DIRECT TORQUE CONTROL OF INDUCTION MOTOR USING ARTIFICIAL NEURAL NETWORK

MS.P. JENITHA DEEPA M.E
Assistant Professor, department of EEE
Saranathan College of Engineering
Trichy, India
jenithadeepa@gmail.com

ANU THILAK.S
B.E, Department of EEE
Saranathan College of Engineering
Trichy, India
reachhanuthilak@gmail.com

HEMAMALINI.N
B.E, Department of EEE
Saranathan College of Engineering
Trichy, India
hemamalini266@gmail.com

MANOCHITHRA.K
B.E, Department of EEE
Saranathan College of Engineering
Trichy, India
manochithra47@gmail.com

Abstract--- Direct torque control (DTC) is one of the most excellent control strategies of torque control in induction machine. It is considered as an alternative to the field oriented control (FOC) or vector control technique. These two control strategies are different on the operation principle but their objectives are the same. They aim to control effectively the torque and flux. This paper presents simple structured Artificial Neural Networks(ANN)for torque estimation of induction motor using direct torque control (DTC) method. The performance evaluation of conventional torque estimator, based DTC scheme is compared with the proposed scheme and the results are validated through simulation.

***Index Terms*—Direct torque control(DTC), Induction motor Drive, ANN, MATLAB/ Simulink, Performance Evaluation.**

I. INTRODUCTION

FOR many years, induction machine have provide to be 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 [4]. They are also robust and immune to heavy loading. Basically, there are two types of instantaneous electromagnetic torque-controlled AC drives used for high performance applications which are:

- **Field Oriented Control (FOC):** based on stator current control in the field rotating reference using PWM inverter control.
- **Direct Torque Control (DTC):** based on stator flux control in the stator fixed reference frame using direct control of the inverter switching [1].

In 1970s, FOC scheme proved success for torque and speed control of induction motor [7]. Decoupling of two components of stator currents (flux and torque producing components) is achieved as DC machines to provide independent torque control. Hence the scheme proves itself superior to the DC machine [2].

The problem faced by FOC scheme is complexity in its implementation due to dependence of machine parameters, reference frame transformation. Above method requires high cost PC or DSP to perform online computations.

DTC was introduced in 1980s. This method requires only the stator resistance to estimate the stator flux and torque. Reference frame transformation is not necessary as in FOC scheme. It is less sensitive to parameter variation.

Its main features are as follows:

1/ Direct control of flux and torque.
2/ Indirect control of stator currents and voltages
3/ Approximately sinusoidal stator fluxes and stator currents.

This method presents the following advantages:

1/ Absence of co-ordinate transform.
2/ Absence of voltage modulator block, as well as other controllers such as PID for motor flux and torque.
3/ Minimal torque response time, even better than the vector controllers.

Although, some disadvantages are also present:
validated through simulation.

1/ Possible problems during starting.
2/ Requirement of torque and flux estimators, implying the consequent parameters identification.
3/ Inherent torque and flux ripple.

The idea of torque control in DTC or Direct Self Control scheme is to [4,8] increase the torque angle (angle between stator flux and rotor flux) in case torque output needs to be increased. The reverse is performed to decrease the torque. But the stator linked flux is kept intact at the desired magnitude. The change in the torque angle is performed by acceleration or deceleration of the angular speed of the stator linked flux vector, by application of the suitable voltage vector using voltage source inverter. The flux linking to rotor changes simultaneously with the change in stator flux. Thus the torque angle can be increased or decreased with acceleration and deceleration of the rotating stator linked flux vector. So control is achieved over the torque developed by motor. In DTC scheme [9,10] stator side two-phase stationary d-q components of voltages, currents are sensed and motor torque, stator linked flux are estimated. Based on the resultant flux position and the errors in flux magnitude and torque, a three-dimensional look up table is referred to decide the inverter switching. The process is implemented through MATLAB/Simulink.

The ANNs are capable of learning the desired mapping between the inputs and outputs signals of the system without knowing the exact mathematical model of the system. Since the ANNs do not use the mathematical model of the system, the same. ANNs are excellent estimators in nonlinear systems [12,13]. In this paper, neural network based torque estimation is proposed to reduce the torque ripple.

II. DTC DEVELOPMENT PRINCIPLE

The control of torque developed by an inverter fed induction machine is carried out by hysteresis control of stator flux magnitude, and torque magnitude that selects one of the six non-zero and two zero inverter voltage vectors shown in Fig. 1. The selection is made in order to maintain torque and flux error inside the hysteresis band in which the errors are indicated by ΔT_e and $\Delta\Psi_s$ respectively.

$$\Delta Te = Te(ref) - Te \quad (1)$$
$$\Delta\psi s = \psi s(ref) - \psi s \quad (2)$$

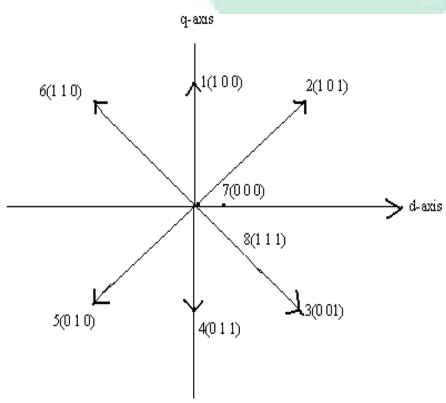

Fig. 1. The inverter output voltages corresponding to switching states

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Basically in DTC scheme stator side 2-phase d-q components of voltages and currents are sensed. Then the resultant emfs are integrated to get the flux components Ψ_{ds} and Ψ_{qs} in d-q axis. These flux components are calculated by means of equation (3) & (4)

$$\psi ds = \int Vds - ids\ Rs\ dt \quad (3)$$
$$\psi qs = \int Vqs - iqs\ Rs\ dt \quad (4)$$

The developed torque of the motor is computed from these d-q axis flux and current components.

The torque component is calculated by means of equation (5)

$$T_e=3/2*p/2(\psi ds*iqs-\psi qs*ids) \quad (5)$$

It is compared with its reference value to get the torque error logic state (S_T). Similarly, the absolute flux (resultant of d-q axis flux) is compared with the reference flux to get the flux error logic state(S_Ψ).

The flux angle θ_{fs} is calculated by means of equation (6).

$$\theta_{fs}=\tan^{-1}(\psi qs/\psi ds) \quad (6)$$

The air gap space plane is divided into six sectors, each spread with 60^0. It is shown in fig (2). The sector or instantaneous angular position of the stator flux in space (S_θ) is determined as in Table I. The three logic states through DTC switching table select the instantaneous switching voltage vector which is shown in Table II.

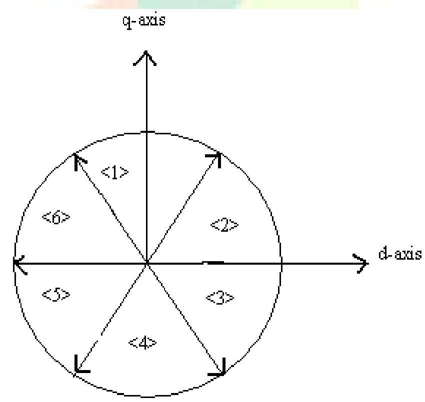


Fig. 2. Stator flux switching sector

TABLE-1

FLUX-PHASOR SEXTANT LOGIC(S_Θ)

Θ_{FS}	Sextant
$0<\theta_{fs}<\pi/3$	<2>
$-\pi/3<\theta_{fs}<0$	<3>
$-2\pi/3<\theta_{fs}<-\pi/3$	<4>
$-\pi<\theta_{fs}<-2\pi/3$	<5>
	<6>
$2\pi/3<\theta_{fs}<\pi$	
$\pi/3<\theta_{fs}<\pi/3$	<1>

TABLE-2

DTC SWITCHING TABLE

S_Ψ	S_T	Sθ					
		<1>	<2>	<3>	<4>	<5>	<6>
1	1	110	100	101	001	011	010
1	0	111	000	111	000	111	000
1	-1	101	001	011	010	110	100
0	1	010	110	100	101	001	011
0	0	000	111	000	111	000	111
0	-1	001	011	010	110	100	101

III.ARTIFICIAL NEURAL NETWORK BASED TORQUE ESTIMATION:

ANN has a very significant role in the field of artificial intelligence. The artificial neurons learn from the data fed to them and keep on decreasing the error during training time and once trained properly, their results are very much same to the results required from them, thus referred to as universal approximates [14]. The most popular neural network used by researchers are the multilayer feed forward neural network trained by the back propagation algorithm [15]. There are different kinds of neural networks classified according to operations they perform or the way of interconnection of neurons. Some approaches use neural networks for parameters estimation of electrical machines in feedback control of their speeds [16, 17]. Here we have used a feed forward neural network to estimate the torque. For this purpose, the following network were used.
The neural network is used to estimate the torque of Induction Motor. It is a one input-one output feed forward network with three layers. The input layer 60 neurons of hyperbolic tangent sigmoid function, hidden layer 10 neurons of hyperbolic tangent sigmoid function, output layer is of linear transfer function. Feedforward networks is used neural network as shown in fig (3) and often have one or more hidden layers of sigmoid neurons followed by an output layer of linear neurons. Multiple layers of neurons with nonlinear transfer functions allow the network to learn nonlinear and linear relationships between input and output vectors.

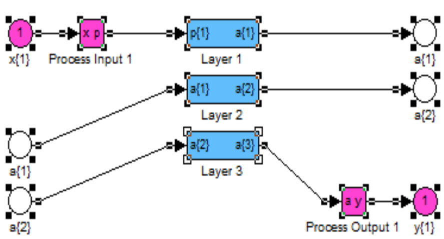


Fig 3: neural network in-build model

As noted in Neuron Model and Network Architectures, for multiple-layer networks the number of layers determines the superscript on the weight matrices. The appropriate notation is used in the two-layer `tansig`/`purelin` network shown next. This network can be used as a general function approximator. It can approximate any function with a finite number of discontinuities arbitrarily well, given sufficient neurons in the hidden layer.

IV.SIMULATION RESULT OF DTC SCHEME:

To study the performance of the developed DTC model, a closed loop torque control of the drive is simulated using Mat lab/Simulink simulation package. The torque error and flux errors are compared in their respective defined hysteresis band to generate the respective logic states as S_T and S_Ψ. The sector determination logic state S_θ is used as the third controlling signal for referring the DTC switching table. These three controlling signals are used to determine the instantaneous inverter switching voltage vector from three-dimensional DTC switching lookup table. The simulation results are compared for conventional DTC scheme and proposed ANN based DTC scheme.
First the conventional DTC scheme is applied to the induction motor to check the performance under no load and then full load [18]

The main observations of the simulation of C-DTC at fig (6) outcomes can be summarized as follows:

-High accuracy of the DTC model has been proved for the stator flux. However, any small variation in the stator flux will cause a massive starting up stator current.
- Effectiveness of the DTC model has been demonstrated for the electromagnetic torque control with small inaccuracy
- The independent control of torque and stator flux has been confirmed for the proposed model.
- Complexity in starting up current control and need of variable switching frequency as well as the need of flux and speed estimation are main drawbacks of the DTC scheme.

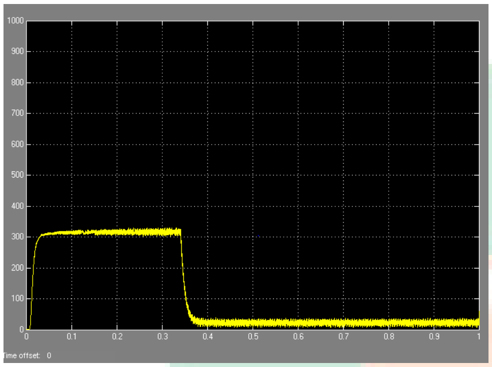
A. C-DTC- Start up with No Load:

The equation of torque for no load running with single inertia and negligible friction is shown below:

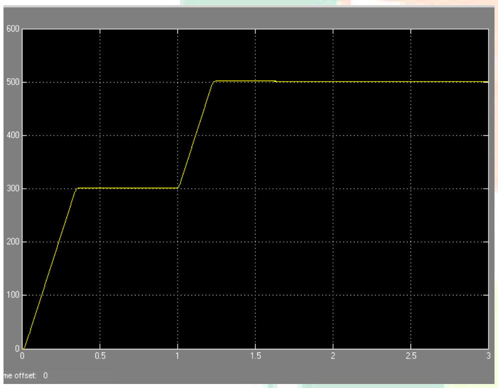
$T_e=J*(d_{wr}/dt)$ (7)

B.C-DTC-Dynamic Behavior:

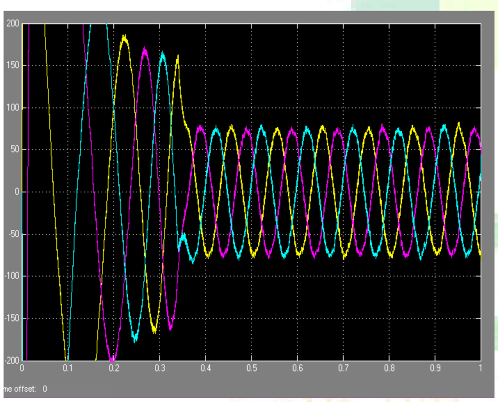
The transient performance of the developed DTC model has been tested by applying a step load torque command from initial value 20 to final value 1Nm and the step time given to induction motor is 10 on the mechanical dynamics. As seen in the figure 4(a-c) estimated electromagnetic torque shows a good response. This demonstrates that the developed DTC achieved high dynamic performance in response to changes in demand torque. However, there are some performance degradation with torque overshoot in the torque transient owing to the hysteresis controllers used.



(a)Electromagnetic torque



(b)Rotor speed



(c)Stator current

Fig 4: (a-c) C-DTC behavior start up with load.

C.DTC using ANN:

The block diagram of ANN-DTC Simulink model is shown in Fig (5). The results for ANN based DTC scheme under the same loading conditions, as in the case of conventional scheme are presented in fig 6, shows the rotor flux, stator current, stator flux, torque, speed with no load and with respect to this machine measurement the desired output is connect to the scope of Fig:3 Simulink diagram representing a ANN- DTC induction motor drive.

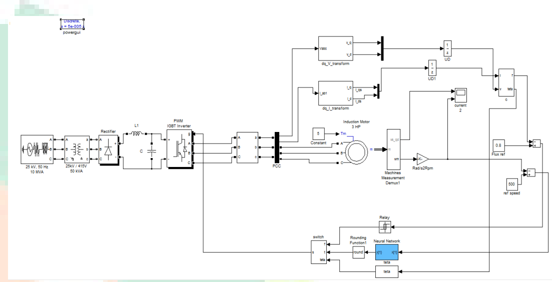


Fig:5 Simulink diagram representing a ANN- DTC induction motor drive

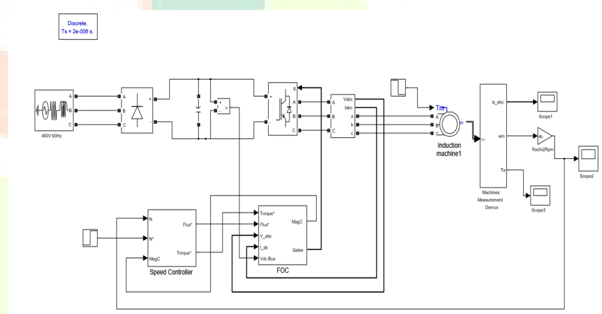


Fig :6 Simulink diagram representing a conventional DTC induction motor

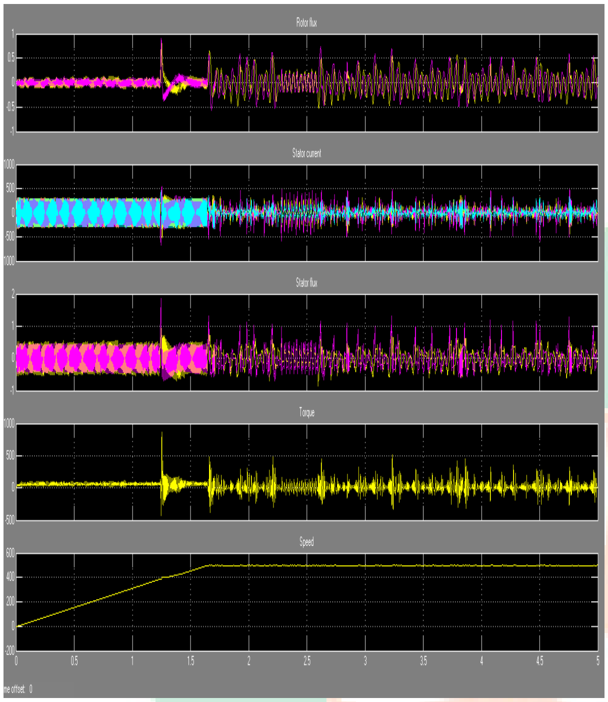


Fig 7: a) rotor flux b) stator current c) stator flux d) torque e) speed in ANN-DTC behaviour during start up with no load

Fig 8: a) stator current b) speed in ANN-DTC behaviour during start up with load

CONCLUSION:

The simulation is done by using 3HP induction motor in MATLAB. In this paper the ANN based torque estimation has been proposed for DTC of induction motor drive. The proposed scheme performance is compared with the conventional DTC scheme under the steady state and dynamic conditions. The simulation study shows satisfactory results of the ANN based DTC than conventional DTC.The ANN is also used for sector selection and the switching voltage vector selection.

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