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High - Performance using Neural Networks in Direct Torque Control for Asynchronous Machine

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ABSTRACT

This article investigates solution for the biggest problem of the Direct Torque Control on the asynchronous machine to have the high dynamic performance with very simple hysteresis control scheme. The Conventional Direct Torque Control (CDTC) suffers from some drawbacks such as high current, flux and torque ripple, as well as flux control at very low speed. In this paper, we propose an intelligent approach to improve the direct torque control of induction machine which is an artificial neural networks control. The principle, the numerical procedure and the performances of this method are presented. Simulations results show that the proposed ANN-DTC strategy effectively reduces the torque and flux ripples at low switching frequency, compared with Fuzzy Logic DTC and The Conventional DTC.

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1. INTRODUCTION

The asynchronous machine is one of the most widely used machines in industrial applications due to its reliability, relatively low cost and modest maintenance requirement [1]. Advanced techniques of artificial intelligence control are becoming increasingly familiar in various fields of application in recent years. Artificial intelligence is a scientific discipline related to knowledge processing and reasoning, with the aim of Machine to perform functions normally associated with human intelligence such as understanding, reasoning, dialogue, adaptation, learning [1].

The neural network is well known for its learning ability and approximation to any arbitrary continuous function. Recently, neural networks are showing good promise for application in power electronics and motion control systems. It has been proposed in the literature that neural networks can be applied to parameter identification and state estimation of asynchronous motor control systems [2].

A neural network is a system of interconnected nonlinear operators, receiving signals from the outside through its inputs, and delivering output signals, which are in fact the activities of certain neurons [3]. For the applications considered in this, these input and output signals consist of numerical sequences. Neural networks are discrete time nonlinear filters [4]. They may be static (or non-looped) or dynamic (or looped).

The DTC method is characterized by its simple implementation and fast dynamic response. This control has some disadvantages, variable switching frequency behavior and hight torque ripples [5]. An additional robust control term is used by a control law and adaptive laws in the Neural Network, the advantage of this technology is the fastest response time, elimination of ripple and performance as the DC machine [6], [7].

The ANNs are capable of learning the desired mapping between the inputs and outputs signals of the system without knowing the exact mathematical model of the system. Since the ANNs do not use the mathematical model of the system, the same. The ANNs are excellent estimators in non linear systems [6-8]. Various ANN based control strategies have been developed for direct torque control induction motor drive to overcome the scheme drawback. In this paper, neural network flux position estimation, sector selection and switching vector selection scheme are proposed.

In this paper, we present a new artificial neural network DTC (ANN-DTC) scheme in section 1 of an Asynchronous machine to improve motor torque performance. For this purpose, the artificial neural network (ANN) is embedded to conventional DTC scheme in Section 2. More detailed information about ANN based scheme is presented in the Section 3 of the paper. The Section 4 present the simulations with Mablab/Simulink software and the results of the methods are discussed and compared with the conventional DTC and fuzzy logic in the Section 5.

2. PRINCIPLES OF ARTIFICIAL NEURAL NETWORK

The artificial neural networks are universal of nonlinear functions [8].One of the most important features of Artificial Neural Networks (ANN) is their ability to learn and improve their operation using a training data [9]. The basic elements of an ANN are the neurons that correspond to computing nodes. Each node performs the multiplication of its input signals by constant weights, sums up the results, and maps the sum to a nonlinear function; the result is then transferred to its output and an activation function is integred as shown in Figure 1. The mathematical model of a neuron is given by:

$$Y = \phi.(\sum_{i=1}^{N} W_i.x_i + b) \tag{1}$$

Where (x1, x2… xN) are the input signals of the neuron, (w1, w2,… wN) are their corresponding weights and b a bias parameter. Φ is a tangent sigmoid function and y is the output signal of the neuron.

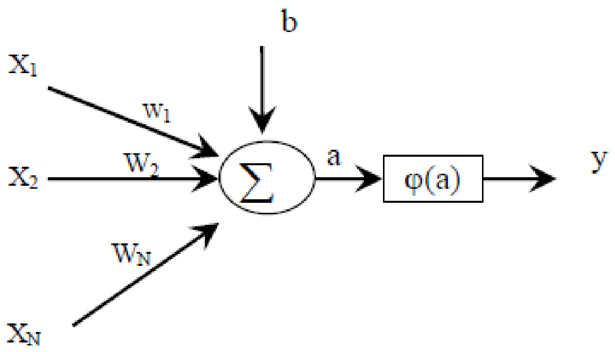

Figure 1. Representation of the artificial neuron

ANN has a very significant role in the field of artificial intelligence. The artificial neurons learn from the data fed t and keep on decreasing the error. Once trained properly, their results are very much same results required from them, thus referred to as universal.

The application of the DTC technique for power supply by a voltage inverter has two level, eight vectors and six angular sectors, then a conventional selector (switching table) twelve sectors will be given. It has been proposed a neuronal selector of the direct control sequences of the two-level inverter with three inputs and three outputs.

2.1. Neuron Network Construction Step

The neural network structure ANN is shown in Figure 2. The inputs of the neural selector are the states of flux, torque, and angular position of the stator flux vector. The outputs are the states of the switches of the inverters with two levels respectively.

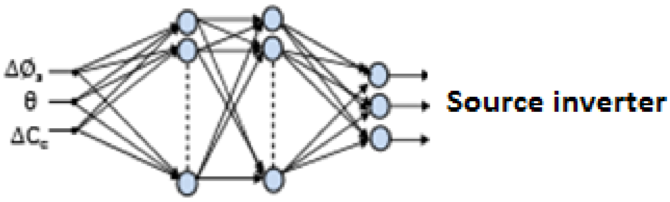

Figure 2. Neural network architecture

2.2. Neural Network Controllers for DTC scheme

A neural network is a machine like human brain with properties of learning capability and generalization. They require a lot of training to understand the model of the plant. The basic property of this network is that it is able to approximate complicated nonlinear functions [10]. The aim is to replace the algorithm for selecting the states of the inverter switches supplying a MAS controlled by DTC by a neural network (RN) capable of generating in the same way the logic signals of the control of the inverter switches. In direct torque control scheme, neural network is used as a sector selector. The direct torque neural controller is shown in Figure 3.

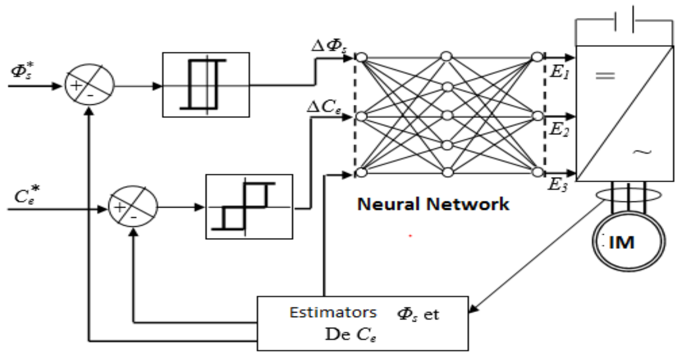

Figure 3. Schematic of DTC using Neural-Network controller

Table 1. Switching Logic

Condition for flux	S_ϕ
$\lvert\phi_s\rvert \leq= \lvert\phi_s^*\rvert - \lvert\Delta\phi_s\rvert$	1
$\lvert\phi_s\rvert \geq \lvert\phi_s^*\rvert + \lvert\Delta\phi_s\rvert$	0
Condition for torque	S_T
$\lvert C_e\rvert \leq= \lvert C_e^*\rvert - \lvert\Delta C_e\rvert$	1
$\lvert C_e\rvert = \lvert C_e^*\rvert$	0
$\lvert C_e\rvert \geq \lvert C_e^*\rvert + \lvert\Delta C_e\rvert$	-1

In this control strategy, the comparators are switched by a neuronal controller whose inputs are torque, stator flux and angle position. The output is the pulses allowing to control the inverter switches, for generating this neural controller by Matlab / Simulink or selecting 10 hidden layers and 3 layers of outputs with the activation functions of 'tansig' and 'purelin' respectively; The torque and flux errors are multiplied by the constant value and which are given as inputs along with the flow position information to the neural network controller. Output of the controller is compared with the previous switching states of inverter. The switching logic given below in the Table 1 developed from the output signals of hysteresis comparators; represent the increment (decrement) of the flux (torque) [11], [12].

The neural network is organized in layers: an input layer, one or more hidden layers, and an output layer [12]. A node in the hidden layer has two functions. The first is to "summarize" the information that comes in as input, the second is to apply a transfer function to this sum and thus provide this result to the output nodes (or the node of another hidden layer if there is one). Figure 4 shows the proposed neural network for DTC scheme in which, input, output and hidden layers are shown. The error signals and stator flux angle are given to input layer. Switching state information is taken from the output layer.

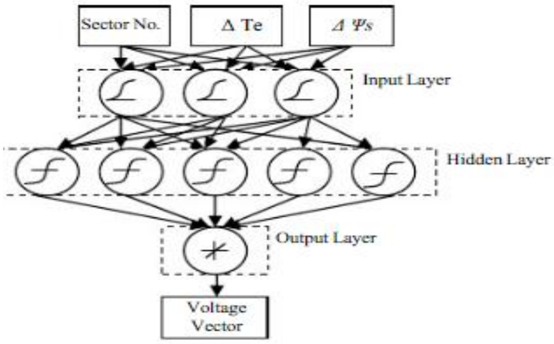

Figure 4. Representation of the artificial neuron

In this case, the inputs of the neural network are the position of the stator flux vector represented by the corresponding sector number, the difference between its estimated value and its reference value and the difference between the estimated electromagnetic torque and the torque or three neurons there are in the input layer.

3. SIMULATION MODEL AND STRUCTURE OF DTC SYSTEM BASED ANN

The ANN is trained by a learning algorithm which performs the adaptation of weights of the network iteratively until the error between target vectors and the output of the ANN is less than an error goal. The most popular learning algorithm for multilayer networks is the backpropagation algorithm and its variants [12]. The latter is implemented by many ANN software packages such as the neural network toolbox from MATLAB [13], [14]. Using Back Propagation algorithm Neural Network was trained with example which is given in MATLAB NN design. The Figure 5 shows the complete structural blocks of the Neural Network controller.

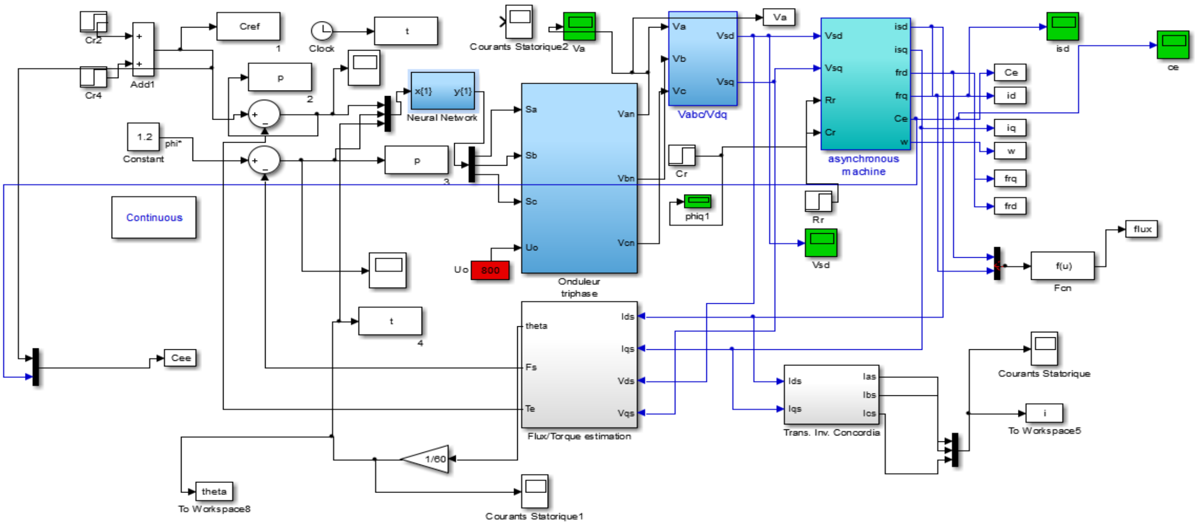

Figure 5. General structure of DTC-ANN control

The block neural network content two layer 1 and 2 illustrated in Figure 6.
The block neural network of layer 1 is given by the Figure 7.

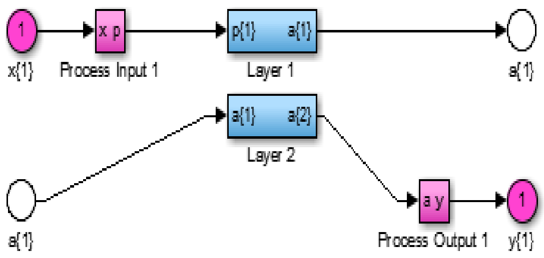

Figure 6. Block neural network layer 1 and layer 2

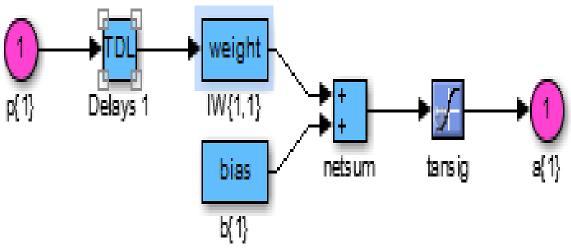

Figure 7. Sub Block neural network layer 1

The block neural network of layer 2 is given by Figure 8:

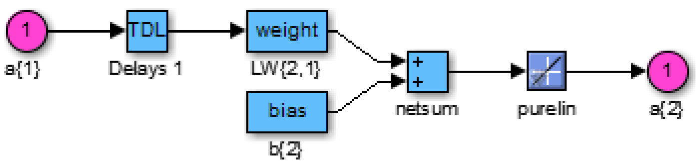

Figure 8. Sub Block neural network layer 2

To study the performance of the fuzzy logic of direct torque control given by [15], [16] and neural network switching table with direct torque control strategy, the simulation of the system was conducted using. Simulation results for a DTC system when controlling the induction machine is given by Figure 9 and Figure 10. It can be seen that the ripple in torque with Fuzzy logic DTC FLDTC and Neural Network DTC ANN_DTC control is less than 0.3 Nm.

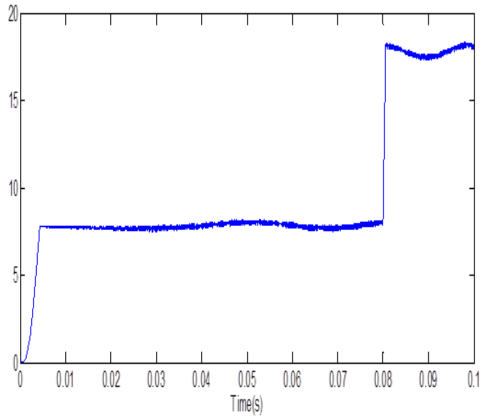

Figure 9. Electromagnetic Torque using Neural Network

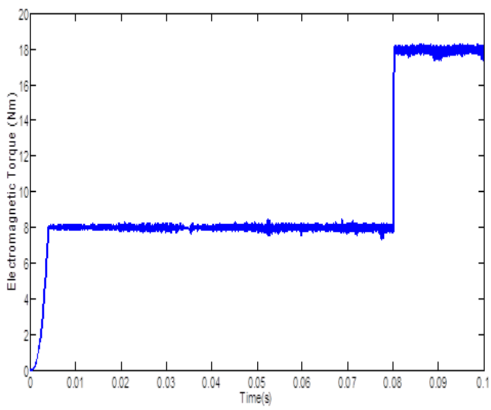

Figure 10. Electromagnetic Torque using Fuzzy Logic Direct Torque control

By FLDTC and ANN_DTC technique presented by Figures 11 and 12, the stator flux are the fast response in transient state and the ripple in steady state is reduced remarkably compared with conventional

DTC, the flux changes through big oscillation and the torque ripple is bigger in FLDTC. Notice that stator flux vector describes a trajectory almost circular in Figure 13.

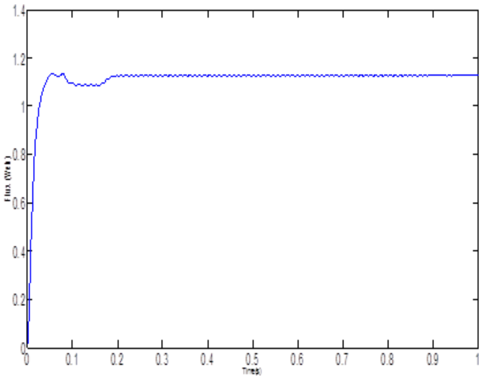

Figure 11. Stator Flux using Neural Network Direct Torque control

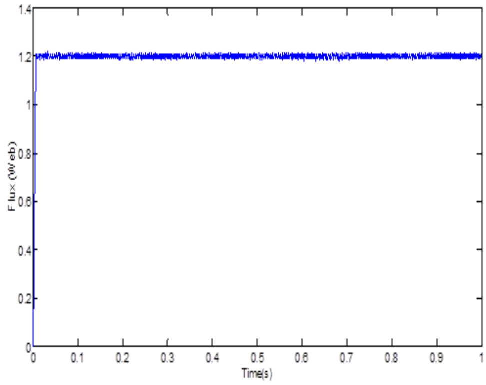

Figure 12. Stator Flux using Fuzzy logic Direct Torque control

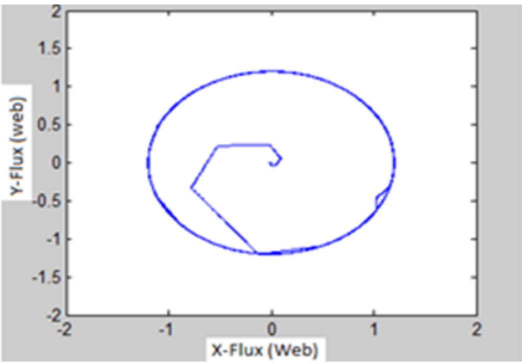

Figure 13. Stator flux trajectory using Neural Network

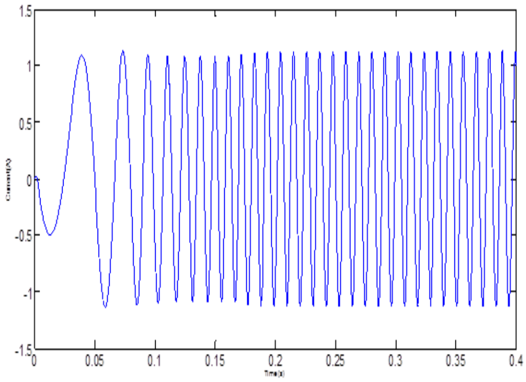

Figure 14.Stator Current using Neural Network Direct Torque control

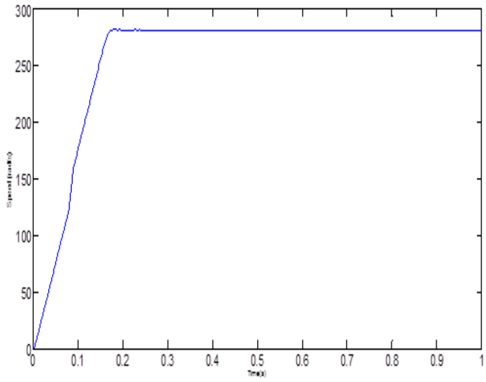

Figure 15. Evolution of Speed using Neural Network Direct Torque control

The Figures 14 and 15 show the steady state current response and speed of the FLDTC and ANN_DTC has negligible ripple in stator current and a nearly sinusoidal wave form while as with conventional DTC the stator current has considerably very high ripple [17].

In comparison study, we have compared the simulations results of neural network with others methods DTC control methods like the conventional Direct Torque Control. The comparison results are classified as follows in the Table 2:

Table 2. Comparison study between conventional DTC and Neural Network DTC

Conventional Direct Torque Control	Direct Torque Control based on Neural Network
Proposed in the mid-1980s by I.Takahashi	Proposed by Mc Culloch (neurophysiologist) et Pitts (logician)
It is robust against the parametric variations of the machine	It is robust against the parametric variations of the machine
Its structure is simple and requires no mechanical sensor.	Its structure is simple and requires no mechanical sensor.
The fast torque and flux dynamics	The fast torque and flux dynamics
At low speeds, the flux is difficult to control.	Fixe the switching frequency.
The undulations of the torque and flux around the hysteresis bands	Have fast flux and torque responses with less distortion.

4. CONCLUSION

In this paper, an improvement for direct torque control algorithm of asynchronous machine is proposed using intelligent neural network approaches which consists of replacing the switching selector block and the two hysteresis controllers. Simulations show that the proposed strategy has better performances than the Conventional DTC and Fuzzy logic DTC .The comparison of the neural network with other results fuzzy logic or the conventional DTC have the same results, which enabled us to validate methods of improving the strategy of the Direct Torque Control based on Neural Network proposed. The ANN-DTC scheme performance has been tested by simulations which is shown as dynamic responses are the faster in transient state and the torque ripple in steady state are reduced remarkably when compared with the conventional DTC for loaded and unloaded conditions. The main improvements shown are:

a. Reduction of torque and current ripples in transient and steady state response.
b. No flux droppings caused by sector changes circular trajectory.
c. Fast stator flux response in transient state.

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