ISSN: 2348 9510
International Journal Of Core Engineering & Management (IJCEM)
Volume 2, Issue 3, June 2015

A Review on Direct Torque Control of Induction Motor

[1]kranti Bhokare, [2]Nishant Yewale, [3]Shital Jamunkar

[1]Department of Instrumentation Engg., Gondwana university, GCOE Chandrapur.
Chandrapur, Maharashtra, 442403, India.
kranti3@rediffmail.com

[2]Department of Instrumentation Engg., Gondwana university, GCOE Chandrapur.
Chandrapur, Maharashtra, 442403, India.
nishantyewale78@gmail.com

[3]Department of Mechanical Engg., Gondwana university, GCOE Chandrapur.
Chandrapur, Maharashtra, 442403, India.
jamunkar09@gmail.com

Abstract

The aim of this paper is to review the origin and developments of Direct Torque Control (DTC), an advanced control technique of induction motor drives yielding superior performance. The direct torque control is one of the excellent control strategies available for torque control of induction machine. It is considered as an alternative to Field Oriented Control (FOC) technique. The DTC is characterized by the absence of PI regulators, co-ordinate transformations, current regulators and pulse width modulated signal generators. DTC also allows a good torque control in steady state and transient operating conditions. The purpose of this study is to control the speed of 3-Phase Induction Motor with fuzzy logic controller. The fuzzy logic controller will be designed and must be tuned. This is about introducing the new ability of in estimating speed and controlling the 3- phase Induction Motor. In this paper, a study of fuzzy logic controller is used to control the speed of 3-Phase Induction Motor. Direct Torque Control (DTC) is one of the latest techniques to control the speed of motor.

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Keywords*: Direct torque control, induction motor, fuzzy logic controller, Fuzzy Logic, Space Vector Modulation, Induction Motor Control*

I. Introduction

Induction motor derives are controlled by Field Oriented Control in high performance industrial applications. Induction motor is either wound type squirrel-cage type Induction motors are widely used in many residential, commercial, industrial and utility applications. This is because the motor have low manufacturing cost, wide speed range, high efficiency and robustness. But they require much more complex methods of control, more expensive and higher rated power converters than DC and permanent magnet machines. Previously, the variable speed drives had various limitations such as poor efficiencies, larger space, low speed etc. The power electronics transformed the variable speed drive into a smaller size, high efficiency and high reliability.

The development of speed control system using frequency control has been designed by combinations of PWM control circuit, driver circuit and H-bridge inverter which makes the system simple, robust and compact open loop PWM controller circuit to control single phase induction motor and single phase induction motor can be driven to variable speed and frequency. But it is desirable to replace the single phase induction motor drives by three phase induction motor drives in residential appliances, farming and low power industrial applications. Induction motors have performed the main part of many speed control systems and found usage in several industrial applications.

The main thing to be understood here is why Induction motors are used in every section or for every action. There are few advantages of using Induction motors which are not provided by any other motor. Some of these advantages of Induction motors are

- Cheap: This is the most important thing in current age of competition. Induction machines are very cheap when compared to synchronous and DC machines. It make them first choice for any operation.
- Robust: induction machines are robust in construction. It is another advantage of using Induction Machine.
- Efficient and Reliable: Induction machines are no doubt very reliable machines and have considerable efficiency.
- Low Maintenance Cost: As construction of induction machine is very simple and hence maintenance is also easy resulting in small maintenance cost.

- High Starting Torque: Starting torque on induction motor is high which make is useful for operations where load is applied before the starting of the motor.

Three phase induction motor is widely used in industrial drive because they are reliable and rugged. Single phase induction motors are widely used for heavier loads for example in fans in household appliances. The fix speed service, induction motors are being increased with variable frequency drives. Induction motor achieves a quick torque response, and has been applied in various industrial applications instead of dc motors. It permits independent control of the torque and flux by decoupling the stator current into two orthogonal components FOC, however, is very sensitive to flux, which is mainly affected by parameter variations. It depends on accurate parameter identification to achieve the expected performance. During the last decade a new control method called DTC (Direct Torque Control) has been developed for electrical machines. The main advantages of DTC are absence of coordinate transformation and current regulator; absence of separate voltage modulation block, Common disadvantages of conventional DTC are high torque ripple and slow transient response to the step changes in torque during start-up.

II. Background and Prior Work

As far as control of 3-phase Induction motor is concerned, the problem arises with it are efficiency, fluctuations in the speed and torque characteristics and losses during its variable speed operation with the existing control efficiently on a job, it must have some special controller with it. Thus, the fuzzy logic controller will be used in the direct torque control technique. In recent years, an advanced control method called direct torque control has gained importance owing to its capability to produce fast torque control of induction motor. Although in these systems such variables as torque, flux modulus and flux sector are required, resulting DTC structure is particularly simplistic. Conventional DTC does not require any mechanical sensor or current regulator and coordinate transformation is not present, thus reducing the complexity. Fast and good dynamic performances and robustness has made DTC popular and is now used widely in all industrial applications.

Despite these advantages it has some disadvantages such as high torque ripple and slow transient response to step changes during start up. The major problem in a DTC-based motor drive is the presence of ripples in the motor-developed torque and stator flux. Generally, there are two main techniques to reduce the torque ripples. The first one is to use a multilevel inverter which will provide the more precise control of motor torque and flux. However, the cost and complexity of the controller increase proportionally. The other method is space vector modulation. Its drawback is that the switching frequency still changes continuously. Advantages of intelligent controllers such as fuzzy logic, neural network, neuro-fuzzy, etc. are well known as their designs do not depend on accurate mathematical model of the system and they can handle non-linearity of arbitrary complexity. Among different intelligent algorithms, fuzzy logic is the simplest, which does not require intensive mathematical analysis.

III. Control Technique

- **Principle of Direct Torque Control Method (DTC)**

The name direct torque control is derived from the fact that on the basis of the errors between the reference and the 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 limits. Direct torque control is a strategy research for induction motor speed adjustment feeding by variable frequency converter. It controls torque on the base of keeping the flux value invariable by choosing voltage space vector. Electromagnetic torque in 3-phase Induction Motor can be

Expressed as:

$$Te = (3/2)\, P\, |\Psi s| * |is| \sin(\alpha s - \rho s)$$

Ψs = stator flux

ρs = stator flux angle

If stator flux modulus is kept constant and its angle is changed quickly, then electromagnetic torque is directly controlled.

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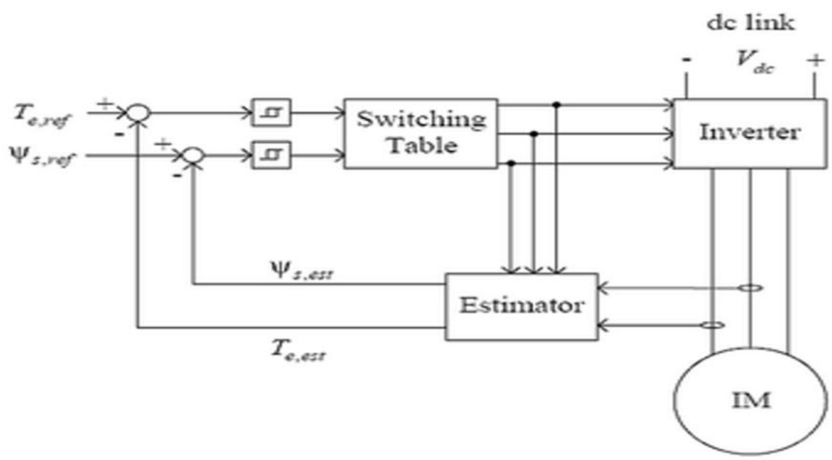

Figure 1: Direct Torque Controller Schematic

There are two different loops corresponding to the magnitudes of stator flux and torque. The reference values of stator flux modulus and torque are compared to their actual values. The resulting errors are fed to the input of look up table. The DTC require stator flux and torque estimations which can be performed as proposed in previous figure, by mean of two different phase currents and state of inverter.

The basic principle of DTC is to directly manipulate the stator flux vector such that the desired torque is produced. This is achieved by choosing an inverter switch combination that drives the stator flux vector by directly applying the appropriate voltages to the motor windings.

- **Space Vector Modulation**

The way to impose the required stator flux is by means of choosing correct inverter state. The position of stator flux is divided into six different sectors**.** Decoupled control of stator flux modulus and torque is achieved by acting on the radial or tangential components respectively of the stator flux linkage space vector in its locus. These two components are directly proportional to the components of the same voltage space vector in the same direction. Below fig, shows the possible dynamic locus of the stator flux and its different variations depending on the VSI states chosen.[5]The possible global locus is divided into six different sectors signaled by is continuous line. VSI can assume only 8 distinct states. Six out of 8 states produce a non – zero output and are known as non-zero switching states, remaining two produce zero output. There are six vectors numbered from V1 to V6. Thus there are six sectors numbered from 1-6

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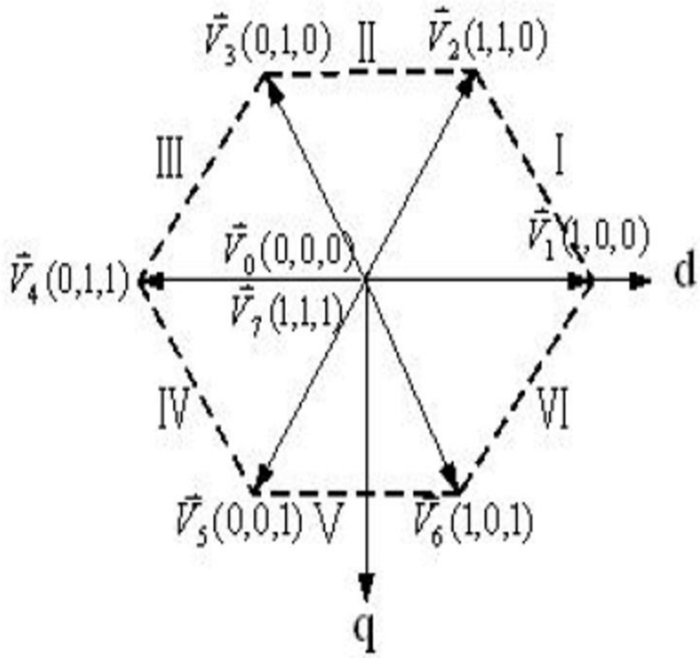

FIGURE2: The diagram of voltage space vector which is Exported by inverter

Basic Principle: "- and "+"signals are delivered to two hysteresis comparators. The corresponding digitized output variables: change of magnetic flux -, of mechanical torque _+ and the stator flux position sector Sn created a digital word, which selects the appropriate voltage vector from the switching table[4]. The selection table generates pulses Sa, Sb, Sc 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_) of _s , appropriate voltage vectors for both the inverters are selected from a switching table as it is shown in Table1.

Table 1. Classical DTC switching table

Flux	Torque	Sector S_ϕ					
Δ_ϕ	Δ_{Γ_e}	$S_{\phi 1}$	$S_{\phi 2}$	$S_{\phi 3}$	$S_{\phi 4}$	$S_{\phi 5}$	$S_{\phi 6}$
1	1	V_2	V_3	V_4	V_5	V_6	V_1
1	0	V_7	V_0	V_7	V_0	V_7	V_0
1	-1	V_3	V_1	V_2	V_3	V_4	V_5
-1	1	V_3	V_4	V_5	V_6	V_1	V_2
-1	0	V_0	V_7	V_0	V_7	V_0	V_7
-1	-1	V_5	V_6	V_1	V_2	V_3	V_4

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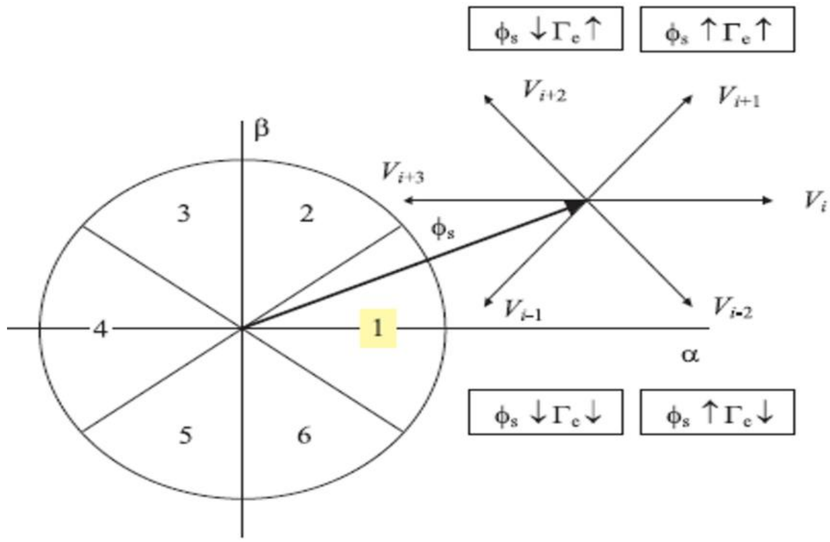

Figure3: Stator Flux Variations

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 behavior is mainly due to the absence of information about torque and rotor speed values in the voltage selection algorithm.

- **Fuzzy Logic Based System**

Conventional DTC of IM drive has the limitations of constant duty ratio for every switching period and high torque ripples. These problems are rectified using fuzzy logic control technique. In it is presented that the implementation of fuzzy logic and neural network reduce the stator flux and torque ripples. A new algorithm for optimized value of stator flux based on the maximum reference value of electromagnetic torque is proposed to operate in conjunction with duty ratio control. Figure 5 shows the proposed DTC with duty ratio controller. To make the torque and duty ratio variations smaller, the universe of discourse of torque error and duty ratio are divided into five overlapping fuzzy sets. However, to reduce the complexity of design, the stator flux position is defined with three overlapping fuzzy sets only. The universe of discourse of all the variables, covering the whole region is expressed in per unit values.

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Table 2: Rule table of fuzzy logic controller

Rules		Flux			
		BD	SD	SI	BI
Torque	BD	-135	-105	-75	-45
	SD	-165	-135	-45	-15
	0	0	0	0	0
	SI	165	135	45	15
	BI	135	105	75	45

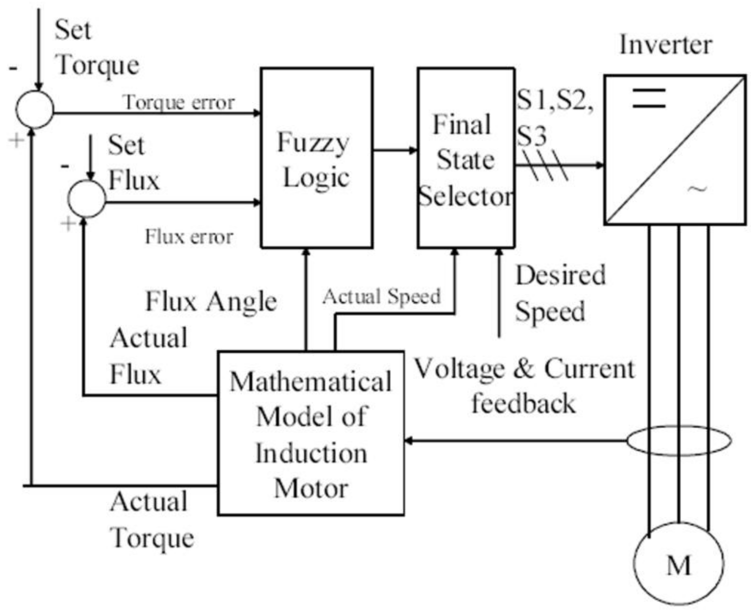
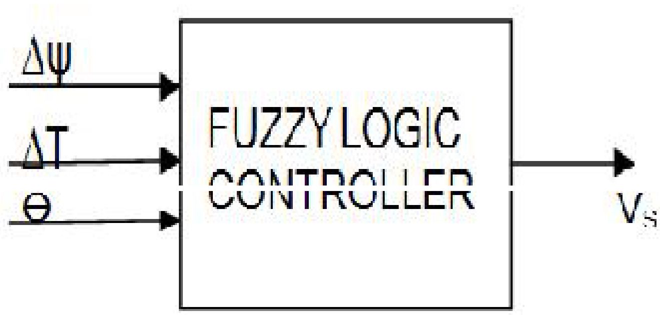


Figure 4: Block Diagram of Direct Torque Control of Induction Motor Using Fuzzy Logic Controllers

Principle of fuzzy direct torque control

The fuzzy logic system involves three steps fuzzification, application of fuzzy rules and decision making and defuzzification.Fuzzification involves mapping input crisp values to Fuzzy variables. Fuzzy inference consists of fuzzy rules and decision is made based on these fuzzy rules (Guohanin and Xu, 2010). These fuzzy rules are applied to the fuzzified input values and Fuzzy outputs are calculated. In the last step, a defuzzifier converts the fuzzy outputs back to the crisp values. The fuzzy controller is designed to have three fuzzy input variables and one output variable for applying the fuzzy control to direct torque control of induction motor, there are three variable input fuzzy logic variables-the stator flux error, electromagnetic torque error, and angle of flux stator(Jose *et al*., 2011) (Fig. 3)



.Fig.5. Fuzzy logic controller.

The membership functions of these fuzzy sets are triangular with two membership function N, P for the flux-error, three membership functions N, Z, P for the torque-error, six membership variables for the stator flux position sector and eight membership functions for the output commanding the inverter (Jalluri and Ram, 2012).The inference system contains thirty six fuzzy rules which are framed in order to reduce the torque and flux ripples. Each rule takes three inputs, and produces one output, which is a voltage vector. Each voltage vector corresponds to a switching state of the inverter. The switching state decides the pulse to be applied to the inverter. Depending on the values of flux error, torque error and stator flux position the output voltage vector is chosen based on the fuzzy rules (Jose *et al.*, 2011). Using fuzzy logic controller the voltage vector is selected such that the amplitude and flux linkage angle is controlled. Since the torque depends on the flux linkage angle the torque can be controlled and hence the torque error is very much reduced.

IV. Future Scope of Study

The work can be extended to use the fuzzy logic, artificial neural network in place of PI regulator used in the speed controller. It can also be practically implemented using the high end microprocessors designed by various chip designing companies. It can also be further extended to other types of motors used for the control purposes. The work can be made more effective and dynamic by the use of proper training methodology for the neurons, taking optimum number of neurons. A lot work can be done on the practical feasibility of the work. The research investigated the applications of advanced signal processing techniques and Artificial Neural Networks DTC operation of induction motor. The research work helps in understanding the applications and limitations of DTC techniques. It is observed that MATLAB is user friendly software and may be helpful in creating models on and off line. It also saves computational time of diagnosis. The DTC with Fuzzy logic controller proposed in this work are able to control motor more sensitively and more reliably. The work can also be extended by various ways and add-on.

V. Conclusion

This paper reviewed the origin and development of advanced control technique called direct torque control and its superior performance on induction motor drive. First the basic principle of DTC and FOC are carefully reviewed and compared. Then the problems associated with DTC. Further, implementation of intelligent control techniques such as fuzzy logic on DTC are reviewed and the improvements are systematically analyzed. It has been concluded that the implementation of intelligent techniques reduced the stator flux and torque ripples and therefore the dynamic performance of the drives are improved.

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About the authors

Kranti s. Bhokare, received B.E. Instrumentation degree from Govrnment college of engineering Chandrapur working as Asst. Professor in Instrumentation department.Life member of ISTE,IE, ISOI and IETE

Nishant m Yewale received B.E. Instrumentation degree from Govrnment college of engineering Chandrapur working as Asst. Professor in Instrumentation department.Life member of ISTE,IE, and ISOI

Shital. C Jamunkar received B.E. Mechanical degree from Bapurao Deshmukha college of engineering Wardha working as Asst. Professor in Mechanical department.
Life member of ISTE