



# **A NOVEL DIRECT TORQUE CONTROL SCHEME FOR INDUCTION MOTOR DRIVE FOR REDUCTION OF COMMON MODE VOLTAGE**

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**ABSTRACT:** The Adjustable Speed Drives (ADS) are generally used in industry. In most variable speed drives Induction motor are generally used. The Direct Torque Control (DTC) technique has the feature of precise and quick torque response and reduction of the complexity of field oriented control (FOC) algorithms. In DTC, the generation of inverter switching state is made to restrict the stator flux and electromagnetic torque errors with in the respective flux and torque hysteresis bands so as to obtain the fastest torque response and highest efficiency at every instant. As the zero voltage vectors being used in conventional DTC the common mode emission are high. Hence to reduce these common mode emissions, a new DTC algorithm has been proposed in this paper. In the proposed method only odd active voltage vectors are used in odd sectors and only even active voltage vectors are used in even sectors. Thus, the zero voltage vectors have been eliminated in the proposed work. To validate the proposed method the simulation has been carried out in Matlab/Simulink environment and the simulation results are presented and compared. From the simulation results, it can be observed that the common mode emission has been reduced with the proposed DTC.

**Key words:** Induction motor, direct torque control (DTC), Adjustable Speed Drives (ADS), MATLAB / SIMULINK, total harmonic distortion, modeling, and common mode voltage.

## **I. INTRODUCTION:**

The standard in those drives are Induction Motors (IM) are widely used in application such as pumps, fans, elevators, electrical vehicles, heating, ventilation and air-conditioning (HVAC), robotics, wind generation systems, ship propulsion etc. [1]-[2]. Previously, DC machines were preferred for variable speed drives. However, DC motors have disadvantages of higher cost, higher rotor inertia and maintenance problem with commutator and brushes. In addition they cannot operate in dirty and explosive environments. Therefore, in last three decades the DC motors are progressively replaced by AC drives. The responsible for those result are development of modern semiconductor devices, especially power Insulated Gate Bipolar Transistor (IGBT) various speed control schemes such as Field oriented control (FOC) and direct torque control (DTC) [3]. The first vector control method of induction motor was *Field Oriented Control* (FOC) presented by K. Hasse [4] and F. Blaschke [5] in early of 70s. the Matlab and Simulink packages were used to perform simulations on a number of control schemes. These schemes were Field Oriented Control, Direct Torque Control (DTC), DTC using Space Vector Modulation, and a novel Direct Torque Control (DTC) with Minimal Common mode voltages and Torque Ripple [6]-[7]. The novel Direct Torque Control (DTC) using Space Vector Modulation was chosen based on its low current distortion. One of the most wide spread techniques for high performance electrical drives with induction machines in industry applications is a novel direct torque control (DTC) based on voltage vectors [8]-[9]. However, its inherent fast switching frequency has, among other effects, the drawback of generating high level common mode voltage variations with resulting high frequency common mode currents flowing to the ground through the parasitic capacitances between the different parts of the drive and the ground, thus causing the drive itself to be less reliable. Another approach consists in limiting the cause of the common mode disturbance by proper selection of the switching pattern of the inverter [10]. In such an approach a new pulse width modulation (PWM) strategy is introduced to reduce the common-mode voltages in PWM inverter motor drives by the use of only three inverter states in each sector of the inverter hexagon, which are alternatively either only even or only odd voltage vectors. It permits only six variations of the common-mode voltage in each period of the fundamental



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of the voltage waveform at steady state and results in fewer emissions. In any case a voltage space vector is created by computing the time intervals during which each inverter state is applied. In this paper, the proposed novel DTC algorithm reduces the common mode emissions of the drive in each of the six sectors of the inverter hexagon, without using any null vector. This approach permits the common mode emissions to be reduced at the expense of a slight increase of the torque and flux ripples as well as of the harmonic content of the voltage and current wave forms. The numerical simulations have been carried out by using MATLAB/SIMULINK software packages.

## II. MATHEMATICAL MODELING OF INDUCTION MOTOR:

To study the dynamic performance of the machine model, a motor model has been developed in a stationary reference frame by using equations (1)-(3).

$$\begin{aligned} v_{ds} &= R_s i_{ds} + \frac{d\lambda_{ds}}{dt} \\ v_{qs} &= R_s i_{qs} + \frac{d\lambda_{qs}}{dt} \\ 0 &= R_r i_{dr} + \omega_r \lambda_{qr} + \frac{d\lambda_{dr}}{dt} \\ 0 &= R_r i_{qr} - \omega_r \lambda_{dr} + \frac{d\lambda_{qr}}{dt} \end{aligned} \quad (1)$$

The stator and rotor flux linkages in the stator reference frame are defined as,

$$\begin{aligned} \lambda_{qs} &= L_s i_{qs} + L_m i_{qr} \\ \lambda_{ds} &= L_s i_{ds} + L_m i_{dr} \\ \lambda_{qr} &= L_r i_{qr} + L_m i_{qs} \\ \lambda_{dr} &= L_r i_{dr} + L_m i_{ds} \end{aligned} \quad (2)$$

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

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

By using the above equations the induction motor model is developed in stator reference frame. The simulation of induction motor has been carried out in the MATLAB-SIMULINK environment under the no-load condition.

## III. PROPOSED DIRECT TORQUE CONTROL:

The electromagnetic torque of a three-phase induction motor can be written as,

$$T_e = \frac{3}{2} \frac{P}{2} \frac{L_m}{\sigma L_s L_r} |\psi_r| |\psi_s| \sin \delta \quad (4)$$

where  $\delta$  is the angle between the stator flux linkage space vector ( $\bar{\psi}_s$ ) and rotor flux linkage space vector ( $\bar{\psi}_r$ ), as

shown in Fig. and  $\sigma$  is the leakage coefficient given by  $\sigma = 1 - \left( \frac{L_m^2}{L_s L_r} \right)$ .

In this new DTC algorithm when the stator flux space vector lies in the  $K^{\text{th}}$  sector, if an increase in the flux is required, then the  $K^{\text{th}}$  voltage vector is applied, otherwise, if an increase in the torque is required, then the  $(k+2)^{\text{th}}$  voltage vector is applied. The vector diagram given in Fig. 1 shows the voltage vector selection when the stator flux vector  $\psi_s$  lies in the first sector and one of the voltage sectors  $V_1$ ,  $V_3$  and  $V_5$  is applied. Actually, when the stator flux linkage lies in the  $k^{\text{th}}$  sector, the application of the  $k^{\text{th}}$  voltage vector produces an increase in the flux amplitude and a slight decrease of the electromagnetic torque the application of the  $(K+2)^{\text{th}}$  voltage vector produces a slight decrease in the flux amplitude and an increase in the electromagnetic torque, while the application of  $(K-2)^{\text{th}}$  voltage vector produces a slight decrease in the flux amplitude and a decrease in the electromagnetic torque.

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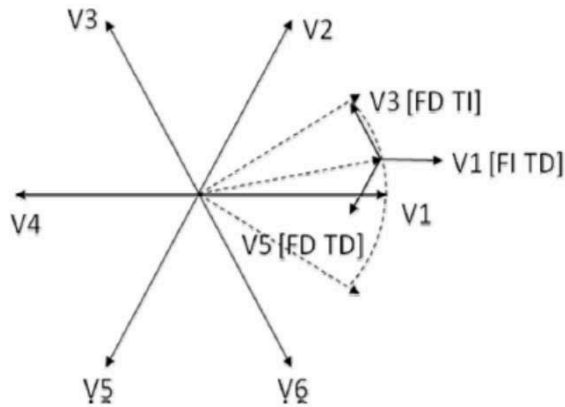


Fig.1.Application of voltage vectors in sector 1

The Switching vector table for proposed DTC is shown in Table 1. In particular the application of  $V_1$  causes a strong increase of the flux amplitude and a slight decrease of the torque, the application of  $V_3$  causes a slight decrease of the flux amplitude strong increase of the torque and finally the application of  $V_5$  causes a strong decrease of the flux amplitude and a strong decrease of the torque. With such a control law, flux control must be performed before torque control, otherwise the machine cannot be magnetized at zero speed without load torque (zero speed operation), or at steady state gets demagnetized rapidly after a series of torque commands.

$S\psi$	$S_T$	I	II	III	IV	V	VI
1	1	$V_1$	$V_2$	$V_3$	$V_4$	$V_5$	$V_6$
	-1	$V_1$	$V_2$	$V_3$	$V_4$	$V_5$	$V_6$
0	1	$V_3$	$V_4$	$V_5$	$V_6$	$V_1$	$V_2$
	-1	$V_5$	$V_6$	$V_1$	$V_2$	$V_3$	$V_4$

Table.1.Switching vector table for proposed DTC

Moreover, it is apparent that a reduction of the flux always causes the torque to be varied. This means that when the flux lies in the odd (even) sector only odd (even) voltage vectors are employed. Each communication of the common-mode voltage variation appears only when the stator flux linkage goes from one sector to the adjacent one. Moreover, at each sector crossing, the common-mode voltage variation is the minimum achievable, equal in magnitude to  $V_{dc}/3$ .

#### IV. COMMON MODE VOLTAGES:

For the most common two-level voltage source inverter there are three switching variables a, b, c one per phase of the inverter. Every terminal of the induction motor will be connected to the pole of one of the inverter legs, and thereby, either to the positive dc bus or the negative dc bus. The CMV is the potential of the star point of the load with respect to the Centre of the dc bus of the VSI. The CMV generated by a star connected three phase electric machine is given by,

$$V_{com} = \frac{(V_{sAo} + V_{sBo} + V_{sCo})}{3} \quad (5)$$

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Where  $V_{sAo}$ ,  $V_{sBo}$  and  $V_{sCo}$  are the inverter output phase voltages referred to the medium point of the dc-link bus, which in this case is assumed to be connected to ground. The lack of this connection to ground causes an additional voltage term. If the machine is supplied by a symmetric sinusoidal three-phase voltage,  $V_{com}$  is instantaneously equal to 0. However, when the machine is supplied by an inverter the common mode voltage is always different from zero and its instantaneous value can be computed on the basis of the dc-link voltage ( $V_{dc}$ ) and the switching pattern of the inverter.

### V. DIRECT TORQUE CONTROLLED BASED INDUCTION MOTOR DRIVE:

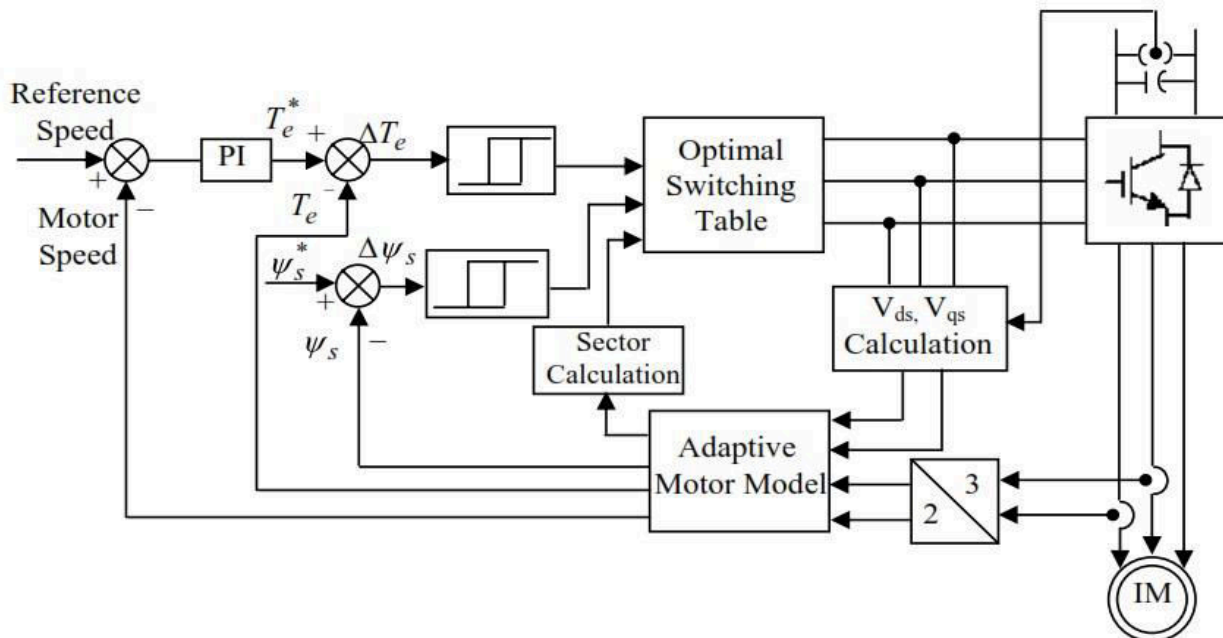


Fig.2 Block diagram of proposed Direct Torque Control of induction motor Drive

The Fig.2 shows the block diagram of conventional direct torque controlled induction motor drive. There are two hysteresis control loops, one for the control of torque and other for the control of stator flux. The flux controller controls the machine operating flux to maintain the magnitude of the operating flux at the rated value till the rated speed. Torque control loop maintains the torque close to the torque demand. Based on the outputs of these controllers and the instantaneous position of stator flux vector, a proper voltage space vector is selected. Based on the outputs of hysteresis controllers and position of the stator flux vector, the optimum switching table will be constructed. This gives the optimum selection of the switching voltage space vectors for all the possible stator flux linkage space vector positions. If a stator flux increase is required then  $S_{\psi} = 1$ ; if a stator flux decrease is required then  $S_{\psi} = 0$ . The digitized output signals of the two level flux hysteresis controller are defined as,

$$\text{If } \bar{\psi}_s \leq \bar{\psi}_s^* - \Delta\psi_s \text{ then } S_{\psi} = 1$$

$$\text{If } \bar{\psi}_s \geq \bar{\psi}_s^* + \Delta\psi_s \text{ then } S_{\psi} = 0$$

If a torque increase is required then  $S_T = 1$ , if a torque decrease is required then  $S_T = -1$ , and if no change in the torque is required then  $S_T = 0$ . The digitized output signals of the three level torque hysteresis controller for the anticlockwise rotation or forward rotation can be defined as,

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$$\text{If } T_e^* - T_e \geq \Delta T_e \text{ then } S_T = 1$$

$$\text{If } T_e \geq T_e^* \text{ then } S_T = 0$$

## VI. SIMULATION RESULTS:

To verify the proposed scheme, numerical simulation studies have been carried out by using Matlab/Simulink. For the simulation, the reference flux is taken as 1wb and starting torque is limited to 15 N-m. The induction motor used in this case study is a 1.5 kW, 1440 rpm, 4-pole, 3-phase induction motor having the following parameters:  $R_s = 7.83\Omega$ ,  $R_r = 7.55\Omega$ ,  $L_s = 0.4751H$ ,  $L_r = 0.4751H$ ,  $L_m = 0.4535H$  and  $J = 0.06 \text{ Kg.m}^2$ . Fig .3 shows the transients during starting and Fig 4 shows the steady state plots of torque, current and stator flux at 1200 rpm. Moreover, it can be observed that, the proposed DTC gives reduced ripples in torque, current and stator flux during steady state when compared to the CDTC. Fig 5 shows the transient responses during the step change in load. The transients in speed, torque and currents during the speed reversals from +1200 rpm to 1200 rpm are shown in Fig 6. The Fig 7 and Fig 8 shows common mode emission of voltage and Harmonic distortion of common mode voltage for the proposed DTC, from which it can be observed that the common mode voltage is low when compared to the conventional DTC. The locus of the stator flux at 1200 rpm is shown in Fig 9, from which it can be observed that the locus is almost is a circle of constant radius. The wave form of the harmonic distortion of the line current is given in Fig 10 along with the total harmonic distortion (THD) value and it has been shown that the THD of proposed DTC is low when compared to the CDTC.

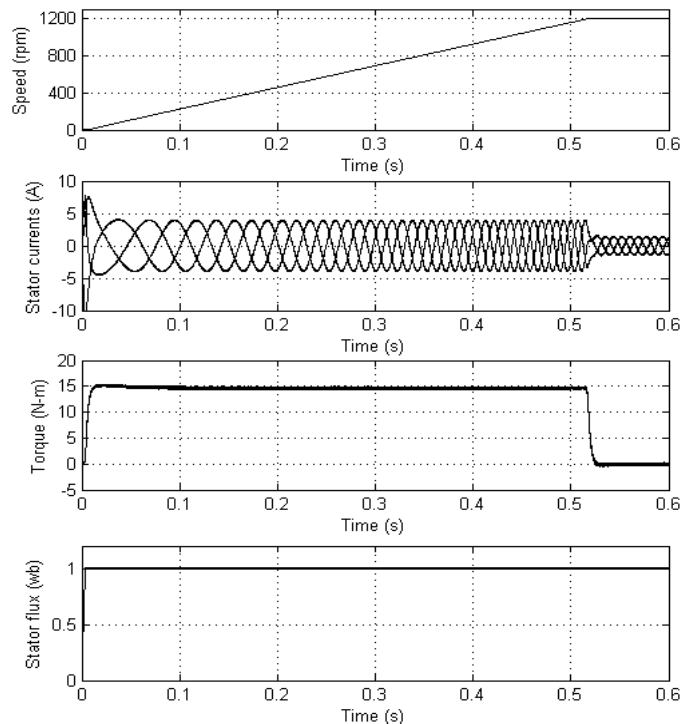


Fig.3 starting transients in proposed DTC based induction motor drive.

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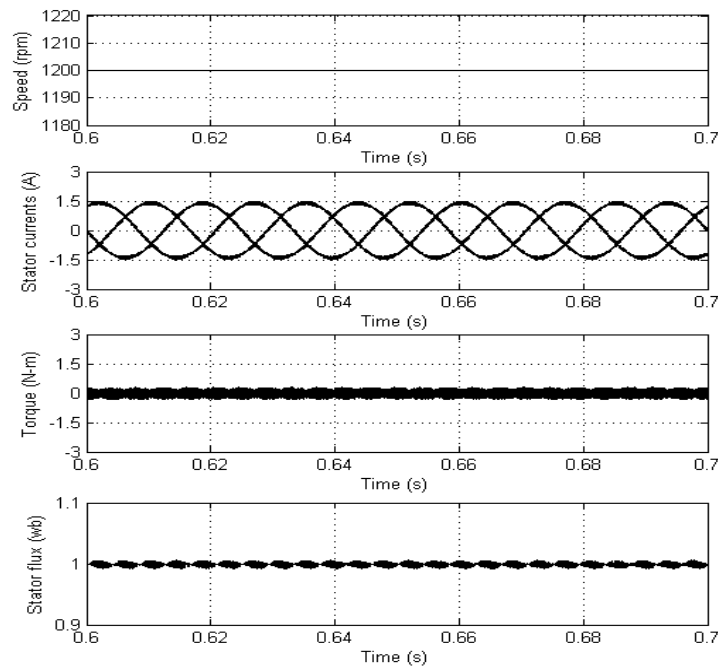


Fig.4 steady state plots for proposed DTC based induction motor drive

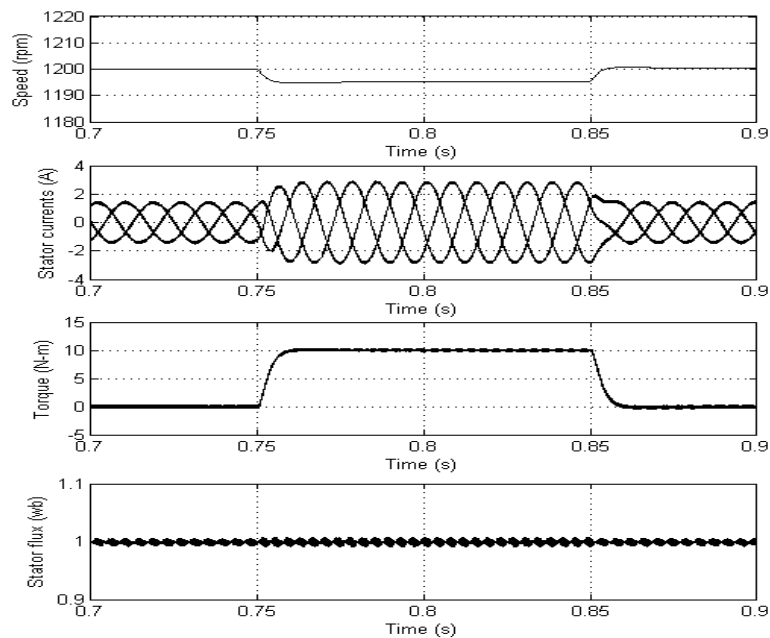


Fig.5 transients in speed, current, torque and flux during step change in load torque (a load torque of 10 N-m is applied at 0.75s and removed at 0.85s) for proposed DTC based induction motor drive

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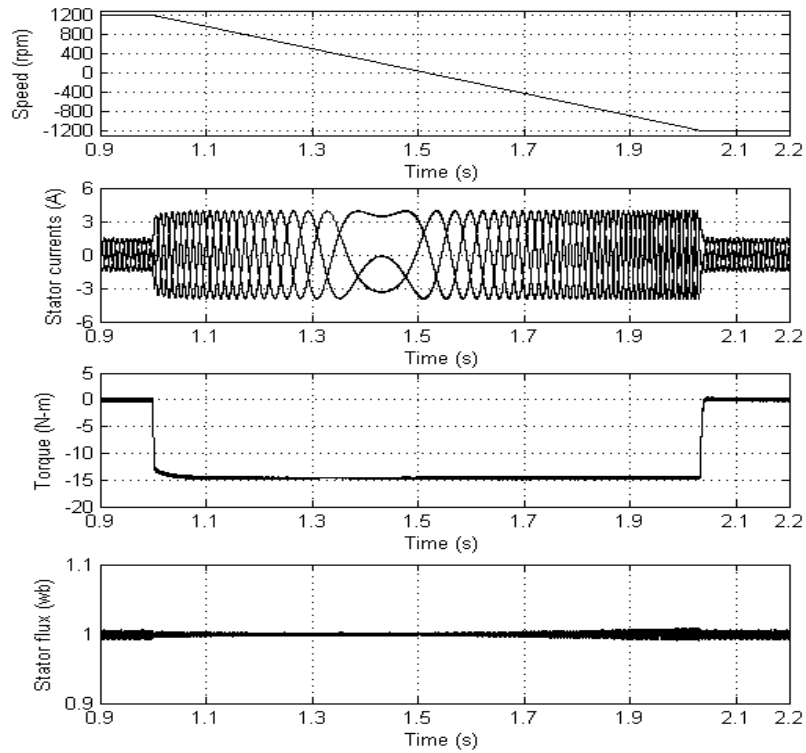


Fig.6 transients in speed, current, torque and flux during speed reversal (the speed is reversed from +1200 rpm to -1200 rpm)

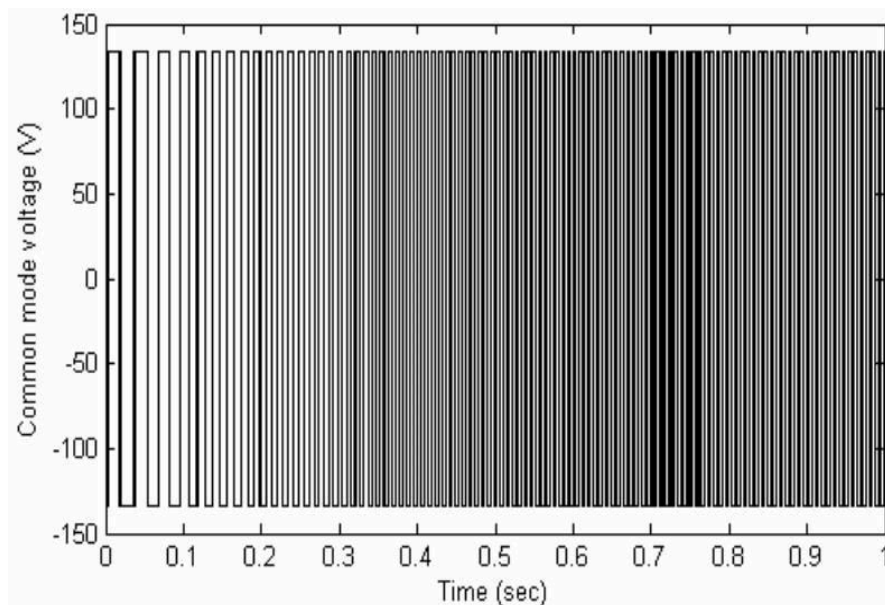


Fig.7 common mode voltage of proposed DTC based induction motor drive

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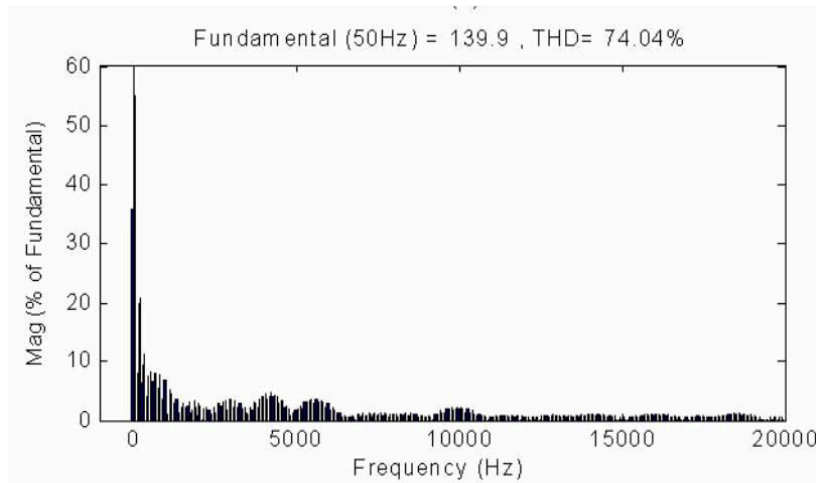


Fig.8 harmonic spectra of common mode voltage of proposed DTC induction motor drive

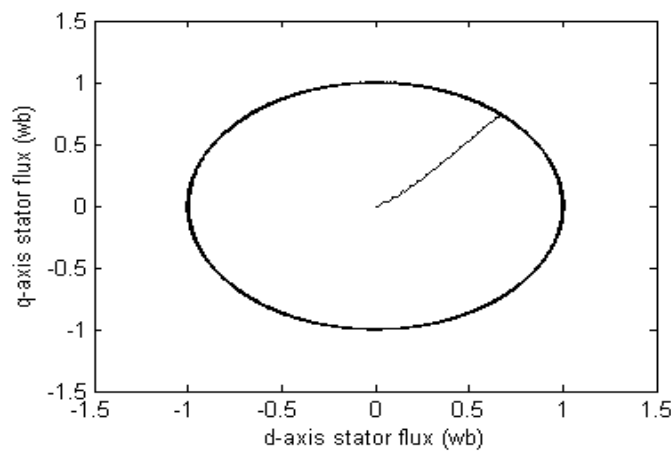


Fig.9 trajectory of stator flux for proposed DTC based induction motor drive

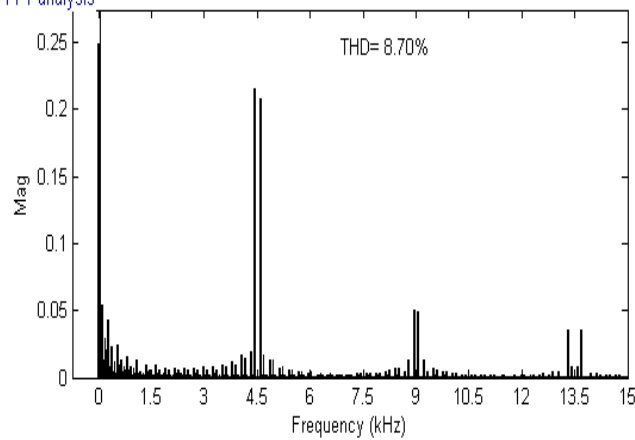


Fig.10 Harmonic spectra of line current for proposed DTC based induction motor drive





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## VII. CONCLUSION

In this paper, the dynamic behaviour of the induction motor under both transient and steady state conditions, an accurate mathematical model of the induction motor has been developed in the stationary reference frame. Thus, with the proposed method, the common mode emissions of direct torque controlled induction motor drive system can be decreased compared to CDTC with slight increase in torque, stator current and stator flux ripples. From the simulation results it can be concluded that with the proposed DTC algorithm the common mode voltages are reduced.

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