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A Review And Harmonic Analysis Of Modified H-Bridge Multilevel Inverter Fed Indution Motor Drive

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Abstract

This paper presents Modified Version of Cascaded H–Bridge Multilevel Inverters as an application for high-power and/or high voltage electric motor drives. Multilevel inverters: 1) can generate near-sinusoidal voltages with only fundamental frequency switching; 2) have almost no electromagnetic interference or common-mode voltage; and 3) are suitable for large volt-ampere-rated motor drives and high voltages. In Multilevel inverters, Cascaded H bridge converters are considered as most preferred form of converters. But in these converters as the number of stair case levels in output voltage increases the dc source requirement also increases, thereby limiting its application. This paper tries to address the above problem by developing a Modified version of Cascaded H-Bridge Multilevel Converters which require less number of dc voltage source for increased levels in output voltage as compared to conventional cascaded converters. The simulation of Modified version of three phase fifteen level multilevel inverter fed induction motor drive is done by using MATLAB/SIMULINK.

Key Words: *Cascaded H-bridge inverter, conventional H-bridge inverter, Induction Motor, Modified cascaded H-bridge inverter, THD*

1. Introduction

The Multilevel converters are one of the recent developments in power electronics technology to meet the high power, good spectral quality voltage requirements of industries. Based on the topology multilevel converters are classified as

1) Diode clamped multilevel converter.
2) Flying capacitor multilevel converter and
3) Cascaded multilevel converter.

While each of these converters fulfills the basic requirements of a multilevel converter advantages, there are also some disadvantages associated with them. A diode clamped converter uses many clamping diodes with the increase in level in multilevel output voltage. The diode reverse voltage rating differs for each level and has to be calculated each time as the number of levels increases. In flying capacitor converters the number of storage capacitors required increases with increase in levels. Balancing the charging and discharging rates of the capacitor is also a problem. This problem is overcome in cascaded H-bridge multilevel inverters. Even in cascaded multilevel converters which require reduced number of electronic devices as compared to other two topologies there is a drawback of increased number of sources with increase in output voltage level.

But comparative study of all three topology suggest cascaded multilevel converter to be the most cost effective converter due to their simple structure and reduced number of components required for particular level of output voltage. Their problem of increased dc source can be solved to certain extent in a simple manner by implementing a modified form of cascaded multilevel converters as described in this paper. These converters can be used in many applications such as operating induction motor in place of cascaded multilevel converter with the added advantage of reduction in cost and space required for the converter implementation.

Power Electronics is playing an important role in the torque and speed control of motor drive. Variable speed AC induction motor drives are advantageous over the conventional DC Drives in industrial drive environment because even though DC motors have excellent speed and torque response, they have inherent disadvantage of commutator and mechanical brushes, which undergo wear and tear with time and must be replaced at regular intervals of time.AC induction machines are singly excited, mechanically rugged and robust, but speed and torque control of these machines are more complex and involved, compared to DC machines. Induction motors have low starting torque and motors carry large amplitude of starting currents, star delta starting or pole changing methods were followed.

The advent of controlled switches the speed and torque control of induction machines have become relative easier. A voltage source inverter can run the induction by applying three phase square wave voltages to the motor stator winding. A variable frequency square wave voltage can be applied to the motor by controlling the switching frequency of the power semi converter switches. The square wave voltage will induce low frequency harmonic torque pulsations in a machine. Also variable voltage control with variable frequencies of operation is not possible with square wave inverters. The recent advancement in power electronics has initiated to improve the level of inverter instead increasing the size of filter. The total harmonic distortion of the classical inverter is very high. The performance of the multilevel inverter is better than classical inverter and other classical inverter.

Power electronic devices contribute with an important part of harmonics, such as power rectifiers, thyristor converters and static var compensators. Even updated pulse-width modulation technique used to control modern static converters such as machine drives, power factor improvement, do not produce perfect waveforms, which strongly depend on the switching frequency of power electronic switches. Voltage or current converters, as they generate discrete output waveforms, force the use of machines with special isolation, and in some applications large inductances connected in series with a respective load. Also, it is well known that distorted voltages and current waveforms produce harmonic contamination, additional power losses, and high frequency noise that can affect not only power load but also associated controllers. All these unwanted operating characteristics associated with PWM converters, in addition to the fact that higher voltage levels can be achieved. This problem of switching losses can be overcome by adopting to multilevel converter which synthesize the output voltage by the use of different staircase levels and this synthesize wave is having less harmonics and these can be eliminated by the use of small filters.

2. Proposed Modified cascaded Converters

A modified H-Bridge converter reduces the number of dc sources for a particular level as compared to conventionally used cascaded H-Bridge converter (conventional converters). Modified cascaded H-Bridge converter is configured by cascading full bridge converters. A full bridge converter consists of four switches fed from a single dc source as shown in the Figure 1.

Switch 1 and switch 2 are triggered simultaneously at α, a voltage of +Vdc appears across the load and the load current is positive. When switches 3 and 4 are turned on at $\pi + \alpha$, a voltage of –Vdc appears across the load and the load current is negative. When all the switches are open, the output voltage is zero and the three level output 0, +Vdc, -Vdc thus obtained is as shown in Figure 2.

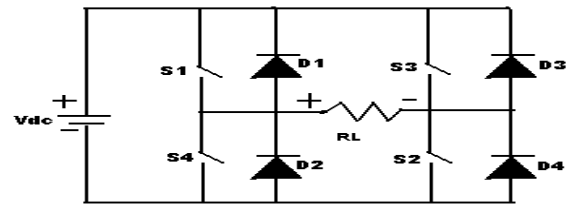
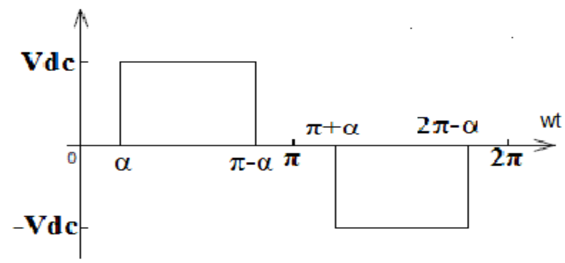


Figure1. Circuit diagram of a full bridge converter

Figure 2. Three level output voltage of single full bridge converter



A. Harmonic Analysis

The total harmonic distortion (THD) is a performance parameter which describes the quality of a waveform. It can be defined as [2] the measure of closeness in shape between the actual waveform and its fundamental component. An inverter output consists of fundamental wave which is used to do real work and its harmonics (multiple of fundamental waveform) which causes heat loss in a system. THD is mathematically defined as the ratio of total harmonic content to the fundamental content in a waveform.

$$THD = \frac{\{\sum_{n=2,3,4\ldots}^{\infty}(V_{on})\}^{\frac{1}{2}}}{V_{01}} \quad (1)$$

Where V_{on}= rms voltage of n^{th} order waveform

V_{01}= rms voltage of fundamental waveform

THD can also be defined as

$$THD = \sqrt{\left\{\left(\frac{V_0^{\frac{1}{2}}}{V_{01}^{\frac{1}{2}}}\right) - 1\right\}} \quad (2)$$

Where,

$$V_0 = \sqrt{\left\{\sum_{n=2,3,4\ldots}^{\infty} V_{on}^{\ 2}\right\}}$$

For an ideal inverter the THD is always zero. To find the THD, The wave form can be expressed in Fourier series as shown below

$$V_{out} = a_0 + \sum_{n=1}^{\infty}(a_n \cos n\omega t + b_n \sin n\omega t) \quad (3)$$

Where,

V_{out} =Fourier series expression of waveform

a_0, a_n, b_n are constants and are defined as

$$a_0 = \frac{2}{T}\int_0^T V_0\,(t).dt$$

$$a_n = \frac{2}{T}\int_0^T V_0\,(t)\cos n\omega t\,.dt$$

$$b_n = \frac{2}{T}\int_0^T V_0\,(t)\,\sin n\omega t\,.\,dt$$

Where,

$V_0(t)$ is the output waveform as a periodic function of time.

Since $a_{0,}a_n$ are zero due to half wave and quarter wave symmetry and contains only odd harmonics present .Hence the above expression can be simplified as follows

$$V_0 = \sum_{n=1,3,5,..}^{\infty} (b_n \sin n\omega t)$$

Where,

$$b_n = \sum_{n=1,3,5..}^{\infty} \frac{4V_{dc}}{n\pi}\cos n\alpha$$

Where,

V_{dc} is the input dc voltage , α is the firing angle

B. Principle of operation

In modified multilevel inverters, various levels of output voltage is obtained by the addition and subtraction of input dc voltage sources unlike in conventional H-Bridge inverters, where the various level of output voltage is obtained by the summation of input dc voltage sources. So the dc input sources requirement also increases as the number of levels increases and make the system impractable as the number of levels increases. This problem can be overcome by the use of modified multilevel inverters where minimum numbers of input dc sources are required for higher levels. Thus modified multilevel inverters start from 7-level.

Seven level Inverter

Consider seven level modified multilevel inverter as shown below, which contains two input dc sources unlike 7-level conventional H-Bridge which requires three input dc sources. Here the input dc voltages are in the ratio of 1:2.

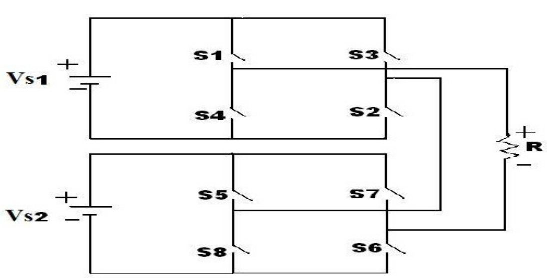


Figure3. Circuit diagram of modified seven level inverter

The input voltage source of first bridge is V and the input voltage source of second bridge is 2V. The output voltage across the resistor is represented as V_{out}. The switching table to generate seven level output is as shown in the following table

Table I
Switching pattern of seven level inverter

Modes	V_0	SWITCHES							
		S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8
1	**+3v**	**1**	**1**	**0**	**0**	**1**	**1**	**0**	**0**
2	**+2v**	**0**	**1**	**0**	**1**	**1**	**1**	**0**	**0**
3	**+1v**	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**1**
4	**0v**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

There are four modes of operation of seven level inverter

I. Mode1:

In this mode of operation switches S1, S2, S5 and S6 are switched on simultaneously. The output voltage in this mode of operation is as given below

$$V_{out} = V_{s1} + V_{s2} = 3V$$

II. Mode2:

In this mode of operation S2, S4, S5 and S6 are switched on simultaneously. The corresponding output voltage is as given below.

$$V_{out} = V_{s2} = 2V$$

III. Mode3:

In this mode of operation switches S1, S2, S6, S8 are switches on simultaneously. The corresponding output voltage is as given below

$$V_{out} = V_{s1} = V$$

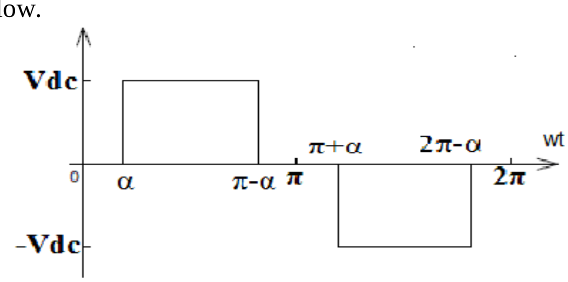
IV. Mode4:

In this mode of operation all switches are open so that the out voltage is zero.

C. Mathematical Analysis

Any Multilevel inverter wave form can be written as summation of three level inverter waveforms.

A typical waveform of the three level inverter is as shown below.



The above square wave form $f(t)$can be expressed in an electrical angular system as shown below

$$f(t) = V_{dc}\{u(\omega t-\alpha) - u(\omega t-\pi+\alpha)\, u(\omega t-\pi-\alpha) + u(\omega t-2\pi+\alpha)\} \quad (4)$$

To calculate the THD, the analytical expression of the square wave shown in above figure is expanded into the Fourier series. Because of the symmetry of the waveform, the Fourier series only contains odd harmonics and sine terms and can be expressed as

$$f(t) = \sum_{n=1,3,5..}^{\infty} b_n \sin n\omega t \quad (6)$$

The expression for b_n can be found by the following expression

$$b_n = \frac{4V_{dc}}{n\pi}\cos n\alpha \quad (7)$$

But, $b_{n,rms} = \frac{b_n}{\sqrt{2}}$

Hence, $$b_{n,rms} = \frac{2\sqrt{2}}{n\pi}V_{dc}\cos n\alpha \quad (8)$$

Where α is firing angle

For 7 level multilevel inverter:

$$V_{out} = \sqrt{{a_0}^2 + {a_{n,rms}}^2 + {b_{n,rms}}^2}$$

But for symmetrical wave both a_0, a_n are zero. Hence $V_{out} = b_{n,rms}$

$$b_{n,rms} = \frac{2\sqrt{2}}{n\pi}V_{dc}(\cos n\alpha_1 + \cos n\alpha_2 + \cos n\alpha_3) \quad (9)$$

For 9 level multilevel inverter:

$$\boldsymbol{b_{n,rms}} = \frac{2\sqrt{2}}{n\pi}V_{dc}(\cos n\alpha_1 + \cos n\alpha_2 + \cos n\alpha_3 + \cos n\alpha_4)$$

$$THD = \frac{\sqrt{({V_{out}}^2 - {V_{01}}^2)}}{V_{01}} \quad (10)$$

For 11 level multilevel inverter:

$$b_{n,rms} = \frac{2\sqrt{2}}{n\pi}V_{dc}(\cos n\alpha_1 + \cos n\alpha_2 + \cos n\alpha_3 + \cos n\alpha_4 + \cos n\alpha_5) \quad (11)$$

$$THD = \frac{\sqrt{({V_{out}}^2 - {V_{01}}^2)}}{V_{01}} \quad (12)$$

For 13 level multilevel inverters:

$$b_{n,rms} = \frac{2\sqrt{2}}{n\pi}V_{dc}(\cos n\alpha_1 + \cos n\alpha_2 + \cos n\alpha_3 + \cos n\alpha_4 + \cos n\alpha_5 + \cos n\alpha_6) \quad (13)$$

$$THD = \frac{\sqrt{({V_{out}}^2 - {V_{01}}^2)}}{V_{01}} \quad (14)$$

For 15 level multilevel inverters:

$$b_{n,rms} = \frac{2\sqrt{2}}{n\pi}V_{dc}(\cos n\alpha_1 + \cos n\alpha_2 + \cos n\alpha_3 + \cos n\alpha_4 + \cos n\alpha_5 + \cos n\alpha_6 + \cos n\alpha_7) \quad (15)$$

$$THD = \frac{\sqrt{({V_{out}}^2 - {V_{01}}^2)}}{V_{01}} \quad (16)$$

For 17 level multilevel inverters:

$$b_{n,rms} = \frac{2\sqrt{2}}{n\pi}V_{dc}(\cos n\alpha_1 + \cos n\alpha_2 + \cos n\alpha_3 + \cos n\alpha_4 + \cos n\alpha_5 + \cos n\alpha_6 + \cos n\alpha_7 + \cos n\alpha_8)$$

$$THD = \frac{\sqrt{({V_{out}}^2 - {V_{01}}^2)}}{V_{01}} \quad (18)$$

For 19 level multilevel inverters:

$$b_{n,rms} = \frac{2\sqrt{2}}{n\pi}V_{dc}(\cos n\alpha_1 + \cos n\alpha_2 + \cos n\alpha_3 + \cos n\alpha_4 + \cos n\alpha_5 + \cos n\alpha_6 + \cos n\alpha_7 + \cos n\alpha_8 + \cos n\alpha_9) \quad (19)$$

$$THD = \frac{\sqrt{({V_{out}}^2 - {V_{01}}^2)}}{V_{01}} \quad (20)$$

3. Induction motor modeling

The speed of the synchronously rotating frame model is

$\omega_c = \omega_s =$ statorsupply angular frequency in rad/sec and the instantaneous angular position is $\theta_c = \theta_s = \omega_s t$

The induction motor model in arbitrary reference is given as shown below

$${V_{qs}}^c = (R_s + L_s P){i_{qs}}^c + (\omega_c L_s){i_{ds}}^c + (L_m P){i_{qr}}^c + (\omega_c L_m){i_{dr}}^c \quad (21)$$

$${V_{ds}}^c = (-\omega_c L_S){i_{qs}}^c + (R_s + L_s P){i_{ds}}^c + (-\omega_c L_m){i_{qr}}^c + (L_m P){i_{dr}}^c \quad (22)$$

$${V_{qr}}^c = (L_m P){i_{qs}}^c + (\omega_c - \omega_r)L_m {i_{ds}}^c + (R_r + L_r P){i_{qr}}^c + (\omega_c - \omega_r)L_r {i_{dr}}^c \quad (23)$$

$${V_{dr}}^c = -(\omega_c - \omega_r)L_m {i_{qs}}^c + (L_m P){i_{ds}}^c + (-(\omega_c - \omega_r)L_r){i_{qr}}^c + (R_r + L_r P){i_{dr}}^c \quad (24)$$

In synchronous reference frames

$$\begin{matrix} {V_{qs}}^e \\ {V_{ds}}^e \\ V_0 \end{matrix} = {T_{abc}}^e \begin{matrix} V_{as} \\ V_{bs} \\ V_{cs} \end{matrix} \quad (25)$$

Where,

$$V_{as} = V_m \sin \omega_s t$$
$$V_{bs} = V_m \sin(\omega_s t - 2*\pi/3)$$
$$V_{cs} = V_m \sin(\omega_s t - 4*\pi/3)$$

$${T_{abc}}^c = \frac{2}{3}\begin{matrix} \cos\theta_s & \cos(\theta_s - 2\pi/3) & \cos(\theta_s + 2\pi/3) \\ \sin\theta_s & \sin(\theta_s - 2\pi/3) & \sin(\theta_s + 2\pi/3) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{matrix} \quad (26)$$

Substituting these and solving for the d and q axes stator voltages in synchronous reference frame yields

$$\begin{matrix} {V_{qs}}^e \\ {V_{ds}}^e \\ V_0 \end{matrix} = {T_{abc}}^e \begin{matrix} V_{as} \\ V_{bs} \\ V_{cs} \end{matrix} = \begin{matrix} 0 \\ V_m \\ 0 \end{matrix} \quad (27)$$

The‘d’ and ‘q’ axes stator voltages are dc quantities; hence the response will be dc quantities because the system is linear. Hence

$$P{i_{ds}}^e = P{i_{qs}}^e = P{i_{dr}}^e = 0 \quad (28)$$

Substituting the above equation in the system equation gives

$$R_s i_{qs}{}^e + \omega_s L_s i_{ds}{}^e + \omega_s L_m i_{dr}{}^e = 0 \quad (29)$$
$$-\omega_s L_s i_{qs}{}^e + R_s i_{ds}{}^e - \omega_s L_m i_{qr}{}^e = 0 \quad (30)$$
$$\omega_{s1} L_m i_{ds}{}^e + R_r i_{qr}{}^e + \omega_{s1} L_r i_{dr}{}^e = 0 \quad (31)$$
$$-\omega_{s1} L_m i_{qs}{}^e - \omega_{s1} L_r i_{dr}{}^e + R_r i_{dr}{}^e = 0 \quad (32)$$

Where, $\omega_{s1} = \omega_s - \omega_r$

The currents are solved by inverting the impedance matrix and premultiplying with the input voltage vector.

The electromagnetic torque is given as

$$T_e = \frac{3}{2}\frac{P}{2} L_m \left(i_{qs}{}^e i_{dr}{}^e - i_{ds}{}^e i_{qr}{}^e \right) \quad (33)$$

The actual phase currents are obtained as

$$i_{abc} = T_{abc}{}^{-1}\, i_{qd0}{}^e \quad (34)$$

4. Simulation Results

In all cascaded H-bridge multilevel inverters the input dc sources are equal. But in modified multilevel inverters the values of input dc voltage sources are unequal and the values of input dc sources depends upon the level of the multilevel inverter. In case of 7 level modified multilevel inverter the input dc sources are in the ratio 1:2

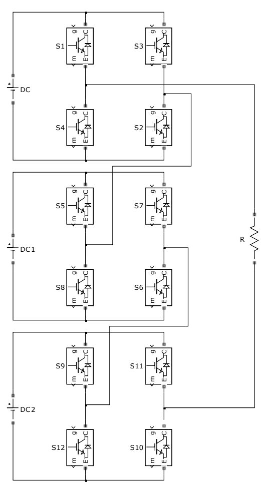


Figure4: 7 level Cascaded H-bridge multilevel inverter

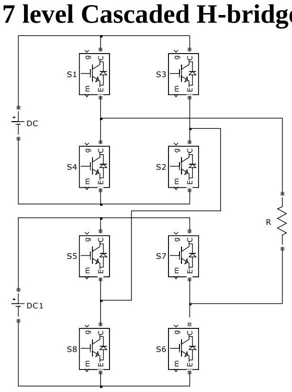


Figure5: 7 level modified multilevel inverter

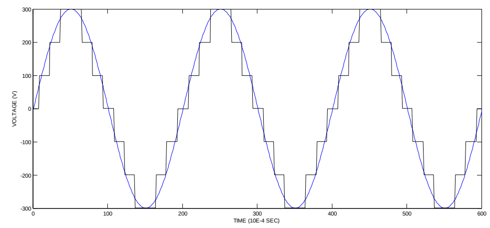


Figure6: Output voltage wave forms

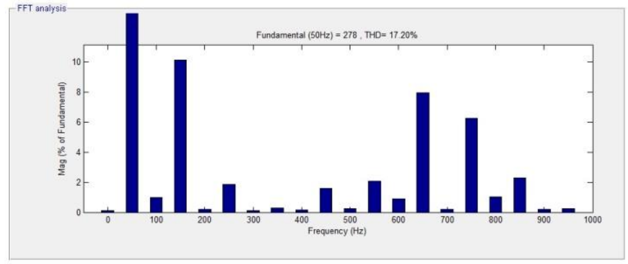


Figure7: FFT Spectrum

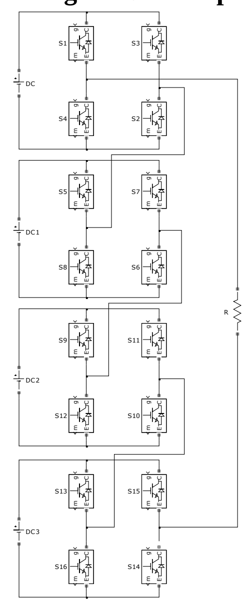


Figure8: 9 level Cascaded H-bridge multilevel inverter

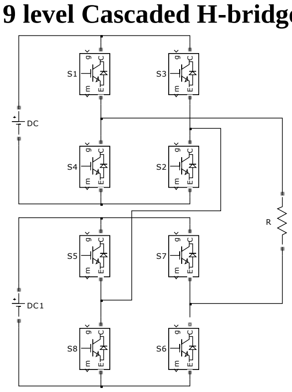


Figure9: 9 level modified multilevel inverter

In the above mofied multilevel inverter the voltage sources are taken in the ratio 1:3.the out put voltage and FFT spectrum are as shown beow

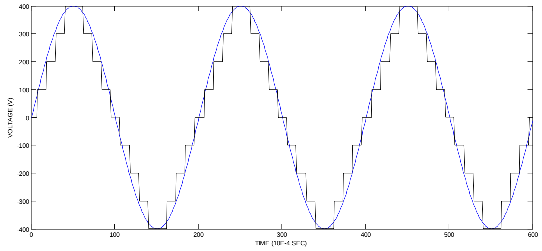


Figure10: Output voltage waveform

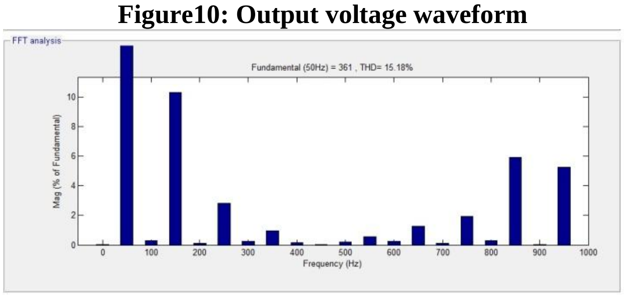


Figure11: FFT spectrum

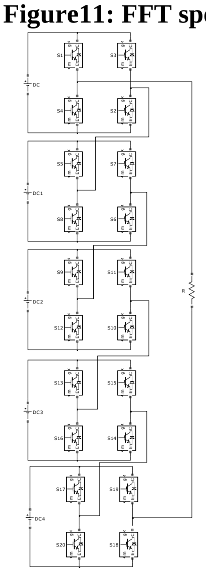


Figure12: 11level Cascaded H-bridge multilevel inverter

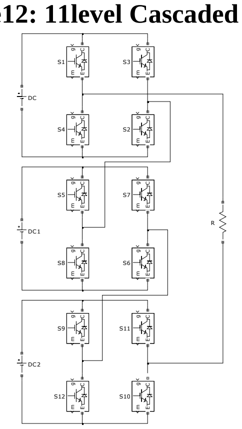


Figure13: 11 level modified multilevel inverter

In the above11 level modified multi level inverter the input dc voltages are in the ratio 1:2:2. The output voltage and FFT spectrum are as shown beow.

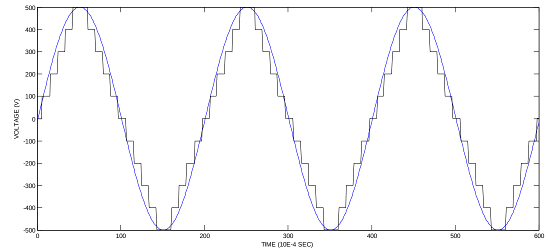


Figure14: output voltage waveform

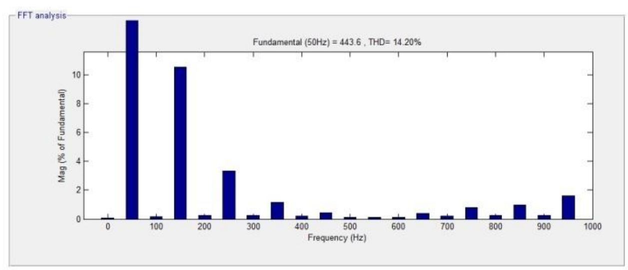


Figure15:FFT spectrum

In modified 13 level H-bridge multilevel inverter in the input dc voltage sources are in the ratio 1:2:3. 13 level modified multilevel inverter, out put voltage form and FFT spectrum are as shown below

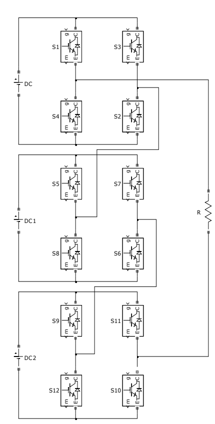


Figure17: 13level modified multilevel inverter

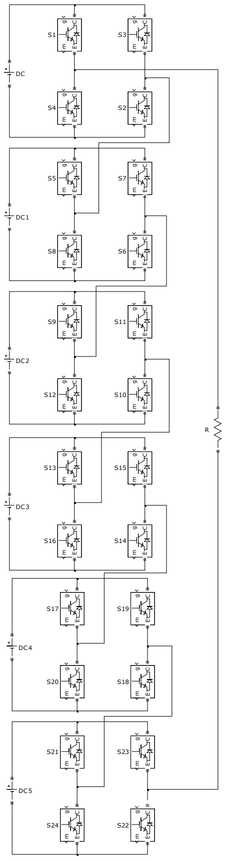


Figure18:13level Cascaded H-bridge multilevel inverter

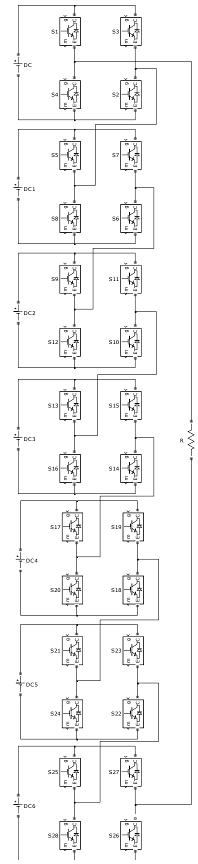


Figure21: 15 level Cascaded H- bridge multilevel inverter

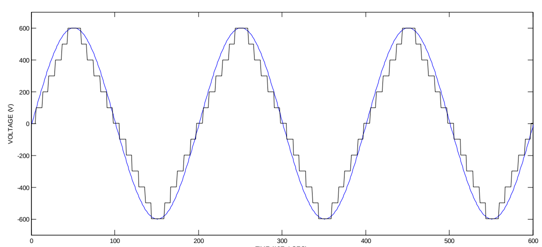


Figure19: output voltage waveform

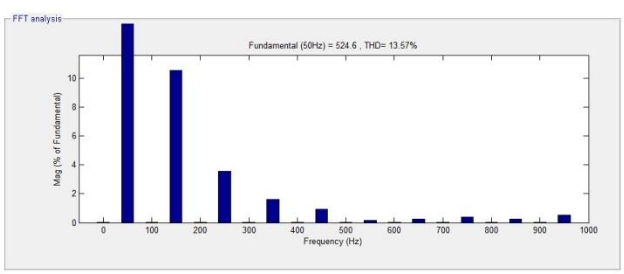


Figure20: FFT spectrum

In fifteen level modified H-bridge multilevel inverter the input dc voltage sources are in the ratio 1:3:3. The output votage waveform and its FFT spectrum are as shown below.

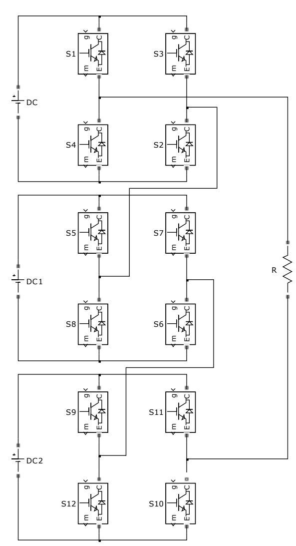


Figure22: 15 level modified multilevel inverter

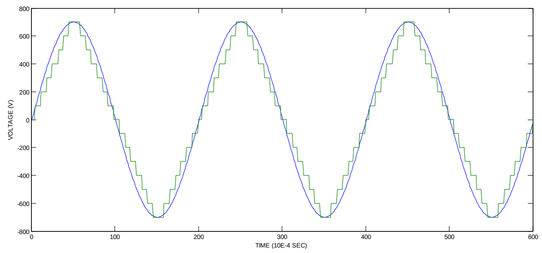


Figure23: Output voltage waveform

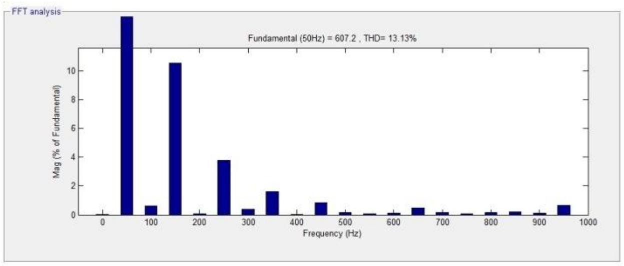


Figure24: FFT spectrum

In seventeen level modified multilevel inverter the input dc voltages are in the ratio 1:3:4. The output voltage and FFT spectrum of modified multilevel inverter are as shown below

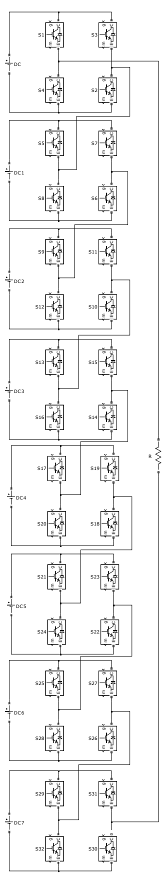


Figure25: 17 level Cascaded H- bridge multilevel inverters

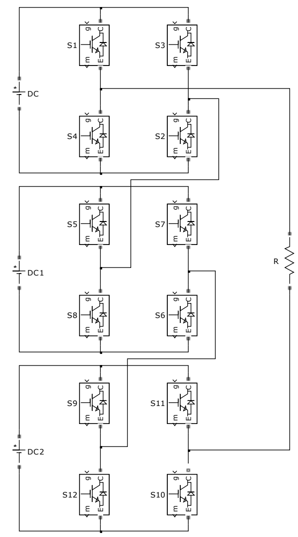


Figure26: 17 level modified multilevel inverter

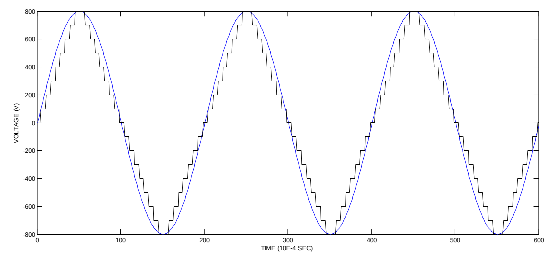


Figure27: Output voltage waveform

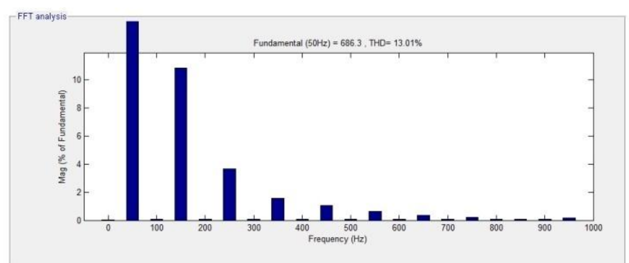


Figure28: FFT spectrum

In nineteen level modified multilevel inverter the voltages are in the ratio 1:3:5. The simulation diagram of modified multilevel inverter, its output voltage waveform and FFT spectrum are as shown below

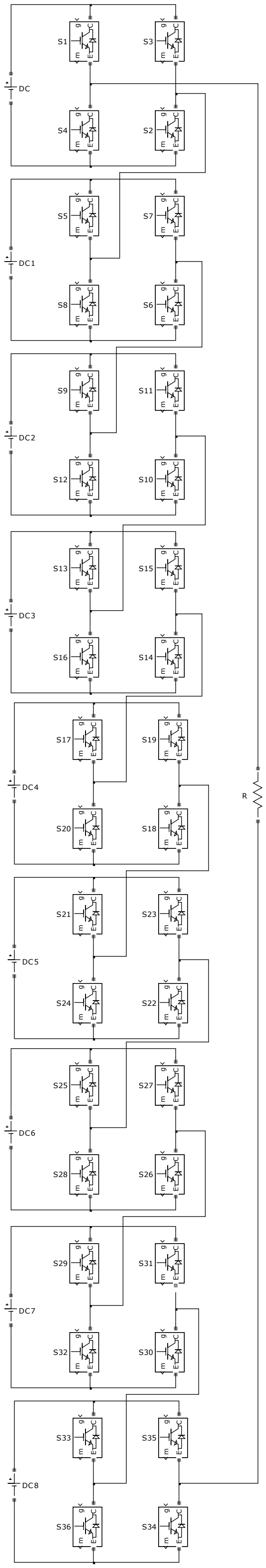


Figure29: 19 level Cascaded H-bridge multilevel inverter

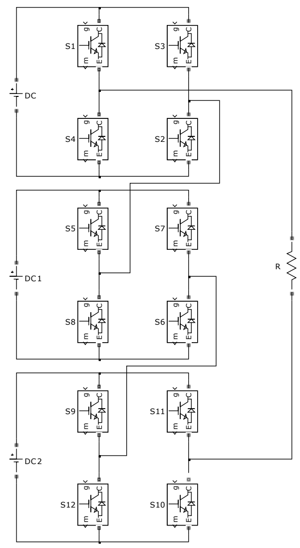


Figure30: 19 level modified multilevel inverter

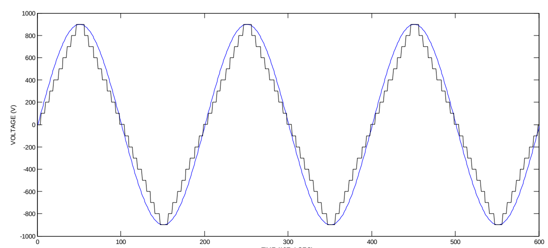


Figure31: Output voltage waveform

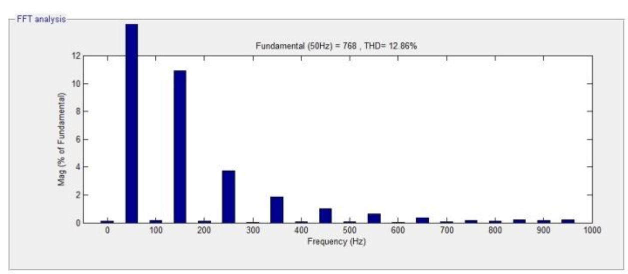


Figure32: FFT spectrum

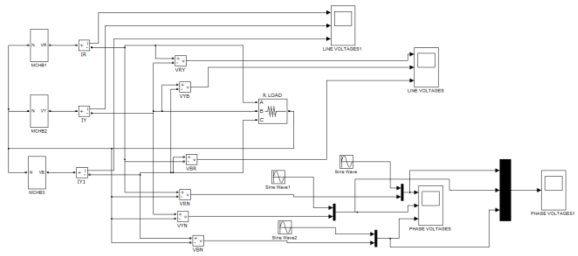


Figure33: Circuit model for three phase 15-level Multi level inverter

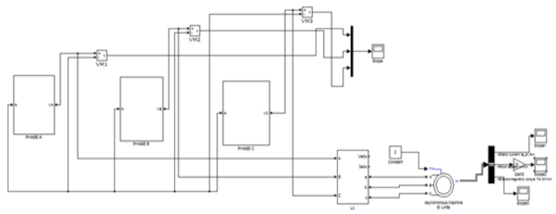


Figure34: Circuit model for three phase induction motor drive

The simulation of a fifteen level modified multilevel inverter fed Induction Motor Drive model was done in by using MATLAB/SIMULINK. The simulation results of voltage, current, motor speed were presented.

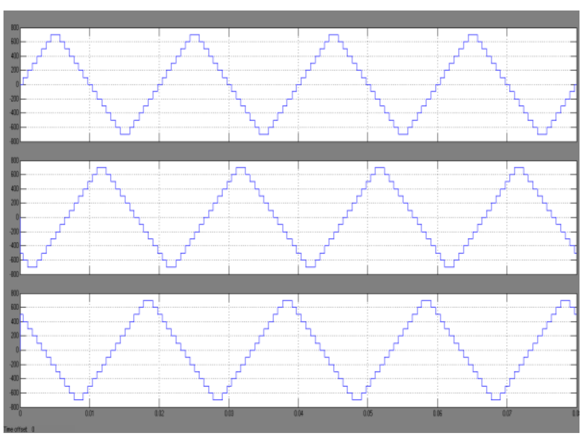


Figure35: Three phase inverter output voltage waveform

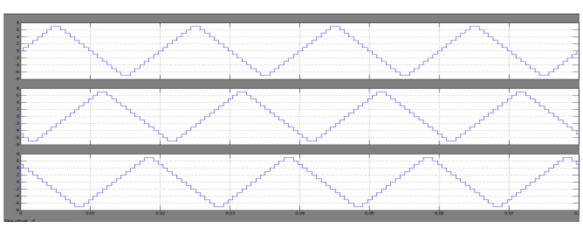


Figure36: Three phase inverter output current waveform

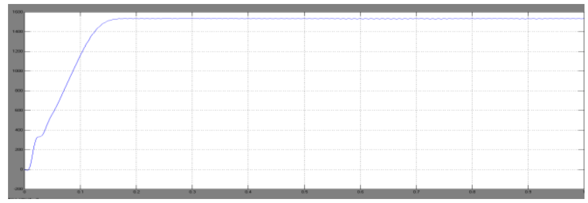


Figure37: Rotor speed wave form

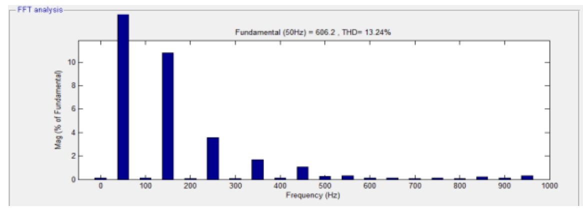


Figure8: FFT Spectrum

5. Result Analysis

In this section comparison is done between the modified cascaded H-bridge inverter and other multilevel inverters for 7, 9, 11, 13, 15, 17, 19 levels.

TABLE II
Comparison of THD of modified multilevel for different levels for different loads

Output voltage level	THD for R LOAD (%)	THD for RL LOAD (%)	THD for RC LOAD (%)	THD for RLC LOAD (%)
7 LEVEL	16.90	18.26	26.24	26.30
9 LEVEL	15.43	16.12	22.86	22.98
11 LEVEL	14.10	14.48	19.87	19.94
13 LEVEL	13.57	13.95	18.75	18.88
15 LEVEL	13.07	13.27	15.62	15.82
17 LEVEL	12.91	13.01	15.21	15.45
19 LEVEL	12.56	12.70	15.02	15.15

From the above table it is obvious that the THD is going to reduce as the level of the multilevel inverter increases. Hence the modified multilevel inverter is more advantageous as the level of the multilevel inverter increases.

In the above table R indicates to resistive load, RL indicates resistive and inductive load, RC indicates resistive and

capacitive load, RLC indicates resistive, inductive, capacitive load.
The values R, L, C considered for the simulation are as follows.

$$R = 1000\Omega$$
$$L = 100m\ H$$
$$C = 1\mu F$$

As seen in the above simulation diagrams that as the number of levels increases then the number of dc sources and the number of components required are more and also as the number of levels increases that the THD is going to decrease . Hence the modified H-bridge multilevel inverter is more advantageous when compared with the conventional cascaded H-bridge inverter.

Comparison of theoretical values of THD with simulated values

Table III
Comparison of THD

Output voltage level	Simulated THD	Theoretical THD
7 LEVEL	16.90	15.80
9 LEVEL	15.43	14.72
11 LEVEL	14.10	13.35
13 LEVEL	13.57	12.97
15 LEVEL	13.07	12.21
17 LEVEL	12.91	11.86
19 LEVEL	12.56	11.45

6. Conclusion

The modeling of fifteen level modified H-bridge multilevel inverter fed induction motor drive is done and simulated by using MATLAB/SIMULINK. In this modified multilevel inverter the numbers of components required are less when compared with the conventional cascaded H-bridge inverter and has less switching losses and also as the number of levels increases the harmonic content in output voltage and hence harmonic losses in motor are less. So the efficiency of drive is high when it is fed by the modified H-bridge multilevel inverter rather than conventional H- bridge multilevel inverter. The size and weight of the modified multilevel inverter is less because the number of components required is less and power density is high. The fifteen level modified multilevel inverter fed induction motor drive has been successfully simulated and the results of voltage waveforms, motor speed and FFT spectrum of output were obtained. This type of inverter system is very much useful for industries where adjustable speed drives are required and significant amount of energy can be saved as the system has less harmonic losses and also speed control of the drive is easy because it has simple control techniques unlike conventional H-bridge multilevel inverter which has more complex control circuit.

7.References

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