A Comparative Analysis Of PI And Neuro Fuzzy Controllers In Direct Torque Control Of Induction Motor Drives

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Abstract:
The implementation of conventional DTC in Induction Motor drives consisting of PI torque controller suffers from complex tuning and Overshoot problems. One of the various methods to tackle this problem is implementation of intelligent controllers like neuro fuzzy-based controller This paper presents the simulation and analysis of a Neuro fuzzy-based torque controller for DTC of Induction motor drives. This control scheme uses the speed error calculated from reference speed and estimated speed which generates the estimated Torque and compared with the actual Torque and generates the inverter switching states. In this paper a modified ANFIS structure is proposed. This structure generates the desired reference voltage which regulates the performance of induction motor. Comparisons and analysis under various operating conditions between hysteresis-based PI torque controller and Neuro fuzzy-based torque controller are presented. The results show that the proposed controller managed to reduce the overshoot and give better performance.

Keywords-direct torque control, induction motor drive, PI controller, complex tuning, Overshoot, neuro fuzzy controller.

1 Introduction

Direct torque control(DTC) of induction motor drives has gained popularity due to its simple control structure and sensorless operation. The structure of conventional DTC drive originally introduced in [1], is simple. It consists of torque and flux hysteresis-based controllers, flux and torque estimator switching look-up table. Despite of its simplicity, it was well known that the implementation of the hysteresis-based DTC –PI controller requires fine tuning and cannot cope with parameters variation.. This resulted in unpredictable switching frequency of the switching devices. Further the variable switching frequency will generate unpredictable harmonic currents.

Various methods have been proposed to overcome these drawbacks, such as variable structure control approach,fuzzy logic control,neural netwok control,adaptive control methods have been proposed for motion control of Induction motor drive[2-12]. The PI control is simple and offers a wide stability margin, but it incorporates tuning,overshoot problems. The fuzzy logic can compensate the system nonlinearities through human expertise. Yet, it relies too much on the intuition and experience of the designer. The neural network can handle the complicated nonlinear characteristics of the system, but suffer from the problem of lengthy training and convergence time. The adaptive control can self adjust the controller parameters to adapt system parameter variations. Unfortunately, it generally requires a reference model of the system.

The controller proposed in this paper is neuro fuzzy-based controller which gives better performance compared to PI controller. The neural network is well known for its learning ability and approximation to any arbitrary continuous function.[9] It has been proposed in the literature that neural networks can be applied to parameter identification and state estimation . The fuzzy logic controller solves the problem of non-linearities and parameter variations of IM drive. It achieves high dynamic performance and accurate speed control with good steady-state characteristics. The fuzzy rules and membership functions are tuned to give better performance. The proposed neuro fuzzy-based controller has been simulated using MATLAB/SIMULINK. The performance of the proposed controller is evaluated under various operating conditions. The simulation results confirm the efficacy of the control system.

This paper is organized as follows : first the machine modeling of Induction Motor, second the direct torque control strategy using PI controller, third the direct torque control strategy using neuro fuzzy-based controller, fourth

Simulation results at different operating conditions, fifth conclusions.

2.Induction Motor Modelling

The induction motor model can be developed from its fundamental electrical and mechanical equations. In the stationary reference frame the voltage equations are given by

$$V_{ds} = R_s i_{ds} + p\lambda_{ds}$$
$$V_{qs} = R_s i_{qs} + p\lambda_{qs}$$
$$0 = R_r i_{dr} + \omega_r \lambda_{qr} + p\lambda_{dr}$$
$$0 = R_r i_{qr} - \omega_r \lambda_{dr} + p\lambda_{qr} \qquad (1)$$

Where p indicates the differential operator(d/dt). The stator and rotor flux linkages are defined using their respective self leakage inductances and mutual inductances as given below

$$\lambda_{ds} = L_s i_{ds} + L_m i_{dr}$$
$$\lambda_{qs} = L_s i_{qs} + L_m i_{qr}$$
$$\lambda_{dr} = L_r i_{dr} + L_m i_{ds}$$
$$\lambda_{qr} = L_r i_{qr} + L_m i_{qs} \qquad (2)$$

The electromagnetic torque in the stationary reference frame is given as

$$Te = (3/2)(P/2)(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}) \quad (3)$$

3. DTC with PI Controller

In the DTC scheme [1] (Figure 1), the electromagnetic torque and flux signals are delivered to two hysteresis comparators. The corresponding output variables and the stator flux position sector are used to select the appropriate voltage vector from a switching table which generates pulses to control the power switches in the inverter. This scheme presents many disadvantages (variable switching frequency - current and torque distortion caused by sector changes - start and low-speed operation problems).

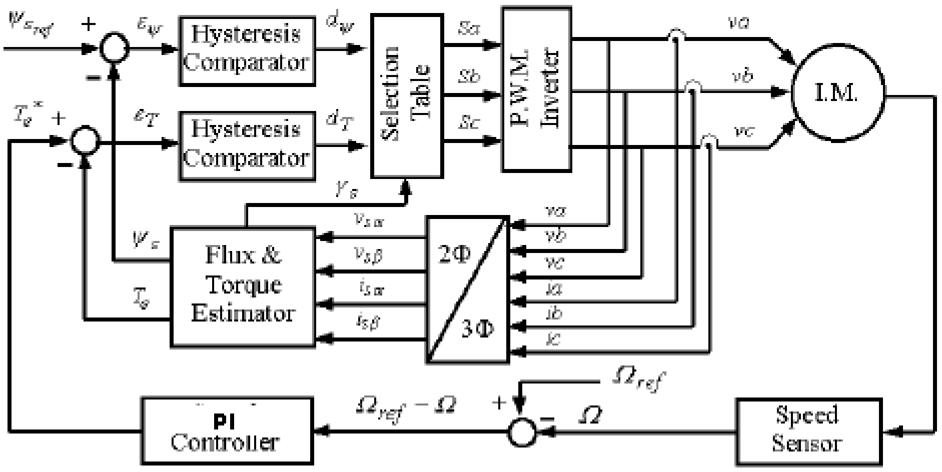

Figure 1 : Direct Torque Control scheme with PI Controller

All the schemes cited above use a PI controller for speed control. The use of PI controllers to command a high performance direct torque controlled induction motor drive is often characterised by an overshoot during start up. This is mainly caused by the fact that the high value of the PI gains needed for rapid load disturbance rejection generates a positive high torque error. This will let the DTC scheme take control of the motor speed driving it to a value corresponding to the reference stator flux. At start up, the PI controller acts only on the error torque value by driving it to the zero border. When this border is crossed, the PI controller takes control of the motor speed and drives it to the reference value.

4. DTC with Neuro-fuzzy controller

Fuzzy logic and artificial neural networks can be combined to design a direct torque neuro fuzzy controller. Human expert knowledge can be used to build an initial artificial neural network structure whose parameters could be obtained using online or offline learning processes. To eliminate the above difficulties, a Direct Torque Neuro Fuzzy Control scheme (DTNFC) has been proposed.

The Neuro Fuzzy inference system (ANFIS) is one of the proposed methods to combine Fuzzy logic and artificial neural networks[17,21,22]. Figure 2 shows the adaptive NF inference system structure It is composed of five functional blocks (rule base, database, a decision making unit, a fuzzyfication interface and a defuzzyfication interface) which are generated using four network layers:

Layer 1: This layer is composed of a number of computing nodes whose activation functions are fuzzy logic membership functions (usually, triangular or bell-shaped functions).

Layer 2: This layer chooses the minimum value of the inputs.

Layer 3: This layer normalises each input with respect to the others (The i^{th} node output is the i^{th} input divided the sum of all the other inputs).

Layer 4: This layer's i^{th} node output is a linear function of the third layer's i^{th} node output and the ANFIS input signals and sums all the input signals. The ANFIS structure can be tuned automatically by a least-square estimation (for output membership functions) and a back propagation algorithm (for output and input membership functions).

The block scheme of the proposed self-tuned direct torque neuro-fuzzy controller (DTNFC) for a voltage source PWM inverter fed induction motor is presented in Figure 3. The internal structure of the NFC is shown in Figure 2.

In the first layer of the NF structure, sampled speed error w_e ,multiplied by respective weights $w\psi$ and wT , is mapped through three fuzzy logic membership functions. These functions are chosen to be triangular shaped as shown in Figure 2.The second layer calculates the minimum of the input signals. The output values are normalised in the third layer, to satisfy the following relation:

$$\sigma_i = w_i / (\Sigma_k w_k) \qquad (4)$$

where w_i and σ_i are the i^{th} output signal of the second and third layer respectively. σ_i is considered to be the weights.

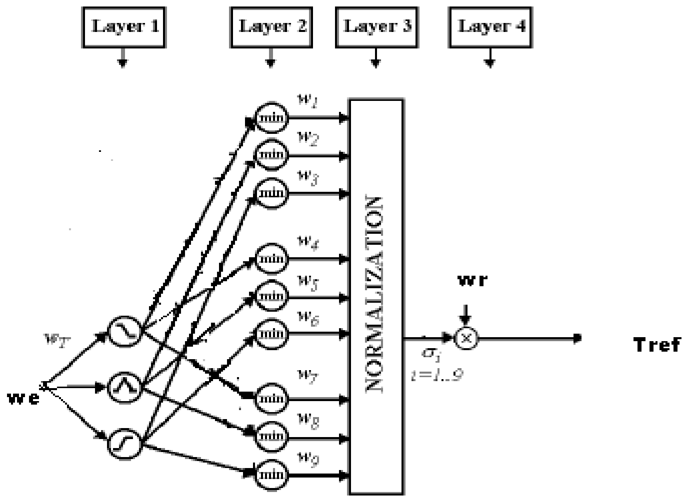

Figure 2 : Proposed Neuro fuzzy structure Controller

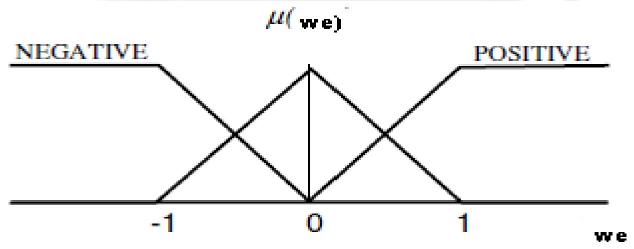

Figure 3 : Triangular membership function sets

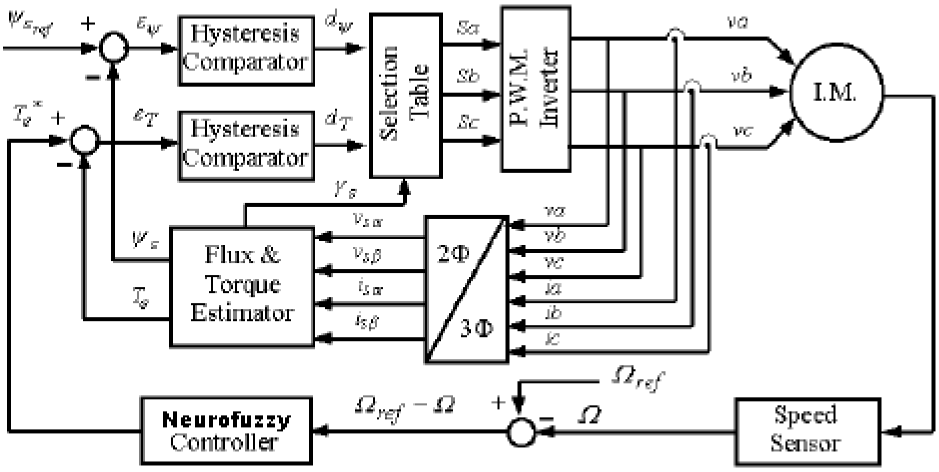

Figure 4 : Direct Torque Control scheme with Neuro Fuzzy Controller

The Neuro Fuzzy speed controller combines fuzzy logic and artificial neural networks to evaluate the reference torque. This evaluation is performed using the reference speed and actual speed errors. This calculated error gives the estimated torque value which is compared with the actual torque value in the Hysteresis comparator. The corresponding torque,flux from hysteresis comparators and angle estimated from Flux Torque estimator are given as inputs to Switching table which generates the appropriate voltage vector for the inverter which in turn controls the Torque parameter of Induction motor[12,15,26].

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5. Simulation Results

Direct Torque control scheme with PI controller and Neuro fuzzy controller are implemented in the Induction motor drive with the following parameters under various operating conditions at no load and sudden change in load applied to the motor. All the results are represented taking time as the x-axis.

V=260/50Hz. Rs=0.9Ω Rr=1.227Ω P=2 Ls=150.64mH, Lr=150.64mH. Lm=143.84mH

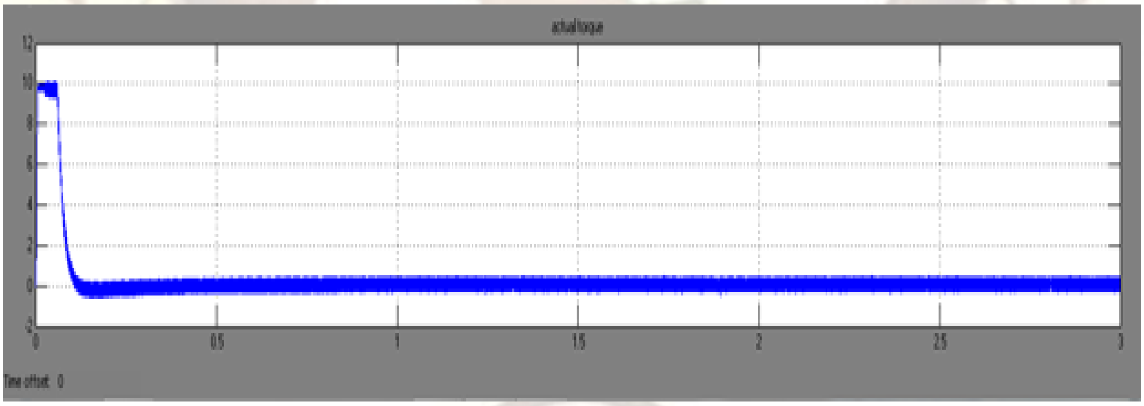

Figure 5 : Torque Characteristics at no load with PI Controller

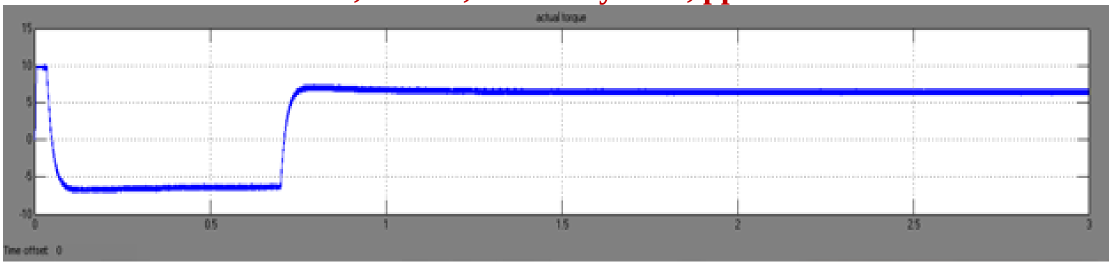

Figure 6 : Torque Characteristics with sudden change in load Torque from -6.4Nm to 6.4Nm with PI Controller

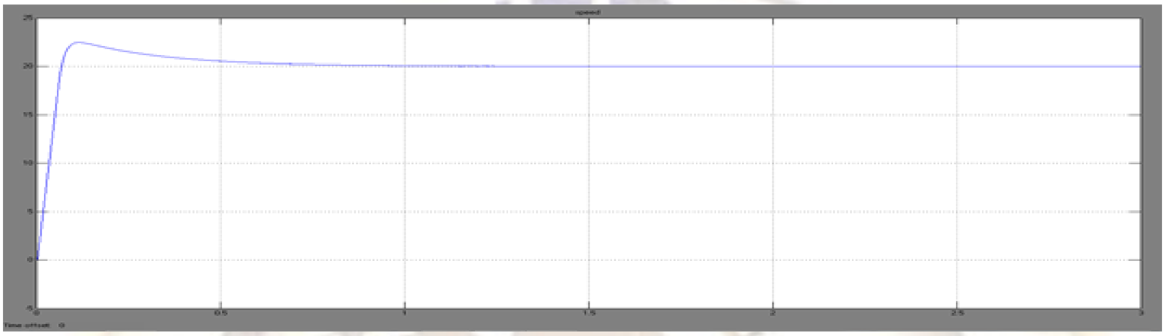

Figure 7 : Speed Characteristics at no load with PI Controller

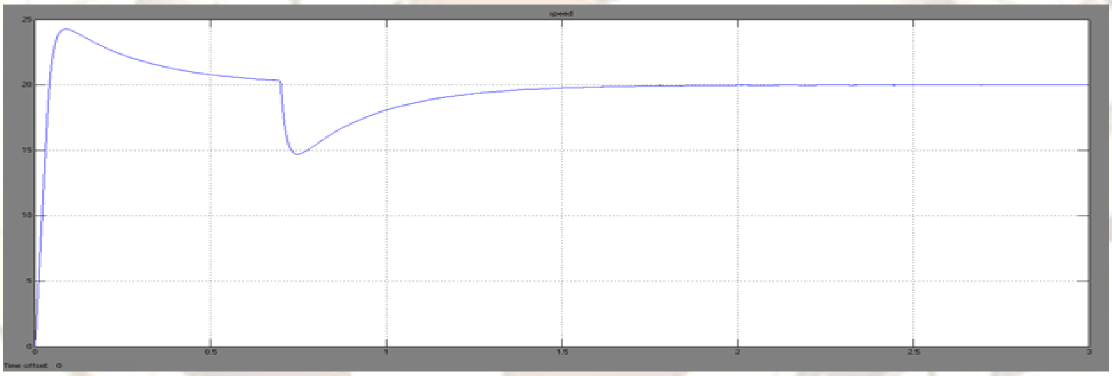

Figure 8: Speed Characteristics at sudden change in load Torque from -6.4Nm to 6.4Nm with PI Controller

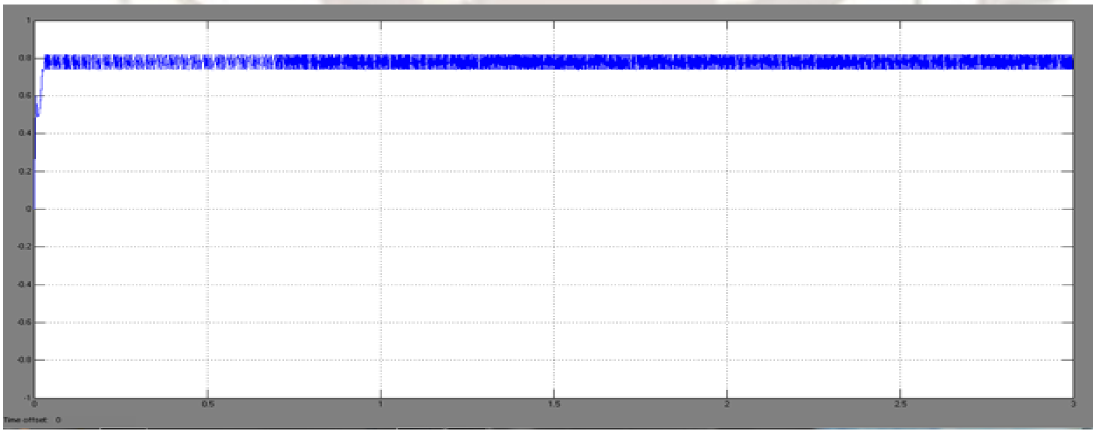

Figure 9 : Stator flux response with PI controller

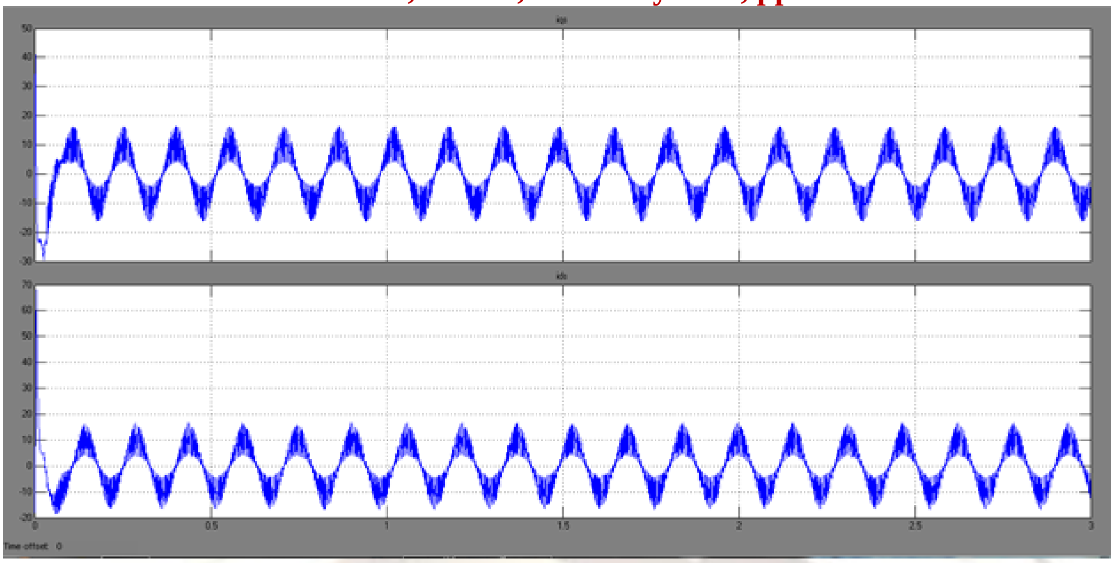

Figure 10 : Magnetizing and Torque components of stator current with PI controller

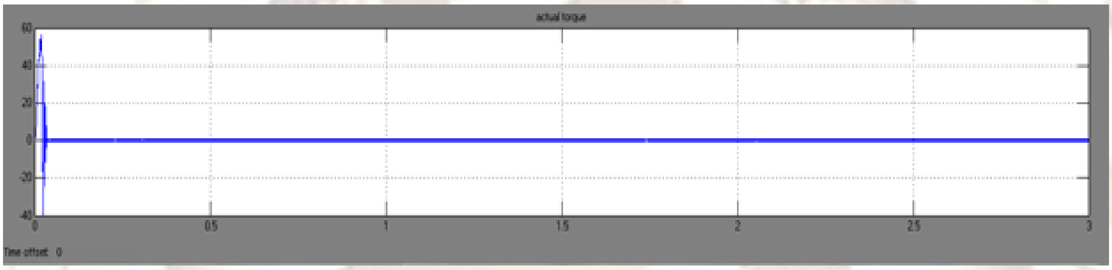

Figure 11: Torque Characteristics at no load with NeuroFuzzy Controller

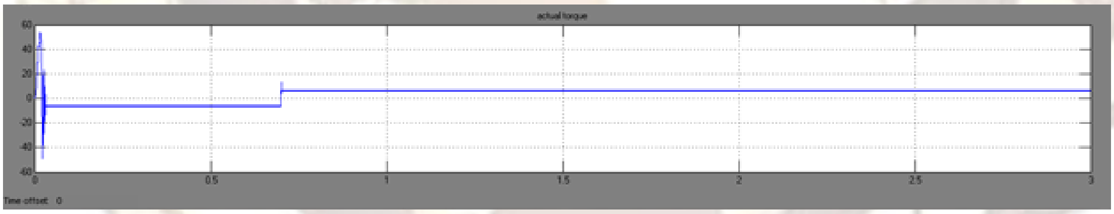

Figure 12 : Torque Characteristics at sudden change in load Torque from -6.4Nm to 6.4Nm with NeuroFuzzy Controller

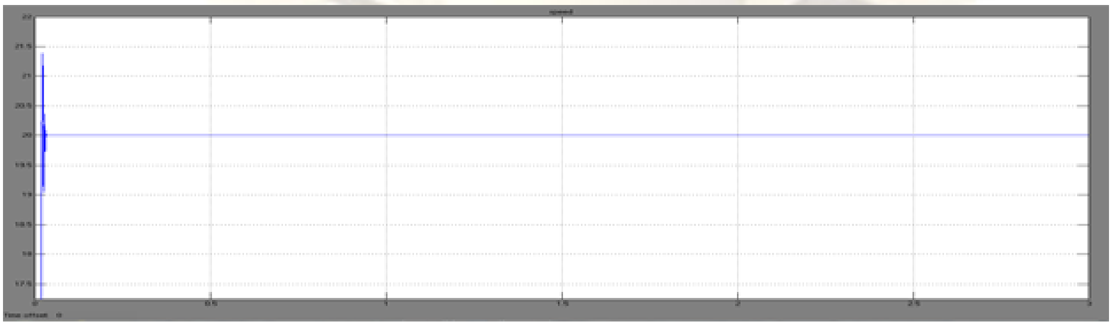

Figure 13 : Speed Characteristics at no load with NeuroFuzzy Controller

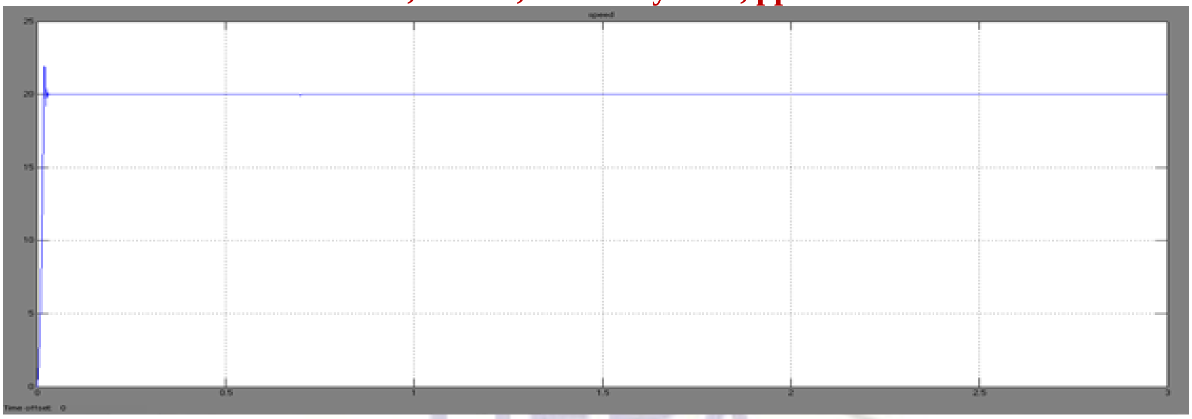

Figure 14 : Speed Characteristics at sudden change in load Torque from -6.4Nm to 6.4Nm with NeuroFuzzy Controller

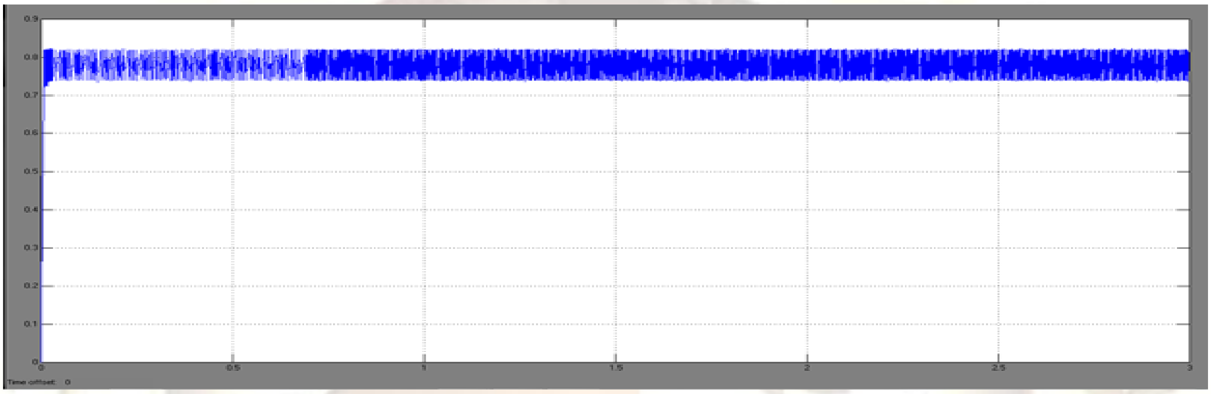

Figure 15 :Stator flux response with Neuro fuzzy controller

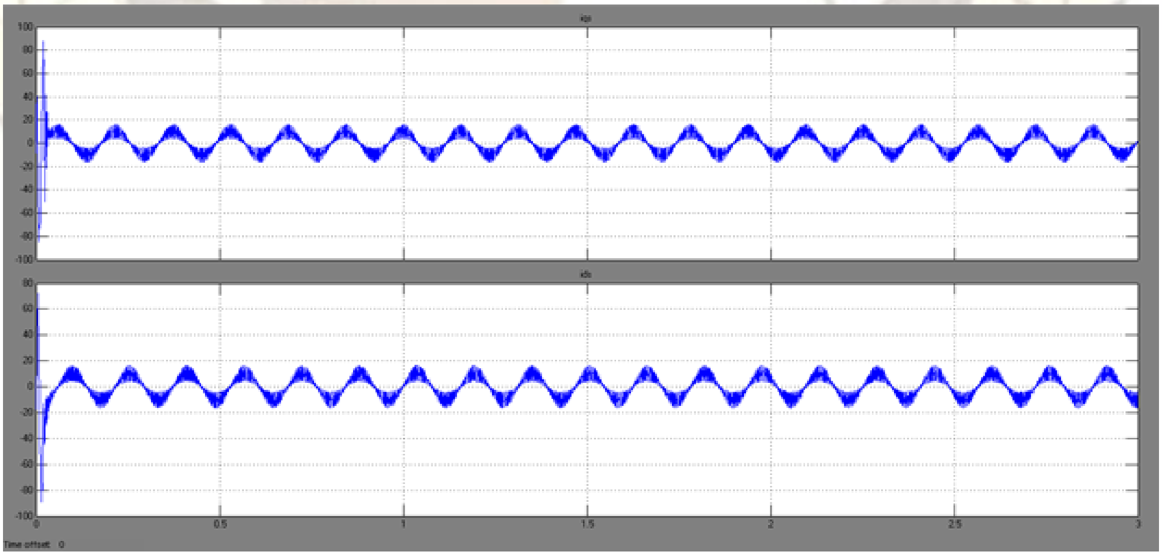

Figure 16 : Magnetizing and Torque components of stator current with Neuro fuzzy controller

Parameters	PI Controller	Neuro-fuzzy Controller
Overshoot	47%	7%
Computational effort	21.6μs	97.2μs

Table I : Comparison between PI Controller and Neuro fuzzy Controller

The overshoot and time for computational effort for PI controller and Neuro fuzzy controller in Direct Torque control of Induction Motor are estimated. Table I shows that DTNFC scheme gives better performances than the conventional DTC scheme with PI controller. We can remark however that the high value of the DTNFC scheme regarding computational effort does not affect the control cycle since it stays below 50% of its value.

6. Conclusions

In this paper, both Direct torque controlled PI controller and neuro fuzzy Controllers are discussed.The PI controller cannot prevent DTC scheme from driving the motor speed to the stator flux corresponding speed. This will most likely result in a speed overshoot. Simulation of the DTNFC Induction motor drive for speed control shows promising results. The motor reaches the reference speed rapidly and with minimum overshoot. The simulation results obtained show the effectiveness of neuro fuzzy controller in speed regulation of induction motor.

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