# THD Minimization of the Output Voltage for Asymmetrical 27-Level Inverter using GA and PSO Methods

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**Abstract:** Multilevel voltage source inverters have several advantages compare to traditional voltage source inverter. These inverters reduce cost, get better voltage waveform and decrease Total Harmonic Distortion (THD) by increasing the levels of output voltage. In this paper Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) methods are used to find the switching angles for achieving to the minimum THD for output voltage waveform of the Cascaded H-bridge Multi-Level Inverters (MLI). These methods are used for a 27-level inverter for different modulation indices. Result of two methods is identical and in comparison to other methods have the smallest THD. To verify results of two mentioned methods, a simulation using MATLAB/Simulink software is presented.

**Keywords:** Asymmetrical Multi-Level Inverter (AMLI), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Total Harmonic Distortion (THD).

## 1 Introduction

Using multilevel voltage-source inverters is a suitable method for achieving to the high power rating and high quality output voltage waveforms [1-4]. These inverters have the ability to produce a waveform with the better harmonic spectrum in comparison to simple square wave inverter. Theirs applications in fuel cells and solar cell are increasing [5, 6]. The topologies of high power Multi-Level Inverters (MLI) are classified in to three groups: the cascaded H-bridge inverters, the diode clamped inverters and the flying capacitor inverters [7]. Cascaded H-bridge Multi-Level Inverters have some advantages. These inverters have higher output voltage and power level and higher reliability due to theirs modular topologies.

Cascaded H-bridge inverters in view of amount of DC voltage sources applied in their input can be classified in two categories: The Symmetric Multi-Level Inverter (SMLI) and Asymmetric Multi-Level Inverter (AMLI) [9]. In SMLI two or more module of H-bridge inverter with the same DC voltage sources are used. The AMLIs decrease the number of input DC voltage sources and increase the number of levels in output waveform [8]. In an AMLI for example, 27-level inverters, with only three DC source (than can be PV or FC), 27 levels is obtained while this number of levels in SMLI needs more DC source, switches and etc. Figure 1 shows a cascaded H-bridge MLI.

Cascaded Multi-Level Inverters are suitable in application such as solar PV systems [8]. In these systems, each solar array produces different voltage levels. This MLI can be used in the high power application as interface with solar PV module and fuel cells. In [8, 13], examples of 27-level inverter application for PV are stated.

Moreover of this advantage, MLIs reduce the loss of switching due to less switching frequency. In these inverter different types of switches used to optimize the inverters efficiency. By increasing levels in output voltage, THD is reduced. Figure 2 illustrate some of advantage of the H-bridge MLI.

For switching of these MLIs, we need to obtain conducting angles of switches. Different strategies are applied in for this purpose. Author in [10], [11] suggested methods such as sinusoidal pulse width modulation (SPWM) and space vector pulse width modulation (SVPWM) for controlling the output voltage and elimination undesired harmonics in MLI. These PWM techniques are very efficient in elimination of low order harmonics and only some high order harmonics (related to switching frequency) remain, but this method cannot eliminate low order harmonics completely. Another method is known as selective harmonic elimination (SHE) [12].In this approach, switching angles are chosen so that some higher order harmonics (such as 5th, 7th, 11th, 13th) in output voltage waveform are suppressed.

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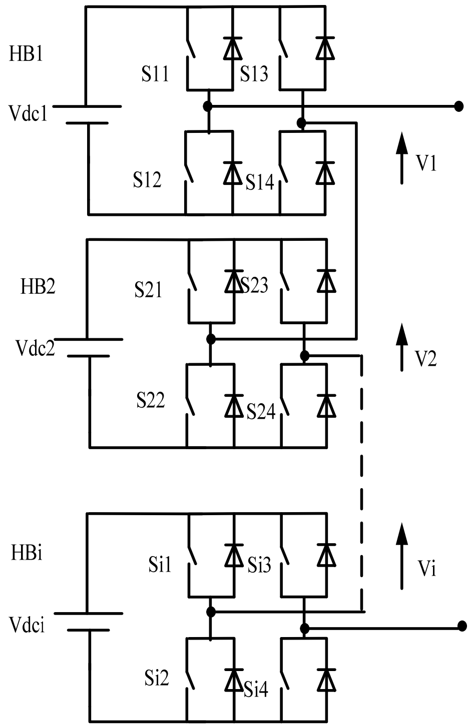


**Fig. 1** Cascaded H-bridge Multi-Level Inverter

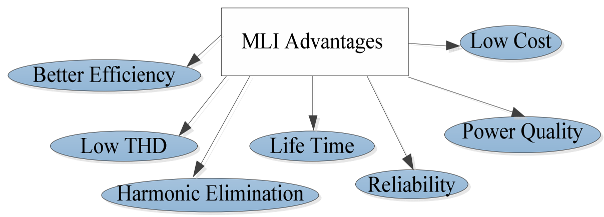


**Fig. 2** Some advantages of H-bridge MLIs.

A criterion of the output voltage quality is THD. The THD of the output voltage of a MLI is a measurement of the harmonic distortion, which is anticipated to be as small as possible. In both SHE and THD minimization methods, obtaining these conducting angles is difficult because conventional methods usually need a classic iterative method such as the Newtone-Raphson. These classic methods for solving of the equations are usually difficult and complicated.

In this paper a 27-level inverter represented and two methods based on GA and PSO for calculation of switching angle is proposed. These methods calculate these angles for minimizing of the output voltage THD. In comparison to [13], THD gained from these methods is lower. Simulation results for a 27-level inverter in MATLAB are given to verify the performance of these methods. Also, using GA and PSO methods, these angles are calculated and results are compared. The objective is minimization of THD of output voltage waveform. In [14], authors used GA for harmonic optimization of MLI. Authors in [15, 16] used PSO for eliminating of some harmonics in output voltage waveform and in [16], PSO is used for reduction of loss in network. The main differences between this paper and other papers are in this subject that in this paper two methods of optimization for a 27-levels inverter is used for comparison and also a general formula for THD as an objective function is applied.

## 2 Modeling of 27-level inverter

As mentioned a MLI has two or more H-bridge inverter. Each full H-bridge inverter has four switches and the output voltage of inverter is given by [13]:

$$V_{oi} = V_{dc}(S_{1i} - S_{2i}) \qquad (1)$$

where $i$=1, 2, 3, … (Number of full bridge inverters). $S_{1i}$ and $S_{2i}$ is the state of switches of each full bridge inverter. For a single phase MLI with N Full bridge inverter, the output voltage of MLI is given by:

$$V_{oN} = \sum_{i=1}^{N} V_{oi} \qquad (2)$$

### 2.1 Topology of 27-Level Inverter

A 27-level inverter consist of three full H-bridge inverter with unequal DC input source. The inverters are placed in series with each other's. In the first inverter, a DC voltage source (can be an output of PV array of battery) with amplitude of Vdc is placed as input. In second and third inverter, respectively, a DC voltage source with amplitude of 3Vdc and 9Vdc are used [11]. Figure 3 show a simplified topology of this MLI.

With this topology, the output voltage has 27 levels as: +13, +12, +11,…, +1, 0, -1,…,-11 , -12, -13. Table 1 shows the conduction switch state for quarter cycle of operation. With this pattern, in $90^0$ operation of this MLI, α1 to α13 are defined. Figure 4 shows these angles. These angles can be determined so that some of harmonic of the output voltage completely eliminated. As well as minimization of THD with good choice of these angles can be possible. In MLI with the n levels, modulation index is defined as follows [17]:

$$m_a = \frac{A_m}{(n-1)A_c} \qquad (3)$$

where $A_m$ is peak to peak reference waveform amplitude and $A_c$ is peak to peak carrier waveform. The output voltage waveform using Fourier analysis can be written as below [18]:

$$V_o(t) = \sum_{n=1}^{\infty} \frac{4V_{dc}}{n\pi}\left(\cos(n\alpha_1) + \cos(n\alpha_2) + \ldots + \cos(n\alpha_{13})\right) \qquad (4)$$

where α1 to α13 are shown in Figure 4 and Vdc is the height of stairs in figure. As well as THD of this waveform can be expressed as follows:

$$THD = \sqrt{\frac{V_{orms}^2 - V_{o1rms}^2}{V_{o1rms}^2}} = \sqrt{\frac{\sum_{n=2}^{\infty} V_{onrms}^2}{V_{o1rms}^2}} \qquad (5)$$

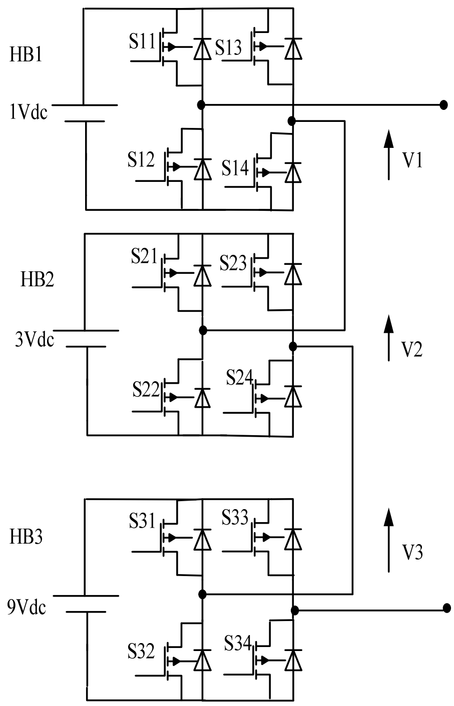


**Fig. 3** Simplified topology of 27-level inverter.

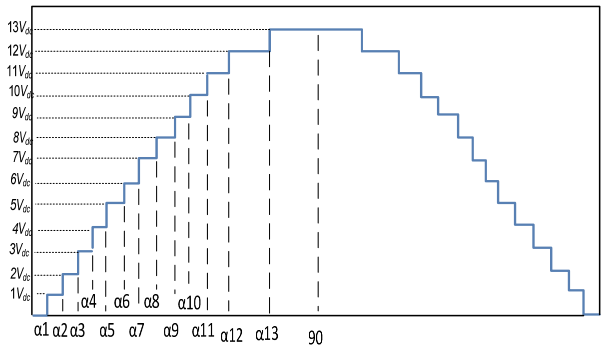


**Fig. 4** output voltage waveform of 27- level inverter in half

**Table 1** Switching pattern for the first $90^0$operation.

| **S. No.** | **Switching pattern for the first $90^0$operation** | **Output voltage** |
|---|---|---|
| **1** | S11,S14,S21,S23,S31,S33 | $1V_{dc}$ |
| **2** | S12,S13,S21,S24,S31,S33 | $2V_{dc}$ |
| **3** | S11,S13,S21,S24,S31,S33 | $3V_{dc}$ |
| **4** | S11,S14,S21,S24,S31,S33 | $4V_{dc}$ |
| **5** | S12,S13,S22,S23,S31,S34 | $5V_{dc}$ |
| **6** | S11,S13,S22,S23,S31,S34 | $6V_{dc}$ |
| **7** | S11,S14,S23,S22,S31,S34 | $7V_{dc}$ |
| **8** | S12,S13,S21,S23,S31,S34 | $8V_{dc}$ |
| **9** | S11,S13,S21,S23,S31,S34 | $9V_{dc}$ |
| **10** | S11,S14,S21,S23,S31,S34 | $10V_{dc}$ |
| **11** | S12,S13,S21,S24,S31,S34 | $11V_{dc}$ |
| **12** | S11,S13,S21,S24,S31,S34 | $12V_{dc}$ |
| **13** | S11,S14,S21,S24,S31,S34 | $13V_{dc}$ |

where:

$$V^{1}_{RMS} = \frac{1}{\sqrt{2}}\frac{4V_{dc}}{\pi}\left(\cos(\alpha_1)+\cos(\alpha_2)+...+\cos(\alpha_{13})\right) \quad (6)$$

## 3. Optimization Algorithms

### 3.1 Genetic Algorithm

Our purpose is determining of the switching angles that generate an output voltage with minimum THD. GA is a simple and powerful technique that inspired from the law of natural selection and genetics. This algorithm is a stochastic global search algorithm that minimizes an objective function [20]. GA decreases the computational burden and search time, and can solve complex objective functions [16]. For minimizing the function $f(x_1,x_2,x_3,\ldots,x_k)$ with GA, first each xi should be coded as a binary or floating-point string. In this paper, a binary string is used as follows: $x_1$=[1011 … 1011], $x_2$=[1101 … 1001], … , $x_k$=[0010 … 0111], where the set of $\{x_1, x_2, x_3,\ldots,x_k\}$ is called chromosome and each $x_i$ is called gene.

GA is a method that is general for any application. The steps of the GA for solving a problem are as follows:

1- Choose between binary or floating-point string.

2- Select the number of chromosomes and genes. In this application the number of variables is the number of switching angles. In the 27-level inverter, the number of switching angles is 13. Each chromosome in 27-level inverter has 13 switching angles $\{\alpha_1, \alpha_2, \alpha_3 ..., \alpha_{13}\}$ and the number of these switching angles for 13-level inverter is 7,$\{\alpha_1, \alpha_2, \alpha_3 ..., \alpha_7\}$.

3- Find a population and initialize this population. If large population is selected, this may be increase the rate of convergence but it increases the execution time. For selecting optimal size for population, a few experiences are required. The numbers of chromosomes for two problems are 20 and initialize with the random number between $0^0$ and $90^0$.

4- Evaluation of the fitness for each chromosome that called cost (objective) function. This function in our problems is equation (5). In this stage best solution is a chromosome with minimum cost function.

5- GA usually runs for a certain number of iteration (in our cases is 300). After any iteration, new offspring is generated. These new population is generated through crossover and mutation operators. In this paper, for selection, stochastic uniform function and for mutation, Gaussian function is used and for crossover function is considered scattered and with crossover fraction=0.8.

### 3.2 Particle Swarm Optimization (PSO)

PSO is a robust stochastic optimization technique based on the movement and intelligence of swarms. In this technique, a number of agents (particles), those constitute a swarm, moving in the whole of search space with the goal of looking for best solution. In the PSO method, each agent in swarm represents as a solution and it defined by its position and velocity [21]. In the PSO method a swarm with random particle initialized, and then it searches for optimum solution by updating generation. In any iteration, each particle is updated by two best values [22]. "L" that Called local best, is the best (solution) fitness that has achieved by that particle and "G' that called global best, is the best value obtained so far by any particle in the neighbourhood of particle. Finally, any particle tries to modify its position using the following equation:

$$v_i(k+1) = w(k)v_i(k) + c_1r_1[L_i(k) - x_i(k)] + c_2r_2[G_i(k) - x_i(k)] \quad (7)$$

$$x_i(k+1) = x_i(k) + v_i(k+1) \quad (8)$$

where $w(k)$ is weighting factor , $v_i(k)$ and $x_i(k)$ is the particle velocity and position of each iteration $k$. Also $r_1$ and $r_2$ are random numbers with uniformly distributed within [0,1]. Amount of $w(k)$ influence on exploration area. Large amount of $w(k)$ encourages global and small amounts cause local exploration. Based on experimental results, it is suggested, it initialize with large value and gradually is reduced to small value [23]. In this paper by using author experiences in [24], value of $w(k)$ is first 1 and final value is zero.

PSO algorithm has the following steps [25]:

1- Initialize particles with random position and velocity. In this paper number of these particles is considered 40.

2- Evaluation of the fitness function for each particles.

3- Updating the position and velocity using the equations 6 and 7 and updating of best local (L) and best global (G).

4- Repeating this procedure for a fixed number iteration. This number is considered 300.

5- Obtaining the best achieved values of (G).

## 4. Simulation Results

### 4.1 Result of PSO and GA for a MLI

A 27-level inverter that is shown in Figure 3, is simulated in MATLAB/Simulink and other calculation is done by MATLAB. Amount of Vdc is considered 30 V. Values for objective function obtained from GA and PSO for a 27-level inverter with ma=1 and ma=0.5 are shown in Figures 5, 6, 7 and 8. For two methods, the number of generation is considered 300 (N=300). Angles from two methods are shown in the Table 2. With increasing of N from 300, THD has a little deviation for two methods and the best value of THD from two methods is 2.94%. From results it can founded that two methods have produce different angles as solution of problem. In some angles such as α11, α12 and α13 this difference is more than other angles. This shows that problem responses is not unique, but by using these algorithm and different changes in parameters, this value is minimum that authors obtained.

### 4.2 Result of Output Voltage Waveform

A 27-level MLI with 3 independent sources (30V, 90V, 270V) is designed in MATLAB/SIMULINK. The switching angles achieved from two methods are set for inverters. Figures 9 and 10 show the output voltage waveforms of inverter. As expected output voltage has a shape that is very close to sine wave.

Figures 11 and 12 show the output voltages of each HB in MLI. These figures show that switching frequency of each HB is different from other. This difference is such that HB with larger DC voltage source has lower switching frequency and vice versa. For verification, a Fourier analysis presented. In this stage, it observed that THD of output voltage with these conducting angles has the same value that obtained from GA and PSO. In Figures 13 and 14 amplitudes of harmonics and fundamental component and THD of output voltage are shown.

**Table 2** Switching angles achieved from two methods

| Switching Angles | GA | SA |
|---|---|---|
| $\alpha_1$ | 2.17 | 4.271 |
| $\alpha_2$ | 6.52 | 7.280 |
| $\alpha_3$ | 10.9 | 11.750 |
| $\alpha_4$ | 15.37 | 16.298 |
| $\alpha_5$ | 19.93 | 21.372 |
| $\alpha_6$ | 24.61 | 26.919 |
| $\alpha_7$ | 29.48 | 31.930 |
| $\alpha_8$ | 34.61 | 37.617 |
| $\alpha_9$ | 40.07 | 43.811 |
| $\alpha_{10}$ | 46.4 | 49.323 |
| $\alpha_{11}$ | 52.68 | 57.575 |
| $\alpha_{12}$ | 60.57 | 70.174 |
| $\alpha_{13}$ | 71.22 | 89.385 |

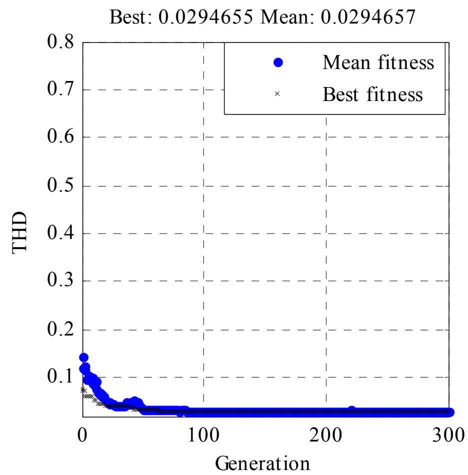


**Fig. 5** Best value for THD in GA for ma=1.

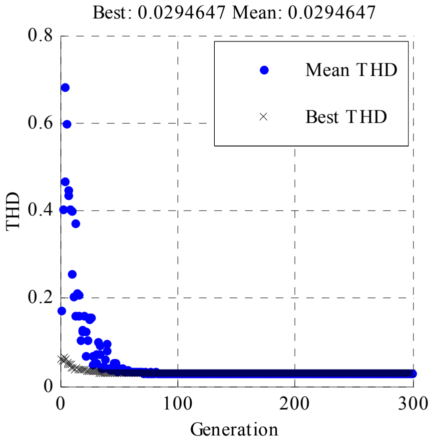


**Fig. 6** Best value for THD in PSO for ma=1.

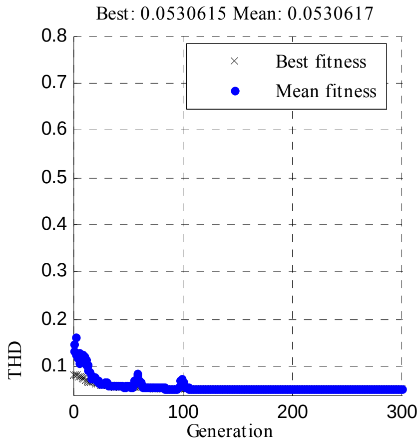


**Fig. 7** Best value for THD in GA for ma=0.5.

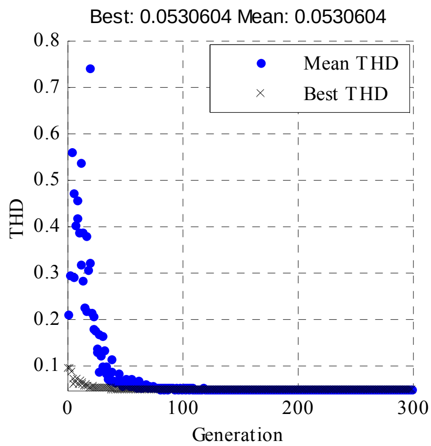


**Fig. 8** Best value for THD in PSO for ma=0.5.

Finally GA and PSO are used for different levels of output voltage waveforms. Parameters of these methods are not changed. Modulation index is obtained based on (3) and results of two methods are presented in Table 3. Similar two previous cases, for other modulation indices, PSO and GA results are identical. Also can be seen, if number of levels are increased, THD reduced. For 3 levels output voltage or ma =0.089 , minimum THD obtained from two methods is almost 28.9% while for a square wave output voltage, by using (5), THD is 48.34. As well as, by using switching algorithm of Table 1, for different levels, different modulation indices can be achieved.

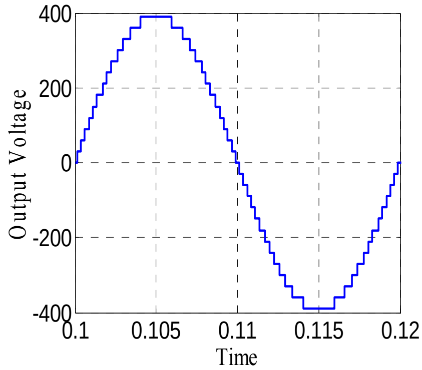


**Fig. 9** Output voltage of MLI with ma=1.

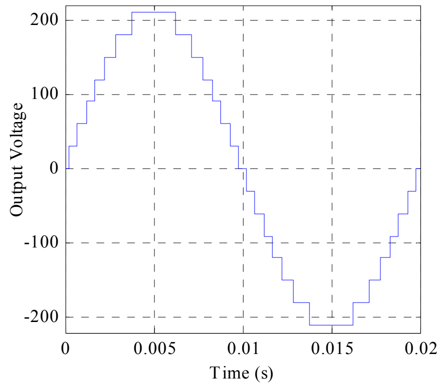


**Fig. 10** Output voltage of MLI with ma= 0.5

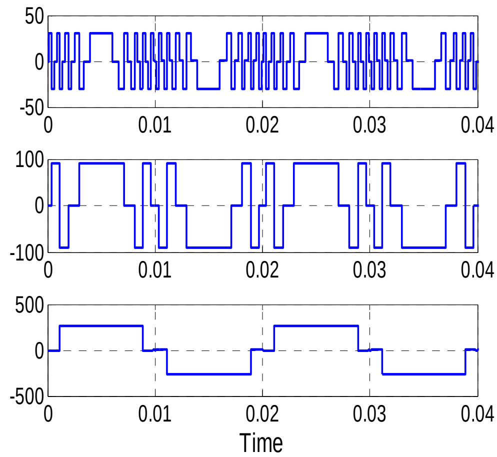


**Fig. 11** Output voltage of each H-Bridge inverter in MLI with ma=1.

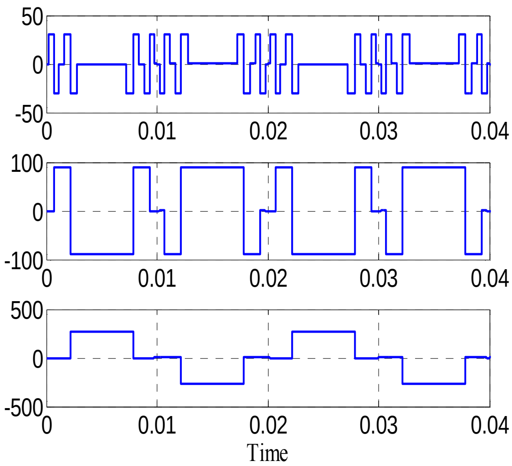


**Fig. 12** Output voltage of each H-Bridge inverter in MLI with ma=0.5.

## 5. Conclusion

In this paper, a topology of 27-levels inverter is described. For these inverters different switching methods exist. One of these method obtaining switching angles from an optimization method. The GA and PSO methods with objective function of THD minimization of the output voltage waveform is applied and switching angles are achieved for 27- level inverter with different modulation indices. These two methods are described and detailed parameters used are stated. MATLAB/Simulink is also used for simulation of inverter. Results of simulations of inverter with angles obtained from optimization methods show that the THD of output voltage waveform in two methods has the same value. Also these methods for different number of levels are applied and result that, minimum THD obtained from two methods is increased with reduction in level numbers.

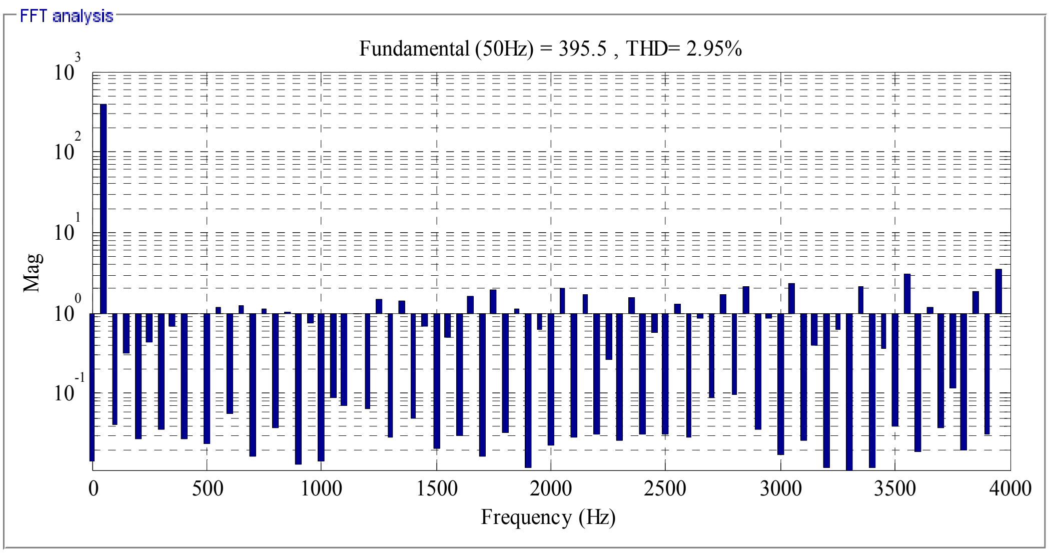


**Fig. 13** Amplitude of THD and harmonics of output voltage with ma=1.

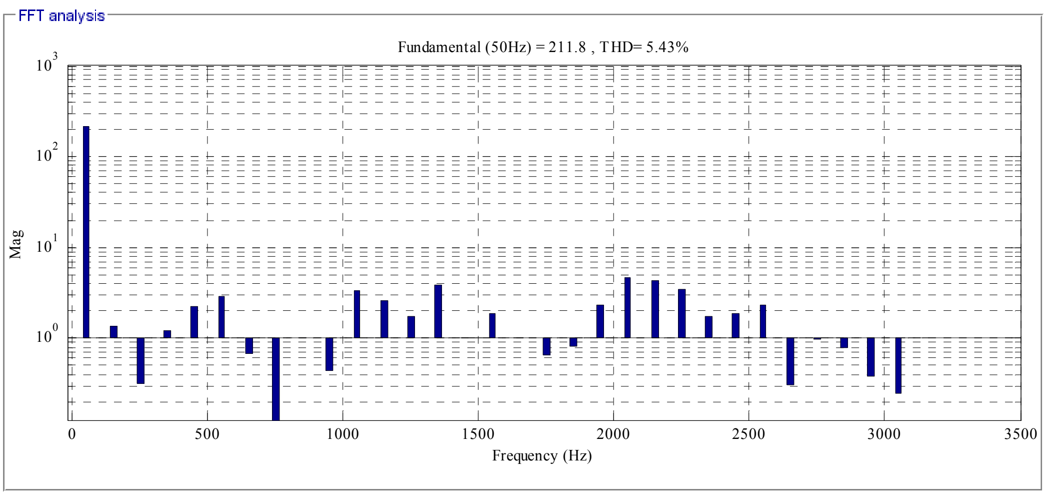


**Fig. 14** Amplitude of THD and harmonics of output voltage with ma=0.5.

**Table 3** THD obtained from two methods for different number in percent.

| N. Lev. | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | 27 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$M_a$** | 0.09 | .17 | .246 | .322 | .393 | .478 | .555 | .623 | .71 | .774 | .852 | .947 | 1 |
| **THD GA** | 28.9 | 16.4 | 11.5 | 8.80 | 7.50 | 6.06 | 5.24 | 4.69 | 4.1 | 3.77 | 3.44 | 3.23 | 2.92 |
| **THD PSO** | 28.9 | 16.3 | 11.5 | 8.90 | 7.257 | 6.128 | 5.30 | 4.67 | 4.2 | 3.78 | 3.45 | 3.18 | 2.92 |

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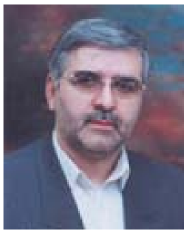

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