Performance of Induction Motor Using 3-Level Cascade Inverter

C. Sudha Parimala[1], M. Harshavardhan Reddy[2]
[1](M. tech E.E.E Department, G. Pulla Reddy Engineering College, Andhra Pradesh, India)
[2](Asst.professor E.E.E Department, G. Pulla Reddy Engineering College, Andhra Pradesh, India)

Abstract

This paper presents performance analysis of induction motor using 3-level cascade inverter. Many schemes have been proposed for the speed control of induction motor drives, among which the indirect vector control is most effective method. An indirect vector controlled induction motor drive performance is poor with two-level inverter. To overcome these problems three-level cascade inverter is used. Space vector pulse width modulation (SVPWM) method is employed to control three-level cascade inverter. Conventional indirect vector control of induction motor drive uses hysteresis current controller, which causes variable switching frequency of the inverter. We can overcome this problem using SVPWM algorithm. To validate the proposed system, simulation studies have been carried out on vector controlled induction motor drive and the results are presented in this paper.

***Index Terms*—**3-level cascade inverter, SVPWM, Indirect vector control.

I. INTRODUCTION

At the present time, the indirect vector control technique is the widespread used in high Performance induction motor drives [1, 2]. It allows, by means a co-ordinate transformation, to decouple the electromagnetic torque control from the rotor flux, and hence manage induction motor as DC motor. In this technique, the variables are transformed into a reference frame in which the dynamic behave like DC quantities. The decoupling control between the flux and torque allows induction motor to achieve fast transient response. Therefore, it is preferred used in high performance motor applications.

Nevertheless the performance of the output voltage of inverter that fed induction motor system is mainly determined by pulse width modulation (PWM) strategy. The simple implementation is use current control based on hysteresis current controller. With this method, fast response current loop will be obtained and knowledge of load parameter is not required. However this method can cause variable switching frequency of inverter [3] and produce undesirable harmonic generation [4, 5]. Another method of PWM that have become popular and received great interest by researcher is SVPWM [5-7]. This technique have better dc bus utilization and easy for digital implementation. SVPWM technique is implemented for 3-level cascade inverter to improve the performance of the system compare to two-level inverter. Three-level inversion is realized by connecting two two-level inverters in cascade, in the proposed configuration [8] .An isolated DC power supply is used to supply each inverter in this power circuit. Each DC-link voltage is equal to half of the DC-link voltage in a conventional inverter topology. Neutral points fluctuations are absent &fast recovery neutral clamping diodes are not needed.

The modeling & simulation of indirect vector controlled induction motor using cascade inverter is performed, the SVPWM principle & algorithm is analyzed. This paper is organized as follows. Modeling of induction motor is introduced in section2,3-level cascade inverter in section3&then the space vector PWM based indirect vector control is presented in section4.The performance of the induction motor is presented in simulation result in section5&finally some concluding remarks are stated in the last section.

II. MODELING OF INDUCTION MOTOR

The mathematical model of a three-phase, squirrel-cage induction motor is described by equations in stationary rotating reference frame, and the equations are given by (1) - (3)

$$\begin{bmatrix} v_{qs} \\ v_{ds} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + L_s p & 0 & L_m p & 0 \\ 0 & R_s + L_s p & 0 & L_m p \\ L_m p & -w_r L_m & R_r + L_r p & -w_r L_r \\ w_r L_m & L_m p & w_r L_r & R_r + L_r p \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \quad (1)$$

Where $w_r = \frac{d\theta}{dt}$ and p= $\frac{d}{dt}$

v_{ds} and v_{qs} are d-q axis stator voltages respectively,
i_{ds} , i_{qs} and i_{dr} , i_{qr} are d-q axis stator and rotor currents respectively,
R_s and R_r are stator and rotor resistances per phase respectively.

The electromagnetic torque of the induction motor in stator reference frame is given by

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left(\psi_{ds} i_{qs} - \psi_{qs} i_{ds}\right) \quad (2)$$

The electro-mechanical equation of the induction motor drive is given by

$$T_e = T_L + J\frac{dw_m}{dt} = T_L + \frac{2}{p}J\frac{dw_r}{dt} \quad (3)$$

III. 3-LEVEL INVERTER CONFIGURATION CASCADING TWO TWO-LEVEL INVERTERS

In this circuit configuration, three-level inversion is achieved by connecting two two-level inverters in cascade. From Fig.1, it may be seen that the output phases of inverter-1 are connected to the DC-input points of the corresponding phases in inverter-2. Each inverter is operated with an isolated DC power supply, with a voltage of $V_{dc}/2$ (Fig.1). The present power circuit can be operated as a two-level inverter in the range of lower modulation, by clamping one inverter to a zero state and by switching the other inverter. The output voltages of inverter-1 (the voltages of the individual phases Al, B1 and C1 of inverter-1), with respect to the point 0, are denoted as $V_{A1o,}V_{B1o}\,and\,V_{C1o}$ respectively (Fig.1). The pole voltages of inverter-2 (the voltages of the individual phases A2, B2 and C2 of inverter-2, with respect to the point 0) are denoted as $V_{A2o,}V_{B2o}\,and\,V_{C20}$ respectively.

The pole voltage of any phase for inverter-2 attains a voltage of $V_{dc}/2$, if

(a) The top switch of that leg in inverter-2 is turned on,

(b) The bottom switch of the corresponding leg in inverter-1 is turned on.

Similarly the pole voltage of any phase in inverter-2 attains a voltage of V_{dc}, if

(a) The top switch of that leg in inverter-2 is turned on and

(b) The top switch of the corresponding leg in inverter-1 is turned on.

Thus, the DC-input points of individual phases of inverter-2 may be connected to a DC-link voltage of either V_{dc} or $V_{dc}/2$ by turning on the top switch or the bottom switch of the corresponding phase leg in inverter- 1.

Additionally, the pole voltage of a given phase in inverter-2 attains a voltage of zero, if the bottom switch of the corresponding leg in inverter-2 is turned on. In this case, the DC-input point of that phase for inverter-2 is floating as the top and bottom switches are switched complementarily in any leg in a two-level inverter. Thus, the pole voltage of a given phase for inverter-2 is capable of assuming one of the three possible values 0, $V_{dc}/2$ and V_{dc}, which is the characteristic of a three-level inverter.

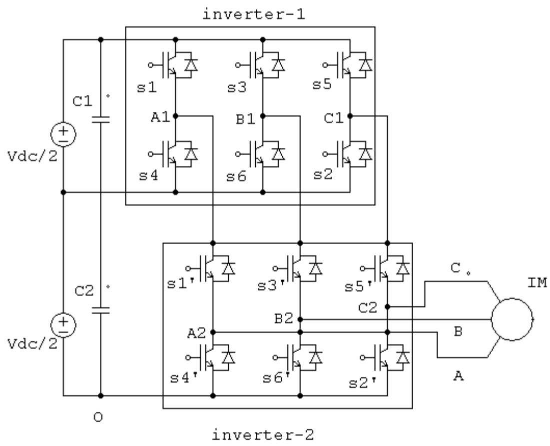

Fig.1Three-level Cascade inverter

IV. SVPWM BASED INDIRECT VECTOR CONTROL

The block diagram of vector controlled induction Motor drive using the SVPWM algorithm is given in Fig. 2. Command currents i_{ds}^* and i_{qs}^* in the vector control are compared with the respective *ids* and i_{qs} currents generated by the transformation of phase currents with the help of the unit vector. From the respective errors, the voltage command signals can be generated through PI controllers. These voltage commands are then converted into stationary frame and given to SVPWM block. The SVPWM can be implemented by:

- DetermineV_{ref} and angle α
- Determine time duration T1, T2 and T0
- Determine the switching time of each transistor

The SVPWM uses two neighboring effective vectors and null vectors of the eight basis space voltage vector and their different act time to obtain the equivalent space voltage vector that the motor needs, as shown in Fig 3

It is show that there are six voltage vectors that can be selected to apply to the motor. The reference V_{ref} and angle α of respective sector can be obtain as

$$|V_{ref}| = \sqrt{V_d^2 + V_q^2} \quad (4)$$

$$\alpha = \tan^{-1}\left(\frac{V_q}{V_d}\right) \quad (5)$$

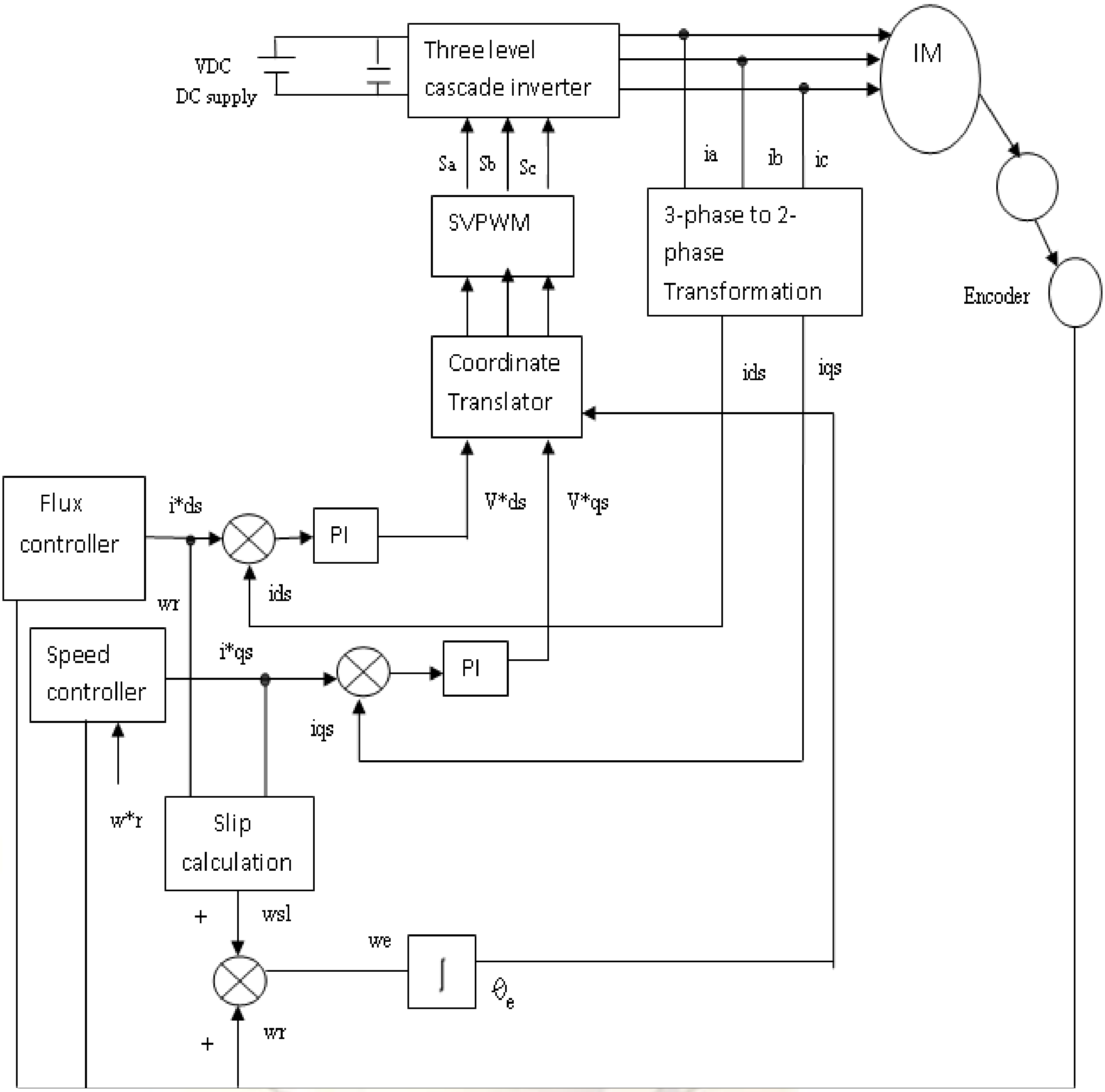

Fig.2 SVPWM based indirect vector control of induction motor

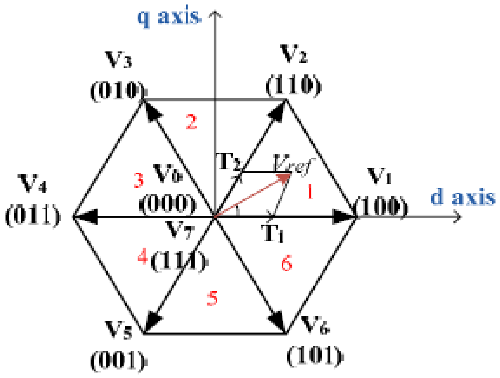

Fig 3 Basic Voltage Vector and Reference Vector

And switching time duration at any sector is as

$$T_1 = \frac{\sqrt{3}\, T_Z\, |V_{ref}|}{V_{dc}} (\sin(60-\alpha)) \quad (6)$$

$$T_2 = \frac{\sqrt{3}\, T_Z\, |V_{ref}|}{V_{dc}} (\sin\alpha) \quad (7)$$

$$T_0 = T_Z - T_1 - T_2$$

Where α is angle between 0° to 60° and $T_Z = 1/f_Z$, sampling frequency. SVPWM switching pattern for sector 1 is shown in Fig. 4 and switching time at any sector sequence is summarized in Table 1. From this table a mathematical equation is built in function block in SIMULINK to generate a SVPWM waveform

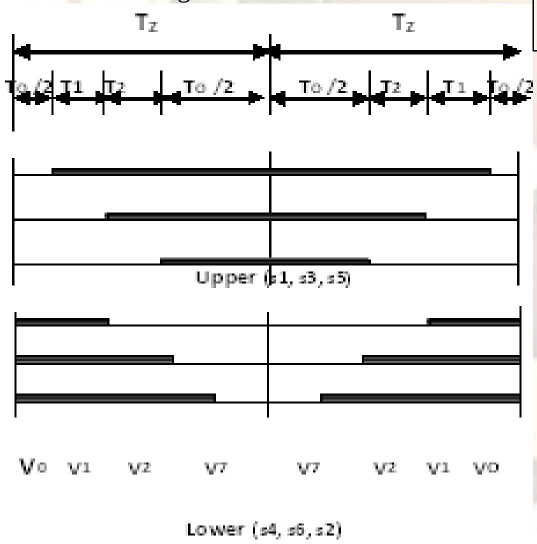

Fig 4 Switching pattern for sector 1

TABLE 1
SWITCHING TIME CALCULATION AT EACH SECTOR

Sector	Upper Switches (S_1, S_3, S_5)	Lower Switches (S_4, S_6, S_2)
1	$S_1 = T_1 + T_2 + T_0/2$ $S_3 = T_2 + T_0/2$ $S_5 = T_0/2$	$S_4 = T_0/2$ $S_6 = T_1 + T_0/2$ $S_2 = T_1 + T_2 + T_0/2$
2	$S_1 = T_1 + T_0/2$ $S_3 = T_1 + T_2 + T_0/2$ $S_5 = T_0/2$	$S_4 = T_2 + T_0/2$ $S_6 = T_0/2$ $S_2 = T_1 + T_2 + T_0/2$
3	$S_1 = T_0/2$ $S_3 = T_1 + T_2 + T_0/2$ $S_5 = T_2 + T_0/2$	$S_4 = T_1 + T_2 + T_0/2$ $S_6 = T_0/2$ $S_2 = T_1 + T_0/2$
4	$S_1 = T_0/2$ $S_3 = T_1 + T_0/2$ $S_5 = T_1 + T_2 + T_0/2$	$S_4 = T_1 + T_2 + T_0/2$ $S_6 = T_2 + T_0/2$ $S_2 = T_0/2$
5	$S_1 = T_2 + T_0/2$ $S_3 = T_0/2$ $S_5 = T_1 + T_2 + T_0/2$	$S_4 = T_1 + T_0/2$ $S_6 = T_1 + T_2 + T_0/2$ $S_2 = T_0/2$
6	$S_1 = T_1 + T_2 + T_0/2$ $S_3 = T_0/2$ $S_5 = T_1 + T_0/2$	$S_4 = T_0/2$ $S_6 = T_1 + T_2 + T_0/2$ $S_2 = T_2 + T_0/2$

V. SIMULATION RESULTS AND DISCUSSION

To validate the proposed method, simulation studies have been carried out by using Mat lab/Simulink. The motor parameters are as follows: DC Voltage VDC=629.3V, Stator resistance R_s = 1.57ohm, rotor resistance R_r =1.21ohm, stator inductance L_s =0.17H, rotor inductance L_r =0.17H, mutual inductance L_m =0.165H, moment of inertia J=0.089Kg-m2.

Figure5 shows the simulation results of pole voltage, line voltage, phase voltage &current of two level inverter.

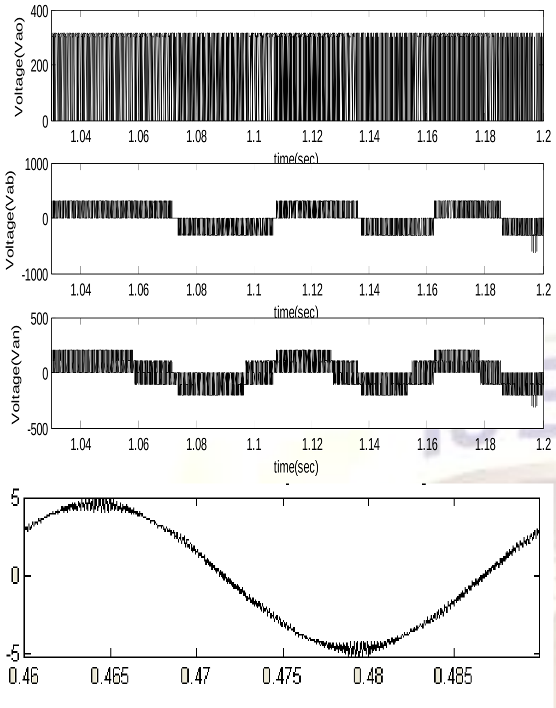

Fig.5 Pole, line, phase voltages &current of two level inverter.

Figure6 shows the simulation results of pole voltage, line voltage, phase voltage &current of three level cascade inverter.

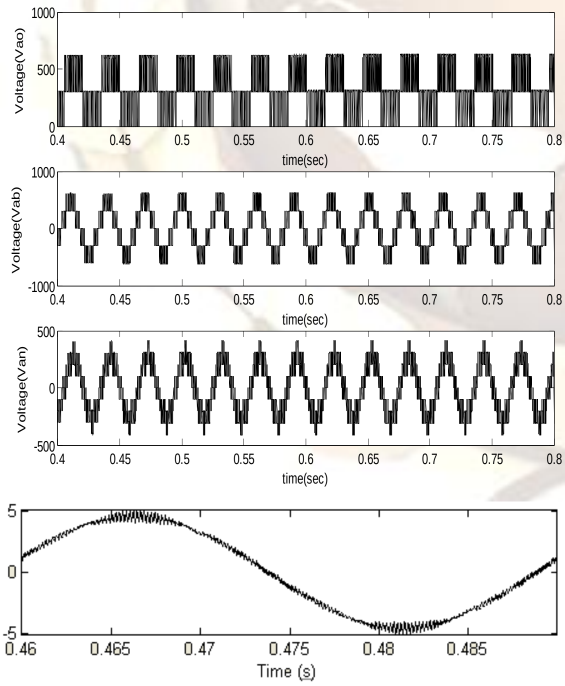

Fig.6 Pole, line, phase voltages &current of 3 level cascade inverter.

Figure7 shows the two level inverter THD analysis of phase voltage &current under steady state.

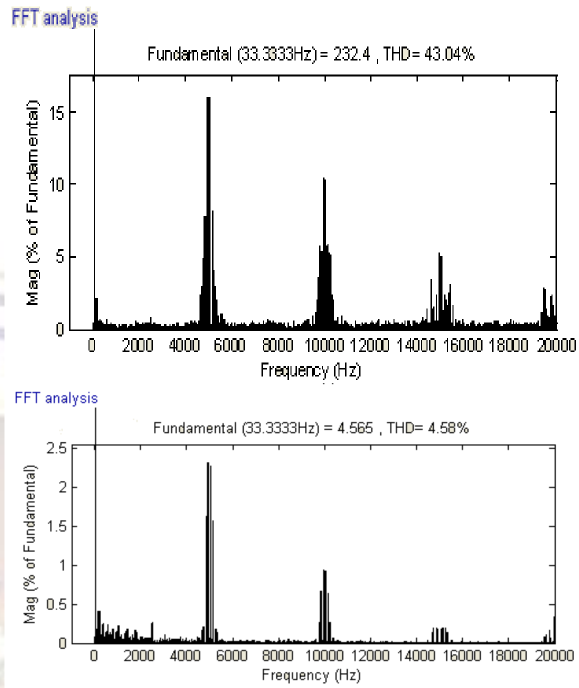

Fig.7 Two level inverter THD analysis of phase voltage &current under steady state

Figure8 shows the three level cascade inverter THD analysis of phase voltage &current under steady state.

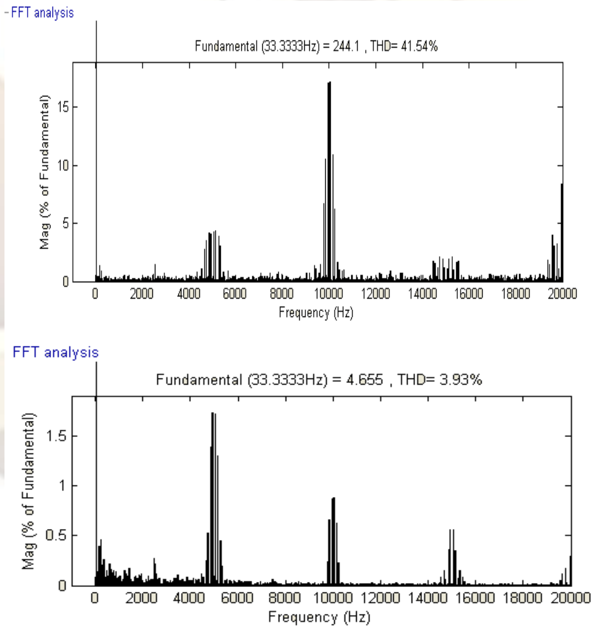

Fig.8 Three level cascade inverter THD analysis of phase voltage &current under steady state.

The performance of the indirect vector controlled induction motor drive during the starting with three-level inverter is shown Figure.9. As shown in the figure maximum current during the starting is reduced, the ripple contentment in the torque is reduced, drive reaches steady state earlier with three-level inverter compared to drive fed from a two-level inverter. The maximum torque obtained with 3-level inverter is 38 N-m. The speed response also reaches steady state earlier with three-level inverter fed indirect vector controlled drive.

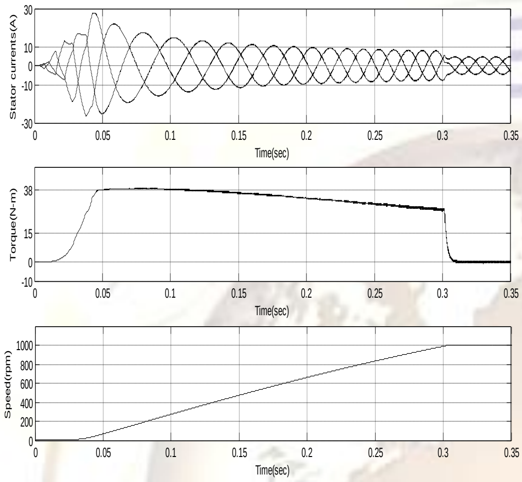

Fig. 9 starting transients of the proposed drive

The steady state phase currents, torque and speed responses of indirect vector controlled drive with three-level is shown Figure.10. It is observed that the torque ripple with three- level inverter is reduced, so there is lot of improvement in the ripple with three-level inverter. The better speed response is obtained with three level compared to two-level inverter fed indirect vector controlled induction motor drive.

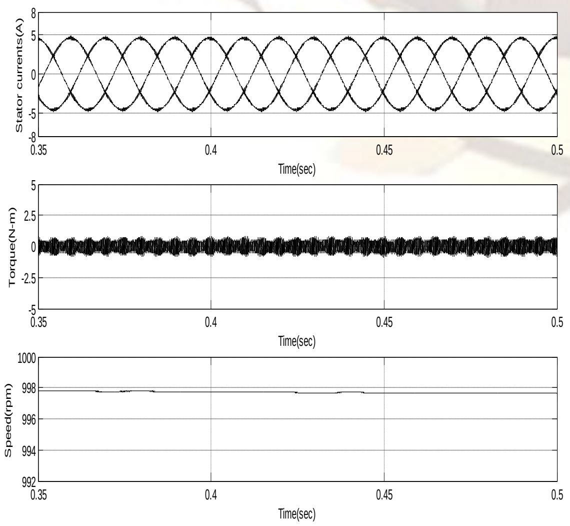

Fig.10 Steady state transients of the proposed drive

Fig.11 shows the transients during the step change in load torque command (here the load torque of 25 N-m is applied at 0.5 sec and removed at 0.7sec). The transients of the drive during speed reversals are given in Fig.12 and Fig.13.From the simulation results, it can be observed that the proposed drive gives good performance with 3-level inverter. Thus, with the proposed system, constant switching frequency operation can be obtained when compared with the conventional vector control.

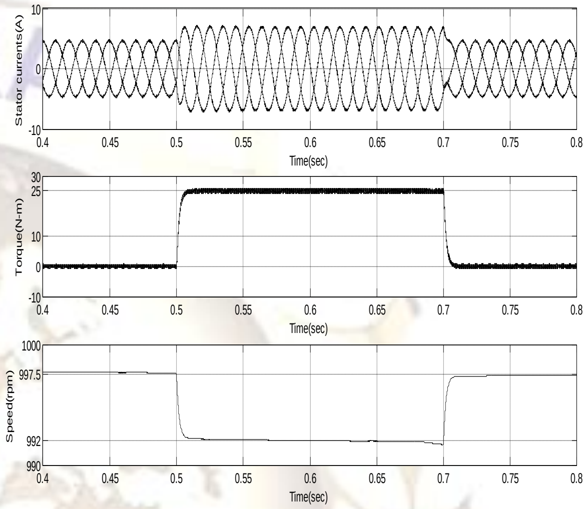

Fig.11.transients during step change in load torque

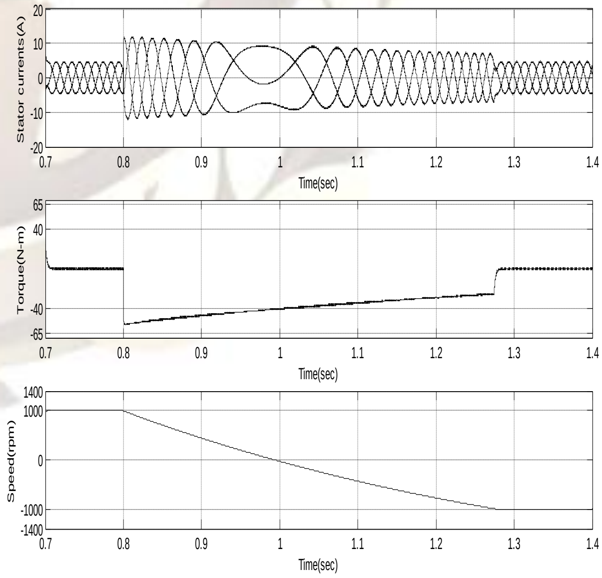

Fig. 12 Transients during speed reversal operation (Speed is changed from +1000 rpm to -1000 rpm)

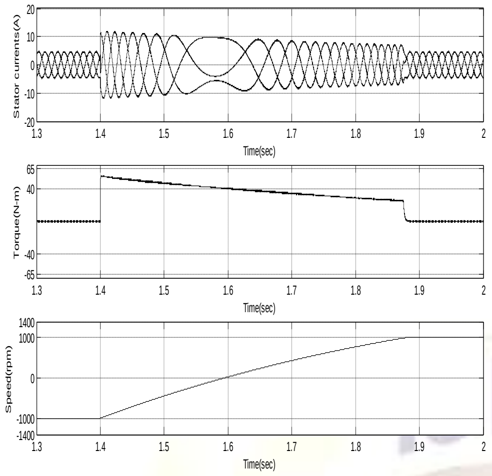

Fig. 13 Transients during speed reversal operation (Speed is changed from -1000 rpm to +1000 rpm)

VI. CONCLUSIONS

The performance of SVPWM based indirect vector controlled induction motor drive fed 3-level is presented. It is observed that the performance of indirect vector controlled induction motor is improved with the three-level inverter compare to two-level inverter. Using 3-level cascade inverter the harmonics are reduced compare to two-level inverter. The steady state ripple content in the current & torque waveforms are less with 3-level inverter.

The ripple content of torque is reduced under steady state due to this smooth speed response is obtained with 3-level inverter. The momentary speed decrease with three-level inverter is little less compared with two-level inverter during the load change. Also from the simulation results SVPWM technique gives better performance in elimination of stator current harmonics& reduction of the torque ripple. So the overall performance of drive is improved with three-level inverter compared to two-level inverter.

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