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Direct Torque Control of Induction Motor

Aswin Bose[1], Jobin V Thomas[2], Jishnu Raj M[3], Kavya M[4], Prof. Kavitha Issac[5]

[1,2,3,4]B.Tech. Student, Department of Electrical and Electronics Engg., Mar Athanasius College of Engineering, Kothamangalam, Kerala, India
[5]Asst. Professor, Department of Electrical and Electronics Engg., Mar Athanasius College of Engineering, Kothamangalam, Kerala, India

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Abstract – *With the arrival of vector control Induction motors can also be controlled similar to a separately excited DC motor and have replaced DC motors from most of its applications. In this project the implementation of a direct torque control (DTC) strategies to control the operation of induction motor (IM) is implemented. A driver circuit is used to amplify the output control signals generated by the processor. There are two current sensors and two voltage dividers. They are given to the main processor. A speed sensor at the motor shaft feedback the output speed. This output speed is compared to the given reference and the error is calculated. Based on the input parameters, control variables are calculated and based on that appropriate control signals are fed to gate terminals. This approach reduces torque and flux ripples and thus it provides more precise controlling.*

Key Words: Direct Torque Control, Induction Motor, Switching Table, Space Vector and Torque Ripples.

1. INTRODUCTION

Earlier DC motors ruled the industries due to their controllability even though Induction Motors were more efficient and robust than DC motors. But with the advancement in technology, Induction motor control became more and more efficient. Different techniques were employed in order to control Induction motor similar to a separately excited DC motor. Now most of the industries use induction motors in place of DC motors. One of common method for controlling torque is v/f control. With v/f control method the constant torque is generated up to the base speed of the motor and at the base speed the voltage of drive reaches to the maximum value. Beyond base speed the frequency can be varied further to increase the speed of the motor. However, the voltage cannot be increased. Therefore, the flux in the air gap of the motor get reduced and the torque delivery get reduced.

The v/f control cannot avoid ripples in the torque completely because this method doesn't have a direct control over torque. The vector controls are much advanced techniques. Field oriented control(FOC) and Direct torque control(DTC) are two of its kind. Direct torque control is much more advanced than field oriented control. In DTC flux and torque of motor are estimated and compared with the standard reference values and error signals are generated which are fed to torque and flux hysteresis comparators whose output is fed to space vector modulation block and corrective action is taken by proper switching of inverter switches. But the main problem associated with DTC is also the presence of torque and flux ripples.

Here DTC is achieved by means of a selection table, the inputs of which are the torque error, the error in magnitude of the stator flux space vector, and the angle of the stator flux space vector. The outputs of the selection table are the settings for the power switching devices of the inverter. The new control strategies proposed to replace motor linearization and decoupling via coordinate transformation, by torque and flux hysteresis controllers. There is no current controller needed in DTC, because it selects the voltage space vectors according to the errors of flux linkage and torque. The strategy may be applied in induction motor drive systems where highest performance and smooth torque are of paramount importance.

2. LITERATURE REVIEW

John R G Schofield [1] Direct Torque Control (DTC) of an AC motor system. The main difference between Direct Torque Control and the traditional AC drive control methods is that with DTC there is no separate voltage and frequency-controlled PWM modulator. DTC provides only effective torque control and estimates of the motor quantities. Calculations are performed every 25 micro-seconds and these include corrections for temperature and saturation effects. The parameters of the motor model are established by an identification run, which is made during commissioning. A two level hysteresis controller in which the torque and flux references are compared with the actual values calculated by the motor model. The magnitude of the stator flux is normally kept constant and the motor torque is controlled by means of the angle between the stator and rotor flux. Optimal switching logic which translates the controller outputs into the appropriate commands to the power switching devices. There are six voltage vectors and two different kinds of zero-voltage vectors available in the two level voltage source inverter and the optimum switching logic determines the required selection every 25 micro-seconds.

Dr. M G Jayne [2] Direct torque control and a new control strategy based on direct torque control have been considered in this paper. It has been found that the full potential of speed control by means of an inverter is not fully utilized by direct torque control. The new strategy described improves the performance of direct torque control further. However, the new strategy makes the selection of switching states complex, since pre calculated values have to be loaded into the control system. The strategy may be applied in induction motor drive systems where highest performance and smooth torque are of paramount importance.

Yesma Bendaha [3] Direct Torque Control (DTC) is a method, which is used to control the flux and torque of a motor. This method uses a flux and torque estimator and two hysteresis controllers. The major problem that is usually associated with DTC drive is the high torque ripple. The stator resistance is used in the flux and torque estimator. So the stator resistance deviation from its set value, might affect fuzzy-DTC performance especially at low speed. To overcome these problems, this paper presents an improved direct torque control based on fuzzy logic technique, where the torque and flux hysteresis controllers are replaced by fuzzy controllers and we also used a fuzzy stator resistance estimator The fuzzy proposed controller is shown to be able to reducing the torque and flux ripples and to improve performance DTC especially at low speeds.

3. DIRECT TORQUE CONTROL

DTC is a closed loop control in which the speed, currents and voltages are used as feedback. The currents flowing through the motor (Ia; Ib; Ic) and the voltage across the motor terminals (Va; Vb; Vc) are measured using current sensors and potential dividers and fed to the processor(dsPIC). Required speed and actual speed (measured by sensor) are also given to the processor. The processor further uses these values and does the required transformations and calculations and appropriate switching signals are generated. Based on this switching sequences the speed of the induction motor is controlled.

A block schematic representation of the whole control system is shown in Figure-1. This diagram denote the basic blocks associated with this DTC. The different blocks of this diagram are also discussed in the coming sections.

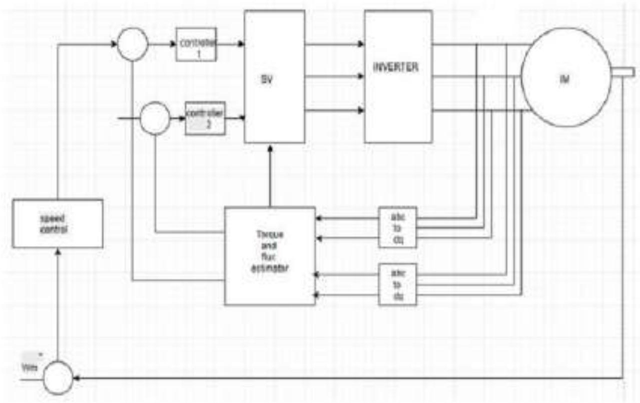


Fig -1: Block Diagram of DTC

3.1 Measurement and transformation block

As mentioned above the measured variables are transformed to dq variables so as to model the induction machine similar to a dc machine. In the processor the clarke and park transformations take place and we get Id; Iq; Vd; Vq. "abc to dq" blocks are used for this transformation. The transformation matrix used for transformation of abc variables to dq variables are shown in the following equitation.

$$i_{\alpha\beta} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix}\begin{bmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{bmatrix} \quad (3.1.1)$$

$$i_{dq0} = \frac{2}{3}\begin{bmatrix} cos\theta & cos(\theta - \frac{2\pi}{3}) & cos(\theta + \frac{2\pi}{3}) \\ sin\theta & sin(\theta - \frac{2\pi}{3}) & sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (3.1.2)$$

3.2 Torque and flux estimator

Using these values, the torque, flux and theta are calculated and then compared with the reference values and error signals are generated. The following equations are used for the calculation of torque and stator flux. The main blocks being the "Measurement and transformation block", "Torque and Flux estimator block" and "Switching Table block".

Torque, $T_e = 0.75(\varphi_{sd}*isq - \varphi_{sq}*i_{sd})$ (3.2.1)

Stator Flux, $|\varphi_x| = (\varphi^2_{sd} + \varphi^2_{sq})^{0.5}$ (3.2.2)

$\varphi_{sd} = \int(V_{sd} - R_s*i_{sd})dt$ (3.2.3)

$\varphi_{sq} = \int(V_{sq} - R_s*i_{sq})dt$ (3.2.3)

3.3 Space vector switching block

The torque and flux error signals are passed to two hysteresis controllers which checks for the error tolerance. Based on the error magnitude hysteresis controller generates binary output.

Table -1: Switching Table

Torque	Flux	S1	S2	S3	S4	S5	S6
T=0	F=0	V5	V6	V1	V2	V3	V4
T=0	F=1	V6	V1	V2	V3	V4	V5
T=1	F=0	V3	V4	V5	V6	V1	V2
T=1	F=1	V2	V3	V4	V5	V6	V1

Using the hysteresis controller outputs and also the value of theta appropriate switching sequence is selected and implemented in the inverter switches based on the switching Table-1. The space vector diagram of 3 phase inverter is shown below.

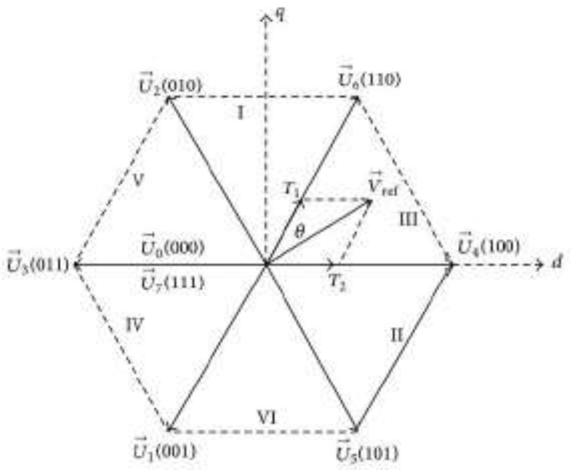
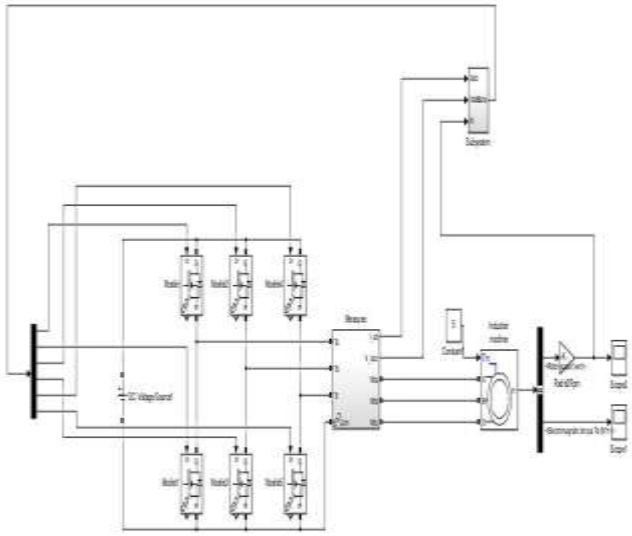


Fig -2: Space Vector Diagram of Three Phase Inverter

4. Simulation of Direct Torque Control

The simulation of direct torque control was done using Matlab Simulink. Figure 3 shows the Simulink model of DTC. The measurement blocks of all currents and voltages are made into a single subsystem.



. **Fig -3**: Simulink Model of DTC

Coordinate transformations, torque and flux estimation, and other calculations and error checking along with generation of switching pulses are made into another subset.

4.1 Simulation Results

Figure 4 shows the Speed Vs Time graph. The reference speed was set to 1000 rpm and it is seen from the graph that the speed has a smooth increase and reaches the set value of 1000 rpm.

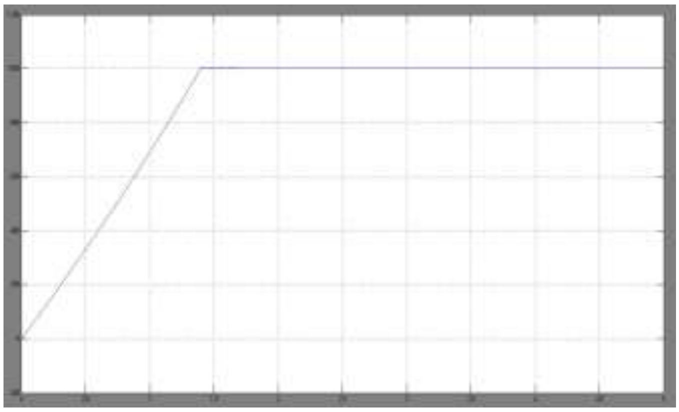


Fig -4: Speed Vs Time Graph

Figure 7.3 shows the Torque Vs Time graph. It can be seen that it has high starting torque and by the time speed reaches a steady value, torque also settles to a steady value.

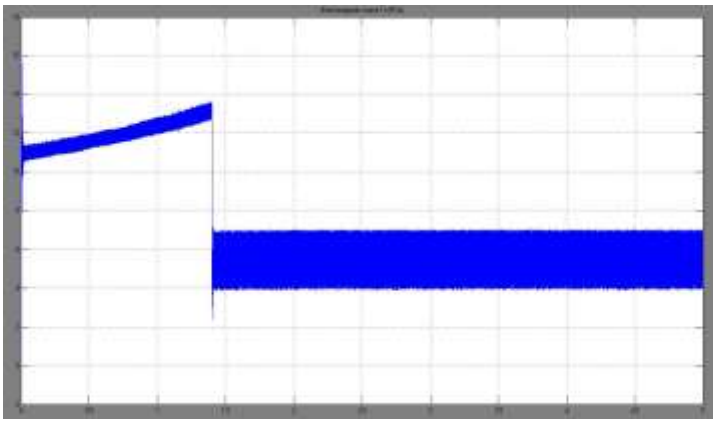


Fig -5: Torque Vs Time Graph

Ripples are present in direct torque control as well but when compared to other older techniques like FOC, it is much more improved. Further improvements may be brought in by using advanced techniques like artificial intelligence or fuzzy logic

3. CONCLUSION

This paper proposes an advanced control strategy for Induction motor using Direct Torque Control techniques. DTC has proved to be a better control method than the traditional methods and also better than Field Oriented Control Strategy(FOC). The improved DTC directly controls the stator flux linkage and electromagnetic torque of machine simultaneously by the selection of optimum inverter switching modes. The use of a switching table for voltage vector selection provides fast responses.SV-DTC is a technique to reduce the ripples.

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