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Direct torque control of three Phase induction motor using matlab

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Abstract: *Induction machines are widely employed in industries due to their rugged structure, high maintainability and economy than DC motors. There has been constant development in the induction motor drive system and their implementation in industrial applications. The improvement of switching speed of power electronic devices has enabled control techniques which possess high switching frequency and feasibility of high efficiency drive systems. In this pretext, Direct Torque Control (DTC) was introduced to obtain quick and better dynamic torque response. The DTC scheme in its basic configuration comprises torque and flux estimator DTC controller, stator voltage vector selector and voltage source inverter. Direct Torque Control of induction motor has increasingly become the best alternative to Field- Oriented Control methods. The performance of an induction motor under the classical Direct Torque Control method and*

improved scheme have been studied and confirmed by simulation using MATLAB .

Keywords: *Digital signal processor, direct field oriented control, direct signal processor, direct torque control, pulse-width modulation, application specific Integrated Circuit (ASIC)*

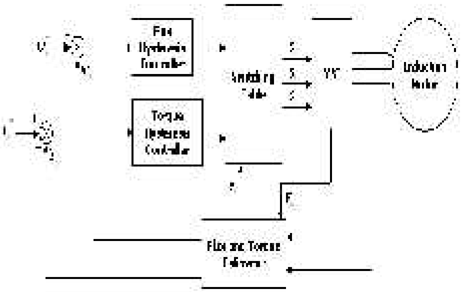
1. Introduction

Industrial loads require operation at wide range of speeds. Such loads are generally termed as variable speed drives. These drives demand precise adjustment of speed in a steeples manner over the complete speed range required. The loads may be constant torque or a function of speed. These loads are driven by hydraulic, pneumatic or electric motors. An industrial drive has some special features when driven by electric motors. Induction machines have provided the most common form of electromechanical drive for industrial, commercial and domestic applications that can operate at essentially constant speed. Induction machines have simpler and more rugged structure, higher maintainability and economy than dc motors.

They are also robust and immune to heavy loading. The possible forms of drive motors are dc drives, ac drives. DC motors are versatile for the purpose of speed control but they suffer from the disadvantage imposed by the commentator. On the other hand ac drives are viable competitors with the advent of thruster power converter technology. The evolution of ac variable speed drive technology has been partly driven by the desire to emulate the performance of dc drive such as fast torque response and speed accuracy, while utilising the advantages offered by standard ac motor.The Field Oriented Control (FOC) and the Direct Torque

Control (DTC) are two types of drives employed for high performance applications. Direct Torque Control was introduced in Japan by Takahashi (1984) and Depenbrock (1985). Vector controlled induction motors are employed in high performance drives having precise speed control and good static as well as dynamic response. Direct Torque Controlled drives have increasingly become the best alternative to Field-Oriented Control methods [10], [2]. Modern control methods use state space techniques. The method of stabilizing the drives and improvement in their transient responses have been realized by modern power electronic devices [3]. The block diagram of Direct Torque Control for an induction motor is as shown in Fig. 1. The DTC scheme comprises torque and flux estimator, hysteresis controllers for flux and torque and a switching table.

Fig. 1. Block diagram of classical DTC scheme



INDUCTION MOTOR MODEL

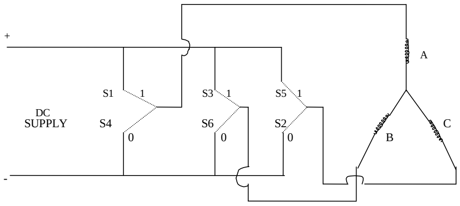
The main objective of DTC is to control the induction motor. The per-phase equivalent circuit of an induction motor is valid only in steady-state condition. In an adjustable speed drive like the DTC drive, the machine normally constitutes an element within a feedback loop and hence its transient behavior has to be taken into consideration [4]. The induction motor can be considered to be a transformer with short circuited and moving secondary. The coupling coefficients between the stator and rotor phases change continuously in the course of rotation of rotor [6], [5]. Hence the machine model can be described by differential equations with time-varying mutual inductances.

2. Literature review

DIRECT TORQUE CONTROL CONCEPT

Direct torque control has its roots in field-oriented control and direct self control. Field-oriented control uses spatial vector theory to optimally control magnetic field orientation. It has been successfully applied to the design of flux vector controls and is well documented. Direct self-control theory is less well known. The fundamental premise of direct self control is as follows. Given a specific dc-link voltage (Edc) and a specific stator flux level (ref), a unique frequency of inverter operation is established. This is true because the time (T) required by the time integral of the voltage (Edc) to integrate up to the field flux level (ref) is unique and represents the half-period time of the frequency of operation. Since the operational frequency is established without a frequency reference, this operational mode is referred to as direct self control [1]. Output frequency is, thus, not requested, but rather, is self-controlled via the actual frequencies present. Once sensed, whether the frequency increases or decreases depends on what the torque reference from the speed regulator requests. Differential changes to operational frequency are determined by the torque request. Direct torque control combines field-oriented control theory, direct self-control theory, and recent advances in digital signal processor (DSP) and application specific Integrated Circuit (ASIC) Technology to achieve a practical sensor less variable frequency drive.

Fig.2.VSI Switching Position



VSI Switching position

For a six-pulse VSI, according to its switch positions (S1 to S6), there are six non-zero active voltage space vectors (V1, V2, V3, V4,V5 and V6) and two zero voltage space vectors (V7 and V8) as shown in fig 3 One switch per leg of the VSI conduct at any time, i.e., if S1 is ON then S4 is OFF; 1 represents the ON state of a upper switch of a leg and 0 represents the ON state of the lower switch of the same leg. The stator flux linkage vector will move fast if non-zero switching vectors are applied and for a zero switching vector it will almost stop (it will move very slowly due to the small ohmic voltage drop.)

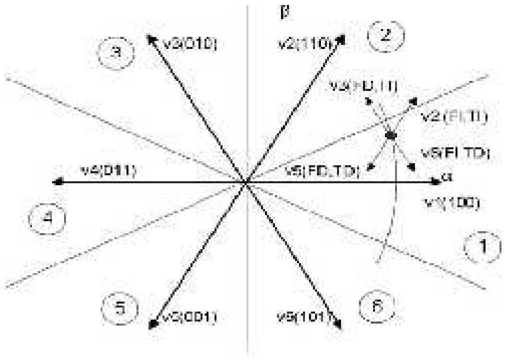


Fig.3 Voltage Switching Vectors

Corresponding to all possible combinations of switching states, active (non-zero) switching-voltage space vectors are shown in fig 3. By applying suitable space vector, changes in flux and torque demand can be met. If stator flux (ψs) lies in sector 1 and if a reduced stator flux linkage space vector modulus is required, the modulus is controlled by applying switching voltage vector which are directed towards the center. Here FD, F1, TD, T1 represent flux decrease, flux increase, torque decrease and torque increase respectively

Torque is controlled by varying the angle between the stator flux vector and the rotor flux vector. This method is feasible because the rotor time constant is much larger than the stator time constant in reality, there are only six active voltage vectors and two zero-voltage vectors that a voltage-source inverter can produce. The analysis performed by the optimal switching logic is based on the mathematical spatial vector relationships of stator flux, rotor flux, stator current, and stator voltage.

Thus, rotor flux is relatively stable and changes quite slowly, compared to stator flux. When an increase in torque is required, the optimal switching logic selects a stator voltage vector (Us) that develops a tangential pull on the stator flux vector (s), tending to rotate it counterclockwise with respect to the rotor flux vector (r). The enlarged angle created effectively increases the torque produced. When a decrease in torque is required, the optimal switching logic selects a zero-voltage vector, which allows both stator flux and produced torque to decay naturally. If stator flux decays below its normal lower limit the flux status output will again request an increase in stator flux. If the torque status output is still low, a new stator voltage vector (Us) is selected that tends to increase stator flux while simultaneously reducing the angle between the stator and rotor flux vectors.

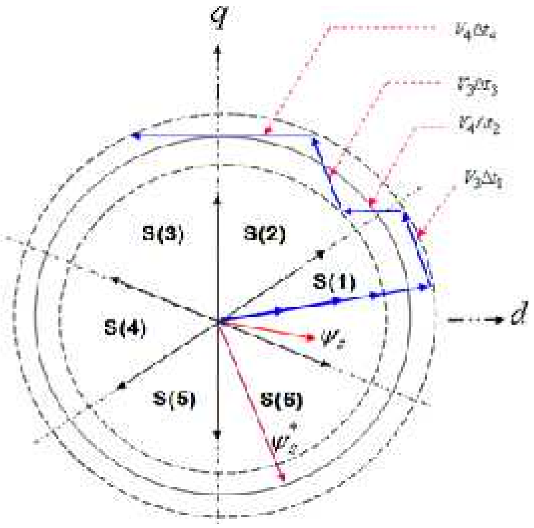


Fig.4.Trajectory of stator flux vector

Note that the combination of the hysteresis control block (torque and flux comparators) and the ASIC control block (Optimal switching logic) eliminate the need for a traditional PWM modulator. This provides two benefits. First, small signal delays associated with the modulator are eliminated and second, the discrete constant carrier frequencies used by the modulator are no longer present[4].

3. DIRECT TORQUE CONTORL DRIVE AND MODELING OF INDUCTION MOTOR

Torque Reference Controller-Within the Torque Reference Controller, the speed control output is limited by the torque limits and DC bus voltage. It also includes speed control for cases when an external torque signal is used. The internal torque reference from this block is fed to the torque comparator.

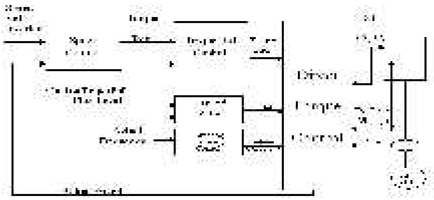


Fig.5. Complete Direct Torque Control Drive.

Speed Controller- the Speed Controller block consists both of a PID controller and an acceleration compensator. The external speed reference signal is compared to the actual speed produced in the motor model. The error signal is then fed to both the PID controller and the acceleration compensator. The output is the sum of outputs from both of them. Flux Reference Controller- An absolute value of stator flux can be given from the flux reference controller to the flux comparator block. The ability to control and modify this absolute value provides an easy way to realize many inverter functions such as flux optimization and flux braking.

3.1 MODELING

Induction motor can be represented by the following equations in “dq0” format, in arbitrary reference frame, which is rotating at an angular speed in the direction of rotation of the rotor:

For electromagnetic torque calculation following equations is used:

$$T_{em} = (3/2)(p/2)(L_m / L_r)(\quad dr\, I_{qs} - \quad qr\, I_{ds}) \qquad (19)$$

$$T_{em} - T_{load} = J\,(d\omega_r / dt) \qquad (20)$$

For motoring operation load torque is positive and for generating mode of operation load torque is negative.

3.2 MODELING OF FUNCTIONAL BLOCKS

The model and control blocks used to arrive at the firing signals for the VSI are described below:

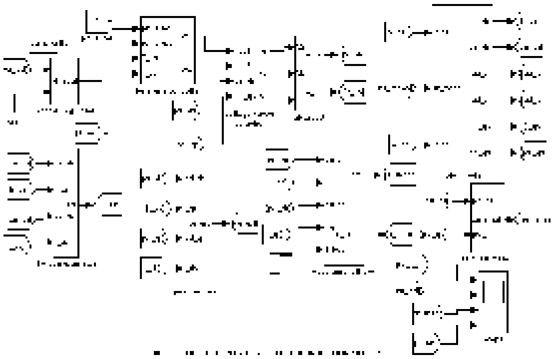


Fig. 6 DTC Model

3.3 FLUX ESTIMATOR

Flux estimation is done using following equation

$$\Psi_{s\_est} = \sqrt{\ \Psi_{ds}2 + \Psi_{qs}2}$$

3.4 TORQUE ESTIMATOR

Torque estimations is done using following equation

$$T_{est} = (3/2)(P/2)(\Psi_{ds} I_{qs} - \Psi_{qs} I_{ds})$$

3.5 SPEED ESTIMATOR

Speed estimation is done using open loop estimator governed by following equation:

$$\omega_{r\_est} = [\Psi_{dr}(d\Psi_{qr}/dt) - \Psi_{qr}(d\Psi_{dr}/dt)][1/(\Psi_{dr}2 + \Psi_{qr}2)] - [(L_m / T_r)$$

$$(\Psi_{dr} I_{qs} - \Psi_{qr} I_{ds})][1/(\Psi_{dr}2 + \Psi_{qr}2)]$$

3.6 HYSTERESIS CONTROLLER

The speed regulator which generates the reference torque signal is compared against estimated torque and torque error is calculated in hysteresis comparator block. Similarly, flux error signal is also calculated This is done using two level flux comparator and three level torque comparator using following consideration:

$$d\Psi = I \text{ if } |\Psi_s| \le |\Psi_{s\,ref}| - |\Delta\Psi_s|$$

$d\Psi=0$ if $|\Psi s| \geq |\Psi s\ ref| + |\Delta\Psi s|$

and

$dt_e=1$ if $|te| \leq |te\_ref| - |\Delta te|$

$dt_e = 0$ if $|te| \geq te\_ref$

$dt_e = -1$ if $|te| \leq |te\_ref| + |\Delta te|$

$dt_e = 0$ if $|te| \leq te\_ref$

Thus the digital output of flux comparator is 1,0 and that of torque comparator is 1,0,-1.

Depending on the flux and torque comparator outputs, switching vector is selected as per following look up table:

d Ψ	d T	Sect. 1	Sect. 2	Sect. 3	Sect. 4	Sect. 5	Sect. 6
1	1	V2	V3	V4	V5	V6	V1
	0	V7	V8	V7	V8	V7	V8
	-1	V6	V1	V2	V3	V4	V5
0	1	V3	V4	V5	V6	V1	V2
	0	V8	V7	U8	V7	V8	V7
	-1	V5	V6	V1	V2	V3	V4

Table :- 1.1

V1, V2, V3, V4, V5 and V6 are active voltage switching vectors, V7 and V8 are zero voltage switching vectors.

Optimum voltage vector selection is done using S-Function block contained in voltage vector selection block. This essentially constructs phase voltages using DC link voltage .

The model also calculates sector (as shown in Table 1.1) in which the stator flux linkage space vector is lying as per following relations.

Sector 1: $(\Psi ds \geq \quad \Psi qs) \ \& \ (\Psi ds \geq 0)$

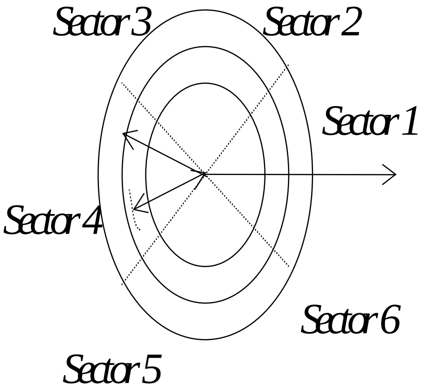
Sector 2: $(\Psi ds < \quad \Psi qs) \ \& \ (\Psi ds \geq 0)$

Sector 3: $(|\Psi ds| < \quad \Psi qs) \ \& \ (\Psi ds < 0)$

Sector 4: $(|\Psi ds| \geq \quad \Psi qs) \ \& \ (\Psi ds < 0)$ Sector 5: $(|\Psi ds| < \quad |\Psi qs|) \ \& \ (\Psi ds < 0) \ \& \ (\Psi qs < 0)$

Sector 6: $(\Psi ds < \quad |\Psi qs|) \ \& \ (\Psi ds \geq 0) \ \& \ (\Psi qs < 0)$

The voltage source inverter is modeled in form of S-function block, contained in voltage vector selection block . It is written in form of an M-file, which gives the output of the inverter in terms of three phase voltages as per the signals received from optimum pulse selector. The M-file is given in appendix B. In fact the inverter output voltages are reconstructed using dc link voltage.



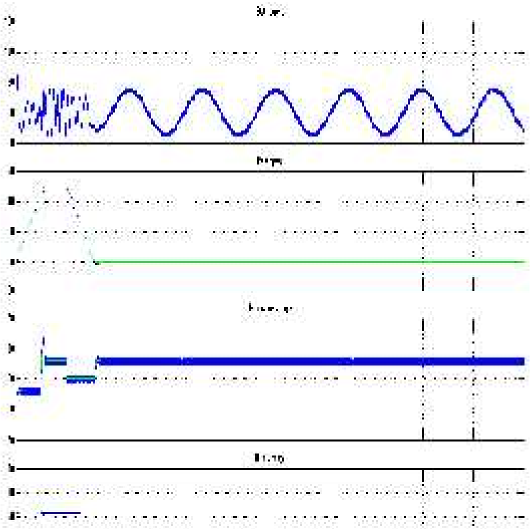
T Fig. 7 Voltage Sectors

4. SIMULATION RESULTS

The model which is developed was simulated for an induction motor of rating 149.2 KW (machine parameters are given in appendix A) Simulation results in form of computer traces of electromagnetic torque developed, estimated torque , estimated and actual speed, stator flux and stator current have been depicted in this chapter.

Simulation is done for following case:

Condition :- The motor was started at no load with a set speed of 150 rad/sec and at t=0.5 sec a load torque of 5 Nm.(65 % of rated torque) was applied .



A PI controller is employed in the speed loop

to make the steady state error in speed zero. The values of Kp and Ki are changed to obtain plots showing the dependence of the Simulation result of Stator current , Rotor speed , Electromagnetic torque and DC bus voltage performance.

Estimated Flux remains the same in all the cases a shown in Fig. From then plots it is seen that estimated torque and electromagnetic torque are close to each other. Also actual and estimated speed plots are close to each other. By increasing the value of Kp, the pulsations in the electromagnetic torque increase.

5. CONCLUSION

Direct torque control combines the benefit of direct flux and torque control into sensor less variable frequency drive that does not require a PWM modulator. Recent advances in digital signal processor and application specific integrated circuit and the theoretical concepts developed so far for direct self control makes this possible. The objective of the present work was to make a model of direct torque control of three phase induction motor .Various speed control schemes were studied and extensive literature survey was carried out for understanding the direct torque control technique. MATLAB/SIMULINK was chosen as modeling and simulation tool because of its versatility. Model for direct torque controlled induction motor was developed using MATLAB/SIMULINK and performance of the system for different operating condition like starting, load changes, speed reversal, effect of changing the values of Kp and Ki on the performance characteristics, was studied. The model was validated by comparing the plots of various performance parameters with those available with literature. It was also observed that for motoring operation, the performance was best in terms of starting time, overshoot and undershoot..

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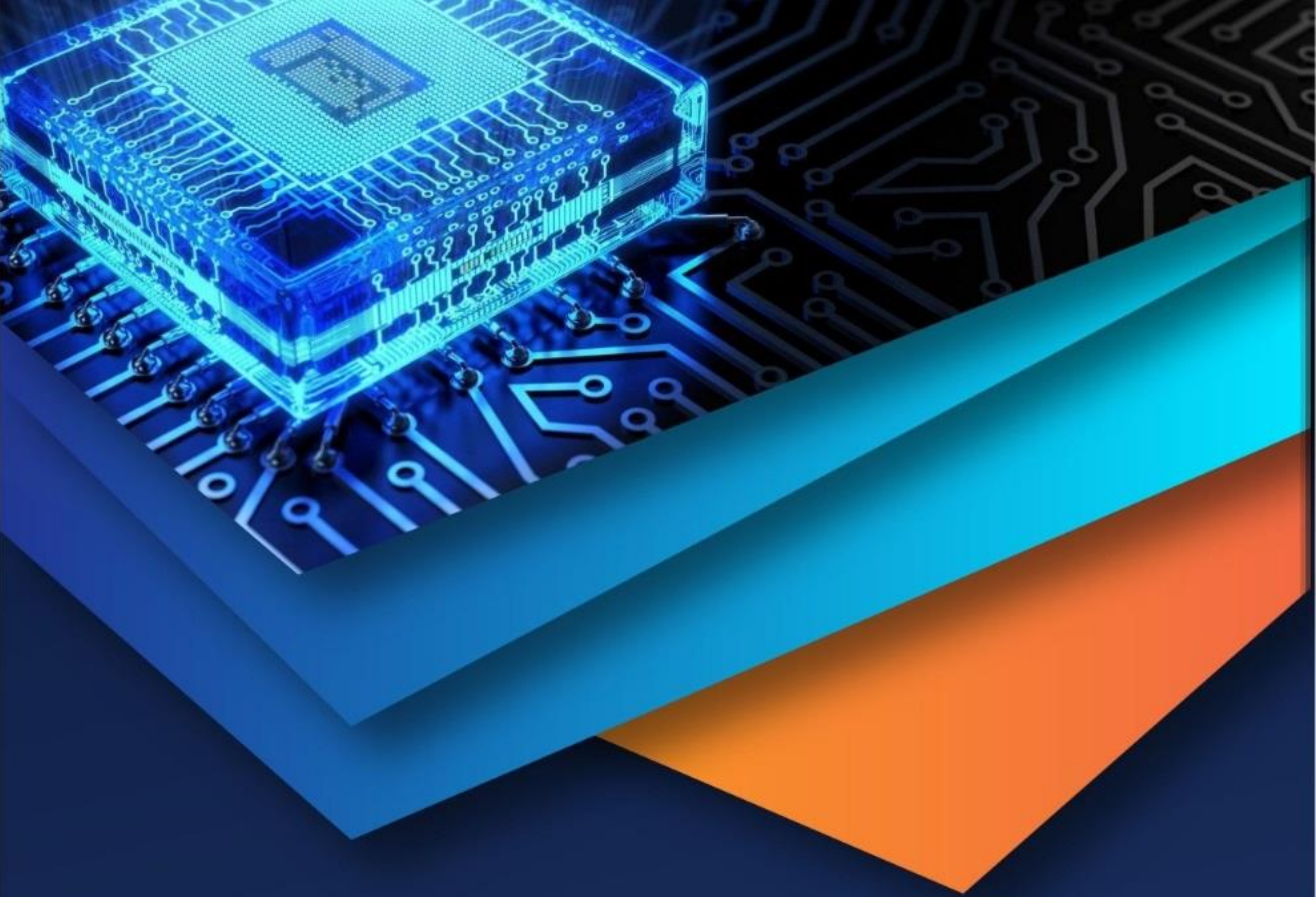

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