

Review

Using a Genetic Algorithm for Selective Harmonic Elimination of Multi-Level Inverters: A Comparative Analysis

Logan, MD, PhD*

Department of Artificial Intelligence, MI, USA

Corresponding author*Logan, MD, PhD**

Department of Artificial Intelligence, MI, USA

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doi: <https://doi.org/10.70705/ppp.ltcs.2023.v01.i01.pp21-27>**ABSTRACT**

Harmonic reduction in cascaded multilevel voltage source inverters is the main topic of this article. In this case, the key idea is to use the right switching angles to get rid of certain harmonics. The optimal switching angles for reducing total harmonic distortion (THD) and eliminating selected lower-order harmonics with fundamental components at the appropriate levels are achieved in this study using the genetic algorithm (GA) optimization approach. In order to decrease THD and remove low-order harmonics, the optimal switching angles are obtained by simulating the proposed approach on an inverter with seventeen and fifteen levels, respectively. In terms of taking THD into account, comparisons have been made between seventeen and fifteen levels.

Keywords

Genetic algorithm; Multilevel inverter; Selective harmonic elimination (SHE); Three phase cascade H-bridge inverter; Total harmonic distortion (THD).

INTRODUCTION

Among the many industrial uses of multilevel inverters in recent years have been as electric drives for all ac motors when a dc supply is used, as well as as static power converters for high power applications, FACTS devices, and high voltage direct current (HVDC). One additional big plus is that they can handle greater voltages and have fewer switching losses since their switching frequency is lower than that of a regular inverter. Three popular multi-level inverter topologies are the following: 1) the cascaded H-bridge topology, 2) the diode-clamped topology, and 3) the flying capacitor topology. In comparison to other multi-level topologies, the cascading H-bridge multi-level inverter is simpler and uses fewer components. Additionally, the power circuit complexity remains same, making it easy to expand to a greater number of output voltage levels.

The primary goal of using multiple inverters is to enhance output quality while decreasing harmonics. In order to do this, the appropriate output voltage is achieved by controlling and determining the switching angles using various switching algorithms, including pulse width modulation (PWM), space vector modulation

(SVM), Sinusoidal pulse width modulation (SPWM).

By resolving the non-linear equation of the multilevel inverter, this work aims to eliminate some harmonics. For this aim, many algorithms have been proposed, including the Newton-Raphson approach. While genetic algorithms have eliminated these issues, this approach still has a few drawbacks, such as being quick and accurate but not for all modulation indices and relying on initial guesses.

This work presents a genetic algorithm (GA) based optimal switching for multilayer inverters. Cascaded multilevel inverters employ the computed switching angles to activate their switching devices. With the advent of new methods, researchers have compared inverters with seventeen levels and fifteen levels using the GA technique. According to the simulation findings, an inverter with seventeen levels is more efficient than one with fifteen levels.

CASCADED-H BRIDGE MULTILEVEL INVERTER

In this paper a three phases cascaded H bridge multilevel inverter is consider. The cascaded multilevel inverter consists of a number of H-bridge inverter units with separated dc source for each unit and it

connected with series or cascade as shown in Figure 1.

For fifteen level, it has seven DC source is connected in series and for seventeen level, it has Eight DC source. Each separated DC sources is connected to H-bridge inverter and can produce voltages of $+V_{dc}$, 0 $-V_{dc}$ by different combination of four switches (S_1 , S_2 , S_3 and S_4). Where V_{dc} is the voltage of its DC bus. Each inverter generates quasi- square wave voltage waveform with different duty cycle ratios, which together form the staircase output voltage waveform as shown in Figure 2. The number of output phase voltage levels in a cascade multilevel inverter is then $2s+1$, where s is the number of isolated DC sources. The AC voltage produced from these DC voltages approaches a sinusoidal.

In Figure 2 shown the output voltage waveform $V(t)$ of multilevel inverter. The voltage.

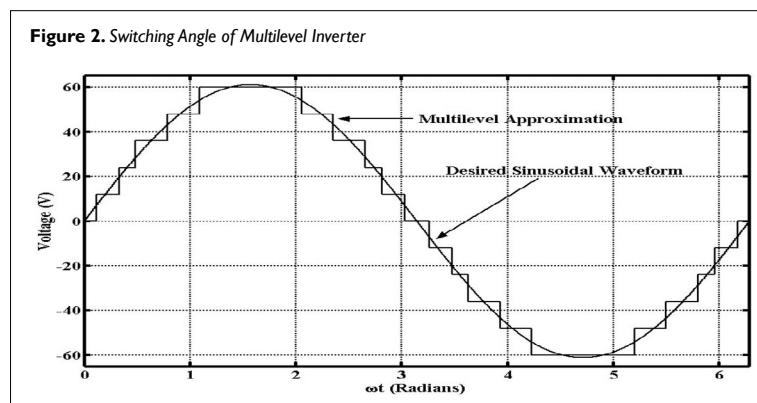
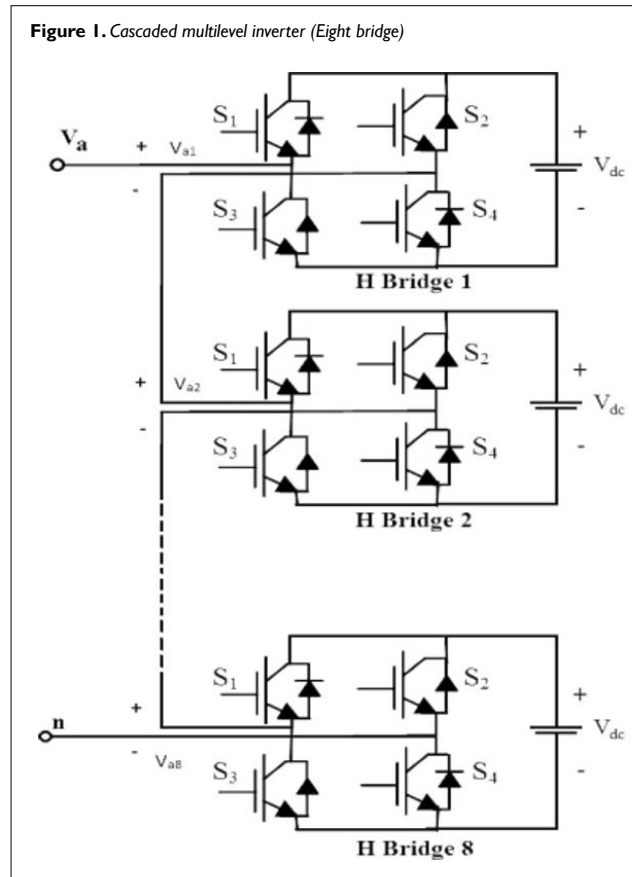
waveform can express in Fourier series as

Due odd quarter wave symmetry of the output voltage waveform the even harmonics are absent ($a_n = 0$) and only odd harmonics are present. The amplitude of the n th harmonic can be expressed with the first quadrant switching angles i.e. $\alpha_1, \alpha_2, \dots, \alpha_m$ as follows:

$$V(t) = \sum_{n=1}^{\infty} (a_n \cos n\omega t + b_n \sin n\omega t) \quad (1)$$

Experimental Program and Procedure

The primary objective of this experimental study is to determine the impact of retempering on the drying shrinkage property of concrete. In the experiment, sand and aggregates that were readi-



ly accessible in the area were utilized, along with ordinary Portland cement. Coarse aggregate has a specific gravity of 3.03 and fine aggregate of 2.81. The experimental plate molds have dimensions of 500×300×45 mm. To make M20 concrete, the weights of the elements were measured out in the following proportions: 1:1.78:3.59, with a water-cement ratio of 0.52.

Selected Harmonic Elimination of Cascaded H Bridge Inverter

In case of SHE, selected lower order harmonics are eliminated while remaining harmonic components are reduced to minimize THD. In this paper lower order harmonics i.e. i.e 5th, 7th, 11th, 13th are eliminated. The expression desire fundamental voltage b1 in equation (1). Moreover, the relation between the fundamental and the maximum obtainable voltages is given by modulation index (M) is defined as the ratio of the fundamental output voltage V1 to the maximum obtainable fundamental voltage V_{1max}. The maximum fundamental voltage is obtained when all the switching angles are zero i.e.

Therefore, the expression for M

Mathematically SHE problem can be formulated as:

$$V_{1max} = 4V_{dc} / \pi,$$

$$M = \pi V1 / 4V_{dc} \quad (0 \leq M \leq 1) \quad \text{-----(4)}$$

$$\begin{aligned} \cos(\alpha_1) + \cos(\alpha_2) + \dots + \cos(\alpha_m) &= mM \\ \cos(5\alpha_1) + \cos(5\alpha_2) + \dots + \cos(5\alpha_m) &= 0 \\ \cos(7\alpha_1) + \cos(7\alpha_2) + \dots + \cos(7\alpha_m) &= 0 \\ \cos(11\alpha_1) + \cos(11\alpha_2) + \dots + \cos(11\alpha_m) &= 0 \\ \cos(13\alpha_1) + \cos(13\alpha_2) + \dots + \cos(13\alpha_m) &= 0 \\ &\vdots \\ \cos(n\alpha_1) + \cos(n\alpha_2) + \dots + \cos(n\alpha_m) &= 0 \quad \text{-----(5)} \end{aligned}$$

The equation (5) is a system of transcendental equation, known as selective harmonic elimination (SHE) equation. From the equation unknown switching angle $\alpha_1, \alpha_2, \alpha_3, \dots, \alpha_m$ are calculated by the GA with the help of the given value of M (from 0 to 1) for trigger semiconductor switches. m is no of h bridge per phase.

Genetic Algorithm

Genetic algorithms (GAs) are a computational adaptive heuristic search algorithm based on the evolutionary ideas of natural selection and genetics. GAs is inspired by Darwin’s theory about - “Survival of Fittest”. It follows biological evolution by using genetic operators referred to as chromosome, selection, crossover and mutation. As a process of optimization it provides the optimal system performance.

Chromosome: In GA, chromosome means the feasible solution for the problem, for multilevel inverter, the number of variables are the

number of controllable switching angles.

Selection: Selection is the stage of a genetic algorithm in which individual genomes are chosen from a population for later breeding. The selection operator determines how the parents are chosen to create the offspring.

Crossover: After the reproduction phase is over, the population is enriched with better individuals. Reproduction makes clone of good strings, but does not create new ones. Crossover operation is applied to the meeting pool with a hope that it would create a better string. Crossover is the most significant operation in GA.

Mutation: Mutation is another vital operation. It works after crossover operation. Mutation means that the element of deoxyribonucleic acid (DNA) is modified. This change is mainly caused by error in copying gens from parents. This process is repeated, until the preferred optimum of the objective function is reached.

Evaluation of fitness function: The fitness function plays a very important role in guiding GA to obtain the best solutions within a large search space. The objective of this paper is to minimize lower order harmonics (5th, 7th, 11th and 13th) and reduce the THD. Therefore, the fitness function has to be associated to THD. The fitness function formulated as

$$FV = \frac{\sqrt{\sum_{n=5,7,11,13} (\frac{1}{n} \sum_{k=1}^5 \cos(n\alpha_k))^2}}{\sum_k \cos\alpha_k}$$

To find the desire value GA need to run for a certain number of iterations (1000 in this case). After the first iteration, fitness values are used to determine new offspring. These go through crossover and mutation operations and a new population is created which goes through the same cycle starting from evaluation. After these iterations, the GA finds one solution. The flow chart showed in Figure 3.

Simulation Results

In this section the proposed technique is implemented on three phase fifteen level and seventeen level cascaded multilevel inverter Genetic Algorithm is use to calculate the switching angles. Three phase fifteen level and seventeen level cascaded H-bridge multilevel inverter are developed in MATLAB Simulink and the calculated switching angles are used to trigger the GTO switching devices. The offline computed switching angles for fifteen level and seventeen level cascaded multilevel inverter are shown in Tables 1 and 2.

The variation of switching angles with modulation indices is plotted in Figure 4.

The variation of switching angles with modulation indices is plotted in Figure 5.

Simulation results for a fifteen-level cascaded h bridge

multilevel inverter operating with equal DC sources (25 volt per h bridge) are shown in Figure 6 with the voltage values indicated. Be-

cause of Modulation index 0.8 the output voltage is approximate $(175 \times 0.8) = 140$ V.

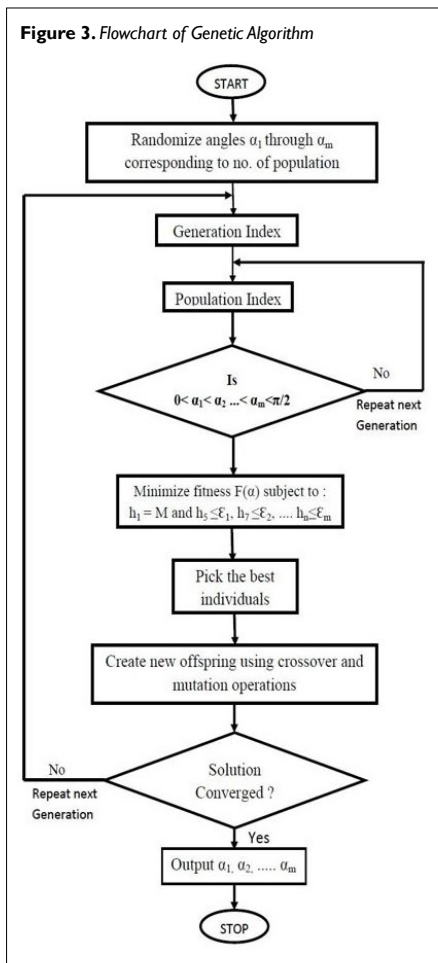


Table 1. Switching Angles at Various Modulation Index (M) of 15 Level Inverter

M	α_1	α_2	α_3	α_4	α_5	α_6	α_7
0.1	0.612	0.789	0.977	1.137	1.355	1.562	1.563
0.2	0.617	0.785	0.974	1.132	1.35	1.458	1.564
0.3	0.609	0.781	0.971	1.123	1.342	1.459	1.562
0.4	0.318	0.592	0.893	1.025	1.17	1.457	1.562
0.5	0.35	0.577	0.849	0.962	1.079	1.214	1.554
0.6	0.103	0.528	0.675	0.808	1.033	1.208	1.476
0.7	0.093	0.314	0.483	0.65	0.856	1.029	1.222
0.8	0.079	0.295	0.462	0.626	0.851	1.002	1.184
0.9	0.04	0.125	0.179	0.314	0.436	0.566	0.736
1.0	0.02	0.125	0.177	0.3	0.427	0.555	0.716

Table 2. Switching Angles at Various Modulation Index (M) of 17 Level Inverter

M	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8
0.1	0.116	0.576	0.692	0.822	1.05	1.366	1.555	1.556
0.2	0.612	0.780	0.969	1.124	1.351	1.564	1.564	1.564
0.3	0.594	0.729	0.892	1.025	1.172	1.373	1.56	1.56
0.4	0.283	0.574	0.654	0.885	0.989	1.072	1.168	1.494
0.5	0.084	0.315	0.562	0.651	0.853	1.025	1.223	1.527
0.6	0.090	0.554	0.654	0.756	0.874	1.055	1.272	1.436
0.7	0.087	0.487	0.652	0.749	0.856	1.034	1.244	1.385
0.8	0.027	0.118	0.334	0.449	0.584	0.767	0.876	1.262
0.9	0.063	0.245	0.347	0.479	0.624	0.852	0.979	1.162
1.0	0.065	0.070	0.169	0.259	0.378	0.467	0.594	0.764

The frequency spectrum for the steady voltage waveform of the simulation result is shown in Figure 7. Where it can be noticed that the target harmonics are minimized with a THD of 1.60%. 5th and 7th harmonic was minimized less than 0.8%, 11th and 13th harmonics was minimized less than 1%.

The frequency spectrum for the steady voltage waveform of the simulation result is shown in Figure 9. Where it can be noticed that the target harmonics are minimized with a THD of 0.79%. 5th and 7th harmonic was minimized less than 0.2%, 11th and 13th harmonics was minimized less than 0.6%.

Similarly, simulation results for a seventeen-level cascaded h bridge multilevel inverter operating with equal DC sources (25 volt per h bridge) are shown in Figure 8 with the voltage values indicated. Because of Modulation index 0.8 the output voltage is approximate $(200 \times 0.8) = 160$ V.

A comparative study of simulated THD for the modulation indices 0.1 to 1.0 for three phase fifteen level and seventeen level cascaded multilevel inverter are shown in Table 3. The variation is shown in Figure 10.

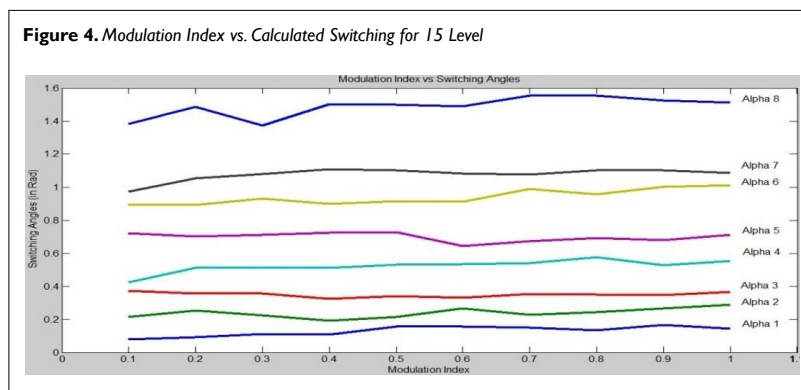


Figure 5. Modulation Index vs. Calculated Switching for Seventeen Level

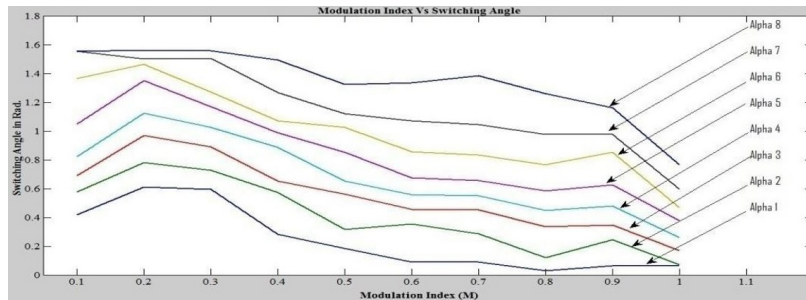


Figure 6. Simulated per Phase Output Voltage for a Fifteen-level Cascaded H Bridge Multilevel Inverter for the Modulation Index 0.8

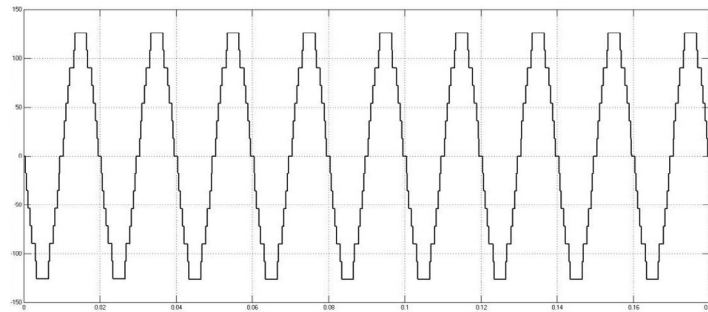


Figure 7. Frequency Spectrum for Output Line-Line Voltage

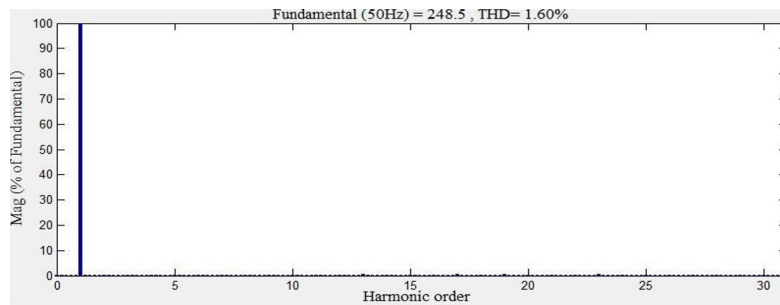
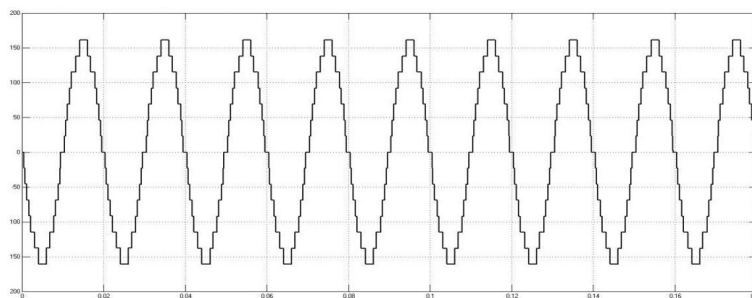


Figure 8. Simulated per Phase Output Voltage for a Seventeen-level Cascaded H Bridge Multilevel inverter for the Modulation Index 0.8



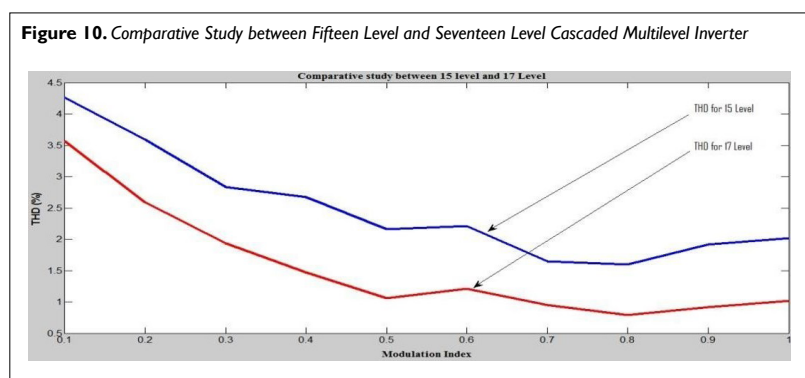
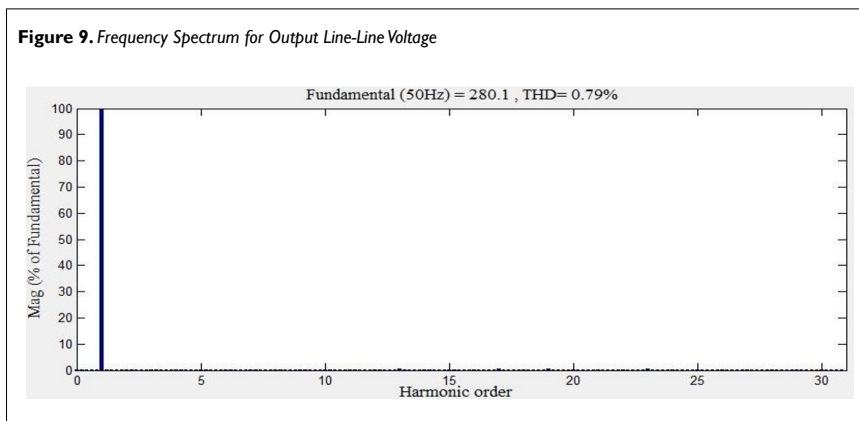


Table 3. THD (%) of Fifteen Level and Seventeen Level Cascaded Multilevel Inverter

Modulation Index	THD (%) for Fifteen Level	THD (%) for Seventeen Level
0.1	4.26	3.56
0.2	3.59	2.59
0.3	2.83	1.93
0.4	2.67	1.47
0.5	2.16	1.06
0.6	2.21	1.21
0.7	1.65	0.95
0.8	1.60	0.79
0.9	1.92	0.92
1.0	2.02	1.02

CONCLUSION

The article proves that GA is an effective solution to the selective harmonics removal issue in multilevel inverters. There has been a comparison between the 15-level and 17-level algorithms with regard to THD, and the genetic algorithm has been validated for the determination of optimal switching angles of staircase waveforms produced by multilevel inverters.

The waveform generated by a cascaded H-bridge multilevel inverter has the lowest harmonic content. Also, compared to other kinds of multilevel inverters, the cascaded H-bridge multilevel inverter produces waveforms that are closer to a sinusoidal shape. The

quantity of harmonics in the output waveform also reduces as the level of the multilevel inverter increases. Nevertheless, the harmonics are reduced, but the price has to go up since more components are utilized. The findings of the simulations may also be confirmed by conducting appropriate experiments.

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