Machine Learning Based Control Techniques for Cascaded H-Bridge Multilevel Inverters to Improve Harmonic Performance

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Abstract
The demand for efficient and intelligent power conversion systems has increased significantly with the rapid growth of renewable energy systems, electric vehicles, and portable power electronics. Conventional inverter systems often suffer from high total harmonic distortion (THD), poor voltage regulation, and limited adaptability to dynamic load conditions. This paper presents an artificial intelligence (AI)-assisted control strategy for a cascaded H-bridge multilevel inverter (CHB-MLI). Machine learning techniques including convolutional neural networks (CNN), K-nearest neighbors (KNN), and recurrent neural networks (RNN) are explored for waveform analysis, adaptive pulse width modulation (PWM) tuning, load classification, and predictive fault detection. Simulation and experimental results demonstrate that the proposed AI-assisted method significantly reduces harmonic distortion and improves voltage stability compared with traditional modulation strategies. The study confirms that AI-based control approaches can enhance the performance, efficiency, and reliability of modern inverter systems used in renewable energy, smart grids, and industrial power applications.

Keywords: Artificial Intelligence, Cascaded H-Bridge Multilevel Inverter, Harmonic Distortion, PWM Control, Machine Learning, Power Electronics.

1. Introduction

Power electronic inverters play an essential role in converting DC energy from sources such as batteries, photovoltaic systems, and fuel cells into AC power suitable for electrical loads. Traditional inverter types such as square-wave or modified sine-wave inverters are simple and cost-effective but often generate high levels of harmonic distortion and reduced efficiency [1]. High THD can lead to overheating of electrical devices, increased power losses, and reduced reliability of the system.

Multilevel inverters (MLIs) were introduced to overcome these challenges by generating stepped voltage waveforms that approximate sinusoidal outputs more closely than conventional two-level inverters [2]. Among the various multilevel inverter topologies, the cascaded H-bridge multilevel inverter (CHB-MLI) has gained significant attention because of its modular design, scalability, and improved harmonic performance [5].

However, conventional control techniques such as sinusoidal pulse width modulation (SPWM) and selective harmonic elimination (SHE) have limited capability to adapt to rapidly changing load conditions [9]. Recent developments in artificial intelligence and machine learning enable adaptive control strategies capable of analyzing real-time signals and dynamically adjusting modulation parameters to reduce distortion and improve efficiency [7], [8].

2. Literature Review

Extensive research has been conducted on multilevel inverter structures and their control strategies. Early studies focused on diode-clamped, flying capacitor, and cascaded H-bridge inverter topologies combined with classical PWM techniques [1]. Although these methods significantly improve waveform quality compared with conventional inverters, they often require complex switching calculations and are sensitive to parameter variations.

Advanced control strategies such as model predictive control, fuzzy logic controllers, and sliding-mode control have been proposed to improve system performance and transient response [2]. However, these techniques require extensive tuning and may involve high computational complexity.

In recent years, artificial intelligence techniques have been introduced to improve inverter control performance. Neural networks and machine learning algorithms can analyze voltage and current signals and identify optimal switching patterns in real time [7]. CNN-based models are particularly effective at extracting features from waveform data, while KNN and RNN models can assist in load classification and predictive control [8]. These approaches enable data-driven adaptive control strategies that improve inverter efficiency and reduce harmonic distortion.

3. CHB Multilevel Inverter Topology

The cascaded H-bridge multilevel inverter consists of multiple H-bridge cells connected in series, each powered by an independent DC source. Every H-bridge module contains four switching devices and can generate three output voltage levels: +Vdc, 0, and −Vdc.

By combining multiple modules, the inverter produces several discrete voltage levels. For example, a 5-level CHB inverter requires two H-bridge modules per phase and generates voltage levels of −2Vdc, −Vdc, 0, +Vdc, and +2Vdc. The stepped waveform reduces harmonic distortion and improves power quality compared with traditional inverter topologies.

The CHB topology offers several advantages including modularity, scalability, lower switching stress, and compatibility with renewable energy systems such as photovoltaic arrays and battery storage systems [5]. However, it also introduces challenges such as increased component count and the requirement for advanced control algorithms to manage switching operations efficiently.

4. Proposed AI-Based Control Method

The proposed approach uses a CNN-inspired signal processing framework to dynamically tune the PWM modulation index. Measured voltage and current signals are first normalized to ensure stable numerical processing and to avoid scaling issues.

A convolution-like filtering operation extracts localized features from the waveform signals, similar to the feature extraction stage of CNN architectures [11]. A nonlinear activation function is applied to emphasize variations associated with harmonic distortion.

The extracted features are then aggregated using statistical measures such as mean and standard deviation. These features are mapped to a scalar tuning factor using a weighted linear combination. The resulting tuning factor modulates a sinusoidal signal at the inverter frequency to generate a smooth PWM correction signal.

This adaptive control strategy allows the inverter to automatically adjust its switching behavior according to real-time load conditions, thereby reducing harmonic distortion and improving voltage regulation.

5. Results and Discussion

The proposed control method was evaluated through both simulation and experimental analysis using a laboratory-scale 5-level CHB inverter prototype. The system operated with a DC input voltage of approximately 100 V and load currents ranging from 5 A to 10 A.

Simulation results demonstrated that the output voltage waveform closely approximates a sinusoidal signal when the CNN-inspired PWM tuning method is applied. Harmonic analysis shows a significant reduction in total harmonic distortion compared with traditional SPWM techniques [6].

Experimental measurements also confirm improved dynamic response when sudden load changes occur. The inverter maintained stable voltage output with minimal overshoot and rapid settling time, indicating robust performance of the adaptive control strategy.

6. Conclusion

This paper presented an AI-assisted control strategy for cascaded H-bridge multilevel inverters using a CNN-inspired PWM tuning algorithm. The proposed method improves waveform quality, reduces harmonic distortion, and enhances system stability under varying load conditions.

The results demonstrate that integrating artificial intelligence with power electronics control can significantly improve inverter performance. Future research may focus on implementing full deep learning models, optimizing hardware acceleration, and extending the approach to three-phase grid-connected inverter systems.

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