



Fuzzy Based Speed Controller for Reduced Switches Multi Level Inverter Fed Induction Motor Drive

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ABSTRACT—

Multi-level inverter technology has emerged recently as a very important alternative in the area of high-power medium-voltage energy control. However, output current of the inverter as well as the time duration of the redundant switching states have been neglected. Moreover the advantages like high quality power output, low switching losses, low electro-magnetic interference (EMI) and high output voltage made multilevel inverter as a powerful solution in converter topology. Conventionally cascaded H-bridge multi level inverter used. The main disadvantage with the cascaded H-bridge inverters is high number of power switches which makes the control method complex and hence high cost. This paper presents a nine level inverter using reverse voltage topology. This topology requires less power switches compared to conventional multilevel inverter and less carrier signals and gate drives. The proposed reverse voltage inverter is studied under open loop and fuzzy based closed loop controllers. For the analysis of the speed responses of the induction motor under open loop and fuzzy based closed loop control techniques detailed simulation has been carried out in MATLAB/Simulink.

Key words: CHBMLI; Reverse voltage technique (reduced switches); fuzzy logic controller; Multi carrier PWM; phase disposition SPWM; THD; 3 phase squirrel cage induction motor drive

I. INTRODUCTION

The multilevel inverters are used in high power and high voltage industry. The main advantages of multilevel inverters are lower Total Harmonic Distortion (THD), less stress on the power switches

and higher efficiency. The harmonic content of the output decreases as the number of level increases. Many topologies have been introduced for multilevel inverters [1], [2]. Multilevel inverters enhances staircase waveform quality, it has less input current distortion, and lower electromagnetic interference. The multilevel inverters are used in drives, PV systems, and automotive applications.

The multilevel inverters are mainly classified as cascaded multilevel inverter [3] [9], Diode clamped multilevel inverter, Flying capacitor inverter. The control method of cascaded H Bridge multilevel is more convenient than other multilevel inverter because it doesn't have any clamping diode and flying capacitor. Cascaded multilevel inverter reaches higher reliability. The cascaded inverter is used for large automotive electric drives .

The main disadvantage is the increase in number of power switches that normally contributes to the complexity in controlling the power switches. Modulation strategies applied to multilevel inverters are selective harmonics elimination [4], carrier based pulse width modulation, space vector modulation [10], and fundamental frequency modulation. The pulse-width modulation (PWM) control is the most efficient method of controlling output voltage within the inverters. The carrier based PWM schemes used for multilevel inverters is the most efficient method, realized by the intersection of a modulating signal with triangular carrier waveform.

This paper proposes a nine-level inverter with reverse voltage topology which requires less number of switches than conventional topologies,

and Comparison of cascaded H bridge and reverse voltage technique nine level inverter is done. Induction motor is fed from cascaded h bridge inverter and open loop controlled, and reverse voltage technique multi level inverter in open loop and closed loop with fuzzy logic controller. Performance characteristics of induction motor at different speeds and torques are obtained.

II. CASCADED H-BRIDGE MULTILEVEL INVERTER

Cascaded multilevel inverters are based on a series connection of several single-phase inverters and are capable of reaching medium output voltage levels using only standard low-voltage mature technology components. Typically, it is necessary to connect three to ten inverters in series to reach the required output voltage. Each inverter can be seen as a module with similar circuit topology and modulation scheme. When a fault occur it is possible to replace it quickly. This inverter is obtained by connecting H-bridge inverters in series and output is sinusoidal. Each inverter level can generate $+V_{dc}$, 0 , $-V_{dc}$ [16] and the output voltage of multilevel inverter is the sum of the voltage that is developed by each inverter. The output voltage resembles sinusoidal waveform. The number of output voltage levels of multilevel inverter are $2n+1$, where n is the number of cells.

It requires less number of components comparative to the diode clamped or the flying capacitor. Fig.1 shows a single phase leg of nine level cascaded H bridge multilevel inverter. The number of switching devices in n level cascaded multilevel inverter is $2(n-1)$, where n is the number of the output voltage level. For a nine level inverter 16 switches and 4 DC sources are needed. The structure of separate DC source makes it possible to use renewable energy sources. It is possible to use soft switching techniques to reduce the switching losses and device stresses.

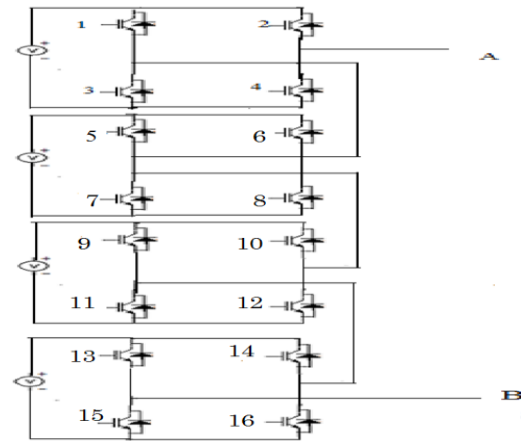


Fig.1 Single phase nine-level cascaded inverter.

Fig.1 shows the single phase leg structure of nine-level cascaded inverter. Here each full bridge inverter produces different output voltages which are $+V_{dc}$, 0 , $-V_{dc}$ through various arrangement of four switches S_1 , S_2 , S_3 and S_4 . To get $+V_{dc}$, S_1 and S_4 are turned on, where $-V_{dc}$ can be acquired by turning on S_2 and S_3 . When turning on all the switches output voltage gives 0 . The output phase voltage levels are given by $m=2N+1$, where ' N ' is the number of dc sources and ' m ' gives number of levels [3]

A. Operation of nine-level cascaded H Bridge MLI fed induction motor drive:

The three phase induction motors are the frequently encountered machines in industry because of its simple design, rugged and easy maintenance. The frequency of induction motor is proportional to the synchronous speed. The rotating magnetic flux produced by three phase currents rotates with a constant speed where the supply frequency of the drive is proportional to synchronous speed. Hence the rotating flux and rotor current generate a force that drives the motor and accordingly torque will develop. For CHBMLI fed induction motor drive the inverter setup is based on series connection of single phase inverters with separate dc sources. The level shifted multi-carrier PWM principle is applied to CHBMLI where it uses many triangular carrier signals and one modulating signal. Fig.2 shows the PWM generation. In this the pulse pattern depends on the ratio of modulating $V_{control}$ to the peak carrier voltage V_{tri} referred as modulation index (M_a).

$$M_a = V_{control} / V_{tri}$$

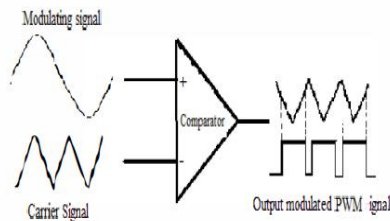


Fig. 2 PWM generation

The peak value of $V_{control}$ controls the amplitude and the frequency of $V_{control}$ controls the fundamental frequency. Fig.3 shows three-phase induction motor fed by nine level cascade inverter where the sub system for pulse generator have eight number of carrier signals. Four of them are applied across the positive half of the modulating signal duty cycle, remaining four is applied across the negative half of the modulating signal duty cycle. So 16 PWM signals are generated and then given to the sixteen switches of a leg. Similarly the pulses are generated for remaining phases. To get balanced three phase output modulation signal is phase shifted by 120°. Through inverter switching state line to ground voltage get easily controlled.

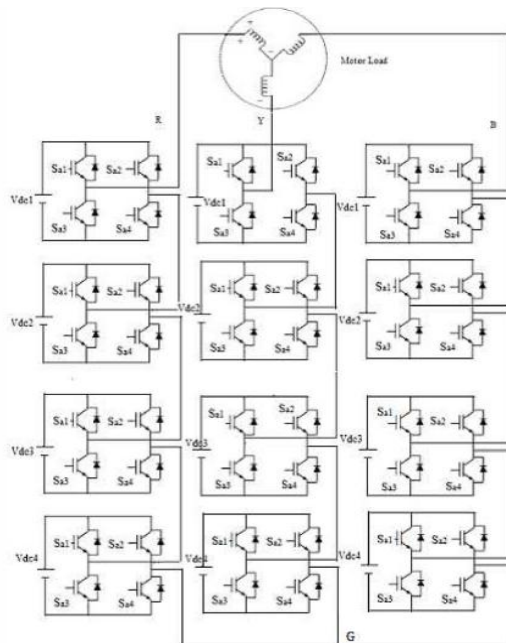


Fig. 3 Three phase induction motor fed by nine- level cascade inverter

III. PROPOSED REVERSE VOLTAGE TOPOLOGY

Conventional cascaded multilevel inverters require large number of switches [7] and the power switches are combined to generate an output in positive and negative polarities. In the proposed multilevel inverter there is no need to use all the switches in high frequency [12].

This topology separates the output voltage into level and polarity generation parts. Level generation part generates levels in positive polarity. And the polarity generation part generates the polarity of the output voltage. Level generation part needs high frequency switches and polarity generation part requires low-frequency switches operating at line frequency. Fig 4 shows the general block diagram of reverse voltage topology. Fig.5 shows schematic diagram of a single phase nine level reverse voltage topology. This multilevel inverter can be increased to higher voltage levels by increasing the middle section.

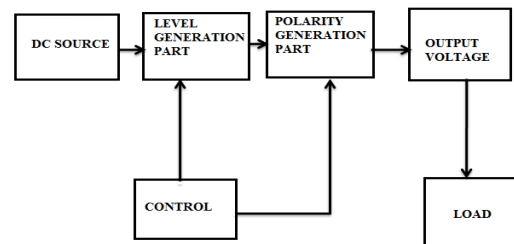


Fig.4 General block diagram

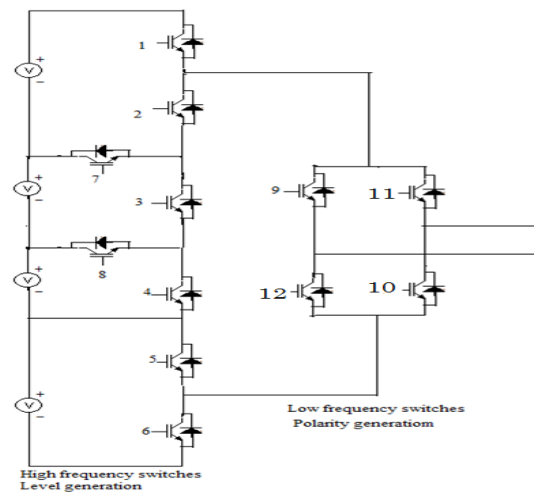


Fig.5 single phase Nine level inverter with reverse voltage topology

This topology requires less switches and it can be applied to three phase application. The Phase Disposition (PD) SPWM needs only half the number of conventional carriers for SPWM. PD-SPWM for nine-level conventional converters requires eight carriers, but in the proposed system only four carriers are needed. To generate polarity, the positive voltage is fed to the polarity generation part. Multilevel inverter control with less number of carriers is the main advantage.

Modes Of Operation

The switching modes are selected such that the switching transitions become minimal for avoiding the unwanted voltage levels. This will minimize switching power dissipation. The sequence of switches (2-3-4-5), (2-3-4-6), (2-3-8-6), (2-7-6) and (1-6) are used for levels 0 up to 4, respectively. The output voltage is the sum of voltage sources. Table I shows the switching sequences.

TABLE I
Switching Sequences For Each Level

Level \ Mode	0	V_{dc}	$2V_{dc}$	$3V_{dc}$	$4V_{dc}$
1	2,3,4,5	2,3,4,6	2,3,8,6	2,7,6	1,6

V_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}
V_4	1	0	0	0	0	1	0	0	1	1	0	0
V_3	0	1	0	0	0	1	1	0	1	1	0	0
V_2	0	1	1	0	0	1	0	1	1	1	0	0
V_1	0	1	1	1	0	1	0	0	1	1	0	0
V_0	0	1	1	1	1	0	0	0	1	0	0	1
$-V_1$	0	1	1	1	0	1	0	0	0	0	1	1
$-V_2$	0	1	1	0	0	1	0	1	0	0	1	1
$-V_3$	0	1	0	0	0	1	1	0	0	0	1	1
$-V_4$	1	0	0	0	0	1	0	0	0	0	1	1

Control Strategies

In this topology phase disposition-SPWM is adopted for its simplicity and all the carriers are in phase with each other. Here phase disposition SPWM is used for driving the high frequency switches and low frequency polarity generation part drive signals are generated with the line frequency (50Hz), and they only change at zero-voltage crossings. In the proposed topology a-phase modulation signal is compared with $(n-1)/2$ triangle waveforms for an n level inverter. The modular and four carriers are shown in Fig .6

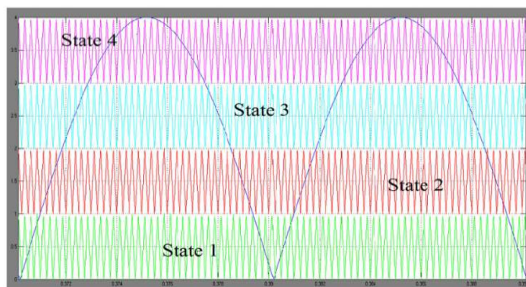


Fig.6 Modulator and SPWM carrier

IV. COMPARISON OF CASCADED H

BRIDGE AND REVERSE VOLTAGE TECHNIQUE NINE LEVEL INVERTER

CASCADED H BRIDGE NINE LEVEL INVERTER	NINE LEVEL INVERTER WITH REDUCED SWITCHES
Number of switching devices per phase are $2(n-1)=16$	Number of switching devices per phase are $(n-1)+4=12$
Requires $(m-1)=8$ carriers per phase	Requires $(m-1)/2=4$ carriers per phase
Switches operate at high frequency	Level generation part switches operate at high frequency. Polarity generation part switches operate at line frequency

The reliability of the system is indirectly proportional to the number of its components. One of the main advantages of this new topology is that it requires less high-switching frequency components. As the number of high-frequency switches is decreased, the reliability of the converter is increased and the number of switches in this topology is less and it will decrease with increase in voltage levels. Since this inverter works only in positive polarity, this topology requires half of the conventional carriers for SPWM controller. Thus new reverse voltage technique multi level inverter is more efficient than cascaded H bridge multi level inverter.

V. INDUCTION MOTOR

The AC induction motor is considered since its discovery as actuator privileged in the applications of constant speed, and it has many advantages, such as low cost, high efficiency, good self starting, its simplicity of design, the absence of the collector brooms system, and a small inertia. The induction motor is a rotating electric machine designed to operate from a 3-phase source of alternating voltage. For variable speed drives, the source is normally an inverter that uses power switches to produce approximately sinusoidal voltages and currents of controllable magnitude and frequency. A cross-section of a two-pole induction motor is shown in Figure 7.

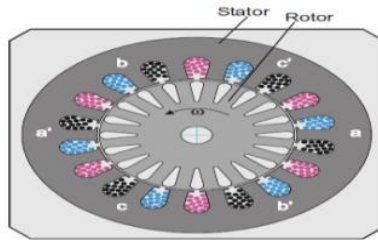


Fig.7 cross-section of induction motor

Slots in the inner periphery of the stator accommodate 3-phase winding a, b, c. The turns in each winding are distributed so that a current in a stator winding produces an approximately sinusoidally-distributed flux density around the periphery of the air gap. When three currents that are sinusoidally varying in time, but displaced in phase by 120° from each other, flow through the three symmetrically-placed windings, a radially-directed air gap flux density is produced that is also sinusoidally distributed around the gap and rotates at an angular velocity equal to the angular frequency, of the stator currents. The most common type of induction motor has a squirrel cage rotor in which aluminum conductors or bars are cast into slots in the outer periphery of the rotor. These conductors or bars are shorted together at both ends of the rotor by cast aluminum end rings, which also can be shaped to act as fans. In larger induction motors, copper or copper-alloy bars are used to fabricate the rotor cage winding.

As the sinusoidally-distributed flux density wave produced by the stator magnetizing currents sweeps past the rotor conductors, it generates a voltage in them. The result is a sinusoidally-distributed set of currents in the short-circuited rotor bars. Because of the low resistance of these shorted bars, only a small relative angular velocity, r , between the angular velocity, s , of the flux wave and the mechanical angular velocity of the two-pole rotor is required to produce the necessary rotor current. The relative angular velocity, r , is called the slip velocity. The interaction of the sinusoidally-distributed air gap flux density and induced rotor currents produces a torque on the rotor. The typical induction motor speed-torque characteristic is shown in Figure 8.

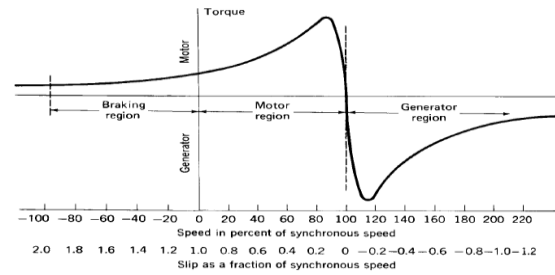


Fig.8 Induction Motor Speed-Torque Characteristics

VI. FUZZY LOGIC CONTROLLER

FLC approach is very useful for induction motor speed drives since no exact mathematical model of the induction motor or the closed-loop system is required. FLC has a fixed set of control rules, usually derived from expert's knowledge.

A fuzzy controller converts a linguistic control strategy into an automatic control strategy. There are basically three essential segments in Fuzzy Logic Controller as in fig 9 viz.

1. Fuzzification block or Fuzzifier.
2. Inference System.
3. Defuzzification block or Defuzzifier.

The first step towards designing a Fuzzy Logic Controller is choosing appropriate inputs which will be fed to the same. These input variables should be such that, they represent the dynamical system completely. Fuzzy logic uses linguistic variables for processing information. But since the inputs to the FLC are in the form of numerical variables (or in other words, crisp sets), they need to be converted into linguistic variables. Fuzzy controller will read error and change in error. Here Triangular membership function and mamdani inference system used.

Fuzzification- The function of converting the crisp sets into fuzzy sets (linguistic variables) is performed by the fuzzifier called as fuzzification.

To convert the numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big) as shown in table II.

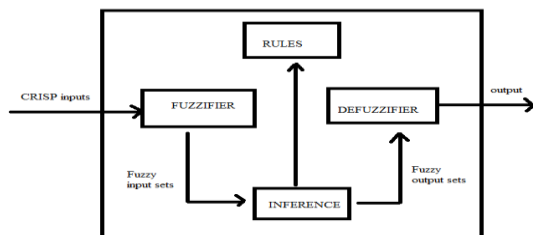


Fig.9 General Structure of the fuzzy logic controller

De-fuzzification- The rules of FLC generate required output in a linguistic variable (Fuzzy Number), according to real world requirements, linguistic variables have to be transformed to crisp output (Real number) by defuzzifier.

Inference- consists of rule base, data base and reasoning mechanism.

Rule Base: It consists of a number of If-Then rules. The If side of the rule is called the antecedent and the Then side is called the consequence. These rules are very much similar to the Human thought process and the computer uses the linguistic variables, derived after fuzzification for execution of the rules. They very simple to understand and write and hence the programming for the fuzzy logic controller becomes very simple. The control strategy is stored in more or less the normal language.

Database: It consists of the all the defined membership functions that are to be used by the rules.

Reasoning Mechanism: - It performs the inference procedure on the rules and the data given to provide a reasonable output. It is basically the codes of the software which are process the rules and the all the knowledge based on a particular situation. It exercises a human brain type of attribute to methodically carry out the inference steps for processing the information.

Table II
Rules for error and change of error

ce	e	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	NVS	Z
NM	NB	NB	NM	NS	NVS	Z	PVS	PVS
NS	NB	NM	NS	NVS	Z	PVS	PS	PS
Z	NM	NS	NVS	Z	PVS	PS	PM	PM
PS	NS	NVS	Z	PVS	PS	PM	PB	PB
PM	NVS	Z	PVS	PS	PM	PB	PB	PB
PB	Z	PVS	PS	PM	PB	PB	PB	PB

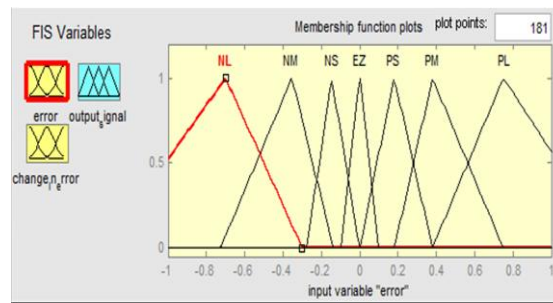


Fig. 10 The Membership Function plots of error

The figure.11 shows the block diagram for Fuzzy Logic Closed Loop Control of 9 level Multi Level Inverter Driven Three phase Induction motor.

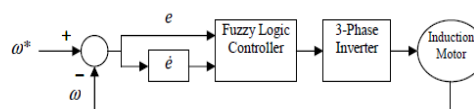


Figure 11. Block diagram of fuzzy logic based speed control system for induction motor

The Induction motor speed can be controlled by varying torque input of the motor. First the reference speed i.e. the rated speed of induction motor is compared with speed feedback. The angular speed obtained from motor is converted into speed using appropriate block. The feedback speed and reference speed are changed into proportionate values of current and compared with actual value of current, thus error and change of error fed to fuzzy logic controller through fuzzification blocks. The fuzzy controller gives the output, which is fed to control signal generation block through defuzzification block. The control signal generation block generates sinusoidal signal which is fed to PWM generation block. Thus switching pattern is generated by comparing a sinusoidal signal with triangular carrier waves at high frequency, for each phase of Inverter and fed to appropriate switches in Multi Level Inverter circuit. Then Multi Level Inverter generates a.c. signal which is given as input to Induction motor, thus motor speed is controlled.

VII. SIMULATION RESULTS

CHBMLI and reverse voltage topology MLI gives the near sinusoidal voltage waveforms to drive the induction motor. The MATLAB/ Simulink are used to simulate the three phase induction motor drive fed by 9-level cascaded h bridge open loop controlled and reverse voltage technique multi level inverter open loop controlled and closed loop

controlled by fuzzy logic controller. By this for specific period of time the user can simulate the system thus it is possible to analyze the time response of system.

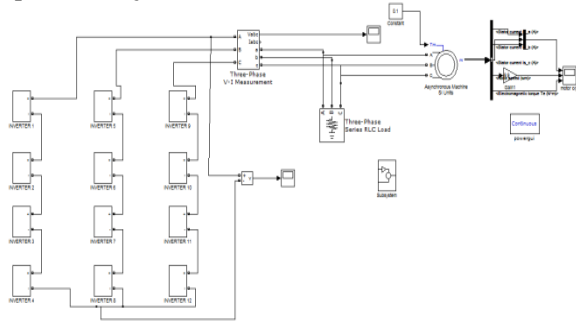


Fig.12 matlab/simulink model of nine level cascaded inverter fed to induction motor and open loop controlled

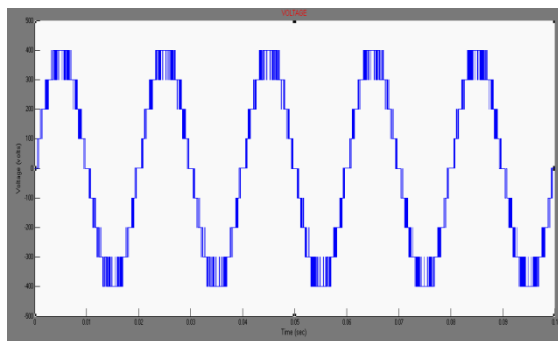


Fig.13 shows the simulation output voltage of nine level inverter

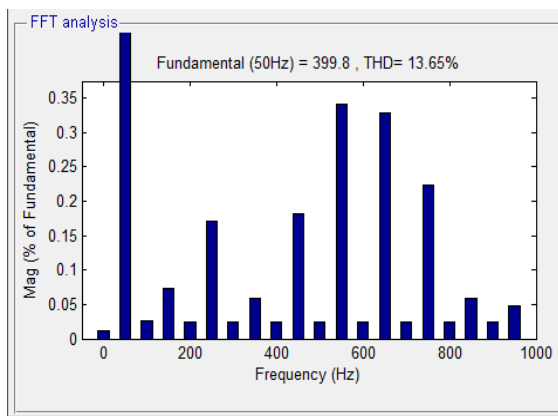


Fig.14 shows the THD analysis of nine level output voltage with cascaded H bridge MLI

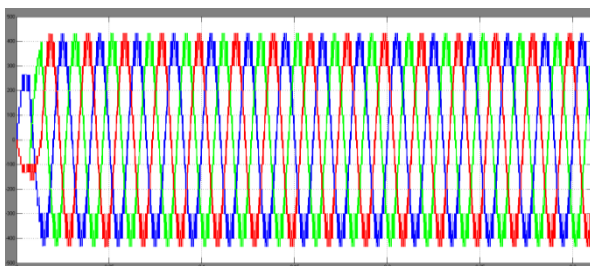


Fig.15 shows the simulation three-phase output voltage of nine level inverter

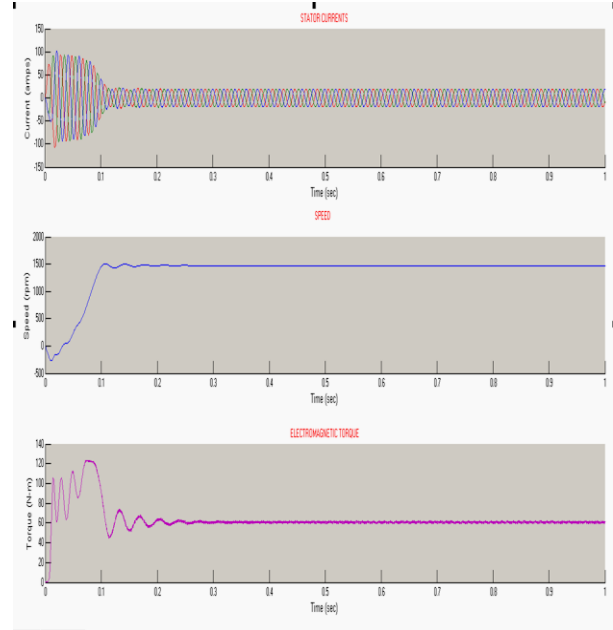


Fig.16 shows the performance characteristics of induction motor fed from Cascaded h bridge nine level inverter and open loop controlled at load torque=60 N-mt

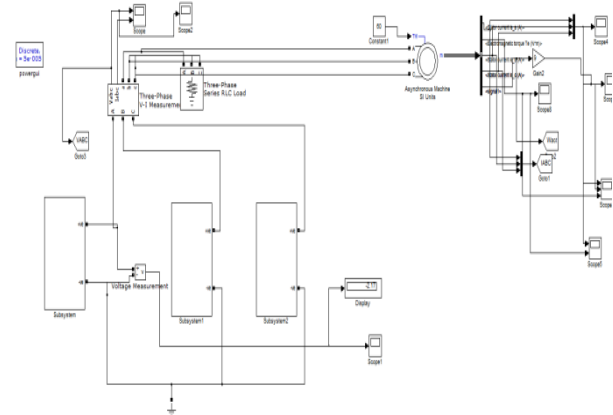


Fig.17 Simulink model of the proposed 9 level inverter fed induction motor with reduced number of switches with open loop controller.

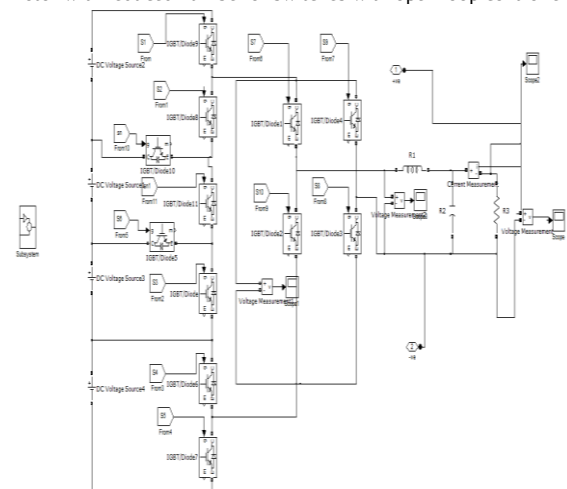


Fig.18 Simulink model of the proposed Single phase 9 level inverter with reduced number of switches and open loop controller

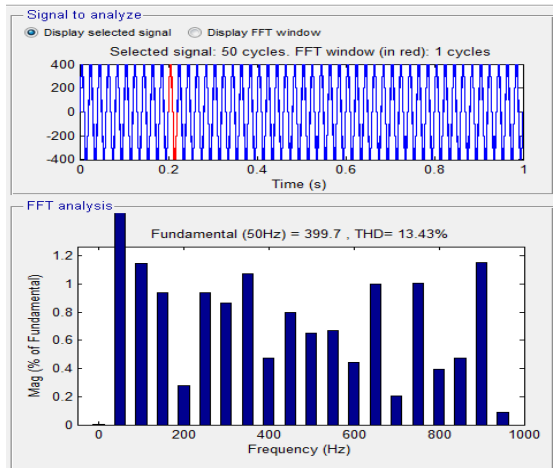


Fig.19 shows the THD analysis of nine level voltage with reverse voltage technique MLI

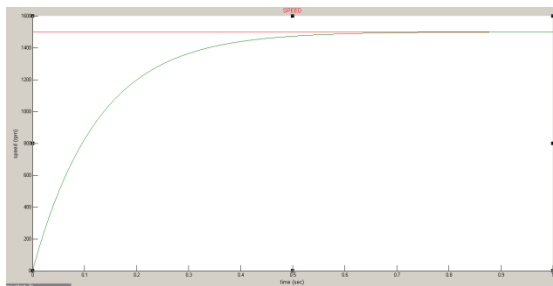


Fig.20. Speed reaching steady state at 0.7 sec under open loop operation of inverter fed IM

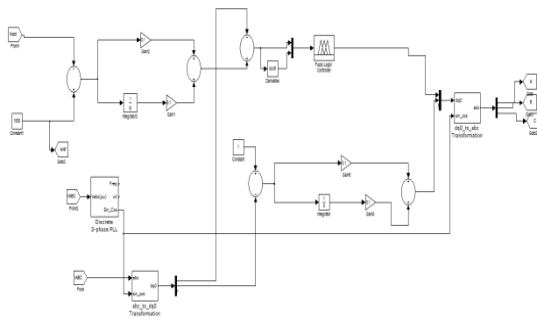


Fig.21 Fuzzy based closed loop Speed controller.

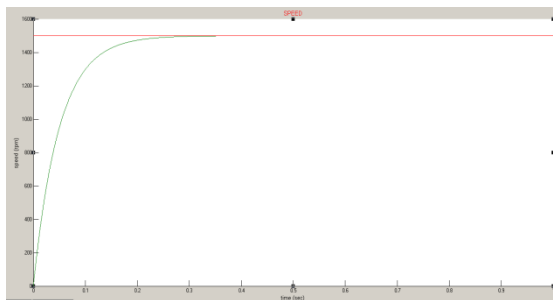


Fig.22 Speed reaching steady state at 0.28 sec under fuzzy controlled closed loop operation of inverter fed IM

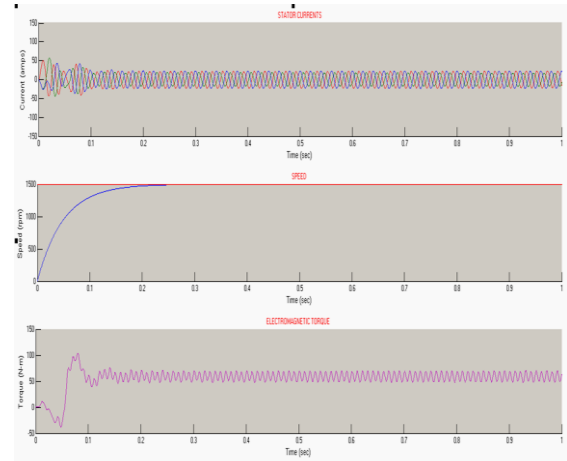


Fig.23 shows the performance characteristics of induction motor fed from nine level inverter with reduced switches and fuzzy controlled closed loop at load torque=60 N-mt.

With fuzzy logic controller

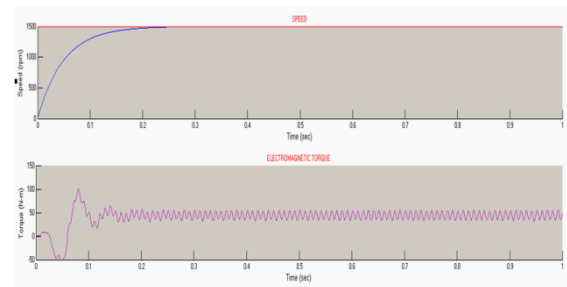


Fig.24 shows the torque-speed variation when T=45 N-m and speed=1500 rpm

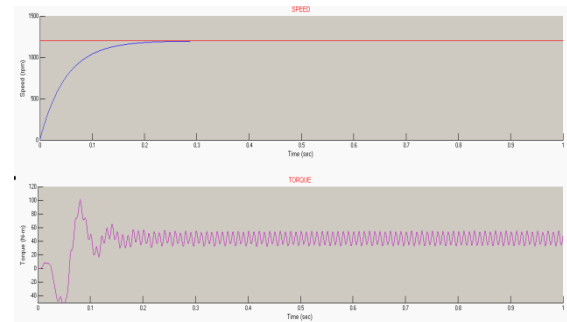


Fig.25 shows the torque-speed variation when T=45 N-m and speed=1200 rpm

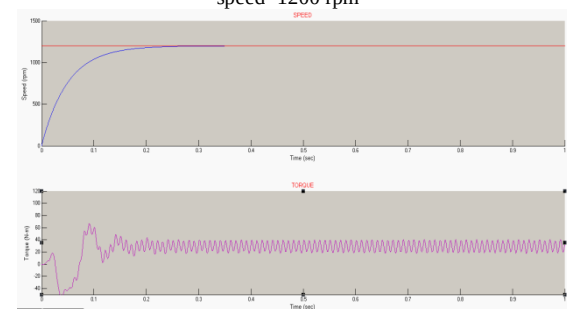


Fig.26 shows the torque-speed variation when T=30 N-m and speed=1200 rpm

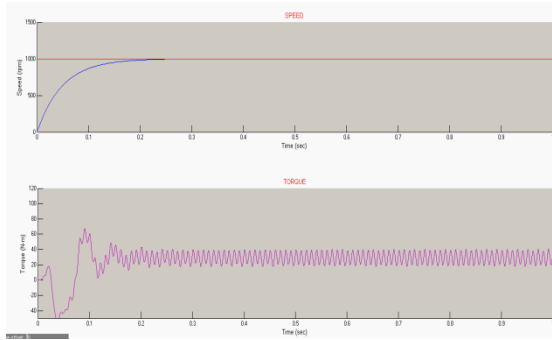


Fig.27 shows the torque-speed variation when
 $T=30$ N-m and speed=1000 rpm

VIII. CONCLUSION

This paper analysis the performance of Induction motor under open loop and fuzzy based closed loop reverse voltage inverter. In the proposed topology switching operations are separated into high and low frequency parts. Instead of using cascaded inverter topology, proposed topology is more convenient for all these applications because it has less complex control method, associated cost is less and gives less THD of 13.43%. Hence proposed topology is more convenient than conventional cascaded inverter. The background study based on the various aspects of the PWM firing scheme was analyzed. The Fuzzy based carrier based PWM scheme using the Phase Disposition (PD) strategy is used here. PD-SPWM control method is less complex since it uses only positive carriers for PWM control. The proposed fuzzy based PWM strategy reduces both error and change in error hence the speed response is high. From the simulation observations the response of the open loop controlled speed characteristics is 0.7secs, the same induction motor when controlled with fuzzy based closed loop control technique its speed response reaches steady state in 0.28 secs.

Appendix-Parameters of Three-phase squirrel-cage induction motor drive

Output power -10kw (13HP)
Rotor type- Squirrel-cage
Voltage(line-line)- 415Vrms
Frequency -50Hz
Stator resistance- 1.115(ohm)
Stator inductance- 0.005974(H)
Rotor resistance -1.083(ohm)
Rotor inductance -0.005974(H)
Mutual inductance- 0.2037(H)
Inertia- 0.02J(kg-m²)

Friction factor
and pairs of poles- 0.005752&2F(N.m.s)

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