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Modelling and Analysis of Vector Controlled Induction Motor Drives in Electric Vehicles

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Abstract : This paper presentsthe design and implementation of vector controlled induction motor drive for electric vehicle system. This method leads to adjust the speed of the motor by using indirect vector controlled electric drive fed from a three phase inverter. The multi-level Pulse Width Modulation (PWM) inverter and various modulation strategies has been implemented and analyzed in the drive system to obtain the better performance. Also a new simplified Space Vector Pulse Width Modulation (SVPWM) method is developed and its dynamic characteristics are studied. Simulation is carried out in MATLAB/SIMULINK environment and results are compared for speed control of induction motor.

Keywords: Electric Vehicles, Vector control, Induction motor drives.

1. INTRODUCTION

Electric vehicles are the future of transport and they are high efficient, produces no pollution, silent, and can be used for power regulation by the grid operator. The main challenges which limits the application of electric drives in transport are driving range, long charging time, and high cost and the battery package. The battery package should both contain enough energy in order to have a certain driving range and it should also have a sufficient power capability for the accelerations and decelerations. In order to estimate the energy consumption of electric vehicles it is very important to have a proper model of the vehicle [1].

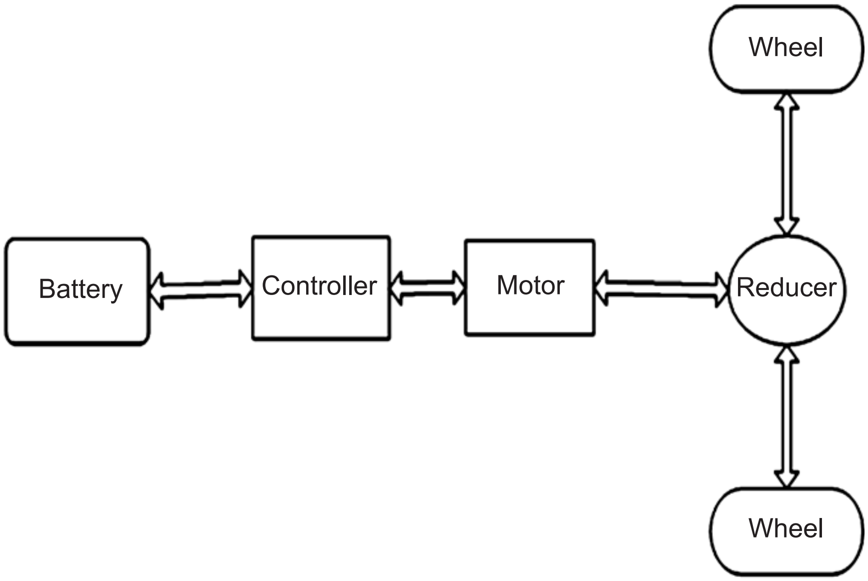

Figure 1: Pure Electric Vehicle Power System Structure

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The model of an electric vehicle is very complex as it contains many different components, like transmission, electric machine, power electronics, and battery. Each component needs to be modeled properly to prevent wrong conclusions. The design and selection of each component is a difficult task as the parameters of one component affect the power level of another one. There is a risk that one component is rated inappropriate which might make the vehicle unnecessary expensive or inefficient. Hence ensure that the requirements of drive system to cover the required driving distance and acceleration.

The focus in this article will be on the modeling and design of the power system of a battery electric vehicle. Less attention will therefore be put on the selection of each component (electric machines, power electronics, batteries, etc.) of the power system as this is a very big task in itself. This article will therefore concentrate on the methodology of the modeling and design process of power system. The inherent advantages of adjustable frequency operation cannot be fully realized unless a suitable control technique is employed.

2. DIFFERENT SPEED CONTROL METHODS OF THREE PHASE INDUCTION MOTOR

2.1. Scalar control

Scalar controlled drives give somewhat inferior performance than the other control schemes but they are the easy to implement. In V/F control methods, the stator voltage is adjusted in a part of the supply frequency, except for low and above base speeds. At low frequency operation the voltagedrop across stator resistance must be taken into account and the voltage of machine can be controlled to control the flux, and frequency or slip can be controlled to control the torque. The flux and torque are also function of voltage and frequency respectively. The advantage of Scalar control is easy to implement and it is widely used in industries, but the inherent coupling torque and flux are function of voltage or current gives sluggish response and the system is easily prone to instability because of higher order (fifth order) system effect. If the torque is increased by incrementing the slip ($T\infty S$) then the flux tends to decrease .It has been noted that the flux variation is also sluggish [7]. Decreases in flux then compensated by the sluggish flux control loop feeding an additional voltage.

This temporary dipping of flux reduces the torque sensitivity with slip and lengthens the response time. However, their importance has diminished recently because of the superior performance of vector or Field Orientated Control (FOC) drives.

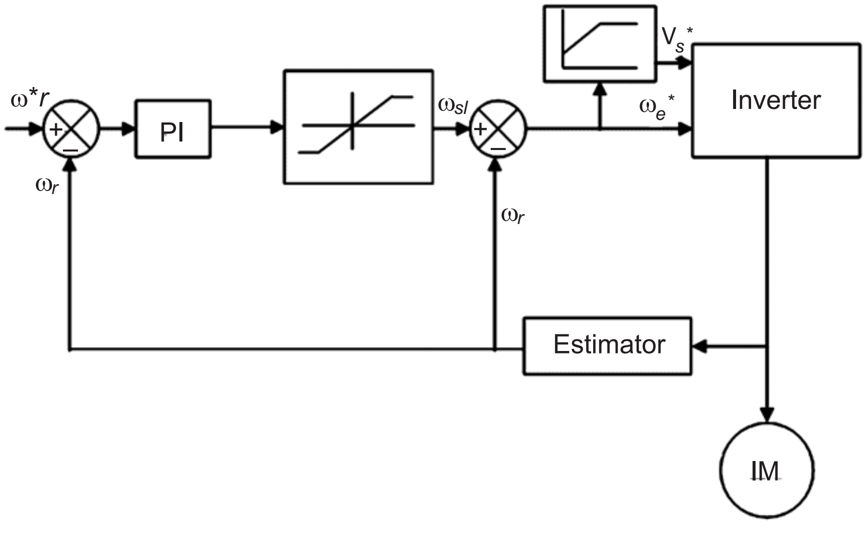


Figure 2: Block Diagram for Scalar control of Induction Motor Drives

To improve the speed control performance of scalar control method, an encoder or speed tachometer is required to feedback the rotor and compensate the slip frequency. However, it is expensive and destroys the mechanical robustness of the induction motor. So these are the limitation of scalar control which is overcome by Field Orientated Control (FOC) for induction motor drive [8]

The major disadvantages of the scalar control methods are :

- Variation of the stator flux due to the variations in the supply voltage.
- The air-gap flux will vary according to the variation in stator resistance with temperature.
- Torque pulsations are present at low speeds owing to presence of fifth, seventh and eleventh and higher harmonics

These drawbacks can be overcome with the help of vector control technique where an induction motor is controlled on the same principles as a separately excited DC motor in which torque component and the flux component are decoupled.

2.2. Vector Control or Field Orientated Control (FOC)

Blaschke in 1972 has introduced the principle of field orientation to realize dc motor characteristics in an induction motor derive. For the same, he has used decoupled control of torque and flux in the motor which is called trans vector control. In D.C machine the field flux is perpendicular to the armature flux. Being orthogonal, these two fluxes produce no net interaction on one another. Adjusting the field current can therefore control the D.C machine flux, and the torque can be controlled independently of flux by adjusting the armature current [9]. An A.C machine speed control is not so simple because of the interactions between the stator and the rotor fields, whose orientations are not held at 90 degrees but vary with the operating conditions. D.C machine-like performance can be obtained by holding a fixed and orthogonal orientation between the field and armature fields in an AC machine by orienting the stator current with respect to the rotor flux so as to attain independently controlled flux and torque. Such a control scheme is called Flux-Oriented Control or vector control. Vector control is applicable to both induction and synchronous motors.

The cage induction motor drive with vector or Field Oriented Control offers a high level of dynamics performance and the closed-loop control associated with this derive provides the long term stability of the system. Induction Motor drives are used in different applications of industrial and process control applications requiring high performances. In high-performance drive systems, the motor speed should closely follow a specified reference trajectory regardless of any load disturbances, parameter variations, and model uncertainties. In order to achieve high performance, field-oriented control of induction motor (IM) drive is employed. However, the controller design of such a system plays a crucial role in system performance. The decoupling characteristics of vector-controlled IM are adversely affected by the parameter changes in the motor. So the vector control is also known as an independent or decoupled control.

2.3. Proportional – Integral (PI) Control

In this paper the complete mathematical model of FOC induction motor is described and simulated in MATLAB for a 10 HP induction motor. The performance of FOC drives with Proportional plus Integral (PI) controller are designed and analyzed. The Proportional-Integral (PI) control is one common linear control strategy in speed control of electric drives.

The preliminary results can be obtained within a short development period. Control law used for this strategy is given by

$$\mathrm{T} = \mathrm{K}_p e + \mathrm{K}_i \int e\, dt \tag{1}$$

The output updates the PI controller gains (K_p and K_i) based on flux estimator. Control performance even in the presence of parameter variation and drive nonlinearity. The use of PI controllers for speed control of induction machine drives is characterized by an overshoot during tracking mode and a poor load disturbance rejection. This is mainly caused by the fact that the complexity of the system does not allow the gains of the PI controller to exceed a certain low value. At starting mode the high value of the error is amplified across the PI controller provoking high variations in the command torque.

If the gains of the controller exceed a certain value, the variations in the command torque become too high and will destabilize the system. To overcome this problem we propose the use of a limiter ahead of the PI controller. This limiter causes the speed error to be maintained within the saturation limits provoking, when appropriately chosen, smooth variations in the command torque even when the PI controller gains are very high. The motor reaches the reference speed rapidly and without overshoot, step commands are tracked with almost zero steady state error and no overshoot, load disturbances are rapidly rejected.

3. MODELLING OF INDIRECT VECTOR CONTROL

The voltage and current equations are based on Direct and Quadrature (*dq*)-coordinate system. Therefore an introduction to coordinate transformations (Clarke's and Park's transformation) is presented in this section. An induction motor is supplied with 3-phase voltages to its windings. The voltages are 120° electrically space shifted and create a field which interacts with the flux from the stator to produce electromagnetic propulsion in the desired direction. Unlike a DC machine in which the armature and field currents are decoupled, AC machines are inherently deprived of this luxury. Therefore to represent 3-phase machine with decoupled voltage, current and flux components, mathematical transformations are required.

Clarke's transformation presents the idea of projecting three-phase stator currents I_a, I_b and I_c in two phase orthogonal stator currents: I_α and I_β . The transformation matrix is given as.

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \frac{1}{2}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \tag{2}$$

Conversely, to obtain three-phase from two-phase stationary system is given byeq(3),

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \tag{3}$$

Park's transformation is then used to convert stationary two-phase reference frame into moving reference frame to get constant quantities. Equations 2 and 3 define how the vectors can be transferred in the moving reference frame. The figure. 3 displays the relationships between the Park and Clarkes transforms.

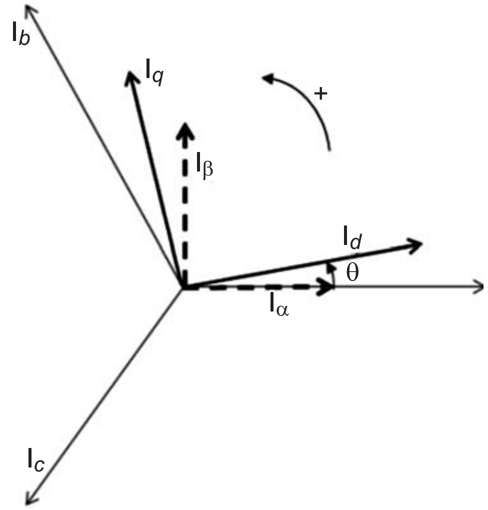


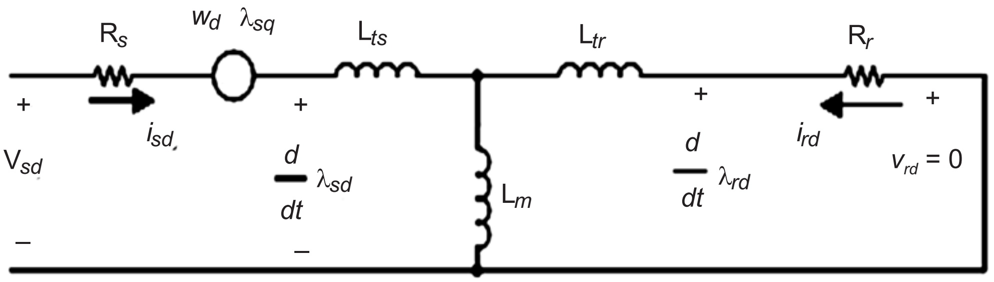
Figure 3: Park and Clark Transformations

$$I_d = I_\alpha \cos\theta + I_\beta \sin\theta \tag{4}$$

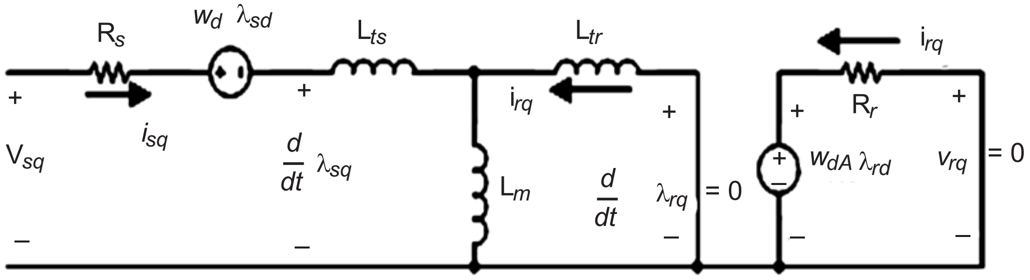
$$I_q = -I_\alpha \sin\theta + I_\beta \cos\theta \tag{5}$$

4. INDUCTION MOTOR DRIVE

By using the qualitative description of vector control, *d*-axis is common to both the stator and the rotor to be along the rotor flux linkage λ_r (= λ re *j*0), as shownin Fig. 4



(*a*) *d*-axis



(*b*) *q*-axis

Figure 4: Dynamic circuits with the *d*-axis aligned with λ*r*

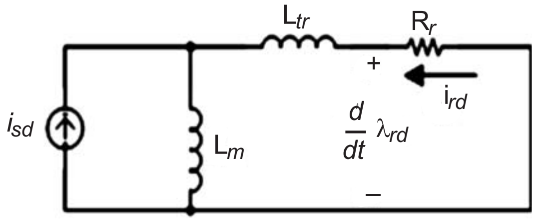


Figure 5: The *d*-axis circuit simplified with current excitation

Where L_s, L_r and L_m are stator, rotor and mutual inductances respectively

D-Axis Rotor Flux Linkage Dynamics

To obtain the dependence of λ_{rd} on i_{sd}, we will make use of the equivalent circuit in Fig. 4, and redraw it as in Fig.5 with a current excitation by i_{sd}. From Fig. 5 in terms of Laplace domain variables,

$$I_{rd}(s) = -\frac{sL_m}{R_f + sL_r} i_{sd}(s) \tag{6}$$

In the rotor *d*-axis winding, from Eq. (5),

$$I_{rd}(s) = -\frac{sL_m}{R_f + sL_r} i_{sd}(s) \tag{7}$$

Substituting for i_{rd} the Eq. (6) into Eq. (8),

$$I_{rd}(s) = -\frac{sL_m}{R_f + sL_r} i_{sd}(s) \tag{8}$$

In time domain, the rotor flux linkage dynamics expressed by Eq. (6-8) is as follows

$$I_{rd}(s) = -\frac{sL_m}{R_f + sL_r} i_{sd}(s) \tag{8}$$

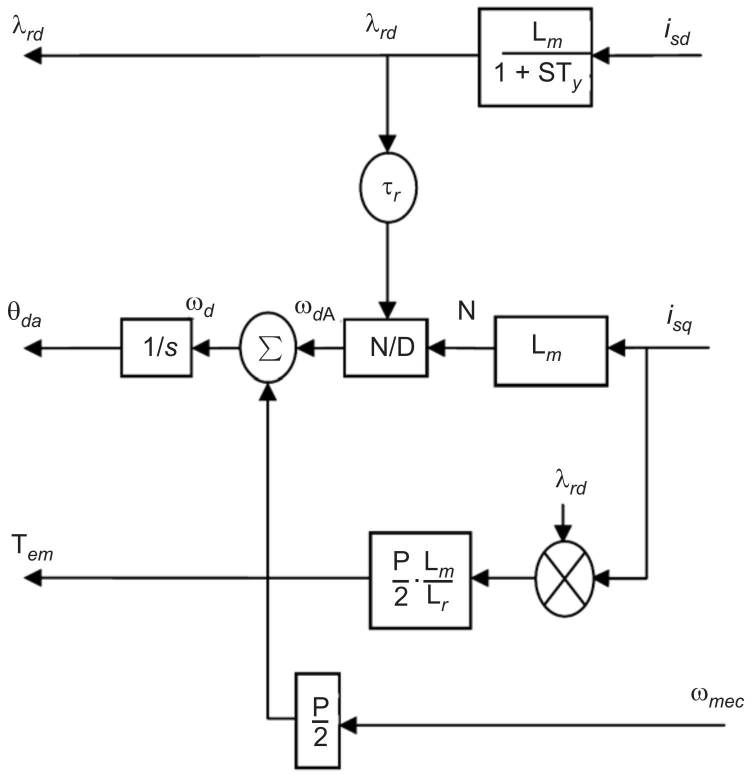


Figure 6: Induction Motor model with d-axis aligned with λ_r

in Fig. 6. The currents i_{sd} and i_{sq} are the inputs, and λ_{rd}, θ_{da}, and T_{em} are the outputs. Note that $\omega d = (\omega d_A + \omega_m)$ is the speed of the rotor field, and therefore, the motor-field angle with respect to the stator a-axis is,

$$\theta_{da}(t) = 0 + \int_0^t \omega_d(\tau) d\tau \tag{10}$$

where τ is the variable of integration, and the initial value of θ_{da} is assumed to be zero at $t = 0$

5. MATLAB SIMULATION OF SPEED CONTROL OF INDUCTION MOTOR DRIVE

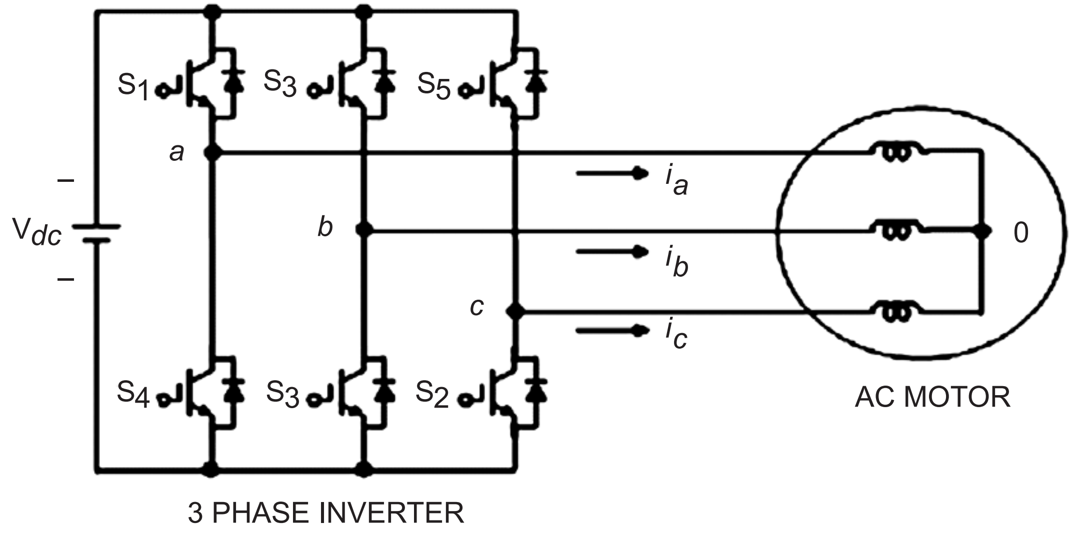


Figure 6: Three phase inverter fed induction motor Drive

The proposed inverter synthesizes a three-phase multilevel waveform from the calculated switching angles. The converter thus generates the variable-amplitude, variable frequency voltage waveforms to drive the induction motor. The MATLAB-Simulink is used is used to simulate inverters of induction motor drives and the performance of Inverter andmotor Drive system for various load change has been analyzed.

The Induction motor parameters:

3 phase 400V, 10HP, 1440 RPM Induction motor parameters

Stator resistance RS = 0.74 Ω
Stator inductance Ls = 0.13 H
Rotor resistance RR = 0.74 Ω
Rotor inductance LR = 0.13 H
Mutual inductance Lm = 0.124 H
Moment of inertia J = 0.01 Kg-*m*2

6. SIMULATION RESULTS

Total Harmonic Distortion (THD %) Levels of inverter

Table 1
Modulation Index Vs THD in proposed Inverter method

S. No	*Modulation Index*	*THD (%)*
1.	1	41.28
2.	0.9	46.32
3.	0.7	49.06
4.	0.5	30.42

Starting Torque and Speed Response of the drive

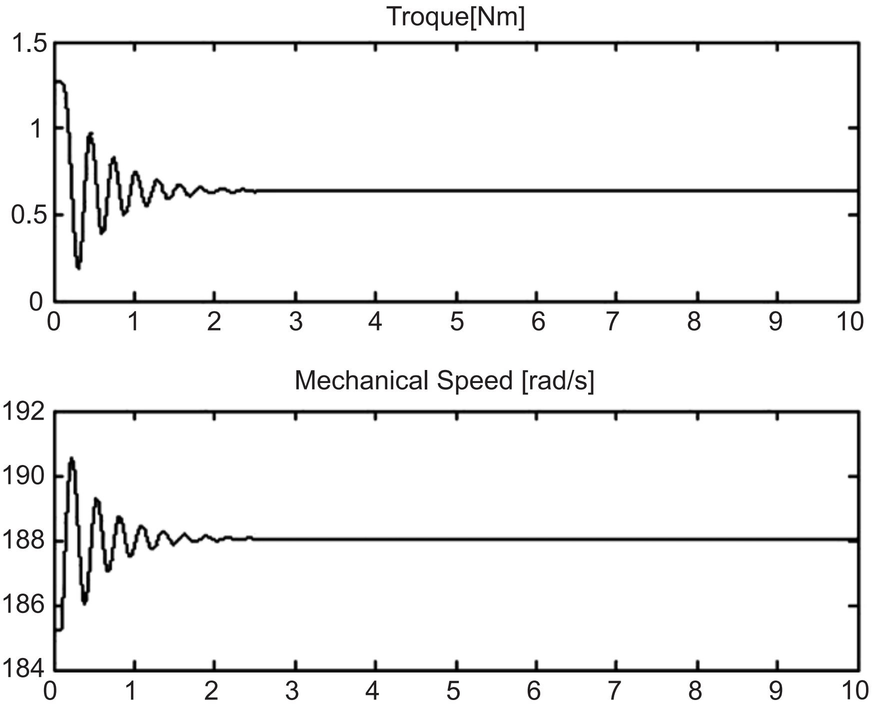


Figure 7: Starting Torque and Speed Response of the Drive System

Response of the drive for different torque variation

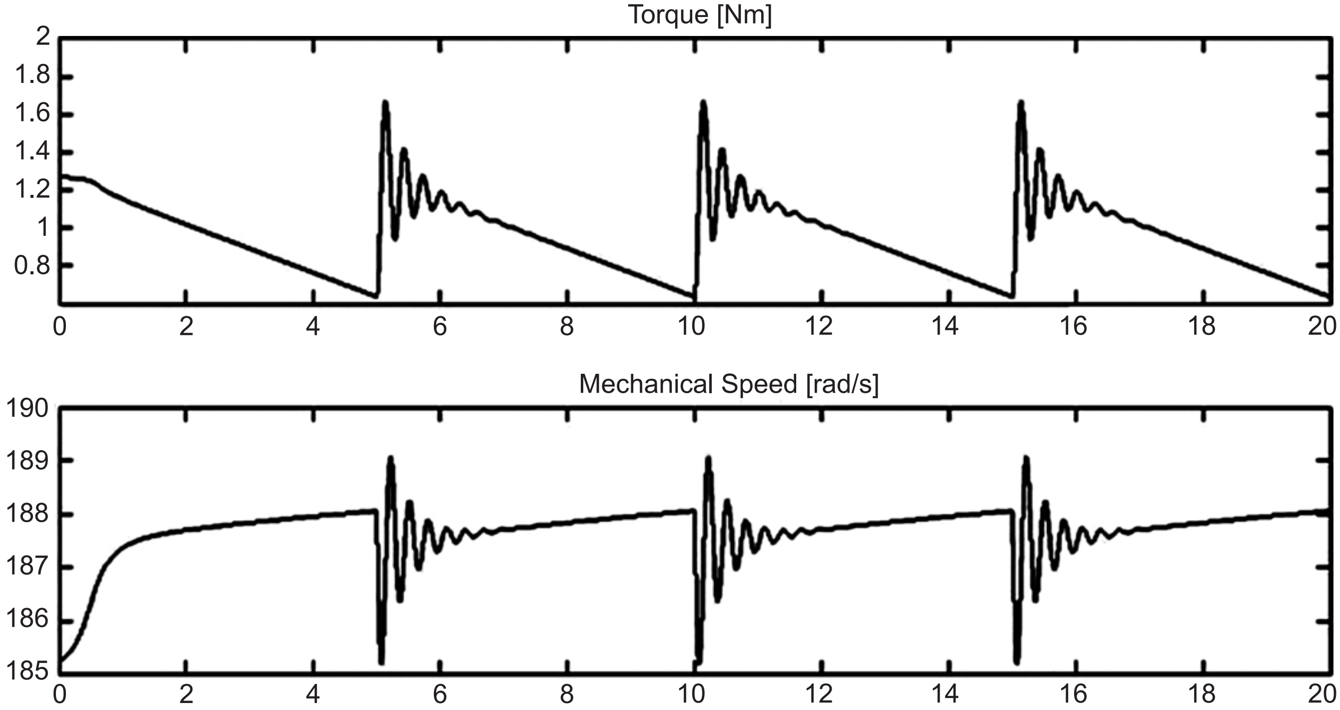


Figure 8: Speed – Torque Characteristics Response of the drive for Dynamic torque variation

Response of the drive for sudden load change

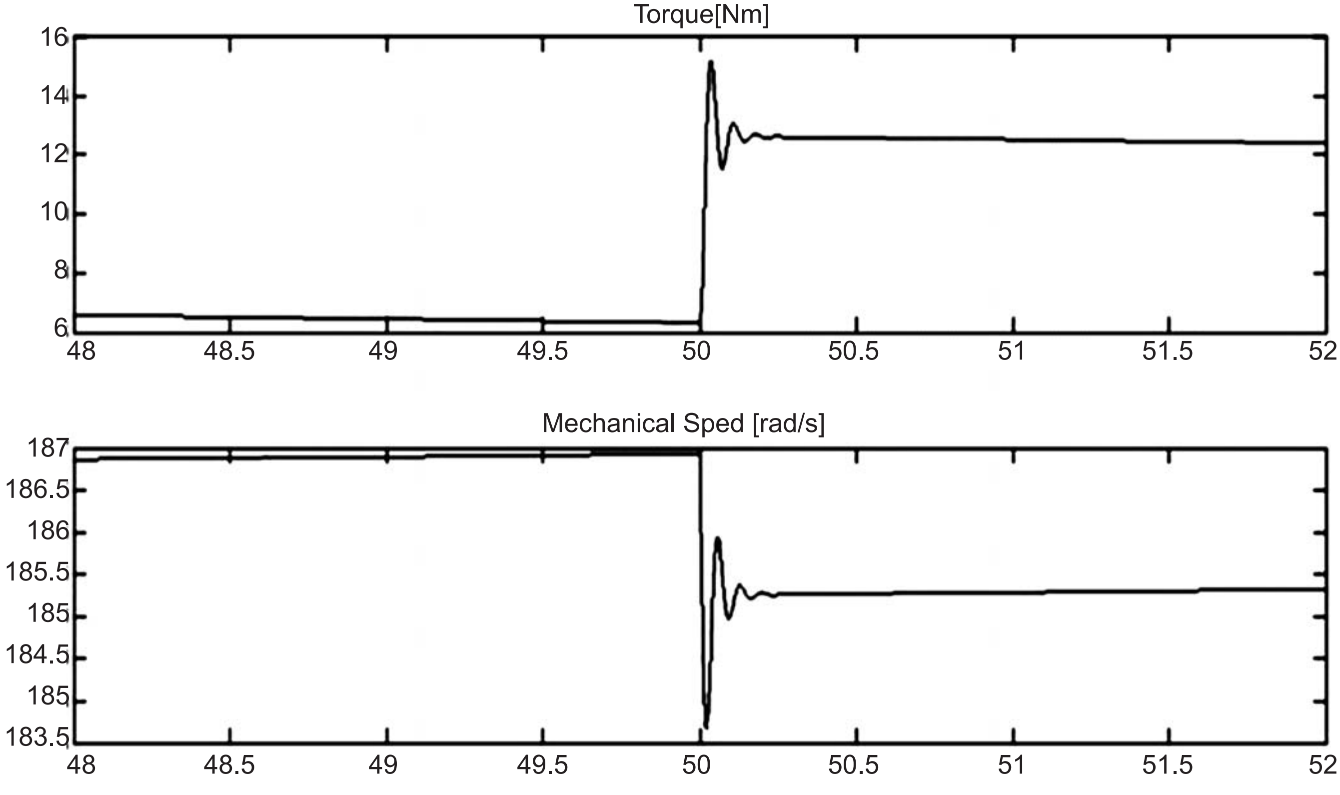


Figure 9: Speed – Torque Characteristics of the drive for sudden load change

7. CONCLUSION

The characteristics and performance of vector control Drive for induction motor is obtained and the results are compared with requirements. In this proposed method we attained maximum response in minimum time. We can control speed by varying parameters of motor, load torque, load limit value. The drive also supports for the sudden load change with permissible harmonics.

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