An Improved DTC of an Induction Motor Drive with Neural Network Controller

Wahyu Mulyo Utomo, Sy Yi Sim, Zainal Alam Haron, Azuwien Aida Bohari, Nooradzianie Muhammad Zin, Roslina Mat Ariff, Waluyo Adi Siswanto
Universiti Tun Hussien Onn Malaysia
Batu Pahat, Johor, Malaysia
wahyu@uthm.edu.my, simsyyi@hotmail.com, zainalal@uthm.edu.my, azuwienaidabohari@yahoo.com, adzianie@gmail.com, roslinamatariff@yahoo.com, waluyo@uthm.edu.my

***Abstract*— A space vector modulation based direct torque Control strategy is suggested and an intelligence controller design based on this strategy is presented. A neural network controller is proposed to replace the conventional PID controllers to improve the drive's performance since the performance of an electric drive really depends on the quality of a speed controller. The neural network controller was trained and realizes for a speed controller. The controller was utilized in the feed-back loop of the control system. The control system renditions as well as the online learning technique of the neural network are described in this paper. The comparison with the conventional PID direct torque controller reveal the effectiveness of the proposed scheme by improved the performance of transient response is presented. A simulation model representing the complete neural network based direct torque control scheme of induction motor drive is developed and verified using S-Function Simulink block program.**

***Index Term*— Direct Torque Control, Induction Motor Drive, Neural Network Control.**

I. Introduction

The emergence of the vector control granted the dynamic performance of the induction motors (IM) with a glut improved at the beginning of 1970[1]. Theoretically, the vector control that based on Fleming's law [2] improved the control performance of IM virtually close to the d.c. motor's where the flux and torque are decoupled and henceforth could be controlled separately. The vector control is based on the relationship valid for dynamic states, instead of only the frequency and magnitude is taking into consideration, the instantaneous positions of voltage and current are also controlled. Thus, the VC works on the position of the space vector for both transients and steady state to furnish their exact orientation. This ensures the fast flux and torque to be dynamically and be part of the high-performance control carry out in closed-loop methods. [1], [3]. The vector control can be complying in various methods but only several basic schemes that are offered in the market. The Field Oriented Control (FOC), Direct Torque Control (DTC) and Direct Torque Control-Space vector Modulation (DTC-SVPWM) are the most welcome control methods.

The use of DTC strategies has become more universal and popular for induction motor drives and seems has a very rapid growth in the development of it. The DTC provides a very accurate and swift torque response excluding the complex field-oriented block and inner current regulation loop [4], in contrast to vector control. The DTC was first introduced by Takahashi and has found great success with the notion to enhance the dynamic and exactness of the torque and flux response while at the same time subside the IM parameter dependency [5].

In conventional SVPWM-DTC, the speed, flux and torque controller was based on PID, the major problem of PID based DTC was the improper transient response with high overshoot, as well as the long settling time. Furthermore, for a high performance DTC IM drive using the PID speed controllers in permanent mode frequently comes with the conundrum of an overshoot during start up response and a poor load disturbance rejection [6]. To overcome this problem, a neural network based DTC was proposed to replace the PI in speed controller of the DTC of IM to obtained a better performance of transient response by reduce the overshoot and settling time. The proposed controller is evaluated by simulation and the results compared with the conventional PID-DTC.

The development of neural network for DTC method has been considered due to their various advantages over conventional ones. The implementation of the off-line learning algorithm could reduce the superiority of the speed control IM drive method. This is due to the training data employ fixed motor parameters. Consequently, for a real time application the performance of the controller will decrease, because the motor parameters vary against the temperature and magnetic saturation [7]. This paper proposes an improvement of the neural network control design for speed controller of DTC induction motor drive. The neural network controller model is developed based on online learning algorithm using Back propagation scheme. The controller is designed to generate speed control signal.

In the following section the basic scheme of the DTC system is described. Development of the proposed neural network SVPWM-DTC will be explained in section III. Simulation block model and the testing result will be presented in section IV. The last section will be a discussion and conclusion.

II. Direct Torque Control Methods

The SVPWM-DTC produces the stator reference voltage vectors by adopt of both torque and flux errors, then feed to the SVPWM algorithm to modulate. The constant switching frequency signal is then exported to the three phase inverter [8] as illustrated in Fig.1.

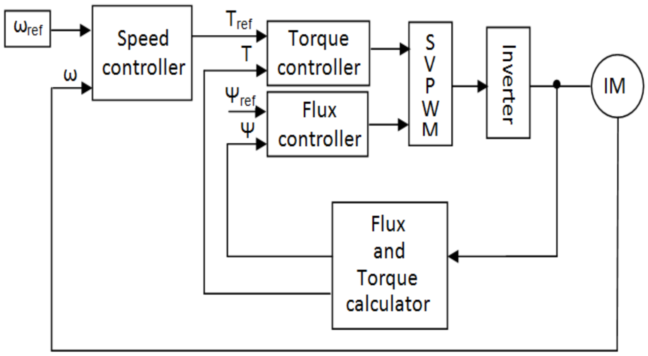

Fig. 1. SVPWM-DTC induction motor drive.

The induction model in the stator-fixed d-q reference frame is described by [9].

$$V_s = R_s i_s + \frac{d}{dt}(\Psi_s). \quad (1)$$

$$V_r = 0 = R_r i_r + \frac{d}{dt}(\Psi_r) - j\omega_r \Psi_r. \quad (2)$$

$$\Psi_s = L_s i_s + L_m i_r. \quad (3)$$

$$\Psi_s = L_m i_s + L_r i_r. \quad (4)$$

The mechanical equations are given as below. The induction motor stator flux and torque are calculated in the flux and torque calculator as follows:

$$\Psi_{ds} = \int (V_{ds} - R_s i_{ds}) dt. \quad (5)$$

$$\Psi_{qs} = \int (V_{qs} - R_s i_{qs}) dt. \quad (6)$$

$$|\Psi_s| = \sqrt{\Psi_{ds}^2 + \Psi_{qs}^2}. \quad (7)$$

$$\theta_{\Psi s} = \tan^{-1}\left(\frac{\Psi_{qs}}{\Psi_{ds}}\right). \quad (8)$$

Then, the electromagnetic torque is estimated as:

$$T_e = \frac{3}{2}\frac{p}{2}\left(\Psi_{ds} i_{qs} - \Psi_{qs} i_{ds}\right). \quad (9)$$

III. DTC-SVPWM Neural Network Speed Controller

Inspired by the successful function of the human brains, the artificial neural network (ANN) was developed for solving many large scale and complex problems. Based on ability to process some information and also to analyze the input and output simultaneously, it makes ANN suitable for dynamic and nonlinear system. The development of the structure and learning algorithm of the Neural Network Direct Torque Control (NN-DTC) is explained as follows [7]. This paper proposed a DTC IM drive with the neural network technique based on SVPWM to reduce the overshoot and torque ripple. The NN control is added to the speed controller to produce the torque reference. The block diagram of the proposed NN-DTC of induction motor drive is shown in Fig.2.

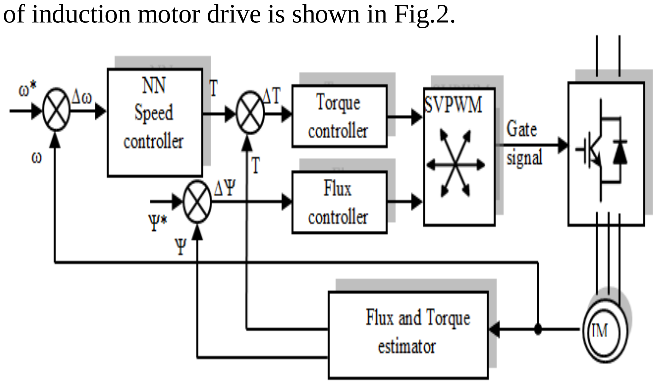

Fig. 2. The block diagram of proposed NN-DTC.

A. The Proposed NN-DTC

Generally, basic concept of the plant is required in design neural network. The input number of the NN controller structure can be determined based on the available input signal number of the system. Further, the number of hidden layers and the total neurons is depended on the complexity of the system and the required training accuracy. To implement speed controller of an induction motor drive, a multilayer perceptrons neural network control is developed In view of the type of the task to be performed, the structure of the proposed NN-DTC is as shown in Fig.3.

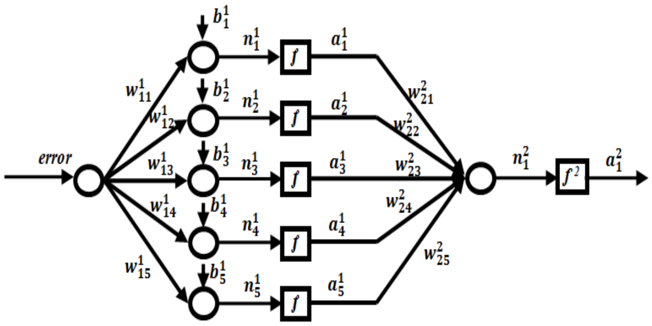

Fig. 3. Diagram block of neural network speed control for DTC induction motor drive.

The controller consists of input layer, hidden layer and output layer. Based on number of the neuron in the layers, the NN-DTC is defined as a 1-5-1 network structure. The first neuron of the output layer is used as a torque reference signal ***(a^2_1=m_f).*** The connections weight parameter between ***j^{th}*** and ***i^{th}*** neuron at ***m^{th}*** layer is given by ***w^m_{ij}***, while bias parameter of this layer at ***i^{th}*** neuron is given by ***b^m_i***. Transfer function of the network at ***i^{th}*** neuron in ***m^{th}*** layer is defined by:

$$n_i^m = \sum_{j=1}^{S^{m-1}} w_{ij}^m a_j^{m-1} + b_i^m \ . \qquad (10)$$

The output function of neuron at ***m^{th}*** layer is given by:

$$a_i^m = f^m(n_i^m) \ . \qquad (11)$$

Where ***f*** is activation function of the neuron. In this design the activation function of the output layer is unity and for the hidden layer is a tangent hyperbolic function given by:

$$f^m(n_i^m) = \frac{2}{1+e^{-2n_i^m}} - 1 \ . \qquad (12)$$

Updating of the connection weight and bias parameters are given by:

$$w_{ij}^m(k+1) = w_{ij}^m(k) - \alpha \frac{\partial F(k)}{\partial w_{ij}^m} \ . \qquad (13)$$

$$b_i^m(k+1) = b_i^m(k) - \alpha \frac{\partial F(k)}{\partial b_i^m} \ . \qquad (14)$$

where ***k*** is sampling time, ***α*** is learning rate, and ***F*** performance index function of the network.

B. Learning Scheme of the Proposed NNDTC

After the neural network architecture is modeled, the learning model is determined in next stage to update network parameters. By this learning capability, it makes the ANN suitable to be implemented for the system with motor parameters which are difficult to define and vary against with environment. The training process minimizes the error output of the network through an optimization method. Generally, in learning mode of the neural network controller a sufficient training data input-output mapping data of a plant is required. Since the motor parameters of the induction motor drive vary with temperature and magnetic saturation, the online learning Back propagation algorithm is developed.

Based on first order optimization scheme, updating of the network parameters are determined. The performance index sum of square error is given by:

$$F(k) = \frac{1}{2}\sum_i e_i^2(k) \ . \qquad (15)$$

$$e_i(k) = t_i(k) - a_i(k) \ . \qquad (16)$$

where ***t_i*** is target signal and ***a_i*** output signal on last layer.
The gradient descent of the performance index against to the connection weight is given by:

$$\frac{\partial F}{\partial w_{ij}^m} = \frac{\partial F}{\partial n_i^m}\frac{\partial n_i^m}{\partial w_{ij}^m} \ . \qquad (17)$$

The sensitivity parameter of the network is defined as:

$$s_i^m = \frac{\partial F}{\partial n_i^m} \ . \qquad (18)$$

$$s_i^m = \frac{\partial F}{\partial a_i^m}\frac{\partial a_i^m}{\partial n_i^m} \ . \qquad (19)$$

Gradient the transfer function again to the connection weight parameter is given by:

$$\frac{\partial n_i^m}{\partial w_{ij}^m} = a_i^{m-1} \ . \qquad (20)$$

From substitution equation (18) and (20) into (13) the updating connection parameter is given by:

$$w_{ij}^{m-1}(k+1) = w_i^{m-i}(k) - \alpha s_i^m(k) a_i^{m-1}(k) \ . \qquad (21)$$

With the same technique the updating bias parameter is given by:

$$b_i^{m-1}(k+1) = b_i^{m-i}(k) - \alpha s_i^m(k)\,. \tag{22}$$

IV. Simulation and Results

Simulation was carried out to investigate the performance of the NN-DTC. In this section the dynamic model of a three-phase induction motor, space vector PWM and neural network control model have been developed. The simulation is developed using Borland C++, and then embedded as S-function in Simulink-Matlab. The parameters for the motor are given in Table 1 while the simulation block diagram of the proposed IM drive systems is shown in Fig. 4.

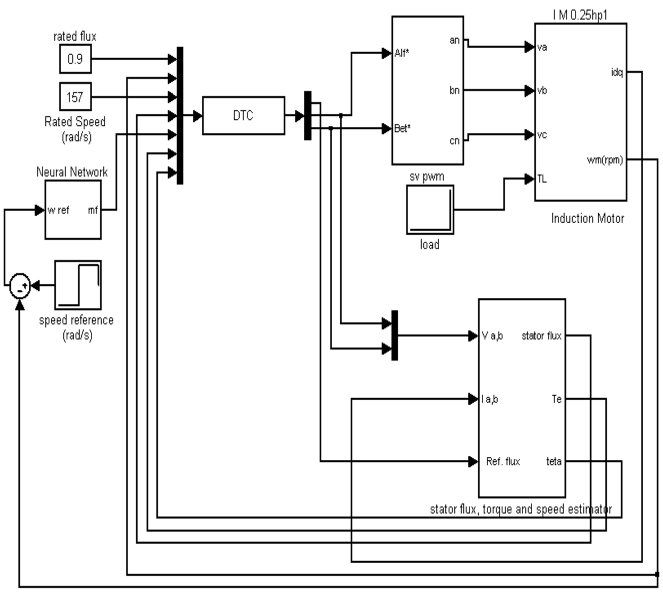

Fig. 4. The simulink block diagram of the proposed NN-DTC.

TABLE I. Motor Parameters

Motor Parameter	Value
Frequency, f	50 Hz
Pole, p	4
Stator resistance, Rs	0.5Ω
Rotor resistance, Rr	0.25 Ω
Stator inductances, Ls	0.0415H
Rotor inductances, Lr	0.0412H
Mutual inductance, Lm	0.0403H
Combined of inertia, J	0.1kg-m^2

To verify performance of the proposed NNDTC, the simulation results for a conventional DTC-SVPWM and the neural network DTC-SVPWM proposed controller are compared. With the same speed and load torque reference, the simulations of both methods are run simultaneously. The simulation is start at the speed on 80 rad/s with a constant load applied. The start-up speed response of both system is shown in Fig.5. Meanwhile, the start-up motor stator current response is shown in Fig. 6 and Fig. 7.

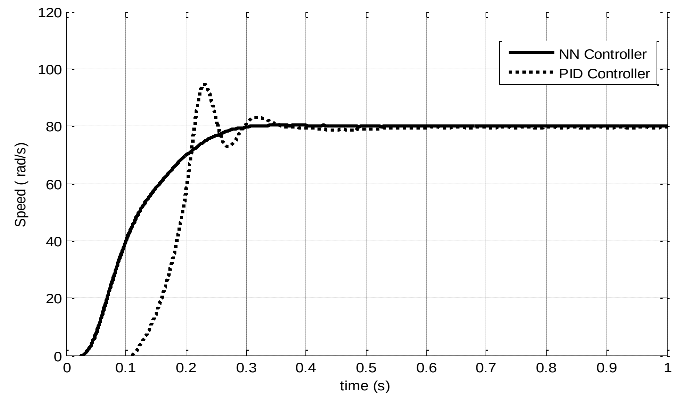

Fig. 5. Start-up speed response comparison between conventional PID-DTC and NN-DTC controller.

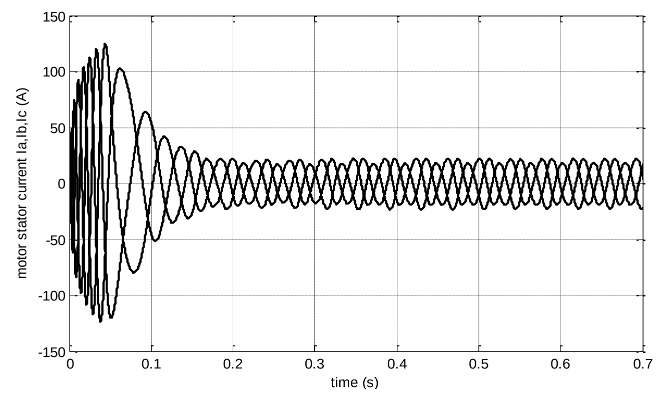

Fig. 6. The motor stator current (Ia, Ib, Ic) for NN-DTC controller.

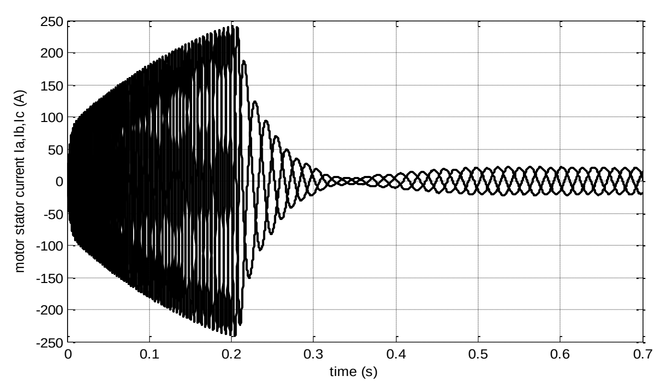

Fig. 7. The motor stator current (Ia, Ib, Ic) for PID-DTC controller.

Fig. 5 illustrated the start-up response of the system. From the figure, it shows that NN-controller have a start-up response improved from the conventional PID controller. It is clearly explain that the start-up speed response has a great improve by reduce the overshoot from 94 rad/s to no overshoot. Besides, it is also show a fast enhancement of the settling time.

In Fig. 6 the motor three phase stator current (Ia, Ib, Ic) are implemented by using NN controller while Fig. 7 are implemented by using PID controller. The overshoot is reducing from 250A to 130A while the settling time is greatly improved from 0.5 second to 0.18 second.

The simulation testing is carry on by vary the speed reference from 80 to 110 rad/s. The performance of two systems is observed. The speed trajectory of the motor when speed varies at the time of 1.5 second is shown in Fig. 8. The step-up motor stator current responses at the time of 1.5 second are shown in Fig. 9 and Fig. 10.

The transient response of the speed when the speed reference is varied is illustrated in Fig. 8. With the constant load applied, the step up response of the speed trajectory again show the fast reduces in overshoot as well as the settling time. The overshoot is removed from 126 rad/s.

Fig. 9 discloses the improvement of the overshoot and settling by implemented a NN controller when compared with Fig. 10 where it is implemented by using PID controller. The overshoot is reducing almost 50% that is from 70A to 35A. The NN controller achieves its steady state condition at the time of 1.6 second while a PID controller takes a longer time, which is 1.7 second.

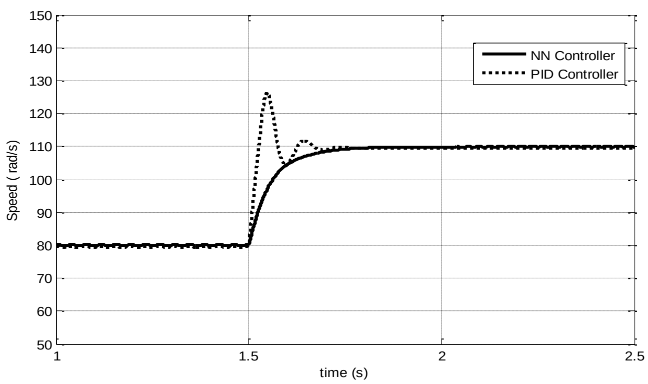

Fig. 8. Step up speed response cmparison between conventional PID SVPWM and NN-SVPWM controller when the speed reference is varied from 80 to 110 rad/s.

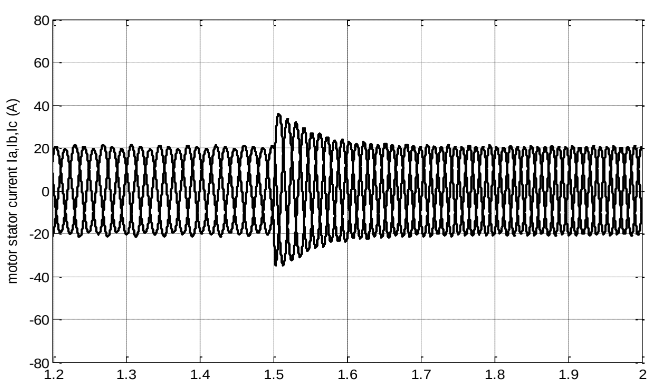

Fig. 9. The motor stator current (Ia, Ib, Ic) for NN-DTC controller.

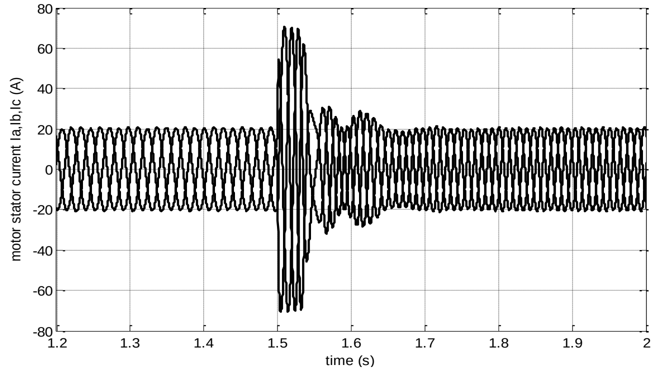

Fig. 10. The motor stator current (Ia, Ib, Ic) for PID-DTC controller.

The simulation testing is continuing by step down the speed from 110 to 90 rad/s at the time of 3 second. The performance of two systems is observed. The speed trajectory of the motor when load is applied to the system at the time of 3s is shown in Fig.11. The motor stator current (Ia, Ib, Ic) of both system are shown in Fig.12 and Fig.13.

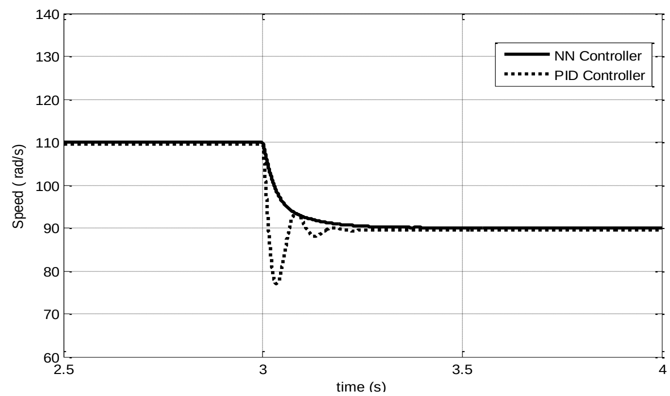

Fig. 11. Step down speed response comparison between conventional PID-DTC and NN-DTC controller when the speed reference is varied from 110 to 90 rad/s.

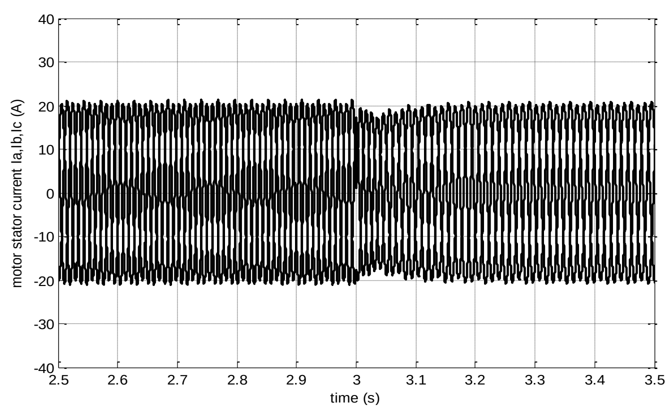

Fig. 12. The motor stator current (Ia, Ib, Ic) for NN-DTC controller.

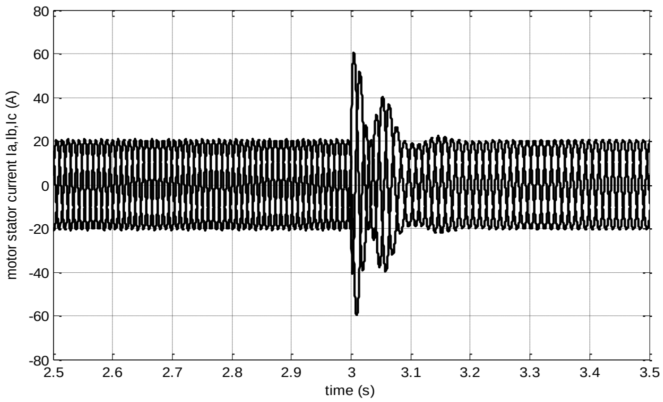

Fig. 13. The motor stator current (Ia, Ib, Ic) for PID-DTC controller.

As illustrated in Fig. 11, the settling time is decreased with the overshoot is also greatly reduce from 83 rad/s to no overshoot by apply of the proposed neural technique, thus, improve the system performance at the same time. It can be seen that there is almost no overshoot comes with an improvement settling time with the proposed speed controller.

Referring to the Fig. 12 and Fig. 13, an overshoot of the motor current during step-down is reducing from 60A to no overshoot while the settling time taken is also boosted up by the NN controllers when compared with the PID controller, which is from 3.2 second by PID controllers to 3.08 second by NN controllers.

V. Conclusion

The neural network controller for SVPWM-DTC speed controller induction motor drive system has been presented in this paper. The proposed method employs a first order online learning back propagation algorithm to generate the torque references. A conventional PID controlled DTC IM drive and a NN controlled DTC IM drive have been tested and compared. The simulation results show that the PID-DTC manages to produce output speeds that follow the given desired reference speed. However, there is an overshoot on the dynamic response before it reaches steady state conditions. The improper system performance can be solved by the proposed NN-DTC. Proposed scheme validate the effectiveness of the method by improved the system performance. The improper transient response with high overshoot as well as the settling time problem of the conventional PID-DTC can be solved. In addition, the controller does not require motor parameters data. The results shows that the performance of transient response is improved by reduce the overshoot and settling time.

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