Optimization of Switching Angles in a Five-Level Cascaded H-Bridge Inverter Using Genetic Algorithms for Harmonic Reduction

Abstract:

This paper presents a method to reduce harmonic distortion in a five-level cascaded H-bridge multilevel inverter by optimizing switching angles using genetic algorithms. The Selective Harmonic Elimination (SHE) technique is employed to formulate equations that eliminate the 5th and 7th harmonics. A genetic algorithm is then used to solve these nonlinear equations and determine the optimal switching angles. Simulation results show a reduction in Total Harmonic Distortion (THD) from 27.35% to 21.62%, and hardware implementation further reduces THD to 17.82%. The proposed method demonstrates significant improvement in power quality for high-power applications.

Introduction:

Multilevel inverters (MLIs) have become essential in high-power applications due to their ability to generate high voltages with reduced harmonic distortion and lower switching losses compared to traditional two-level inverters. Among various MLI topologies, the cascaded H-bridge (CHB) inverter is particularly attractive for its modularity, simplicity, and ability to produce a stepped output waveform with multiple voltage levels. For a five-level CHB inverter, the output waveform consists of five distinct voltage levels, which closely approximate a sinusoidal wave, thereby reducing harmonic content.

However, harmonic distortion remains a critical issue in power systems, as it leads to inefficiencies, overheating, and potential damage to connected loads. Selective Harmonic Elimination (SHE) is a well-established technique to mitigate specific low-order harmonics by determining optimal switching angles for the inverter. The challenge lies in solving the nonlinear transcendental equations associated with SHE, which often require advanced optimization techniques.

This research aims to implement a five-level CHB inverter and optimize its switching angles using genetic algorithms (GAs) to minimize the 5th and 7th harmonics. The study includes both simulation and hardware implementation, demonstrating the effectiveness of the proposed approach in improving power quality.

Literature Review:

Multilevel inverters are categorized into three primary topologies: diode-clamped, flying capacitor, and cascaded H-bridge. The diode-clamped topology, while effective, suffers from voltage balancing issues and requires numerous clamping diodes as the number of levels increases. The flying capacitor topology offers better voltage balancing but demands a large number of capacitors, increasing complexity and cost. In contrast, the CHB topology requires fewer components and provides inherent modularity, making it ideal for high-power applications.

Various modulation techniques have been developed for MLIs, including Sinusoidal Pulse Width Modulation (SPWM), Space Vector Modulation (SVM), and SHE. SHE is particularly advantageous for its ability to eliminate specific harmonics at low switching frequencies, thereby reducing switching losses. However, solving the SHE equations is computationally intensive due to their nonlinear nature. Evolutionary algorithms, such as genetic algorithms, have been successfully applied to solve these equations, offering robust solutions even for complex optimization problems.

Methodology:

Theoretical Background:

A five-level CHB inverter consists of two H-bridges per phase, each powered by a separate DC source. The output voltage levels are +2Vdc, +Vdc, 0, -Vdc, and -2Vdc, where Vdc is the DC source voltage. The switching angles α1 and α2 determine the points at which the voltage steps occur, directly influencing the harmonic content of the output waveform.

The SHE technique involves solving a set of nonlinear equations to eliminate specific harmonics. For a five-level inverter, the equations to eliminate the 5th and 7th harmonics while controlling the fundamental voltage are:

$$\cos(\alpha 1) + \cos(\alpha 2) = 2mI,$$

$$\cos(5\alpha 1) + \cos(5\alpha 2) = 0,$$

$$\cos(7\alpha 1) + \cos(7\alpha 2) = 0,$$

where mI is the modulation index.

Simulation Model Development:

A simulation model of the five-level CHB inverter was developed using MATLAB/Simulink. The model included two H-bridges per phase, each with four MOSFET switches and separate 48V DC sources. Pulse generators were used to control the switching angles, with an output frequency of 50 Hz (20 ms period). Initial switching angles were set to α1 = 25° and α2 = 70° for baseline testing.

Genetic Algorithm Application:

A genetic algorithm was employed to solve the SHE equations and determine optimal switching angles. The GA parameters were set as follows:

- Chromosome Representation: Each chromosome represented a pair of switching angles (α1, α2).
- Population Size: 200 individuals.
- Fitness Function: Designed to minimize the 5th and 7th harmonics, e.g., $y = [10 \times (1.2738 \times \cos(\alpha 1) + 0.254 \times \cos(5\alpha 1))]$.
- Operators: Reproduction, crossover, and mutation were used to evolve the population over generations.
  The GA yielded optimal angles of α1 = 36° and α2 = 72°.

Hardware Design:

The hardware implementation included:

- H-Bridges: Two H-bridges, each with four IRF740 MOSFETs and LEDs for status indication.
- Optocouplers (4N35): For isolating control signals.
- Microcontroller (Arduino): Programmed to generate firing pulses.
- Power Supply: A 230/48V AC transformer, rectified to 48V DC per H-bridge.
- Filter Capacitors: 1000 µF, 100V to reduce ripple.
- Load: A 10W resistive bulb (capable of driving up to 400V, 10A loads).

Implementation:

The Arduino was programmed to generate pulses with phase delays corresponding to the optimized angles:

- Phase delay for $\alpha 1 = 36°$: 2 ms.
- Phase delay for $\alpha 2 = 72°$: 4 ms.
  The hardware was tested with both initial and optimized angles, and the output waveforms were analyzed using a digital oscilloscope and FFT.

Results and Discussion:

Simulation Results:

- Initial Simulation: With $\alpha 1 = 25°$ and $\alpha 2 = 70°$, the THD was 27.35%, with significant 5th and 7th harmonics.
- Optimized Simulation: Using $\alpha 1 = 36°$ and $\alpha 2 = 72°$, the THD reduced to 21.62%, with the 5th and 7th harmonics minimized.

Hardware Results:

- Optimized Hardware: The THD was further reduced to 17.82%, demonstrating even better performance than the simulation, likely due to practical filtering effects.

The results confirm that the genetic algorithm effectively optimized the switching angles, leading to a substantial reduction in harmonic distortion. This improvement is crucial for enhancing power quality in applications such as motor drives and renewable energy systems.

Conclusion:

This research successfully implemented a five-level cascaded H-bridge inverter and optimized its switching angles using genetic algorithms to reduce harmonic distortion. The simulation and hardware results demonstrate a significant decrease in THD, from 27.35% to 17.82%, with the elimination of the 5th and 7th harmonics. The proposed method offers a practical solution for improving power quality in high-power applications. Future work could explore higher-level inverters, alternative optimization techniques, or real-time adaptive control for dynamic load conditions.

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