# ANALYSIS AND SIMULATION OF CASCADE H-BRIDGE MULTILEVEL INVERTER FED INDUCTION MOTOR DRIVE

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***Abstract Simple construction and robust in nature, fine speed-torque characteristics, good efficiency gives induction motor an edge over other type of electric motors. Induction motors are maintenance free motors due to the absence of commutator and brush assembly. Speed control of induction motor is very much needed when used in electric vehicle application. Variable voltage with variable frequency maintaining constant V/F ratio is one of the prominent method of speed control in induction motors. Induction motor when used in speed drive applications needs an inverter. Inverter converting DC type of supply to AC can produce the required output voltage with required frequency to control the speed of induction motor.***

***CHB topology of inverter is controlled with PWM technique. Many PWM techniques are explained and out of which sinusoidal PWM technique is employed for proposed work due to its simplicity. Many types of carrier based sinusoidal PWM techniques are there and explained but in-phase disposition (IPD or PD) PWM technique was used to trigger switches of CHB inverter. CHB topology of multi-level inverter under healthy conditions using IPD PWM technique for 5- level, 7-level and 9-level inverters was explained.***

***Further a novel mitigation technique was proposed using redundant cell activated from a simple algorithm calculating average value of voltage across bridges.***

***Simulation work was carried out for 7-level inverters and results were presented. Complete simulation work and results presented was carried out using MATLAB/SIMULINK software. The proposed topology was found simple and can be applied for higher level of multi-level topologies with low cost and good efficiency.***

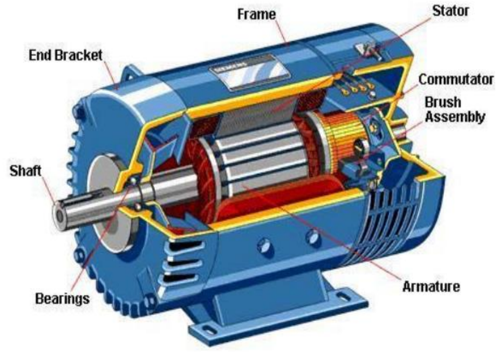
## 1. INTRODUCTION

Recent advancements in solid-state electronics have increased the use of power converters in industries to control motor drives, Electric Vehicles (EVs), power systems, Uninterruptible Power Supplies (UPS), etc. The voltage source inverter is one of the most widely used power converters in power electronics. Voltage Source Inverters (VSI) produce positive (+ Vdc) and negative (- Vdc) output voltages if they are two level inverters. High frequency Pulse Width Modulation (PWM) techniques are employed in these inverters to acquire a quality output voltage waveform with a minimum amount of harmonic content. In medium and high power applications, high switching frequency based PWM inverters have more switching losses and require high power rating devices.

## 2. ELECTRIC MOTOR

Today Electric motors can be found in a variety of Appliances used for domestic and industrial needs. Electric motors were developed to reduce the human efforts mainly in terms of mechanical operations. An electric motor is an energy conversion device which can perform rotary operations. Energy conversion is very essential in many of the modern methods used today. According to law of conservation of energy, energy can neither be created nor destroyed but can only change its form. Out of many energy forms available in the universe, only conversion between reversible forms of energy processes is efficient which can improve the overall efficiency. Of available energies, mechanical and electrical energies can be reversed and constitutes to a reversible process. It is easy to convert mechanical form of energy to electrical and vice-versa improving the system performance.

An electrical machine is a device which converts one form of energy to other wherein an electric motor is an electro-mechanical device which converts electrical energy to mechanical energy. Scientifically, the first electric motor was developed by Michael Faraday in 1820s which worked by using a simple current carrying conductor with a magnetic field. Since then many scientists worked electric motors and brought the present shape looking like cylinder



An electric motor works on the basic principle – a current carrying coil placed in a magnetic field experiences a force. The force exerts torque on the freely mounted part of the motor called rotor and hence rotor rotates producing mechanical energy. This mechanical energy produced can be tapped to use for many rotational applications in industrial, domestic and in some special purpose applications [2].

## 3. DRIVE SYSTEM

Now-a-days, speed control of electric motors is very much essential in many of their applications rather than constant speed applications to increase the efficiency of the system reducing the system losses [5]. Almost in every domestic or industrial applications speed control of electric motors is made necessary for human convenience and special purpose applications. When there is a mention about motors, the general scenario is that the speed of the motor is only controlled by applied voltage and the frequency of source current. But with the help of a separate control circuit to control the speed of a motor, smooth and precise control over speed can be obtained increasing the efficiency. This speed control of a motor with help of a control circuit is called electrical motor drive or simply a motor system with a motion control is called electrical drive. Combination of different systems for electrical motor motion control is called electrical motor drive.

If the motor used in the motor drive system is a DC motor, it is called DC drive and if the motors used are of AC type, they are called AC drives. Generally the available supply is AC supply which is obtained from the grid. If DC motors are used for driving load, the available AC supply is to be converted to DC supply with extra accessory circuits assisted. This increases the cost of the drive system and hence AC drive systems are preferred over DC drives on economic aspects. AC motors are more robust in construction when compared to DC motors and many more reasons shifts the focus to use AC drives. Due to the said reasons, AC drive systems are more preferred over DC drive systems. The model block diagram of electric drive system was shown in figure 2

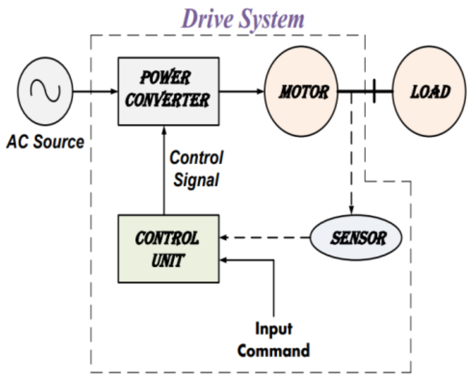



Fig 2: Block diagram of Electric Motor drive system

## 4. INVERTER FOR DRIVE SYSTEM

Variation in motor speed by using a separate control circuit is called motor drive system. The speed of the induction motor can be effectively varied by using variable frequency method of speed control. The synchronous speed of the induction motor is given by:

$$Ns = 120f/P \tag{1.1}$$

From the equation (1.1), synchronous speed is directly proportional to frequency of the power supply and inversely proportional to number of poles. Since the number of poles in a machine remains constant and cannot be varied, speed of induction motor can be varied by varying supply frequency [6].

As a general phenomenon, since induction motor is an AC type of motor, the supply with fixed frequency is directly given to the induction motor terminals. But for an induction motor drive to vary the speed, supply frequency needs to be varied. This variable frequency which can change the speed of induction motor can be obtained by using an inverter circuit. So inverter fed induction motor can deliver variable speeds required for a particular application. Some of the notified advantages of inverter driven drives are:

- Save in consumed energy
- Improved reliability
- Fine starting
- Good speed variation
- Elevated power factor
- Less maintenance
- Improved life span of motor

Variable frequency induction motor drives are used from KW rating to few MW rating. Induction motor drives are used in modern day's refrigerators, pumps, elevators, lifts etc.

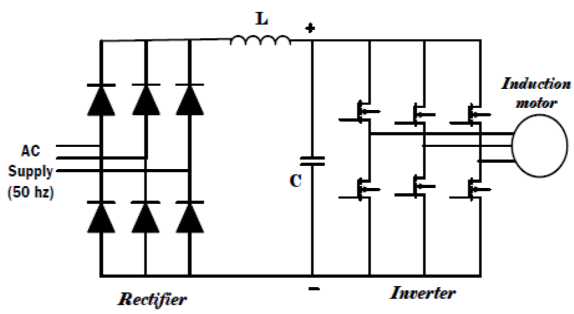



Fig 3: Circuit showing inverter fed Induction Motor drive

## 5. CASCADE H-BRIDGE TOPOLOGY OF MLI

A 5-level cascade H-Bridge topology of multi-level inverter was shown in figure 3.3. One phase of the circuit was shown and by adding another two similar legs, a three phase topology can be obtained. The look-a-like output waveform was also shown in figure 3.3.

The voltage levels of $V_{dc}$, $V_{dc}/2$, 0, $-V_{dc}/2$ and $-V_{dc}$ can be obtained by switching power switches from $T_1$ to $T_8$. Power switches $T_1$, $T_2$, $T_5$ and $T_6$ are termed as positive switches while switches $T_3$, $T_4$, $T_7$ and $T_8$ are termed as negative switches. Turning ON positive switches gives positive output while turning ON negative switches produces negative output. Turning ON $T_1$, $T_2$, $T_5$ and $T_6$ produces $V_{dc}$ at the output while all other power switches are turned OFF. Turning ON $T_1$, $T_2$ and $T_5$, $T_7$ gives $V_{dc}/2$. Turning $T_1$, $T_3$ and $T_5$, $T_7$ produces zero level of output across output terminals. Similarly, turning ON $T_3$, $T_4$ and $T_7$, $T_8$ produces $-V_{dc}$ at the output while all other power switches are turned OFF. Turning ON $T_3$, $T_4$ and $T_5$, $T_7$ gives $-V_{dc}/2$.

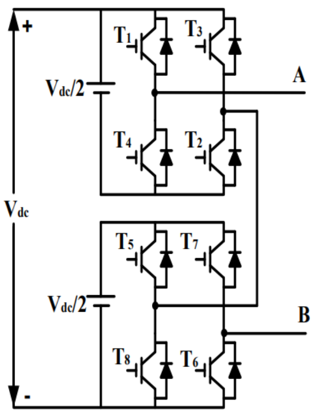



Fig 4: 5-level Cascade H-Bridge topology of multi-level inverters

Cascade H-Bridge topology uses separate DC sources for its operation. As shown in figure 3.3, upper bridge contains one DC source and similarly the lower bridge is driven from another DC voltage source. If the two or multiple DC sources have the same voltage, it is termed as symmetrical topology or else asymmetrical cascade H-Bridge topology of MLI. Switching ON the positive switches in upper bridge and lower bridge constitute the output voltage of $(V_{dc1}+V_{dc2})$ across A-B terminals. Higher voltage ratings at the output can be obtained from low input using this kind of topology which can be easily adopted for renewable energy source integration to grid. PV cell, fuel cell can be taken as input DC voltages and the output level can be increased while inverting to AC with this kind of topology.

## 6. PULSE WIDTH MODULATION (PWM) FOR CHB MLI

Pulse width modulation (PWM) is modulation in pulse sent to switch for its operation. PWM is nothing but how long the pulse is set to ON command in a prescribed time period. PWM is a digital signal used to control power electronic devices.

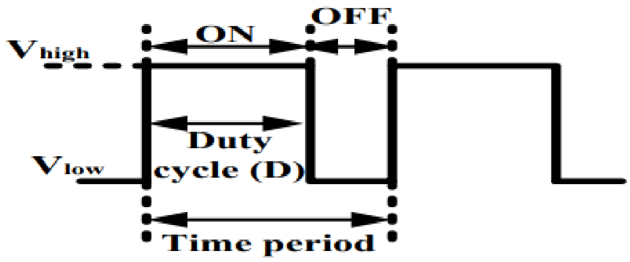



Fig 5: Pulse Width Modulation (PWM) pulse

A model PWM pulse was shown in figure 5. Pulse consists of two states high and low. The main element on which the pulse modulation depends on is duty cycle (D). Duty cycle is the period of pulse in which the pulse remains in ON state or high pulse. By modulating the pulse or otherwise, by varying the duty cycle ON time of pulse (high state) can be varied. With high pulse a power electronic static switch can be controlled.

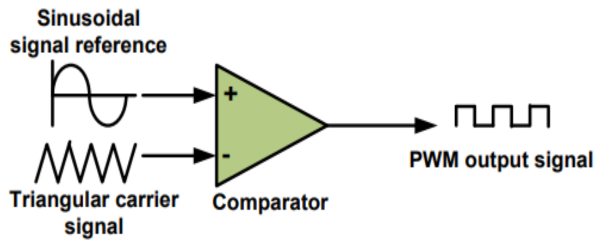



Fig 6: Diagram showing generation of pulse signal

The schematic arrangement for generation of pulse was depicted in figure 6. Pulse can be generated by comparing the reference signal with carrier signal using a comparator. Reference signal when super imposed on a carrier signal produces a pulse at the intersection points of reference and carrier waveforms. Whenever the reference sinusoidal signal is higher than the carrier waveform, pulse is high and vice-versa.

## 7. SEVEN-LEVEL CHB FED INDUCTION MOTOR DRIVE

A 7-level CHB topology fed induction schematic circuit was shown in figure 3.8. A 7-level CHB topology consists of four switches in H-shape fashion per bridge and three similar bridges connected in each phase. Similar another two phases together constitutes three- phase 7-level CHB inverter fed to induction motor. Inverter is at healthy condition and the simulation was carried out for the system with 7-level CHB fed induction motor under healthy condition and the results pertaining to the said system were shown. Phase voltage and line voltage of the 7-level inverter were shown under healthy conditions without fault along with line current and induction motor characteristics. Total Harmonic Distortion (THD) in phase voltage of inverter and stator current of induction motor were shown.

This chapter presents the basic introduction to inverters and multi-level inverters. Types of Multi-Level Inverters (MLI) are presented in detail. Comparison of MLI topologies is tabulated. PWM techniques for MLI are also presented in detail. 3-level CHB MLI fed induction motor (under healthy condition) is simulated and the results are presented. Similarly, 7-level CHB fed induction motor are simulated. Induction motor characteristics when inverter is healthy and respective harmonic distortion in phase voltage of inverter and harmonic distortion in stator current of induction motor are depicted.

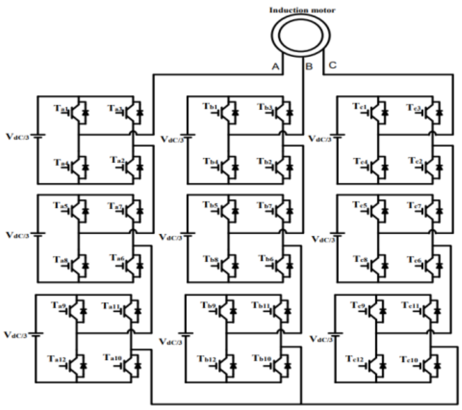



Fig 7: 7-level CHB fed induction motor

## 8. SIMULATION AND RESULTS

Inverter circuits are power electronic converter converting the DC type of electrical power to alternating type. Inverters employ power electronic switches for its conversion process. Failure in power electronic switches is very common in occurrence due to many reasons and faults in inverter are very common phenomenon.

This section discusses the methodology of the research work and tools that involved in the process to complete the design and implementation of the work. The methodology of the research is basically divided into four main phases. These phases are started with detailed study of the relevant topics followed by the design process, implementation, and test and result analysis.

## 9. SIMULATION OF CASCADE H BRIDGE SEVEN-LEVEL INVERTER

This section discusses the simulation and implementation of cascaded H bridge seven level inverter. For the understanding purpose section is divided into three part, the first one is three phase inverter model named as main inverter model, followed by subsystems and then will discusses the individual control block.

The main inverter model has three subsystems named as subsystems1, subsystems and subsystems as shown in the figure 8. The individual subsystem has 12 switches connected in the H shape. For seven -level inverter, three full bridge inverters are connected in series for making one phase, with a total number of 12 switches per phase are required. Fig 4.1 shows the simulation diagram for Seven-level inverter.

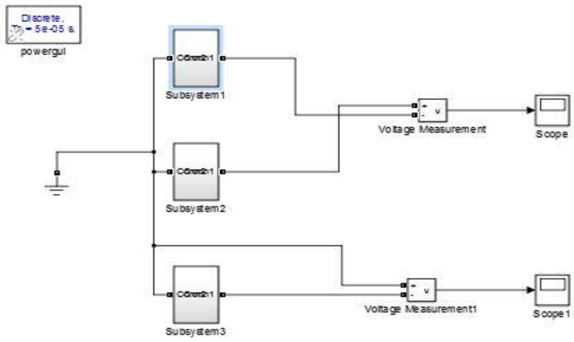



Fig 8 simulation diagram for seven-level inverter

As shown in fig. 8 output line-line voltage and phase to ground voltage of seven-level inverter are analyzed in terms of THD, order of harmonics. The three subsystems named 'subsystems 1', 'subsystems 2', and 'subsystems 3' shown All the switches are switched at fundamental frequency of 60 Hz. There are three waveforms have to be generated for three full bridge inverters and switching angle of these waveforms, which have calculated earlier, are described below.

$\alpha = 11.5^{o}$, $\beta = 28.71^{o}$, $\Upsilon = 57.1^{o}$,

So corresponding to these switching angles, suitable values of one block of MATLAB named 'constant' as shown in fig. 6.2, can be calculated from formulae described below, For $\alpha = 11.5^{o}$

$$\frac{90}{11.5}{}^{\circ} = \frac{2}{\text{Value of constant block equivalent to } 11.5^{\circ}}$$

$\alpha =$ 0.25 units

Similar calculation has to be done for $\beta, \Upsilon$, by the same formula given above giving the following values

$\beta = 0.638$ units, $\Upsilon = 1.268$ units,

Here control strategy for $\alpha = 0.25$ units is shown in fig. 4.2. For the remaining two full bridge inverters of phase-1, the control strategy is same as shown in fig. 4.2, except the value of 'constant' block is changed from 0.25 units to 0.638 units for '$\beta$', 1.268 units for '$\Upsilon$' . For the remaining phase the control strategy is same as shown in fig. 4.2, except the delay in triangular waveform of $120^{o}$is introduced in control strategy of phase 2 .Similarly in phase 3 delay is given of $240^{o}$.

## 10. RESULTS & DISCUSSION FOR SEVEN-LEVEL INVERTER

As according to theoretical concept, by adjusting the suitable value of MATLAB block set the output phase to neutral voltage of seven-level inverter is free from $5^{th}$, $7^{th}$, $11^{th}$ order harmonic. The output phase to neutral voltage waveform of seven-level inverter is shown, which has seven steps, each step has the size of 50 volts. Fig. 9 shows the FFT analysis of phase to neutral voltage, in which $5^{th}$ order harmonic voltage is 0.08% of fundamental component of output voltage, $7^{th}$ order harmonic voltage is 0.20% of fundamental component of output voltage and 11thorder harmonic voltage is 0.34% of fundamental component of output voltage and THD of output phase to neutral voltage is 12.49%. The maximum value of fundamental component of line-neutral voltage is 159.2volts.

The simulation results of phase voltage for the phase are shown in Figure 9. In the figure x axis shows the time scale while y axis is shows the magnitude of the phase voltage. The figure clearly shows that all of the desired voltage levels i.e 7 levels are generated using the cascaded H bridge inverter.

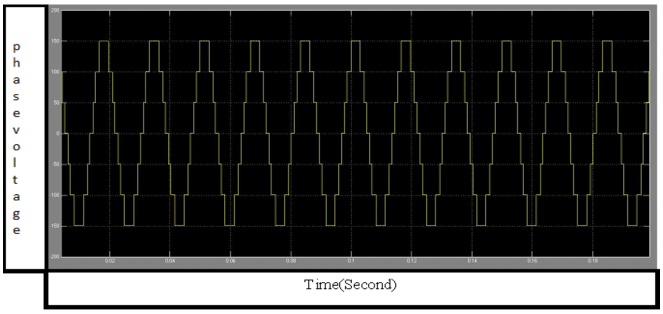



Fig.9 Output phase to neutral voltage waveform of seven-level inverter

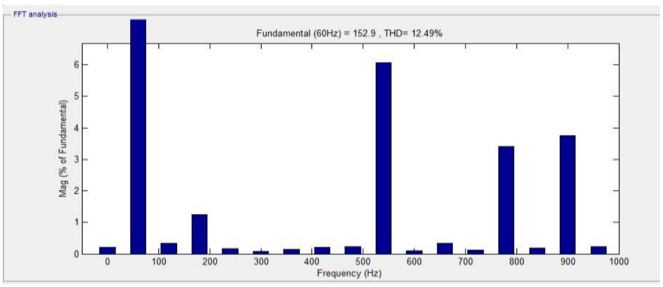



Fig. 10 FFT analysis of phase to neutral voltage waveform of seven-level inverter

In seven-level inverter, seven levels/steps are observed in output phase to neutral voltage. Fig. 10 shows the output line-line voltage waveform of seven-level inverter, which has more than seven steps. Fig. 11 shows the FFT analysis of output line-line voltage of seven-level inverter, in which maximum value of fundamental component of line-line voltage is 259.5 volts with THD of 8.94.

It can be verified from the figure 4.5 that the THD of the voltage waveform is 12.49 % while the magnitude of the Fundamental component is 152.9.

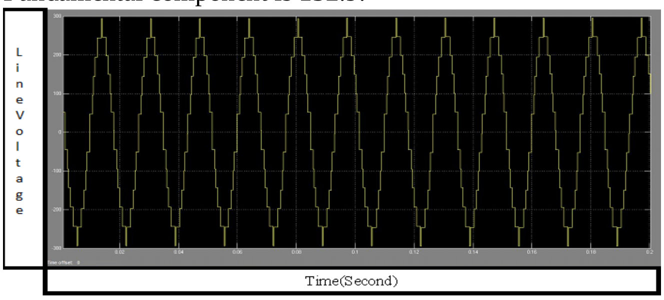



Fig.11 Output line-line voltage waveform of seven-level inverter

Above figure i.e. figure 11 shows the output waveform of line to line voltages. As the figure depicts that X axis shows the magnitude of the line voltage and Y axis shows the time in Seconds(s). It is observed from the figure that the output has all the seven level as desired in the case, but it is also noted that upper most and lower most steps has steep pulse shape.

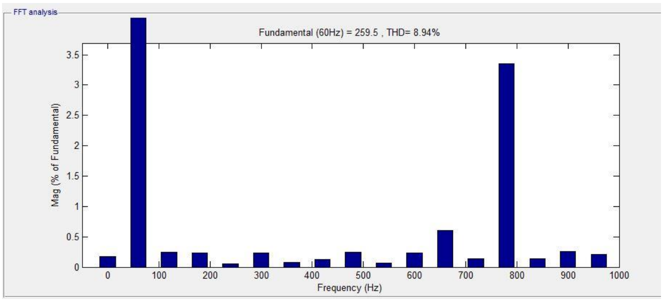



Fig. 12 FFT analysis of line-line voltage waveform of seven-level inverter

Another important conclusion that can be drawn from the results is that of the THD of the line to line voltage is further improved. Since third harmonic injection results in an increase of magnitude in voltage and THD of the line to line voltage. It can be verified from the fig.12 that THD is about 8.94% and the magnitude of the line to line voltage is 259.5.

## 11. SIMULATION OF CASCADE H-BRIDGE SEVEN-LEVEL INVERTER FED INDUCTION MOTOR DRIVE

The effectiveness of the proposed scheme is verified through simulation in MATLAB/Simulink on a three-phase induction motor, which has simulation parameters shown on the table 4.1. We use 5 HP power rating of the motor, Rotor type - Squirrel cage, Frequency – 60 Hz, Rated Speed – 1750 rpm, Stator and rotor resistance(Rs(ohm)) Ls(H) - 1.115, 0.05974 respectively and Mutual inductance Lm(H) – 0.2037 for the simulation purpose.

**Table 1** – Parameters of three-phase induction motor

| Serial No. | Parameter | Value |
|---|---|---|
| 1 | Power rating | 5HP |
| 2 | Rotor type | Squirrel cage |
| 3 | Frequency | 60 |
| 4 | Rated Speed | 1750 rpm |
| 5 | Stator and rotor resistance(Rs(ohm)) Ls(H) | 1.115, 0.05974 |
| 6 | Mutul inductance Lm(H) | 0.2037 |

Here, below the cascade h-bridge MLI fed induction motor drive is shown in fig 4.8.The motor used here is asynchronous induction motor.

An electrical machine is a device which converts one form of energy to other wherein an electric motor is an electro-mechanical device which converts electrical energy to mechanical energy. Scientifically, the first electric motor was developed by Michael Faraday in 1820s which worked by using a simple current carrying conductor with a magnetic field. Since then many scientists worked electric motors and brought the present shape looking like cylinder.

Electrical supply is given to the motor and mechanical output is collected as an output. Motors are mainly classified as AC and DC motors. This classification is based on the supply given to or passed to conductors. When DC current is passed to conductors constitutes DC motor and if supply is AC current, called as AC motor. There will be constructional changes for AC and DC motors. The previously given construction is for DC motors and AC motors are constructed with slight difference but not much varied from DC motors.
AC motors are mainly used in linear applications, pumps, fans, machine tools, boilers, mills, rotary compressor fan of air-conditioner, robots.

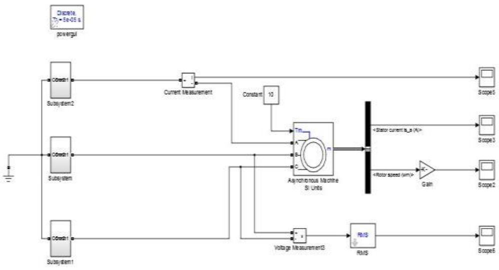


Fig 13 simulation diagram for seven-level inverter fed induction motor drive

Figure 13 shows the main simulation model of seven-level inverter fed induction motor drive. In the model we have use the same subsystems as simulated in the preceding section of simulation of the seven level h bridge cascaded inverter.
The output of the seven level h bridge cascaded inverter is fed to the induction motor which has 5 HP power rating of the motor, Rotor type - Squirrel cage, Frequency – 60 Hz, Rated Speed – 1750 rpm, Stator and rotor resistance(Rs(ohm)) Ls(H)) - 1.115, 0.05974 respectively and Mutual inductance Lm(H) – 0.2037 for the simulation purpose.

The analysis is being taken from the asynchronous machine i.e. from induction motor by an electrical bus. The electrical bus is then connected to the scope2 and scope3 where we take the output for stator current and rotor speed. The results of the simulation of the seven level h bridge cascaded inverter fed induction motor drive is discusses in the subsequent sections.

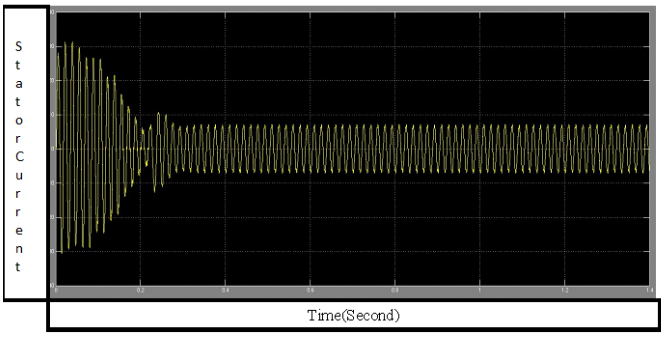



Fig 14 waveform of stator current of three phase induction motor

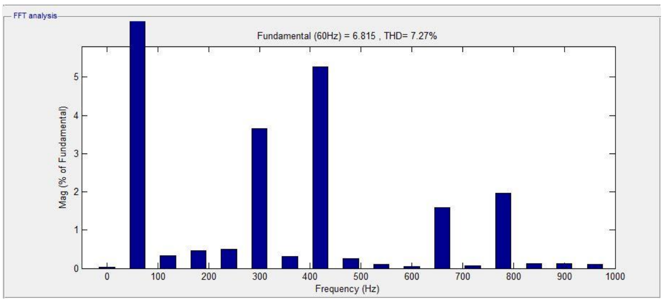



Fig 15. FFT analysis of stator current of three phase induction motor

The result indicates improvement in quality of torque. As a consequence, we managed to get a good response of induction motor by sending information through 24 IGBTs. The comparison results for using 5-level cascaded H-bridge inverter, and using the classical inverter [8], shows that the introduction of the 5-level cascaded H-bridge inverter on the control system, gives better control and robustness.

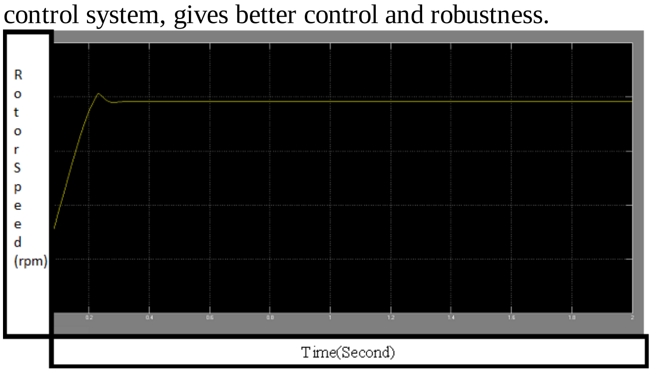



Fig4.18waveform of rotor speed of induction motor

## 12. CONCLUSION

The proposed technique for multilevel inverter fed induction motor drive is an effective and promising approach. The given modulation technique is a selective harmonic elimination for performance improvement. Types of multi-level inverters and different types of PWM techniques for inverters were discussed.
CHB topology of multi-level inverters is found to have less number of switching components giving simple structure. CHB topology with in-phase disposition PWM technique was developed to drive induction motor using MATLAB/SIMULINK software and the induction motor characteristics along with inverter outputs were studied for 7-

level MLIs when inverter is under healthy condition with no fault.

Simulation results for the proposed work were presented. THDs in stator current of induction motor and phase voltage of inverter were tabulated for the proposed work before and after fault occurrence.

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