Neural Network Based Predictive DTC Algorithm for Induction Motors

N.Vahdatifar Ss.Mortazavi R.Kianinezhad

Abstract—In this paper, a Neural Network based predictive DTC algorithm is proposed .This approach is used as an alternative to classical approaches .An appropriate Feed - forward network is chosen and based on its value of derivative electromagnetic torque ; optimal stator voltage vector is determined to be applied to the induction motor (by inverter). Moreover, an appropriate torque and flux observer is proposed.

Keywords—Neural Networks, Predictive DTC

I. INTRODUCTION

THE use of the induction motor in servo drives is limited by its complex highly coupled nonlinear structure . This complexity implies certain control related   problems However ,due to its ruggedness, maintenance free operation and many other advantages ,squirrel cage induction motor are still ideal actuators for industrial applications(in some cases).

The basic problem of the induction motor control is the lack of the inverse model. Inverse model could be applied to calculate the desired applied stator voltage from the desired values of torque and flux. Hence, the FOC and later DTC methods were developed [1-5] . However, none of these methods analytically connects applied stator voltages to the torque(although some work has been done in that area [6]) . A popular approach is using torque and flux derivative functions for the presentation and execution of DTC[7].. However ,in order to get an improved performance other factors like   back - emf have to be taken into account .A substantial amount of work has been performed on this subject,and promising results have been obtained with use of predictive algorithms. Several predictive DTC approaches have been presented in last few years[9-13].

In most cases the PWM duty cycle is calculated to reduce the error of torque and flux from their desired values. In [14] the motivation was to use the Lyapunov stability function as a criteria function , which implies the inherent stability of control.

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In this paper , a novel approach using Feedforward network is proposed. Torque and derivative functions are chosen as ANN inputs to calculate the optimal voltage vector.

II . INDUCTION MOTOR MODEL

In smooth rotor and stator (i.e. with constant air gap) , phase windings are symmetrical. Both neutrals of the star connected winding are isolated. The permeability of fully laminated stator and rotor iron is infinite. Saturation ,iron losses , end - winding and slot-effects are ignored. Hence, model of a three - phase squirrel cage induction motor in the stator reference frame can be expressed as   [1, 2, and 8]:

$$\frac{d\psi_s^s}{dt} = u_s - R_s i_s^s \tag{1}$$

$$\frac{d\psi_r^s}{dt} = \frac{L_m}{L_r} R_r i_s - R_r \psi_r^s + \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} p\omega_r \psi_r^s \tag{2}$$

$$\frac{di_s^s}{dt} = \frac{1}{\sigma L_s}\left(u_s^s - \left(R_s + R_r\left(\frac{L_m}{L_r}\right)^2 \right)i_s^s - \frac{L_m}{L_r}\frac{R_r}{L_r}\psi_r^s + \right.$$

$$\begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} p\omega_r \frac{L_m}{L_r}\psi_r^s = \frac{1}{\sigma L_s}\left(u_s^s - e_s^s \right) \tag{3}$$

$$e_s^s = R_s i_s^s + \left(\frac{L_m}{L_r}\right)\frac{d\psi_r^s}{dt}, \tag{4}$$

$$\psi_s^s = \frac{L_m}{L_r}\psi_r^s + \sigma L_s i_s^s, \tag{5}$$

Where $\psi_s^s = \left[\psi_{sa}^s \ \psi_{sb}^s\right]^T$ is stator flux, $\psi_r^s = \left[\psi_{ra}^s \ \psi_{rb}^s\right]^T$ is rotor flux and $u_s^s = \left[u_{sa}^s \ u_{sb}^s\right]^T$ is the stator voltage , and $i_s^s = \left[i_{sa}^s \ i_{sb}^s\right]^T$ is the stator current , ω_r is the rotor axis speed . σ is the total leakage factor $\left(\sigma = 1 - L_m^2 /(L_r L_s)\right)$ and p is number of pole pairs . R_S and R_r are stator and rotor resistance ; L_s and L_r denote stator and rotor self - inductance, whereas L_m is mutual inductance. T_e the torque produced by the drive is calculated as:

$$T_e = \frac{3p}{2}\left(\psi_{sa}^s i_{sb}^s - \psi_{sb}^s i_{sa}^s\right) \tag{6}$$

The mechanism can be presented with the following equation:

$$J\frac{d\omega_r}{dt} = T_e - T_L \tag{7}$$

Where J is the inertia and T_L is the applied load torque including motor friction.However, the applied torque derivative can be calculated from (6):

$$\frac{dT_e}{dt} = \frac{3pL_m}{2\sigma L_s L_r}\left(\begin{array}{c} \frac{d\psi_{ra}^s}{dt}\psi_{sb}^s + \frac{d\psi_{sb}^s}{dt}\psi_{ra}^s - \frac{d\psi_{rb}^s}{dt}\psi_{sa}^a \\ -\frac{d\psi_{sa}^a}{dt}\psi_{rb}^s \end{array}\right) \quad (8)$$

With the use of (1) ,(2) and(3) , the equation can be rewritten as:

$$\frac{dTe}{dt} = \frac{3pL_m}{2\sigma L_s L_r}(\underbrace{\psi_{ra}^s u_{sb}^s - \psi_{rb}^s u_{sa}^s}_{part1} - \underbrace{(\frac{R_s}{\sigma L_s} + \frac{R_r}{\sigma L_r})}_{part2}$$

$$\underbrace{(\psi_{ra}^s\psi_{sb}^s - \psi_{rb}^s\psi_{sa}^s) - p\omega_r(\psi_{ra}^s\psi_{sa}^s + \psi_{rb}^s\psi_{sb}^s))}_{part2} \quad (9)$$

Which result in:

$$\frac{dT_e}{dt} = -\left(\frac{R_s}{\sigma L_s} + \frac{R_r}{\sigma L_s}\right)Te + \frac{3pL_m}{2\sigma L_s L_r}$$
$$\left(\psi_{ra}^s u_{sb}^s - \psi_{rb}^s u_{sa}^s - p\omega_r\left(\psi_{ra}^s\psi_{sa}^s + \psi_{rb}^s\psi_{sb}^s\right)\right) \quad (10)$$

In a simpler from (10) can be rewritten with the use of (4) as:

$$\frac{dT_e}{dt} = \frac{3pL_m}{2\sigma L_r L_s}\left(\left(\psi_{ra}^s u_{sb}^s - \psi_{rb}^s u_{sa}^s\right) - \left(\psi_{ra}^s e_{sb}^s - \psi_{rb}^s e_{sa}^{s)}\right)\right) \quad (11)$$

III. DIRECT TORQUE CONTROL

The main idea of Direct Torque Control (DTC) is to directly control the torque and flux produced by the machine,without current control, as it is the case in FOC [4] , [5] .Different approaches have been developed [12] ,[13]. However, in this paper only a basic approach and a new proposed algorithms will be presented.

Let us first present the basic conventional DTC control scheme, as described in [2],[3],[4] . The control scheme is presented in Fig.2, where in the presentation of sectors of the stator flux angle is included also(Fig.1).The applied switching table is presented in I .[14]

TABLE I SWITCHING TABLE-STATOR FLUX ORIENTED DTC ALGORITHM

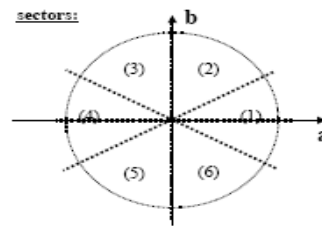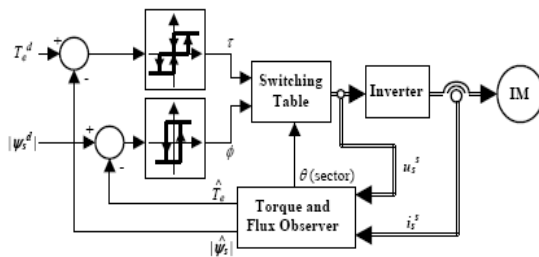| ϕ τ θ		$\theta(1)$	$\theta(2)$	$\theta(3)$	$\theta(4)$	$\theta(5)$	$\theta(6)$
$\phi=0$	$\tau=-1$	V5	V6	V1	V2	V3	V4
	$\tau=0$	V0	V7	V0	V7	V0	V7
	$\tau=1$	V3	V4	V5	V6	V1	V2
$\phi=1$	$\tau=-1$	V6	V1	V2	V3	V4	V5
	$\tau=0$	V1	V2	V3	V4	V5	V6
	$\tau=1$	V2	V3	V4	V5	V6	V1

Fig. 1. Sectors which table 1 is configured

Fig. 2.DTC control scheme - stator flux oriented DTC algorithm

IV. BASIC PRINCIPLE OF ARTIFICIAL NEURAL NETWORK USED FOR TRINING

Neural networks have self- adapting compatibilities which makes them well suited to handle non-linarites,uncertainness and parameter variations.A multilayered feed forward neural network constructs a global approximations to non- linear input-output mapping [15]. Neural networks are capable of generalization in regions of the input space, where little or no training data are available.The structure of the proposed neural network used in this paper,is shown in Fig .3
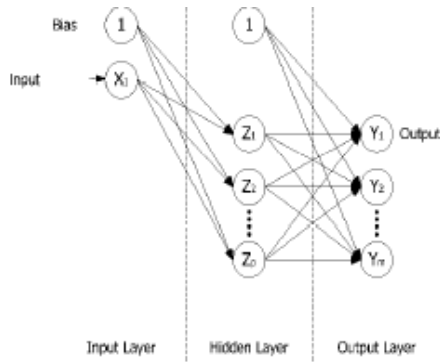
Fig. 3. Structure of proposed artificial neural networks

The proposed neural networks have three layers, i.e. input layer, hidden layer and the output layer.Input layer has 10 neurons,output layer has only one neuron and hidden layer has 15 neurons.Momentum coefficient,learning rate and final error is 0.9, 0.09 and 1e-6 respectively.Neural network based predictive control scheme is present in Fig.4.
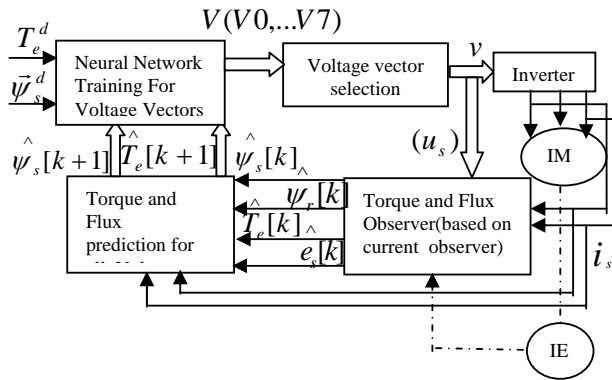

Fig. .Neural network based predictive control scheme.

In order to reach the best convergence behavior ,the voltage vector is selected from the existing 8 (actually7) choices.The equation 9 has two parts. Part 2 is independent of voltage vector.Values of the inputs of neural network are divided to 7 vectors according to 7 switching states. However, the following formulas are calculated (estimated values are denoted by ^):

$$\frac{dT_e}{dt}[k] = \frac{3pL_m}{2\sigma L_s L_r} \left(\left(\overset{\wedge}{\psi}_{ra}^{s}[k]u_{sb}^{s}[k] - \overset{\wedge}{\psi}_{rb}^{s}u_{sa}^{s}[k] \right) - \left(\overset{\wedge}{\psi}_{ra}^{s}[k]e_{sb}^{s}[k] - \overset{\wedge}{\psi}_{rb}^{s}[k]e_{sa}^{s}[k] \right) \right) \tag{12}$$

$$\frac{d\hat{i}_s}{dt} = \frac{1}{\sigma L_S}(u_s^s - \hat{e}_s^s) \tag{13}$$

$$\hat{T}_e[k+1] = \hat{T}_e[k] + T\frac{d\hat{T}_e}{dt}[k], \tag{14}$$

$$\overset{\wedge}{\psi}_s^s[k+1] = \overset{\wedge}{\psi}_s^s[k] + T\frac{d\overset{\wedge}{\psi}_s^s}{dt}[k], \tag{15}$$

V . TORQUE AND FLUX OBSERVOR

Torque and flux observer(Fig. 5) is based on (3),which is rewritten in following form[14]:

$$\frac{d\overset{\wedge}{\psi}_s^s}{dt} = u_s^s[k] - R_s i_s^s[k], \tag{16}$$

Where

$$\hat{e}_s^s = R_s \hat{i}_s^s + \left(\frac{L_m}{L_r}\right)\left(\frac{d\overset{\wedge}{\psi}_r^s}{dt} + k(\hat{i}_s - i_s^s)\right) \tag{17}$$

and

$$\frac{d\overset{\wedge}{\psi}_r^s}{dt} = \frac{L_m}{L_r}R_r i_s - \frac{R_r}{L_r}\overset{\wedge}{\psi}_r^s + k(\hat{i}_s^s - i_s^s). \tag{18}$$

Stator flux is calculated with (5),whereas torque calculation is performed with (6).
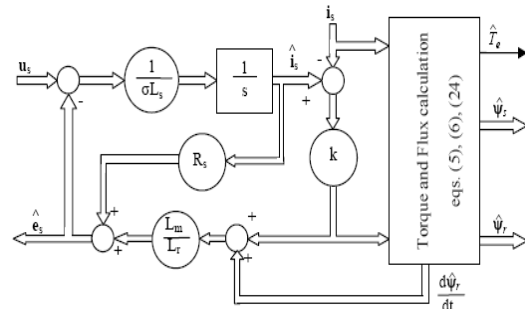

Fig. 5 Torque and Flux observer based on the current observer.

VI . SIMULATION RESULTS

Simulation results for the presented algorithm are shown in Fig 5 – 12. Excellent torque and flux tracking can be observed , torque ripple is reduced for a considerable rate and stator current is sinusoidal . Fig.5 shows the seven group data which train with back propagation algorithsm.The quadrature axis is different state swiching which is normalized.The . and denote to output without training and with training respectively. Fig.7 shows difference between target and output of neural network in different outputs. Stator voltages are presented in Fig.11.
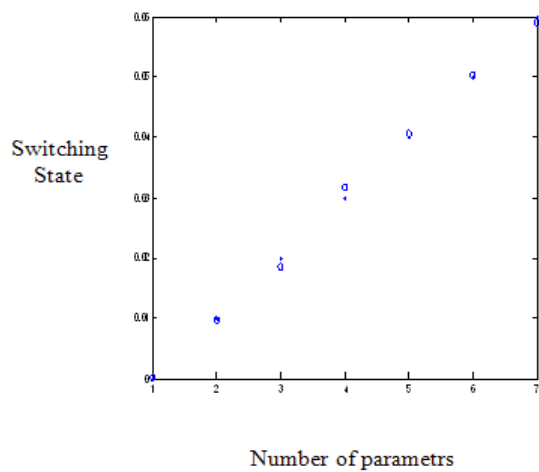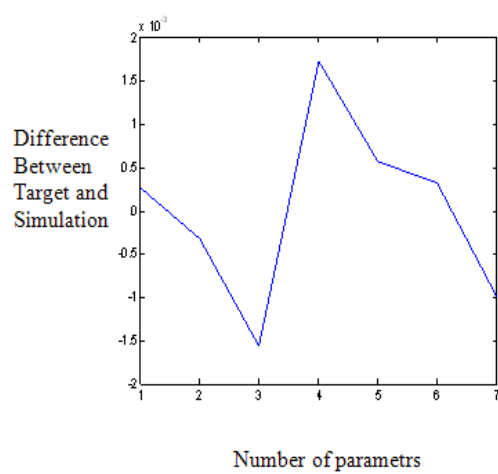
Fig. 6.Output after trainig network

Fig.7. Difference between target and simulation result
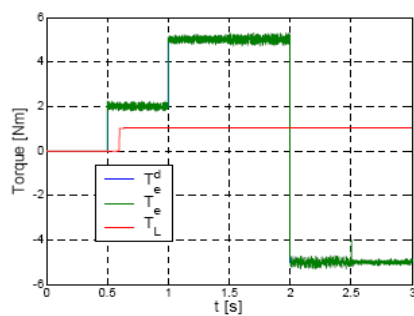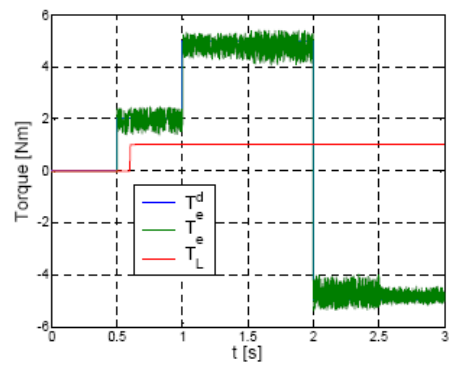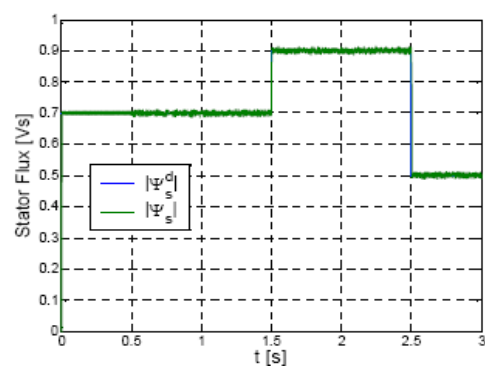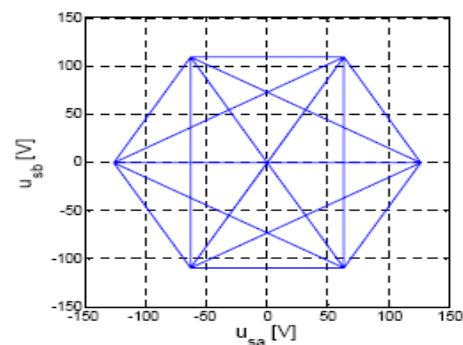

Fig .8.Simulation results – Neural network based DTC Applied torque (*T*e), its desired value(*T*ed) and applied load torque (*T*L).

Fig. 9. Simulation result- classic DTC – Applied torque (*T*e), its desired value (*T*ed) and applied load torque (*T*L).

Fig .10. Simulation results – Neural network based DTC - Stator flux ($\left|\psi_s\right|$) and its desired value ψ_s^d

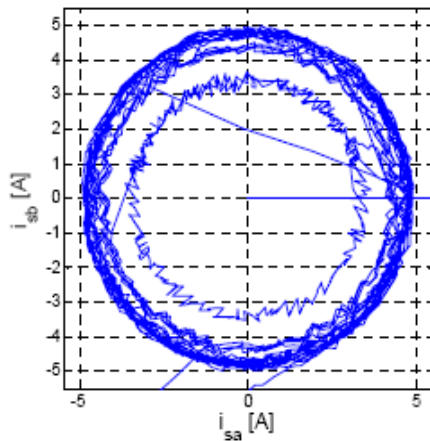Fig. 11. Simulation results – Neural network based DTC - Stator voltage

Fig. 12. Simulation results Neural network based DTC - Stator current

VII. CONCLUTION

A neural network based predictive DTC for induction motors is presented in this paper. To control the motor , an appropriate torque and flux observer is proposed also. Torque and its derivative are chosen as ANN inputs to calculate the optimal voltage vector. It is shown in simulation results, that under identical conditions the results obtained by the use of proposed method, are improved compared to classical DTC, which is especially true for the torque ripple. Torque ripple is reduced by a considerable ratio due to soft interpolation property of ANN. A comprehensive simulation study in MATLAB shows satisfactory results.

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