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AIDTC Techniques for Induction Motors

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Abstract: Artificial intelligent systems are widely used in control applications. The proposed techniques controller of Induction Motor are used to reduce torque and flux ripples producing by the hysteresis comparators in the conventional DTC at very low speed. In addition the proposed speed controllers are presented in this paper to guarantee that the motor speed converges very well to the desired speed. The simulation results confirm the validity of the proposed techniques.

Keywords: *ANN; DTC; fuzzy logic; PI; IM; speed controller.*

Mathematics Subject Classification (2010): 03B52, 93C42, 94D05.

1 Introduction

Induction motors have been widely applied in industry because of the advantages of simple construction, ruggedness, reliability, low cost, and minimum maintenance. The recent challenge is to apply induction motors to precision servo machines such as robots and NC machines. The problem arises from the load variation during the motion of the motor [3]. The apparition of the field oriented control (FOC) made induction machine drives a major candidate in high performance motion control applications. However, the complexity of field oriented algorithms led to the development in recent years of many studies to find out different solutions for the induction motor control having the features of precise and quick torque response [4]. Direct torque control (DTC) of induction machines (IM) is a powerful control method for motor drives. Featuring a direct control of the stator flux and torque instead of the conventional current control technique, it

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provides a systematic solution to improve operating characteristics of the motor and the voltage inverter source [1, 5]. It has emerged over the last decade to become 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 [6]. In addition, direct torque control minimizes the use of machine parameters, so it is very little sensible to the parameters variation [7]. Several solutions with modified DTC are presented in the literature. Due to its simple structure, DTC can be easily integrated with an artificial intelligence control strategy [8]. The fuzzy logic solution of flux and torque control is given in [9, 13] During years, many solutions have focused to reduce high level of torque and flux ripples producing by the hysteresis comparators in the traditional DTC. Both open and closed loop speed and position estimators are widely used in literature [8]. This paper investigates the control by neural network and fuzzy logic in order to reduce torque ripples and to compare the traditional DTC with DTC based on Artificial Intelligent systems (DTAIC) with and without speed regulation.

2 Direct Torque Control Strategy

Direct torque control (DTC) of induction motors has aroused significant interest among researchers looking for an efficient and high performance ac motor drive [10].

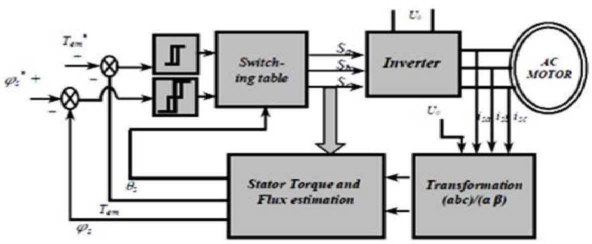

Figure 1: Schematic diagram of CDTC strategy.

The scheme of the classical DTC (Figure 1) consists of two hysteresis controllers. Stator flux controller defines the time duration of the active voltage vectors, which moves the stator flux along the reference trajectory, and torque controller determinates the time duration of the inverter zero states, which keep the motor torque in the defined range by hysteresis value tolerance band. Finally, in every sampling time the voltage vector selection block defines the inverter switching state ($S_A,\ S_B,\ S_C$), which reduces the instantaneous flux and torque errors.

3 Estimated Torque and Flux

In the DTC, the stator flux vector is estimated by taking the integral of difference between the input voltage and the voltage drop across the stator resistance given by [11].

The component α and β of vector φ_s can be obtained:

$$\varphi_{s\alpha} = \int_0^t (V_{s\alpha} - Ri_{s\alpha})\, dt, \quad \varphi_{s\beta} = \int_0^t (V_{s\beta} - Ri_{s\beta})\, dt. \tag{1}$$

Stator flux amplitude and phase angle are calculated in expression (2):

$$\varphi_s = \sqrt{\varphi_{s\alpha}^2 + \varphi_{s\beta}^2} \arg \varphi_s = \arctan\left(\frac{\varphi_{s\beta}}{\varphi_{s\alpha}}\right). \tag{2}$$

Once the two components of flux are obtained, the electromagnetic torque can be estimated from the relationship cited below:

$$T_e = \frac{3}{2} p(\varphi_{s\alpha} i_{s\beta} - \varphi_{s\beta} i_{s\alpha}). \tag{3}$$

4 Proposed DTAIC

To resolve torque ripple problem, this paper propose a direct torque control based on artificial intelligent of induction motor to replace the hysteresis comparators and switching table in open loop and artificial intelligent speed controller to replace the PI controller in closed loop as shown Figure 2.

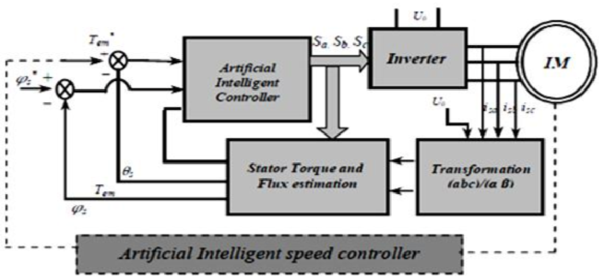

Figure 2: Schematic diagram of DTC-PMSM control.

The proposed IA has three inputs:

1. ***Flux linkage errors:*** The error of flux linkage E_φ is related value of stator's flux φ_s^* and real value of stator's φ_s,

$$E_{\varphi_s} = \varphi_s^* - \varphi_s. \tag{4}$$

2. ***Electromagnetic torque errors:*** Error of torque E_{Te} is related to desired torque value T_e^* and real torque value T_e,

$$E_{Te} = T_e^* - T_e. \tag{5}$$

3. ***Angle of flux linkage θs:*** The angle of flux linkage θ_s is an angle between stator's flux Φs and a reference axis is defined by the equation

$$\theta_s = \arctan\left(\frac{\varphi_{s\beta}}{\varphi_{s\alpha}}\right). \tag{6}$$

The output is: 1. The Boolean switching controls (***Sa, Sb, Sc***).

So we have three controllers based on artificial intelligent as fuzzy, neural fuzzy and neural networks.

4.1 Fuzzy controller

Fuzzy control is a way for controlling a system without the need of knowing the plant mathematic model. It uses the experience of people's knowledge to form its control rule base [12]. The fuzzy logic controller is comprised of fuzzification part, fuzzy inference part and defuzzification part [13].

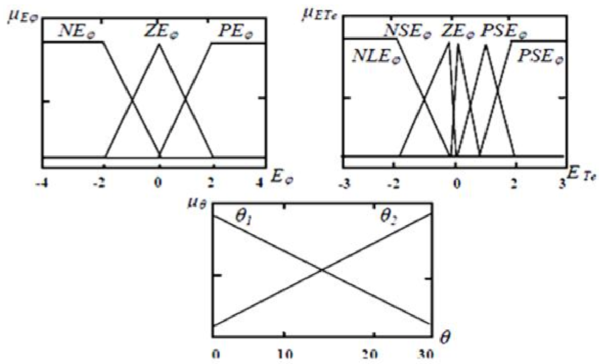

Figure 3: Membership distribution of fuzzy variable.

Fuzzification: The fuzzification is the process of a mapping from measured or estimated input to corresponding fuzzy set in the universe of discourse as shown in Figure 3.

Fuzzy inference: The fuzzy reasoning used is Mamdani's method. The fuzzy control rule-base is shown in Table I.

Deffuzification: The Mamdani's minimum operation rule is used as the interface method and, the output obtained by the center of gravity method used for defuzzification.

	P	*Z*	*N*			*P*	*Z*	*N*
PL	*V1*	*V2*	*V2*		*PL*	*V1*	*V1*	*V2*
PS	*V1*	*V2*	*V3*		*PS*	*V1*	*V2*	*V2*
ZE	-	-	-		*ZE*	-	-	-
NS	*V6*	-	*V4*		*NS* *NL*	*V5*	-	*V4*
NL	*V6*	*V5*	*V5*			*V5*	*V5*	*V4*

Table 1: Set of fuzzy rules.

4.2 Neural fuzzy controller

Artificial Neural Networks (ANNs) tend to imitate the human learning process in a very limited way by a computer program or electronic circuit. The ANNs do not require the mathematical model of the system [14], they just use experimental or simulated input/output data to be trained.

The Neural Fuzzy proposed in this paper based on desired fuzzy output, consists of three input nodes (torque error, flux error and stator flux angle); one hidden layer and an output layer with three neurons with (3-11-3).

4.3 Neural network controller

The third proposed controller is composed of three principal layers: the input layer, the hidden layer and the output layer, as shown Figure 4 with 10 neurons in hidden layer.

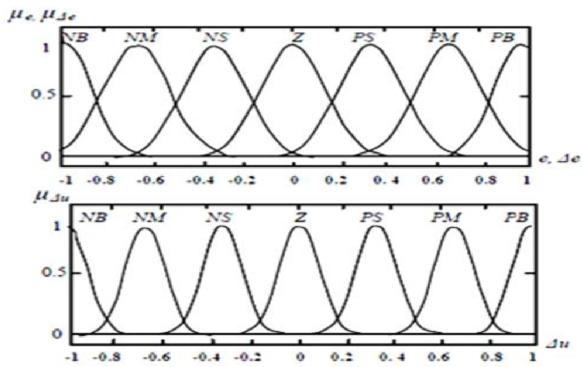

Figure 4: Architecture of neural network controller.

5 Proposed Speed Controller Based on Artificial Intelligent (AI)

The motor speed can be controlled indirectly by controlling the torque with a traditional controller such as PI or controller based on Artificial Intelligent including Fuzzy Logic and Neural Networks.

So this paper presents direct torque control of induction motor based on AI in closed loop, under transient and steady state uncertainties caused by the variation in load torque, the proposed speed controllers are PI, Fuzzy Logic, Neural Fuzzy logic and Neural networks.

5.1 The Proportional Integral (PI) controllers

The PI controller for the above system can be expressed as

$$u = K_p e(t) + k_i \int e(t)dt, \tag{7}$$

where Kp and Ki are the proportional and integral gain constants [15]. The speed error e(k) and $\triangle e(k)$ are defined as:

$$e(k) = \omega_r^*(k) - \omega_r(k), \tag{8}$$

$$\Delta e(k) = e(k+1) - e(k). \tag{9}$$

5.2 Fuzzy controller

The input linguistic variables speed error e(k), change in speed error $\triangle e(k)$ and output linguistic variable u(k) membership functions will be divided into seven fuzzy sets with the linguistic values NL (negative large), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), PL (positive large) respectively and are given in Table 2.

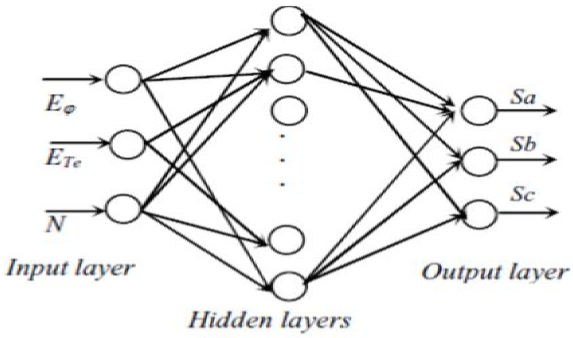

Figure 5: Membership functions of the Fuzzy controller.

	e	PL	PM	PS	ZE	NS	NM	NL
Δe								
PL		PL	PL	PL	PL	PM	PS	ZE
PM		PL	PL	PL	PM	PS	ZE	NS
PS		PL	PL	PM	PS	ZE	NS	NM
ZE		PL	PM	PS	ZE	NS	NM	NL
NS		PM	PS	ZE	NS	NM	NL	NL
NM		PS	ZE	NS	NM	NL	NL	NL
NL		ZE	NS	NM	NL	NL	NL	NL

Table 2: Fuzzy control table.

5.3 Neural fuzzy controller

This proposed controller is obtained by learning ANN controller based on data inputs/outputs of fuzzy controller cited below, the NF controller has two inputs/one output (error and variation error of speed rotor/ torque command) as shown in Figure 6 and the hidden layer contains 25 neuron.

5.4 Neural network

The controller presented in this section has also two inputs/one output and one hidden layer (Figure 7) contains 20 neurons. The sum squared error falls under 5.34.e-5 after 2201 iterations.

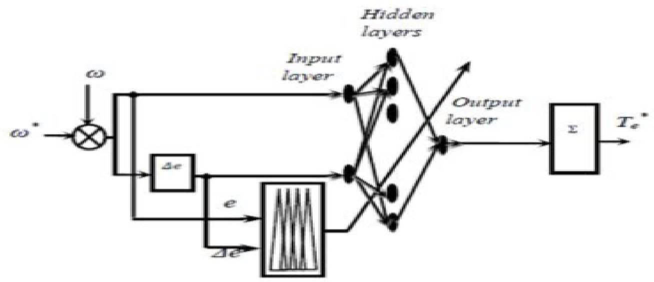

Figure 6: Basic structure of neural fuzzy speed controller.

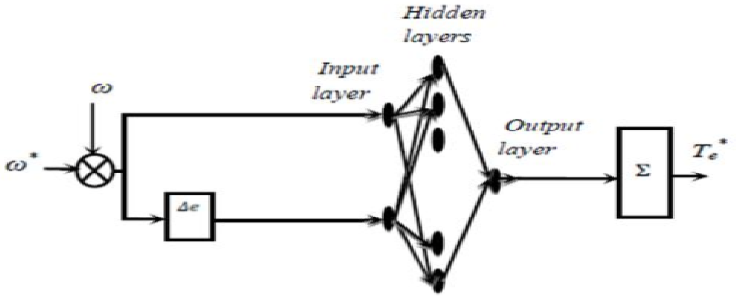

Figure 7: Basic structure of neural speed controller.

6 Simulation Result

A simulation configured SIMULINK environment has been carried out for the evaluation of the proposed system. The parameters of the induction motors used in this study are shown in Table 3.

Parameters of IM setting		
P	Power	1.5 Kw
Rs	Stator resistance	4.85 Ohm
Rr	rotor resistance	4.85 Ohm
j	Inertia	0.031Kg.m2
f	frequency	50Hz
P	Poles	2

Table 3: Parameters of IM setting.

The constant load torque of 10Nm and a constant flux of 1.1Wb were used, Figure 8 shows comparison between fuzzy (DTFLC), neural fuzzy (DTNFC), neural network (DTNNC) and traditional DTC (CDTC), in this figure the stator current is nearly sinusoidal and stator flux trajectory is evidently circular. It can be seen that the torque and flux ripple is significantly reduced by using fuzzy logic controller compared to neural network, neural fuzzy logic and traditional controller in open loop, we have nearly the same remarks in closed loop, the estimated values of electromagnetic torque and stator flux track the references with load torque applied (10Nm) as shown (Figure 9, Figure 10 and Figure 11) and the ripple in torque, current and flux is less by using fuzzy controller compared to the others controller in Figure 11 the rotor speed flow the reference quickly and without overshoot by using neural and neural based on fuzzy logic. We find finally that the neural speed controller based on fuzzy logic gives better performances.

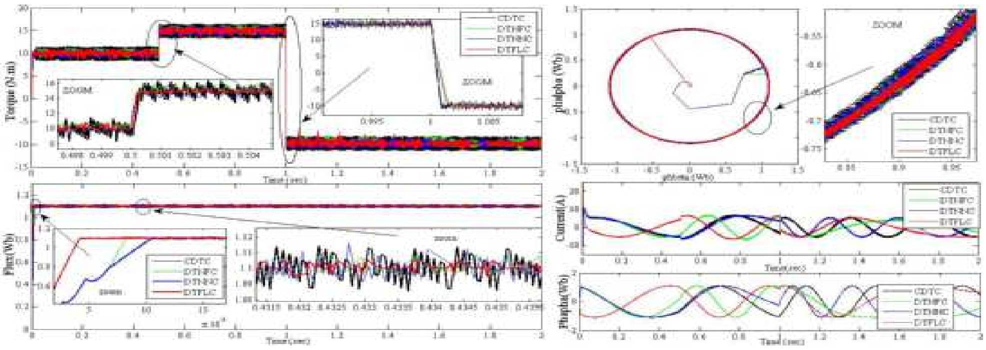

Figure 8: Responses of flux, torque and stator current with a load torque applied.

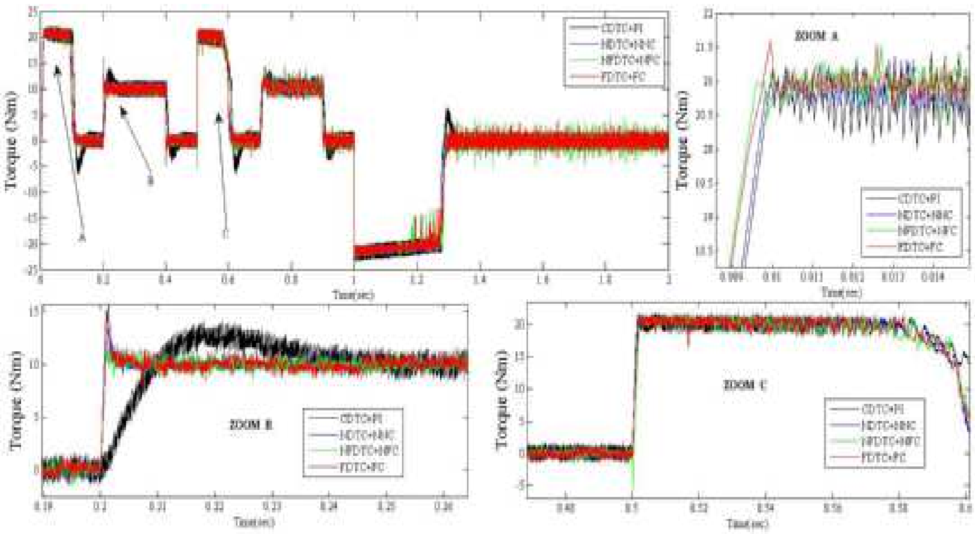

Figure 9: Torque response.

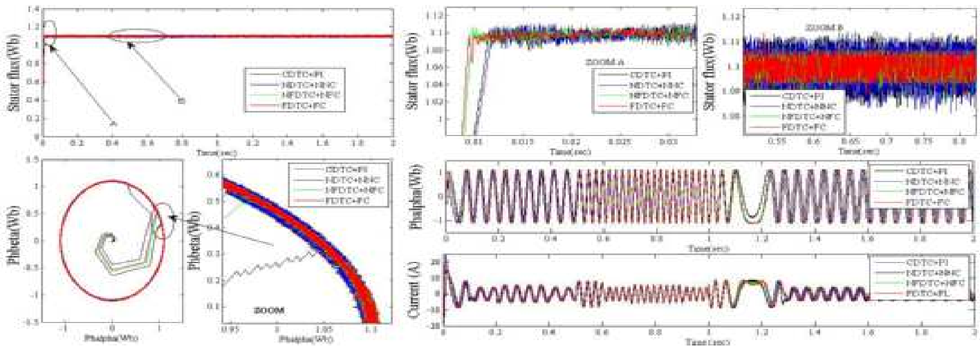

Figure 10: Rotor speed response.

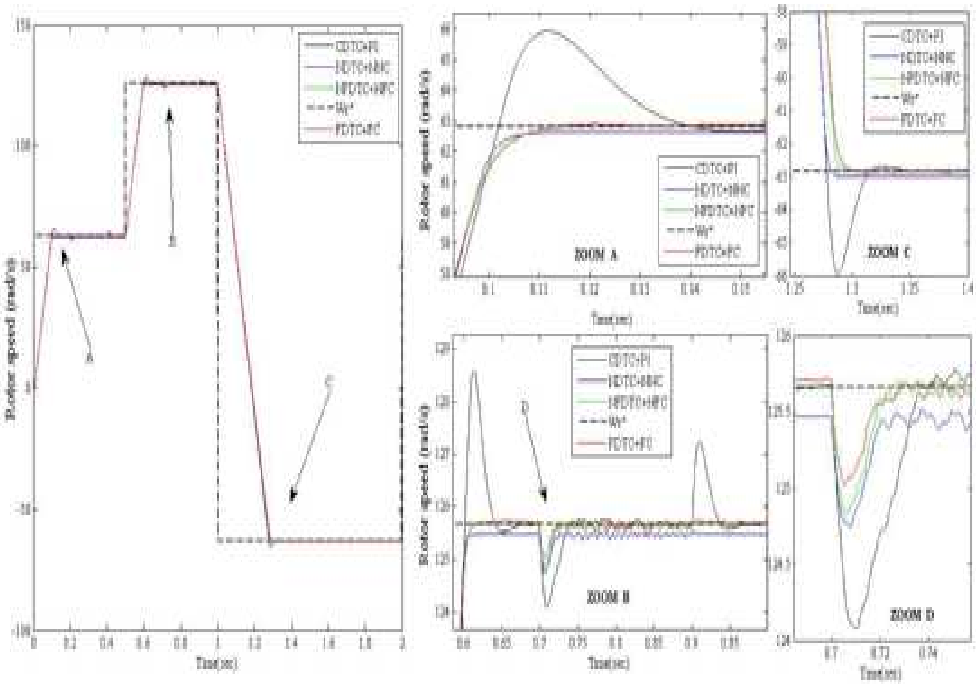

Figure 11: Stator flux response.

7 Conclusion

This paper presents comparative study of DTC-IM with and without speed controller based on artificial intelligent system such as fuzzy logic, neural network and neural fuzzy logic.

The obtained simulation results show good performance of proposed methods which are better than conventional method. The motor reaches the reference speed rapidly and without overshoot, load disturbances are rapidly rejected; torque and flux ripples are significantly attenuated.

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