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DIRECT TORQUE CONTROL OF INDUCTION MOTOR DRIVE FED BY VSI: MODELING AND SIMULATION

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Abstract- To improve the performance of an induction motor drive, there is always a need of an efficient controller to control the motor parameters and regulate torque and flux. Direct Torque Control (DTC) has emerged as a powerful tool with promising characteristics like faster torque response with improved dynamic performance. This paper investigates DTC for Induction motor drive using a three-phase voltage source inverter. The performance of the system is verified with the help of MATLAB/SIMULINK environment.
Keywords: direct torque control, induction motor drive, speed control.

Nomenclature

Is = Stator Current
ψr = Rotor Flux
Vs = Stator Voltage
Rs= Stator Resistance
Rr= Rotor Resistance
Ls= Stator Self Inductance
Lr= Rotor Self Inductance
M= Mutual Inductance
σ=Leakage Coefficient
τr = Rotor Time Constant
ωr = Motor Angular Velocity

1. INTRODUCTION

Induction motor have been widely used in the industries as well as households due to their advantages such as ruggedness, low cost, reliability and faster response to load disconnection. But it is most important to control the induction motor to provide faster dynamic response and improve steady state accuracy. Various control techniques have been introduced in the past in which the Direct Torque Control have proved to be most commonly used technique. DTC as initially introduced by Takahashi and Depenbrock in the middle of 1980s, was one of the most adopted technique for IM drives. This strategy is based on selecting the appropriate sequence of command applied to the switches of the inverter feeding the motor.

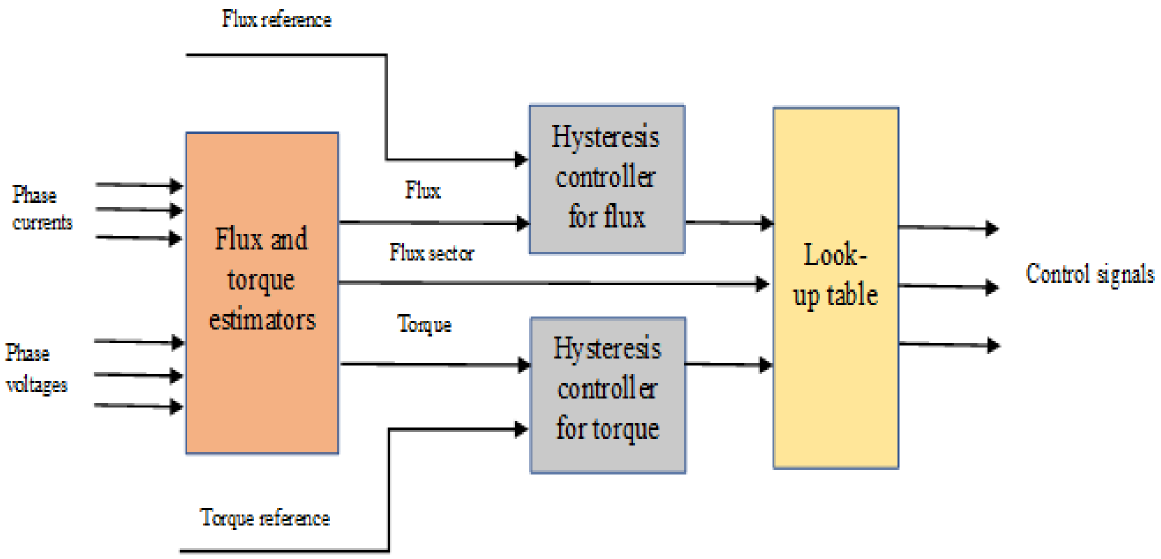

Fig. 1.1 Block diagram of DTC controller

It should be chosen with reference to the errors of flux linkage and torque in order to maintain flux and torque variables within two hysteresis bands. DTC also leads to undesirable torque and flux ripples despite its multiple advantages, such as less machine parameter dependence, quicker torque response, simpler structure and implementation. In [5], authors have used SVPWM technique to control the inverter fed IM under DTC strategy.

This technique consists of selecting a proper voltage vector by means of space vector modulation which can further be imposed leading to required switching of the inverter.

2. MODELLING OF INDUCTION MOTOR

The machine is modelled in stationary reference frame where a d-q model is developed to study the transient behavior of the machine.

$$\psi da = \int Vda - ida.Ra\, dt \quad (1)$$

$$\psi qa = \int Vqs - iqs.Ra\, dt \quad (2)$$

$$\psi dr = \int \omega r.\psi qr - idr.Rr\, dt \quad (3)$$

$$\psi qr = \int \omega r.\psi dr - iqr.Rr\, dt \quad (4)$$

$$\frac{di}{dt}\begin{bmatrix} i \\ \psi \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}\begin{bmatrix} is \\ \psi r \end{bmatrix} + \begin{bmatrix} B1 \\ 0 \end{bmatrix} Vs$$

$$= Ax + Bvs \quad (5)$$

Which can also be written as

$$Is = Cx \quad (6)$$

Here,

$$Is = [ids\ iqs]\mathbf{T}$$

$$\psi r = [\psi ds\ \ \psi qs]\mathbf{T}$$

$$Vs = [Vds\ \ Vqs]\mathbf{T}$$

A11=-{Rs/(σLs) + (1-σ) / (στr)}I

A12= M/(σLsLr) {(1/τr)I-ωr}

A21 =(M/τr)I

A22 = - (1/ τr)I + ωr J

B1 = (1/σLs)I

C =[I 0]

$$I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$J = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$$

3. PRINCIPLE OF DIRECT TORQUE CONTROL

The DTC scheme illustrated in figure 3.1 is based on selecting one of eight voltage vectors used to control the switches of inverter fed induction motor. The choice of sequences depends on torque and stator flux errors, which are calculated through hysteresis comparators. In DTC controlled induction motors, two hysteresis comparators are used for stator flux and torque which then utilizes the look up table for the voltage vectors.

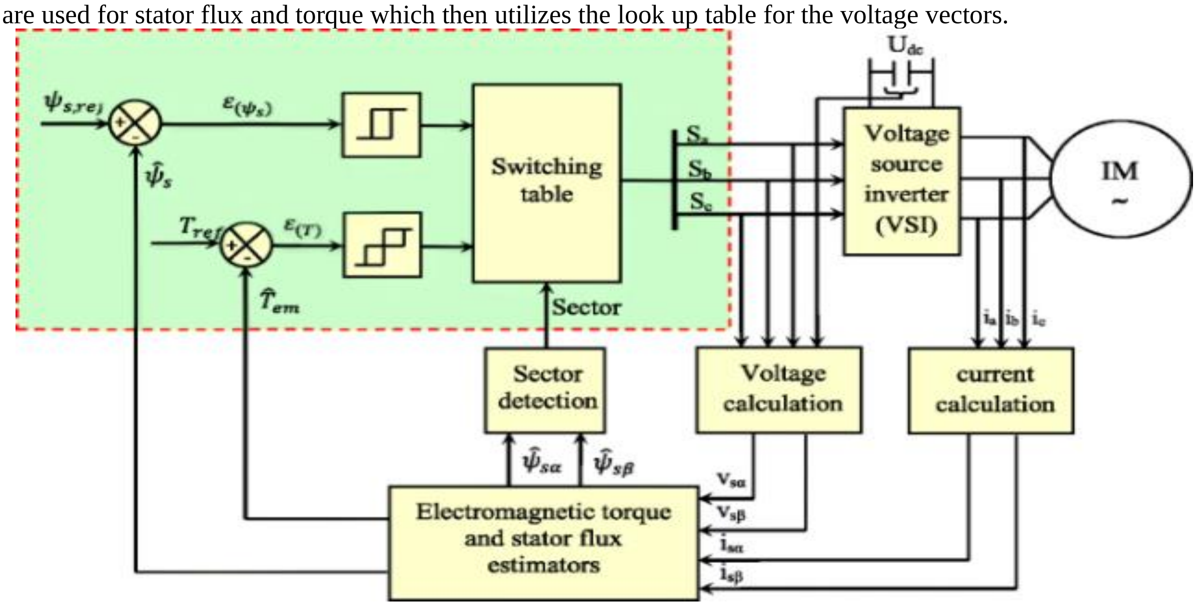

Fig. 3.1 Schematic diagram of DTC using VSI fed IM

This results in switching pattern for the voltage source inverter. Unlike FOC, the Direct torque control (DTC) of induction motor does not require any decoupling or coordinate transformation. It has fast torque and flux responses, no need for speed or position sensors. These advantages of the DTC scheme have led to the study and investigation for a long time. Fig 3.2 shows the schematic diagram of DTC methods using VSI.

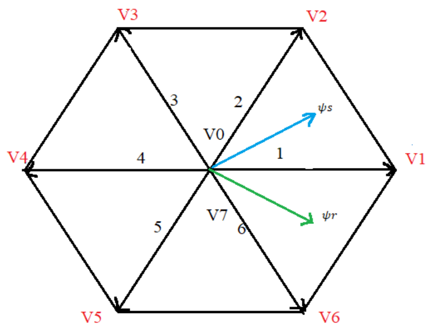

Fig. 3.2 Sector Selection Diagram

As shown in figure 3.2, the selection of the adequate voltage vector is based on the switching table given in Table 3.1. The input variables are the stator flux sector and the outputs of two hysteresis comparators, which are the torque and flux errors. The inverter converts dc to ac using power switching devices. In space vector technique there are eight states including six non - zero states and two null voltages. The ON states are indicated by '1' and OFF states are indicated by '0'. The stator flux angle, torque status and stator flux status are used for determining the appropriate voltage vector to the IM operating using DTC.

Table-3.1 Voltage Vector Selection

Ψs	Te	Sectors I	II	III	IV	V	VI
1	1	V2	V3	V4	V5	V6	V1
1	0	V0	V7	V0	V7	V0	V7
1	-1	V6	V1	V2	V3	V4	V5
0	1	V3	V1	V5	V6	V1	V2
0	0	V7	V0	V7	V0	V7	V0
0	-1	V5	V6	V1	V2	V3	V4

4. SIMULATION AND RESULTS

The simulation diagram of the proposed system is presented in this section. It has been modeled with stationary reference frame with hysteresis flux and torque controllers. The pulses for inverter has been generated using Space Vector PWM technique.

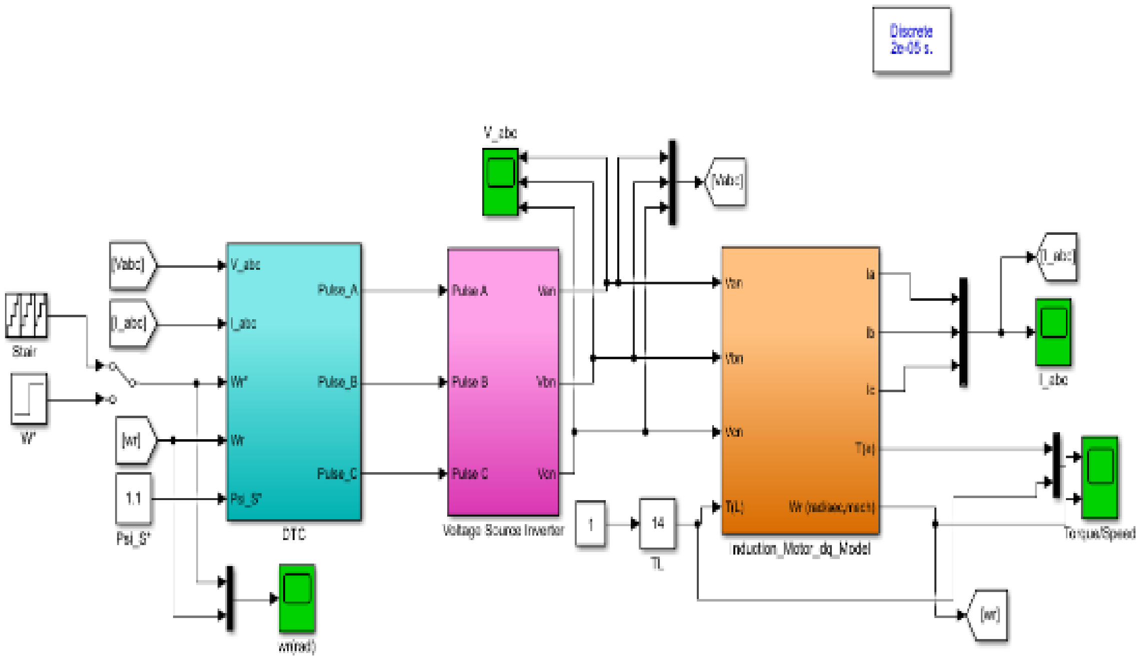

Fig. 4.1 DTC Controlled VSI Fed Induction Machine Simulink Model

Table -4.1 Mulation Parameters Details

Simulation parameters	**Value**
Rated motor power	4KW
Rated motor voltage	400V
Rated frequency	50 Hz
Rated speed	1430 r.p.m.
Stator resistance Rs	1.40 ohms
Rotor resistance Rr	1.39 ohms
Mutual inductance M	17.2 mH
Stator inductance Ls	58.3 mH
Rotor inductance Lr	58.3 mH
No. of poles	2

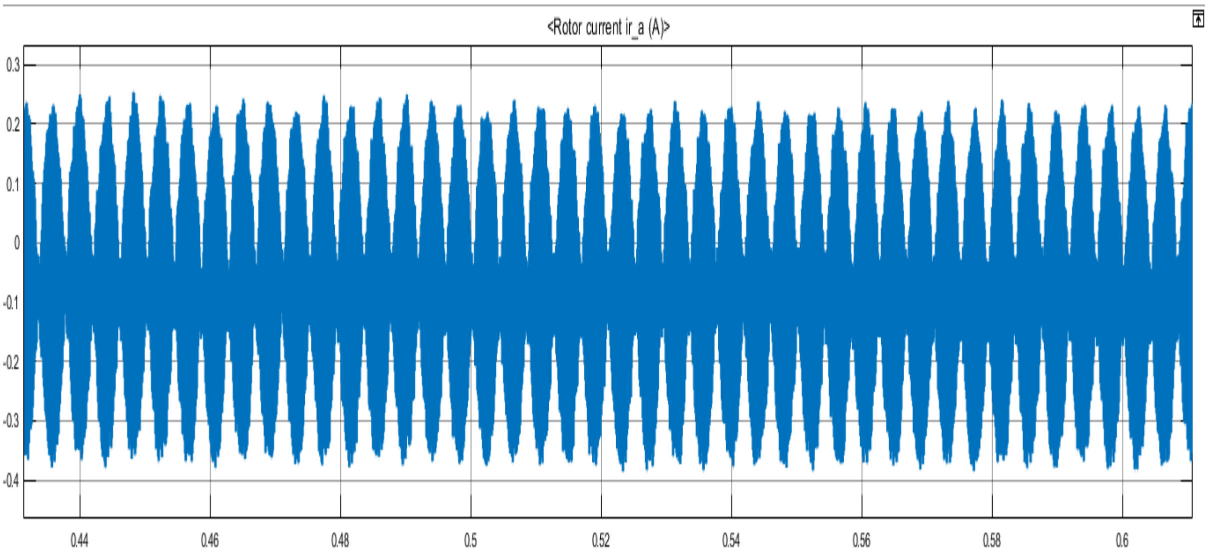

Fig. 4.2 Rotor Current of Phase A

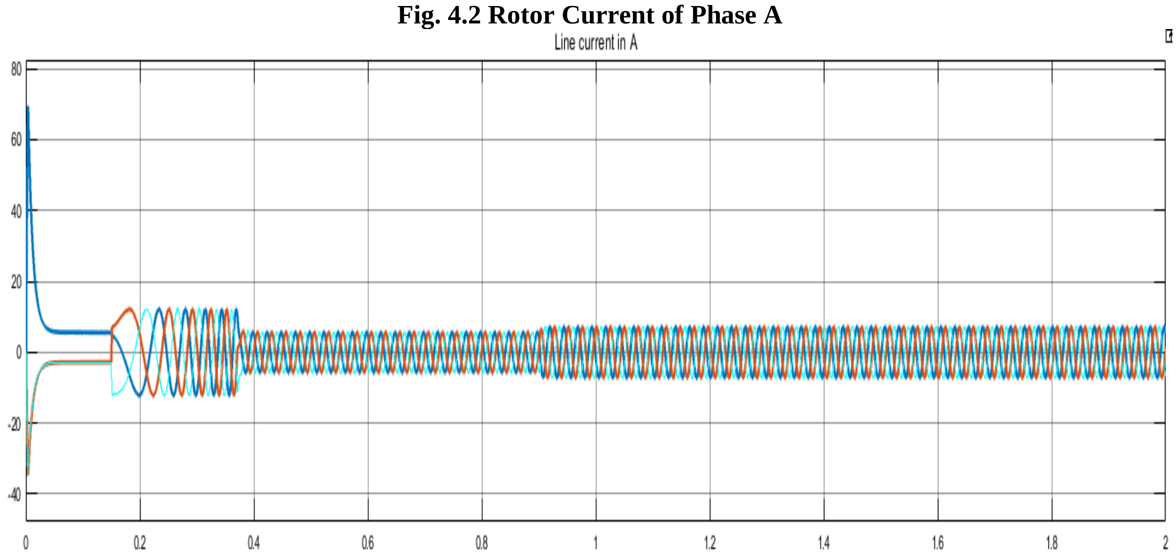

Fig. 4.3 d-q axis Stator Current

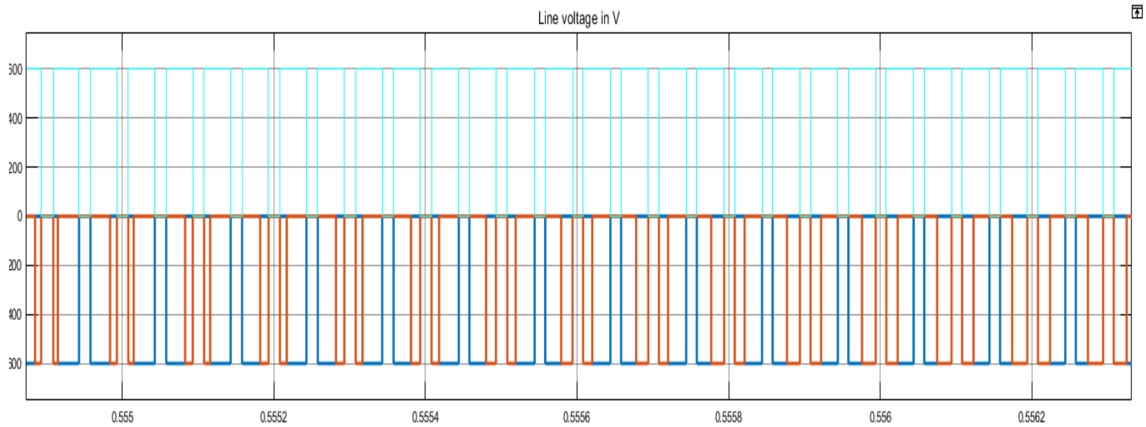

Fig. 4.4 Input Line Voltage

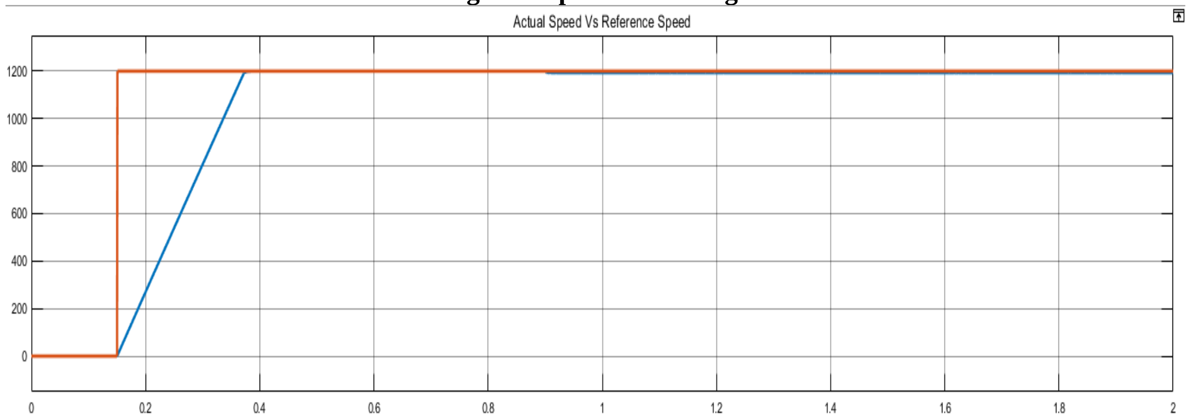

Fig. 4.5 Actual Speed vs Reference Speed under Load Conditions

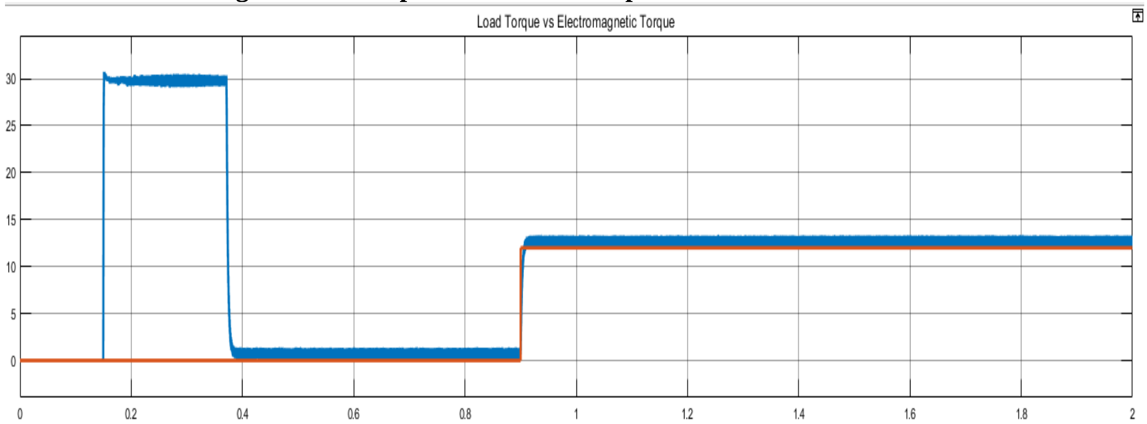

Fig. 4.6 Load Torque vs Electromagnetic Torque

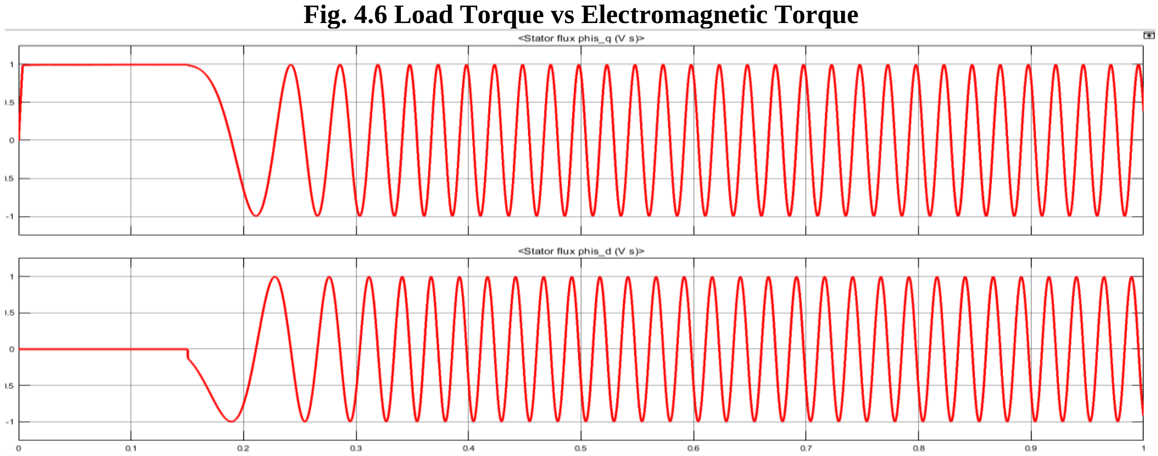

Fig. 4.7 Stator Flux in d-q Axis Frame

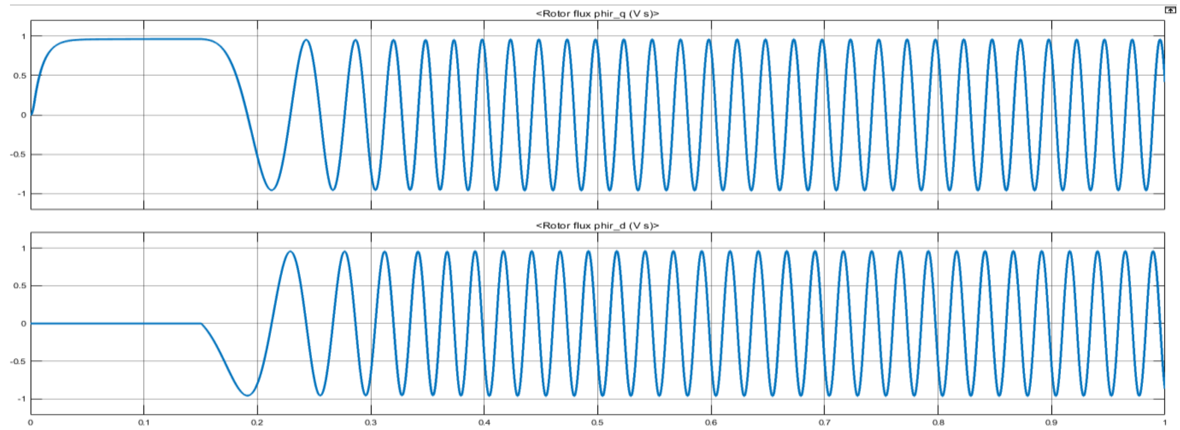

Fig. 4.8 Rotor Flux in d-q Axis Frame

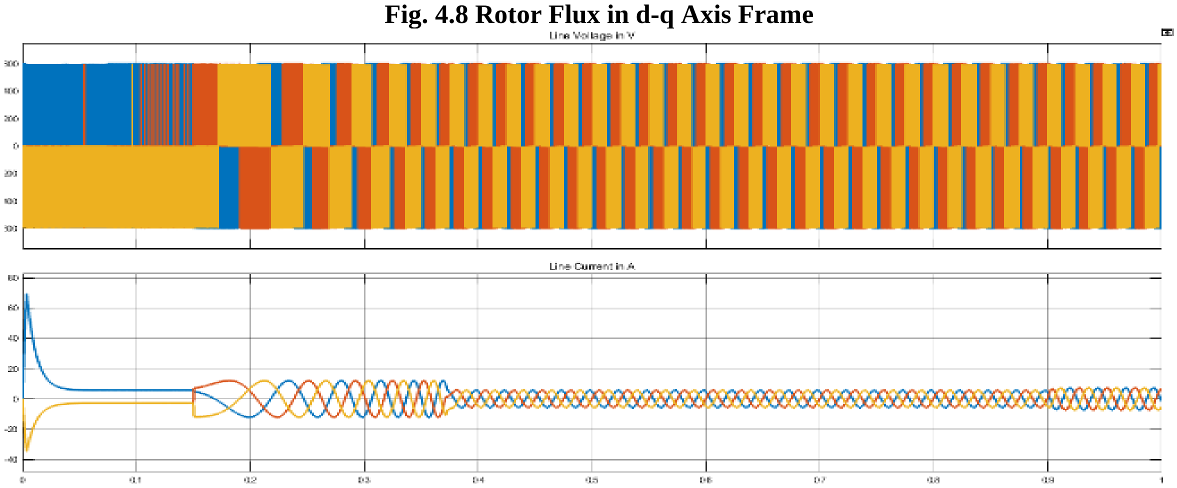

Fig. 4.9 Input Line Voltage and Line Current

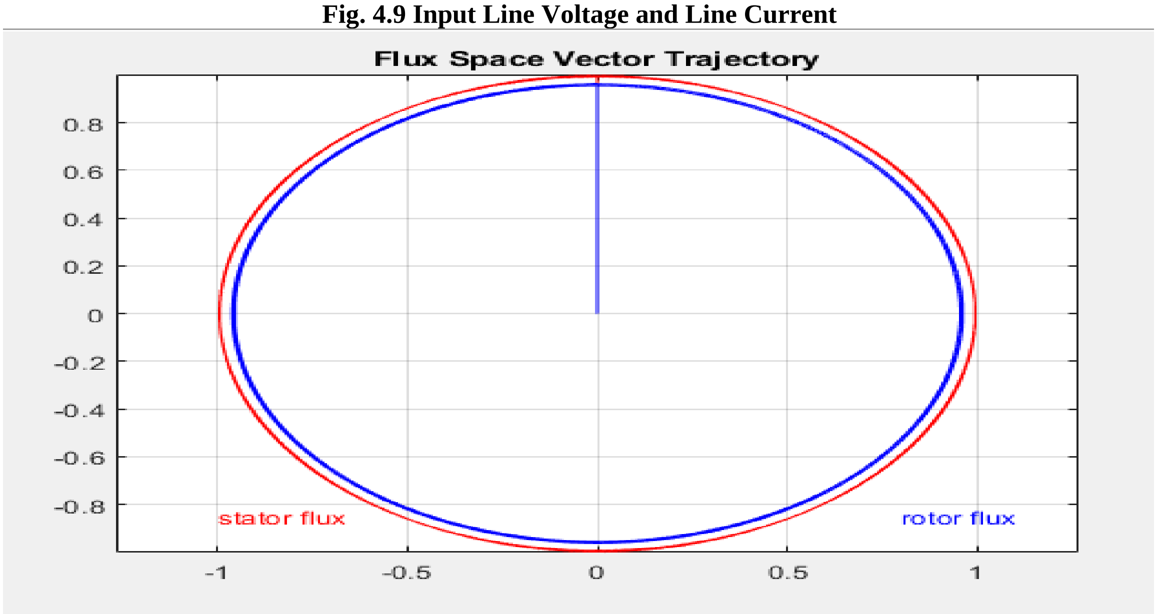

Fig. 4.10 Flux Trajectory under Load Conditions

CONCLUSION

Modeling of three – phase VSI fed induction motor drive has been done in stationary reference frame with Direct Torque control and observed that there is a speed and torque oscillation during starting and the speed settles at 0.39 sec. And the torque settles at 0.915 sec. This shows the that the direct torque controller technique has fast speed response reducing the settling time for speed-torque. The proposed DTC model was simulated. The outcomes demonstrate precise flux and torque control. The rotor currents are sinusoidal with a smooth flux trajectory. The good properties of the DTC depicts sinusoidal flux control exclusively and the simplicity of design. This method is vastly implemented in industries to improve the performance of the Induction motor drive.

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