

Direct Torque Control of Induction Motor Drives

Mr. Ravindra Pawar¹, Prof. Ashok Jhala²

M.Tech Research Student, RKDF college of Engineering, Bhopal¹

Head of the Department (Elect. & Electronics Engg) RKDF college of Engineering, Bhopal²

Abstract: This paper presents improved performance of Direct Torque Control (DTC) of induction motor drives. At the time of switching DTC drive gives the high torque ripple. In DTC induction motor drive there are torque and flux ripples because of incorrect voltage vector selection by VSI states is unable to generate the exact voltage value required to make zero both the torque electromagnetic error and the stator flux error. To overcome this problem a Fuzzy Logic Controller is proposed. The fuzzy logic controller is used to reducing the torque and flux ripples and it improve performance DTC especially at low speed.

Keywords: direct torque control, induction motor, fuzzy logic, torque ripple minimization, fuzzy logic controller.

I. INTRODUCTION

Increasing The Induction Motor (IM) drives controlled with the vector control method has mostly accepted in the industry. However, this control technique requires complex coordinate transformation, inner current control loop and accurate system parameters. On the other hand, the Direct Torque Control (DTC) method provides robust and fast torque response without such coordinate transformation, PWM pulse generation and current regulators. Moreover, DTC minimizes the use of motor parameters technique suffers from a major disadvantage of steady state ripple in torque and flux, because none of the inverter-switching vector is able to generate the exact stator voltage at proper instants as well as in space. These torque and flux ripples affect the accuracy of speed estimation; result in high acoustic noise and harmonic losses. There are many methods to reduce this torque and flux ripple: (a) the alternative inverter topologies, multilevel inverters and matrix converters which increase the number of switches, and thus cost and complexity; (b) the higher switching frequencies reduce the harmonic content of stator current and thus torque and flux ripple. However, such higher switching frequencies lead to increased switching losses and stress on semiconductor switches of the inverter (c) yet, another method of reducing torque and flux ripples is fuzzy logic controller gives constant switching frequency. Moreover this method requires complex control schemes than classical DTC and is machine parameter dependent

DTC drive over the last decade becomes one possible alternative to the well-known Vector Control of Induction Machines. Its main characteristic is the good performance, obtaining results as good as the classical vector control but with several advantages based on its simpler structure and control diagram. DTC (Direct Torque Control) is characterized, as deduced from the name, by directly controlled torque and flux and indirectly controlled stator current and voltage. The DTC has some advantages in comparison with the conventional vector-controlled drives, like: Direct torque control and direct stator flux control, Indirect control of stator currents and voltages, Approximately sinusoidal stator fluxes and stator currents, High dynamic performance even at locked rotor, Absences

of co-ordinates transform, Absences of mechanical transducers, Current regulators, PWM pulse generation, PI control of flux and torque and co-ordinate transformation are not required, Very simple control scheme and low computation time, Reduced parameters sensitivity, Very good dynamic properties. Conventional DTC has also some disadvantages: Possible problems during starting and low speed operation, High requirements upon flux and torque estimation, Variable switching frequency. These are disadvantages that we want to remove by using fuzzy logic.

II. DTC SCHEMATIC

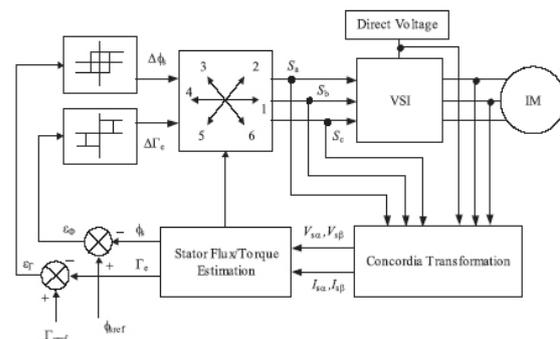


Fig.1 Block diagram of DTC scheme

DTC scheme is given in Fig. 1, the ϵ_Φ and ϵ_τ signals are delivered to two hysteresis comparators. The corresponding digitized output variables: change of magnetic flux $\Delta\Phi$, of mechanical torque $\Delta\tau_e$ and the stator flux position sector S_N created a digital word, which selects the appropriate voltage vector from the switching table.

The selection table generates pulses S_a, S_b, S_c , to control the power switches in the inverter. Three-level torque and two level flux hysteresis controllers are used according to the outputs of the torque controller and the sector information S_Φ of Φ_s , appropriate voltage vectors for both the inverters are selected from a switching table as it is shown in fig.2

Flux	Torque	Sector Sφ					
Δφ	Δτ	Sφ1	Sφ2	Sφ3	Sφ4	Sφ5	Sφ6
1	1	V2	V3	V4	V5	V6	V1
1	0	V7	V0	V7	V0	V7	V0
1	-1	V6	V1	V2	V3	V4	V5
-1	1	V3	V4	V5	V6	V1	V2
-1	0	V0	V7	V0	V7	V0	V7
-1	-1	V5	V6	V1	V2	V3	V4

Fig.2 Classical DTC switching table

Figure.3.5 shows the voltage vectors which are usually employed in DTC scheme when the stator flux vector is lying sector I is shown in fig 3.8. The selection of a voltage vector at each cycle period is made in order to maintain the torque and the stator flux within the limits of two hysteresis bands. This simple approach allows a quick torque response to be achieved, but the steady state performance is characterized by undesirable ripple in current, flux and torque. This behaviour is mainly due to the absence of information about torque and rotor speed values in the voltage selection algorithm.

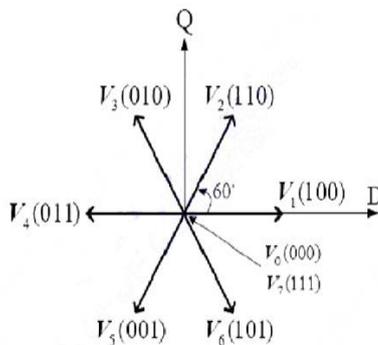


Fig.3 Eight possible voltage space vectors

III. VECTOR TRANSFORMATIONS

Concordia transformation for voltages

By using this transformation, two voltages V_{sd} and V_{sq} are obtained. The measured voltage U_0 is necessary and the switching table also S_a, S_b, S_c .

$$V_{sd} = \sqrt{\frac{2}{3}} U_0 \left(S_a - \frac{1}{2} (S_b + S_c) \right)$$

$$V_{sq} = \frac{1}{\sqrt{2}} U_0 (S_b - S_c)$$

3.4.2 Concordia transformation for currents

This transformation is used to obtain currents I_{sd} and I_{sq} , after measures of I_{sa}, I_{sb} and I_{sc} of the stator.

$$I_{sd} = \sqrt{\frac{3}{2}} I_{sa}$$

$$I_{sq} = \frac{1}{\sqrt{2}} (I_{sb} - I_{sc})$$

3.4.3 Flux and torque estimations

DTC command is based on estimation in flux and in torque. In order to realize these estimators, we used results of Concordia transformations.

Because stator voltage is define by:

$$V_s = R_s * I_s + (d\phi_s/dt)$$

We have $\phi_s = \int V_s - R_s * I_s$

That's why, we have two equations:

$$\Phi_{sd} = \int_0^t (V_{sd} - R_s I_{sd}) dt$$

$$\Phi_{sq} = \int_0^t (V_{sq} - R_s I_{sq}) dt$$

We can now estimate torque,

$$\tau_e = p[\Phi_{sd} I_{sq} - \Phi_{sq} I_{sd}]$$

IV. DTC CONTROLLER

The way to impose the required stator flux is by means of choosing the most suitable Voltage Source Inverter state. If the ohmic drops are neglected for simplicity, then the stator voltage impresses directly the stator flux in accordance with the following equation:

$$\frac{d}{dt} \bar{\psi}_s = \bar{u}_s$$

Or

$$\Delta \bar{\psi}_s = \bar{u}_s \Delta t$$

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 in its locus. These two components are directly proportional ($R_s=0$) to the components of the same voltage space vector in the same directions

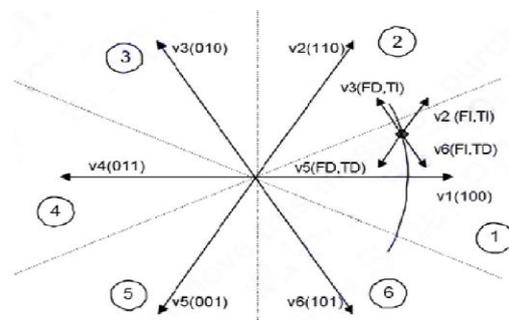


Fig-1: Stator flux vector locus

The hysteresis band has to be set large enough to limit the inverter switching frequency below a certain level that is usually determined by thermal restriction of power devices. Since the hysteresis bands are set to cope with the worst case, the system performance is inevitably degraded in a certain operating range, especially in a low speed region. In torque hysteresis controller, an elapsing time to move from lower to upper limit, and vice versa can be changed according to operating condition.

SIMULATED RESULTS for DTC Model

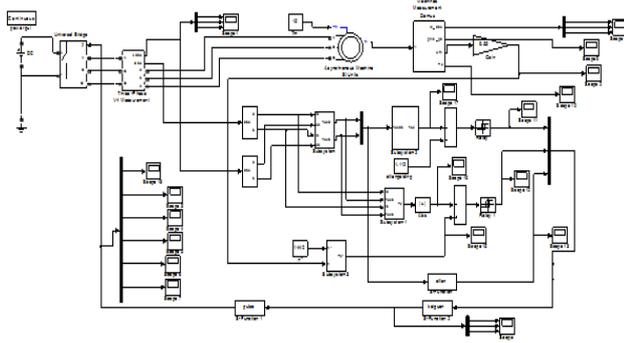


Figure 4.8: Direct Torque Control of Induction Schematic using SIMULINK/MATLAB.

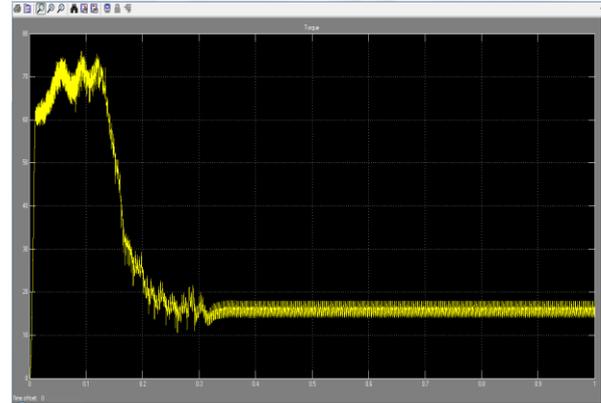


Fig 4.15: Torque in DTC

V. SIMULATION

Motor characteristics

The rating of induction motor is 5Hp, 415V, 50Hz, 1430 rpm star connected induction motor. For all simulation, the motor characteristics will be utilized as below:

- Stator Resistance (ohm) = 1.405
- Rotor Resistance (ohm) = 1.395
- Stator Self Inductance(H) = 0.005839
- Rotor Self Inductance(H) = 0.005839
- Mutual Inductance(H) = 0.2037
- No. of poles = 4
- Moment of Inertia (kg.m²) = 0.03
- Load torque (Nm) = 15
- Sampling time,(Ts) = 1 sec

The simulations of the DTC induction motor drive were carried out using the Matlab/Simulink simulation package. From figure torque ripple is significantly reduced when DTC used. Also DTC gives better performance not only at lock rotor but also at standstill. It is seen that the steady state performance of the DTC.

4.6 Study Case:

a) For DTC model:

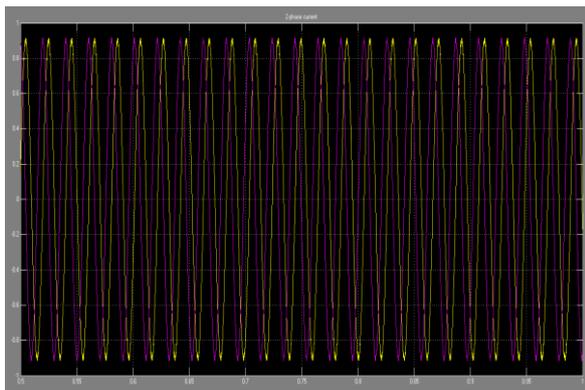
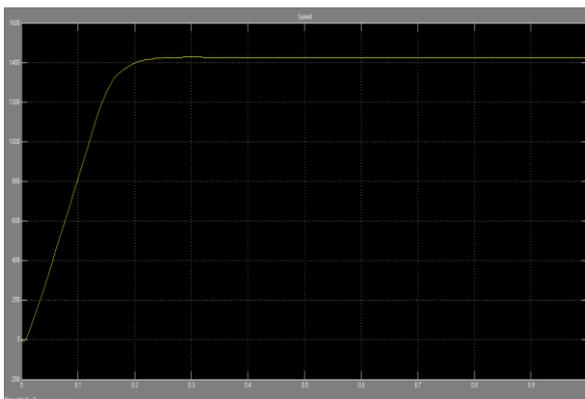
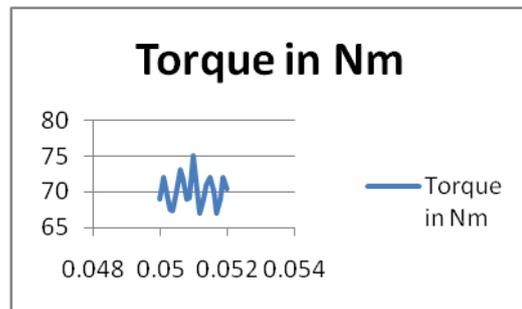
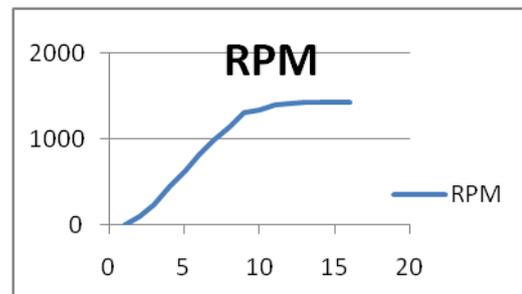


Fig 4.13: 2-phase current in DTC



4.14 Fig: Speed in DTC

VI. CONCLUSION

For any IM drives, direct torque control is one of the best controllers proposed so far. It allows decoupled control of motor stator flux and electromagnetic torque. From the analysis it is proved that, this strategy of IM control is simpler to implement than other vector control methods as it does not require pulse width modulator and co-ordinate transformations. But it introduces undesired torque and current ripple. DTC scheme uses stationary d-q reference frame with d-axis aligned with the stator axis. Stator voltage space vector defined in this reference frame control the torque and flux. The main inferences from this work are:

1. In transient state, by selecting the fastest accelerating voltage vector which produces maximum slip frequency, highest torque response can be obtained.
2. In steady state, the torque can be maintained constant with small switching frequency by the torque hysteresis comparator by selecting the accelerating vector and the zero voltage vectors alternately.
3. In order to get the optimum efficiency in steady state and the highest torque response in transient state at the same time, the flux level can be automatically adjusted.
4. If the switching frequency is extremely low, the control circuit makes some drift which can be compensated easily to minimize the machine parameter variation.

The estimation accuracy of stator flux is very much essential which mostly depends on stator resistance because an error in stator flux estimation will affect the behaviour of both torque and flux control loops. The torque and current ripple can be minimized by fuzzy logic controller technique.

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