REVIEW OF DIRECT TORQUE CONTROL TECHNIQUE ON INDUCTION MOTOR

[1]Disha N. Patel, [2]Sajid M. Patel
Student (M.Tech-E.E), Assistant Professor
Email: [1]99dishapatel@gmail.com, [2]sajidpatel.ee@charusat.ac.in

Abstract—Initially Scalar & Vector controlled drives such as Volt-Hertz & F.O.C control was used in many industrial applications. Recent advancement in technology has led to the development of high controlling drives. Direct Torque Control (DTC) is a technique which is emerging, due to its precise and quick control of motor's flux and torque without calling any complex computation. This paper deals with the implementation of Direct Torque Control technique on Induction motors (I.M).Analysis of torque control under various load conditions is simulated.

Index Terms—Direct Torque, Control, Motor drive, Induction motor.

I. INTRODUCTION

Over the past decades DC machines were used extensively for variable speed applications due to the decoupled control of torque and flux that can be achieved by armature and field current control respectively. DC drives are advantageous in many aspects as in delivering high starting torque, ease of control and nonlinear performance, but due to the major drawbacks of DC machine such as presence of mechanical commutator and brush assembly, DC machine drives have become obsolete today in industrial applications. Due to the advantages of the induction motors such as starting, braking, speed change and speed reversal etc many new techniques of control has been implemented on it. Now a days using modern high switching frequency power converters controlled by microcontrollers, the frequency, phase and magnitude of the input to an AC motor can be changed, hence the motor speed and torque can be controlled. As a result Vector controlled strategy such as Field Oriented controlled was developed. But due to its complex computation and high switching loss led to the development of a new drive controlling technique i.e. Direct Torque Control (DTC) technique. DirectTorque Control techniquewas originally proposed by Takahashi and Noguchi in 1986. This paper presents detailed study of DTC on its torque and flux response [1].

II. PRINCIPLE OF DIRECT TORQUE CONTROL

The basic functional blocks used to implement the DTC scheme in an induction motor is shown in Fig. 1.DTC method has been first proposed for induction machines. DTC technique introduced by Takahashi and Noguchi for low and medium power application and DTC technique introduced by Depenbrock for high power application are

Popular in industry. DTC strategy is quite different from that of the field orientation control (FOC) or vector control, which does not need complicated coordination transformations and decoupling calculation. The basic model of the conventional DTC induction motor scheme is shown in Fig 1. Stator currents and DC-bus voltage are sampled. The d-q components of stator voltage and current space vectors in the stationary reference frame and also magnitude of the stator flux and electric torque are calculated

[1].The magnitude of stator flux and electric torque calculated are compared with their reference values in the hysteresis comparators shown in Fig 1 and then the outputs of the comparators are fed to a switching table to select an appropriate inverter voltage vector. The switching table is shown in Table 3 determine the voltage vector to apply based on the position of the stator flux and the required changes in stator flux magnitude and torque [8]. The selected voltage vector will be applied to the induction motor at the end of the sampling time. In VSI, there are six equally spaced voltage vectors having the same amplitude and two zero voltage vectors. In DTC, torque and flux are controlled independently by selecting the optimum voltage space vector for entire switching period and the errors are maintained with in the hysteresis band .Hence the IGBT inverter switches arecontrolled by the direct torque control algorithm. The output of the inverter is connected to the stator terminals of inductionmotor.[10]

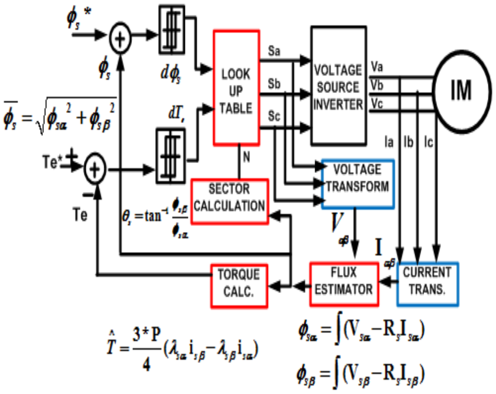

Fig 1 Basic DTC Block diagram [1]

A. Stator flux Control

The stator voltage vector equation, in a stator reference frame, is given by:

$$\overline{V}_s = R_s \overline{I}_s + \frac{d\phi_s}{dt} \qquad 1$$

Where Rsis the stator resistance and

$$\overline{V}_s = V_{s\alpha} + jV_{s\beta} \qquad 2$$

So,

$$\overline{\phi}_s = \overline{\phi}_0 + \int_0^t (\overline{V}_s - R_s \overline{I}_s)\,dt \qquad 3$$

For high speeds, the term Rs Is can be neglected, so the equation is given by:

$$\overline{\phi}_s = \overline{\phi}_0 + \int_0^t (\overline{V}_s) \qquad 4$$

$\overline{\phi}_0$ is the initial stator flux at that instant

Because during one sampling period T_e the selected stator voltage vector is always constant ,the last question becomes

$$\overline{\phi}_s(k+1) \approx \overline{\phi}_s(k) + \overline{V}_s T_e \qquad 5$$

$$\Delta\overline{\phi}_s = \overline{V}_s T_e \cong \overline{\phi}_s(k+1) - \overline{\phi}_s(k) \qquad 6$$

With: T_e is the sampling period.

Φsis the stator flux vector at the actual sampling period.

Φs (k + 1) is the stator flux vector at the next sampling period.

ΔΦs is the variation of stator flux vector.

From equation 6, it is seen that the variation of the stator flux is directly proportional to the stator voltage consequently the control is carried out by varying the stator flux vector by selecting a suitable voltage vector with the Voltage Source Inverter (VSI) [3].

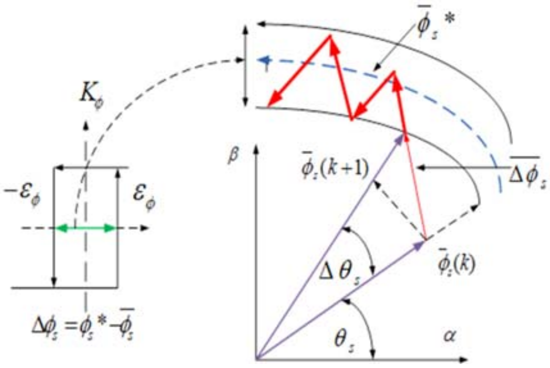

Fig 2. Stator flux vector evolution in the αβ subspace [3]

Fig 2 shows that the stator flux vector is varied in the same direction as the applied stator voltage vector. Therefore, apply a collinear stator voltage vector as the stator flux vector and in the same direction as it is a sufficiently condition to increase it, and vice versa. Indeed, to control the stator flux vector Φs(k) an estimator of its module Φs and its argument θ_s is needed; the stator flux can be estimated from the measure of stator currents and voltages and their transformation in the αβ subspace, by integrating of difference between the input voltage and the voltage drop across the stator resistance as given by

$$\phi_{s\alpha} = \phi_{PM} + \int_0^t (V_{s\alpha} - R_s I_{s\alpha})\,dt \qquad 7$$

$$\phi_{s\beta} = \int_0^t (V_{s\beta} - R_s I_{s\beta})\,dt \qquad 8$$

Note that ϕ_{PM} is the permanent magnet flux. From equations 7 and 8, the stator flux magnitude and its argument are given by

$$\overline{\phi_s} = \sqrt{\phi_{s\alpha}^{\ 2} + \phi_{s\beta}^{\ 2}} \qquad 9$$

B.Torque control:

The electromagnetic torque equation is defined as follows

$$T = k(\overline{\phi_s}.\overline{\phi_r}) = \left\|\overline{\phi_s}\right\|.\left\|\overline{\phi_r}\right\|.\sin\delta \qquad 10$$

Where δ is the angle between the rotor and the stator flux vectors and the constant k is expressed as (when Ld = Lq):-

$$k = \frac{3P}{2L_q} \qquad 11$$

Equation 9 indicates that the electromagnetic torque depends to the rotor and stator amplitude, and the angle δ[3]. So, if the stator flux vector is perfectly controlled, by mean of the stator voltage vector Vs, in module and in position; consequently, the electromagnetic torque can be controlled by the same stator voltage vector.The torque variation generated by a comparator of electromagnetic torque reference (T*)and the estimated torque ($\hat{T}$) is given by:

$$\Delta T = T* - \hat{T} \qquad 12$$

Torque is calculated by the equation:

$$\hat{T} = \frac{3*P}{4}(\lambda_{s\alpha}\mathrm{i}_{s\beta} - \lambda_{s\beta}\mathrm{i}_{s\alpha}) \qquad 13$$

The estimated torque Te is calculated and compared with the requested torque T e*[3]

C. Sector Calculation:

To determine the motors operating sector, the flux vector angle has to be calculated from the estimated flux Depending on the angle of the flux vector, the correct sector is chosen according to

$$\tan^{-1}(\theta_{\lambda s}) = \frac{\lambda_\beta}{\lambda_\alpha} \qquad 14$$

Now according to above calculated torque, flux errors and the angle following switching table is being tabulated [1,3]

D. Flux Comparator:

A flux error thus determines which voltage phasor has to be called, and this flux error is converted to a digital signal with a window comparator with a hysteresis of .The switching logic to realize from is given in the following.

Table No1: Flux output signal [1]

Condition	S_λ
$\lambda_{er} > \delta\lambda_s$	1
$\lambda_{er} <= \delta\lambda_s$	0

The flux hysteresis comparator output is denoted by Boolean variable KΦ which indicates directly if the amplitude of flux must be increased KΦ = 1 or decreased KΦ = 0 : if KΦ = 1, it means that the actual value of the flux linkage is below the reference value and outside the hysteresis limit; so the stator flux must be increased, while if KΦ = 0, it means that the actual value of the flux linkages is above the reference value and outside the hysteresis limit; so the stator flux must be decreased.

E. Torque Comparator:

Torque control is exercised by comparison of the command torque to the torque measured from the stator flux linkages and stator currents as the error torque is processed through a window comparator to produce digital outputs, s_T as follows:

Condition	s_T
$(T_e * - \hat{T}_e) > \delta \mathrm{T}_e$	1
$-\delta \mathrm{T}_e < (T_e * - \hat{T}_e) < \delta \mathrm{T}_e$	0
$(T_e * - \hat{T}_e) < -\delta \mathrm{T}_e$	-1

Table No 2: Torque output signal

Where $\delta \mathrm{T}_e$ □is the torque window acceptable over the commanded torque. When the error exceed $\delta \mathrm{T}_e$ □it is time to increase the torque, denoting it with a +1 signal. If the torque error is between positive and negative torque windows then the voltage phasor could be at zero state. If the torque error is below - $\delta \mathrm{T}_e$ □it amounts to calling for regeneration, signified by -1 logic signal. Interpretation of $\delta \mathrm{T}_e$ □is as follows: when it is 1 amounts to increasing the voltage phasor. 0 means to keep it at zero, -1 requires retarding the voltage phasor behind the flux phasor to provide regeneration. Combining the flux error output S□□the torque error output s_T and the sextant of the flux phasor a switching table can be realized to obtain the switching states of the inverter it is given in Table 3. To determine the correct control commands one flux and one torque hysteresis comparators are used. The comparators evaluate the difference between requested values and estimated values, and thereby determine if the flux and torque vectors should be:

- Increased - Output is 1
- Decreased - Output is -1
- Constant - Output is 0

Flux	Torque	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6
1	**1**	V2	V3	V4	V5	V6	V1
1	**0**	V7	V0	V7	V0	V7	V0
1	**-1**	V6	V1	V2	V3	V4	V5
0	**1**	V3	V4	V5	V6	V1	V2
0	**0**	V0	V7	V0	V7	V0	V7
0	**-1**	V5	V6	V1	V2	V3	V4

Table. No 3-Switching Vectors [14]

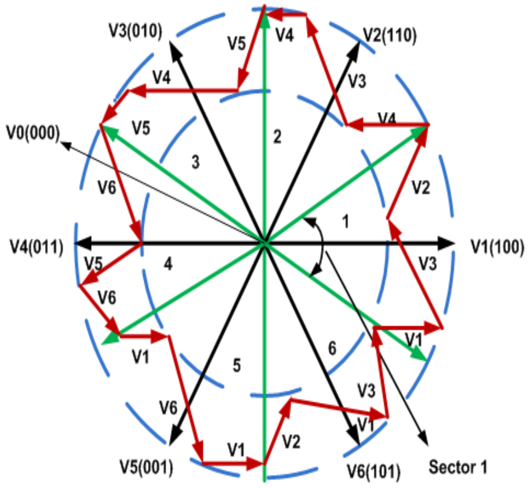

Fig 3 Control of stator flux by selection of the suitable voltage vector Vi (i=0,...,7)[3]

III. SIMULINK MODEL OF DTC:

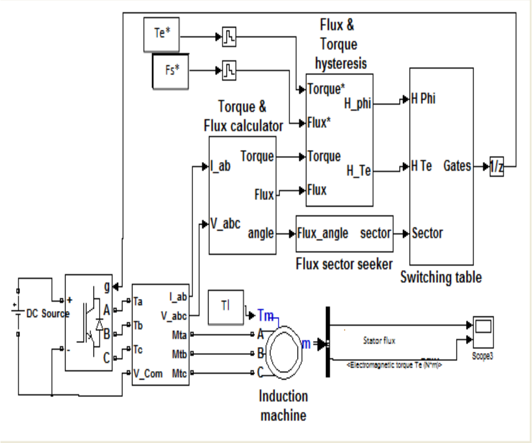

Fig 4 Simulink model of DTC

IV. SIMULATION RESULT:

System shown in Fig 4 has been modeled with the parameters given in table 2.To verify the results, Direct torque control technique is being implemented on Induction motor:

TableNo.2-Induction Motor Parameters

MOTOR PARAMETERS	VALUES
Power	1.1kW
Supply Voltage	415V
Frequency	50Hz
Stator Resistance, Rs	6.03Ω
Rotor Resistance, Rr	6.085Ω
Stator self-Inductance,	29.9mH
Rotor self-inductance,	29.9mH
Mutual Inductance,	489.3mH
Moment of Inertia, J	0.011787Kg.m2
T_bw(torque bandwidth)	0.1
F_bw(flux bandwidth)	0.2

Case1: T_reference=3.5 N.m; T_Load= 3.5 N.m Analysis shows the effect on Stator flux linkage and torque given in fig 5 and 6.As from the fig 5 we can observe that at t=0.001 sec the actual torque tracks the commanded torque which has a magnitude of 3.5 N.m., hence the response is dynamic with the DTC. Moreover fig 7 indicates the stable flux trajectory .Here the locus of the stator flux-linkages phasor is almost a uniform circle, even during large speed changes and hence torque commands, thus showing the complete decoupling of the flux from the torque

producing channels in the drive system

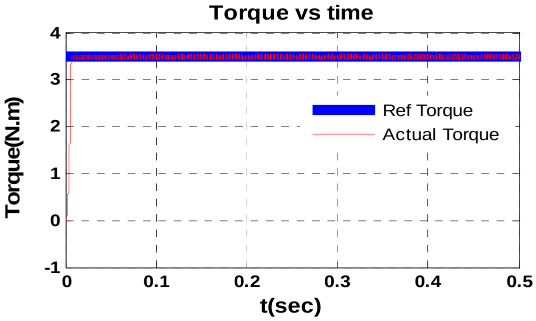

Fig 5 Torque response

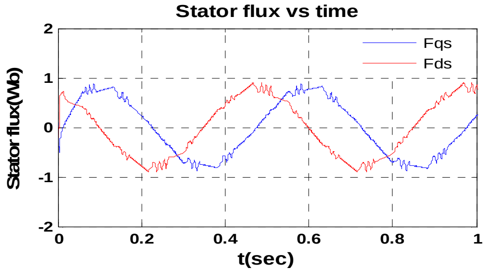

Fig 6 Stator flux response

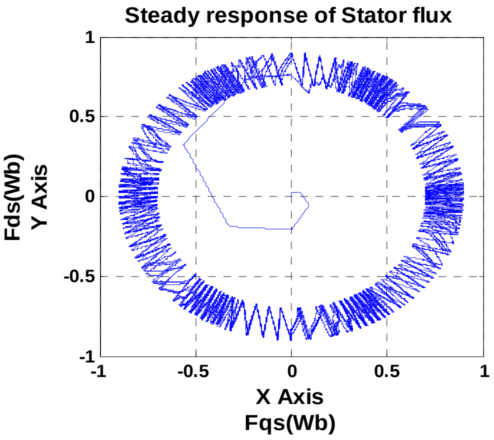

Fig 7 Stable flux trajectory

Case2: T_reference=Step Load**:**

Analysis shows the effect on Stator flux linkage and torque given in fig 8 and 9.Fig 8 show that reference torque changes abruptly from 0 to 3.5 Nm, from 3.5 Nm to -3.5 Nm and again from -3.5 Nm to 0.Hence we can observe that as our commanded torque changes, actual torque also changes dynamically and the required torque response is obtained. Also stable flux trajectory for the same load torque is shown.

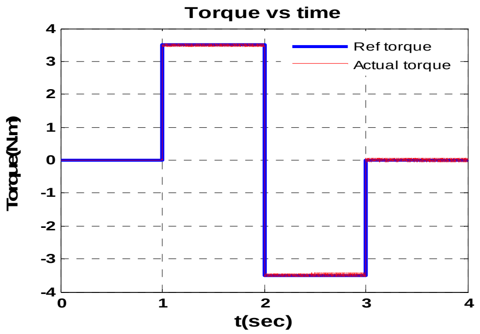

Fig 8 Torque response

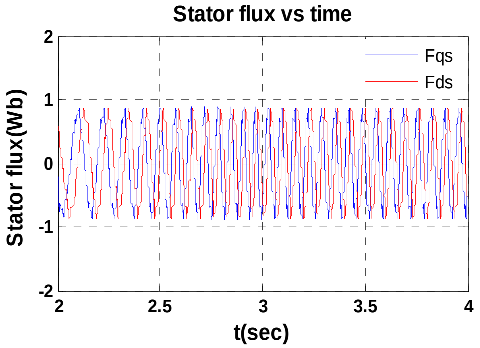

Fig 9 Stator flux response

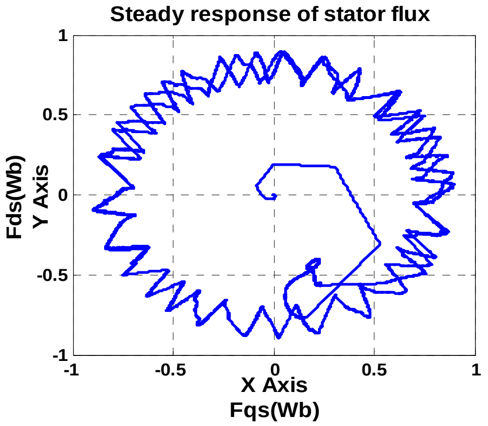

Fig 10. Stable flux trajectory

V. CONCLUSION:

Direct Torque Control technique is widely used because of its dynamic torque response and due to its less complexity. Analysis shows that for various load condition DTC technique provides dynamic and fast torque response without requirement of any core motor variable, except the stator resistance.

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