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Comparative Analysis of 31-level Asymmetrical Inverter Using Different Control Techniques

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ABSTRACT: Multilevel inverters(MLI) generate stepped AC output voltage using input DC voltage sources. For a Cascade H-bridge (CHB) MLI, several H-bridges are connected in cascade and each of the H-bridges consists of a separate DC source. In case of Symmetrical CHB inverters, the magnitudes of the input voltage sources are identical. Where as in case of Asymmetrical CHB inverters the input voltage sources are unequal,thus requiring less number of H-bridges to produce higher level in the output waveform. In this paper, a Cascaded H-Bridge Multilevel Inverter in asymmetrical configuration with four unequal DC sources is operated to produce 31-level output using control techniques such as Equal Phase Angle and Genetic Algorithm. In Equal Phase Angle technique the switching angles are considered to be spaced at equal intervals to obtain the output voltage. Where as in Genetic Algorithm technique, the SHE non linear equations are solved using MATLAB code to obtain optimum values of the switching angles. The circuit for both the techniques are simulated with MATLAB/ Simulink software & the results obtained are analyzed and presented.

KEYWORDS: Multilevel Inverter (MLI), Cascaded H-Bridge (CHB), Equal Phase Angle Technique, Genetic Algorithm (GA), Selective Harmonic Elimination (SHE), Total Harmonic Distortion (THD).

I. INTRODUCTION

With Multilevel Inverter (MLI) is broadly used in high & medium power applications. Different types of MLI are present like: Flying Capacitor Inverter (FC) [1], Neutral Point Clamped Inverter (NPC) [2] & Cascaded H-Bridge Inverter (CHB) [3]. NPC topology makes use of large number of diodes to give different voltage levels to the series connected capacitor banks making it unsuitable. FC topology uses capacitors to transfer the voltage to the electrical devices but suffers from voltage imbalance[4]. In CHB topology, several H-Bridges are connected in cascaded manner & each H-Bridge consists of a separate DC voltage source. Among these topologies, CHB is preferred due to its simple structure, easy expandability to higher voltage levels, modularity, reliability & interfacing capability with renewable energy resources[5].

Depending upon the input DC voltage sources, the CHB MLI has two types: Symmetrical CHB inverter in which all input voltage sources will have same magnitude and Asymmetrical CHB inverter in which the input DC voltages have unequal magnitude. Among these types the Asymmetrical CHB MLI is advantageous as it uses less number of power devices for producing higher level output voltage waveform[6]. Due to this reason, the switching losses are also reduced significantly.

Lot of work has been carried out in the literature on 15-level Asymmetrical CHB MLI consisting of three H-bridges and three input DC voltages sources having the ratio 1:2:4 [7]. Additional H-bridge can be added to this circuit in order to produce higher level output voltage waveform. The output is said to approach sinusoidal waveform with the rise in

number of levels in the output waveform. In this paper, a 31-level Asymmetrical CHB MLI having four H-bridges and four input DC voltage sources with ratio 1:2:4:8 is considered.
The stepped output from a MLI can be obtained using Equal Phase Angle technique where the thickness of every step is considered equal and the corresponding switching angles are obtained. These stepped outputs contain fundamental & other multiples frequency components which results in significant THD. This THD can be minimized using different modulation techniques. The most popular Pulse Width Modulation (PWM) techniques [8] are Sinusoidal PWM technique, Space Vector PWM technique & Selective Harmonic Elimination PWM technique. Here SHE-PWM technique is incorporated to reduce specific lower order harmonics in the output voltage. Finding solution to different non-linear equations in SHE technique is quite complex. Therefore intelligent methods such as Particle Swarm Optimization technique(PSO)[9], Genetic Algorithm technique(GA)[10], Ant Colony Optimization technique(ACO)[11] etc can be adopted. Among these Genetic Algorithm technique is efficient and most commonly used procedure to eliminate specific order harmonics & to minimize THD[12].

In this paper, a 31-level Asymmetrical CHB-MLI is considered & a comparative study on the performance of the same has been made for different control techniques namely Equal Phase Angle & Genetic Algorithm. The simulation results obtained from both these techniques are studied and conclusions are drawn.

II.PRINCIPLE OF OPERATION OF PROPOSED CIRCUIT

In a symmetrical CHB MLI, if 'N' is the number of H-bridges that are connected, it produces upto 'M' levels in the output voltage related by the equation given as

$$M=2N+1$$

A symmetrical CHB MLI uses 15 H-bridges to generate 31-level output voltage waveform as shown in Figure 1. Thus in this paper, an Asymmetrical CHB MLI making use of 4 H-bridges is considered to generate 31-level output voltage waveform. The values of input voltage DC sources are in ratio V1:V2:V2:V3=1:2:4:8. Hence we can obtain the following relation for Asymmetrical CHB MLI

$$M=(2Nx2)-1$$

Where, M = number of levels in output voltage waveform & N = number of H-bridges in the circuit.
Table 1 shows the switching states to generate 31-level output voltage.

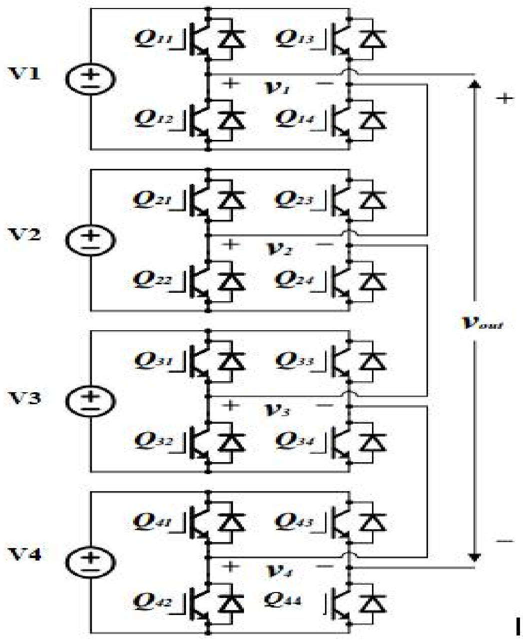

Figure 1. Circuit for 31-level asymmetrical CHB inverter with DC voltage sources in ratio 1:2:4:8

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Table 1. Switching table designed for 31-level asymmetrical CHB inverter for source ratio 1:2:4:8

Level	Q_{11}	Q_{12}	Q_{13}	Q_{14}	Q_{21}	Q_{22}	Q_{23}	Q_{24}	Q_{31}	Q_{32}	Q_{33}	Q_{34}	Q_{41}	Q_{42}	Q_{43}	Q_{44}
15	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1
14	1	0	0	0	1	0	0	1	1	0	0	1	1	0	0	1
13	1	0	0	1	1	0	0	0	1	0	0	1	1	0	0	1
12	1	0	0	0	1	0	0	0	1	0	0	1	1	0	0	1
11	1	0	0	1	1	0	0	1	1	0	0	0	1	0	0	1
10	1	0	0	0	1	0	0	1	1	0	0	0	1	0	0	1
9	1	0	0	1	1	0	0	0	1	0	0	0	1	0	0	1
8	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1
7	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	0
6	1	0	0	0	1	0	0	1	1	0	0	1	1	0	0	0
5	1	0	0	1	1	0	0	0	1	0	0	1	1	0	0	0
4	1	0	0	0	1	0	0	0	1	0	0	1	1	0	0	0
3	1	0	0	1	1	0	0	1	1	0	0	0	1	0	0	0
2	1	0	0	0	1	0	0	1	1	0	0	0	1	0	0	0
1	1	0	0	1	1	0	0	0	1	0	0	0	1	0	0	0
0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0
-1	0	1	1	0	0	1	0	0	0	1	0	0	0	0	1	0
-2	0	1	0	0	0	1	1	0	0	1	0	0	0	0	1	0
-3	0	1	1	0	0	1	1	0	0	1	0	0	0	0	1	0
-4	0	1	0	0	0	1	0	0	0	1	1	0	0	0	1	0
-5	0	1	1	0	0	1	0	0	0	1	1	0	0	0	1	0
-6	0	1	0	0	0	1	1	0	0	1	1	0	0	0	1	0
-7	0	1	1	0	0	1	1	0	0	1	1	0	0	0	1	0
-8	0	1	0	0	0	1	0	0	0	1	0	0	0	1	1	0
-9	0	1	1	0	0	1	0	0	0	1	0	0	0	1	1	0
-10	0	1	0	0	0	1	1	0	0	1	0	0	0	1	1	0

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-11	0	1	1	0	0	1	1	0	0	1	0	0	0	1	1	0
-12	0	1	0	0	0	1	0	0	0	1	1	0	0	1	1	0
-13	0	1	1	0	0	1	0	0	0	1	1	0	0	1	1	0
-14	0	1	0	0	0	1	1	0	0	1	1	0	0	1	1	0
-15	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0

III.CONTROL TECHNIQUES FOR MULTILEVEL INVERTER

3.1. Equal Phase Angle Technique

In this technique, the switching angles are equally spaced. Hence, for a particular inverter level required, the width of every level in the output waveform is considered equal.
Let θ_1, θ_2…….θ_{15}be the switching angles. For 31-level inverter, the conduction period of each level is equal i.e

$$\Delta\ \theta=180^\circ / 31=5.79^\circ$$

Therefore the switching angles are:
$\theta_1=5.79^\circ$; $\theta_2=\theta_1+5.79^\circ=11.592^\circ$; $\theta_3=\theta_2+5.79^\circ=17.388$ $\theta_4=\theta_3+5.79^\circ=23.184^\circ$; $\theta_5=28.98^\circ$; $\theta_6=34.77^\circ$; $\theta_7=40.572^\circ$; $\theta_8=46.368$; $\theta_9=52.164^\circ$; $\theta_{10}=57.96^\circ$; $\theta_{11}=63.756^\circ$; $\theta_{12}=69.552^\circ$; $\theta_{13}=75.348^\circ$; $\theta_{14}=81.144^\circ$; $\theta_{15}=86.94^\circ$.

3.2. Genetic Algorithm (GA) Technique

This isa soft computingtechnique which applies biological evolution in the optimization process. This method is straightforward & trouble-free because it doesn't involve any mathematical modeling and initial guess. Hence, this technique can be readily used to evaluate the non-linear equations.Here the purpose of using GA is to find the optimum switching angles such that the objective function value gets minimized so that the THD is reduced. The procedure to apply Genetic Algorithm for optimization is as follows:

1) Initialization of the population: Algorithm is initialized with a population size which gives the number of general solutions(chromosomes). Every switching angle is a Gene.
   Here the population size is chosen to be 20 and 15 genes are the switching angles θ1,θ2, θ3,….. θ15 for a 31-level CHB MLI. Initial population is chosen arbitrarily to comply with the constraint which says that the angles have to be in ascending order between 0° to 90°.
2) Evaluation of fitness function: Objective function is associated with a fitness value which gives the measure of the quality of answer. Here objective function is the THD, which is to be minimized for getting better quality of output.
3) Selection: Parents are chosen by the selection rules to generate offspring that produce the next generation. The individuals that are fittest survive and the rest get eliminated.
4) Crossover & Mutation: Genes are interchanged during crossover to reproduce superior offspring. Mutation is a operator in which the changes take place within the same gene. This broadens the search space & avoids the algorithm to fall into local minimum.
5) Stop Criterion: Is the condition in which the algorithm terminates. The algorithm is set to 250 iteration as the stop criterion.

Selective Harmonic Elimination(SHE) method is used to eliminate the selected order harmonics to minimize the size of the filter used in the output and reduces the THD of the output voltage. The equations obtained in SHE method is highly nonlinear in nature hence solving these become complex. Therefore different evolutionary algorithms are present such as: Particle Swarm Optimization technique, Genetic Algorithm technique, Ant Colony Optimization

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technique etc to find the optimum solution for the equations . In this paper, Genetic Algorithm technique is incorporated for solving the SHEPWM nonlinear equations.
SHE method is illustrated bellow:
The Fourier series expansion of the staircase voltage waveform of multilevel inverter is given as,

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

Due to quarter symmetry of the waveform, the even harmonics are canceled (bn=0) and only odd harmonics are considered. The value of an is computed from Fourier series factor & only the first quadrant switching angles, α_1, α_2, …, α_m, is expressed due to symmetry as:

$$a_n = (4V_{dc}/n\pi)\sum_{k=1}^{m}\cos(n\alpha_k)\ldots\ldots\ldots\ldots (2)$$

$$0<\alpha_1<\alpha_2<\alpha_3<\ldots\ldots\alpha_m<\frac{\pi}{2}\ldots\ldots\ldots\ldots (3)$$

For any harmonics, (2) is expressed up to k^{th} term, where 'm' is the number of variables corresponding to switching angles α_1 to α_m of the first quadrant satisfying equation (3). In selective harmonic elimination, M is designated as desired value for fundamental component & the other harmonics to be removed are equated to zero as shown in equation (4),(5),(6)

$$a_1 = (4V_{dc}/\pi)\sum_{k=1}^{m}\cos(\alpha_k) = M\ldots\ldots\ldots\ldots (4)$$

$$a_5 = (4V_{dc}/5\pi)\sum_{k=1}^{m}\cos(5\alpha_k) = 0\ldots\ldots\ldots\ldots (5)$$

$$a_n = (4V_{dc}/n\pi)\sum_{k=1}^{m}\cos(n\alpha_k) = 0\ldots\ldots\ldots\ldots (6)$$

By solving the above equations using GA MATLAB code, we obtain the optimum switching angles for fixed population size and number of iterations as shown below.

Switching Angles		Switching Angles		Switching Angles	
θ_1	2.96°	θ_6	22.23°	θ_{11}	47.60°
θ_2	7.26°	θ_7	27.58°	θ_{12}	55.64°
θ_3	14.87°	θ_8	39.38°	θ_{13}	61.27°
θ_4	16.99°	θ_9	45.57°	θ_{14}	61.79°
θ_5	19.27°	θ_{10}	47.21°	θ_{15}	84.78°

IV.SIMULATION OF PROPOSED CIRCUIT & DICUSSION OF RESULTS

The circuit for 31-level Asymmetrical CHBMultilevel Inverter is developedin MATLAB/Simulink software and simulation studies are conducted using both the techniques.

The output voltage of inverter is fixed as V_{orms}=230V
Thus, the peak voltage is calculated $V_m = \sqrt{2} * V_{orms} = \sqrt{2} * 230 = 324V$

Now to generate 31-level voltage output, 15 steps are required in each half cycle.
Thus, each step will have voltage magnitude as $V_m/15 = 324/15 = 21.6V$

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The DC voltage sources are in ratio 1:2:4:8 to generate 31-levels, having magnitudes:

V_1	V_2	V_3	V_4	$V_m = V_1+V_2+V_3+V_4$
21.6V	43.2V	86.4V	172.8V	324V

Figure 2 shows the MATLAB/Simulink circuit for Asymmetrical CHB 31-level inverter in which four H-bridges and 16 switching devices (MOSFETs) are used.The pulses are given to switches by connecting pulse generator to the gate terminal of each switch.

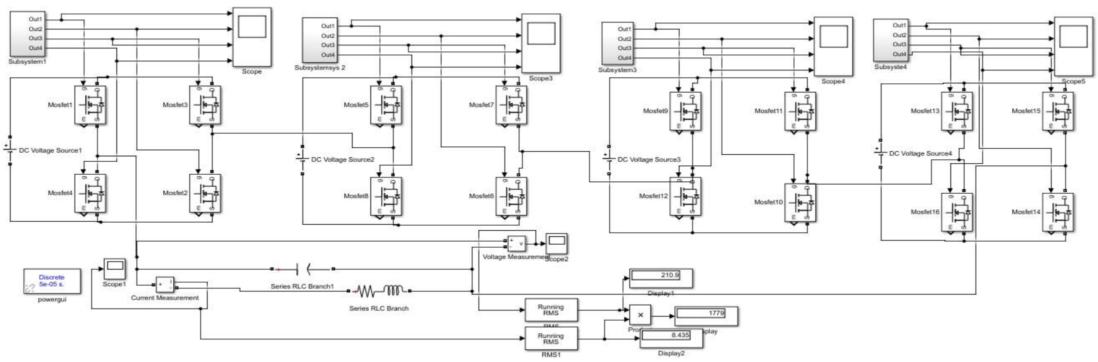
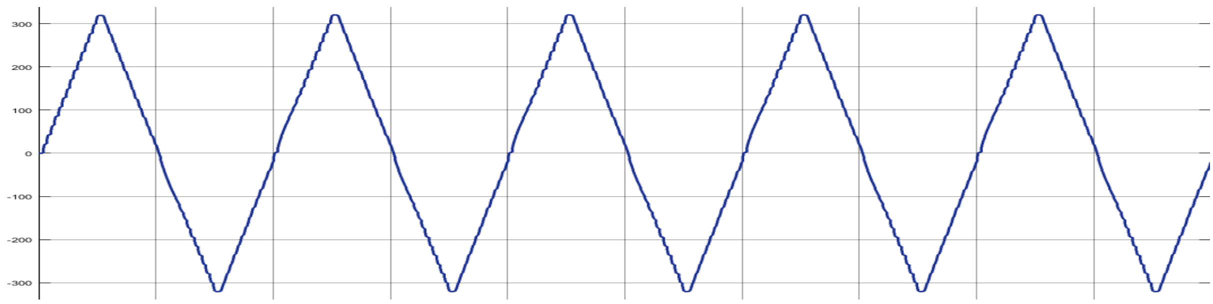


Figure 2. MATLAB Simulink circuit for 31-level Asymmetrical CHB inverter

Figure 3 & Figure 4 gives the output voltage waveform and its FFT analysis for load R=25Ω, L=100mH using Equal Angle and GA technique respectively.nThe simulated results obtained by FFT analysis of output voltage waveform for load R=25Ω & inductance varying from 20mH to 100mH is tabulated in Table 2 & Table 3 using Equal phase angle technique and GA respectively. By using Genetic Algorithm technique,particular lower order harmonics can be eliminated. In table 3 we can observe that the 5th harmonic has been eliminated thereby reducing the overall %THD. Alsousing GA the 3rd harmonic is minimizedbecause optimum switching angles are obtained.

Figure 5 shows variation of THD for various loads using Equal Phase Angle and GA techniques respectively. It is observed thatthe lowest %THD is obtained for R=25 Ω & L=100mH is 11.38% for Equal Phase Angle technique, where as for GA is 5.13%. From the figures it is seen that the %THD reduces, with decrease in resistance and with increase in the inductance varying from 20mH to 100mH.



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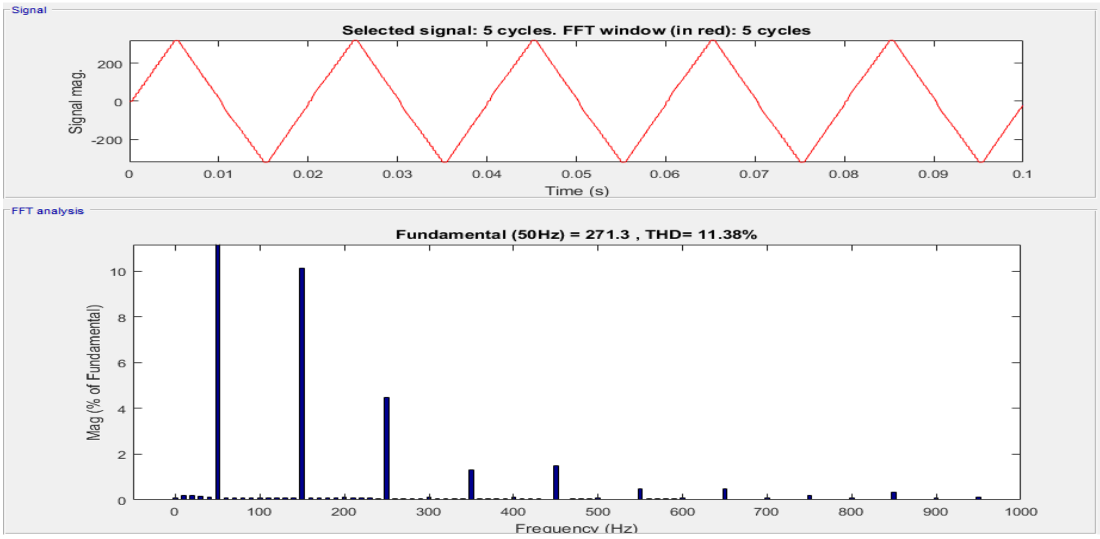

Figure 3.Output voltage waveform and FFT analysis with R=25 Ω, L=100mH using Equal angle criteria

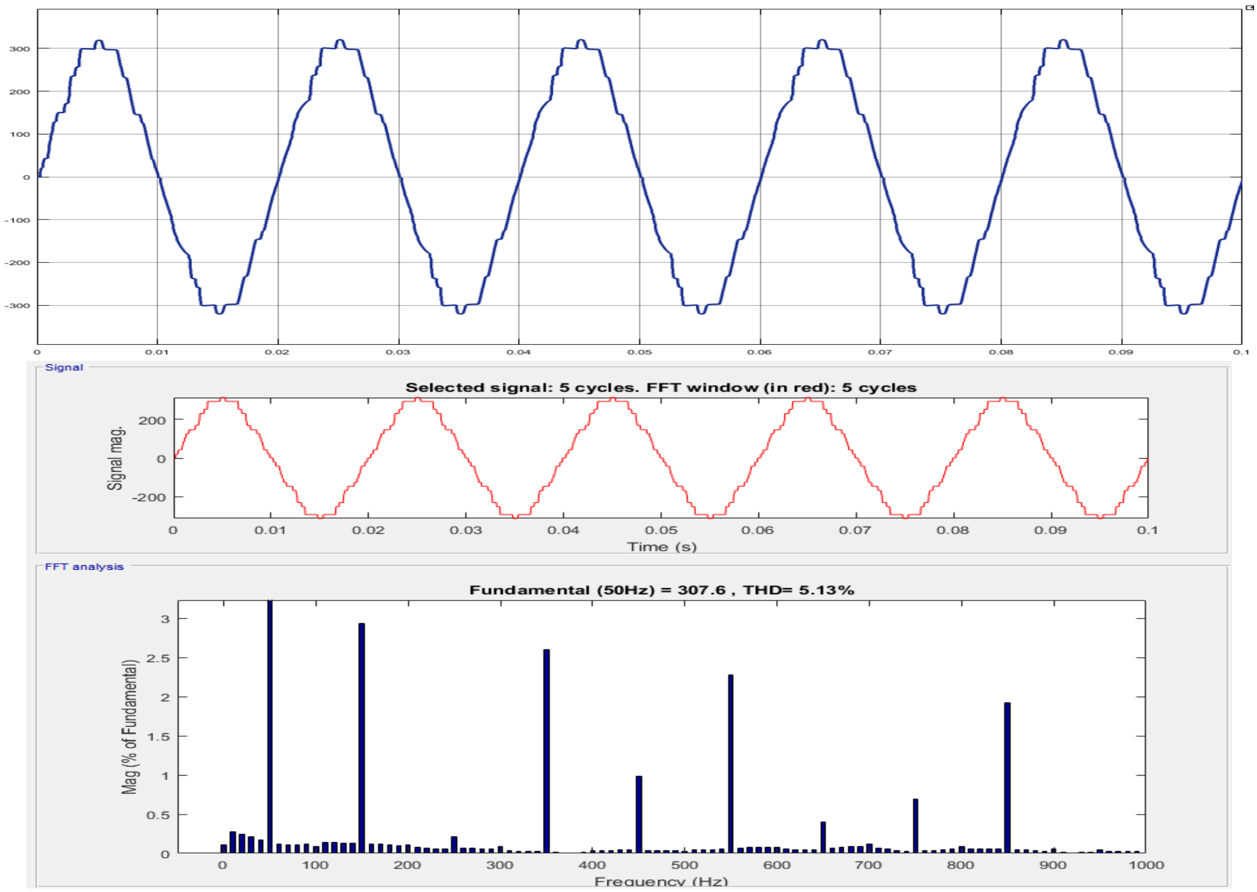

Figure 4.Output voltage waveform and FFT analysis with R=25 Ω, L=100mH using GA

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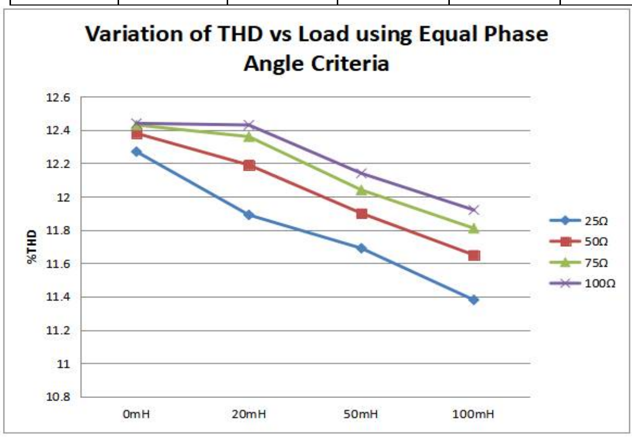
Table 2. Results for various parameters obtained for 31-level CHB-MLI using Equal Phase Angle technique

R in Ω	L in mH	C in μF	Vo rmsVolts	Io rms Amps	Po rms Watt	THD in %	Harmonics			
							3rd	5th	7th	9th
25	0	0	187.7	7.5	1408	12.27	10.9	3.7	1.8	1.3
25	20	30	188.4	7.3	1375	11.89	10.7	4	1.6	1.5
25	50	57	190.2	6.4	1217	11.69	10.5	4.3	1.4	1.6
25	100	62	193	4.8	926	11.38	10.1	4.5	1.3	1.5

Table 3. Results for various parameters obtained for 31-level CHB-MLI using GA technique

R in Ω	L in mH	C in μF	Vo rmsVolts	Io rms Amps	Po rms Watt	THD in %	Harmonics			
							3rd	5th	7th	9th
25	0	0	210.8	8.43	1779	6.96	4.76	0.13	2.31	2.13
25	20	30	211.8	8.19	1737	6.68	4.38	0.07	2.70	1.73
25	50	57	214.0	7.24	1551	6.22	3.93	0.22	2.90	1.24
25	100	62	217.7	5.47	1192	5.13	2.94	0.22	2.60	0.99



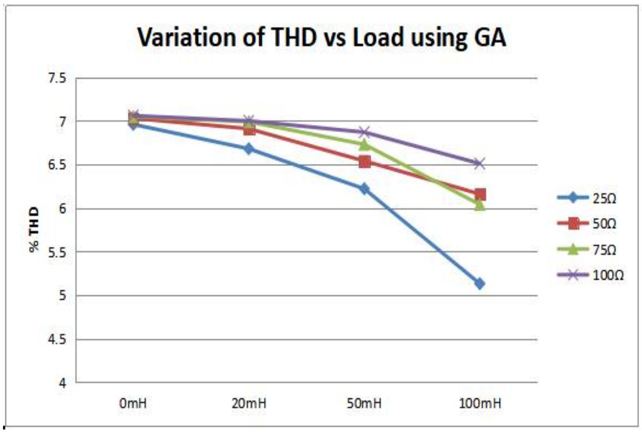


Figure 5.Variation of THD Vs RLC-Load using Equal Phase Angle criteria & GA respectively

V.CONCLUSION

In this paper a comparative study on performance of 31-level Asymmetrical CHB MLI using Equal Phase Angle Technique and Genetic Algorithm technique is carried out. The simulation for both the techniques is done using MATLAB/ Simulink and the results obtained are presented.

From the obtained results it is clear that the 4 H-bridge Asymmetrical Inverter considered is able to generate 31-level in the output. This topology uses only 16 switches compared to 60 switches in the Symmetrical configuration. The simulation results shows that the THD obtained for load R=25 Ω & L=100mH the THD obtained is 11.38% for Equal Phase Angle technique, where as for GA is 5.13%. Hence it can be concluded that GA is able to generate output voltage waveform having the THD values within the standards defined.

Further studies can be conducted by incorporating other optimization switching technique such as Artificial Neural Network, Particle Swarm Optimization for better results.

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