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Fifteen Level Cascaded H-Bridge Multilevel Inverter Fed Induction Motor

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Abstract: ***In power electronics, Multilevel Inverter (MLI) plays very important role. It has spectacular applications in the field of high power & medium voltage energy control. The simulation of "Fifteen Level Cascaded H-Bridge Multilevel Inverter (MLI) Fed Induction Motor" is studied in this paper. The MLI's are used to get high magnitude output voltage with reduced harmonic distortion. The reduction of harmonic distortion and the purity of the output waveform when compared with five level and nine level multilevel inverters is seen in this paper.***

Keywords: Multilevel Inverter (MLI), Direct Current (DC), Alternating Current (AC), Cascaded H-Bridge (CHB), Sinusoidal Pulse Width Modulation (SPWM), Pulse Width Modulation (PWM), Total Harmonic Distortion (THD), fig (Figure), Number(no.).

I. INTRODUCTION

A Multilevel Inverter plays very important role in power electronics. The concept of MLI is a modification of 2-level inverter. In general a 2-level Inverter creates two different voltages for the load i.e. if we provide DC input voltage "V" to a 2-level inverter then it will provide "+V/2" and "–V/2"as output.

There are different types of MLI's are present in the power electronics. The main difference here is the switching pattern and the sources of input voltage. The regularly used MLI topologies are Diode Clamped MLI, Flying Capacitor MLI, CHB MLI. From these we are using CHB MLI. Because, the advantages of CHB MLI. I.e. it is having less no. of components as compared to the other two types of inverters. So, the overall weight and price will also less.

The Cascaded H-bridge MLI uses several H-bridge inverters connected in series as shown in the figure1 to provide a smooth sinusoidal output voltage. If there are 'p' cells in CHB MLI then the no. of output voltage levels will be '2p+1'.As we increase the voltage levels the smoothness of the output waveform will also increases(pure sinusoidal). But the main disadvantage is as the levels are increasing the no. of components requirement and the complexity of control circuit will also increases.

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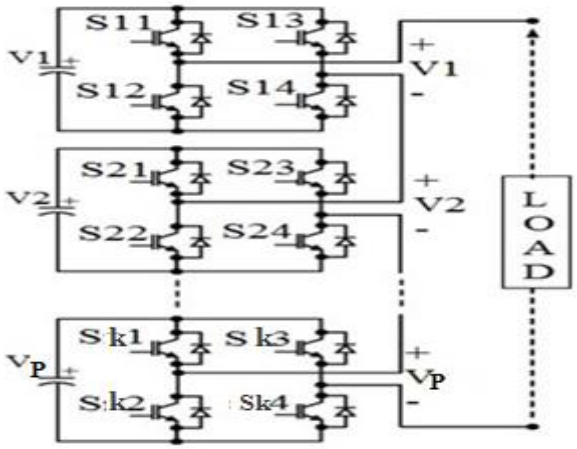

Fig. 1.Cascaded Multilevel Inverter

II. PULSE WIDTH MODULATION (PWM)

The switching devices used in the inverter are bipolar junction transistors, silicon controlled rectifiers, MOSFET, IGBT, etc. In inverter the output AC waveform amplitude & the harmonic content are controlled by controlling the duty cycle of the switches. There are different PWM techniques are present and each has its own advantages and also disadvantages.

In this paper sinusoidal PWM is used to trigger the switches.

A. Sinusoidal PWM (SPWM)

The sinusoidal PWM technique is most popular PWM technique. In this PWM technique the pulses are generated by comparing the two signals i.e. carrier signal and reference signal. Here the carrier signal is "triangular" and the reference signal is "sinusoidal". The sinusoidal PWM is shown in the fig.2, where the triangular signal is compared to a sinusoidal signal of the desired fundamental frequency. The pulse widths and controlling of switching devices are determined by using the relative levels of two signals.

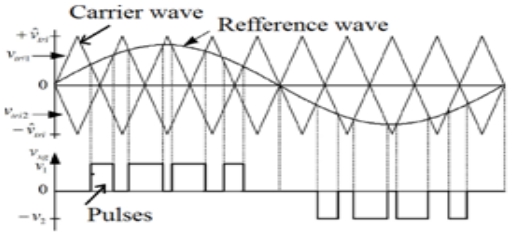

Fig. 2.Sinusoidal PWM

III. SINGLE PHASE FIFTEEN LEVEL CASCADED H-BRIDGE MLI

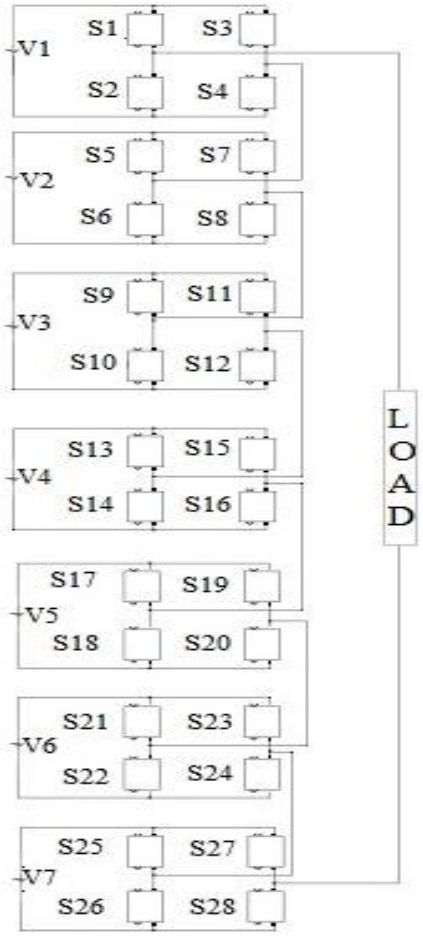

Fig. 3.Circuit diagram of fifteen level cascaded MLI

The circuit diagram of fifteen level CHB MLI is shown in the fig.3.

For P-level CHB MLI the requirements are

$$\text{Number of H} - \text{bridges} = \frac{P-1}{2}$$

Each H-bridge consists of four switches and dc voltage source.

$$\text{So, The Number of dc voltage sources} = \frac{P-1}{2}$$

$$\text{Number of switches} = 2(P-1)$$

From figure3, the fifteen level CHB MLI consists of seven H-bridges which are connected in the cascaded manner i.e. one of the output terminal in first is connected to the input of the second H-bridge and so on. Each H-bridge consists of four switches with equal input dc voltage sources.

A. SIMULATION RESULTS

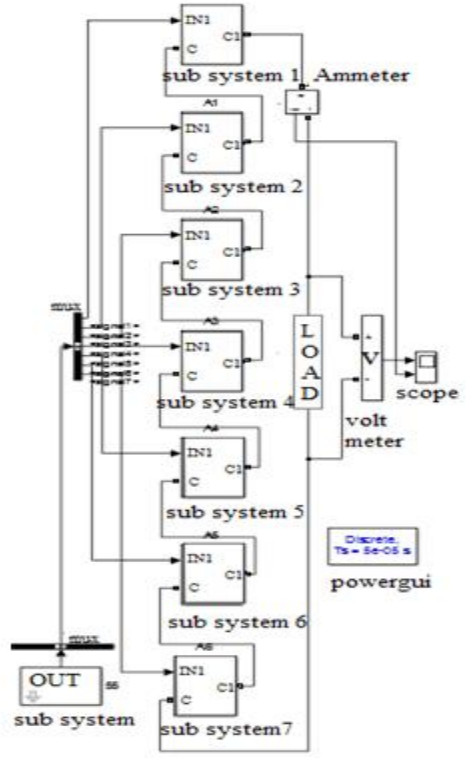

Fig. 4.Simulation of single phase fifteen level CHB MLI

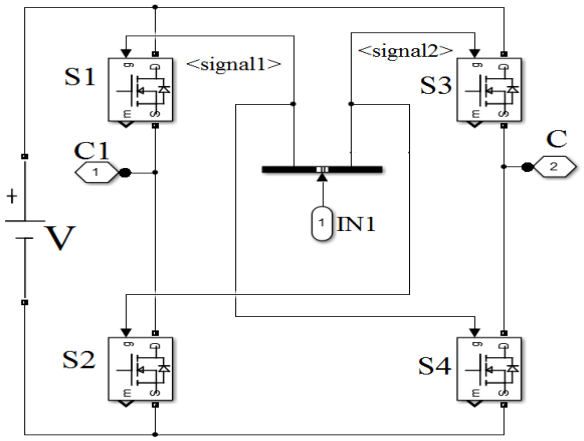

Fig. 5.H-bridge of fifteen level MLI

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Table-I: Switching pattern of fifteen level CHB MLI

S.no.	Fifteen level cascaded h-bridge MLI switching pattern	
	Output Voltage (volts)	*Switches to be ON*
1	Vdc	S1,S4,S6,S8,S10,S12,S14,S16,S18,S20,S22, S24,S26,S28
2	2Vdc	S1,S4,S6,S8,S10,S12,S14,S16,S18,S20,S22, S24,S25,S28
3	3Vdc	S1,S4,S6,S8,S10,S12,S14,S16,S18,S20,S21, S24,S25,S28
4	4Vdc	S1,S4,S6,S8,S10,S12,S14,S16,S17,S20,S21, S24,S25,S28
5	5Vdc	S1,S4,S6,S8,S10,S12,S13,S16,S17,S20,S21, S24,S25,S28
6	6Vdc	S1,S4,S6,S8,S9,S12,S13,S16,S17,S20,S21,S 24,S25,S28
7	7Vdc	S1,S4,S5,S8,S9,S12,S13,S16,S17,S20,S21,S 24,S25,S28
8	0	S2,S4,S6,S8,S10,S12,S14,S16,S18,S20,S22, S24,S26,S28
9	-Vdc	S2,S3,S6,S8,S10,S12,S14,S16,S18,S20,S22, S24,S26,S28
10	-2Vdc	S2,S3,S6,S8,S10,S12,S14,S16,S18,S20,S22, S24,S26,S27
11	-3Vdc	S2,S3,S6,S8,S10,S12,S14,S16,S18,S20,S22, S23,S26,S27
12	-4Vdc	S2,S3,S6,S8,S10,S12,S14,S16,S19,S20,S22, S23,S26,S27
13	-5Vdc	S2,S3,S6,S8,S10,S12,S14,S15,S19,S20,S22, S23,S26,S27
14	-6Vdc	S2,S3,S6,S8,S10,S11,S14,S15,S19,S20,S22, S23,S26,S27
15	-7Vdc	S2,S3,S6,S7,S10,S11,S14,S15,S19,S20,S22, S23,S26,S27

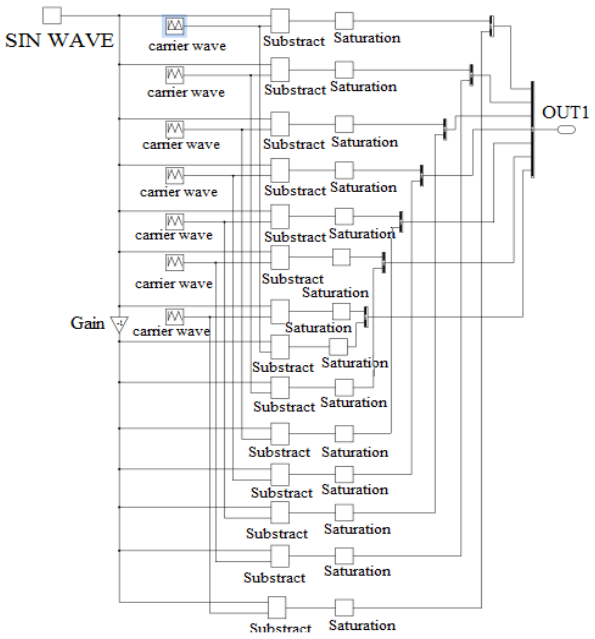

Fig. 6.Subsystem of fifteen level CHB MLI

In the above figure the sin wave is compared with the carrier wave in order to get the required pulse for turning on the respective switches.

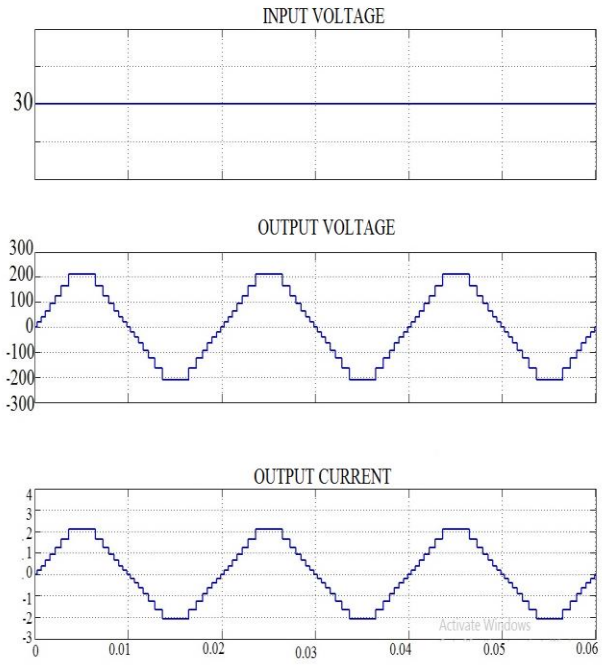

Fig. 7.Output voltage and current wave forms

From the above figure we observe that the given input voltage is 30volts dc, and the output voltage is 210volts ac i.e. seven times the input voltage. This is the main advantage of the cascaded multilevel inverter which uses small magnitude of dc as input and adds the voltage at each level converts to high magnitude ac which seems to sinusoidal.

IV. FOURIER SERIES ANALYSIS

The Fourier series equation is

$$f(t) = a_0 + \sum_{n=1}^{\infty} (a_n \cos nwt + b_n \sin nwt) \quad (1)$$

Where $a_0 = dc\ component$

The output of the waveform is odd function

So, the value of $a_0 = 0$

And $a_n = 0$

$$b_n = \frac{2}{2\pi} \sum_{n=0}^{2\pi} f(wt)(\sin nwt)dwt \quad (2)$$

The output waveform is half wave symmetry. The condition for half wave symmetry is

$$f(\theta) = -f(\pi + \theta)$$

Then the value of

$$b_n = \left(\frac{2}{2\pi} \sum_{n=0}^{2\pi} f(wt)(\sin nwt)dwt \right) * 2 \quad (3)$$

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The output is also a quarter wave symmetry.
i.e.

$$f(90+\theta) = f(90-\theta)$$

$$f(270+\theta) = f(270-\theta)$$

Then the value of

$$b_n = \left(\frac{2}{2\pi}\sum_{n=0}^{\frac{\pi}{2}} f(wt)(\sin nwt)dwt\right) * 4 \quad (4)$$

The Fourier series expansion is

$$V_{orms} = \sum_{n=odd}^{\infty} (b_n \sin nwt)dwt \quad (5)$$

$$THD = \sqrt{(\frac{1}{g^2} - 1)} \quad (6)$$

where g = distortion factor

$$\text{Distortion factor} = \frac{\text{fundamental rms voltage}}{\text{Total phase rms voltage}} \quad (7)$$

V. THREE PHASE FIFTEEN LEVEL CHB MLI FED INDUTION MOTOR

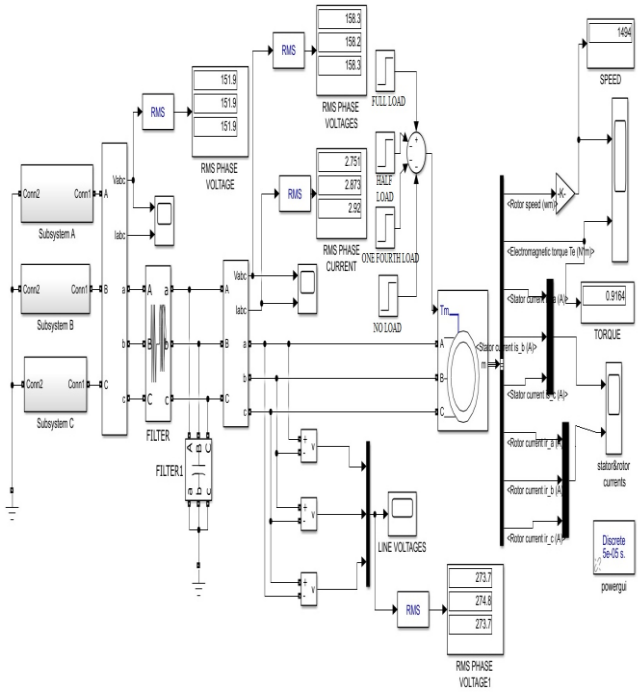

Fig. 8.Three phase fifteen level CHB MLI fed induction motor

Now the output voltage of single phase fifteen level CHB MLI is connected to load i.e. asynchronous machine (induction motor) as three phases with phase difference of 120 degrees each is shown in the figure8. These three single phases connected in star connection.

$$\text{Vmax} = \frac{\sqrt{2} * Vrms}{\sqrt{3}} \quad (8)$$

As we know that

$$\text{Output power (P)} = \text{load torque}(Tsh) * \text{speed}(w)$$

Here the

$$\text{Output power (P)} = 4000\text{watts}$$

$$\text{angular speed}(w) = \frac{2\pi n}{60} \quad (9)$$

$$= \frac{2\pi * 1475}{60}$$

$$= 155.98 \text{ rad/sec}$$

Now

$$\text{load torque (Tsh)} = \frac{Pout}{w} \quad (10)$$

$$\text{load torque (Tsh)} = \frac{4000}{150}$$

$$\text{load torque (Tsh)} = 26.27\text{N} - \text{m}$$

At half of the full load torque is

$$\left(\frac{Tsh}{2}\right) = \frac{26}{2} = 13\text{N} - \text{M}$$

At one fourth of the full load torque is

$$\left(\frac{Tsh}{4}\right) = \frac{26}{4} = 6.5\text{ N} - \text{M}$$

Table-II: Motor speed and torque at different loads

Load torque Tsh (or) T_L(N-M)	Motor Torque(N-M)	Motor Speed(N) (rpm)
Tsh or T_L at 1sec	26	1340
Tsh or T_L at 3secs	13	1410
Tsh or T_L at 5secs	6.5	1450
Tsh or T_L at 7secs	0	1480

Here from the above table we absorb that as the load on the motor changes the motor torque and speed of the motor changes.
I.e. the motor speed is inversely proportional to the motor toque.
Here the asynchronous machine is used as the load because the cost of induction motor is very low when compared to other motors and it can be operated at different loads and different speeds, it is having less losses due to the absence of slip rings and brushes.

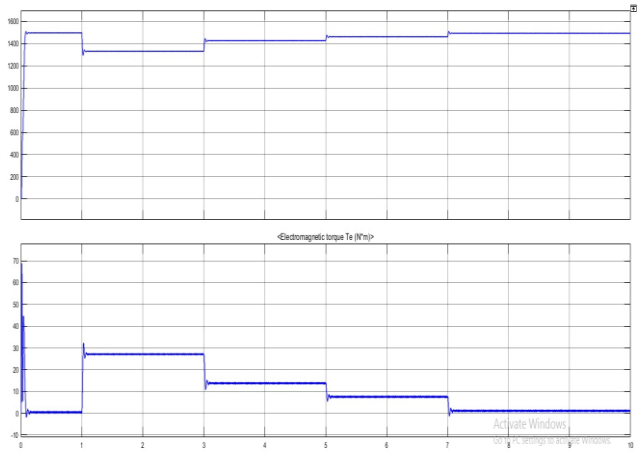

Fig. 9. Speed and torque of 3-phase induction motor at different loads

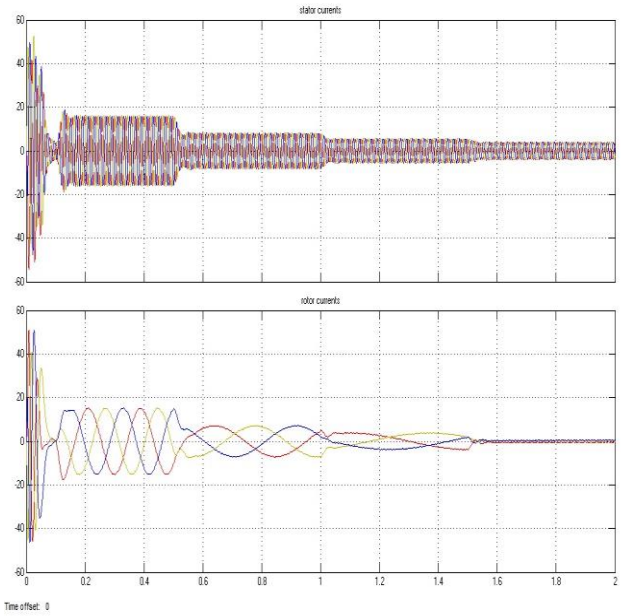

Fig. 10. Stator and Rotor currents of 3-phase induction motor at different loads

A. OUTPUT WAVEFROMS

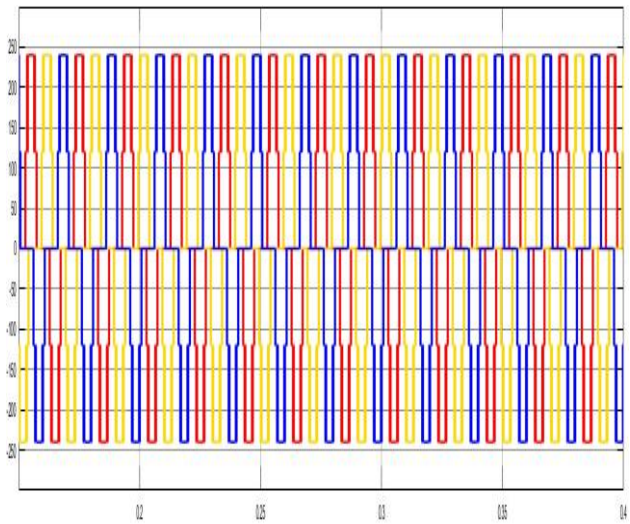

Fig. 11. Output of five level cascaded MLI

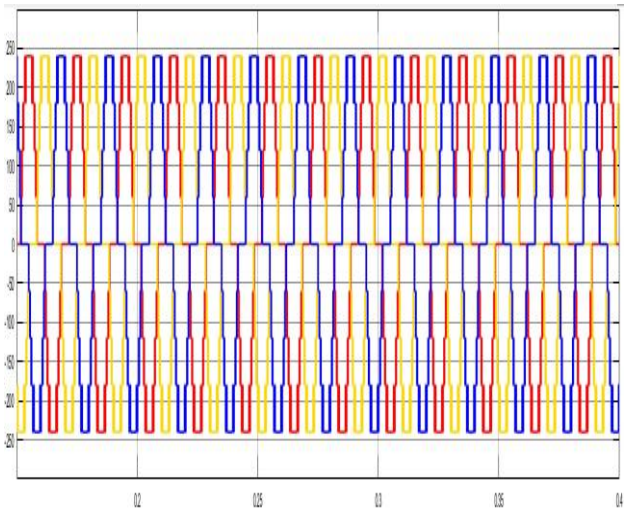

Fig. 12. Output of nine level cascaded MLI

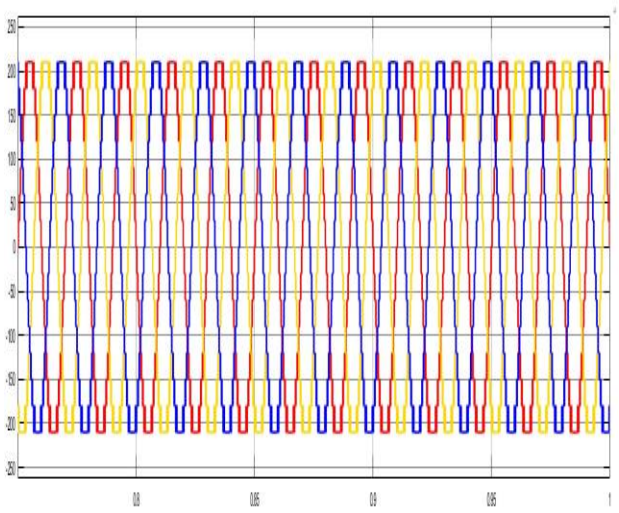

Fig. 13. Output of fifteen level cascaded MLI

B. THD ANALYSIS

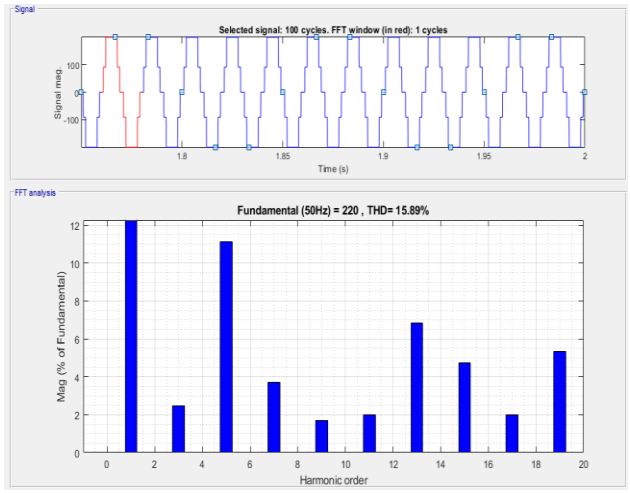

Fig. 14. Five Level Cascaded MLI

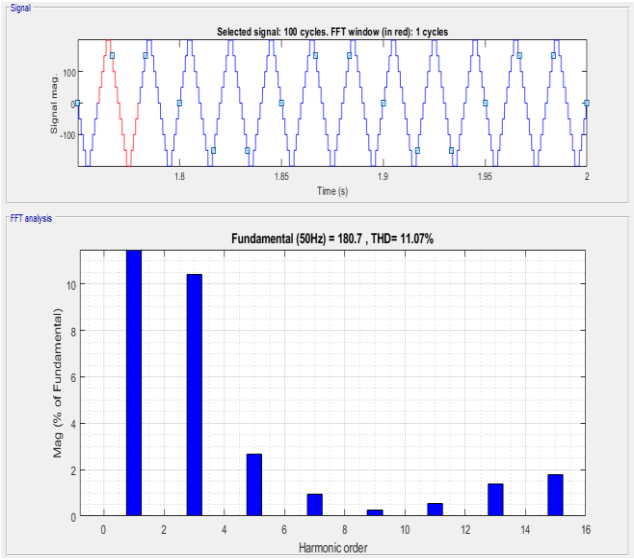

Fig. 15. Nine level cascaded MLI

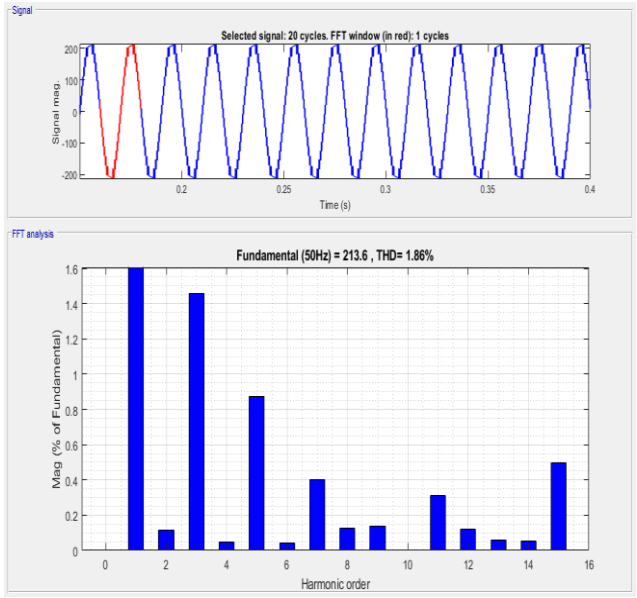

Fig. 16. Fifteen level cascaded MLI

Table-III: comparison of THD for different levels

S.no.	Level of MLI	%THD
1	Five Level MLI	15.89
3	Nine Level MLI	11.07
6	Fifteenn Level MLI	1.86

VI. CONCLUSION

In this paper the simulation of Fifteen Level CHB MLI Fed Induction Motor with sinusoidal pulse width modulation (SPWM) is performed and also shown the output waveforms and THD of different CHB MLI's. The THD of fifteen level CHB MLI is improved and also the output waveforms is more sinusoidal as compared to other level MLI.

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