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Comparative Analysis of DTC & FOC of Induction Motor

Murtuza Y Saifee[1], Hitesh R Khunt[2], Ankit B Lehru[3], Niraj B Danidhariya[4], Dhaval A Vora[5]

[1]Assistant Professor, Department Of Electrical Engineering,
Atmiya Institute of Technology & Science, Rajkot, Gujarat, India.
[2]Assistant Professor, Department Of Electrical Engineering,
Atmiya Institute of Technology & Science, Rajkot, Gujarat, India.
[3]Assistant Professor, Department Of Electrical Engineering,
Atmiya Institute of Technology & Science, Rajkot, Gujarat, India.
[4]Assistant Professor, Department Of Electrical Engineering,
Atmiya Institute of Technology & Science, Rajkot, Gujarat, India.
[5]Assistant Professor, Department Of Electrical Engineering,
Atmiya Institute of Technology & Science, Rajkot, Gujarat, India.

Abstract *— Speed control of three phase induction motor is of great significance for industry. Scalar control, Field oriented control (FOC) and Direct Torque control (DTC) are most advanced techniques for speed control of induction motor. Scalar control method is not used in application, where accurate response of torque required. In all the operating conditions of Induction motor FOC scheme provides lower values of the three-phase rms current ripple. The DTC scheme provides better torque response in terms of settling time. Here Simulations and Results of both FOC and DTC technique have been carried out.*

Keywords *— Electrical Drives, Three Phase Induction Motor, Field Oriented Control, Direct Torque Control.*

I. INTRODUCTION

Over the past decades DC machines were used extensively for variable speed applications due to the decoupled control of torque and flux that can be achieved by armature and field current control respectively. Squirrel cage induction motors (SCIM) are more widely used than all the rest of the electric motors as they have all the advantages of AC motors and are cheaper in cost as compared to Slip Ring Induction motors. The dynamic operation of the induction machine drive system has an important role on the overall performance of the system of which it is a part. Field Oriented Control (FOC) and Direct Torque Control (DTC) are very popular speed control methods for Three Phase Induction Motor Drives. For the Inverter Switching topology Hysteresis Band Pulse Width Modulation (HBPWM) technique was employed. The scalar controlled induction motor drives give sluggish response due to the coupling between the various variables of induction motor. By using the concept of vector control, the induction motor can be controlled like a separately excited dc motor. DTC offers many advantages like absence of coordinate transformation and PWM modulator when compared with vector control strategy. [1,3]

II. FIELD ORIENTED CONTROL

The vector control technique gives a decoupled torque and flux control like a separately excited dc motor and gives fast torque response. The FOC controls the stator current vector, which is represented in a synchronously rotating reference frame in order to control the torque and flux. [2]

Depending upon the method of acquisition of flux information, the vector control or field oriented control method can be termed as: direct or indirect. In the direct method the position of the flux to which orientation is desired is strictly measured with the help of sensors, or estimated from the machine terminal variables such as speed and stator current/voltage signals. Direct field orientation method has its inherent problem at low speed where the voltage drops due to resistances are dominant. The indirect vector control eliminates the direct measurement or computation of rotor flux from the machine terminal variables, but controls its instantaneous flux position by summing the rotor position signal with a commanded slip position signal (also known as slip frequency control or feed forward control scheme). The direction of rotor position need an accurate rotor speed information and the commanded slip position is calculated from the model of the induction motor, that again involves machine parameters which may vary with temperature, frequency and magnetic saturation. This current vector consists of a torque producing component (iqs*) and flux producing component (ids*).[4]

The Current component of electromagnetic torque of an induction motor is given as

$$i_{qs}^{*} = \frac{4}{3}\frac{1}{\Psi dr}\frac{Lr}{Lm}\frac{Te^{*}}{P} \tag{1}$$

The Current component of Flux of an induction motor is given as

$$i_{ds}^{*} = \frac{\Psi r}{Lm} \tag{2}$$

The Slip Speed and Rotor Flux position vector can be derived from following equations:[5]

$$\omega sl=\frac{Lm}{Lr} * \frac{Iqs}{(\Psi r+0.001)} * Rr \tag{3}$$

$$\theta e = \int \omega e \, dt \tag{4}$$

$$\omega e= \omega sl+\omega e \tag{5}$$

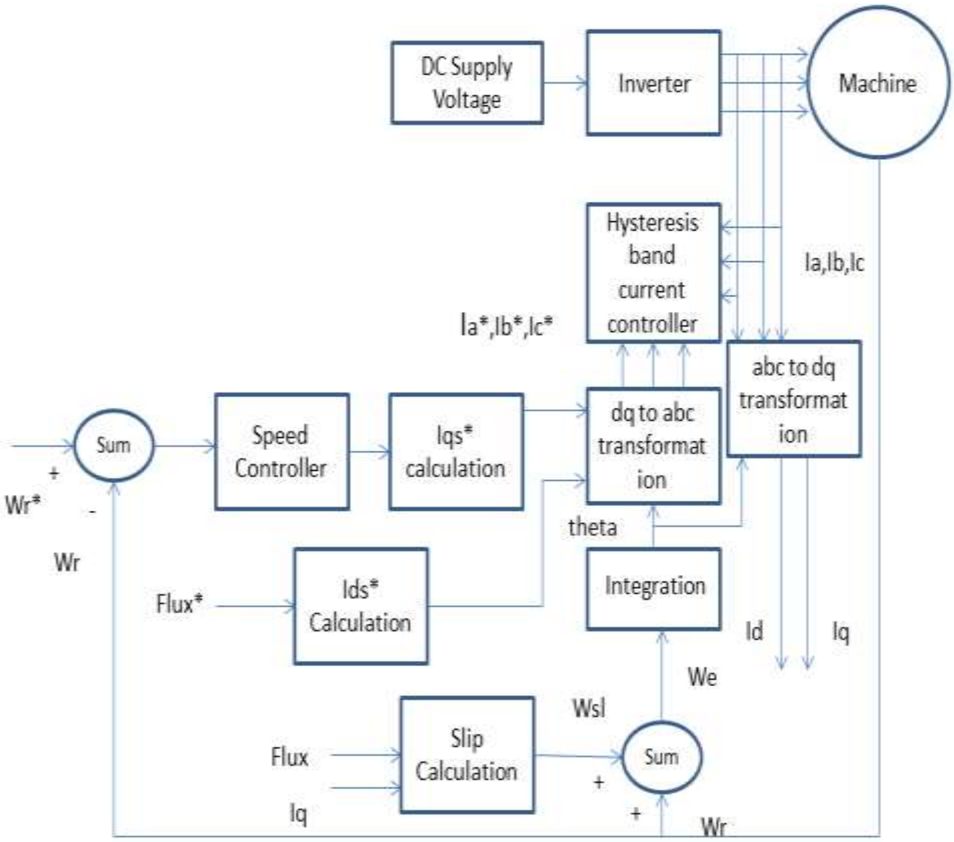


Fig. 2.1: Block Diagram of Indirect Field Oriented Control

III. DIRECT TORQUE CONTROL

Direct Torque Control (DTC) scheme is considered as the world’s most advanced AC Drives control technology. This is a simple control technique which does not require coordinate transformation, PI regulators, and Pulse width modulator and position encoders. This technique results in direct and independent control of motor torque and flux by selecting optimum inverter switching modes. The electromagnetic torque and stator flux are calculated from the primary motor inputs e.g. stator voltages and currents. The optimum voltage vector selection for the inverter is made so as to restrict the torque and flux errors within the hysteresis bands. The advantages of this control technique are quick torque response in transient operation and improvement in the steady state efficiency.[3]

The principle of DTC is based on limit cycle control, and it makes possible both quick torque response and high efficiency operation at the same time. Fig. 3.1 shows a system configuration of the DTC scheme. In this system, the instantaneous values of the flux and torque are calculated from only the primary variables. They can be controlled directly and independently by selecting optimum inverter switching modes. The selection is made so as to restrict the errors of the flux and torque within the hysteresis bands and to obtain the fastest torque response and highest efficiency at every instant. It enables both quick torque response in the transient operation and reduction of the harmonic losses and acoustic noise. Moreover, the implementation of an efficiency controller for the improvement of efficiency in the steady-state operation is also considered.[6,7]

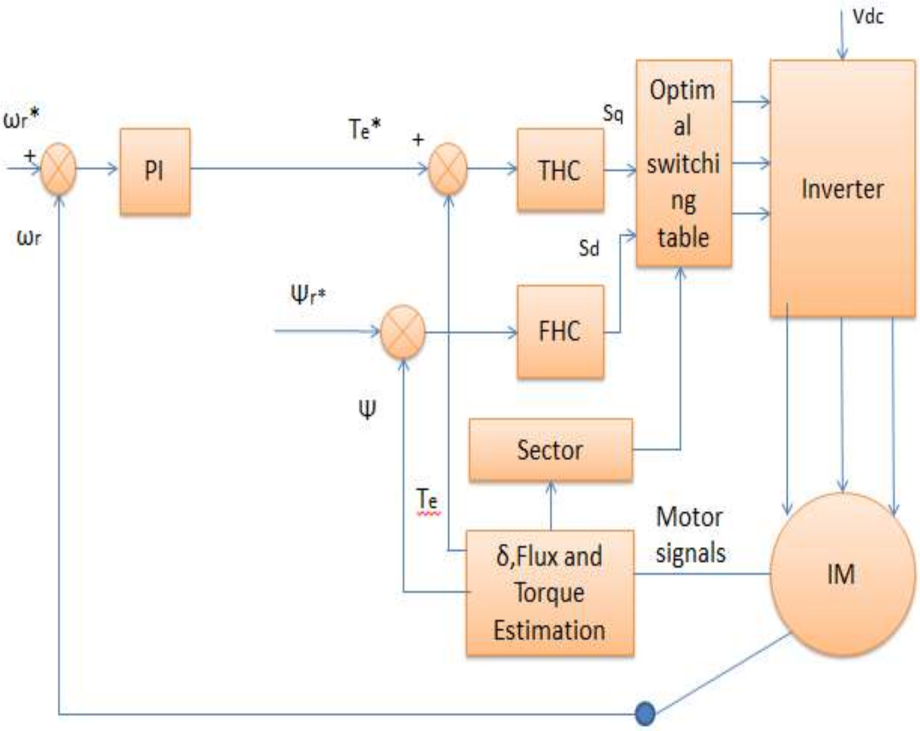
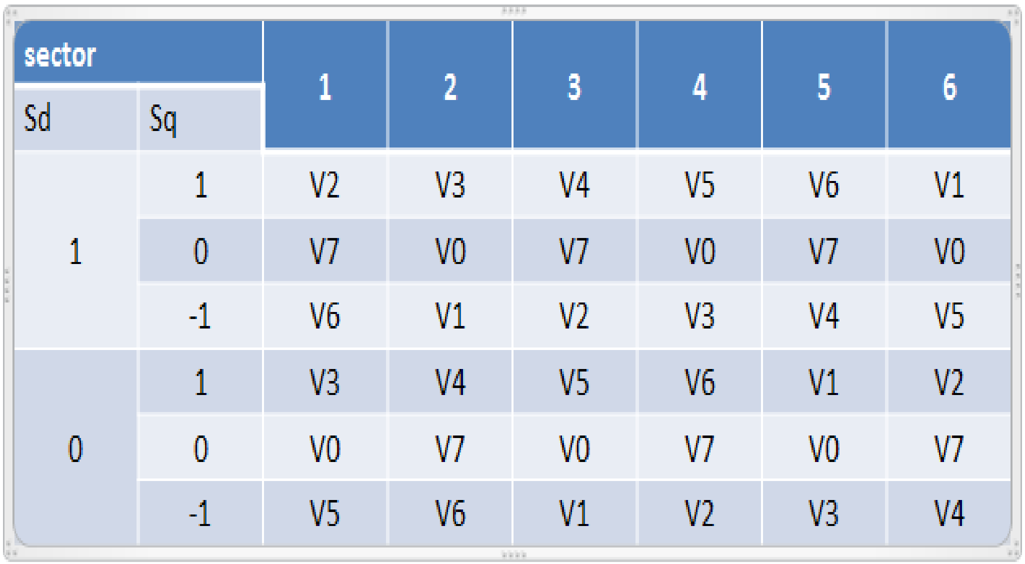


Fig. 3.1: Block Diagram of Direct Torque Control

As shown in Fig. 3.1 various subsystem of the DTC scheme is shown. Flux Hysteresis Comparator (FHC) and Torque Hysteresis Comparator (THC) were used to generate appropriate Flux Error and Torque Error respectively. FHC is a two level hysteresis Comparator and THC is a three level Hysteresis comparator. From Estimation of Flux and Estimation of torque appropriate sector was selected. From output signal from FHC, THC and appropriate sector selection optimal switching voltage vector was selected from switching table.[8]

TABLE 1
SWITCHING TABLE



sector		1	2	3	4	5	6
Sd	Sq						
1	1	V2	V3	V4	V5	V6	V1
	0	V7	V0	V7	V0	V7	V0
	-1	V6	V1	V2	V3	V4	V5
0	1	V3	V4	V5	V6	V1	V2
	0	V0	V7	V0	V7	V0	V7
	-1	V5	V6	V1	V2	V3	V4

IV. SIMULATION OF FOC & DTC

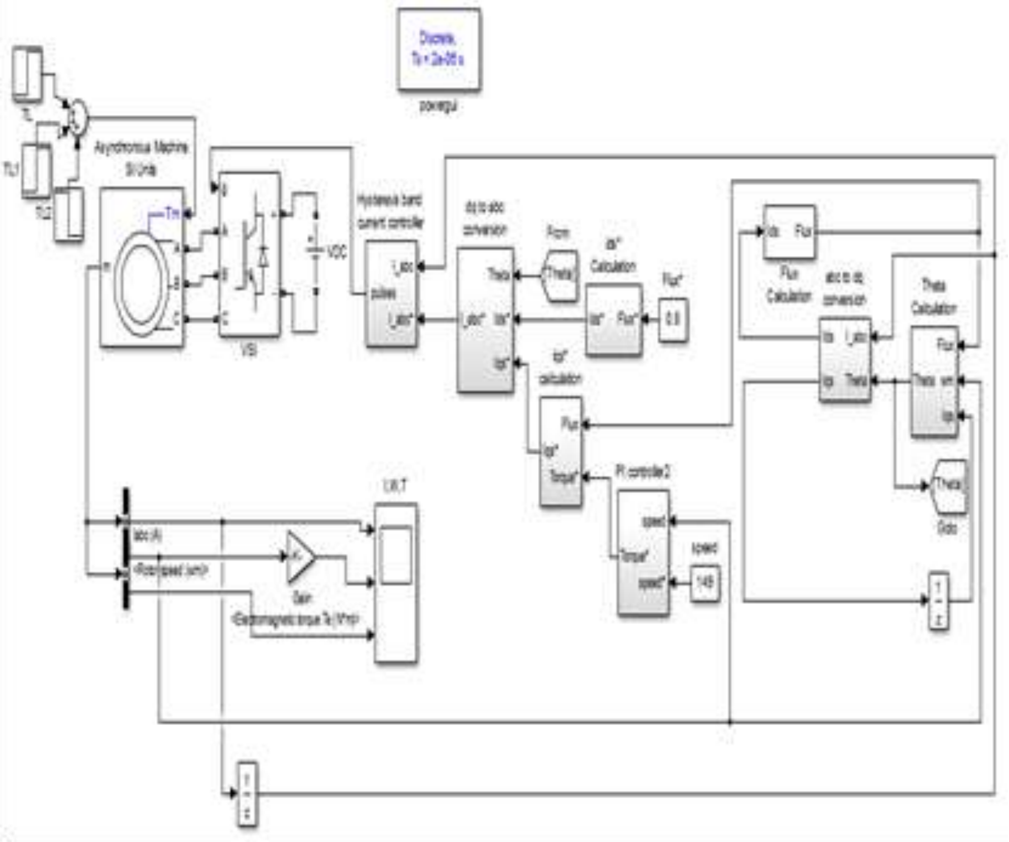


Fig. 4.1: Simulation of FOC

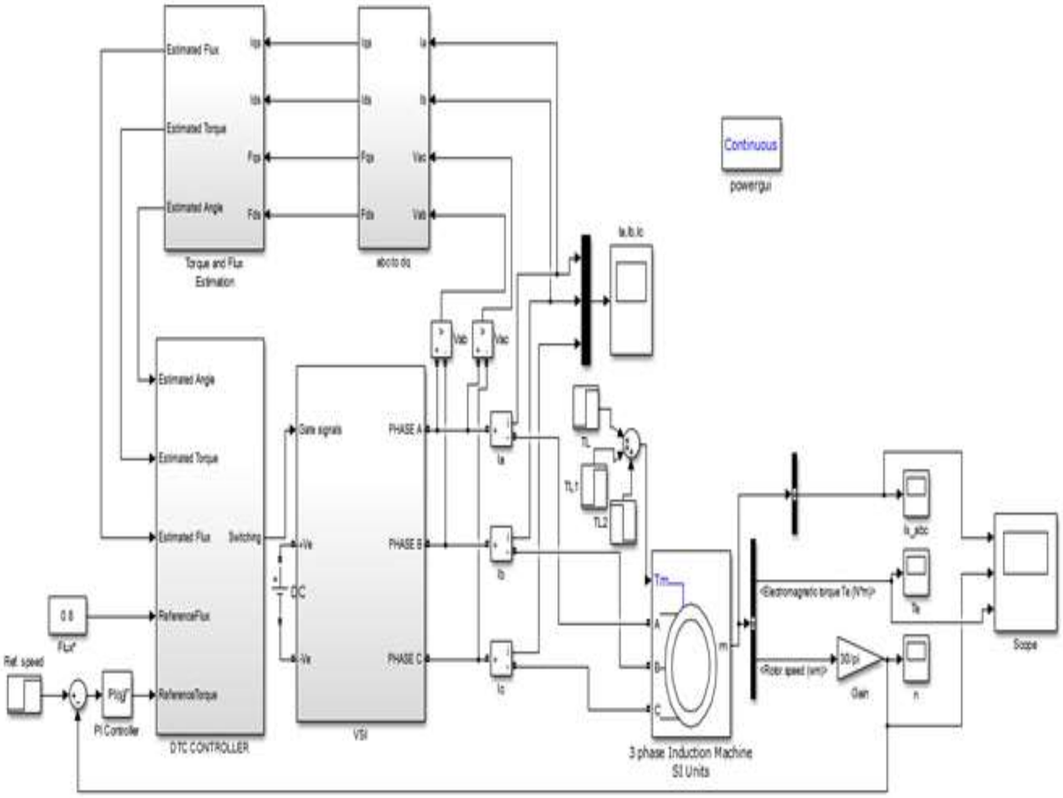


Fig. 4.2: Simulation of DTC

V. SIMULATION RESULTS

To validate the proposed FOC and DTC algorithms numerical simulation studies have been carried out using Matlab-simulink. For the Simulation studies motor parameters are taken as follows:
Power Rating = 5hp, Rated speed = 1430rpm, stator resistance Rs = 1.395Ω, Rotor resistance Rr = 0.7402Ω, stator inductance Ls = 5.839mH, rotor inductance Lr=5.839mH, Mutual inductance Lm = 172.2mH, No. of poles P = 4, DC link voltage Vdc = 581.2V.

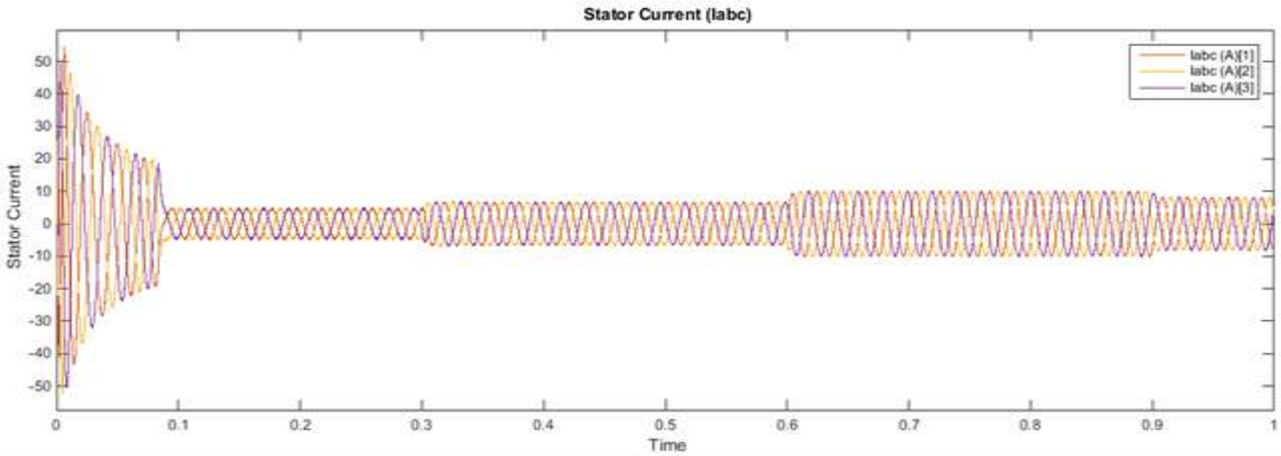


Fig. 5.1: Stator Current (FOC)

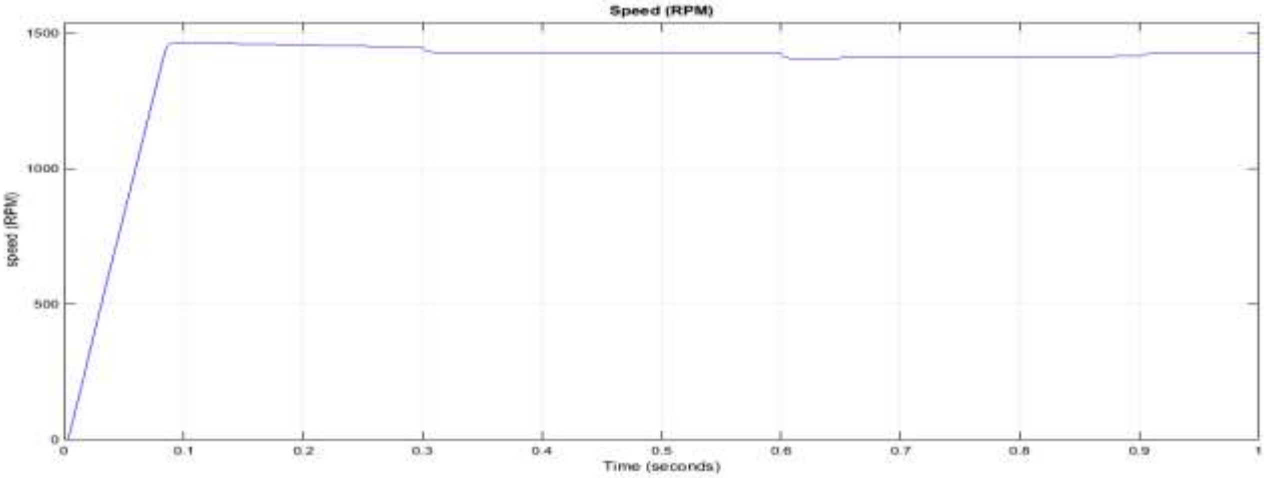


Fig. 5.2: Rotor Speed in RPM (FOC)

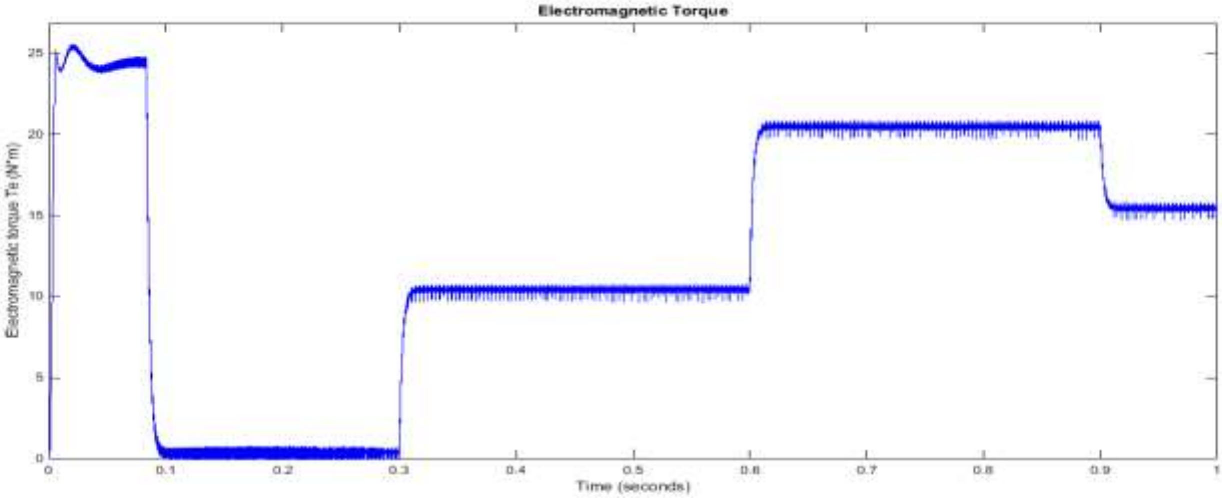


Fig. 5.3:Electromagnetic Torque Under Varying Load Conditions (FOC)

Here simulation of FOC is carried out for 1sec under varying load condition. Upto 0.3 sec load torque is 0 N-M, from 0.3-0.6 sec load torque is 10 N-M, 0.6-0.9 sec load torque is 20 N-M, above 0.9 sec load torque is 15 N-M. For this condition output waveform of stator current , rotor speed and Electromagnetic torque is shown in Fig.4.1, Fig.4.2 and Fig.4.3 respectively.

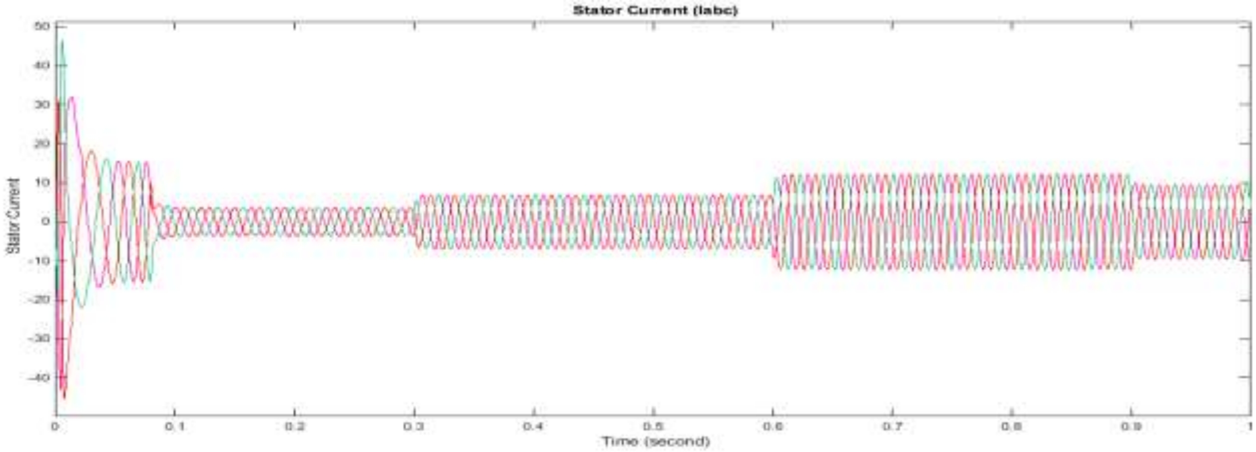


Fig. 5.4:Stator Current (DTC)

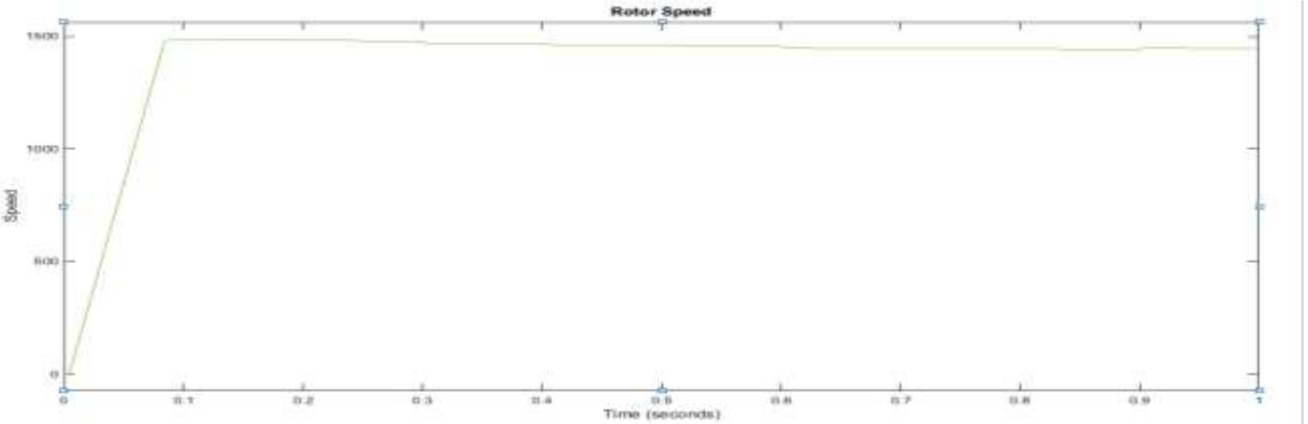


Fig. 5.5:Rotor Speed in RPM (DTC)

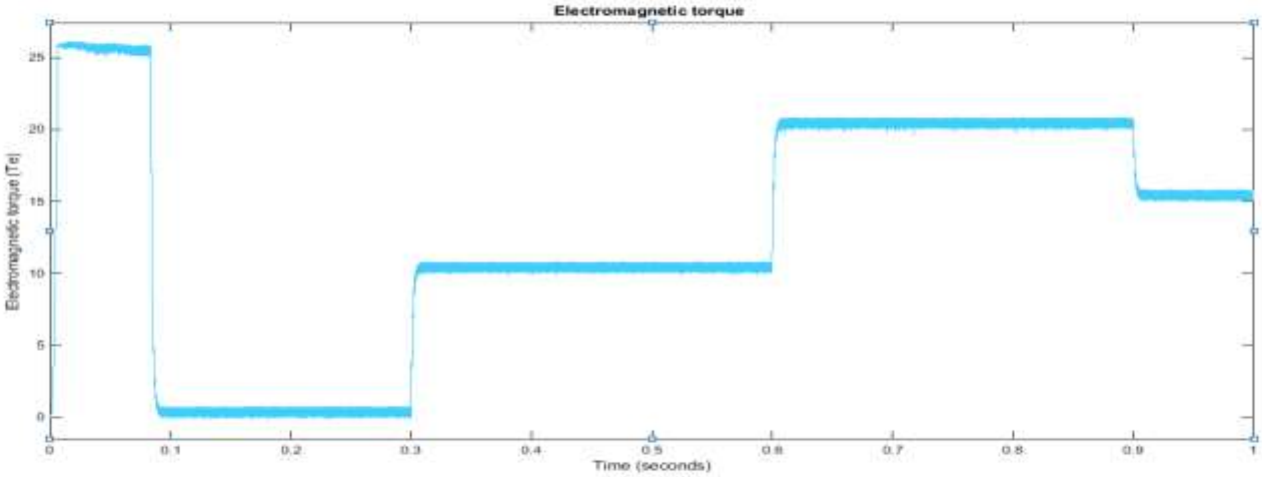


Fig. 5.6:Electromagnetic Torque Under Varying Load Conditions (DTC)

Here simulation of DTC is carried out for 1sec under varying load condition. Upto 0.3 sec load torque is 0 N-M, from 0.3-0.6 sec load torque is 10 N-M, 0.6-0.9 sec load torque is 20 N-M, above 0.9 sec load torque is 15 N-M. For this condition output waveform of stator current , rotor speed and Electromagnetic torque is shown in Fig.4.4, Fig.4.5 and Fig.4.6 respectively.

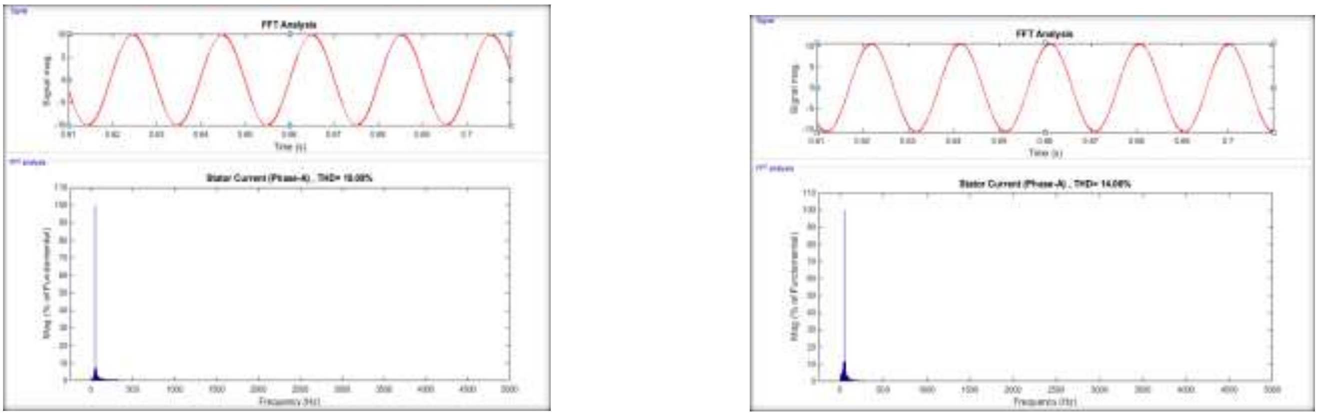


Fig. 5.7:THD Analysis of Stator Current (a) Field Oriented Control, (b) Direct Torque Control

From Fig. 4.7, THD Analysis has been done for Phase-A of stator current between time 0.61 sec to 0.71 sec. It was observed that THD content in stator current of FOC was 10.08%. In DTC THD content in stator current of DTC is 14.06%.

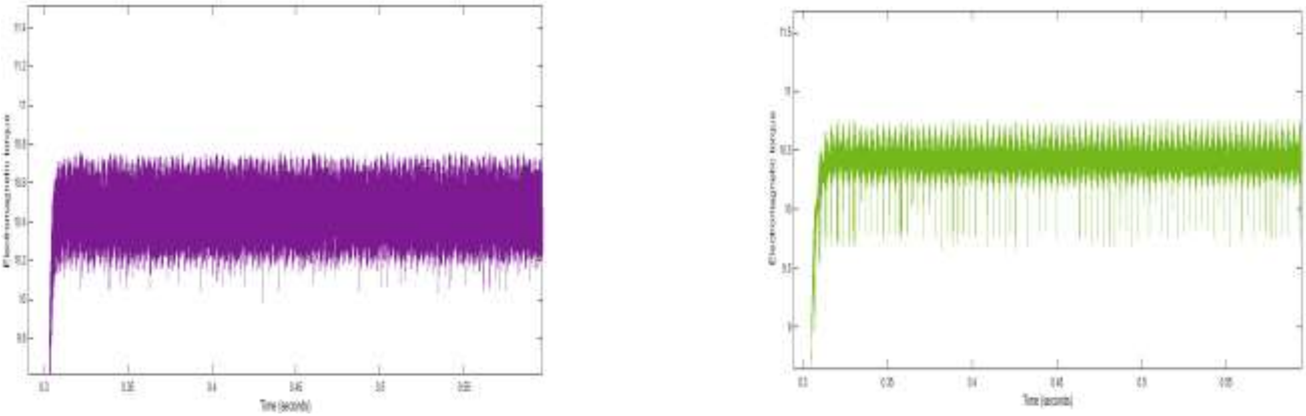


Fig. 5.8:Torque Ripple (a) Direct Torque Control, (b) Field Oriented Control

From Fig. 4.8, Analysis of Torque ripple has been done for Electromagnetic torque. It was observed that DTC has Torque ripple of 1.2 Nm and FOC has Torque ripple of 0.8 Nm.

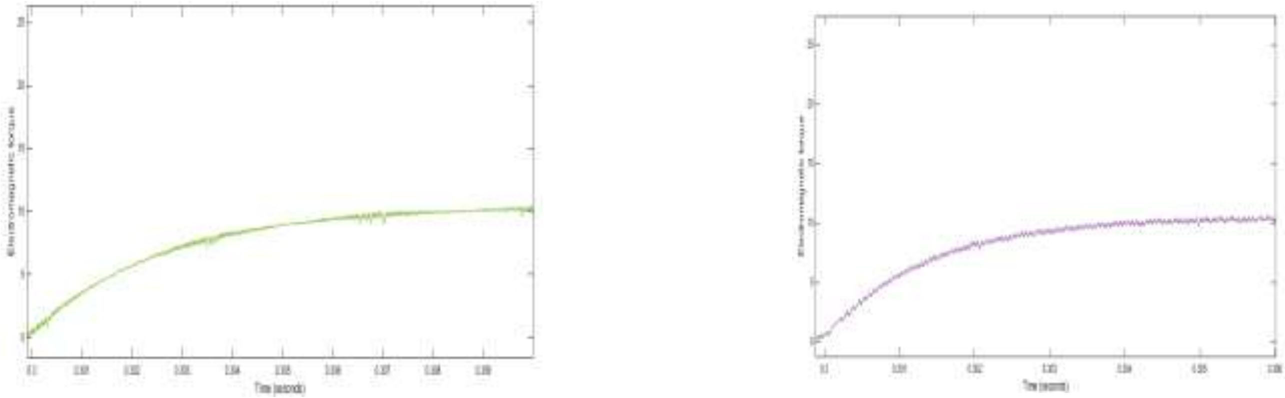


Fig. 5.9:Torque Settling Time (a) Field Oriented Control, (b) Direct Torque Control

From Fig. 4.9, Analysis of Torque Settling time has been done for Electromagnetic torque. It was observed that FOC has torque settling time of 10msec and DTC has Torque Settling time of 5msec.

VI. CONCLUSION

This work proposes Field Oriented Control and Direct Torque Control Scheme for speed control of Three Phase Induction motor. In varying load operating conditions the behavior of FOC scheme is characterized by lower values of THD in stator current and less torque ripple, where DTC scheme has better torque response in terms of settling time. The FOC and DTC model were developed and simulated in MATLAB/SIMULINK environment.

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