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# Performance Analysis of a DTC and SVM Based Field-Orientation Control Induction Motor Drive

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**ABSTRACT**

This study presents a performance analysis of two most popular control strategies for Induction Motor (IM) drives: direct torque control (DTC) and space vector modulation (SVM) strategies. The performance analysis is done by applying field-orientation control (FOC) technique because of its good dynamic response. The theoretical principle, simulation results are discussed to study the dynamic performances of the drive system for individual control strategies using actual parameters of induction motor. A closed loop PI controller scheme has been used. The main purpose of this study is to minimize ripple in torque response curve and to achieve quick speed response as well as to investigate the condition for optimum performance of induction motor drive. Depending on the simulation results this study also presents a detailed comparison between direct torque control and space vector modulation based field-orientation control method for the induction motor drive.



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## 1. INTRODUCTION

The most common type of ac motor being used throughout the world today is the induction motor (IM). Three phase induction motors are widely used in various industries as prime workhorses to produce rotational motions and forces. Traditionally, it has been used in constant and variable-speed drive applications that do not cater for fast dynamic processes [1]. Due to the requirements of the load and the need for economy have resulted in developments of several types of induction motor drives and these induction motor drives require a great attention in controlling speed. Because of the marriage of power electronics with motors and recent development of several new control technologies this situation is changing rapidly. Such control technologies are direct torque control (DTC), space vector modulation (SVM) and field-orientation control (FOC) technique. These technologies are widely used in high performance motion control of induction motors [2].

This work presents a comparative study on three most popular control strategies for induction motor (IM) drives: direct torque control (DTC), space vector modulation (SVM) and field-oriented control (FOC) [3]-[5]. Here fixed value of the proportional and integral gain of PI controller is used to achieve quick speed response. In DTC it is possible to control the stator flux and the torque is controlled by selecting the appropriate inverter state [6]. But conventional DTC scheme has two main disadvantages [7]: Current and torque distortions caused by the sector changes and starting and low - speed operation problems. To overcome these problems SVM technique is implemented. For applying SVM scheme power is taken from dc source and converts it to three phase ac using dc-to-ac converter [8]. In order to achieve fast speed response and improved torque characteristic, field-orientation control (FOC) technique is used [9]. The methodology of field-orientation control is normally developed based on estimation of induction motor fluxes.

## 2. RESEARCH METHOD

### 2.1. Induction Motor Model under Field-Orientation Control Principle

To study the transient and dynamic conditions generally mutually perpendicular stationary and synchronously rotating fictitious coils are considered. For the induction motor considered will have the following assumptions: symmetrical two-pole, three phases windings, slotting effects are neglected, permeability of the iron parts is infinite, the flux density is radial in the air gap, iron losses are neglected, stator and the rotor windings are simplified as a single, multi-turn full pitch coil situated on the two sides of the air gap.

From stationary two axis model and synchronously rotating two axis model the fifth order non-linear state space model of induction motor is represented in the synchronous reference frame (d-q) as follows:

$$v_{ds} = (R_s + pL_s)i_{ds} - L_s\omega_e i_{qs} + pL_m i_{dr} - L_m\omega_e i_{qr} \tag{1}$$

$$v_{qs} = \omega_e L_s i_{ds} + (R_s + pL_s)i_{qs} + L_m\omega_e i_{dr} + pL_m i_{qr} \tag{2}$$

$$0 = pL_m i_{ds} - \omega_{sl} L_m i_{qs} + (R_r + pL_r)i_{dr} - L_r\omega_{sl} i_{qr} \tag{3}$$

$$0 = L_m\omega_{sl} i_{ds} + pL_m i_{qs} + (R_r + pL_r)i_{qr} + L_r\omega_{sl} i_{dr} \tag{4}$$

$$T_e = Jp\omega_m + B\omega_m + T_L \tag{5}$$

From the developed electromagnetic torque in terms of *d*- and *q*- axes components is given by:

$$T_e = \frac{3}{2}P_p L_m\left(i_{qs}i_{dr} - i_{ds}i_{qr}\right) \tag{6}$$

Components of rotor flux are:

$$\psi_{dr} = L_r i_{dr} + L_m i_{ds} \tag{7}$$

$$\psi_{qr} = L_r i_{qr} + L_m i_{qs} \tag{8}$$

From (7) and (8),

$$i_{dr} = \frac{1}{L_r}(\psi_{dr} - L_m i_{ds}) \tag{9}$$

$$i_{qr} = \frac{1}{L_r}(\psi_{qr} - L_m i_{qs}) \tag{10}$$

Substituting from (7) to (10) into (3) and (4) yields:

$$\frac{d\psi_{dr}}{dt} + \frac{R_r}{L_r}\psi_{dr} - \frac{L_m}{L_r}R_r i_{ds} - \omega_{sl}\psi_{qr} = 0 \tag{11}$$

$$\frac{d\psi_{qr}}{dt} + \frac{R_r}{L_r}\psi_{qr} - \frac{L_m}{L_r}R_r i_{qs} + \omega_{sl}\psi_{dr} = 0 \tag{12}$$

If the field orientation is established such that q-axis rotor flux is set zero, and d-axis rotor flux is maintained constant then Equation (11), (12), (9), (10) and (6) becomes $\psi_{dr} = L_m i_{ds}$; $\omega_{sl} = \frac{1}{\tau_r}\frac{i_{qs}}{i_{ds}}$; $i_{dr} = 0$; $i_{qr} = -\frac{L_m}{L_r} i_{qs}$ $T_e = \frac{3}{2} P_p \frac{L_m}{L_r} \psi_{dr} i_{qs}$; where $\tau_r (= L_r / R_r)$ is the time constant of the rotor.

### 2.2 Direct Torque Control Technique

Direct torque control technique is used in variable frequency drives to control the torque (and thus finally the speed) of three-phase ac electric motors. In direct torque it is possible to control directly the stator flux and the torque by selecting the appropriate state [10]. The way to impose the required stator flux is by means of choosing the most suitable Voltage Source Inverter (VSI) state. Decoupled control of the stator flux modulus and torque is achieved by acting on the radial and tangential components respectively of the stator flux-linkage space vector. Figure 1. shows the possible dynamic locus of the stator flux, and its different variation depending on the VSI states chosen [10]. The possible global locus is divided into six different sectors signaled by the discontinuous line. In accordance with Figure 1, the general table I can be written.

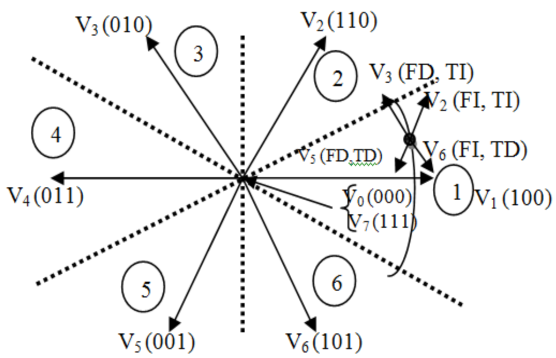



Figure 1. Stator flux vector locus and possible switching.

Table 1. Selection Table for DTC

| Voltage Vector | Increase | Decrease |
|---|---|---|
| Stator Flux | $V_k$, $V_{k+1}$, $V_{k-1}$ | $V_{k+2}$, $V_{k-2}$, $V_{k+3}$ |
| Torque | $V_{k+1}$, $V_{k+2}$ | $V_{k-1}$, $V_{k-2}$ |

The sectors of the stator flux space vector are denoted from S1 to S6. Stator flux modulus error after the hysteresis block (Δψ) can take just two values. The zero voltage vectors V0 and V7 are selected when the torque error is within the given hysteresis limits, and must remain unchanged.

Table 2. Lookup Table for DTC

| Torque error (Δψ) | Torque error (ΔT) | Sector $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ |
|---|---|---|---|---|---|---|---|
| FI | TI | $V_2$ | $V_3$ | $V_4$ | $V_5$ | $V_6$ | $V_1$ |
| FI | TE | $V_7$ | $V_0$ | $V_7$ | $V_0$ | $V_7$ | $V_0$ |
| FI | TD | $V_6$ | $V_1$ | $V_2$ | $V_3$ | $V_4$ | $V_5$ |
| FD | TI | $V_3$ | $V_4$ | $V_5$ | $V_6$ | $V_1$ | $V_2$ |
| FD | TE | $V_0$ | $V_7$ | $V_0$ | $V_7$ | $V_0$ | $V_7$ |
| FD | TD | $V_5$ | $V_6$ | $V_1$ | $V_2$ | $V_3$ | $V_4$ |

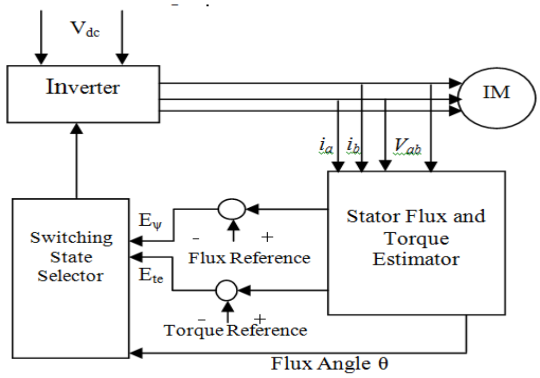



Fig. 2. DTC Block diagram.

### 2.3 Space Vector Modulation Technique

Space Vector Modulation principle [4] is shown in Fig.3. The reference vector $u^*$ is sampled at the fixed clock frequency $2f_s$. The reference voltage vector $u^*$ can be generated from the machine command $-\alpha$ and $-\beta$ axes voltages $v_{\alpha s}^*$ and $v_{\beta s}^*$ as:

$$u^* = \sqrt{v_{\alpha s}^{*\,2} + v_{\beta s}^{*\,2}} \tag{13}$$

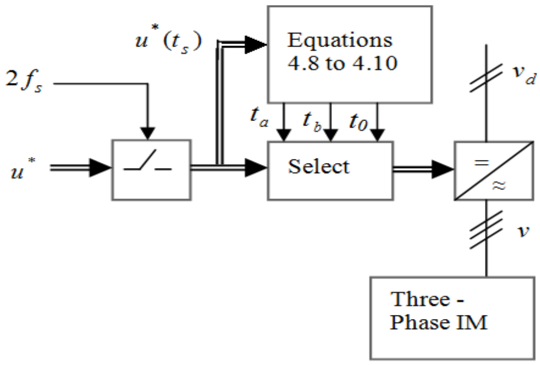



Figure 3. SVM Signal flow diagram

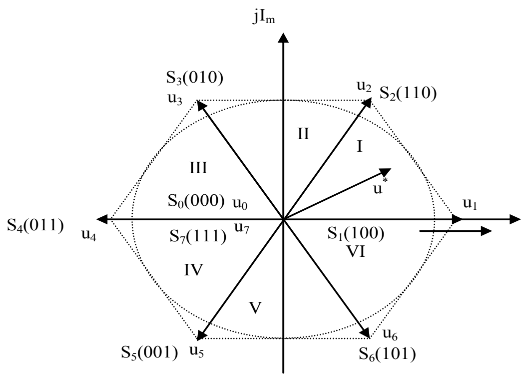



Figure 4. All voltage space vectors

If $T_s$ is the sampling time then the sampled value reference voltage vector $u^*(t_s)$ is used to solve the equations.

$$\frac{2}{T_s}\left(t_a u_a + t_b u_b\right) = u^*(t_s) \tag{14}$$

$$t_0 = t_7 = \frac{1}{2}(T_s - t_a - t_b) \tag{15}$$

$$t_a = T_s u^*(t_s)\frac{3}{\pi}(\cos\alpha - \frac{1}{\sqrt{3}}\sin\alpha) \tag{16}$$

$$t_b = T_s u^*(t_s)\frac{2\sqrt{3}}{\pi}\sin\alpha \tag{17}$$

$$t_0 = t_7 = \frac{1}{2}(T_s - t_a - t_b) \tag{18}$$

### 2.4. Field-Orientation Control Method

The field-orientation control consists of controlling the stator currents represented by a vector. This control is based on projections which transform a three phase time and speed dependent system into a two co-ordinate (d and q co-ordinates) time invariant system. Figure 5. Shows the Basic scheme of FOC for IM drive [5].

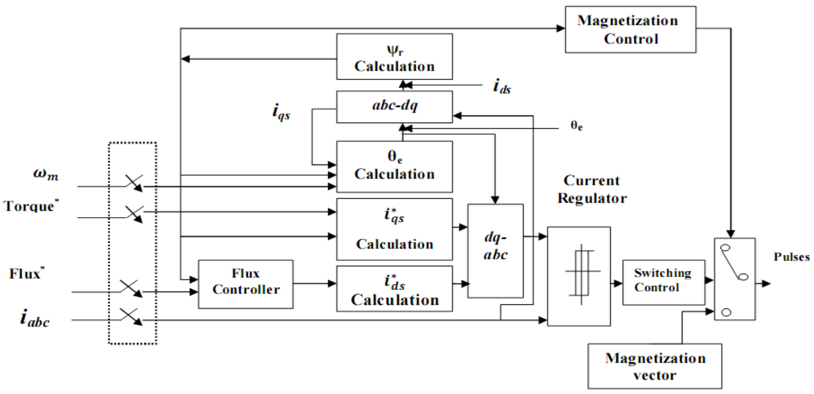



Figure 5. Basic scheme of FOC for IM drive

## 3. RESULTS AND ANALYSIS

The simulation scenarios shown in this thesis paper cover the following situations: Generation of pulses for inverter, transient and steady state behavior of 3-phase current, speed and torque response, a step change in load torque, a step change in speed reference [11] and condition for optimum performance.

### 3.1. Rotor and Stator flux

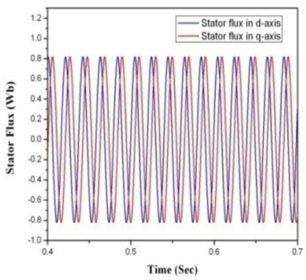



Figure 6. *d*-*q* axis stator fluxes

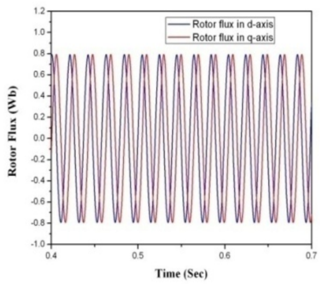



Figure 7. *d*-*q* axis rotor fluxes

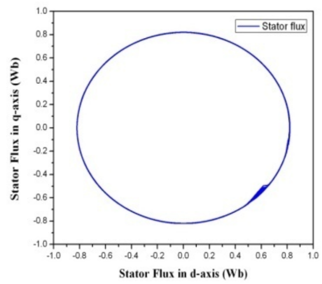



Figure 8. Locus of stator fluxes in Stationary reference frame

Figure 6 and Figure 7. shows the stator and rotor fluxes. It is noticed that 90º phase difference is obtained and are approximately sinusoidal. Figure 8. indicates the locus of the stator flux and it is noticed that flux follows a circular shape. The components of stator fluxes in stationary reference frame are sinusoidal and 90º phase displacement to each other.

### 3.2. Simulation Results for DTC based FOC method

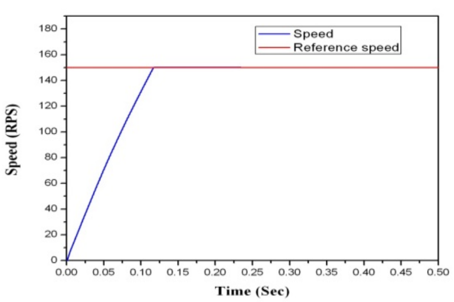



Figure 9. Speed response in DTC using FOC

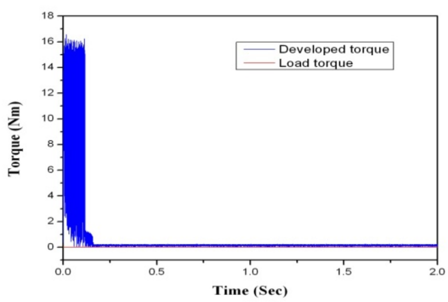



Figure 10. Torque developed in DTC using FOC

With the help of field-orientation control method quick speed response is achieved and catches the reference speed within 0.10 sec. as indicated in Figure 9 and Figure 10 shows the actual torque developed curve for DTC based FOC method. It can be said that, region of torque distortion is smaller than DTC.

### 3.3. Simulation Results for SVM based FOC Method

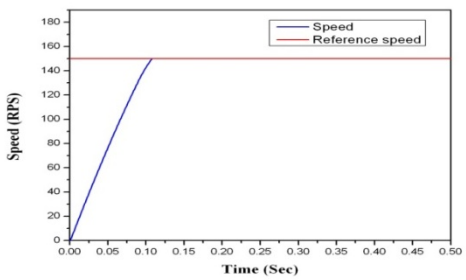



Figure 11. Speed response in SVM using FOC

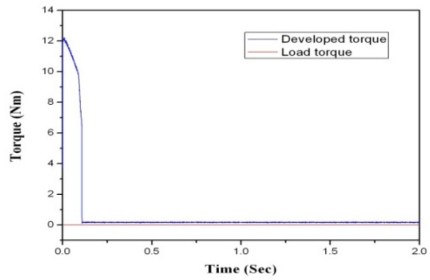



Figure 12. Torque developed in SVM using FOC

By using field-orientation principle in SVM technique overshoot problem is eliminated as well as quick speed response is achieved as shown in Figure 11. Figure 12. shows the torque response when the motor is unloaded, it is evident that the torque response is better than DTC based FOC method.

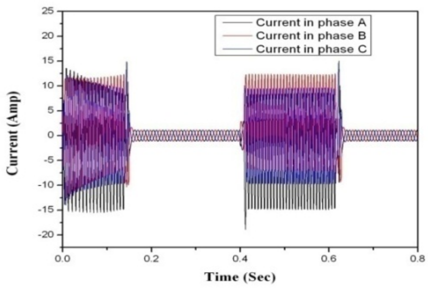
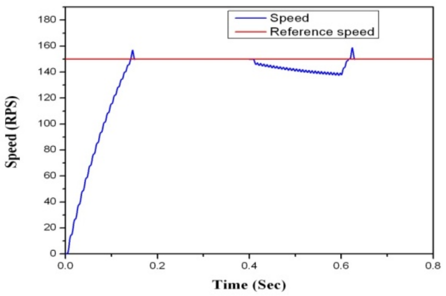



Figure 13. Three-phase currents under load condition

### 3.4. Effect of Change of Load for DTC Technique

Sudden application of load torque from 0 Nm to 6 Nm at t = 0.4 sec. to t = 0.6 sec. causes a change in three-phase current and transient phenomenon is occurred and after few seconds latter steady state condition has been reached when load adjustment is done. Figure 14. indicates the simulated response of the motor speed when it is suddenly loaded from 0 Nm to 6 Nm. It is observed that sudden application of load torque causes a non-uniform dip and overshoot in the speed curve. Sudden application of load torque from t = 0.4 sec. to t = 0.6 sec. causes torque ripple at that particular time in the developed torque curve as shown in Figure 15.




Figuure 14. Effect of change of load torque on speed response

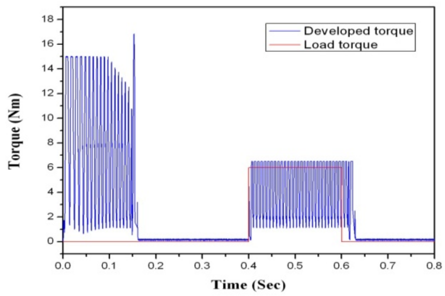



Figure 15. Torque developed when load torque is increased suddenly

### 3.5. Simulation Results for SVM Technique under Load Condition

Effect of change of load torque on three-phase current is illustrated in Figure 16. Sudden application of load torque from 0 Nm to 6 Nm causes a change in three-phase currents but the oscillation of current is smaller than that of DTC technique. Figure 17. indicates the motor speed when it is suddenly loaded. It is observed that sudden application of load torque causes a very little dip and there is no overshoot in the speed curve.

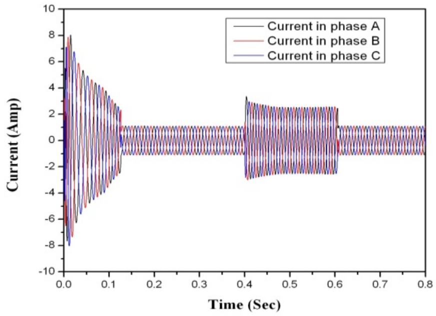



Figure 16. Three-phase currents under load condition

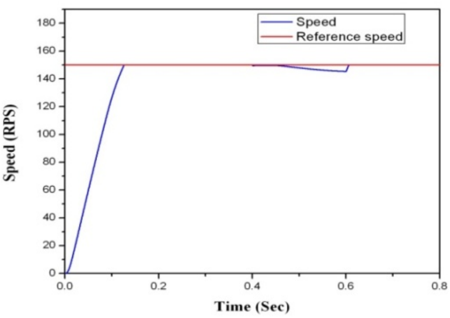



Figure 17. Effect of change of load torque on speed response

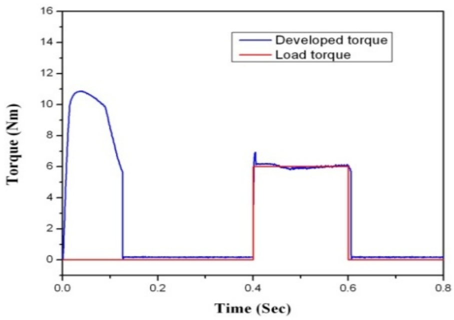



Figure 18. Torque developed when load torque is increased suddenly

Hence, better speed response curve has been achieved by using SVM than that of DTC technique. The oscillation found in the torque developed curve under load condition is also reduced as shown in Figure 18.

## 4. CONCLUSION

In this paper, main characteristics of direct torque control and space vector modulation based field-orientation control scheme for induction motor drives are studied and performance analysis has been investigated with the help of simulation results with a view to highlighting the advantages of each schemes. For achieving high performance IM drive, a suitable mathematical model is used. Performance analysis of individual scheme is carried out by changing the load torque at a particular time interval and by changing the reference speed. Lower value of reference stator flux during the simulation causes greater torque distortion and bad speed response curve. That is why the reference stator flux is determined from the IM parameters. From the simulation results for DTC and SVM based field-orientation control method; it can be concluded that the SVM based field-orientation control method shows better performance for induction motor drives because of its quick speed response and elimination of the overshoot problem unlike DTC based field-orientation control. When field-orientation principle is introduced in SVM technique; there is a reduction of ripple in the developed torque. Moreover, SVM based FOC method is capable to follow the reference speed quickly and has practically thus will find many applications.

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