Contribution to the Artificial Neural Network Direct Control of Torque Application Utilizing Double Stars Induction Motor.

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Abstract— **In this paper we propose to study a control strategy known as Neural Network direct control for the study of the control of torque when using speed loop regulation of double start induction motor. The research discussed below indicates that it is possible to replace a conventional switching table by a neural network.**

The neural networks used are the back-propagation, to reduce the training patterns and increase the execution speed of the training process, the inputs of switching table are converted to digital signals, i.e., one bit represent the flux error, one bit the torque error, and one bit represent the location of tension Vector.

As results we achieved can be summarised as follows:

1-amelioration the responding time of the system

2-Minimization of the torque ripples.

3-Minimization of the current total harmonic distortion

Key words-- the double start asynchronous motor, artificial neural network (ANN).direct control of torque. Regulator PI.

I. INTRODUCTION.

Significant developments have occurred in recent years regarding the material advances in many different fields (magnetic, mechanical, thermal ...), the power electronics (high powers, high frequencies, new topologies ...), machine control (digital technologies, control methods), the sensors and also the engines structures. All these advances have been considered earlier in the electrical machine control [4].

The multi-phase machine is one case increasingly used in dual applications mode, tri mode application for reasons of reliability and power segmentation. We propose to study in this paper about the double star asynchronous machine. whose figure(1) expresses the windings of the double star induction machine and the offset angle between the two stars windings.

-A1,B1,C1: Winding of stator 01.

-A2,B2,C2: Winding of stator 02

-γ: offset angle between Two stators.

-θ: offset angle between the rotative part and the stators 01&02.

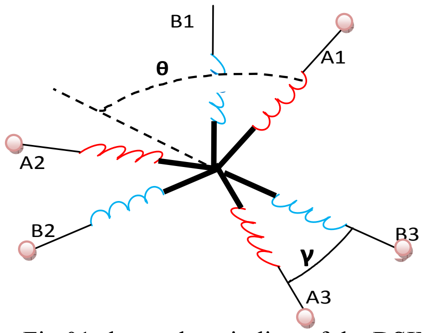


Fig.01.shows the winding of the DSIM

The control of the double star asynchronous machine has progressed significantly in recent times, in particularly with the method of torque control and specifically the direct control of torque. This method law controls the direct opening and closing of the inverter switches from the values calculated by using the stator flux and electromagnetic torque references, the Classic DTC uses the errors signs of torque and electromagnetic flux values.on of many modified DTC schemas that attempt to improve DTC behavior is **neural network DTC,** in this paper it is suggested that it is possible and practical to use a neural network controller that will be insensitive to system parameters variation and take advantage of the learning capability of the neural network.

Today, **neural network** is a technique used in artificial intelligence and with widely used in various areas including: control, automation, robotics ... etc. Indeed this is a new method of dealing with problems of adjustment, control and decision making.

II. MODELING OF THE DOUBLE STAR INDUCTION MOTOR.

The mathematical model of the machine is can be expressed by the following set of electrical/mechanical equations

The first star:

$$[V_{abc,s_1}] = [Rs_1][abc,s_1] + \frac{d[\varphi abc,s_1]}{dt} \qquad (2.1)$$

For the rotative part:

$$[V_{abc,r}] = [Rr][abc,r] + \frac{d[\varphi abc,r]}{dt} \qquad (2.3)$$

The mechanical equations:

$$J\frac{d\Omega}{dt} = Tem - Tr - kf\Omega \qquad (2.4)$$

Where J is the moment inertia of the rotating parts, K_f is the friction coefficient related to the engine bearings, and T_{em} represents the torque loading[5].

The electrical state variables in "αβ" system are the electrical flux, and the input variable in the system "αβ" expressed by the vector [U] then the state space representation of the machine can be modeled and expressed in the form:

$$\dot{X} = \frac{dX}{dt} = AX + BU \qquad (2.5)$$

With; X : state variables

$$X = [\varphi_{Salph1} \quad \varphi_{Sbeta1} \quad \varphi_{Sa\,lph2} \quad \varphi_{Sbita2} \quad \varphi_{R\,alpha} \quad \varphi_{Rbita}]$$

A: system evolution matrix

$$A = \begin{bmatrix} A11 & A12 & A13 & A14 & A15 & A16 \\ A21 & A22 & A23 & A24 & A25 & A26 \\ A31 & A32 & A33 & A34 & A35 & A36 \\ A41 & A42 & A43 & A44 & A45 & A46 \\ A51 & A52 & A53 & A54 & A55 & A56 \\ A61 & A62 & A63 & A64 & A65 & A66 \end{bmatrix} \qquad (2.6)$$

B: control Vector

$$B = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \qquad (2.7)$$

U: input vector it is represented by the tension vector

$$U = [V_{Salph1} \quad V_{Sbeta1} \quad V_{Sa\,lph2} \quad V_{Sabeta2}] \qquad (2.8)$$

III.PRINCIPLE OF DIRECTE CONTROL OF TORQUE

Direct control of torque, is an approach that allows control of the direct switch converter using a simple algorithm. The DTC (Direct Torque control) appeared in the 1980 [1], after a variety of algorithms has been proposed based on refinements developed from heuristic switching choices [6],

If we consider the first start and the equations used for vectorial representation of the stator characteristics of the machine which binds to the stator reference.

$$\begin{cases} \overline{Vs_{alph_1}} = Rs_1 \overline{Is_{alph_1}} + \dfrac{d\overline{\varphi_{s\,alph\,1}}}{dt} \\ \overline{Vr} = \overline{0} = Rr\,\overline{Ir} + \dfrac{d\overline{\varphi r}}{dt} - j\omega\overline{\varphi_r} \end{cases} \qquad (3.1)$$

From the electrical flux expression the rotor current can be expressed as:

$$\overline{Ir} = \frac{1}{\sigma}\left(\frac{\overline{\varphi_r}}{Lr} - \frac{Lm}{LrLs}\overline{\varphi_{s\,alpha_1}}\right) \qquad (3.2)$$

With the dispersion coefficient

$$\sigma = 1 - \frac{L_m^{\ 2}}{LsLr}$$

The expressions (3.1) become

$$\begin{cases} \overline{V_{s\ alpha\ 1}} = Rs_1 \overline{I_{s\,alph\ 1}} + \dfrac{d\overline{\varphi_{s\,alph\ 1}}}{dt} \\ \dfrac{d\overline{\varphi_r}}{dt} + \left(\dfrac{1}{\sigma\tau_r} - j\omega\right)\overline{\varphi_r} = \dfrac{Lm}{Ls}\dfrac{1}{\sigma\tau_r}\overline{\varphi_{s\,alph\ 1}} \end{cases} \qquad (3.3)$$

Relation (3.3) shows that:

It is possible to control the vector $\varphi_{s\,alph_1}$ from the vector Vs to the voltage drop near R_{sIs}.

The vector follow the variation of $\varphi_{s\,alph_1}$ with $\sigma\tau_r$ as a time term constant, the rotor act as a filter (time constant $\sigma\tau_r$) between the flux $\varphi_{s\,alph_1}$ and φ_r.

Moreover φ_r reach in the steady state value;

$$\overline{\varphi_r} = \frac{L_m}{Ls}\frac{\overline{\varphi_{s\,alph\ 1}}}{1 + j\omega r\sigma\tau_\tau} \qquad (3.4)$$

By putting $\gamma = (\overline{\varphi_s}\,\overline{\varphi_r})$ the representation of torque expression becomes.

$$\Gamma_{elm} = p\frac{Lm}{\sigma LsLr}\varphi_{s\,alpha_1}\varphi_r \sin\gamma \qquad (3.5)$$

From the expression (3.6) we know that, the torques value is dependents on the amplitude of the two vectors $\varphi_{s\,alph_1}$ and φ_r with relative position. If flux control $\varphi_{s\,alph_1}$ can be perfectly managed from the module and the position of tension vector Vs. It is therefore possible to control the amplitude and the relative position of φ_r so clearly changes to the torque value and thus torque control will be a consequence of course this is possible only if the control period Te of the voltage Vs satisfies the fault condition.

$$Te \prec\prec \sigma\tau_\tau$$

One of the most important characteristics of the Direct Control of torque is the nonlinear regulation of the stator flux and electromagnetic torque.

Figure(2.1) shows a block diagram representation of direct Artificial neural network control of torque.

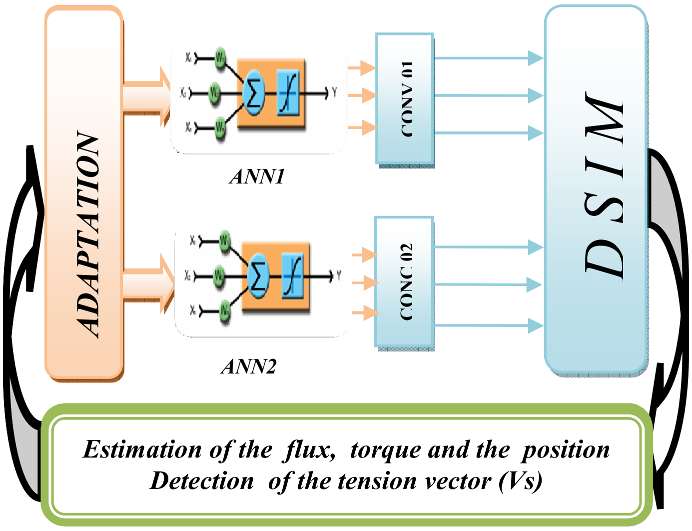


Fig.2.1. Block diagram of the Artificial Neural Network direct control of torque Application on the DSIM

III.1.SETTING OF THE STATOR FLUX

The expression of the stator flux with the reference associated to the stator is obtained from the following equation $\varphi sj = \int_0^t (Vsj + RsjIsj)dt$ j=1,2 (3.1.1)

Using interval [0,Te] corresponding to a sampling period (Te), the switch state (Sa Sb Sc) are fixed, and if we consider the value (R_sI_s) to be negligible when compared with voltage (Vs),we can assume:

$\varphi sj(t) \approx \varphi_{S0} + V_{Sj}T_E$ j=1,2 (3.1.2)

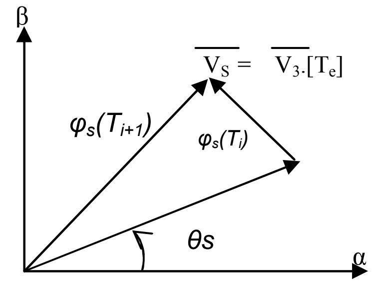


Fig.3.1.Evolution of the end of the flux i.e(Vs=V3)

With φ_{S0} being the flux vector at Time t=0

This relation shows that if we apply a non-zero voltage vector, the end of the stator flux vector moves on a straight line whose direction vector is given by the applied voltage. Figure(3.1) illustrates this principle, taking as example the voltage vector(V3).

III.2. CONTROL OF THE ELECTROMAGNETIC TORQUE

In a steady state, we can assume for simplicity that the stator flux vector φ_s rotates with a constant amplitude φ_{s_0}, and with an average speed ω_s . It can also be assumed that the rotor flux vector maintains constant amplitude and rotates with same pulsation ω_{s0} as the vector φ_s . We put at t_0 ;

$$\overline{\varphi}_s = \varphi_{s_0} e^{j\theta_{s0}}$$

$$\overline{\varphi}_r = \varphi_{r_0} e^{j\theta_{r0}} \qquad (3.2.1)$$

From the relation between flow, current and the main expression of electromagnetic torque, the electromagnetic torque equation can be transformed into a sinusoidal function as follows:

$$\Gamma_{em0} = P\frac{L_m}{\sigma L_s L_r}\varphi_{s0}\varphi_{r0}\sin(\gamma_0) \qquad (3.2.2)$$

Where γ_0 is the angle between the stator and the flux rotor vector. let's Apply at time t_0 an adequate voltage vector Vs, and we impose along with a pulse $\Delta\omega s1$ as rotational speed and Immediately after t_0, we can note a modification in the value on the terms of stator and rotor flux:

$$\varphi_s = \varphi_{s_0} e^{j(\theta_{s0}+\Delta\theta_s)}$$

$$\varphi_r = (\varphi_{r0} + \Delta\varphi_r)e^{j(\theta_{r0}+\Delta\theta_r)} \qquad (3.2.3)$$

$$\Delta\theta_s = (\omega_{s_0} + \Delta\omega_{s1})(t - t_0)$$

From the flux rotor (3.2.3)expression, we can deduce the value derivative relation of this quantity with respect to time (3.3.4), namely:

$$\frac{d\varphi_r}{dt} = \frac{d\Delta\varphi_r}{dt}e^{j\theta_r} + j\frac{d\Delta\theta_r}{dt}\varphi_{r0} \qquad (3.2.4)$$

With;

$$\Delta\theta_r = \Delta\theta_s - \Delta\gamma$$

So we can improve the rotor flux φ_r vector by continuous rotation with the same pulsation ω_{s_0}, and by maintaining a similar amplitude φ_{r_0} . Also after t_0, the torque value can be expressed as:

$$\Gamma_{em} = P\frac{L_m}{\sigma L_s L_r}\varphi_{s0}\varphi_{r0}\sin(\gamma_0 + \Delta\gamma) \qquad (3.2.5)$$

III.3. SELECTION OF THE VOLTAGE VECTOR

The choice of tension vector Vs depends on the desired variation of the flux module, but also for the desired change of the rotational speed and therefore for the couple. It generally defines the evolution space φ_s between the fixed reference, and stator reference, by dividing the space into six symmetrical areas (N = 6) with respect to the direction of nonzero voltage vectors. The position of the flow vector in these areas is determined from its components $\varphi_{s_{alpha}}$ and $\varphi_{s_{beta}}$ When the vector flow is located inside zone i, the two vectors V_i et V_{i+3} have the bigger flux component . Also their effect on the torque depends of the position of the flow vector in the same area.

Both the flux and the torque control are ensured by selectingone of the four non-zero vectors or one of the two null vectors:

- If V_{i+1} is selected , the flux amplitude will increase and the torque will increase
- If V_{i-1} is selected, the flux amplitude will decrease and the torque will increase.
- If V_{i+2} is selected , the flux amplitude will increase and the torque will decrease.
- If V_{i-2} is selected, the flux amplitude will decrease and the torque will decrease.
- if V_0 or V_7 is selected, the vector flux will maintain it's value and the torque will decrease if the speed is positive and will increase if speed is negative.

ARTIFICIAL NEURAL NETWORK THEORY

The Artificial Neural networks consist of a large class of different architectures. In many cases, the issue is approximating a static nonlinear, mapping f x() with a neural network $f_{NN}(x) where\ x \in R^K$

The most useful neural networks in function approximation are Multilayer Layer Perceptron (MLP) and Radial Basis Function (RBF) networks. Here we concentrate on MLP networks.

A MLP consists of an input layer, several hidden layers, and an output layer. Node i, also called a neuron, in a MLP network is shown in Figure(3.2) It includes a summer and a nonlinear activation function g.

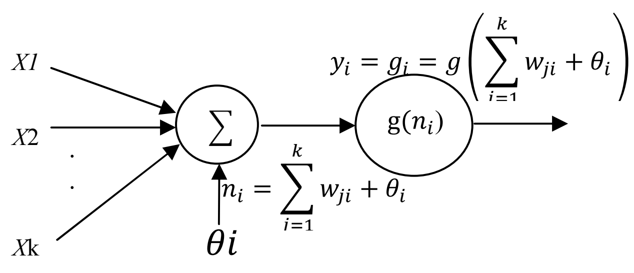


Fig.3.2. Single node in an artificial neural network.

The inputs X_k, k=1…..K neuron are multiplied by weigh W_{ki} and summed up together with the constant bias term θ_i . The resulting n_i is the input to the activation function g The activation function was originally chosen to be a relay function, but for mathematical convenience a hyperbolic tangent (tanh) or a sigmoid function are most commonly used. Hyperbolic tangent, the function used in this paper is 'tansig' . Connecting several nodes in parallel and series, a MLP network is formed as it shown figure xx.

Many algorithms exist for determining the network parameters. In neural network literature the algorithms are called learning or teaching algorithms, in system identification they belong to parameter estimation algorithms. The most well-known are back-propagation and Levenberg-Marquardt algorithms. Back-propagation is a gradient based algorithm, which has many variants. Levenberg-Marquardt is usually more efficient, but needs more computer memory. Here we will concentrate only on using the algorithms.

IV. USE OF ANN IN THE CONTROL DIRECT OF TORQUE

Our proposed structure of the neural network to perform the DSIM controlled with DTC satisfactorily is a back-propagation controller with three input nodes, ten neurons in the hidden layer, and three neurons in the output layer, as shown in Figure(4.1).

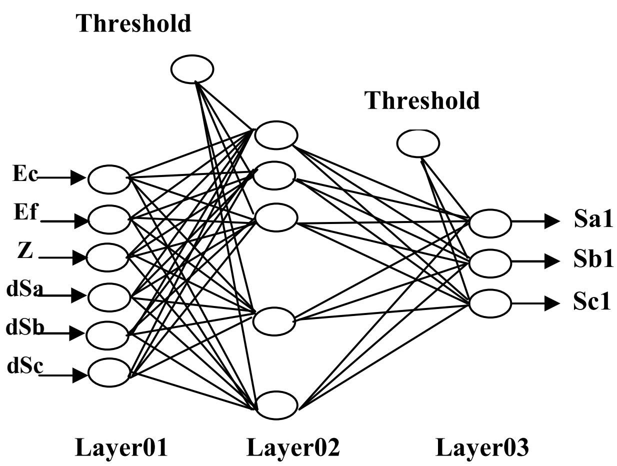


Fig.4.1. Proposed artificial neural network

IV.1.ANN ALGORITHEM

According to the principle of DTC, the input to the neural net-work controller are the electromagnetic torque error (Ec),the stator flux error (Ef), the position of flux angle (Z). also Derivative of Sa1,Sb1,Sc1.
The output of the neural network are the converter switchs controller Sa1 Sb1 Sc1 for the the first start of our DSIM.
The figure xx shows the details the details of the Artificial neural network used in the ANN DTC to drive the switchs of those converts used to control the double stars induction machine(DSIM)

IV.2.THE PROGRAME USED IN ANN_DCT

To create the block ANN switching table we

passed by this program Matlab.

ANN inputs;

H=[Ef Ec Z def dec dz];

ANN output;

Q=[Sa Sb Sc];

Network configuration;

Net=newff([minEf maxEc;minEc maxEc; minZ maxZ.......... ,[10 3],{'tansig' 'purelin'});

Nombre d'itération:

net.trainParam.epochs=1000;

Erreur:

net.trainParam.goal=0;
net.trainParam.mu=0.9;

Training :

net=train(net,H',Q');

gneration of the artificail neural netwotk:

gensim(net,-1)

IV.3.SIMULATION OF THE NEURAL NETWORK DIRECT CONTROL OF TORQUE

The figure shows the simulink model utilize the artificial neural network in the direct control of torque of double stars induction machine. We also pass via an adptator bloc, those outputs are direct use to drive the converter of the first start the same method used to drive the second start with minor changes.

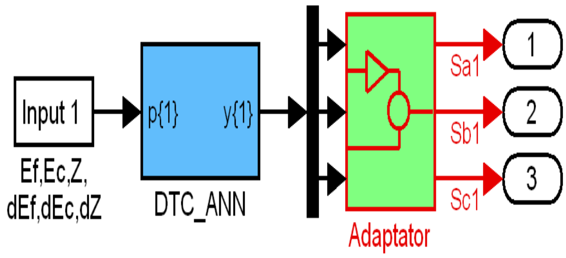


Fig.4.3. Model simulink of ANN used in DTC of DSIM

The figure(4.4) shows the evolution of the ANN training From the convergence curve we can deduce that is would still be a chance to improve the network parameters by increasing the number of iterations (epochs) to reach enough performance. In ANN_DTC. the algorithm back propagation has been chosen after many tests of others algorithms. Those tests highlights the trade-offs involved in various algorithms available for restructuring the ANN system.

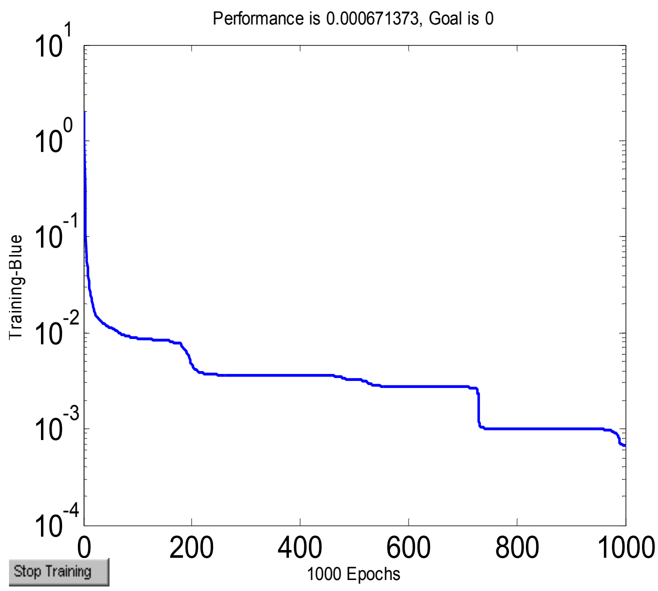


Fig.4.4.Performace of the training back propagation

V.SIMULATION RESULTS;

The modeling and simulation of the control method used To drive the double stars induction machine in this paper contain the state-space formulation in MATLAB/Simulink. Version 7.1.246 (R14).
The proposed method has been successfully implemented in a simulation package use also Sim Power System and OD4(range-kutta) as solver.

The system shown in Fig.2.1. Has been modeled with the speed loop regulation. a neural network toolbox from MATLAB/SIMULINK program is used to simulate the artificial neural network DTC. To verify the Analysis in the previous section, an ANN_DTC is used in simulation

Figure (5.1) shows the dynamic performance of the PI controller while starting and in the event of load disturbance. The starting type is characterized by an excess of 0.06% and a response time of 0.71secondes. at t = 1.5s we did apply 10N.m as load on the rotative part of motor, the classical controller PI rejects the disturbance with a speed drop of 0.015% and a rejection time 0.002s.

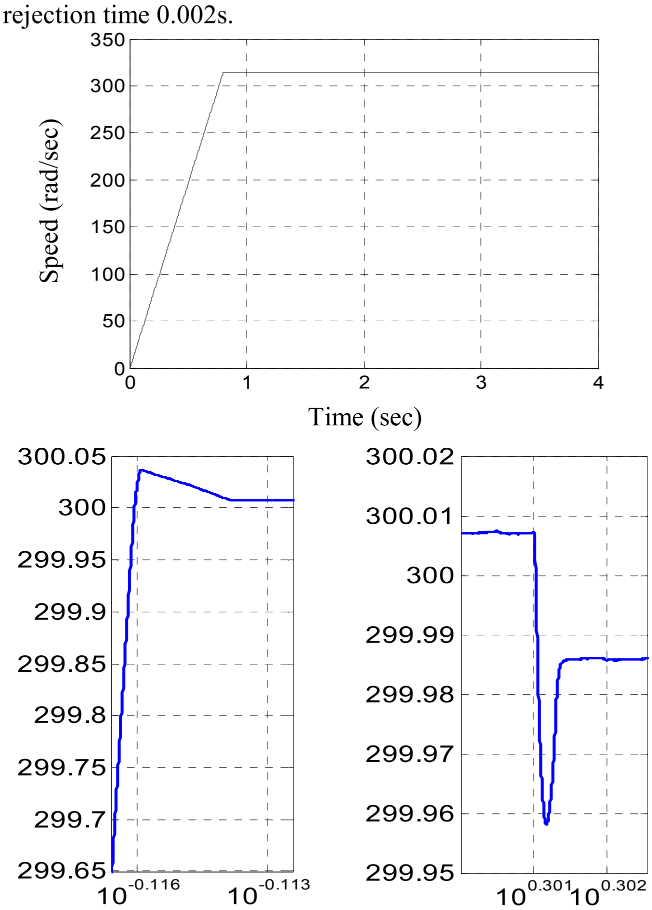


Fig.5.1.PI performance of ANN_DTC of DSIM with Enlarged view while starting & load disturbance.

Figure.5.2. shows the behavor concerning the current. this inrush current reach 06 time the nominal current.

There is an increase current above the nominal current because it takes real power to accelerate the rotor from standstill to 3000RPM. The ANN_DTC control low improved that is capable to handel the starting time.

as it is showed in same figure. The system delivre the current less than 0.74second witch very good starting time. Because the generation of the large current produces heat, the current can only be delivered for a short time, usually 4-10 seconds. This is however long enough to start the vast majority of motors.

At 0.75sec the motor reach 3000RPM and the current became equal to the nominal current.

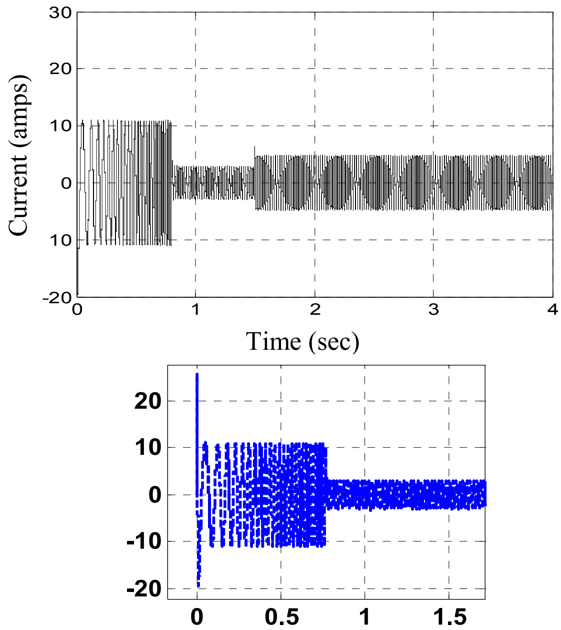


Fig.5.2.current and Enlarged view of starting time

The figure (5.3) illustrates motor behavior in the event of load disturbance and also the enlarged view shows the electromagnetic torque ripples encountered while using the fuzzy direct method of torque control, The torque ripple is reduced by 40% compared with the classical method of direct control of torque.

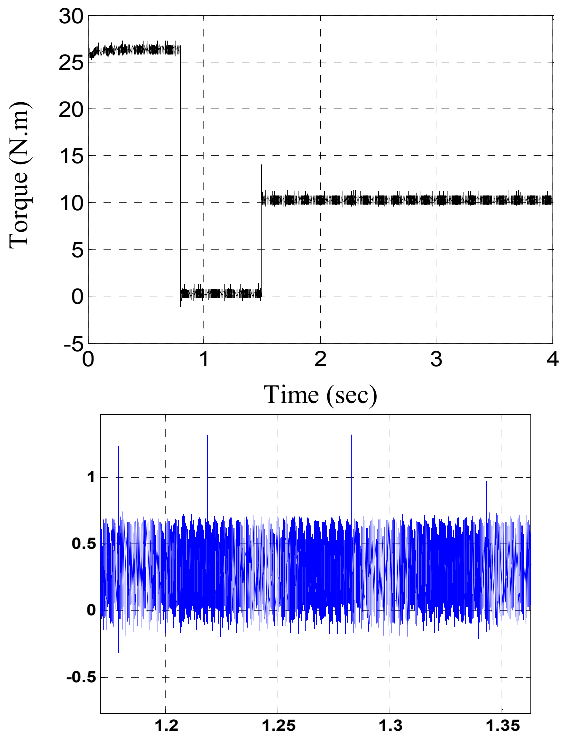


Fig.5.3.Enlarged view of torque ripple

From the figure.5.4. it clear that ANN_DTC use to manage drop flux which became an issue is other method control it show also the uncoupling between the Flux and torque.

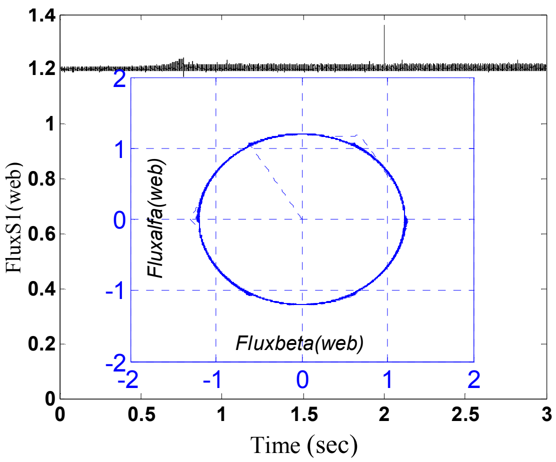
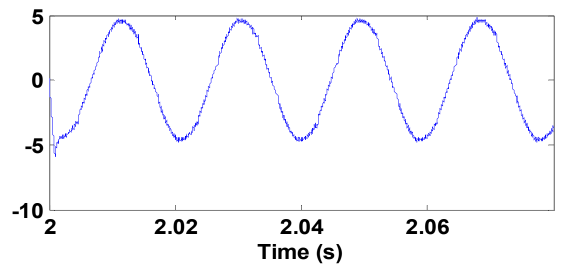


Fig.5.4.show the Direct and quadratic stator flux of ANN DTC

Figure.5.4. shows the FFT analyses of the stator current and the Harmonic order when use the artificial neural network In direct control of torque.



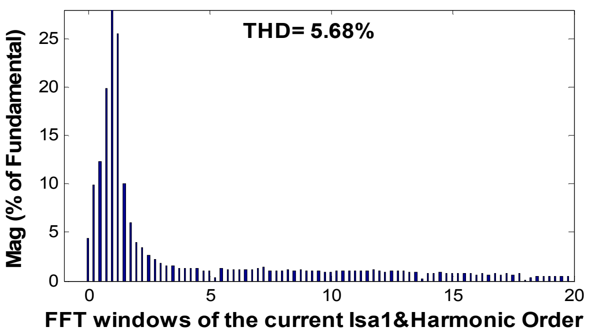


Figure.5.4. Harmonic order of the Isa1 current

CONCLUSION

In beginning we did developed the theory of the Artificial neural network Direct control of torque method utilizing a double star induction motor whose mathematical model was used to construct a simulation model using the (Simulink) as a simulation tool. This allowed us in the second step to make some investigation on the speed control using the PI as a regulator and artificial neural network as a control method. The speed simulation of the double star induction motor using artificial neural network showed superior performance of neural network direct control of torque when compared with the speed conventional direct control of torque.

We have managed to demonstrate that with this new type of control there are following performance advantages:

1.Faster response times on the torque;

2.Total elimination of the excess and considerable decrease the starting time;

3.Significant reduction of the load disturbance rejection time with a low speed dropout rate;

4.Significant minimization of the electromagnetic torque ripple.

Finally as shown in Figure (5.3) by simulation we improved the Artificial neural network direct control of torque method of torque of a double star induction motor with conventional PI speed controller is far more efficient than the direct torque control method, but it requires a high capacity of calcul and also a ANN controller require a lot of training to understand the model of a plant or a process. Issues such as learning speed, stability, and weight convergence remain as areas of research and comparison of many training algorithms.

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