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Direct Torque Control Sensorless Induction Motor Drive Using Space Vector Modulation

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***ABSTRACT** : The basic scheme presents a contribution for detailed comparative analysis between Field-Oriented Control and Direct Torque Control techniques for high performance induction motor drive. The toque and flux are controlled simultaneously by applying suitable voltage vectors, and by limiting these quantities within their hysteresis bands, de-coupled control of torque and flux can be achieved. This paper presents the evaluation technique of space vector modulation applied to the induction machines. The simulations were carried out using MATLAB/SIMULINK simulation package. Evaluation is made based on the drive performance, which includes dynamic torque and flux responses, feasibility and the complexity of the systems. However, the basis of DTC SVM strategy is the calculation of the required voltage space vector to compensate the flux and torque errors exactly by using a predictive technique and then its generation using the Space Vector Modulation. We can note a slight advance of DTC scheme compared to FOC scheme regarding the dynamic flux control performance and the implementation complexity. The choice of one or the other scheme will depend mainly on specific* requirements of the application.

***General Terms :** Sector implementation, ripple in torque, ripple in current, inverter states.*
***Keywords:** Induction motor, Field oriented control (FOC), Direct torque control (DTC), Sensorless, Space Vector Pulse Width modulation (SVPWM).*

I. INTRODUCTION

In recent years, several studies have been developed which propose alternative solutions to the FOC control motor drive with two objectives: first, achievement of an accurate and fast response of the flux and the torque, and second, reduction in the complexity of the control system. Since the introduction of field-oriented control in the beginning of 1970s, the foregoing problem can be solved by vector or field-oriented control and in the mid-1980s an advanced control technique, known as direct torque and flux control (DTFC or DTC) was introduced for voltage-fed PWM inverter drives. Despite its simplicity, DTC is able to produce very fast torque and flux control in steady-state and transient operating conditions [13], if the torque and the flux are correctly estimated. Among the various proposals, Direct Torque Control has found wide Acceptance. [1] [10].

II. DYNAMIC MACHINE MODEL OF AN INDUCTION MOTOR

Among all types of ac machines, the induction machine, particularly the cage type, is most commonly used in industry.

The induction motor stator equations are shown as:

$$Vqs = r_s i_{qs} + \frac{d\lambda qs}{dt} + \omega \lambda_{ds} \qquad \text{----- (1)}$$

$$Vds = r_s i_{ds} + \frac{d\lambda_{ds}}{dt} + \omega\lambda qs \qquad \text{----- (2)}$$

The torque equation shown below is the cross product of rotor flux and stator current and other equation as the cross product of stator flux and stator current.

$$T_{em} = \frac{3}{2} \cdot \frac{P}{2} \cdot \frac{L_m}{L_r} (\lambda_{dr} i_{qs} - \lambda_{qr} i_{ds}) \quad \text{----- (3)}$$

$$T_{em} = \frac{3}{2} \cdot \frac{P}{2} \cdot \frac{L_m}{L_r} (\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}) \quad \text{----- (4)}$$

The transformation relations of currents are

$$I_{ds}^{s} = -\frac{1}{\sqrt{3}} I_{bs} + \frac{1}{\sqrt{3}} I_{cs} \quad \text{----- (5)}$$

$$I_{qs}^{s} = \frac{2}{3} I_{as} - \frac{1}{3} I_{bs} - \frac{1}{3} I_{cs} \quad \text{----- (6)}$$

III. PRINCIPLE OF FIELD ORIENTED CONTROL

The principle of vector control of electrical drives is based on the control of both the magnitude and the phase of each phase current and voltage. This control is based on projections which transform a three phase time and speed dependent system into a two co-ordinate time invariant system. Field orientated controlled machines need two constants as input references: the torque component and the flux component. This makes the control accurate in steady state and transient working operation and independent of the limited bandwidth mathematical model. The FOC thus solves the classic scheme problems. We can then control the torque by controlling the torque component of stator current vector. [2] [10]

The ease of applying direct torque control because in the (d, q) reference frame the expression of the torque is:

$$m \propto \psi_R i_{sq} \quad \text{----- (7)}$$

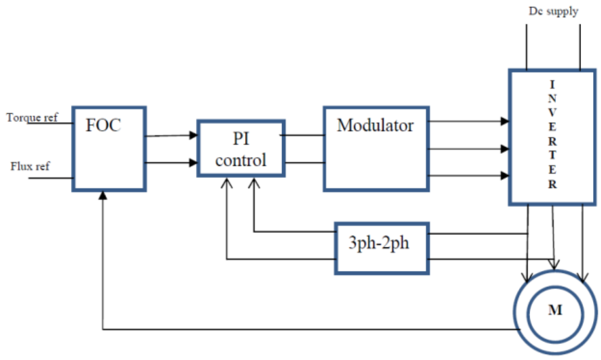

Figure 1: Basic scheme of field oriented control

IV. PRINCIPLE OF DIRECT TORQUE CONTROL

The name direct torque control is derived by the fact that, on the basis of the errors between the reference and estimated values of torque and flux, it is possible to directly control the inverter states in order to reduce the torque and flux errors within the prefixed band (Hysteresis band) limits.[8][11][12]
The stator flux linkage of an IM can be expressed in the stationary reference frame with the help of the following two equation

$$V_{qs} = r_s i_{qs} + \frac{d\lambda_{qs}}{dt} + \omega\lambda_{ds} \quad \text{----- (8)}$$

$$V_{ds} = r_s i_{ds} + \frac{d\lambda_{ds}}{dt} + \omega\lambda_{qs} \quad \text{----- (9)}$$

The torque produced is dependent on the stator flux as well as rotor flux according to the equation

$$3 \quad P \quad L \qquad \text{----- (10)}$$

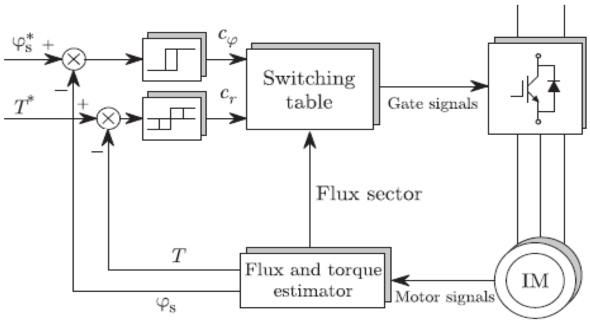

Figure 2: Basic scheme of direct torque control

V. DEVELOPMENT OF DTC AND ITS SWITCHING OPERATION

The operation of direct torque control of induction motor depends on the voltage vector selection. Here we are using a two level inverter for direct torque control operation. The vector space is divided into six sectors equally spaced (as shown in the figure) such that the six voltage vectors that the inverter can produce reside at the centre of each sector.

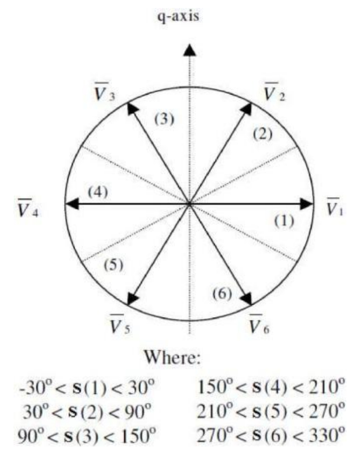

Figure 3: Inverter voltage vector and stator flux switching sector

Table 1. Switching table of inverter voltage vector

Table 2. Parameters of induction motor

dλ	dTe	SECTOR 1	2	3	4	5	6
1	1	V2	V3	V4	V5	V6	V1
	0	V0	V7	V0	V7	V0	V7
	-1	V6	V1	V2	V3	V4	V5
-1	1	V3	V4	V5	V6	V1	V6
	0	V7	V0	V7	V0	V7	V0
	-1	V5	V6	V1	V2	V3	V4

Nominal Power[Pn]	2238 Watts
Voltage (line-line)	220 Volts(Vrms)
Frequency[fn(Hz)]	60 Hz
Stator Resistance[Rs(Ohm)]	0.435Ω
Stator Inductance[Lls(H)]	2*2.0e-3H
Rotor Resistance[Rr'(Ohm)]	0.816Ω
Rotor Inductance[Llr'(H)]	2.0e-3 H
Mutual Inductance[Lm(H)]	69.31e-3
Inertia[J(Kg.m^2)]	0.089Kg.m^2
Pole Pair	2

Above table shows the two level flux comparator for the and three-level hysteresis comparator are used torque error evaluation.

VI. SIMULATION RESULTS

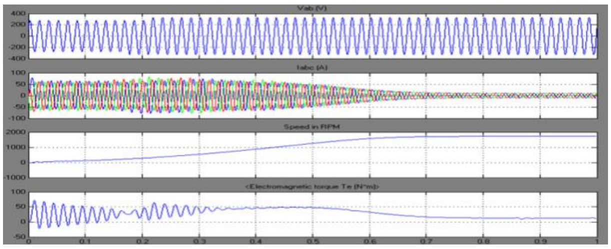

Figure 4: Plot of V, I, speed & torque w. r.t. time of FOC

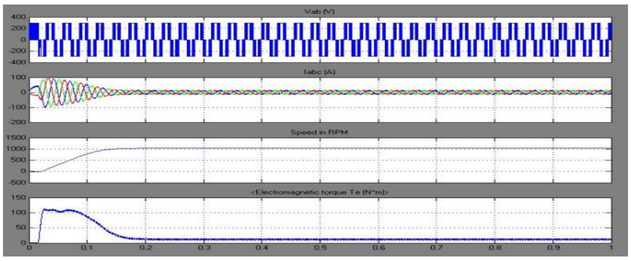

Figure 5: Plot of V, I, speed & torque w. r.t. time of DTC

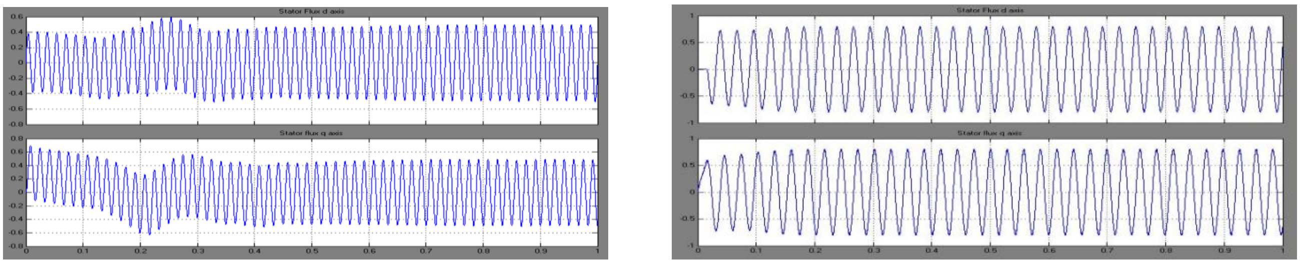

Figure 6: Plot of stator flux of d-q axis w. r. t. time of DTC & FOC.

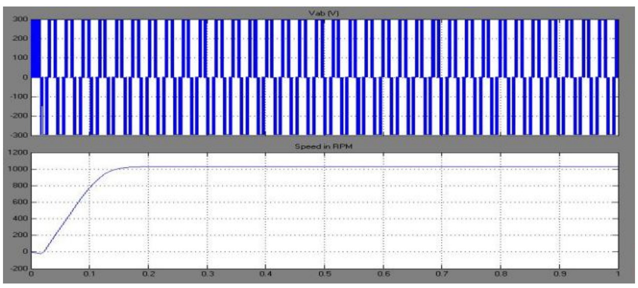

Figure 7: Plot of V and Speed w.r.t. time of DTC

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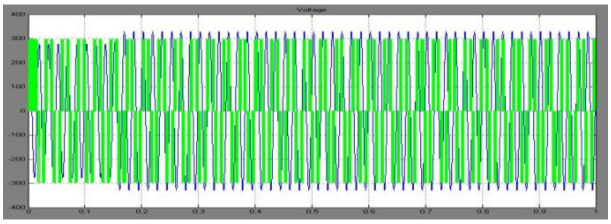

Figure 8: Plot of FOC & DTC of voltage comparison w. r. t. time (GREEN DTC, BLUE FOC)

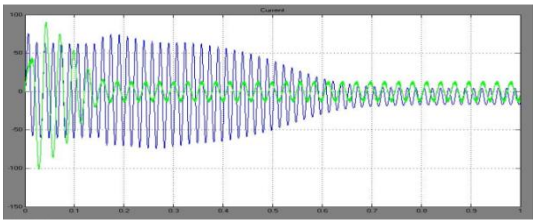

Figure 9: Plot of FOC & DTC at of current comparison w. r. t. time (GREEN DTC, BLUE FOC)

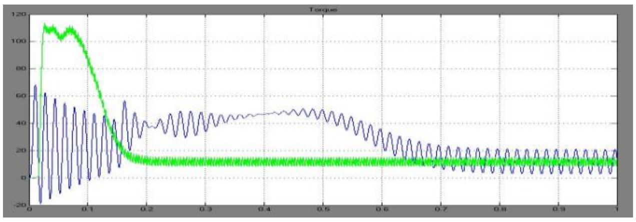

Figure 10: Plot of FOC & DTC of torque comparison w. r. t. time (GREEN DTC, BLUE FOC)

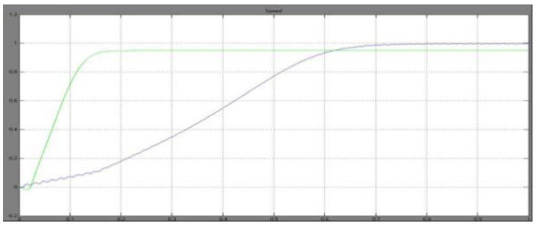

Figure 11: Plot of FOC & DTC of speed comparison w. r. t. time (GREEN DTC, BLUE FOC)

Above figures, shows the performance of current, speed & torque comparison of two techniques.

6.1 Current Comparison

The DTC presents a more oscillating current at starting, contrary to the FOC.
Current pattern is also better for DTC.

6.2 Speed Comparison

Dynamic Speed Response is fast in Case of DTC as compared to FOC.
The DTC presents a high dynamics at starting instant and rapid load torque disturbance rejection without overshoot compared to the FOC.
DTC is a better choice as compared to FOC as far as speed response is considered.

6.3 Torque Comparison

DTC presents a high dynamics at starting instant and rapid load torque disturbance rejection without overshoot compared to the FOC.
It should be noted that the amplitude of the torque ripple in DTC is slightly higher than that of FOC.
The oscillations in FOC scheme are more regular and uniform than the DTC.
Torque initially increases in DTC and later on it stabilizes at lower values as compared to FOC.
FOC is better if starting torque limit is posed by an application.

VII. CONCLUSION

The synthesis of this simulation reveals a advantage of DTC scheme compared to FOC scheme regarding the dynamic flux control performance.

Dynamic speed response is fast in case of DTC as compared to FOC.Torque initially increases in DTC and later on it stabilize at lower values as compared to FOC. Current pattern and Stator fluxes are also better for DTC.

The users to identify the more suitable solution for any application that requires torque control. Several numerical simulations have been carried; the conclusion is that the whole performance of the schemes is comparable. DTC with SVM might be preferred for high dynamic applications, but, on the other hand, shows higher current and torque ripple. The DTC scheme is simpler to implement, requiring a very small computational time.

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