Abstract—Direct torque control based on neural network of an induction motor was presented in this paper. The neural network was trained for a speed controller. The complete proposed neural network based direct torque control scheme of induction motor as well as the generic direct torque control scheme is simulated using MATLAB. With the same speed and load torque reference, the simulations of both methods are run simultaneously. The acquired results compared with the conventional Proportional Integral Derivative direct torque control reveal the effectiveness of the neural network based direct torque control schemes of induction motor drives. The proposed scheme improved the performance of transient response by reduces the overshoot. Simulation results are presented to highlight the validity of the proposed method.

Index Terms—Induction motor drive, direct torque control, neural network control.

I. INTRODUCTION

DC motor were used immensely in areas where variable-speed operation was demanded, essentially because control of the torque and flux are inherent decoupled and could be achieved by the field and armature current control respectively, even thought d.c motors have several weakness. Due to the mechanical commutator and brush assembly, the d.c. motor required intermittent maintenance, restrict the used in corrosive or explosive environment and under high speed, the commutator capability is limited. These problems can be solved by the applicant of a.c. motors, which require less maintenance, economy, simple structure and robust. The main drawbacks that makes a.c. motor retreats from industry was the control between flux and torque are inherent coupling. However this advantage was amend by the exits of vector control credit to the latter development in power electronic device that expand the use of a.c. motor instead of d.c. motor [1] and [2].

Theoretically, vector control that based on Fleming’s law [2] makes the control performance of induction motor virtually close to the d.c. motor and ensure the torque and flux are decoupled and hence could be controlled individually. The vector control can be comply in various method where Field Oriented Control (FOC), Direct Torque Control (DTC) and Direct Torque Control-Space vector modulation (DTC-SVM) are the most welcome control methods. During the practical practice of engineering application, the actual performance of FOC will be worse than predicted due to the effect of variable motor parameters and inaccurate control model [7]. In addition, the complexity is also one of the main drawbacks of FOC scheme. In recent past, an innovative control method namely DTC has gained the attraction [8].

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. DTC enables both quick and precise torque response excluding the inner current regulation loop and complex field-oriented block, less parameter dependence and increase the precision and the dynamic of flux and torque response, in contrast to FOC [9-10].

In section II, the Direct Torque Control system is described. Development of the proposed neural network DTC-SVM will be explained in section III. Simulation result is given in section IV. The last section will be a discussion and conclusion.

II. DIRECT TORQUE CONTROL PRINCIPLE

The conventional DTC scheme consists of a pair of hysteresis comparator for torque and flux where the switching condition of the VSI is generating directly from the torque and flux error. Variable switching frequency is the major
drawbacks of conventional DTC. Recently a new digital modulation technique known as space vector modulation (SVM) has become very prevalent with the vector control concepts and its offer superior performance and control over the others modulation technique. SVM refers to a special technique of determining the switching sequence of the upper three power transistors of a three phases VSI. This kind of schemes in VSI drives offers improved bus voltage utilization, less commutation losses and has been shown to generate less harmonic distortion in the output voltages or current in the windings of the motor load. Therefore, the SVM-DTC uses two errors to produce stator reference voltage a vector is used in this paper.

In conventional SVM-DTC, the speed, flux and torque controller was based on proportional Integral Derivative (PID), the major problem of PID based DTC was the improper transient response with high overshoot, as well as the high torque ripple. Furthermore, the use of PID speed controllers in a high performance direct torque controlled induction motor is often characterized by an overshoot during start up and a poor load disturbance rejection in permanent mode [11]. To overcome this problem, a neural network based DTC was proposed to replace the PID in speed controller of the DTC of IM to obtained a better performance of transient response by reduce the overshoot and torque ripple. The proposed controller is evaluate by simulation and the results compared with the conventional DTC illustrates the ability of proposed control structure by improves the performance of DTC drive system as shown in Fig. 1.

The induction model in the stator-fixed d-q reference frame is described by [10].

\[ V_s = R_s i_s + \frac{d}{dt} (\Psi_s) . \]  
\[ V_r = 0 = R_i i_r + \frac{d}{dt} (\Psi_r) - j \omega \Psi_r . \]  
\[ \Psi_s = L_s i_s + L_{sr} i_r . \]  
\[ \Psi_r = L_s i_s + L_{rr} i_r . \]  

Whereas the mechanical equation is given as below:

\[ \Psi_{ds} = \int (v_{ds} - R_s i_{ds})dt . \]  
\[ \Psi_{qs} = \int (v_{qs} - R_s i_{qs})dt . \]  

Then, the electromagnetic torque is estimated as

\[ \Psi_{qs} = \int (v_{qs} - R_s i_{qs})dt . \]  

III. NEURAL NETWORK DTC-SVM

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 neural network for Direct Torque control method has been considered due to their various advantages over conventional ones. The implementation of the offline learning algorithm could reduce the superiority of the online efficiency optimization control 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 [11]. 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. The design of the controller is verified by simulation. The development of the structure and learning algorithm of the Neural Network Direct Torque Control (NNDTC) is explained as follows [12].

A. Proposed NN Speed Controller

This paper proposed a NN control method of DTC based on SVM 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-SVM of induction motor drive is shown in Fig. 1.

![Fig. 1. Complete block diagram of proposed NN DTC-SV.](image)

B. Structure of NNDTC

To design the neural network control some information about the plant is required. Basically, the numbers of input and output neuron at each layer are equal to the number of input and output signals of the system respectively. Based on the type of the task to be performed, the structure of the proposed NNDTC is as shown in Fig. 2.

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 \((a_i,z_m)\). The connections weight parameter between \(j^{th}\) and \(i^{th}\) neuron at \(m^{th}\) layer is given by \(w_{ij}^m\) while bias parameter of this layer at \(i^{th}\) neuron is given by \(b_i^m\) [7]. Transfer function of the network at \(i^{th}\) neuron in \(m^{th}\) layer is defined by:

\[
 n_i^m = \sum_{j=1}^{m-1} w_{ij}^m a_j^{m-1} + b_i^m .
\]  

(8)

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

\[
 a_i^m = f^m (n_i^m) .
\]  

(9)

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:

\[
 f^m (n_i^m) = \frac{2}{1 + e^{-2n_i^m}} - 1 .
\]  

(10)

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

\[
 w_{ij}^m (k+1) = w_{ij}^m (k) - \alpha \frac{\partial F}{\partial a_j^m} .
\]  

(11)

\[
 b_i^m (k+1) = b_i^m (k) - \alpha \frac{\partial F}{\partial b_i^m} .
\]  

(12)

Where \(k\) is sampling time, \(\alpha\) is learning rate, and \(F\) performance index function of the network.

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**IV. SIMULATION AND RESULTS**

Simulation has done for the NNDTC to examine its performance. The dynamic model of a three-phase induction motor, space vector PWM and neural network control model have been developed in this section. The simulation is developed using Borland C++, and then embedded as S-function in Simulink-Matlab. The simulation is done with the stator and rotor resistance are 0.5Ω and 0.25Ω respectively while the Stator and rotor self inductances are 0.0415H and 0.0412H. The frequency is 50 Hz with 4 poles.

To verify performance of the proposed NNDTC, the simulation results for a conventional DTC-SVM and the NN DTC-SVM proposed controllers are compared. The simulations of both methods are run simultaneously with the same speed and load torque reference. The simulation is start at the speed on 80 rad/s with a constant load applied. The startup speed response of both systems is shown in Fig. 3. It is clearly explain that the startup speed response has a great improve by reduce the overshoot from 94 rad/s to no overshoot. Both responses show a vast enhancement of the settling time. The speed reference is varying from 80 to 120 rad/s for the subsequence simulation. The performance of two responses is observed. The speed trajectory of the motor when speed varies at the time of 1.5s is shown in Fig. 4.

As illustrated in Fig. 4, the step up response of the speed trajectory again show the vast reduce in overshoot as it is removed from 135 rad/s. The simulation testing is continuing by step down the speed from 110 to 90 rad/s at the time of 3s. The performance for both systems is observed. The speed trajectory of the motor is shown in Fig. 5. As illustrated in Fig. 5, the overshoot of transient speed response is removed from 83 rad/s by applies the proposed neural technique. The settling time taken is also boosted up by the NN controllers when compared with the PID controller.
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1.5 2 2.5
50 60 70 80 90 100 110 120 130 140 150
time (s)
Speed (rad/s)

NN Controller
PID Controller

Fig. 4. Step up speed response comparison between conventional PID SVM and NN-SVM controller when the speed reference is varied from 80 to 110 rad/s.

2.5 3 3.5 4
60 70 80 90 100 110 120 130 140
time (s)
Speed (rad/s)

NN Controller
PID Controller

Fig. 5. 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.

V. CONCLUSION
The NN controller for DTC-SVM speed controller induction motor drive system has been presented in this paper. The proposed method employs a multilayer perception with a 1-5-1 structure neural network algorithm for the speed controller to generate the torque references. The proposed controller is a nonlinear controller which can be employed without required any motor parameter data. The conventional PID controlled DTC IM drive, and a NN controlled DTC IM drive has been presented and compared to investigate the improvement of the performance. Proposed scheme point out the good simulated result where the system performance is augment by using a NN controller compared with the PID controller. It is clear that the improper transient response with high overshoot problem of the conventional PID-DTC can be solved and the improvement of the system performance is achieved. In addition, the results show that the settling time taken is also boosted up by proposed control method.

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REFERENCES