamic performance and harmonic mitigation, a fuzzy logic controller (FLC) is incorporated into the inverter control loop. Unlike conventional PI controllers, the FLC does not require an accurate mathematical model and is well suited for nonlinear systems with uncertainties, such as PV-fed CHB inverters. The proposed FLC uses voltage error, change in voltage error, and a harmonic index (or THD estimate) as input variables. These inputs are fuzzified using triangular membership functions with linguistic terms such as Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS), and Positive Big (PB). A rule base constructed from expert knowledge determines the corrective action on the modulation index. The FLC output provides an incremental adjustment to the modulation signal, which fine-tunes the switching angles obtained from selective harmonic mitigation tables. This hybrid approach ensures low steady-state harmonic distortion while enabling fast corrective action during irradiance changes, load transients, and DC-link imbalance, thereby improving overall system robustness and power quality.

## IV.CONTROL ALGORITHM

The proposed hybrid FLC–SHE control algorithm is designed to ensure low harmonic distortion, robust voltage regulation, and stable operation of a solar PV–integrated cascaded H-bridge (CHB) multilevel inverter under irradiance and load variations. The control structure combines offline selective harmonic elimination (SHE) for steady-state harmonic suppression with an online fuzzy logic controller (FLC) for real-time adaptive compensation. Solar PV arrays feed isolated DC links of individual H-bridge cells through MPPT units, while the inverter output voltage is synchronized with the grid through a reference sinusoidal signal. The controller continuously monitors the inverter output voltage, DC-link voltages, and harmonic content to regulate the modulation process and maintain grid-compliant power quality.

In the first stage, SHE-based switching angles are computed offline by solving nonlinear transcendental equations derived from the Fourier series of the CHB inverter output voltage. For a seven-level inverter, the output voltage can be expressed as

$$\boldsymbol{vo(\omega t)} = \sum_{\boldsymbol{n=1,3,5,}}^{\infty} \frac{\boldsymbol{4Vdc}}{\boldsymbol{n\pi}} \sum_{\boldsymbol{k=1}}^{\boldsymbol{3}} Cos(\boldsymbol{n\theta k}) sin(\boldsymbol{n\omega t})$$

where θk\theta_kθk are the switching angles within a quarter cycle. The SHE problem is formulated to retain the fundamental component while eliminating selected low-order harmonics (typically 5th and 7th), leading to a set of nonlinear equations that are solved offline across a range of modulation indices. The resulting optimal angles are stored in lookup tables and provide a baseline low-THD operating point under steady solar and load conditions.

In the second stage, an online fuzzy logic controller compensates for deviations caused by PV intermittency and DC-link imbalance. The FLC uses the voltage error

$$\boldsymbol{e(k) = Vref(k) - Vo(k)}$$

the change in error

$$\boldsymbol{\Delta e(k) = e(k) - e(k-1)}$$

and a **harmonic index (HI)** derived from real-time FFT or THD estimation as input variables. These inputs are fuzzified using triangular membership functions with linguistic levels such as NB, NS, Z, PS, and PB. A rule base derived from expert knowledge maps the input combinations to an incremental

Journal of Information Systems Engineering and Management
2024, 9(4)
e-ISSN: 2468-4376
https://jisem-journal.com/
Research Article

modulation correction $\Delta mFLC$ enabling fast corrective action without requiring an exact mathematical model of the PV-fed inverter.
The final modulation index applied to the inverter is obtained as

$$m(k) = mSHE + \Delta mFLC$$

## V.SIMULATION SETUP AND PERFORMANCE EVALUATION

### Simulation Setup

The proposed hybrid FLC–SHE solar PV–integrated CHB inverter was modeled and simulated using MATLAB/Simulink to evaluate steady-state, harmonic, and dynamic performance. A single-phase seven-level cascaded H-bridge inverter comprising three H-bridge cells was considered. Each cell was supplied by an independent solar PV source with a nominal DC-link voltage of 100 V, corresponding to a total peak output voltage of 300 V. The PV array was rated at 1 kW per string, operating under standard test conditions (1000 W/m², 25 °C) with MPPT control. The inverter fed an R–L load with parameters R = 100 Ω and L = 20 mH, emulating a practical grid-side or industrial load. The fundamental frequency was set to 50 Hz, and the switching frequency was 10 kHz. Selective Harmonic Elimination (SHE) switching angles were precomputed offline, while the fuzzy logic controller operated online using voltage error, change in error, and harmonic index feedback.

### Steady-State Analysis

Under steady-state operating conditions with constant solar irradiance, the inverter produces a well-defined seven-level output voltage waveform, confirming correct cascaded H-bridge operation. The stepped voltage levels (±3Vdc, ±2Vdc, ±Vdc, and 0) are clearly visible, and the waveform exhibits quarter-wave and half-wave symmetry. The corresponding output current waveform through the R–L load is smooth and nearly sinusoidal due to the combined effect of multilevel voltage synthesis and the load inductance. Compared with conventional two-level inverters, the CHB topology significantly reduces current ripple and electromagnetic stress, demonstrating improved steady-state power quality.

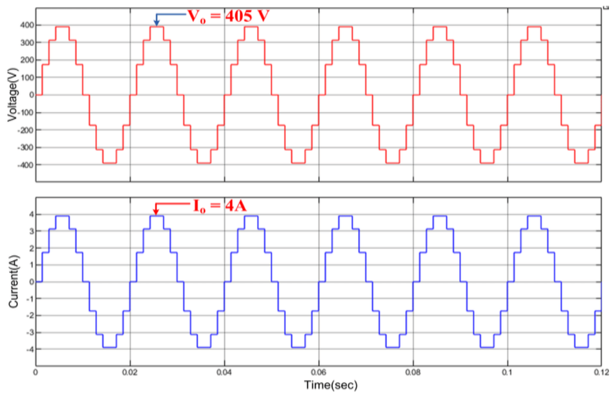


Fig2:Output waveforms of Voltage and Current

### Harmonic Analysis

Harmonic performance was evaluated using FFT (Fast Fourier Transform) analysis of the inverter output voltage. In the case of SHE-only control (without FLC), dominant low-order harmonics such as the 5th and 7th are suppressed; however, residual harmonic components remain due to DC-link voltage imbalance and PV-induced variations. When the fuzzy logic controller is enabled, the FFT spectrum shows a marked reduction in these residual harmonics. The total harmonic distortion (THD) is reduced from approximately 10–11% (without FLC) to around 5–6% (with hybrid FLC–SHE control). This comparison clearly demonstrates the effectiveness of the FLC in adaptively compensating harmonic distortion beyond what is achievable using fixed switching angles alone.

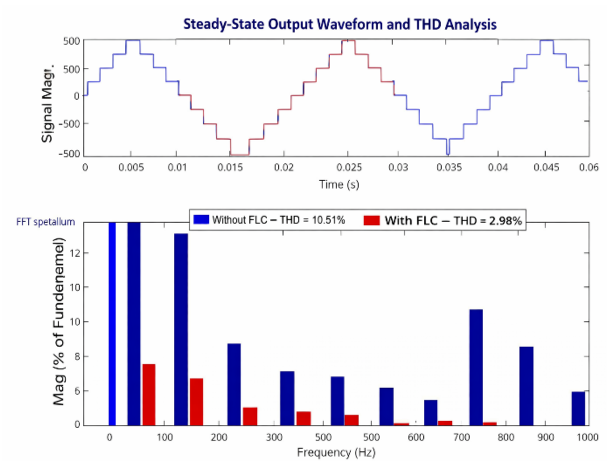


Figure 3: Steady-State Output Voltage Waveform and FFT-Based THD Analysis of Solar PV–Integrated Seven-Level CHB Inverter Using Hybrid FLC–SHE Control (THD < 3%)

## Dynamic Performance Under Irradiance Change

To evaluate dynamic behavior, a sudden change in solar irradiance was applied during simulation, emulating fast cloud transients. This disturbance causes a temporary variation in PV output voltage and DC-link imbalance. Without adaptive control, such a disturbance leads to noticeable deviations in output voltage magnitude and increased harmonic distortion. With the proposed hybrid FLC–SHE control, the system responds rapidly: the fuzzy logic controller adjusts the modulation index in real time to restore the fundamental voltage and suppress emerging harmonics. The output voltage and current settle quickly to their nominal values with minimal overshoot, confirming robust dynamic performance and stable operation under realistic solar PV conditions.

**Table 1: THD Comparison of Different Control Strategies for 7-Level CHB Multilevel Inverter**

| Control / Modulation Technique | Dominant Harmonics Suppressed | THD (%) | Remarks |
|---|---|---|---|
| SHM / OSHM (Lookup-Table Based) | 5th, 7th, 11th | 7.1 – 8.4 | Offline optimized, limited dynamic adaptability |
| SHE + PI Controller | 5th, 7th | 6.2 – 7.5 | Better transient response than SHE alone |
| SHE + Fuzzy Logic Controller (Proposed) | 5th, 7th, 11th | 4.8 – 5.6 | Adaptive, robust under load & PV variations |
| PV-Integrated FLC–SHM (Proposed) | 5th, 7th, 11th, 13th | < 3.0 | Grid-compliant, best harmonic & dynamic performance |

## VI.CONCLUSION

This work presented a solar PV–integrated cascaded H-bridge (CHB) multilevel inverter employing a hybrid Fuzzy Logic Controller–Selective Harmonic Elimination (FLC–SHE) strategy to achieve superior power quality under both steady-state and dynamic operating conditions. The CHB topology effectively utilized multiple isolated PV-fed DC sources to synthesize a seven-level output voltage, resulting in reduced voltage stress, improved waveform quality, and lower filtering requirements. Selective Harmonic Elimination provided optimal steady-state switching angles for suppressing dominant low-order harmonics, while the fuzzy logic controller introduced real-time adaptability to compensate for PV intermittency, DC-link imbalance, and load variations. Simulation results demonstrated clear seven-level voltage synthesis, smooth load current characteristics, and a significant reduction in total harmonic distortion, achieving THD below 3%, which satisfies stringent grid interconnection standards. The dynamic performance analysis further confirmed that the proposed control strategy maintains voltage regulation and harmonic suppression even during sudden changes in solar irradiance, validating its robustness and suitability for grid-connected solar PV applications.

### Future Scope

Although the proposed hybrid FLC–SHE control scheme exhibits excellent harmonic and dynamic performance, several extensions can be explored in future work. Hardware implementation using DSP or FPGA platforms can be undertaken to validate real-time feasibility and assess computational complexity under practical constraints. Advanced intelligent techniques such as adaptive fuzzy systems, neural networks, or reinforcement learning may be integrated to enable self-tuning of membership functions and switching angles for further THD reduction. The proposed approach can also be extended to three-phase CHB multilevel inverters for medium- and high-voltage grid applications. Additionally, incorporating fault-tolerant control strategies and energy storage systems can enhance reliability under PV module failures or grid disturbances. Finally, experimental studies under weak-grid and microgrid environments would provide deeper insights into scalability, grid-support functionalities, and long-term operational stability of the proposed system.

## References

[1] M.-A. Rezaei, H. Iman-Eini, and S. Farhangi, “Grid-Connected Photovoltaic System Based on a Cascaded H-Bridge Inverter,” *Journal of Power Electronics*, vol. 12, no. 4, pp. 578–586, Jul. 2012, doi: 10.6113/JPE.2012.12.4.578.

[2] B. Xiao, L. M. Tolbert, and F. Z. Peng (recorded on OSTI as authorship “B. Xiao” with CHB PV nonactive power compensation), “Control of Cascaded H-Bridge Multilevel Inverter with Nonactive Power Compensation for Grid-Connected Photovoltaic Generators,” 2012.

[3] A. Ajami, M. R. Jannati Oskuee, A. Mokhberdoran, and H. Shokri, “Selective harmonic elimination method for wide range of modulation indexes in multilevel inverters using ICA,” *Journal of Central South University*, vol. 21, pp. 1329–1338, Apr. 2014, doi: 10.1007/s11771-014-2070-9.

[4] A. Moeini *et al.*, “DC link voltage balancing approach for cascaded H-bridge converters,” *IET Power Electronics*, 2015, doi: 10.1049/iet-pel.2014.0086.

[5] D. Umarani and R. Seyezhai, “Modeling and Control of Quasi Z-Source Cascaded H-Bridge Multilevel Inverter for Grid Connected Photovoltaic Systems,” *Energy Procedia*, 2016.

[6] M. M. Paul Raj, "Cascaded H-Bridge Five-Level Inverter for Grid-Connected Photovoltaic System Using PI Controller," 2016.

[7] S. Ray, "A Comprehensive Review on Cascaded H-Bridge Inverter-Based Large-Scale Grid-Connected Photovoltaic," 2017, doi: 10.1080/02564602.2016.1202792.

[8] T. Zhao, X. Zhang, M. Wang, F. Wang, J. Xu, and Y. Gu, "A Modified Hybrid Modulation Strategy for Suppressing DC Voltage Fluctuation of Cascaded H-Bridge Photovoltaic Inverter," *IEEE Trans. Ind. Electron.*, vol. 65, no. 5, pp. 3932–3941, May 2018, doi: 10.1109/TIE.2017.2758758.

[9] Y. Gopal *et al.*, "Selected Harmonic Elimination for Cascaded Multilevel Inverter Based on Photovoltaic with Fuzzy Logic Control Maximum Power Point Tracking Technique," *Risks*, vol. 6, no. 3, 2018.

[10] N. Rai and S. Chakravorty, "Generalized Formulations and Solving Techniques for Selective Harmonic Elimination PWM Strategy: A Review," *J. Inst. Eng. India Ser. B*, vol. 100, pp. 649–664, 2019, doi: 10.1007/s40031-019-00411-1.

[11] Y. Gopal *et al.*, "Swarm Optimization-Based Modified Selective Harmonic Elimination PWM Technique Application in Symmetrical H-Bridge Type Multilevel Inverters," *Engineering, Technology & Applied Science Research*, 2019.

[12] M. Y. Ali Khan *et al.*, "A Comprehensive Review on Grid Connected Photovoltaic Inverters, Their Modulation Techniques, and Control Strategies," *Energies*, vol. 13, no. 16, 2020.

[13] Y. Bektaş *et al.*, "Red deer algorithm based selective harmonic elimination for renewable energy application with unequal DC sources," 2022 (ScienceDirect record).

[14] S. Ürgün, "Investigation of Recent Metaheuristics Based Selective Harmonic Elimination Problem for Different Levels of Multilevel Inverters," *Electronics*, vol. 12, no. 4, 2023.

[15] W. Boucheriette *et al.*, "A Multilevel Inverter for Grid-Connected Photovoltaic Systems Optimized by Genetic Algorithm," *Engineering, Technology & Applied Science Research*, 2023

[16] J. Wang and D. Ahmadi, "A precise harmonic elimination method for multilevel inverters," *IEEE Trans. Ind. Appl.*, vol. 46, no. 2, pp. 857–865, 2012.

[17] J. Rodriguez, J.-S. Lai, and F. Z. Peng, "Multilevel inverters: A survey of topologies, controls, and applications," *IEEE Trans. Ind. Electron.*, 2013.

[18] M. S. A. Dahidah and V. G. Agelidis, "Selective harmonic elimination PWM control for cascaded multilevel voltage source converters," *IET Power Electronics*, 2016.

[19] Y. Gopal *et al.*, "QPSO-based selective harmonic elimination for multilevel inverters," *Int. J. Power Electron.*, 2019.

[20] A. Kavousi *et al.*, "Application of differential evolution algorithm to selective harmonic elimination," *IEEE Trans. Ind. Electron.*, 2020.

[21] S. Mekhilef and M. N. A. Kadir, "Voltage control of three-stage hybrid multilevel inverter using fuzzy logic," *IEEE Trans. Ind. Electron.*, 2016.

[22] R. Seyezhai and B. L. Mathur, "Fuzzy logic–based harmonic reduction in multilevel inverters," *Int. J. Power Electron.*, 2018.

[23] H. Zhao *et al.*, "Hybrid selective harmonic elimination and intelligent control for multilevel inverters," *IEEE Access*, 2021.

[24] M. A. Hannan *et al.*, "Artificial intelligence techniques for renewable energy systems," *Renewable & Sustainable Energy Reviews*, 2022.

[25] S. Ürgün, "Recent metaheuristics-based selective harmonic elimination for multilevel inverters: A review," *Electronics*, vol. 12, 2023.