A NOVEL PWM BASED DIRECT TORQUE CONTROL OF INDUCTION MOTOR DRIVE

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ABSTRACT

Generally induction motors are used in industrial applications i.e. they are used as adjustable speed drives in most of the cases. The technique of Direct Torque Control has the feature of exact accurate and quick torque response and complexity reduction of Field Oriented Control algorithms. In order to obtain the fastest torque response and high efficiency at every instant in Direct Torque control, the generation of the inverter switching state is made to restrict stator flux and the electromagnetic torque errors within the torque and hysteresis band. Losses occurred due to the optimal switching table are reduced by using a new technique called optimal switching table. The common mode emissions are high in the conventional Direct Torque Control due to the zero voltage vectors. So to reduce the common mode emissions, a new DTC algorithm as been proposed in this paper. In the proposed method the selection of vectors are made by using the sector. Only odd voltage vectors are used in odd sectors and even voltage vectors are used in even sectors so as to eliminate the zero voltage vectors in the proposed work. In this PWM based Direct Torque Control of IMD no manual interruption is needed when compared to conventional DTC. By using this method Torque ripples, common mode emissions, THD are decreased compared to other methods. To validate the simulation as been carried out in MATLAB/SIMULINK environment and results are presented and compared. Hence from the result of simulation, it is observed that common mode emissions are reduced.

Keywords: Induction Motor, Direct Torque Control (DTC), Adjustable Speed Drives (ADS), Adaptive Control, MATLAB/SIMULINK, Total Harmonic Distortion, Modelling, And Common Mode Voltage

I. INTRODUCTION

Rotational mechanical loads which can operate with wide range of speeds are often called as variable speed drives or adjustable speed drives. The standard in those drives are Induction motor Drives and their applications in machine tools, fans, compressors, pumps, paper mills, steel and textile industries, robotics, electric traction, ship propulsion systems, automation[1]-[2]. Previously DC machines were preferred in variable speed applications, due to their disadvantages like robust, higher rotor inertia, cannot operate in dirty and explosive environmental conditions. Therefore these DC Drives are progressively replaced by AC Drives, after the invention of the power semi conductor devices like MOSFET; IGBT AC drives are preferred in variable speed drive applications[3]. The first vector control method of Induction motor was Field oriented control (FOC)[4], Direct Torque Control, Direct Torque Control using space vector modulation[5], and A Novel PWM based DTC of Induction motor drive with minimal torque ripples and common mode voltages. One of the most wide spared techniques for high performance electrical drives with Induction machines in Industry applications is a novel PWM based Direct Torque Control of Induction motor Drive. 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 different parts of the drive and the ground. To reduce these common mode emissions the selection of Inverter switching are limited[6]. High current and Torque ripple is observed in DTC which is mainly because of the Look Up table arrangement. This can be overcome by employing improved switching table by using adaptive control. To reduce the emissions a Optimal switching table is used instead of look up table, in which each sector consists of three vectors, the odd voltage vectors are used in odd sectors and even voltage vectors are used in even sectors therefore the zero voltage vectors are eliminated, which reduces the Torque ripples, Flux and Total Harmonic Distortions[8]-[9]. At the initial stage of developing the DTC method a VSI is employed to generate the voltages that control the speed and torque of the induction motor. In this paper, the proposed novel PWM based DTC algorithm reduces the common mode emissions of the drive[10].

In each of the six sectors of the inverter hexagon, without using drive in each of the six sectors of the inverter hexagon, with out 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 MODELLING OF INDUCTION MOTOR DRIVE

To study the dynamic performance of the machine model has been developed in stationary reference frame by using equations

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

The stator and rotor flux linkages in the stationary reference frame are defined by B.K.Bose [2].

$$\Psi_{qs} = L_s i_{qs} + L_m i_{qr} \quad (2)$$

$$\Psi_{ds} = L_s i_{ds} + L_m i_{dr} \quad (3)$$

$$\Psi_{qr} = L_r i_{qr} + L_m i_{qs} \quad (4)$$

$$\Psi_{dr} = L_r i_{dr} + L_m i_{ds} \quad (5)$$

The expression for the electromagnetic torque of an induction machine in the stationary reference frame is given by R. Krishnan, B. K. Bose [1, 2].

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left(\Psi_{ds} i_{qs} - \Psi_{qs} i_{ds}\right) \quad (6)$$

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 3-Phase Induction motor can be written,

$$T_e = (3/2)\,(P/2)\,(L_m/\delta L_S L_R) \mid \Psi_r \mid \mid \Psi_s \mid \sin\delta \qquad (7)$$

Where,

$$\delta = 1-(L_m^2/L_S\, L_r) \qquad (8)$$

In this new DTC algorithm when the stator flux space vector lies in the Kth sector, if an increase in the flux is required ,then the Kth voltage vector is applied , otherwise , if an increase in the torque is required , then the (k+2)th voltage vector is applied The vector diagram given in Fig.5.1 shows the voltage vector selection when the stator flux vector lies in the first sector and one of the voltage sectors V1, V3 and V5is applied. Actually, when the stator flux linkage lies in the kth sector, the application of the kth voltage vector produces an increase in the flux amplitude and a slight decrease of the electromagnetic torque the application of the (K+2)th voltage vector produces a slight decrease in the flux amplitude and an increase in the electromagnetic torque, while the application of (K-2)th voltage vector produces a slight decrease in the flux amplitude and a decrease in the electromagnetic torque.

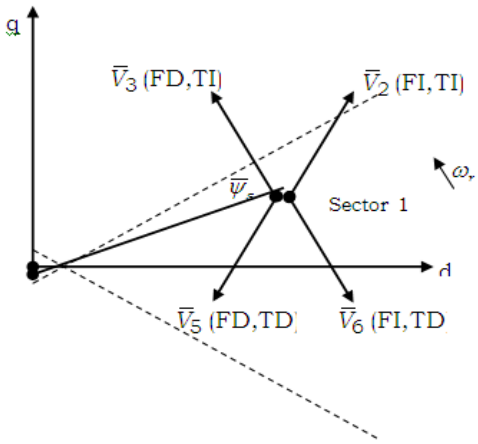

Fig 1. Sector calculation of DTC

SΨ	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

Depending on the position of stator flux linkage space vector, it is possible to switch the appropriate voltage vectors to control both stator flux and torque. As an example, if stator flux linkage space vector is in sector I as shown in the Fig. 5.1, then voltage vectors $\overline{V}_2$ and $\overline{V}_6$ can increase the stator flux and $\overline{V}_3$ and $\overline{V}_5$ can decrease the stator flux. Similarly, $\overline{V}_2$ and $\overline{V}_3$ can increase the torque and $\overline{V}_5$ and $\overline{V}_6$ can decrease the torque when the stator flux linkage vector is in sector-II. Similarly, the suitable voltage vectors can be selected for other sectors. The Switching vector table for proposed DTC is shown in Table 1. In particular the application of V1 causes a strong increase of the flux amplitude and a slight decrease of the torque, the application of V3causes a slight decrease of the flux amplitude strong increase of the torque and finally the application of V5 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.

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 Vdc/3.

IV. 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.

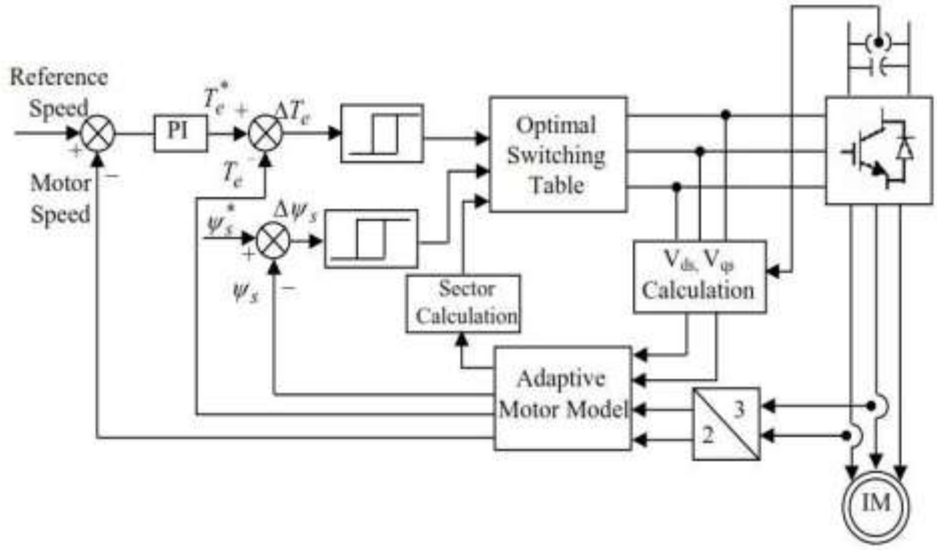

Fig2.Block Diagram of Proposed DTC of Induction Motor Drive

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 require then S_Ψ=1; if a stator flux decrease is required then S_Ψ= 0.

The digitized output signals of the two level flux hysteresis controller are defined as,

$$\text{If} \quad \Psi_S \le \Psi_S^* - \Delta\Psi_S \text{ ; then } S_\Psi = 1 \tag{9}$$

$$\Psi_S \le \Psi_S^* + \Delta\Psi_S \text{ ; then } S_\Psi = 0 \tag{10}$$

If a torque increase is required then $S_T = 1$, if a torque decrease is require 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,

$$\text{If} \quad T_e^* - T_e \ge T_e \text{ then } S_T = 1, \tag{11}$$

$$T_e \ge T_e^* \quad \text{then } \mathbf{S}_T = 0 \tag{12}$$

V. SIMULATION RESULTS

To validate the conventional DTC based induction motor drive, several numerical simulation studies have been carried out by using Matlab/Simulink at various operating conditions such as starting, steady state, step change in load and speed reversal. The specifications of induction motor and simulation parameters used in this thesis are given in Appendix. For the simulation, the reference flux is taken as 1wb and starting torque is limited to 15 N-m. The results for conventional direct torque controlled induction motor drive are presented.

For the simulation, the reference flux is taken as 1wb and starting torque is limited to 15 N-m. Various conditions such as starting, steady state, step change in load, speed reversal are simulated. The results for conventional direct torque controlled induction motor drive are shown in Fig 3 to Fig 9. Fig.4 shows the starting transients of CDTC. Fig. 5 shows the steady state plots of torque, current and stator flux at 1300 rpm. Moreover, it can be observed that, the CDTC gives high ripples in torque, current and stator flux during steady state.

The locus of the stator flux at 1200 rpm is shown in Fig.8, from which it can be observed that the locus is almost is a circle of constant radius. Fig.7 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.7. Fig.9 shows the common mode emission of conventional DTC, from which it can be observed that the common mode voltage is very high and is varying between $(+V_{dc}/2)$ to $(-V_{dc}/2)$. The wave form of the harmonic distortion of the common mode voltage is given in Fig.9 along with the total harmonic distortion (THD) value.

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: Rs = 7.83Ω, Rr = 7.55 Ω, Ls = 0.4751H, Lr = 0.4751H, Lm = 0.4535 H and J = 0.06 $Kg.m^2$.

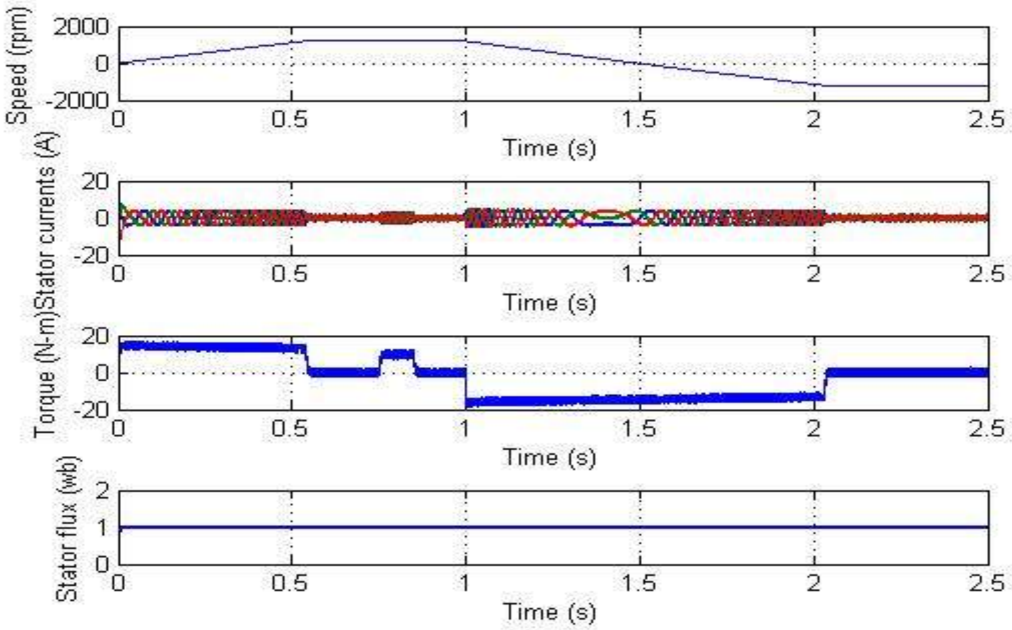

Fig 3 Response of Proposed DTC Based Induction Motor Drive for Starting, Steady State, Load Change and Speed Reversal

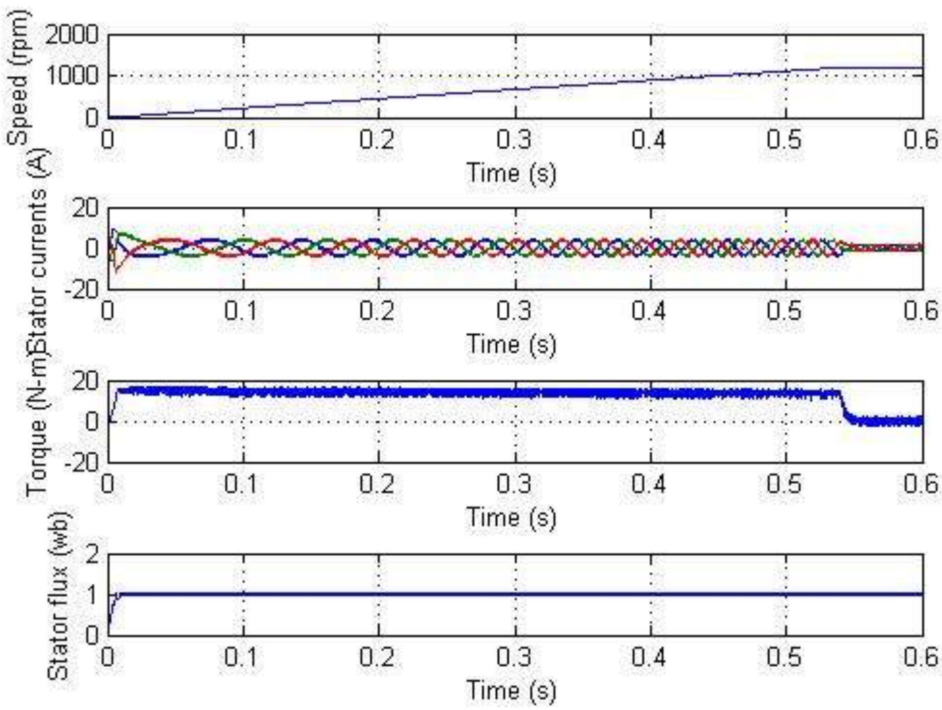

Fig.4 Starting Transients In Proposed DTC Based Induction Motor Drive.

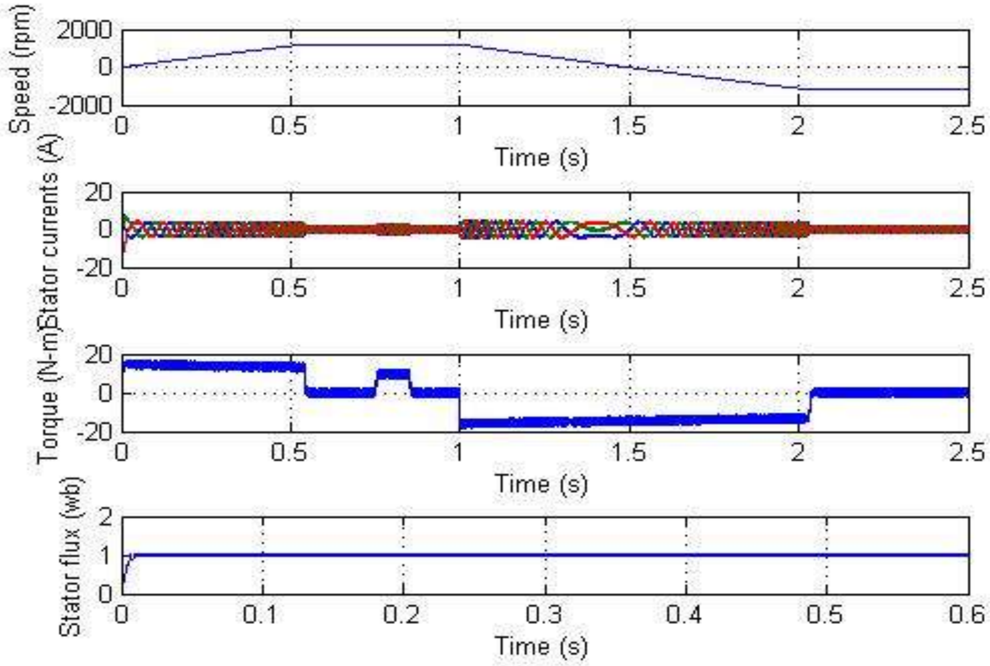

Fig.5 Steady State Plots for Proposed DTC Based Induction Motor Drive

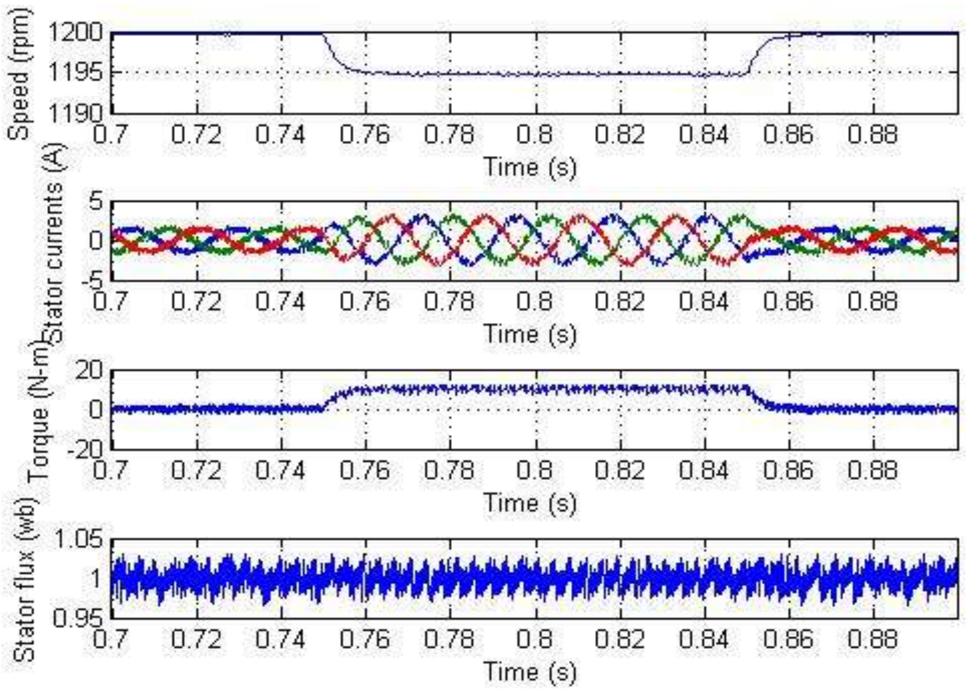

Fig.6 Transients in Speed, Current, Torque and Flux during Step Change In Load Torque (A Load Torque of 10 N-M Is Applied At 0.75s and Removed At 0.85s) For Proposed DTC Based Induction Motor Drive

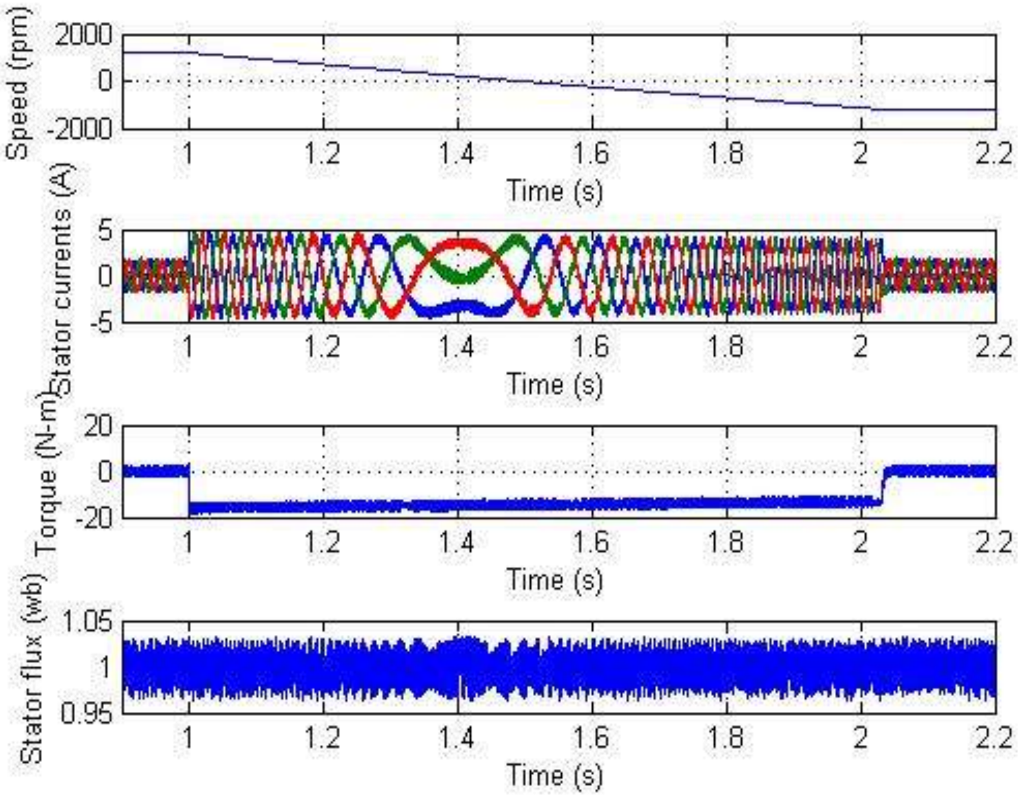

Fig.7 Transients In Speed, Current, Torque and Flux During Speed Reversal (The Speed Is Reversed From +1200 Rpm To -1200 Rpm)

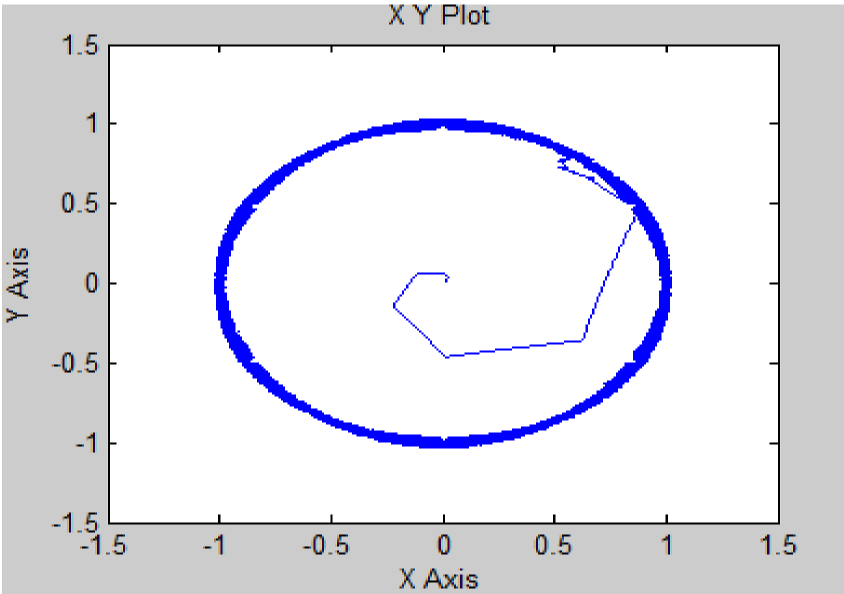

Fig.8 Trajectory of Stator Flux for Proposed DTC Based Induction Motor Drive

The locus of the stator flux at 1200 rpm is shown in Fig 6.8 from which it can be observed that the locus is almost is a circle of constant radius.

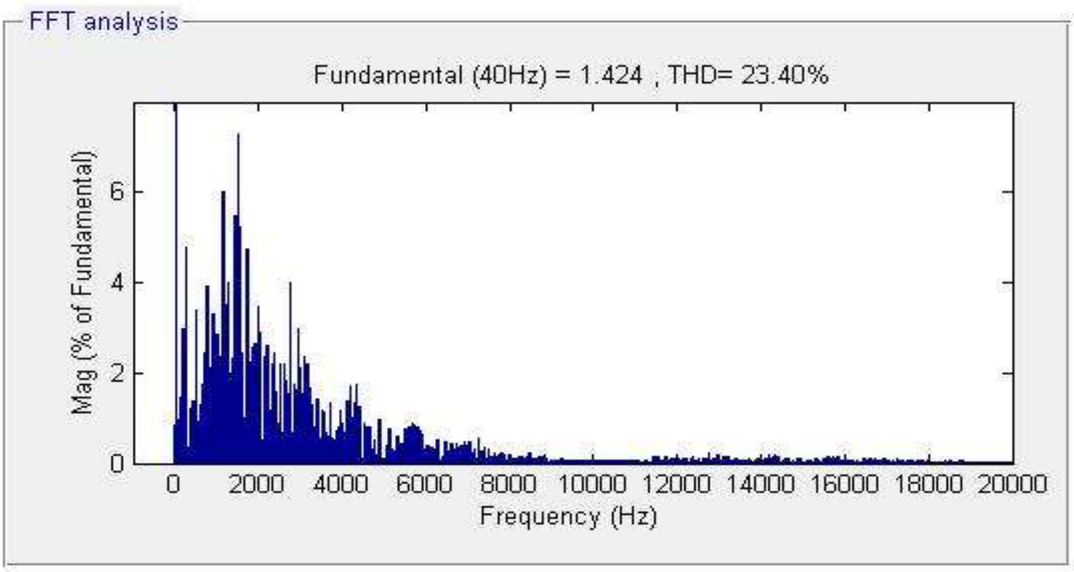

Fig.9 Harmonic Spectra of Line Current for Proposed DTC Based Induction Motor Drive

In the proposed direct torque control technique the Total Harmonic Distortion is given as THD= 23.4%

VI. CONCLUSION

The direct torque controlled induction motor drive has decoupled control of stator flux and torque and 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. But in conventional DTC, the common mode voltage is very high because of the switching of zero voltage vectors.

Hence, to reduce the common mode voltage, a novel algorithm has been developed in this thesis. In the proposed algorithm, only odd active voltage vectors have been applied in the odd sectors, whereas only even active voltage vectors will be applied in the even sectors. Thus, by eliminating the zero voltage vectors, the common mode emissions have been reduced.

To validate the proposed algorithm, the simulation has been carried out and from the simulation results; it can be observed that the common mode voltage is very less in the proposed algorithm compared to CDTC. But, there is slight increase in the steady state torque, current and flux ripples.

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