# COMPARATIVE ANALYSIS OF SELECTIVE HARMONIC ELIMINATION OF MULTILEVEL INVERTER USING GENETIC ALGORITHM

S.Saha[1], C.Sarkar[2], P.K. Saha[3] & G.K. Panda[4]

[1&2]PG Scholar, Department of Electrical Engineering, Jalpaiguri Govt. Engg. College, W.B., India, 735102
[3&4]Professor, Department of Electrical Engineering, Jalpaiguri Govt. Engg. College, W.B., India, 735102

## Abstract

This paper focuses on, elimination of harmonics of a cascaded multilevel voltage source inverter. Here the basic concept is to eliminate specific harmonics with a proper choice of switching angles. In this paper Genetic Algorithm (GA) optimization technique is use to achieve proper switching angles for reduce the THD and elimination of a selective lower order harmonics with fundamental components at the desired values. As a case study, the proposed method is simulated on a seventeen levels and fifteen levels inverter and optimum switching angles are determined to eliminate low order harmonics and to minimize THD. Comparative analysis has been done between seventeen levels and fifteen levels with respect to the consideration of THD.

*key-words:-* Genetic Algorithm, Multilevel Inverter, Selective Harmonic Elimination (SHE), Three Phase Cascade H-Bridge Inverter, , Total Harmonic Distortion (%THD).

## 1.Introduction

In some few years multilevel inverter has taken a vast place in industrial application and widely used in different application such as static power converter for high power applications, FACTS devices, HVDC and also as electric drives for all ac motors when dc supply is used. Another major advantage is that their switching frequency is lower than a traditional inverter, for this it has less switching losses and higher voltage capability. The well-known multi level topologies are: 1) Cascaded H-bridge multi-level inverter, 2) Diode-clamped multi-level inverter, and 3) Flying capacitor multi-level inverter. Cascaded H-bridge multi-level inverter is superior to another multilevel topology for simple, requires the least number of components. Also it is easily extensible for higher number of output voltage levels without increase in power circuit complexity.

The main motive with the multilevel inverters is reducing the harmonics and improves the quality of output. For this several switching algorithm such as pulse width modulation (PWM), space vector modulation (SVM) , Sinusoidal pulse width modulation (SPWM), and elimination of some specific harmonics are applied to control and determine switching angles to achieve the desired output voltage.

This paper focuses on elimination of some specific harmonics by solving the non linear equation of multilevel inverter. Several algorithms have been suggested for this purpose Such as the Newton-Raphson method is one of them. The disadvantage of this method, it is fast and exact but not for all modulation indices and it depends on initial guess while Genetic algorithm overcome this problems.

In this paper an optimum switching for multilevel inverter using Genetic Algorithm (GA). The calculated switching angles are used to trigger switching devices of cascaded multilevel inverter. As new approaches has been investigated in comparison between seventeen levels inverter and fifteen levels inverter with GA method. The simulation results showed that Seventeen levels inverter more efficient than fifteen levels inverter.

## 2. 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 Fig. 1.
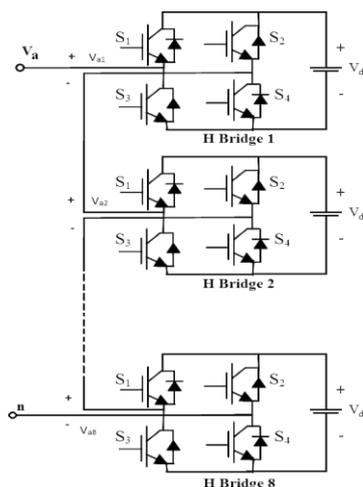


Fig.1 Cascaded multilevel inverter(Eight bridge)

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 fig 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.
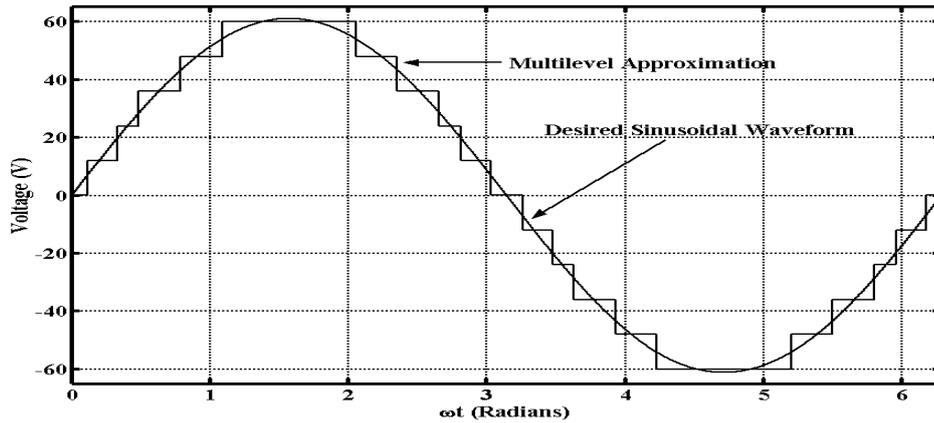


Fig.2 switching angle of multilevel inverter

In fig 2 shown the output voltage waveform V(t) of multilevel inverter. The voltage waveform can express in Fourier series as

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

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. $\alpha_1, \alpha_2,..... , \alpha_m$ as follows:

$$b_n = (4V_{dc}/n\pi) \sum_{n=1}^{\infty} \sin \omega t \qquad (2)$$

and,

$$0 < \alpha_1 < \alpha_2 < \cdots \alpha_m < \frac{\pi}{2} \qquad (3)$$

## 3. 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 $b_1$ 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 $V_1$ to the maximum obtainable fundamental voltage $V_{1max}$. The maximum fundamental voltage is obtained when all the switching angles are zero i.e.

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

Therefore the expression for M

$$M = \pi V_1/4V_{dc} \quad (0 \leq M \leq 1) \qquad (4)$$

Mathematically SHE problem can be formulated as:

$$\cos(\alpha_1) + \cos(\alpha_2) + ..............+ \cos(\alpha_m )= mM$$
$$\cos(5\alpha_1) + \cos(5\alpha_2) + ...............+ \cos(5\alpha_m )= 0$$
$$\cos(7\alpha_1) + \cos(7\alpha_2)+.................+ \cos(7\alpha_m )= 0$$
$$\cos(11\alpha_1)+\cos(11\alpha_2)+..............+\cos(11\alpha_m )= 0$$
$$\cos(13\alpha_1)+\cos(13\alpha_2)+...............+\cos(13\alpha_m )=0$$
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$$.$$
$$\cos(n\alpha_1)+\cos(\alpha_2)+....................+\cos(n\alpha_m )=0 \qquad (5)$$

The equation (5) is a system of transcendental equation, known as selective harmonic elimination (SHE) equation. From the equation unknown switching angle $\alpha_1$, $\alpha_2$, $\alpha_3$, $\alpha_4$, $\alpha_5$, $\alpha_6$, $\alpha_7$ ………$\alpha_m$ are calculated by the Genetic Algorithm (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 .

## 4. 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.

### 4.1 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.

### 4.2 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.

### 4.3 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.

### 4.4 Mutation

Mutation is another vital operation. It works after crossover operation. Mutation means that the element of 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.

### 4.5 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 ($5^{th}$, $7^{th}$, $11^{th}$, and $13^{th}$) and reduce the THD. Therefore the fitness function has to be associated to THD. The fitness function formulated as.

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

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 Fig.3
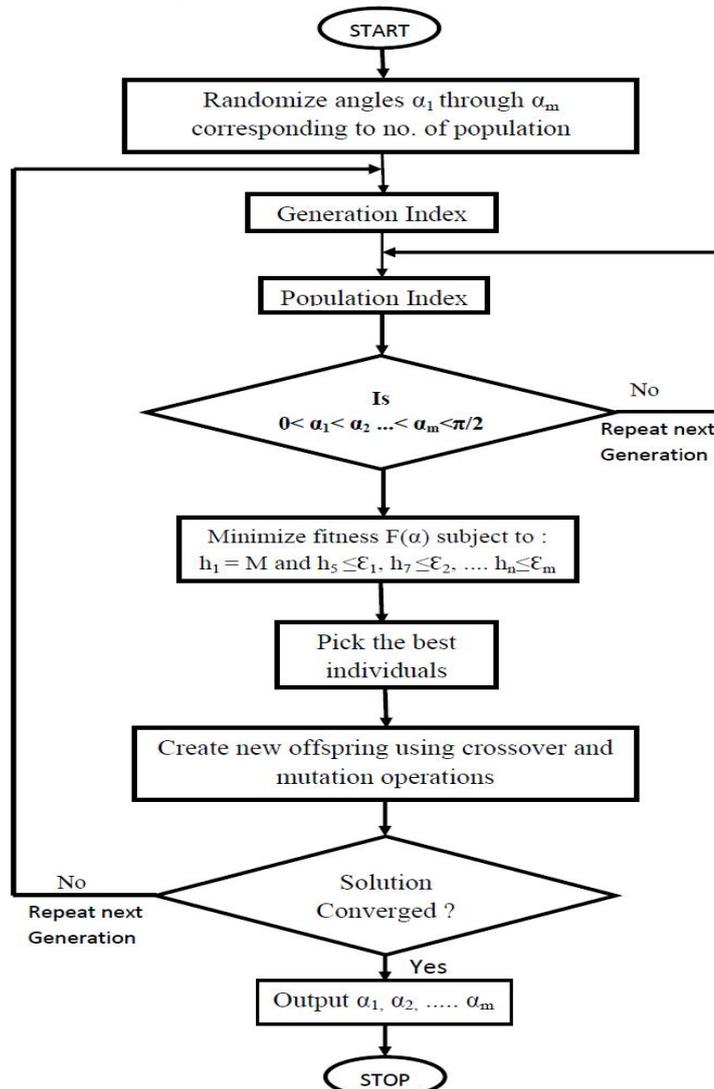


Fig.3 Flowchart of Genetic algorithm

## 5. 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 Table I and Table II.

TABLE I: Switching angles at various modulation Index (M) of 15 level inverter

| M | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | $\alpha_4$ | $\alpha_5$ | $\alpha_6$ | $\alpha_7$ |
|---|---|---|---|---|---|---|---|
| 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 |

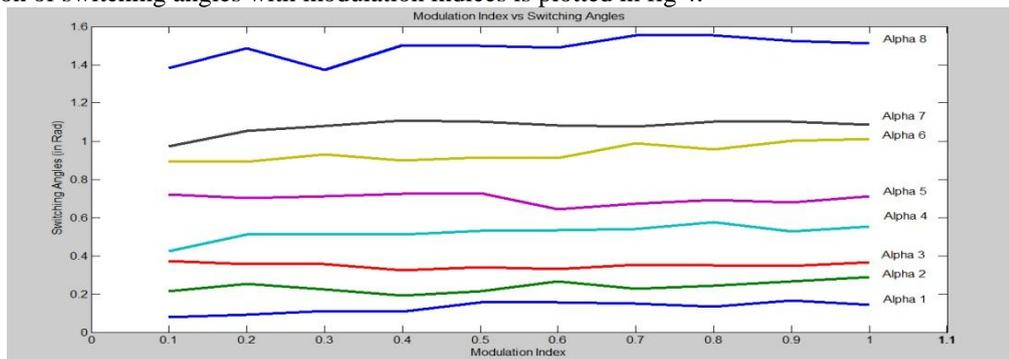The variation of switching angles with modulation indices is plotted in fig 4.



Fig. 4. Modulation Index vs. Calculated switching for 15 level

TABLE II: Switching angles at various modulation Index (M) of 17 level inverter

| M | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | $\alpha_4$ | $\alpha_5$ | $\alpha_6$ | $\alpha_7$ | $\alpha_8$ |
|---|---|---|---|---|---|---|---|---|
| 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 variation of switching angles with modulation indices is plotted in fig 5.
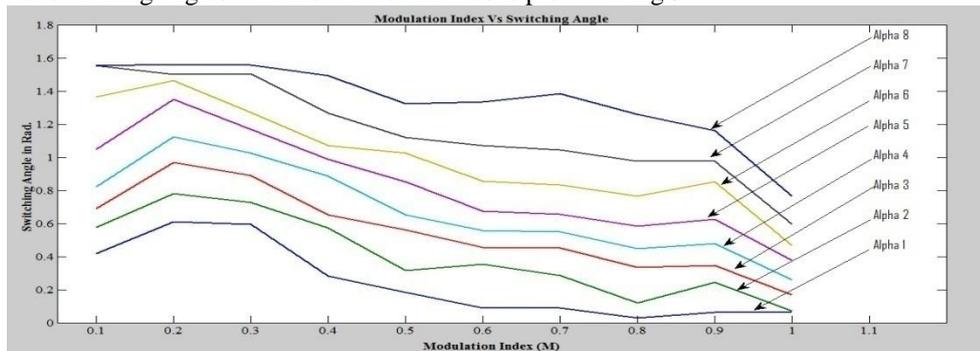


Fig. 5. Modulation Index vs. Calculated switching for seventeen level

Simulation results for a fifteen-level cascaded h bridge multilevel inverter operating with equal DC sources (25 volt per h bridge) are shown in fig. 6 with the voltage values indicated. Because of Modulation index 0.8 the output voltage is approximate (175*0.8) = 140 V.
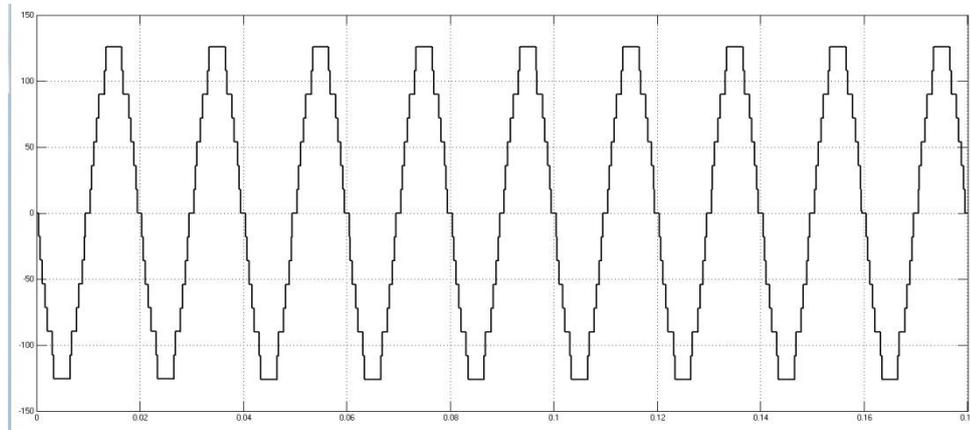
Fig. 6. Simulated per phase output voltage for a fifteen-level cascaded h bridge multilevel inverter for the Modulation Index 0.8

The frequency spectrum for the steady voltage waveform of the simulation result is shown in Fig. 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%.
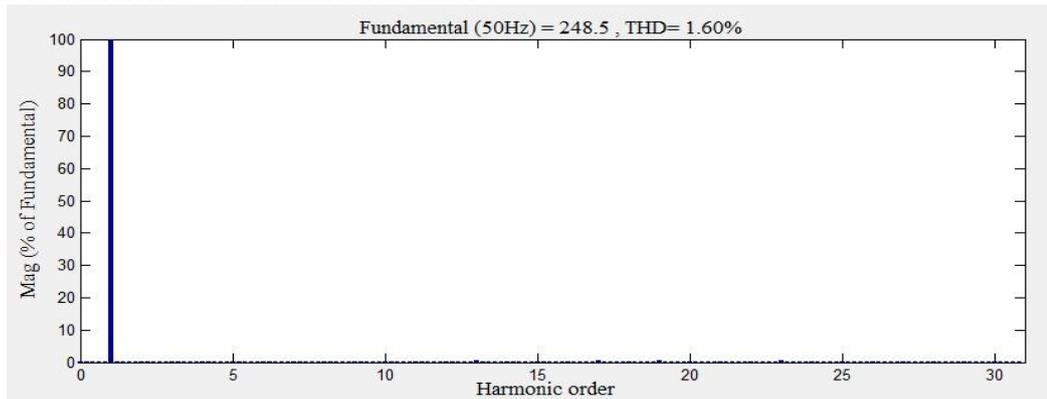


Fig. 7. Frequency spectrum for Output Line-Line Voltage

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 fig. 8 with the voltage values indicated. Because of Modulation index 0.8 the output voltage is approximate (200*0.8) = 160V
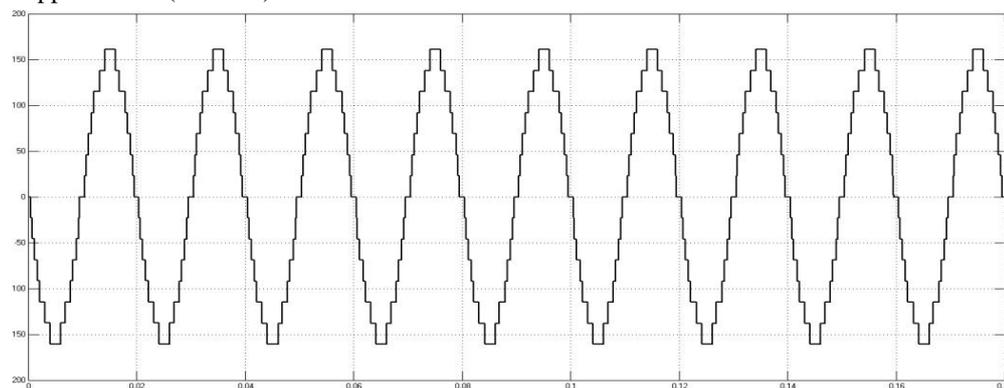


Fig. 8. Simulated per phase output voltage for a seventeen-level cascaded h bridge multilevel inverter for the Modulation Index 0.8

The frequency spectrum for the steady voltage waveform of the simulation result is shown in Fig. 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%.
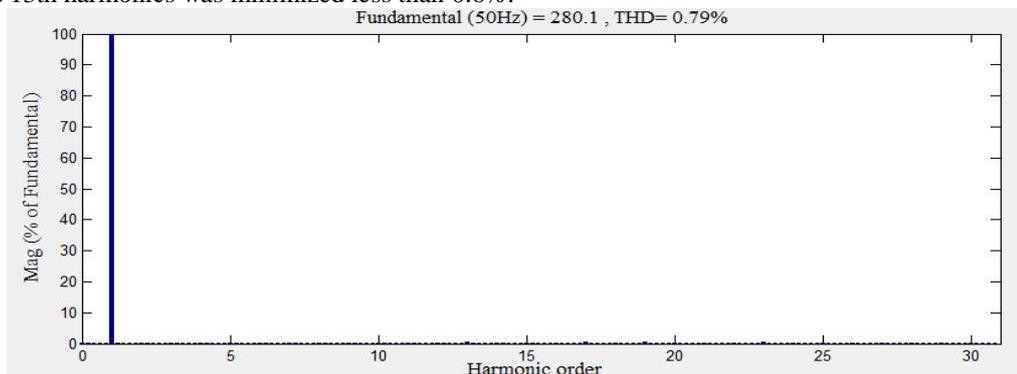


Fig. 9. Frequency spectrum for Output Line-Line Voltage

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 III. The variation is shown in fig. 10

TABLE III: THD (%) of fifteen level and seventeen level cascaded multilevel inverter

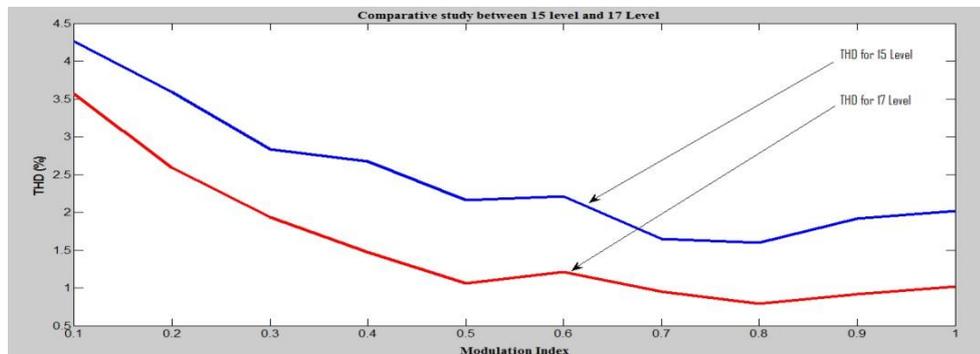| Modulation Index | THD (%) for fifteen level | THD (%) for seventeen level |
|---|---|---|
| 0.1 | 4.26 | 3.56 |
| 0.2 | 3.59 | 2.59 |
| 0.3 | 2.83 | 1.93 |
| 0.4 | 2.67 | 1.47 |
| 0.5 | 2.16 | 1.06 |
| 0.6 | 2.21 | 1.21 |
| 0.7 | 1.65 | 0.95 |
| 0;8 | 1.60 | 0.79 |
| 0.9 | 1.92 | 0.92 |
| 1.0 | 2.02 | 1.02 |



Fig. 10. Comparative study between fifteen level and seventeen level cascaded multilevel inverter

## 6. Conclusion

The paper demonstrates that the selective harmonics elimination problem in multilevel inverter by using GA successfully. The validation of genetic algorithm for the estimation of optimum switching angles of staircase waveform generated by multilevel inverters, and Comparison has been done between the 15-level and 17-level with respect to the consideration of THD.

It is found that the harmonic content present in waveform produced by cascaded H-bridge multilevel inverter is lowest. Also, the waveform produced by the cascaded H-bridge multilevel inverter approximate sinusoidal shape better than the other types of multilevel inverters. And the amount of harmonics in the waveform produced decreases with increase in the level of multilevel inverter. However, the decrease in the harmonics is at the cost of increase in the components used, that is increase in cost. The simulated results also can be validate through suitable experiments.

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