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Analysis of modular multilevel inverter topology with different modulation techniques

Chethan Kumar T[1] | Mamatha N[2] | Dr.Ramesh H R[3]

[1]M Tech Student, Department of Electrical Engineering, University Visvesvaraya College of Engineering, Bengaluru.

[2]Research scholar Department of Electrical Engineering , University Visvesvaraya College of Engineering, Bengaluru. [3]Professor, Department of Electrical Engineering, University Visvesvaraya College of Engineering Bengaluru.

ABSTRACT

Multilevel inverter plays an important role in the field of modern power electronics and is widely being used for many medium voltage and high power industrial and commercial applications. It has many advantages compared to conventional two level inverter such as high dc link voltages, reduced harmonic distortion, fewer voltage stresses, and low electromagnetic interferences (EMI). For higher voltage level it has some major disadvantages such as the use of higher number of voltage sources and power switches, voltage balancing issues and complex pulse width modulation control. In this paper seventeen level multilevel inverter with different Pulse width modulation(PWM) techniques are implemented and analysis of total harmonic distortion(THD) is carried out. proposed circuit topology which requires only nine switches and four dc sources. Design, simulation and comparison of different switching techniques like equal phase method, feed forward method, half equal angle method and half height method are carried out in MATLAB/Simulink environment.

KEYWORDS: multi level inverter**,** equal phase angle modulation technique ,half height modulation technique ,feed forward method ,half equal angle method, PWM, THD.

INTRODUCTION:

The word “inverter” comes under the class of power electronic conversion devices which operates under the DC input and converts it into an AC output. The multilevel inverters (MLI) are been the alternative for medium and high power applications. Due to the huge demand and wide utilization of multilevel inverters in industrial applications, renewable energy systems, machine drive systems, HVDC and FACTS drives etc, the power electronic researchers have made efforts in developing the multilevel inverters by altering their structures and topology, in terms of reducing their number of components and decreasing the value of THD, resulting in the decrease in size and reduction in losses. There are mainly three basic topologies that comes under multilevel inverters listed as

1. Neutral Point Clamped (NPC) MLI

2. Flying Capacitor (FC) MLI

3. Cascaded H Bridge (CHB) MLI

3a. Symmetric source configuration CHB MLI

3b. Asymmetric source configuration CHB MLI

Due to the requirement of large number of clamping diodes in Neutral Point Clamped (NPC) MLI topology and the requirement of huge number of capacitors in Flying Capacitor (FC) MLI and unbalanced DC links limits their application for higher number of voltage levels. Voltage balancing has become the main drawback for both Neutral Point Clamped (NPC) and Flying Capacitor

(FC) MLI topologies. The third basic topology is the cascaded H-bridge (CHB) multilevel inverter which is further separated as asymmetric source configuration CHB MLI (employing same magnitude of DC sources) and asymmetric source configuration (employing different magnitude of DC sources). The requirement of same magnitude of DC voltage sources increases with the increase in the level of output voltage, which was observed to be the major disadvantage of the symmetric source configuration hence the reduction in number of sources and switching components is the main target in the design of asymmetric source configuration CHB MLI employing different magnitude of DC sources.

Researchers have been looking for various topologies to remove these demerits[5-7]. The proposed topology consists of nine switches one bidirectional switch and eight unidirectional switch four dc sources with the ratio 1Vdc:1Vdc:3Vdc:3Vdc. The PWM is given to the gate terminal of the switch different PWM like equal angle method, half equal angle method, feed forward method and half height method. The circuit is simulated in matlab/SIMULINK environment and total harmonic distortion(THD) is analyzed

PROPOSED CIRCUIT:

In figure 1 shows single phase multilevel inverter which consists of nine switches, eight unidirectional switches ,one bidirectional switch and four dc sources with the ratio of 1Vdc:1Vdc:3Vdc:3Vdc.

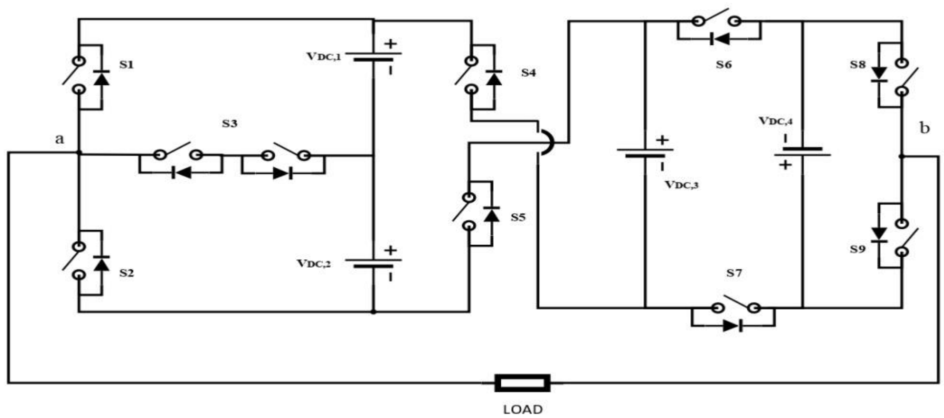


Figure 1: seventeen level multilevel inverter.

SWITCHING TABLE:

Voltage levels	S1	S2	S3	S4	S5	S6	S7	S8	S9
$+8V_{dc}$	1	0	0	0	1	0	1	1	0
$+7V_{dc}$	0	0	1	0	1	0	1	1	0
$+6V_{dc}$	0	1	0	0	1	0	1	1	0
$+5V_{dc}$	1	0	0	0	1	0	1	0	1
$+4V_{dc}$	0	0	1	0	1	0	1	0	1
$+3V_{dc}$	0	1	0	0	1	0	1	0	1
$+2V_{dc}$	1	0	0	0	1	1	0	1	0
$+V_{dc}$	0	0	1	0	1	1	0	1	0
0	1	0	0	1	0	0	1	0	1
$-V_{dc}$	0	0	1	1	0	0	1	0	1
$-2V_{dc}$	0	1	0	1	0	0	1	0	1
$-3V_{dc}$	1	0	0	1	0	1	0	1	0
$-4V_{dc}$	0	0	1	1	0	1	0	1	0
$-5V_{dc}$	0	1	0	1	0	1	0	1	0
$-6V_{dc}$	1	0	0	1	0	1	0	0	1
$-7V_{dc}$	0	0	1	1	0	1	0	0	1
$-8V_{dc}$	0	1	0	1	0	1	0	0	1

Table 1: switching table of seventeen level MLI

SWITCHING SCHEME:

1)Feed Forward method

- For 1ST quadrant i.e. 0 to 90^o

  $\theta_1, \theta_2, \theta_3, \theta_4\ \theta_5\ \theta_6\ \theta_7\ \theta_8 \ldots\ldots\ldots\ldots \theta_k$……………………………………..…….(1)

  Where

  θ = switching angle

  k = (n-1)/2

  n = number of levels

- For the 2nd quadrant i.e. from 90^o to 180^o

  $180-\theta_1\ 180-\theta_2\ 180-\theta_3\ 180-\theta_4 \ldots\ldots\ldots\ldots\ 180-\theta_k$ ……………………….....(2)

- For the 3rd quadrant i.e. from 180^o to 270^o

  $180+\theta_1,\ 180+\theta_2,\ 180+\theta_3,\ 180+\theta_4 \ldots\ldots\ldots\ldots\ 180+\theta_k$ …………..(3)

- For the 3rd quadrant, i.e. from 180^o to 270^o

  $360-\theta_1, 360-\theta_2, 360-\theta_3, 360-\theta_4 \ldots\ldots\ldots\ldots\ 360-\theta_k$ ……….(4)

The output obtained from this method results the more width in the highest level, which also widens the output waveform compared to other methods.

$$\theta j = \frac{\sin^{-1}(2j-1)}{2*(n-1)} \ldots\ldots(5)$$

j = 1, 2, 3, 4, 5….(n-1)/2

2) **Equal Angle method**

The output waveform generated using this method resembles a triangular wave shape as the angles are estimated and arranged with equal space from 0 to 180^o.In the following switching angle calculation method, quarter cycle will be considered for which the angles will be calculated as shown below for 0 to 90^o

$\theta_1, \theta_2, \theta_3, \theta_4\ \theta_5\ \theta_6\ \theta_7\ \theta_8 \ldots\ldots\ldots\ \theta_k$………………………………………...(6)

Where

θ = switching angle (in degree)

k = (n-1)/2

n = number of levels

For the 2nd quadrant i.e. from 90^o to 180^o

$180-\theta_1\ 180-\theta_2\ 180-\theta_3\ 180-\theta_4 \ldots\ldots\ldots\ 180-\theta_k$ …………………………..(7)

For the 3rd quadrant, i.e. from 180^o to 270^o

$180+\theta_1, 180+\theta_2, 180+\theta_3, 180+\theta_4 \ldots\ldots 180+\theta_k$ ……………….………(8)

For the 4rd quadrant, i.e. from 180^o to 270^o

$360-\theta_1, 360-\theta_2, 360-\theta_3, 360-\theta_4 \ldots\ldots\ldots\ 360-\theta_k$ ……………………….…(9)

The output waveform generated using this method is rather peaky as the pulse width remains the same throughout the cycle

$$\theta j = \frac{180*j}{n} \ldots\ldots(10)$$

j = 1, 2, 3, 4, 5…. (n-1)/2

3) Half Equal Angle method

The waveform obtained from EP method looks like a triangular waveform, so to get some better output waveform HEP method is used. In the following switching angle calculation method, quarter cycle will be considered for which the angles will be calculated as shown below for 0 to 90^o

$\theta_1, \theta_2, \theta_3, \theta_4\ \theta_5\ \theta_6\ \theta_7\ \theta_8 \ldots\ldots\ldots\ \theta_k$……………………………………………..(11)

Where

θ = switching angle

k = (n-1)/2

n = number of levels

For the 2nd quadrant i.e. from 90^o to 180^o

$180-\theta_1$ $180-\theta_2$ $180-\theta_3$ $180-\theta_4$............ $180-\theta_k$ ………………………………..(12)

For the 3rd quadrant, i.e. from 180^o to 270^o

$180+\theta_1$, $180+\theta_2$, $180+\theta_3$, $180+\theta_4$............ $180+\theta_k$ ………………………..…(13)

For the 3rd quadrant, i.e. from 180^o to 270^o

$360-\theta_1$, $360-\theta_2$, $360-\theta_3$, $360-\theta_4$............ $360-\theta_k$ …………………………(14)

This method is quite similar to Equal phase but the little variation in the pulse width which changes the shape of the output waveform.

$\theta j = \frac{180*j}{(n+1)}$……………………………………………………………………(15)

j = 1, 2, 3, 4, 5…. (n-1)/2

4) Half Height method

The half-height (HH) method offers the lowest total harmonic distortion. HH calculates the switching angle when the reference sine wave becomes equal to the half-height of the source. The ith switching angle θi can be obtained for balance voltage source as

First quarter cycle will be considered for which the angles will be calculated as shown below for 0 to 90^o

$\theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6, \theta_7, \theta_8$............$\theta_k$………………………………………………….(16)

Where

θ = switching angle

k = (n-1)/2

n = number of output levels

For 2nd quadrant i.e. from 90^o to 180^o

$180-\theta_1$, $180-\theta_2$, $180-\theta_3$, $180-\theta_4$............ $180-\theta_k$ ………………………………..(17)

For 3rd quadrant i.e. from 180^o to 270^o

$180+\theta_1$, $180+\theta_2$, $180+\theta_3$, $180+\theta_4$............ $180+\theta_k$ ………………………………(18)

For 3rd quadrant i.e. from 180^o to 270^o

$360-\theta_1$, $360-\theta_2$, $360-\theta_3$, $360-\theta_4$............ $360-\theta_k$ ………………………………..(19)

Basically reduced THD means that output waveform is nearly sinusoidal, the pulse width obtained from this method has different width and the area under the cycle is wide enough to resemble the sine waveform.

Formulae to calculate the angle is,

$$\theta j = \frac{\sin^{-1}(2j-1)}{(n-1)} \quad \text{......(20)}$$

Where

j = 1, 2, 3, 4, 5….(n-1)/2

SIMULATION RESULTS:

In order to prove the ability and the performance of the proposed 17 level asymmetrical multilevel inverter to generate 17 output voltage levels , the presented circuit with equal phase, feed forward, half equal angle, half height switching angle modulation technique is simulated through MATLAB Simulink software.

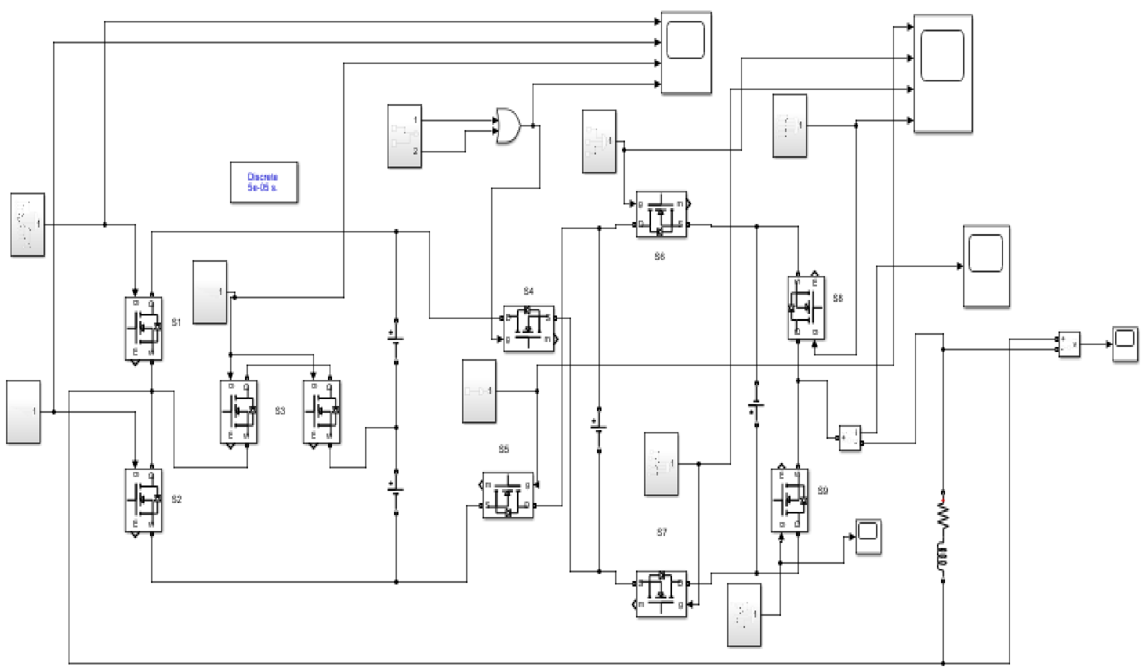
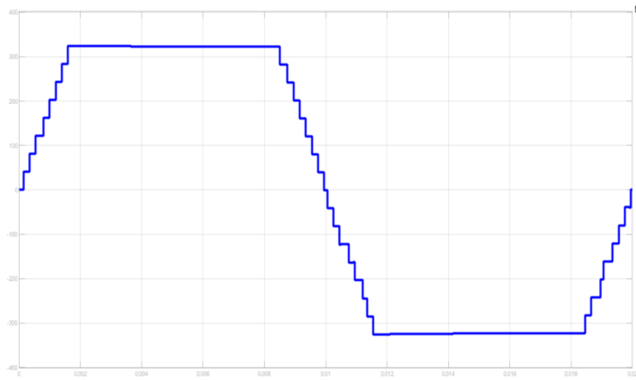


Figure 2: simulink model for seventeen level MLI

The magnitude of the DC links used in the simulation circuit are $40.625V_{dc}$, $40.625V_{dc}$, $121.875V_{dc}$, $121.875V_{dc}$ for which the inverter generates output voltage with maximum positive amplitude of +325V and with maximum negative amplitude of -325V. the each step of the output voltage is 40.625V the switches used are MOSFET with operate at the fundamental switching frequency of 50Hz.

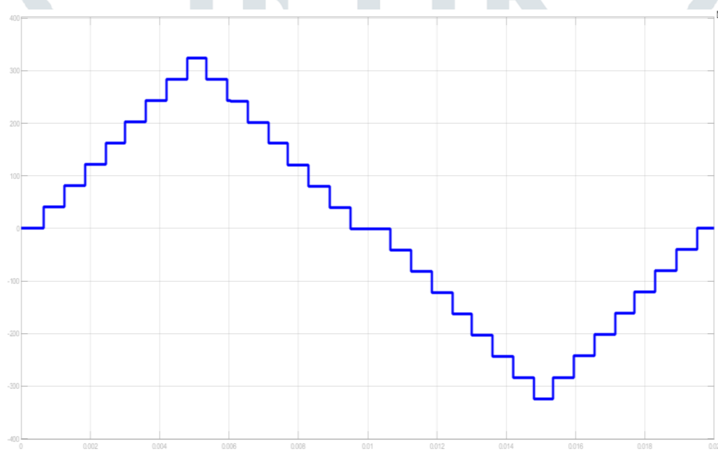
The 17 level output voltage waveform obtained for feed forward method (FF) is as shown in the figure :



Time in sec.

Figure 3: output voltage waveform of feed forward method(FF).

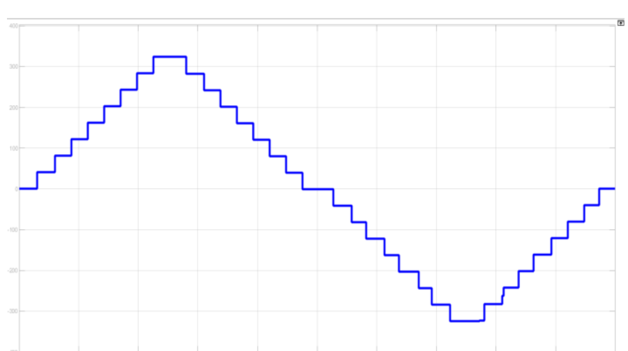
The 17 level output voltage waveform obtained for equal phase (EP) method is as shown in the figure :



Time in sec

Figure 4: output voltage waveform of equal phase method(EP)

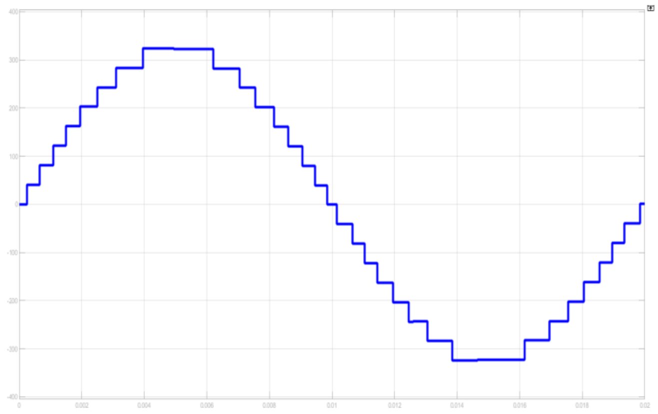
The 17 level output voltage waveform obtained for half equal angle (HEA) method is as shown in the figure :



Time in sec

Figure 5 : output voltage waveform of half equal angle method(HEA)

The 17 level output voltage waveform obtained for half height method (HH) method is as shown in the figure :



Time in sec

Figure 6: output voltage waveform of half height method(HH)

With the aid of fast fourier transform function(FFT) in MATLAB Simulink the total harmonic distortion(THD) for the output voltage waveform are computed.

Figure 7 shows the THD analysis of the output voltage feed forward method.

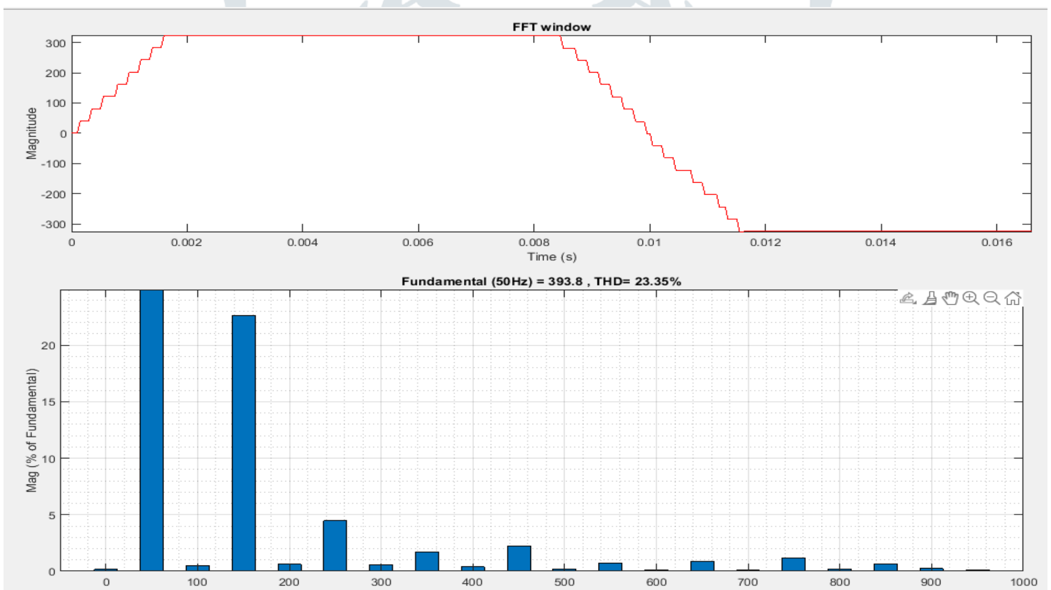


Figure 7 : output voltage harmonic spectrum of feed forward method.

Figure 8: shows the THD analysis of the output voltage equal phase method

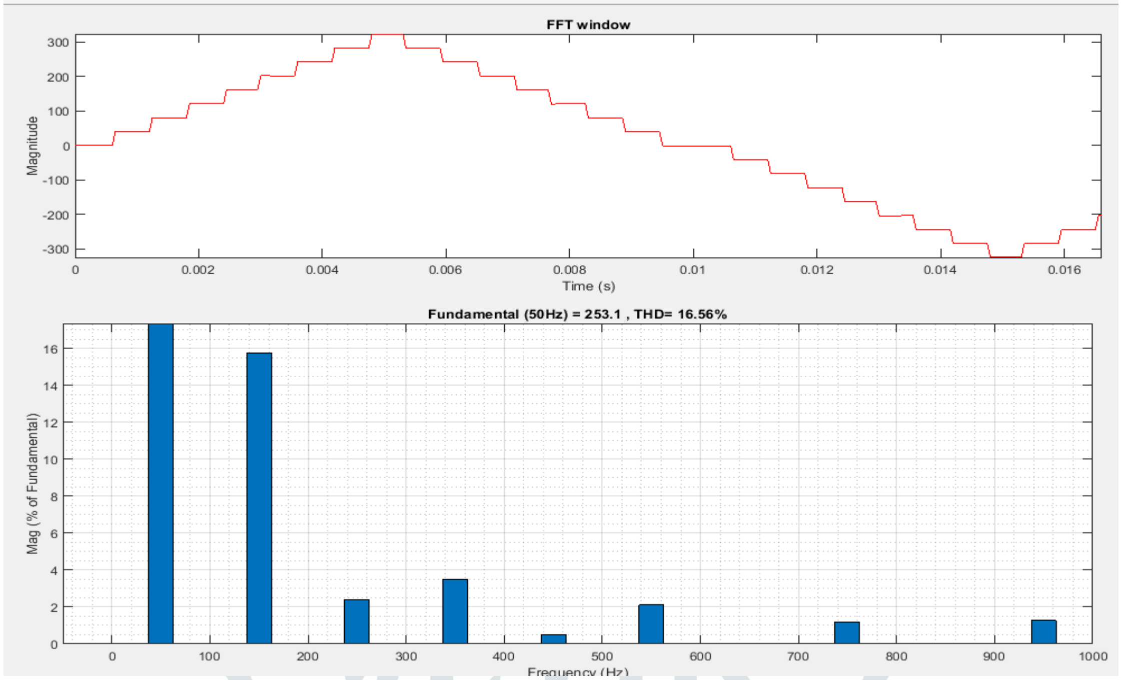


Figure 8: output voltage harmonic spectrum of equal phase method

Figure 9: shows the THD analysis of the output voltage half equal angle method.

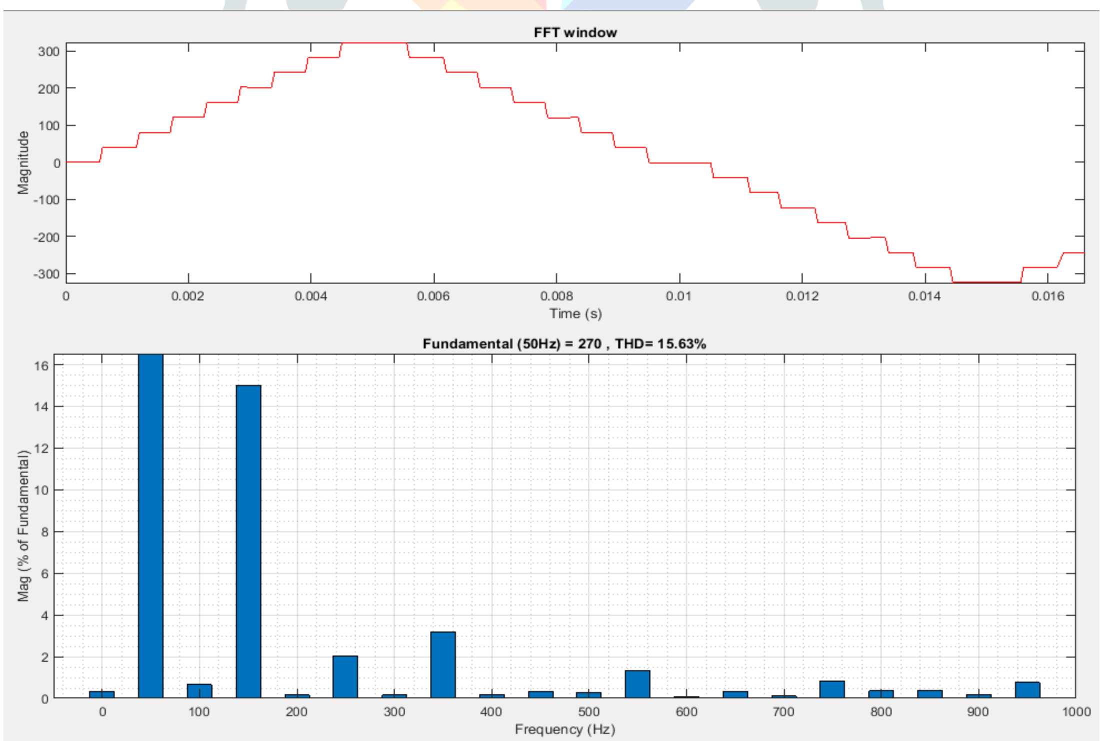


Figure 9: output voltage harmonic spectrum of half equal angle method

Figure 10: shows the THD analysis of the output voltage half height method(HH).

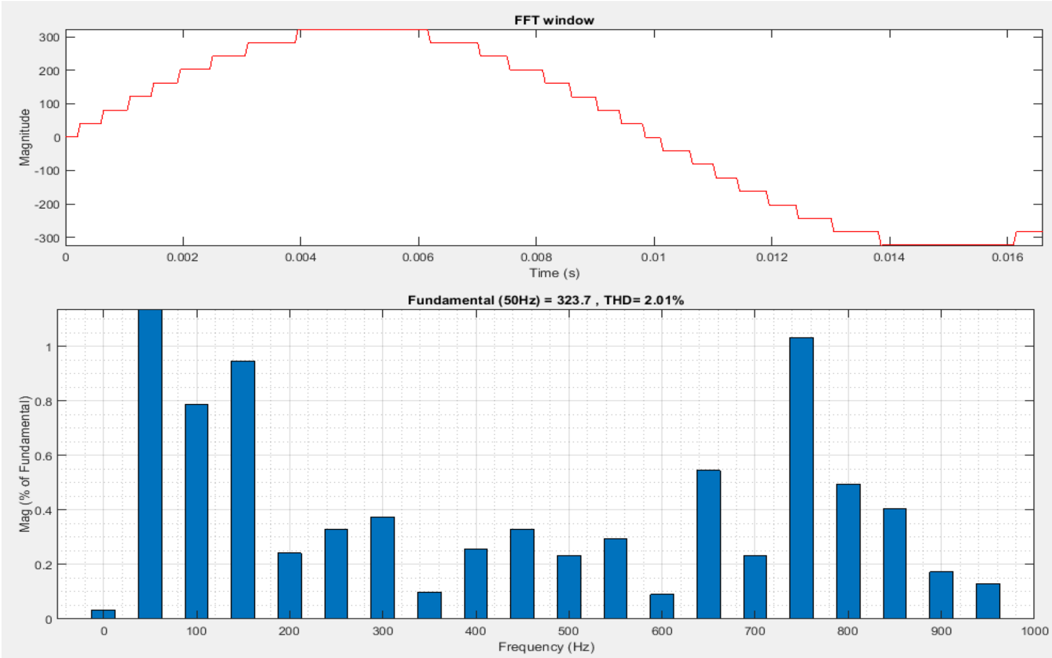


Figure 10: output voltage harmonic spectrum of half height method(HH)

The feed forward, equal phase, half equal angle, half height switching calculation techniques are distinguished in table 2.it can be summarized that the half height method offers very less value of THD when compared to other switching technique

TABLE 2. COMPARISON OF THD BASED ON SWITCHING MODULATION TECHNIQUES

Switching techniques	**Load voltage THD**
Feed forward method	23.65
Equal angle method	16.56
Half equal angle method	15.63
Half height method	2.01

CONCLUSION:

This paper presents an improved asymmetrical multilevel inverter topology . the proposed topology generates seventeen level output voltage levels by using four dc sources and nine switching devices. Eight switching devices are unidirectional and one switching device is bidirectional. The switching technique of feed forward , equal phase , half equal angle, half height method switching technique is analyzed in matlab/SIMULINK and total harmonic distortion(THD) is analyzed. Among four switching technique half height method switching technique offered 2.01% which is very low compared to other four techniques. Therefore the proposed seventeen level asymmetrical multilevel inverter topology with half height switching modulation technique is reasonable for medium and high voltage application.

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