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Analysis of Seven and Nine Levels Multilevel Inverters for Energy Saving in Induction Motor Drive for VTL Application

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***Abstract*: In This paper proposes the concepts of seven and nine levels multilevel inverter for energy saving in induction motor drives for variable torque load (VTL) application. The main objective here is to analyze the seven level and nine level diode clamped multilevel inverter for control the speed of an induction motor with respect to their variable loads. To give high quality sinusoidal input voltage with reduced harmonics to IMD(Induction motor Drive) The proposed Scheme for diode clamped multilevel inverter is multicarrier SPWM(sinusoidal pulse width modulation) control. The V/f technique is used to obtain an open loop speed control. This method can be implemented by changing the supply voltage and frequency applied to the three phase induction motor at constant ratio. The proposed method (7-Level MI) are an effective replacement for the conventional method which has high switching losses, as a result a poor drive performance. The 9-level multilevel inverter having better performance than 7-level multilevel inverter. According to the simulation results point of view the effective control in the motor speed and an enhanced drive performance through reduction in total harmonic distortion (THD) with 9 level is optimum. The effectiveness of the system is verified through simulation using MATLAB SIMULINK 7.8.0.347(R2009a) package.**

***Keywords:* Diode clamped multilevel inverter; Sinusoidal Pulse Width Modulation; Induction motor; Multicarrier PWM technique; THD; V/*f* method.**

I. INTRODUCTION

1. *Induction Motor*

An induction motor being rugged, reliable, and relatively inexpensive makes it more preferable in most of the industrial drives. They are mainly used for constant speed applications because of unavailability of the variable-frequency supply voltage. But many applications are in need of variable speed operations. In early times, mechanical gear systems were used to obtain variable speed. Recently, power electronics and control systems have matured to allow these components to be used for motor control in place of mechanical gears. These electronics not only control the motor's speed, but can improve the motor's dynamic and steady state characteristics. Adjustable speed ac machine system is equipped with an adjustable frequency drive that is a power electronic device for speed control of an electric machine. It controls the speed of the electric machine by converting the fixed voltage and frequency to adjustable values on the machine side. High power induction motor drives using classical three – phase converters have the disadvantages of poor voltage and current qualities. To improve these values, the switching frequency has to be raised which causes additional switching losses. Another possibility is to put a motor input filter between the converter and motor, which causes additional weight. The diode clamped method can be applied to higher level converters. As the number of level increases, the synthesized output waveform adds more steps, producing a staircase waveform. A zero harmonic distortion of the output wave can be obtained by an infinite number of levels.

In this paper, a three-phase diode clamped multilevel inverter fed induction motor is described. The diode clamped inverter provides multiple voltage levels from a five level unidirectional voltage balancing method of diode clamped inverter. The voltage across the switches has only half of the dc bus voltage. These features effectively double the power rating of voltage source inverter for a given semiconductor device. The proposed inverter can reduce the harmonic contents by using multicarrier SPWM technique. It generates motor currents of high quality. Here the speed of an induction motor is precisely controlled by using seven level diode clamped multilevel inverter.

1. Multilevel Inverter

Recently, the multilevel converter is widely applied in the industries because the demand to operate switching, power converters in high power application has the development continuously. The ability of multilevel converters to operate at high voltages of the AC waveforms has low distortion, high quality and high efficiency. However, the multilevel converter technology has improved efficiency by employing various controls to achieve the high efficiency and maximize to save energy. In this paper, the topology presented nine-level diode-clamp inverter and principle are implemented to control the output waveform approaching to the sine-wave as close as possible. A nine-level PWM inverter to reduce the Total Harmonic Distortion (THD) of the inverter output voltages for three-phase induction motor drive are presented.

Inverter is a device that converts DC power into AC power at desired output voltage and desired frequency. Inverters used in some industrial applications as induction heating, UPS for computers, hvdc transmission lines. In the multilevel inverter the level indicates the accuracy of the pulses like when the number of levels increases accuracy will increases. Inverter levels referred to as the number of nodes to which it is accessible.

There are three types of multi level inverters they are

1. Cascade H-bridge multilevel inverter
2. Diode clamped multilevel inverter
3. Flying capacitor type multilevel inverter

It includes utility interface of renewable energy, voltage regulation. Inverters are used as VAR compensation and harmonic filtering in power systems. These multi level inverters are used in Uninterruptable Power System. These are used in low power energy applications like Sense Amplifier Pass Transistor Logic (SAPTL) Transistor Logic (SAPTL) VLSI Circuits.

II. CONVENTIONAL METHOD

The seven level diode clamped multi level inverter as shown in figure 1 .It contains 36 unidirectional switches and 30 neutral point clamping diodes. The middle point of the 6 capacitors “n” can be defined as the neutral point. The major benefit of this configuration is each switch must block only one-half of the dc link voltage (Vdc/6). In order to produce seven levels, only two of the twelve switches in each phase leg should be turned on at any time. The diodes are all same type to provide equal voltage sharing and to clamp the same voltage level across the switch, when the switch is in off condition. Hence this structure provides less voltage stress across the switch..

Principle of Operation:

The below Table.1. Shows the voltage levels and their corresponding switch states. In this switch states shows 1 means the switch is on, 0 means the switch is off. There are two complementary switch pairs in each phase. The pairs of the inverter are (A1,A1’) , (A2,A2’) , (A3,A3’) , (A4,A4’) , (A5,A5’) , (A6,A6’) . If one of the complementary switch pairs is turned on, the other of the same pair must be off.

TABLE 1. Output voltage levels and their switching states

Voltage V_{a0}	Switch State											
	A 1	A 2	A 3	A 4	A 5	A 6	A 1’	A 2’	A 3’	A 4’	A 5’	A 6’
V7	1	1	1	1	1	1	0	0	0	0	0	0
V6	0	1	1	1	1	1	1	0	0	0	0	0
V5	0	0	1	1	1	1	1	1	0	0	0	0
V4	0	0	0	1	1	1	1	1	1	0	0	0
V3	0	0	0	0	1	1	1	1	1	1	0	0
V2	0	0	0	0	0	1	1	1	1	1	1	0
V1	0	0	0	0	0	0	1	1	1	1	1	1

To produce a staircase-output voltage, The steps to synthesize the seven-level voltages are as follows.

- For an output voltage level V_{ao}=Vdc, turn on all upper-half switches A1,A2.A3,A4,A5 and A6
- For an output voltage level V_{ao} = 5Vdc/6, turn on upper switch A2.A3,A4,A5,A6 and one lower switch A1'.
- For an output voltage level V_{ao}= 4Vdc/6, turn on all lower half switches A3, A4, A5, A6 and A1', A2'.
- For an output voltage level V_{ao}= Vdc/2, turn on all lower half switches, A4, A5, A6, and A1', A2'.A3'.
- For an output voltage level V_{ao}= Vdc/3, turn on all lower half switches, A5, A6, and A1', A2'.A3', A4'.
- For an output voltage level V_{ao} = Vdc/6, turn on all lower half switches, A6 and A1', A2'.A3', A4', A5'.
- For an output voltage level V_{ao} = 0, turn on all lower half switches , A1',A2'.A3',A4',A5' and A6'

The most attractive features of multilevel inverters are as follows:

- They can generate output voltage switch extremely low distortion and lower dv/dt.
- They draw input current with very low distortion.
- They generate smaller common mode (CM) voltage, thus reducing the stress in the motor bearings.

They can operate with a lower switching frequency.

III. DRIVE SYSTEM DESCRIPTION

Initially we are using PWM technique, so the voltage and current are poor qualities and the switching frequency causes more switching loses. Those drawbacks are rectified using three phase diode clamped multilevel inverter. Improving this in 7 and 9 levels we are using 3-ø diode clamped multilevel inverter (DCIM). The voltage and current quality are better and the switching losses are reduced when compared to the conventional technique. Also the THD is found to be better.

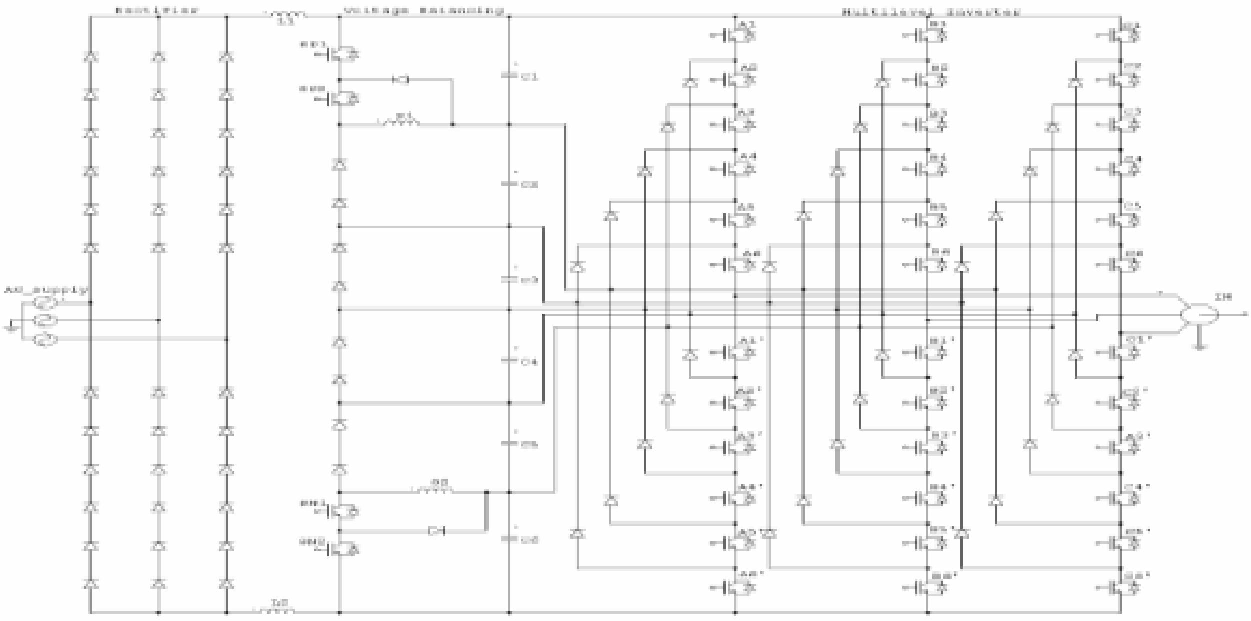

Figure. 1 seven level inverter based drive circuit

IV. PROPOSED SCHEME

The block diagram of multilevel inverter fed three phase induction motor is show in figure.2. The complete system will consist of two sections; a power circuit and a control circuit. The power section consists of a power rectifier, filter capacitor, and three phase diode clamped multilevel inverter. The motor is connected to the multilevel inverter. An ac input voltage is fed to a three phase diode bridge rectifier, in order to produced output voltage across a capacitor filter. A capacitor filter, removes the ripple contents present in the dc output voltage. The pure dc voltage is applied to the three phase multilevel inverter through capacitor filter. The nine-level multilevel inverter has 48 IGBT switches that are controlled in order to generate an ac output voltage from the dc input voltage. The control circuit of the proposed system consists of three blocks namely microcontroller, opto-coupler and gate driver circuit. The microcontroller is used for generating gating signals required to drive the power IGBT switches present in the multilevel inverter. The voltage magnitude of the gate pulses generated by the microcontroller is normally 5V. To drive the power switches correctly the opto-coupler and driver circuit are necessary in between the controller and multilevel inverter. The output ac voltage is obtained from the multilevel inverter can be controlled in both magnitude and frequency (V/f open loop control). The controlled ac output voltage is fed to the induction motor drive. When the power switches are on current flows from the dc bus to the motor winding. The motor windings are highly inductive in nature; they hold electric energy in the form of current. This current needs to be dissipated while switches are off. Diodes are connected across the switches give a path for the current to dissipate when the switches are off. These diodes are also called freewheeling diodes. The V/f control method permits the user to control the speed of an induction motor at different rates. For continuously variable speed operation, the output frequency of multilevel inverter must be varied. The applied voltage to the motor must also be varied in linear proportion to the supply frequency to maintain constant motor flux.

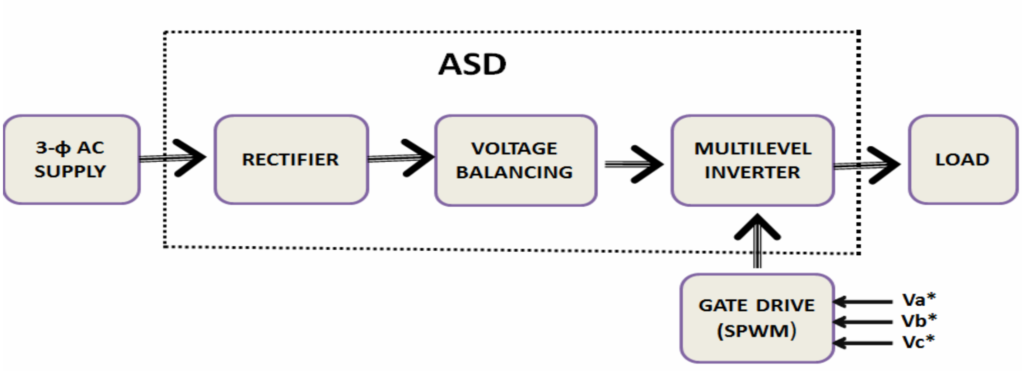

Figure.2 Basic block diagram

Table2. Shows the Nine-level multilevel voltage levels and their switch states. In this 1 means the switch is on, 0 means the switch is off. There are two complementary switch pairs in each phase. These pairs are(A1,A1'),(A2,A2'),(A3,A3'),(A4,A4'),(A5,A5'),(A6,A6'),(A7,A7'),(A8,A8').if one of the complementary switches turned on, the other of the same pairs must be off.

Table2. Nine level multilevel inverter switching states

Voltage(Vao)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	$Q1^1$	$Q2^1$	$Q3^1$	$Q4^1$	$Q5^1$	$Q6^1$	$Q7^1$	$Q8^1$
V_9	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
V_8	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
V_7	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0
V_6	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0
V_5	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
V_4	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0
V_3	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0
V_2	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0
V_1	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1

Energy Saving In Variable Torque Load Applications:

Many systems are used constant speed motors and control process flow rates or pressures by mechanically regulation using throttling valves, dampers, fluid couplings or variable inlet vanes etc. These devices generally do not control flow or pressure efficiently because energy is dissipated across the throttling device. Running a motor at full speed while throttling the input or output is like driving a car with one foot on the accelerator and the other on the brake; a part of the produced output immediately goes to waste. A variable speed drive can save over 60% of the energy. Variable speed drives and the loads they are applied to can generally be divided into 3 groups.

- Constant power
- Constant torque
- Variable torque

In variable torque load applications, both torque and power change with speed. Torque varies with speed squared, and power varies with speed cubed. This means that at half speed, the power required is approximately one eighth of rated maximum. Common examples of variable torque loads are

Centrifugal fans, blowers and variable discharge pressure pumps. The use of a variable speed drive with a variable torque load often returns significant energy savings. In these applications the drive can be used to maintain various process flows or pressures while minimizing power consumption. In addition, a drive also offers the benefits of increased process control, which often improves product quality and reduces scrap. Effective speed ranges are from 50% to 100% of speed and can result in substantial energy savings.

$$P = (2\pi * T * N)/60 \qquad \text{-------------------- (1)}$$

$$T = K * N^2 \qquad \text{-------------------- (2)}$$

$$P = (2\pi * K * N^3)/60 \qquad \text{-------------------- (3)}$$

P = Power in Watts; T = Torque in N-m; N = Motor rotation speed in rpm; A variable speed drive can also make it possible to stop a motor completely when it is not required as re-starting with a variable speed drive causes far less stress than starting direct on line - soft start is an inherent feature of the drive. Regulating the motor speed has the added benefit of easily accommodating capacity rises without extra investment, as speed increases of 5-20% is no problem with an AC variable speed drive as long as there is enough spare capacity in the system. Reduced maintenance compared to DC systems (brushes and commentators) reduced motor/application noise levels.

V. MULTILEVEL TOPOLOGIES

MULTILEVEL INVERTER	DIODE CLAMPED	FLYING CAPACITOR	CASCADED H-BRIDGE
FEATURES	1.High-voltage rating for blocking diodes 2.Unequal switching device rating 3.Capacitor voltage unbalance	1.Large number of capacitors 2.Balancing capacitor voltages	1. For real power conversion from ac to dc and then to ac to dc, the cascaded inverters need separate dc sources. The structure of separate dc sources is well suited for various renewable energy sources such as fuel cell, photovoltaic, and biomass. 2. Connecting dc sources between two converters in a back-to-back fashion is not possible because a short circuit can be introduced when two back-to-back converters are not switching synchronously.

ADVANTAGES	1. When the number of levels high enough, the harmonic content is low enough to avoid the need for filters. 2.Inverter efficiency is high because all devices are switched at the fundamental frequency 3. The control method is simple.	1. Like the diode-clamped inverter with more levels, the harmonic content is low enough to avoid the need for filters. 2. Both the real and reactive power can be controlled.	1. Optimized circuit layout and packing are possible because each level has the same structure and there are no extra clamping diodes or voltage–balancing capacitors. 2. soft-switching techniques can be used to reduce switching losses and device stresses.
DISADVANTAGES	1.Excessive clamping diodes are required when the number of levels high 2.It is difficult to control the real power flow of the individual converter in multi converter system	1. High level inverters are more difficult to package with the bulky power capacitors and are more expensive too. 2.The inverter control can be very complicated, and the switching frequency and switching losses are high for real power transmission	It needs separate dc sources for real power conversions, thereby limiting its applications.

VI. SIMULATED CIRCUITS AND WAVEFORMS

The below figure.3. Shows the Simulation diagram for nine level multilevel inverter fed induction motor.

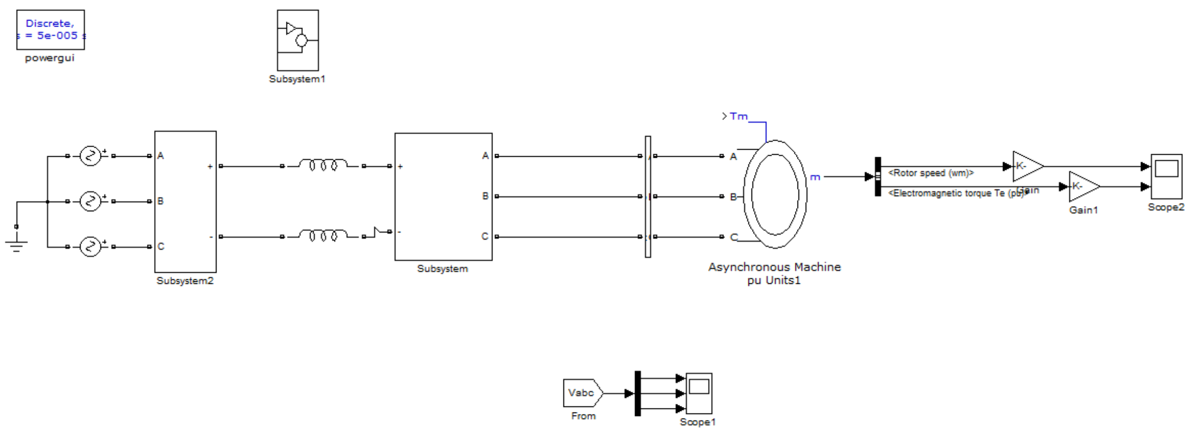

Figure.3. Simulation diagram for nine level multilevel inverter fed induction motor.

Output phase voltage for seven level multilevel inverter

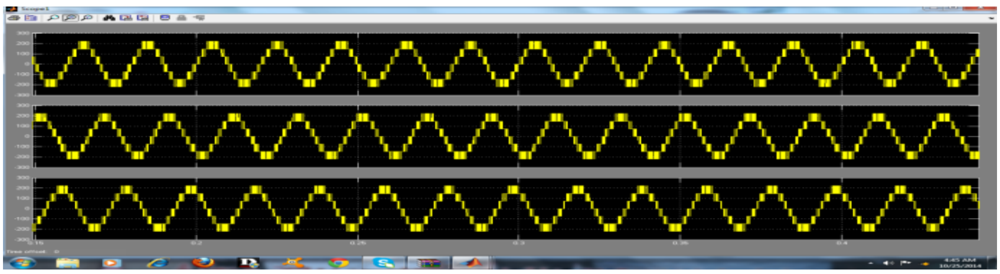

Figure.4. Output phase voltage for nine-level multilevel inverter

The speed torque characteristics for the seven- level multilevel inverter for 50 Hz and 45 Hz are shown in the below

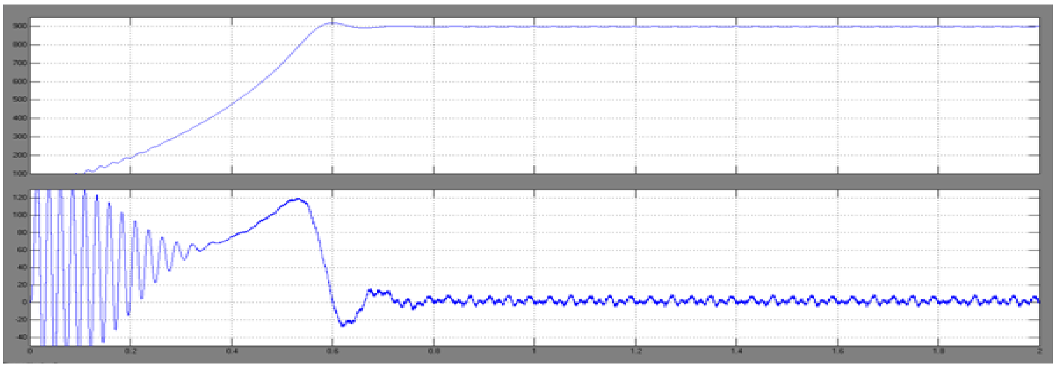

Figure.5. N-T curves for seven-level multilevel inverter for 45Hz frequency

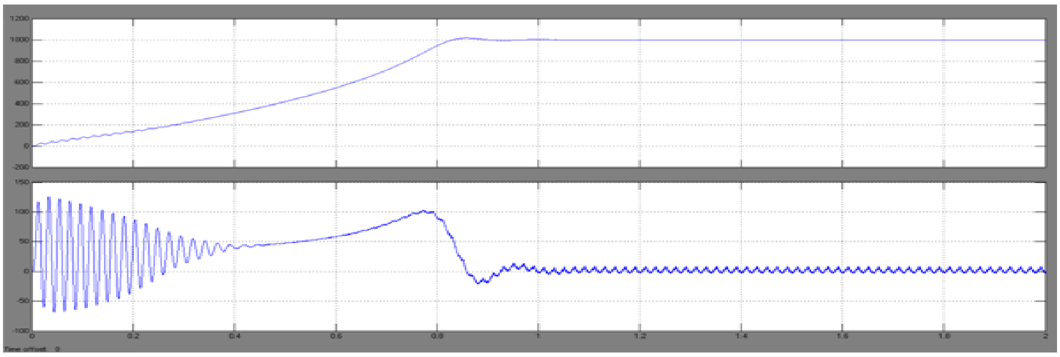

Figure.6. N-T curves for seven-level multilevel inverter for 50Hz frequency

The output voltage for the nine level multilevel inverter for 50 Hz and 45 Hz are shown in the below figure

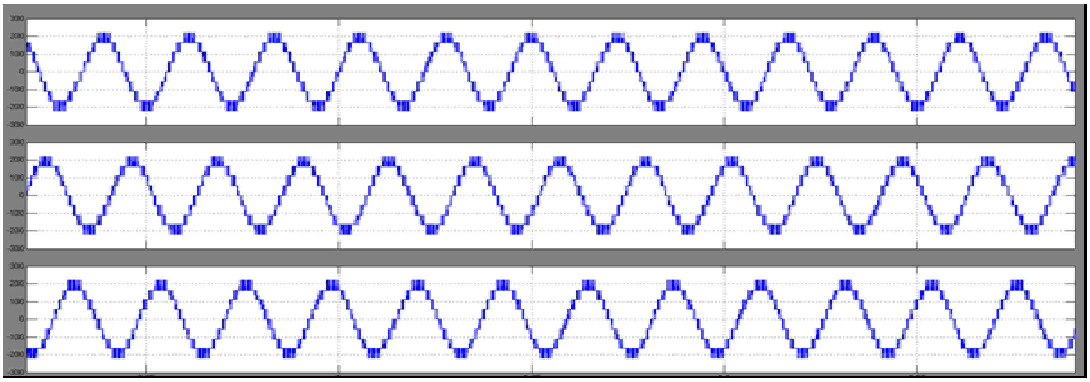

Figure.7. Output phase voltage for nine-level multilevel inverter

Speed and torque curves for 50 Hz and 45Hz frequencies are shown in below figures

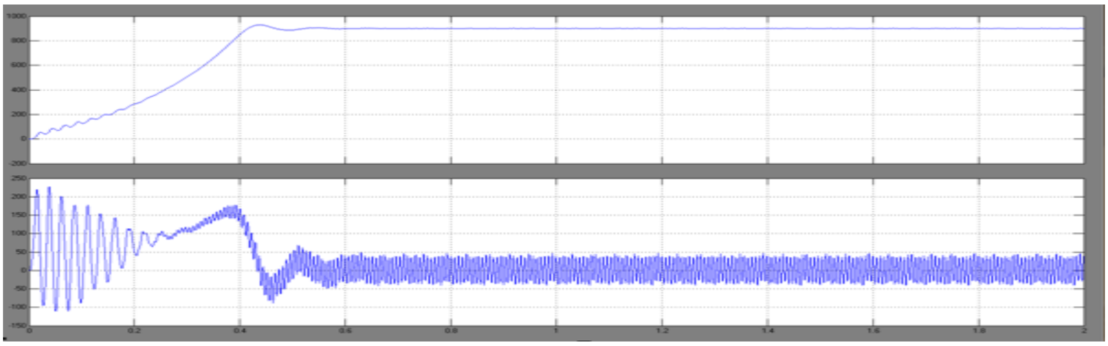

Figure.8. N-T curves for nine-level multilevel inverter for 45Hz frequency

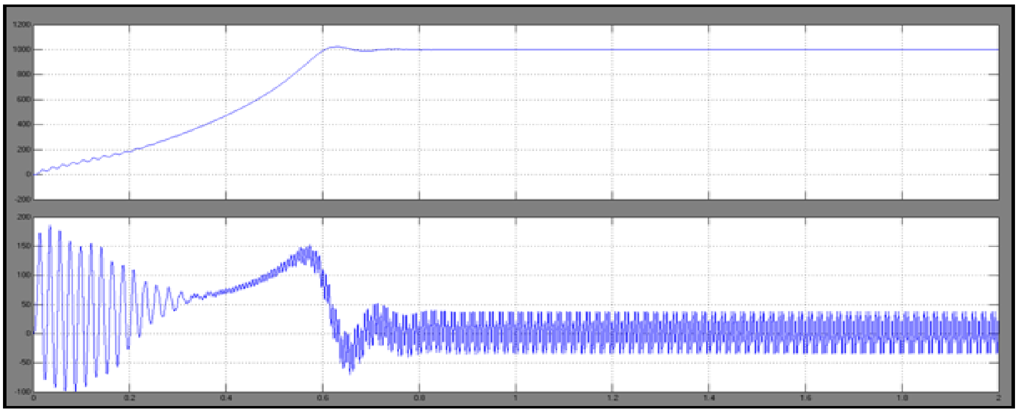

Figure.9. N-T curves for nine-level multilevel inverter for 50Hz frequency

VII. CONCLUSION

In this paper a diode clamped multilevel inverter has been presented for drive applications. The output voltages and the N-T characteristics of the 7-level and the 9-level multilevel inverters for 50Hz and 45Hz and verified that the 9-level inverter is better than the 7-level inverter. This drive system can be used energy saving in variable torque load applications like boiler feed pumps conveyors, rolling mills, printing machines etc.

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