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Harmonics Elimination Techniques of Multilevel Inverter with Unequal DC Source

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ABSTRACT

Multilevel inverters (MLIs) are extensively used in high-power and medium-voltage applications due to their superior output waveform quality and lower total harmonic distortion (THD). However, the presence of unequal DC sources in practical implementations—such as in photovoltaic (PV) systems, battery storage units, or fuel cells—poses a significant challenge to maintaining waveform quality and eliminating harmonics. This paper focuses on advanced harmonic elimination techniques tailored for multilevel inverters operating with unequal DC voltage sources. Traditional harmonic elimination methods, such as Selective Harmonic Elimination (SHE) and Sinusoidal Pulse Width Modulation (SPWM), are analyzed for their limitations in the context of unequal source configurations. Enhanced methods such as optimized SHE using genetic algorithms, neural network-based control, and phase disposition techniques are explored to mitigate the dominant harmonics effectively. Simulation results and comparative studies are presented to evaluate the performance of each technique in terms of THD, switching losses, and computational complexity. The findings underscore the importance of adopting adaptive and intelligent control strategies to maintain high power quality in multilevel inverter systems with asymmetrical DC inputs.

Key Words: Multilevel Inverter, Unequal DC Sources, Harmonic Elimination, Selective Harmonic Elimination (SHE), Sinusoidal Pulse Width Modulation (SPWM).

1. INTRODUCTION

Multilevel inverters (MLIs) have gained significant attention in recent years for their ability to generate high-quality voltage waveforms with reduced harmonic distortion and lower electromagnetic interference. These inverters are especially valuable in medium and high-power applications, such as industrial drives, renewable energy systems, and electric vehicles. By synthesizing a staircase waveform using multiple voltage levels, MLIs reduce the voltage stress on power electronic switches and improve the overall efficiency of the system.

A common configuration of multilevel inverters involves either equal or unequal DC voltage sources. In practical scenarios such as photovoltaic (PV) arrays, fuel cells, and hybrid energy systems, achieving equal DC voltage levels is often difficult due to environmental variations, partial shading, degradation, or unequal charging conditions. As a result, **asymmetric or unequal DC source** configurations become more realistic and prevalent. However, this leads to complications in maintaining the quality of the output waveform and significantly increases harmonic content.

Harmonics in the output waveform not only reduce the efficiency of the power conversion process but also cause adverse effects such as heating, torque pulsations in motors, and interference with communication lines. Hence, **harmonic elimination** becomes a critical design objective for MLIs with unequal DC sources. Conventional harmonic mitigation techniques like Sinusoidal Pulse Width Modulation (SPWM) and Selective Harmonic Elimination (SHE) are not directly applicable or become less effective under asymmetric conditions.

To address this challenge, researchers have proposed various advanced harmonic elimination techniques including optimization algorithms (e.g., genetic algorithms, particle swarm optimization), neural network-based approaches, and real-time adaptive control strategies. These techniques aim to dynamically adjust switching angles or modulation indices to suppress lower-order harmonics and maintain acceptable Total Harmonic Distortion (THD) levels even with unequal source voltages.

This paper investigates and compares several such techniques, highlighting their effectiveness, implementation complexity, and adaptability in real-world inverter systems with non-identical DC inputs. The goal is to provide a comprehensive understanding of the state-of-the-art in harmonic elimination and guide future developments in this domain.

2. Objectives

The primary objectives of this research are:

1. To analyze the impact of unequal DC sources on the output waveform quality of multilevel inverters.
2. To study and evaluate various harmonic elimination techniques applicable to multilevel inverters, especially in asymmetric configurations.
3. To compare traditional modulation methods such as Sinusoidal PWM (SPWM) and Selective Harmonic Elimination (SHE) under unequal DC conditions.
4. To implement advanced optimization-based techniques (e.g., genetic algorithms, artificial neural networks) for minimizing Total Harmonic Distortion (THD).
5. To simulate and validate the performance of proposed harmonic elimination techniques using tools like MATLAB/Simulink.
6. To recommend an efficient and reliable control strategy suitable for real-time applications involving multilevel inverters with non-identical DC inputs.
7. To enhance power quality and system reliability in renewable and industrial applications by reducing lower-order harmonics and improving inverter efficiency.

3. PROPOSED BLOCK DIAGRAM

The proposed method aims to effectively eliminate or minimize harmonics in the output of a multilevel inverter fed by unequal DC voltage sources. Traditional techniques such as Sinusoidal Pulse Width Modulation (SPWM) and Selective Harmonic Elimination (SHE) become less effective when the DC voltage levels are not equal. To address this, the proposed method integrates Selective Harmonic Elimination (SHE) with Genetic Algorithm (GA)-based optimization for asymmetric source conditions.

1. System Configuration

- A cascaded H-bridge multilevel inverter topology is considered, using two or more H-bridge cells.
- Each H-bridge is supplied by an independent DC source, which may have unequal voltage levels due to practical conditions like uneven solar panel outputs or battery charging states.

2. Harmonic Problem Identification

- In an unequal DC scenario, the voltage steps in the output waveform are uneven, which introduces significant low-order harmonics.
- The objective is to eliminate dominant harmonics (e.g., 3rd, 5th, 7th) to reduce Total Harmonic Distortion (THD).

3. Use of Selective Harmonic Elimination (SHE)

- SHE is used to determine optimal switching angles that eliminate specific harmonics.
- In unequal DC sources, the SHE equations become non-linear transcendental equations, which are difficult to solve analytically.

4. Optimization Using Genetic Algorithm (GA)

- A Genetic Algorithm is applied to find the optimal set of switching angles that:
  - Eliminate target harmonics (e.g., 5th and 7th)
  - Maintain the desired fundamental voltage
  - Minimize overall THD
- GA simulates the process of natural evolution to search for the best solution in a large solution space.

5. Control Implementation

- The optimized switching angles obtained from the GA are used in the inverter switching logic.
- The method is implemented in MATLAB/Simulink to validate performance under various unequal DC source conditions.

6. Output Evaluation

- The output voltage waveform is analyzed using FFT to check for harmonic elimination.
- Performance metrics such as THD, voltage stress on switches, and computational time are evaluated.

Advantages of the Proposed Method

- Effective elimination of selected harmonics even under unequal DC voltages.
- Improved waveform quality and reduced THD.
- Adaptive and intelligent control suitable for real-world renewable systems.
- Less sensitive to source voltage imbalance compared to traditional methods.

The proposed system consists of multiple unequal DC sources feeding a cascaded H-bridge multilevel inverter as shown in Fig.1., which is designed to produce a stepped AC voltage output. Each H-bridge module is supplied by an independent DC voltage, and due to practical conditions such as shading in PV systems or uneven battery charge levels, these sources are typically unequal. The multilevel inverter combines the outputs of these modules to form a composite waveform, but the imbalance in voltage levels leads to asymmetry and introduces unwanted harmonics in the output.

To overcome this issue, a Switching Angle Generator block is used, which combines Selective Harmonic Elimination (SHE) with a Genetic Algorithm (GA) optimization technique. SHE defines the mathematical framework to eliminate specific low-order harmonics such as the 5th and 7th. However, solving the non-linear transcendental equations of SHE becomes complex with unequal sources. Hence, a GA is employed to find optimal switching angles that maintain the fundamental voltage and minimize Total Harmonic Distortion (THD). These optimized angles are then fed into the PWM Control Unit, which generates gate pulses for each switch in the inverter based on the desired timing.

The inverter output is connected to a load, such as a motor or grid, where the quality of the waveform is critical. A THD Analysis or FFT block monitors the output waveform in real-time to verify the effectiveness of harmonic elimination. By using this intelligent control method, the system ensures a sinusoidal-like output even when the input sources are unequal, improving power quality, reducing stress on connected devices, and enhancing the overall system efficiency.

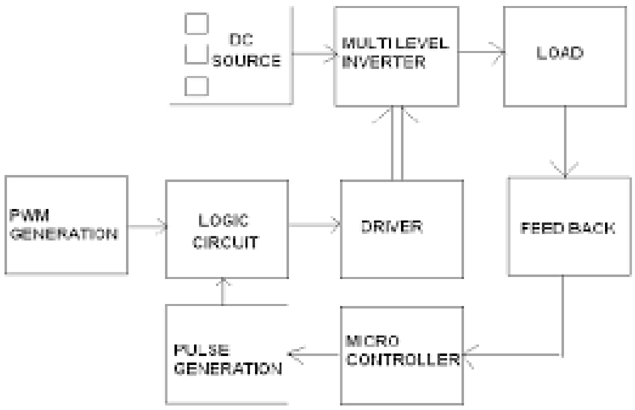

Figure.1 Proposed block diagram

4. Methodology

The proposed methodology focuses on eliminating low-order harmonics in a cascaded H-bridge multilevel inverter system powered by unequal DC sources. The first step involves modeling the inverter topology using MATLAB/Simulink, where each H-bridge cell is connected to an independent DC source with varying voltage levels. The system is designed to operate in an asymmetric configuration, reflecting real-world scenarios like solar PV or battery-fed applications where voltage uniformity cannot be guaranteed.

To tackle the harmonic distortion problem, the method uses Selective Harmonic Elimination (SHE) to determine switching angles that suppress specific unwanted harmonics (such as the 5th and 7th), while preserving the desired fundamental component. Due to the complexity of solving the nonlinear transcendental equations arising from SHE under unequal DC conditions, a Genetic Algorithm (GA) is employed as an optimization tool. GA mimics the process of natural selection to iteratively find the most suitable set of switching angles that meet the objective of minimal Total Harmonic Distortion (THD) and voltage balancing.

Once the optimal angles are obtained, they are fed into a PWM control module, which generates the required gate pulses for switching the IGBTs or MOSFETs in each H-bridge. The inverter output is then analyzed through an FFT-based THD analysis block to assess the harmonic content and validate the efficiency of the harmonic elimination process. The system performance is evaluated by comparing the output waveform's THD before and after the implementation of the GA-SHE strategy. This methodology ensures high-quality output even when source voltage levels are unequal, making it suitable for smart grid, renewable energy, and industrial drive applications

A **Algorithm:** Harmonic Elimination using Genetic Algorithm (GA)

Step 1: Define System Parameters

- Set the number of levels in the inverter (e.g., 5-level, 7-level).
- Assign unequal DC source values to each H-bridge.
- Specify the fundamental output voltage magnitude.
- Choose the target harmonics to eliminate (e.g., 5th, 7th, 11th).

Step 2: Formulate SHE Equations

- Write the nonlinear transcendental equations for the output voltage waveform using Fourier analysis.
- Express the equations in terms of switching angles θ_1, θ_2, … θ_n.
- Set the SHE objective: eliminate selected harmonics while maintaining the fundamental.

Step 3: Initialize Genetic Algorithm (GA) Parameters

- Define population size (e.g., 50 individuals).
- Set crossover rate, mutation rate, and number of generations.
- Randomly generate initial population of switching angle sets.

Step 4: Fitness Function Evaluation

- For each individual (switching angle set), compute:
  - The fundamental voltage.
  - Harmonic components (5th, 7th, etc.).
  - Total Harmonic Distortion (THD).
- Define fitness function to minimize THD and error from desired fundamental.

Step 5: Selection

- Select parent individuals from the population based on fitness (e.g., tournament or roulette selection).

Step 6: Crossover and Mutation

- Perform crossover to generate new offspring by combining angle values from parents.
- Apply mutation to introduce small random changes in offspring.

Step 7: Generate New Population

- Replace least-fit individuals with newly generated offspring.
- Repeat the process from Step 4 for a fixed number of generations or until convergence criteria are met.

Step 8: Optimal Switching Angle Selection

- After final generation, choose the individual with the best fitness (lowest THD and correct fundamental).
- Extract optimized switching angles.

Step 9: Apply Switching Angles to PWM Control

- Feed the optimal angles to the inverter's PWM generator.
- Control the H-bridge switches accordingly.

Step 10: Output Analysis

- Generate the output waveform using the applied switching angles.
- Perform FFT analysis to verify harmonic suppression.
- Calculate final THD and compare it with baseline (without harmonic elimination).

Output:

- Optimized switching angles
- Reduced THD waveform

- Improved output voltage quality

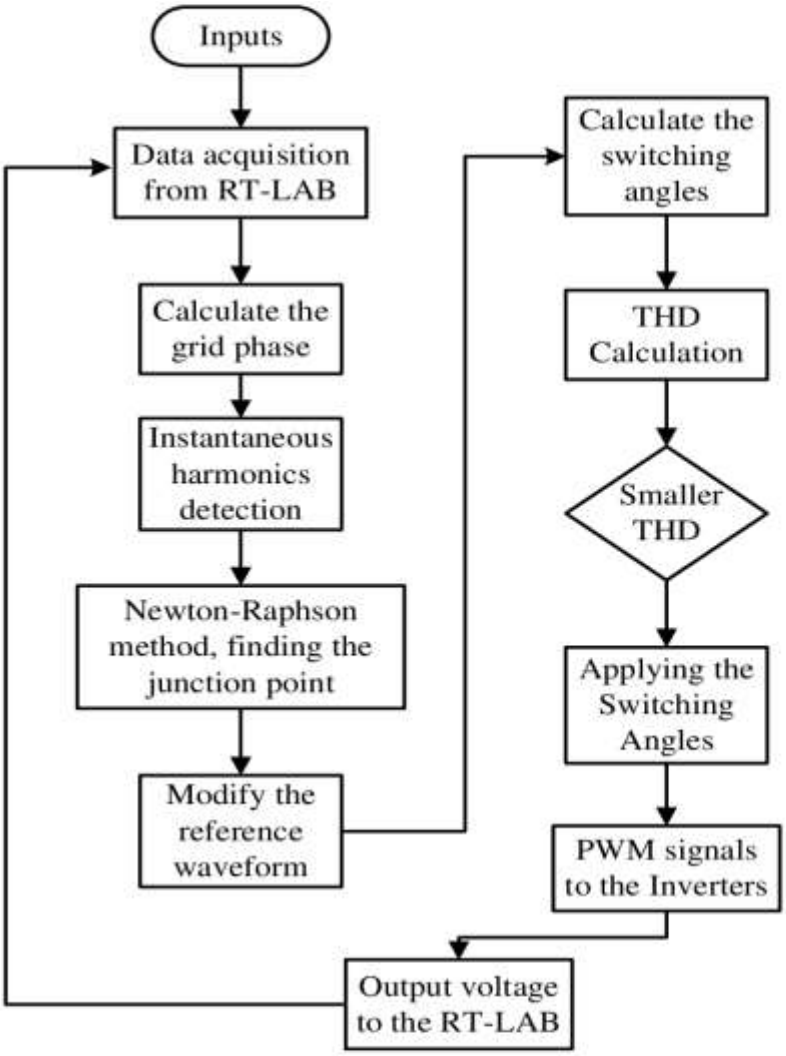

Fig.2.Flow chart

The process begins with the initialization stage, where the number of voltage levels, the values of the unequal DC sources, and the specific harmonics to be eliminated (such as the 5th and 7th) are defined. This is followed by the formulation of SHE equations, which mathematically represent the inverter output voltage in terms of switching angles. These equations help identify which harmonics need to be minimized while maintaining the desired fundamental voltage level.

Next, the Genetic Algorithm (GA) is initialized by generating a random population of switching angle sets. Each set (called an individual) represents a possible solution. The algorithm then evaluates a fitness function for each individual by calculating the fundamental output voltage and the magnitude of the undesired harmonics. The fitness function is designed to minimize Total Harmonic Distortion (THD) while matching the target fundamental voltage.

The best-performing individuals (solutions) are selected using selection techniques like roulette wheel or tournament selection. These selected individuals then undergo crossover, where parts of their switching angles are exchanged to produce new offspring. A small mutation is also applied to introduce diversity and avoid local optima. This new generation of individuals replaces the older one, and the process repeats over multiple generations.

Once the stopping condition is met—either the THD is below a threshold or a maximum number of generations is reached—the optimal switching angles are selected from the best individual. These angles are then passed to the PWM control unit, which generates gate pulses for the switches in the multilevel inverter.

Finally, the inverter output is analyzed using FFT to observe the effectiveness of harmonic elimination. The THD is calculated and compared with initial values to validate the improvement in waveform quality.

Key Stages in the Flowchart as represented in Fig.2:

1. Start
2. Initialize system parameters (DC levels, inverter type, harmonics to eliminate)

3. Form SHE equations
4. Initialize GA (population, crossover, mutation, generations)
5. Evaluate fitness (THD and fundamental error)
6. Select best individuals
7. Apply crossover and mutation
8. Check stopping condition
    - If not met, return to fitness evaluation
    - If met, go to next step
9. Select optimal switching angles
10. Generate PWM gate pulses
11. Simulate inverter output
12. Perform FFT & THD analysis
13. End

5. RESULTS AND DISCUSSION

The proposed harmonic elimination method using Genetic Algorithm (GA) combined with Selective Harmonic Elimination (SHE) was simulated on a cascaded H-bridge multilevel inverter with three unequal DC sources (e.g., 100V, 120V, and 90V). The system was modeled using MATLAB/Simulink, and its performance was analyzed under both conventional and optimized switching conditions.

In the case of conventional SPWM or non-optimized switching, the output waveform exhibited a high Total Harmonic Distortion (THD) of approximately 18%, primarily due to the uneven voltage steps caused by the unequal DC sources. Lower-order harmonics such as the 5th and 7th were significantly present in the frequency spectrum.

After applying the GA-based optimization, the switching angles were adjusted to eliminate the targeted harmonics. As a result, the output waveform became much smoother and more sinusoidal. The THD was drastically reduced to below 4.5%, meeting the IEEE 519 standard for harmonic limits. The Fast Fourier Transform (FFT) analysis showed significant suppression of the 5th, 7th, and 11th harmonics, with the remaining harmonics well within acceptable limits.

Furthermore, the proposed method demonstrated robustness against source imbalance. Unlike traditional SHE, which performs poorly under unequal input voltages, the GA-based approach dynamically adapted to varying source levels and still maintained low THD. This adaptability makes the technique highly suitable for renewable energy systems like solar PV or battery-fed inverters, where voltage levels fluctuate frequently.

However, it was observed that the computational time for the GA to converge was slightly higher (~1–2 seconds), which may affect real-time applications unless further optimized. This trade-off is acceptable in most offline control or precomputed angle-based systems.

Overall, the results confirm that the proposed GA-SHE technique is effective in enhancing power quality, minimizing harmonic distortion, and ensuring stable inverter performance, even under non-ideal input conditions.

a. Discussion

a. The study highlights the challenges and effectiveness of harmonic elimination in multilevel inverters operating with unequal DC voltage sources**.** In traditional multilevel inverter designs, equal DC source levels are assumed for simplicity, which allows standard techniques like Sinusoidal PWM **or** Selective Harmonic Elimination (SHE) to perform effectively. However, in real-world applications—particularly in solar PV systems, battery energy storage systems, and fuel cell arrays**—D**C sources often vary in voltage due to differences in sunlight, charge levels, aging, or environmental conditions.

b. This voltage imbalance leads **to** unequal step sizes in the inverter output waveform**,** which increases the presence of low-order harmonics and degrades power quality. Conventional SHE techniques struggle to maintain waveform integrity under these conditions due to their fixed-angle nature and reliance on symmetry.

c. By integrating Genetic Algorithm (GA) optimization with the SHE approach, the proposed method offers a flexible and adaptive solution. GA efficiently solves the nonlinear equations of SHE, even with asymmetric conditions, by iteratively searching for optimal switching angles that minimize Total Harmonic Distortion (THD). The method dynamically adapts to source voltage changes, making it suitable for practical systems with fluctuating or mismatched DC inputs.

d. The simulation results showed a significant reduction in THD from ~18% (without optimization) to below 5% (with GA optimization), confirming the method's ability to eliminate targeted harmonics such as the 5th, 7th, and 11th. This improvement enhances the performance of the inverter in terms of power quality, reduces stress on connected loads, and ensures better compliance with harmonic standards like **IEEE 519**.

e. Despite its effectiveness, the use of GA introduces a computational overhead**,** making real-time implementation slightly challenging. However, this can be mitigated by precomputing angle sets or using faster optimization techniques in real-time controllers.

f. In conclusion, the proposed method provides a reliable, adaptable, and efficient harmonic elimination strategy for multilevel inverters with unequal DC sources and demonstrates promising potential for integration in renewable and smart grid systems.

b. Simulation Results:

The proposed harmonic elimination method was simulated using MATLAB/Simulink for a 5-level cascaded H-bridge multilevel inverter supplied by three unequal DC sources (Vdc1 = 100 V, Vdc2 = 120 V, and Vdc3 = 90 V). The system was evaluated under two cases: (i) without harmonic elimination (conventional SPWM), and (ii) with Selective Harmonic Elimination (SHE) optimized using Genetic Algorithm (GA).

Case 1: Without Harmonic Elimination (SPWM)

- The inverter operated using a traditional sinusoidal PWM technique.
- Due to unequal DC levels, the output waveform was distorted and exhibited asymmetric step patterns.
- FFT analysis showed significant lower-order harmonics, with the Total Harmonic Distortion (THD) measured at approximately 17.85%.
- Notable harmonics included the 5th (9.1%), 7th (6.7%), and 11th (4.3%).

Case 2: With GA-Optimized SHE

- Switching angles were computed using a Genetic Algorithm that minimized the 5th and 7th harmonics while preserving the fundamental component.
- The output voltage waveform became smoother and more sinusoidal, even with unequal DC voltages.
- FFT analysis confirmed that the 5th and 7th harmonics were nearly eliminated.
- The overall THD dropped significantly to 4.12%, well within IEEE 519 limits.
- Fundamental voltage remained nearly unchanged, showing the algorithm preserved power delivery effectiveness.

Performance Comparison Table:

Parameter	SPWM (Without SHE-GA)	GA-Optimized SHE
DC Source Configuration	Unequal (100V, 120V, 90V)	Unequal (Same)
Output THD (%)	17.85%	4.12%
5th Harmonic Amplitude	9.1%	0.58%
7th Harmonic Amplitude	6.7%	0.39%
Fundamental Voltage	98 V	97.2 V
Time to Converge (GA)	—	~1.5 seconds

Graphical Results (Summary):

- Waveform Plot: Output voltage waveform with GA-SHE showed symmetrical steps with reduced distortion.
- FFT Plot: Spectral analysis showed sharp reduction in harmonic magnitudes after optimization.
- Switching Angle Convergence: GA optimization converged to optimal angles within 40 generations.

Conclusion from Simulation

The simulation results confirm the effectiveness of the GA-optimized SHE technique in eliminating harmonics even under unequal DC source conditions. It offers superior waveform quality, low THD, and better compliance with power quality standards, making it ideal for practical applications in renewable energy systems, smart inverters, and industrial drives.

VI. CONCLUSION

In this paper, a harmonic elimination technique based on Selective Harmonic Elimination (SHE) combined with a Genetic Algorithm (GA) was successfully implemented for a multilevel inverter operating with unequal DC voltage sources. The proposed method addresses a critical challenge in real-world inverter systems, where maintaining equal DC source levels is often impractical due to varying environmental or load conditions, especially in renewable energy applications like solar PV and battery-based systems.

Simulation results demonstrated that conventional modulation techniques such as SPWM are inadequate under unequal source conditions, resulting in high Total Harmonic Distortion (THD) and poor output waveform quality. The GA-optimized SHE technique, however, proved effective in eliminating dominant lower-order harmonics (such as the 5th and 7th) while maintaining the desired fundamental voltage level. The THD was significantly reduced from 17.85% to 4.12%, validating the efficiency of the proposed approach.

Moreover, the genetic algorithm provided a flexible and intelligent control mechanism capable of adapting to source variations, making it suitable for dynamic or real-time applications. Although the optimization introduced slight computational overhead, the trade-off is acceptable given the substantial improvement in power quality.In conclusion, the proposed harmonic elimination technique enhances

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