CONTROL OF AN INDUCTION MOTOR WITH DOUBLE ANN MODEL BASED DTC

Fatih Korkmaz

Department of Electric-Electronic Engineering, Çankırı Karatekin University, Uluyazı Kampüsü, Çankırı, Turkey
fkorkmaz@karatekin.edu.tr

ABSTRACT

Direct torque control (DTC) is preferably control method on high performance control of induction motors due to its advantages such as fast dynamic response, simple and robust control structure. However, high torque and current ripples are mostly faced problems in this control method. This paper presents artificial neural network (ANN) based approach to the DTC method to overcome mentioned problems. In the study, by taking a different perspective to ANN and DTC integration, two different ANN models have been designed, trained and implemented. The first ANN model has been used for switch selecting process and the second one has been used for sector determine process. Matlab/Simulink model of the proposed ANN based DTC method has created in order to compare with the conventional DTC and the proposed DTC methods. The simulation studies have proved that the induction motor torque and current ripples have been reduced remarkably with the proposed method and this approach can be a good alternative to the conventional DTC method for induction motor control.

KEYWORDS

Direct torque control, Induction motor control, Artificial neural networks, Vector control

1. INTRODUCTION

In the early 1970s, vector control method was firstly proposed by Blaschke and it was named as field oriented control (FOC). About ten years later, another vector based control method was presented by Takahashi and it was called as direct torque control (DTC). Control of motors with parameters which converted to veal identities, can be acceptable prominent features of the both control methods. [1-2].

Due to rapid development in the field of power switches and microcontrollers technologies , the both methods have shown great development, since they were first presented. When compared with the FOC, the DTC method has some structural advantages such as simple control algorithm, robust controller character due to independency of motor parameters, needs only stator phase resistance, and fast dynamic response. However, the DTC method has some handicaps that can be listed as, high torque and current ripples, variable switching frequency behavior, and implementation limitations owing to necessity of low sampling time [3].

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Over the last decades, different types of the DTC algorithms have been proposed by researchers and academics to overcome mentioned handicaps and most of them have focused on torque ripples side in their studies. In [4], researchers proposed matrix converter based model predictive control approach and they proved that it can be effective in minimizing torque ripples. In [5], authors present a modified DTC algorithm for permanent magnet synchronous motor drives with fast torque dynamics and constant switching frequency. The authors presents the DTC method using fuzzy controller to minimize torque ripples for BLDC in [6] and for induction motors in [7]. Artificial neural network model based DTC systems have also been investigated to reduce torque ripples in [8].

This paper presents a different approach to ANN based DTC model to reduce torque ripples on DTC controlled induction motor drives. Two different ANN models have been designed, trained and performed in the same model. The first ANN model has been used for switch selecting process and the second one has been used for sector determine process. Matlab/Simulink model of the proposed ANN based DTC method was created in order to compare with the conventional DTC and the proposed DTC methods. Basics of the DTC method was explained in Section 2 and proposed ANN based DTC method was documented in detail in Section 3. Simulation results were presented and commented in Section 4.

2. DIRECT TORQUE CONTROL

Mathematical model of the DTC method contains simpler and fewer equations when compared the FOC. Unlike the FOC, the DTC model needs only one motor parameter in the modelling of the control system. Thus, the DTC is considered to be more simple and reliable [9].

The both control techniques methodology base on mathematical transformation that transforms three phase motor parameters to two phase components. The mathematic model of the DTC system bases on Clarke transformation. Thus, some measured three phase parameters of the motor are converted to two phase components, such as voltages and currents. Instant values of the stator flux and produced motor torque can be calculated with these components as defined with following equations. The Clarke transformation matrix is given as:

$$\begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} \tag{1}$$

Where, f_α, f_β are $\alpha-\beta$ components of motor parameters, and f_a, f_b, f_c are the abc frame components[10-11].

$\alpha-\beta$ components of the stator voltages and flux are expressed in following equations.

$$v_{s\alpha} = R_s i_{s\alpha} + L_s \frac{di_{s\alpha}}{dt} \tag{2}$$

$$v_{s\beta} = R_s i_{s\beta} + L_s \frac{di_{s\beta}}{dt} \tag{3}$$

$$\lambda_{s\alpha} = \int (v_{s\alpha} - R_s i_{s\alpha}) dt \tag{4}$$

$$\lambda_{s\beta} = \int (v_{s\beta} - R_s i_{s\beta}) dt \quad (5)$$

The magnitude of the flux can be calculated with:

$$\lambda = \sqrt{\lambda_{s\alpha}^2 + \lambda_{s\beta}^2} \quad (6)$$

and position of the stator flux vector is calculated with:

$$\theta = arctan \frac{\lambda_{s\beta}}{\lambda_{s\alpha}} \quad (7)$$

And finally produced motor torque equation can be written as:

$$T_e = \frac{3}{2} p (\lambda_\alpha i_\beta - \lambda_\beta i_\alpha) \quad (8)$$

In the DTC, motor torque and flux can be controlled directly with control of stator flux vector. In this control, rotation speed of the flux vector controls produced torque while the length controls value. The DTC control algorithm is bases on selecting the appropriate inverter switching state to directly control stator flux vector's speed and length that explain why the method is named as DTC. In order to keep the torque and flux errors within the predefined limits, hysteresis comparators are used [12].

In this control process, six active voltage vectors are used to keep stator flux vector in predefined hysteresis band limit. The flux vector rotation is divided to six different sectors. Figure 1 represents six sector and active voltage vectors.

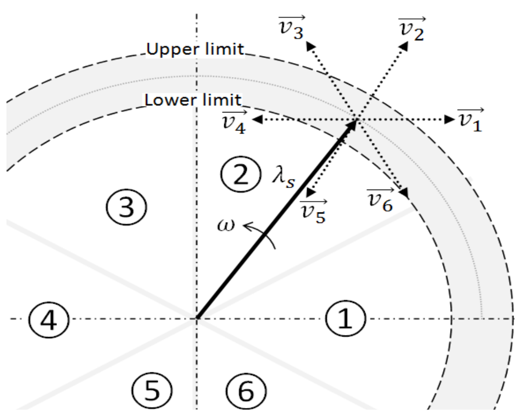

Figure 1. Six sector and active voltage vectors

3. ANN MODEL BASED DTC SYSTEM

ANN models of the control systems are inspired by biological nervous systems and interconnected points, that called neurons, are designed to solve complex problems. In substance, this structure bases on actually working principles of human brain to solve problems.

In recent decades, ANN models have rising popularity in different kind of control systems due to their learning abilities, robust structures, beside their modeling success on non-linear and complex mathematical models.

In the proposed ANN based DTC model, two different ANN models have designed to solve complex processes in conventional DTC approach; selecting appropriate inverter switching states and determining stator flux vector region.

$\alpha - \beta$ components of stator flux were used in the ANN model to determining stator flux vector region process. The ANN model structure is shown in Figure 2

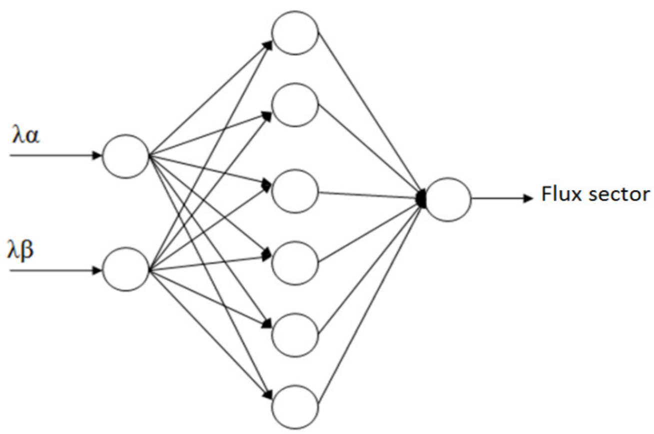

Figure 2. Structure of ANN model for determining stator flux sector

As shown in Figure 2, flux sector ANN model has two neurons in input layer, six neurons in hidden layer and one neuron in output layer. The flux sector ANN was trained about 100000 input data which were obtained with conventional DTC model. 70000 input data were used to train the network while 15000 input data were used for validation and 15000 input data were used for test processes after training. Simulink model of the flux sector ANN given in Figure 3.

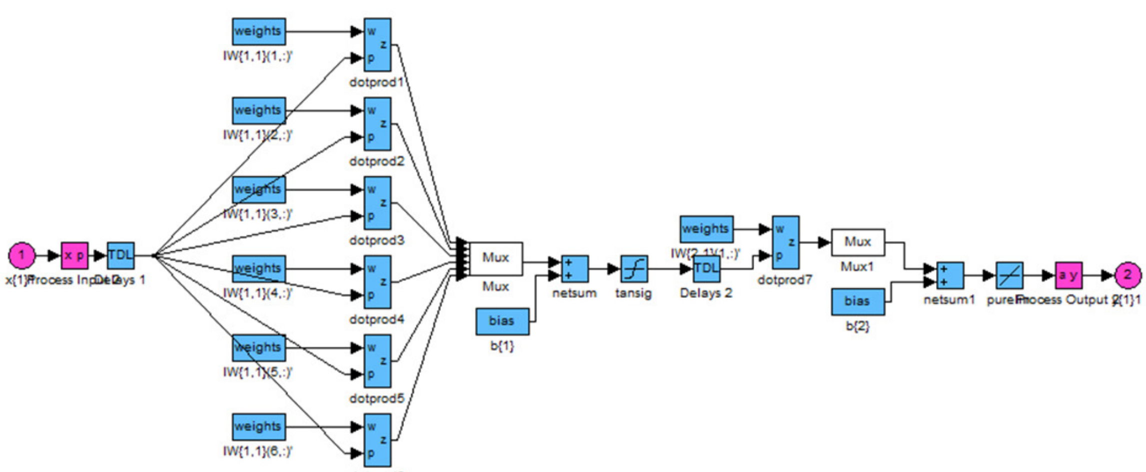

Figure 3. Simulink model of the flux sector ANN unit

Outputs of the flux hysteresis, torque hysteresis and flux region data were used as inputs of the second ANN model which was created to determine optimum inverter switching states.

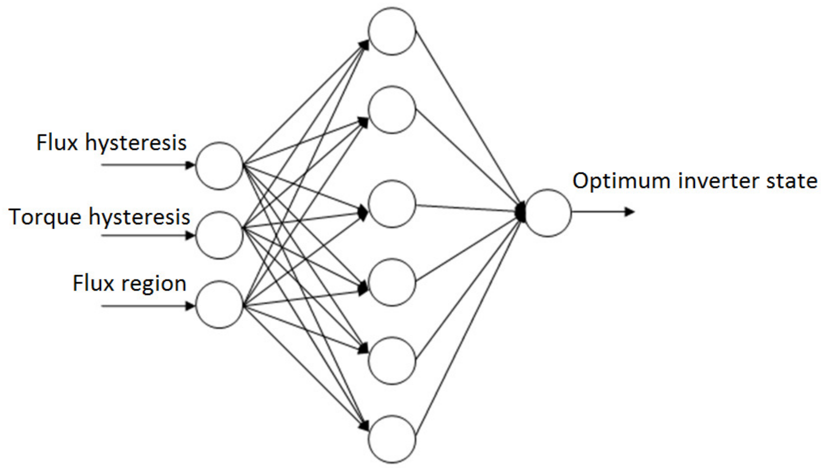

Figure 4. Structure of ANN model for determining optimum inverter switching states

As shown in Figure 4, inverter state ANN model has three neurons in input layer, six neurons in hidden layer and one neuron in output layer. The flux sector ANN was trained about 50000 input data which were obtained with conventional DTC model. 35000 input data were used to train the network while 7500 input data were used for validation and 7500 input data were used for test processes after training. Overall Simulink block diagram of the proposed ANN based DTC system is shown in Figure 5.

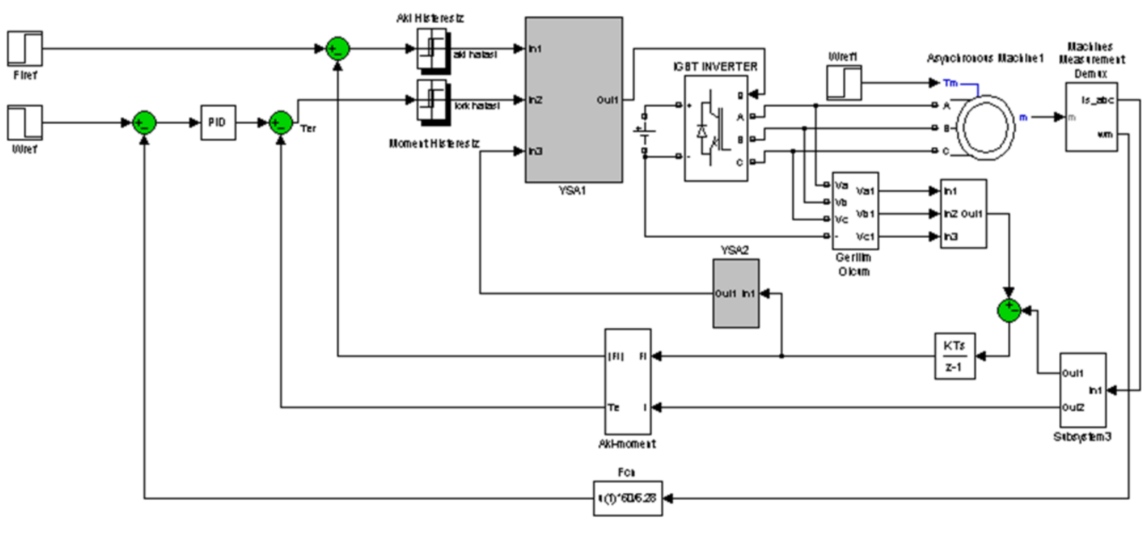

Figure 5. Overall Simulink block diagram of the proposed ANN based DTC system

4. SIMULATIONS

This section presents comparatively simulation results between conventional DTC (C-DTC) and proposed ANN based DTC (ANN-DTC) models. Two different scenarios were applied and investigated to obtain fare comparison between both methods. Induction motor and simulation parameters were presented in Table 1. Total simulation time was 5 sec. and motor load was 0 Nm at the first 3 sec. then switched to 3 Nm reference torque after 3. sec

Table 1. The induction motor and simulation model parameters

Motor Power (kW)	4
Bus Voltage (V)	300
Phase resistance(ohm)	1,54
Flux Reference (Wb)	0,5
Flux Hysteresis Band	±0,05
Torque Hysteresis Band	±0,5
Sample time (μs)	10

In the first scenario, motor was tested at low speed condition with no-load and loaded conditions. The motor speed and torque responses are given in Figure 6 and Figure 7, respectively.

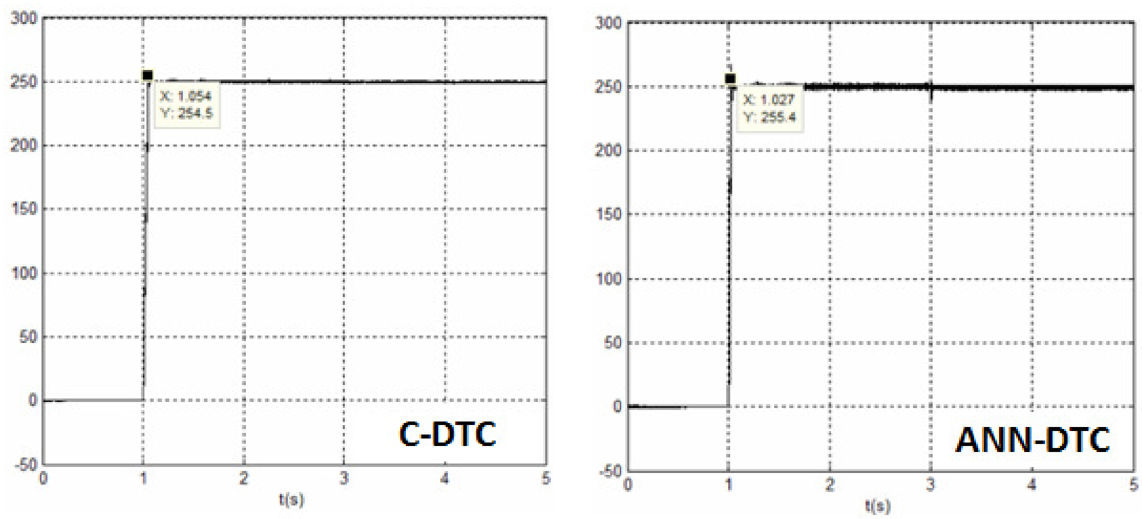

Figure 6. Motor speed curves at 250 rpm reference

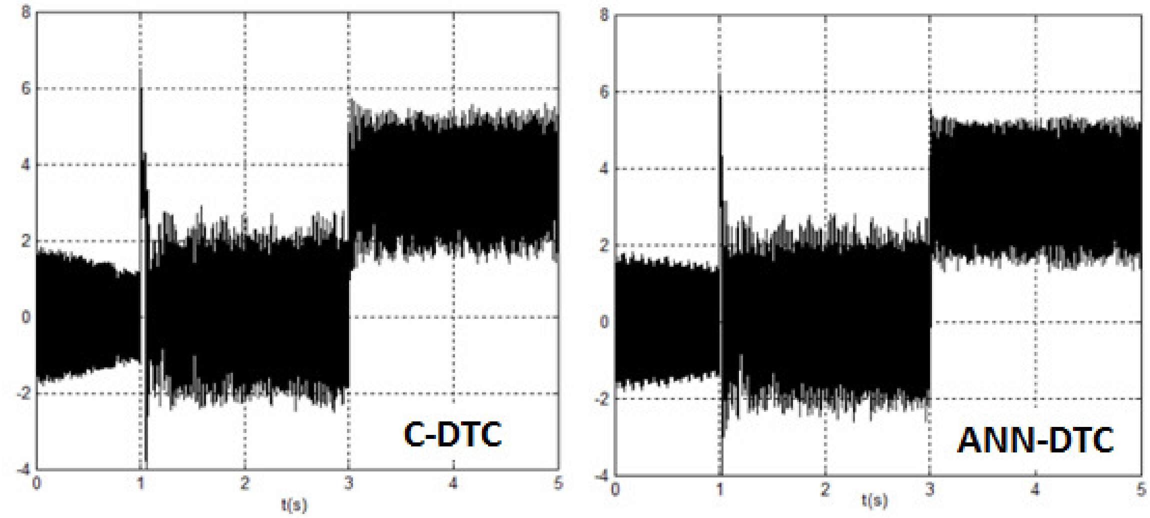

Figure 7. Motor torque curves at 250 rpm reference

As shown in Figure 6 and Figure 7, motor speed and torque performances are almost same in low speed working conditions. In both control approach, torque ripples are about ±2 Nm for unloaded period while torque ripples are about +5/1,7 Nm for loaded conditions. Briefly, it can be said that there are no meaning difference between the both methods for low speed conditions.

In the second scenario, motor was tested at rated speed (2800rpm) with no-load and loaded (3Nm) conditions. The motor speed and torque responses are given in Figure 8 and Figure 9, respectively.

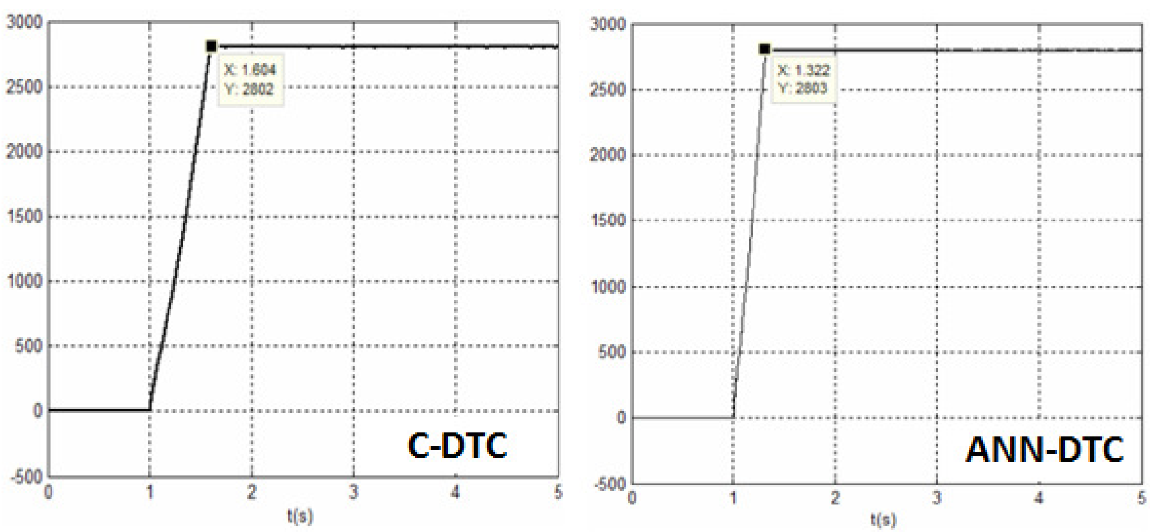

Figure 8. Motor speed curves at 2800 rpm reference

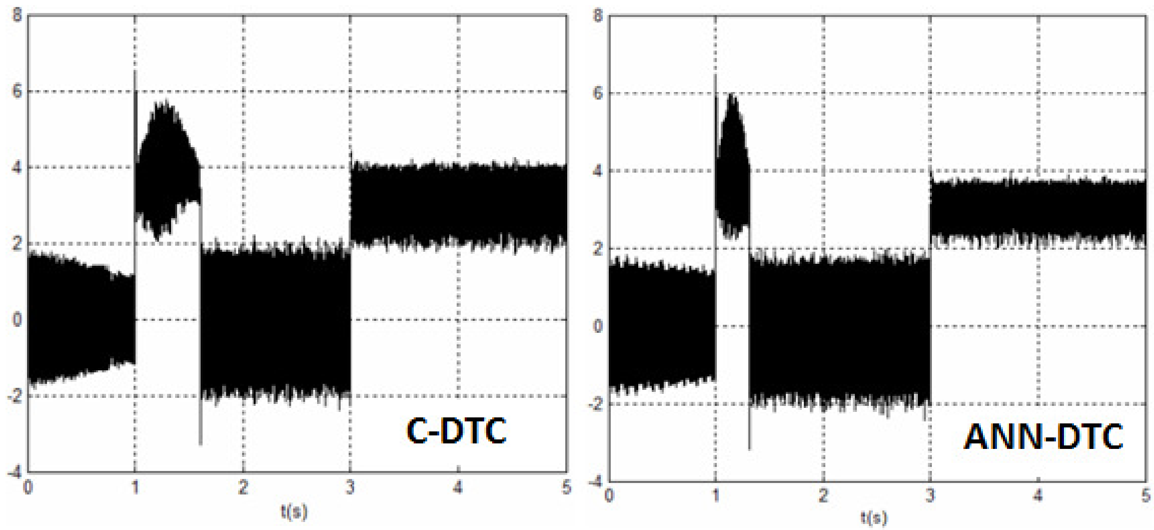

Figure 9. Motor torque curves at 2800 rpm reference

The main difference for the proposed ANN-DTC method emerged in the secondary group of tests as can be seen clearly in Fig 8 and Fig 9. The speed response of the motor proved that ANN-DTC method had faster dynamic responses when compared C-DTC method. Time to reach the reference speed was about %50 shorter in the proposed method. On the other hand, when the torque curves examined closely, it can be seen that torque ripples of the motor were reduced remarkably with the ANN-DTC method.

5. CONCLUSIONS

This paper presents a new artificial neural networks based approach to conventional direct torque control method for high performance control of induction motors. The aim of the paper is simplifying the complex mathematical process in conventional direct torque control method by usage of neural network models. For this aim, two independent neural models have been designed, trained and tested. The first neural model was designed for sectors determine process and the second one were designed for optimum switching select unit. Numerical simulations have been performed to investigate the effects of the proposed method on the overall system performances. Low speed and rated speed performances of the motor were simulated at zero loads and rated loads working conditions. Simulation results have been comparatively presented and they have been showed that proposed neural network based DTC method has better dynamic performance especially closer to rated speed values. The proposed method has faster acceleration time in transient state region and torque ripples were reduced with the proposed method in steady-state region. The practical works on the proposed method as a real time application are still going on and experimental results will be presented by researchers in the future works.

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