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DTC CONTROL BASED ARTIFICIAL NEURAL NETWORK FOR HIGH PERFORMANCE PMSM DRIVE

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ABSTRACT

In this paper, we propose an approach intelligent artificial technique for improvement of Direct Torque Control (*DTC*) of Permanent Magnet Synchronous Motor such as artificial neural network (*ANN*), applied in switching select voltage vector and estimator flux and torque. This intelligent technique was used to replace, on the one hand the conventional comparators and the switching table in order to reduce torque ripple, flux and stator current. The effect of the speed estimation error is analyzed, and the stability proof of the control system is also proved. The simulations results are presented to show the validity and efficiency of the proposed system.

Keywords: *Permanent Magnet Synchronous Machine, ANN, Direct Torque Control, DTC_ANN.*

1. INTRODUCTION

DTC has a relatively simple control structure yet performs at least as good as the *FOC* technique. It is also known that *DTC* drive is less sensitive to parameters de-tuning (only stator resistor is used to estimate the stator flux) and provides a high dynamic performances than the classical vector control (fastest response of torque and flux).

This method allows a decoupled control of flux and torque without using speed or position sensors. This type of command involves nonlinear controller type hysteresis, for both stator flux magnitude and electromagnetic torque, which introduces limitations such as a high and uncontrollable switching frequency [1-3]. This controller produces a variable switching frequency and consequently large torque and flux ripples and high currents distortion. The DTC is mostly used in the objective to improve the reduction of the undulations or the flux's distortion, and to have good dynamic performances. It's essentially based on a localization table which allows selecting the vector tension to apply to the inverter according to the position of the stator flux vector and of the direct control of the stator flux and the electromagnetic torque.

Several studies are planned to decrease the swings on the level of the flux and torque. For that, we developed an intelligent technique to improve the dynamic performances of the *DTC* control; this method consists in replacing the hysteresis comparators and the switching table applied to the asynchronous machine *DTC* by a controller based on the artificial neurons networks in order to lead the flux and the torque towards their reference values during a fixed time period.

In recent years, much interest has focused on the use of artificial intelligence techniques (fuzzy logic, neural networks, genetic algorithms…) in identification and non linear control systems [4]. This is mainly due to their ability learning and generalization.

Among the different control strategies that were applied to achieve improved performance include:

- The switching frequency is maintained constant by associating the *DTC* to the space vector modulation;
- The space voltage is divided into twelve sectors instead of six with the classic *DTC*, and used some changes of the switching table.

The general characteristics of a direct torque control are:

- Direct control of torque and flux, from selecting the optimal switching vectors of the inverter.
- The indirect control of the stator currents and voltages of the machine.

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- Obtaining the flux and stator currents close to sinusoidal.
- Dynamic response of the machine very quickly.
- The existence of oscillations of the torque depends, among other factors the width of hysteresis band controllers.
- The switching frequency of the inverter depends on the amplitude of hysteresis band.

Many researchers have been performed using the multi-level inverter and, for example, some articles described a novel *DTC* algorithm suited for a three level inverter, and proposed a very simple voltage balancing algorithm for the *DTC* scheme.

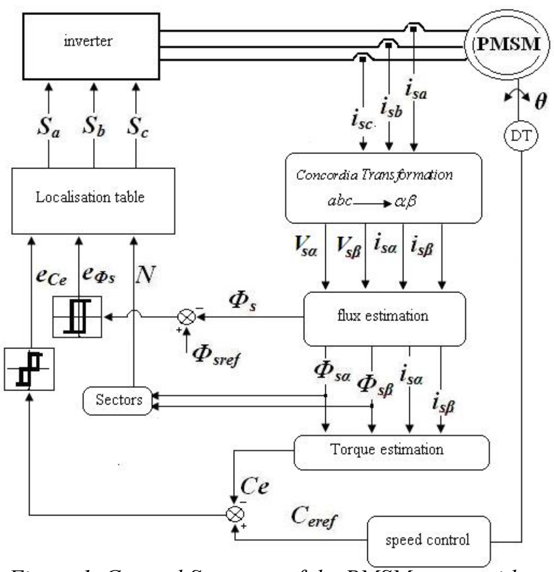

Figure.1. General Structure of the PMSM motor with DTC and speed regulation

The Artificial Neural Networks are capable of learning the desired form between the inputs and outputs signals of the system without knowing the exact mathematical model of the system. Since the Artificial Neural Networks do not use the mathematical model of the system, the same. The ANNs are excellent estimators in non linear systems.

In this paper, neural network flux position estimation, sector selection and switching vector selection scheme, to reduce the current ripple by regulating the switching frequency, are proposed.

2. DIRECT TORQUE CONTROL STRUCTURE

2.1. Structure

The torque of the permanent magnet synchronous motor is controlled by inspecting the armature current since electromagnetic torque is proportional to the armature current [11-14]. For high dynamic performance, the current control is applied on rotor flux (*d-q*) reference system that is rotated at synchronous speed. In this system, if the change of the back electromotor force and the inductance are sinusoidal, armature circuit inductance and magnet magnetic flux are constant.

The main principle of *DTC* is to select the appropriate voltage vectors according to the stator magnetic flux, difference between the reference and real torque. The current control circuit that is constituted with the pulse width modulation (*PWM*) comparator circuit is not used in *DTC*. Therefore, if the *DTC* method is compared to *PWM* current control, it yields advantages such as; less parameter dependence and fast torque response. If the initial position of the rotor is known, it is possible to work with *DTC* without sensors.

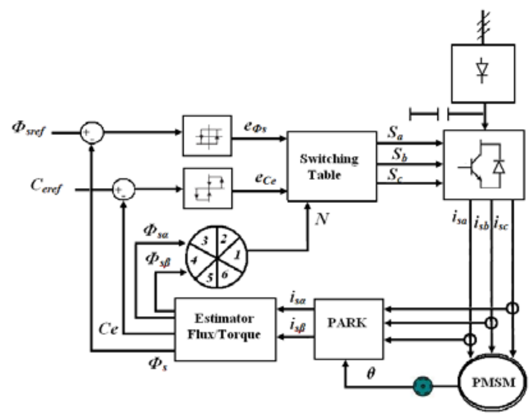

Figure.2. DTC Control Structure

The *Fig.2* presented the chosen control. The characteristics memorized for an optimal torque control strategy generates the *d-q* component of the vector stator current. Then, an *abc-to-αβ* transformation generates the flux and torque electromagnetic. Finally, these generated parameters are compared to the references and hysteresis controllers to allow the determination of the switching table status S_a, S_b and S_c of the voltage inverter.

In this paper, we apply the command on a machine type *PMSM* (Permanent Magnet Synchronous Motor), which consists of three stator windings and a rotor magnet. This motor is described by the following equation (Voltage, Flux, Torque…) [11],

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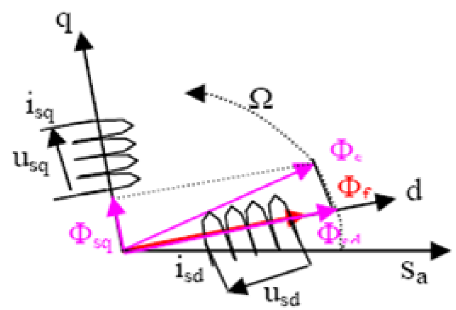

Figure.3: Scheme of the synchronous machine

$$u_{sd} = r_s.i_{sd} + \frac{d\Phi_{sd}}{dt} - \omega.\Phi_{sq} \quad (1)$$

$$u_{sq} = r_s.i_{sq} + \frac{d\Phi_{sq}}{dt} - \omega.\Phi_{sd} \quad (2)$$

Where the direct and quadrate axis flux linkages are,

$$\Phi_{sd} = L_d.i_{sd} + \Phi_f \quad (3)$$

$$\Phi_{sq} = L_q.i_{sq} \quad (4)$$

The electromagnetic torque of the motor can be evaluated as follows,

$$Ce = \frac{3}{2} p\left[\phi_f.I_q + (L_d - L_q).I_d.I_q\right] \quad (5)$$

The motor dynamics can be simply described by the equation (6).

$$Ce - C_r = J.\frac{d\Omega}{dt} + f.\Omega \quad (6)$$

With:
Ω: rotation's speed mechanical of the *PMSM.*
ω: rotation's speed electric.
p: Number of pairs of poles.
J : Total moment of inertia brought back on the tree of the *PMSM*.
f : Coefficient of viscous friction.
C_r: Resistive torque.
f: flux produced by the permanent magnet.
Φ_{sd}: d axis stator magnetic flux,
Φ_{sq}: q axis stator magnetic flux,
L_{sd}: d axis stator leakage inductance,
L_{sq}: q axis stator leakage inductance,
r_s: stator winding resistance,
C_e: electromagnetic torque,

2.2. Principle

The objective of the *DTC* is the regulation direct of the torque control of the machine, by applying different voltage vectors of the inverter, which determines its status. The controlled variables are the stator flux and electromagnetic torque which are usually controlled by hysteresis controllers. This is to maintain the greatness of stator flux and electromagnetic torque within the hysteresis bands. The output of these regulators determines the vector of optimal voltage of the inverter to be applied to every moment of switching [15-18].

This control method has advantages:

- Not require calculations in the rotor reference (d, q);
- There is no calculation block voltage *PWM* modulation;
- There is no need to make a decoupling of the currents relative to control voltages, as in the case of vector control;
- To have only one regulator, one of the outer loop of speed;
- The dynamic response is very fast.

2.3. Concordia Transformation

As *DTC* is a vector control, it is necessary to have the components of Concordia of the currents and stator tensions of the *PMSM*. One thus breaks up the three stator currents i_{sabc} and the three stator voltage V_{sabc} into components direct ($V_{s\alpha}$) and quadratic ($V_{s\beta}$) such as [19]:

$$\begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \quad (7)$$

2.4. Flux and Torque Estimator

Flux Estimator:

The stator electric equations of the *PMSM*, in the reference mark (α-β) are given by:

$$\begin{cases} V_{s\alpha} = r_s.i_{s\alpha} + \frac{d\Phi_{s\alpha}}{dt} \\ V_{s\beta} = r_s.i_{s\beta} + \frac{d\Phi_{s\beta}}{dt} \end{cases} \quad (8)$$

Then,

$$\begin{cases} \hat{\Phi}_{s\alpha} = \int_0^t (V_{s\alpha} - r_s.i_{s\alpha}).dt \\ \hat{\Phi}_{s\beta} = \int_0^t (V_{s\beta} - r_s.i_{s\beta}).dt \\ \hat{\Phi}_s = \hat{\Phi}_{s\alpha} + j.\hat{\Phi}_{s\beta} \end{cases} \quad (9)$$

Or

$$\begin{cases} \Phi_s = \sqrt{\Phi_{s\alpha}^2 + \Phi_{s\beta}^2} \\ \delta = Arc\tan(\frac{\Phi_{s\beta}}{\Phi_{s\alpha}}) \end{cases} \quad (10)$$

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Torque Estimator:

The electromagnetic torque is:

$$Ce = \frac{3p}{2}\left(\Phi_{s\alpha}.i_{s\beta} - \Phi_{s\beta}.i_{s\alpha}\right) \quad (11)$$

p: Number of pairs of poles

Knowing the real sizes $(i_{s\alpha}, i_{s\beta})$ the estimated sizes $(\hat{\Phi}_{s\alpha}, \hat{\Phi}_{s\beta})$, the estimated torque can be given by:

$$\hat{C}_e = \frac{3p}{2}(\hat{\Phi}_{s\alpha}.i_{s\beta} - \hat{\Phi}_{s\beta}.i_{s\alpha}) \quad (12)$$

Control switches of the inverter:

The three-phase voltage inverter is described by the following figure:

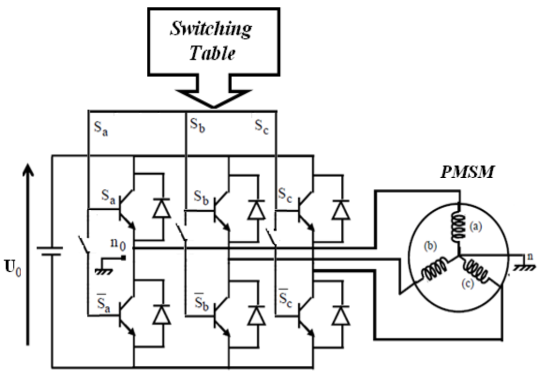

Figure.4. Inverter of tension

The switches of the converter of tension (*Fig.4*) must be controlled so as to maintain the flux and the torque of the machine. The vector of the stator voltage can be written in the form:

$$V_s = \sqrt{\frac{2}{3}}.U_0.(S_a + S_b.e^{j\frac{2\pi}{3}} + S_c.e^{j\frac{4\pi}{3}}) \quad (13)$$

Where (S_a, S_b, S_c) represent the logical state of the 3 switches: $S_i = 1$ means that the high switch is closed and the low switch is open and $S_i=0$ mean that the high switch is opened and the low switch is closed [20].

One will thus seek to control flow and the couple via the choice of the vector of voltage which will be done by a configuration of the switches. As we have *3* switches, there are thus $2^3=8$ possibilities for the V_s vector.

2 vectors (V_1 and V_8) correspond to the null vector: $(S_a,S_b,S_c) = (0,0,0)$ et $(S_a,S_b,S_c) = (1,1,1)$.

$$\begin{cases} V_1 = V_8 = 0 \\ V_2 = \sqrt{\frac{2}{3}}.U_0 \\ V_3 = \sqrt{\frac{2}{3}}.U_0.(0.5 + j\frac{\sqrt{3}}{2}) \\ V_4 = \sqrt{\frac{2}{3}}.U_0.(-0.5 + j\frac{\sqrt{3}}{2}) \\ V_5 = -\sqrt{\frac{2}{3}}.U_0 \\ V_6 = \sqrt{\frac{2}{3}}.U_0.(-0.5 - j\frac{\sqrt{3}}{2}) \\ V_7 = \sqrt{\frac{2}{3}}.U_0.(0.5 - j\frac{\sqrt{3}}{2}) \end{cases} \quad (14)$$

The eight tensions V_i can be represented on the plan complexes as follows (*Fig.5*):

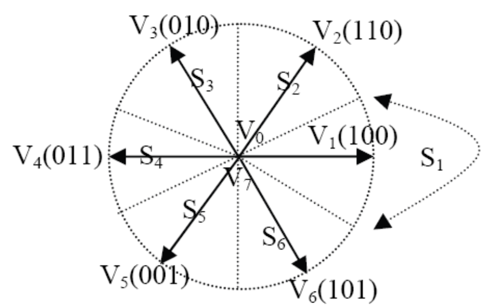

Figure.5. Vectors tensions and sectors of detection

Control Vector flux:

So as to obtain very good dynamic performances, the choice of a corrector with hysteresis with two levels seems to be the simplest solution and best adapted to the studied control. Indeed, with this type of controller, one can easily control and maintain the end of the vector flux Φ_s in a circular ring.

The exit of the corrector represented by a Boolean variable e_Φ (*=0* or *1*) must indicate if the module of flux must decrease (e_Φ*=0*) or increase (e_Φ=1) by such kind to always maintain $\left|\Phi_{sref} - \hat{\Phi}\right| \le \Delta\Phi_s$.

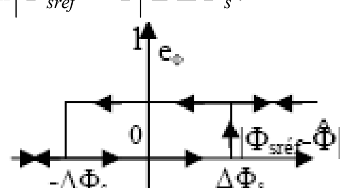

Figure.6. Corrector Flow with Hysteresis on 2 Levels

Φ_{sref} : Flux reference.

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The practical realization of control *DTC* is generally done on charts *DSP*, *FPGA* or with microcontrollers having one period of sampling for the period you to you, the vector tension chooses does not change what allows, starting from the equation (8), to write:

$$\begin{cases} \hat{\Phi}_{s\alpha} = \int_0^{T_e} V_{s\alpha}.dt = V_{s\alpha}.T_e \\ \hat{\Phi}_{s\beta} = \int_0^{T_e} V_{s\beta}.dt = V_{s\beta}.T_e \\ \hat{\Phi}_s = \hat{\Phi}_{s\alpha} + j.\hat{\Phi}_{s\beta} = V_s.T_e \end{cases} \quad (15)$$

Where Te: Sample period.

The following figure shows the selected voltage vector for each sector to maintain the stator flux in the hysteresis bound (*Fig.7*) [21].

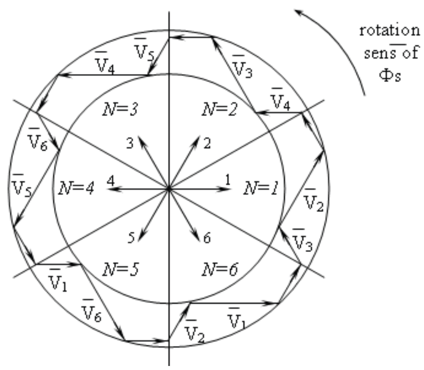

Figure.7. Vectors for space vector modulation

Control Couple:

The corrector on 3 levels, he makes it possible to control the engine in the two directions of rotation that is to say for a positive or negative couple. The exit of the corrector represented by the Boolean variable e_{Ce} what must limit the couple to a value such as $\left| C_{eref} - \hat{C}_e \right| \le \Delta C_e$.

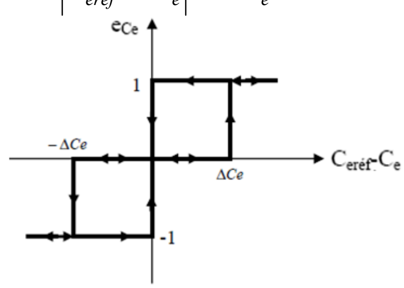

Figure.8. Corrector of the Couple with Hysteresis on 3 levels

Law of control:

According to the sector determined by the phase (δ=Arctang(Φ_β/Φ_α)) of estimated flux and the evolution magnitude of this last as well as the evolution of the estimated torque one can choose the voltage V_s to be applied so as to respect the instructions of flux and the torque. There are thus 3 parameters (e_Φ, e_{Ce}, N) for the choice of vector V_S, that allow choosing the adequate vector [9-10].

Table I:
Table that allows choosing the adequate vector

e_Φ	Sector / e_{Ce}	1 δ€ [-π/6,π/6]	2 δ€ [π/6,3π/6]	3 δ€ [3π/6,5π/6]	4 δ€ [5π/6,7π/6]	5 δ€ [7π/6,9π/6]	6 δ€ [π/6,11π/6]
1	1	V_3	V_4	V_5	V_6	V_7	V_2
	0	V_1	V_8	V_1	V_8	V_1	V_8
	-1	V_7	V_2	V_3	V_4	V_5	V_6
0	1	V_4	V_5	V_6	V_7	V_2	V_3
	0	V_8	V_1	V_8	V_1	V_8	V_1
	-1	V_6	V_7	V_2	V_3	V_4	V_5

In the example of *Fig.9*, flux is in sector *1*, if flux Φ_s increases (e_Φ=*1*) and if the torque also increases (e_{Ce}=*1*), the vector voltage to be applied to the *PMSM* will be V_3 this choice will make it possible to make decrease.

The magnitude of flux Φ_s and the torque bus when the angle of flux Φ_s increases (Δw>0) the torque also increase whereas when (Δw<0) the torque decreases.

- If V_6 is then selected flux must decrease (e_Φ=0) and also torque it (e_{Ce}=-1).
- If V_1 or V_8 is selected flux must remain constant (e_Φ= the preceding state) and the torque decreases (e_{Ce}=0).
- If V_3 is then selected flux must increase (e_Φ=1) and also torque it (e_{Ce}=1).
- If V_7 is then selected flux must increase (e_Φ=1) and the torque must decrease (e_{Ce}=-1).
- If V_4 is then selected flux must decrease (e_Φ=0) and the torque must increase (e_{Ce}=1).

Vector *V*	V_{i+1}	V_{i+2}	V_{i-1}	V_{i-2}
Φ_s	↑	↓	↑	↓
C_e	↑	↑	↓	↓

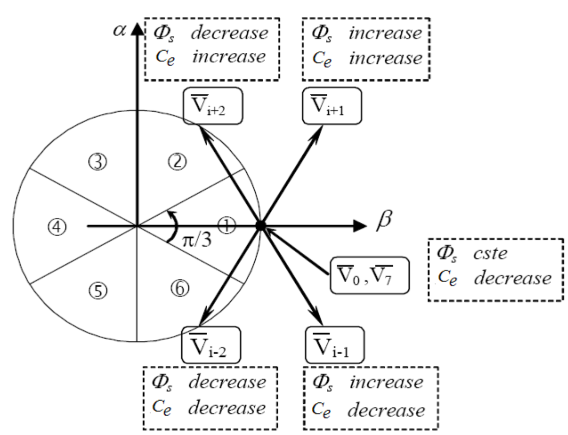

Figure.9. Detection of vector voltage

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2.5. Results of simulations

The *Fig.10* shows the general structure of the Direct Torque Control *DTC* of the *PMSM* in the reference mark *dq*.

The currents i_{sd}, i_{sq}, V_{sd} and V_{sq} are subjected to the transformation of Clark in order to obtain the components $i_{s\alpha}$, $i_{s\beta}$, $V_{s\alpha}$ and $V_{s\beta}$.

Its applied components have a block of estimator of torque and flux as well as the detector of sector.

These values estimated thereafter are compared with values of reference to be included in correctors of hysteresis to 2 and has 3 levels, to introduce its errors into a table of commutation which functions by report sector to generate the impulses of the inverter.

This will generate the tension three-phase current thereafter which will be transformed into coordinates *d-q*, the output voltages V_{sd} and V_{sq} are applied in average values at the boundaries of the phases stator of the *PMSM*.

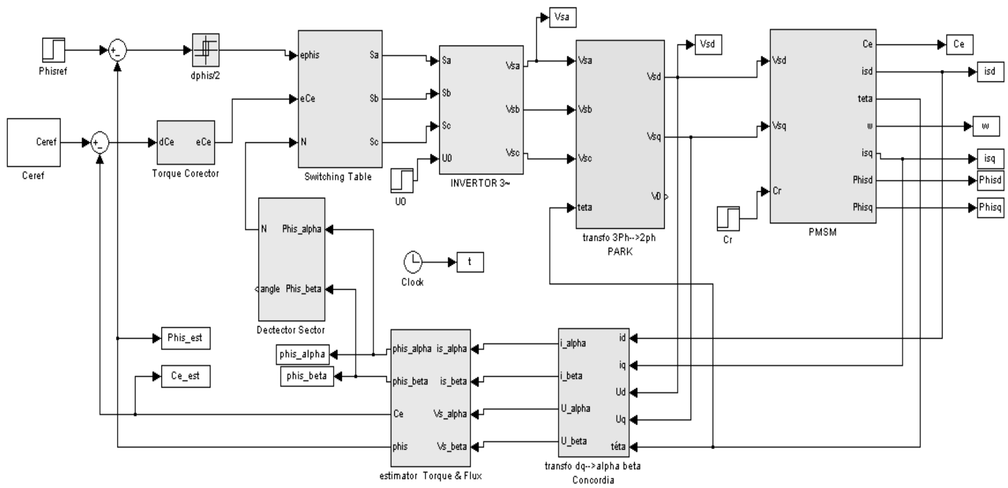

Figure.10. Blocks for the simulation of the DTC under Matlab/Simulink

By applying a set level (Φ_{sref} = *0.13wb*) to the reference flux and a set square to the reference electromagnetic torque (*Fig.13: +8 Nm, -8 Nm, 10Nm*). Changing system parameters is:

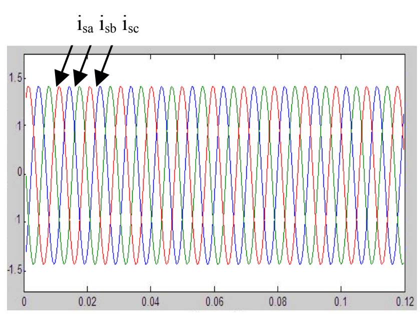

Figure.11. Stator current (A)

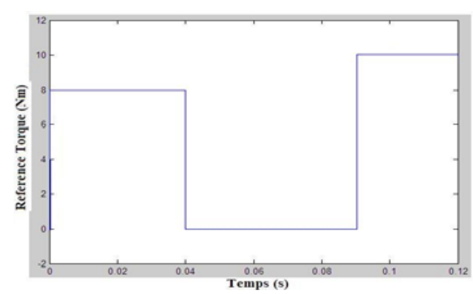

Figure.13. Reference Torque (C_{eref}) (Nm)

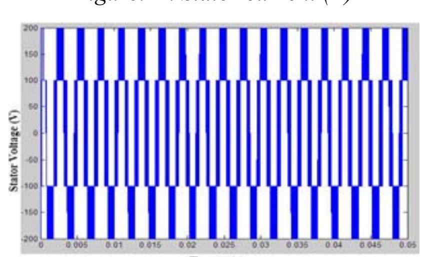

Figure.12. Stator voltage (V_{sd})

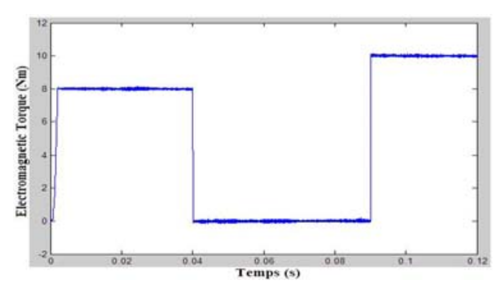

Figure.14. Electromagnetic Torque (C_e) (Nm)

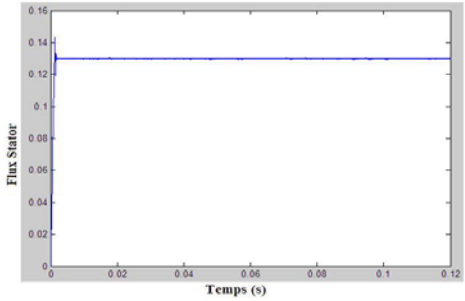

Figure.15. Evolution of the Amplitude of Φ_s

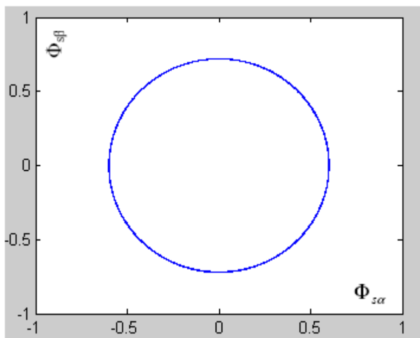

Figure.16. Trajectory of flux ($\Phi_{s\alpha}$, $\Phi_{s\beta}$)

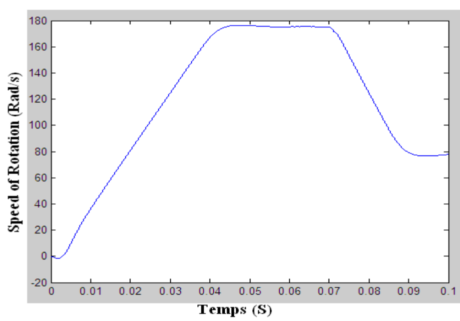

Figure.17. Rotor Speed (ω)

In the performed simulation, certain stator flux and torque references are compared to the values calculated in the driver and errors are sending to the hysteresis comparators.

The *Fig.11* and *Fig.12* show the variation of the stator voltage and current phase of the *PMSM*, which shows the great performance of the inverter voltage due to the switching table.

The evolution of the electromagnetic torque (*Fig.14*) follows a very specific set the reference, its amplitude is very low, giving high accuracy and stability to the permanent magnet synchronous machine by report further work.

The *Fig.15* shows the evolution known stator flux follows obviously the reference set by cons we see a small excess at the beginning because of the start of the electrical machine, the change in amplitude and well done periodically.

The outputs of the flux and torque comparators are used in order to determine the appropriate voltage vector and stator flux space vector. Vector locations are shown in *Fig.16*.

From all results it is clear that the system is faster, a simulation with a time of *0.12* gives us the best results concerning the speed, stability and accuracy.

3. DTC BASED ARTIFICIAL NEURAL NETWORK

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 capable of approximating complicated nonlinear functions.

It constitutes an approach which gives more opportunities to approach the problems of perception, memory, learning and analysis under new angles. It is also a very promising alternative to avoid certain limitations of the classic numeric methods. Due to its parallel treatment of the information, it infers emergent properties able to resolve problems qualified in the past as complex [12-14, 23].

The structure of the direct neuronal torque control of a permanent magnet synchronous machine is illustrated bellow in *Fig.18*.

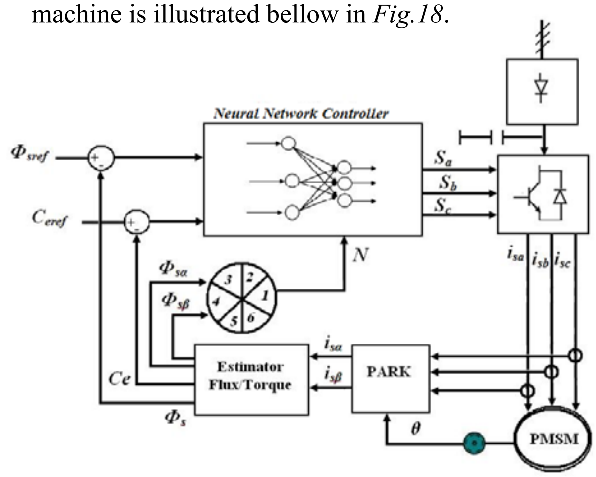

Figure.18. DTC neural networks controller scheme

In this work, we proposed are three neural networks. First is to estimate the value of stator flux position δ (*Fig.19*). This is the angle between the stator flux and the rotor flux. It is a *2 input-1 output feed-forward* network with 3 layers. The input layer has 6 neurons of hyperbolic tangent "sigmoid" transfer function, first hidden layer has 4 neurons of log sigmoid transfer function and the output layer has 1 neuron of linear function. The necessary steps to adjust these weights associated with the hidden

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neurons can be found in [15-17]. The training method used was back-propagation method [18]. The inputs given are the "d-axis stator flux" and "q-axis stator flux".

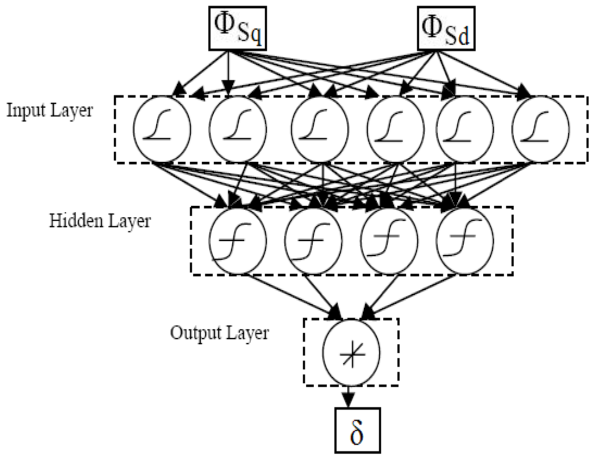

Figure.19. Structure Neural Network for delta estimation

The second neural network is used to determine the sector zone for the estimated value of δ. There are total of six sectors, each sector of π/3 rad. Again three layers of neurons are used but with a *5-4-1* feed forward configuration (*Fig.20*). Input layer is of log sigmoid transfer function, hidden layer is of hyperbolic tangent sigmoid function and the output layer is of linear transfer function. The training method used was back-propagation. The input given is the angle δ since sector selection is purely based on δ.

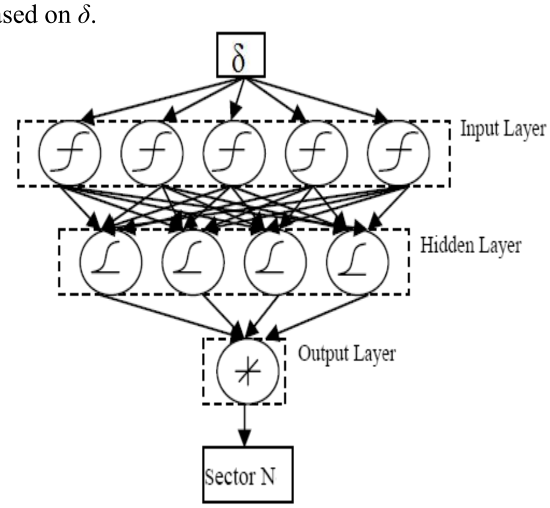

Figure.20. Structure Neural Network for selection Sector

Last neural network is for the selection of impulsion vector as given in *Fig.21*, which is based on three inputs, error flux & torque and the sector.

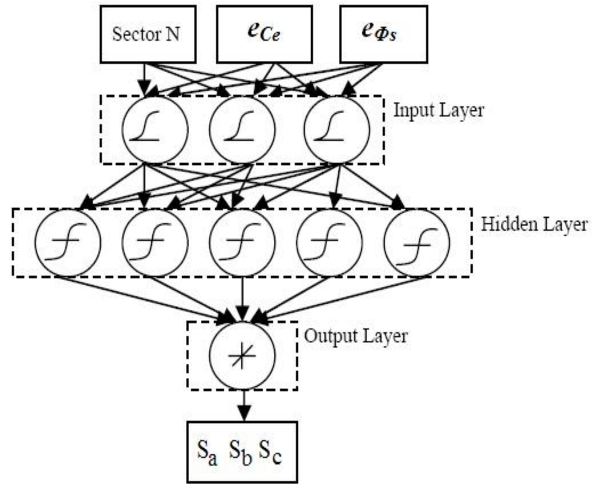

Figure.21. Structure Neural Network for impulsion vector

The network taken this time is a 3-5-1 *feed-forward* network with first layer of log sigmoid transfer function, second layer of hyperbolic tangent sigmoid transfer function and third layer of linear transfer function. Training method used was again *back-propagation*. All the three neural networks were trained to performance 0.001 msec. The back-propagation algorithm is used to train the neural networks. The training function used is *Levenberg-Marquardt* back propagation, it updates weights and bias values according to *Levenberg-Marquardt* optimization. As soon as the training procedure is over, the neural network gives almost the same output pattern for the same or nearby values of input. This tendency of the neural networks which approximates the output for new input data is the reason for which they are used as intelligent systems.

In Matlab command we generate the Simulink block ANN of switching table by "**gensim (net10)**'' given this model show *Fig.22.*

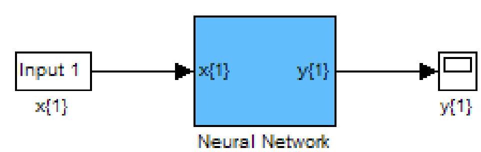

Figure.22. ANN Model Switching Table

The block ANN content two layer 1 and 2:

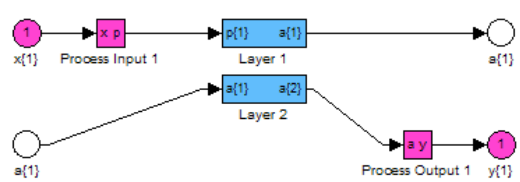

Figure.23. Neural Network Block

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Where the Layer1 and Layer2 given by:

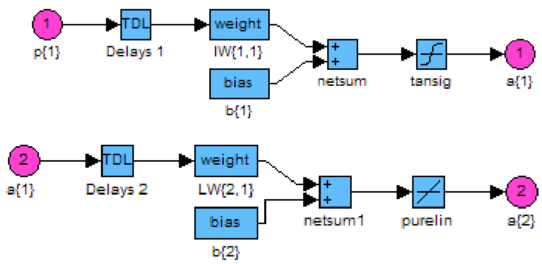

Figure.24. Block Layer1 and Layer2

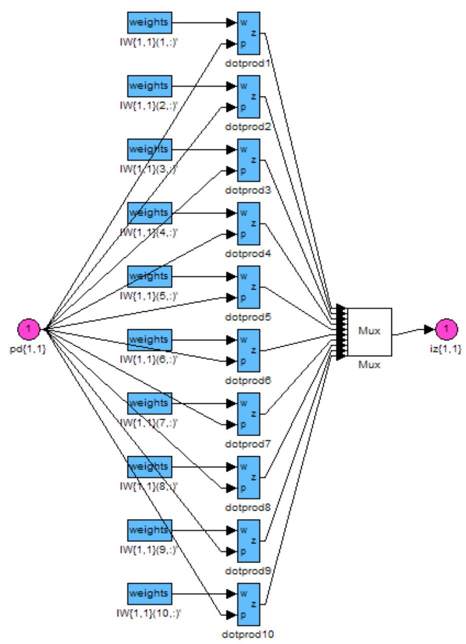

Figure.25. Block weight IW (1,1)

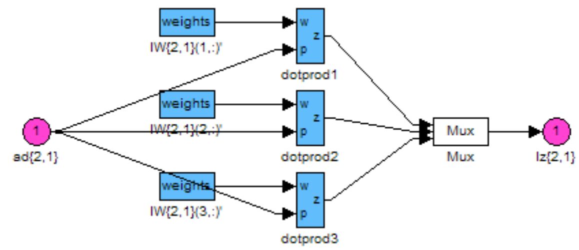

Figure.26. Block weight LW (2,1)

4. SIMULATION DTC_ANN RESULTS AND DISCUSSION

Simulation results for a *DTC* system when controlling the permanent magnet synchronous machine is following parameters:

Parameter	Values
Max voltage	*300V*
Speed max	*3000tr/mn*
Torque nominal C_{enom}	*11Nm*
Resistance stator r_s	*0,412Ω*
Number of pole pairs p	*4*
d-axis inductance L_{Sd}	*3,24 mH*
q-axis inductance L_{Sq}	*3,28 mH*
Moment inertia J	*0,0001473 $Kg.m^2$*
Coefficient of friction f	*0,0003035 Nm.s/rad*
Magnet flux linkage Φ_m	*0,171Wb*

Simulations were performed to show the performances of the technique used in this section and based on neural corrector for the control of the *IM* speed. The following figure presents the model structure tested in the Matlab / Simulink environment (*Fig.27*).

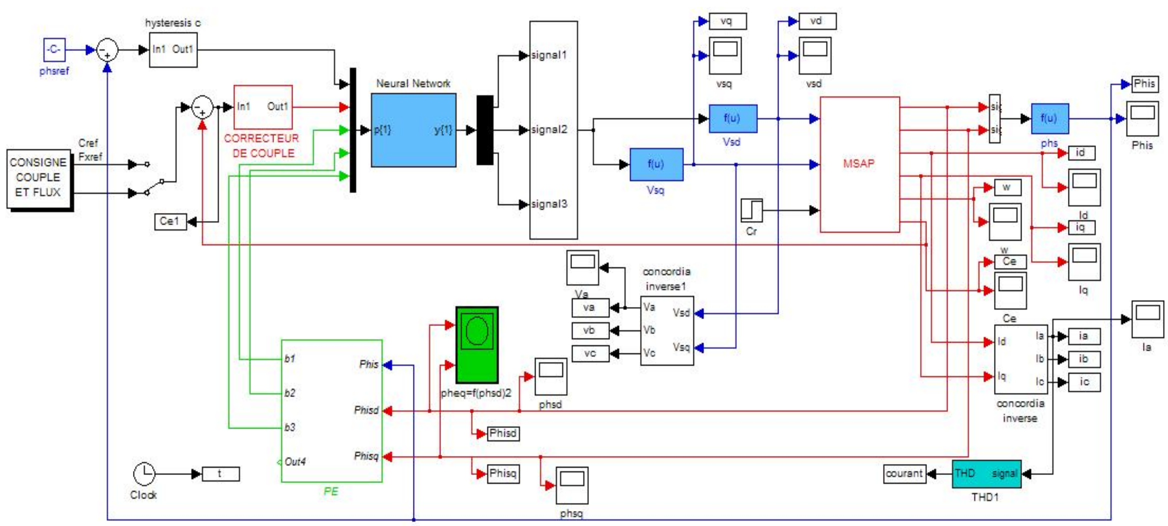

Figure.27. realization and simulation of the DTC_ANN under Matlab/Simulink

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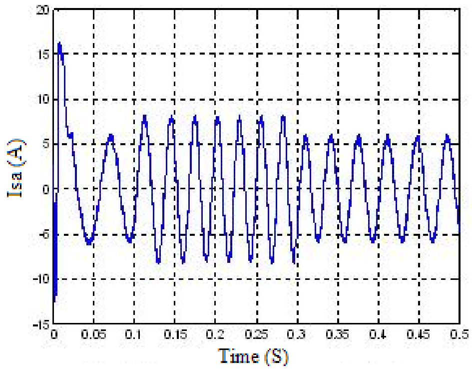

Figure.28. a-axis Stator Current response I_{sa}

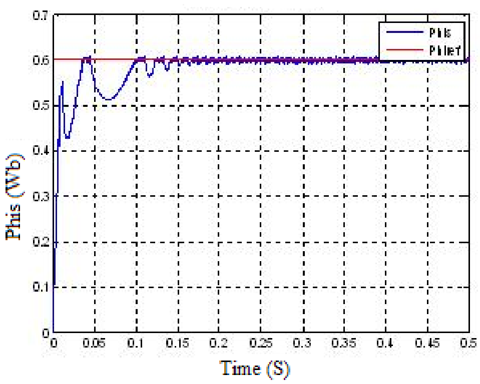

Figure.29. Stator flux response Φ_s

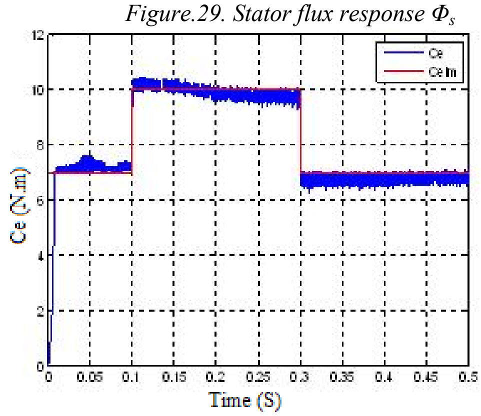

Figure.30. Torque response of ANN based DTC

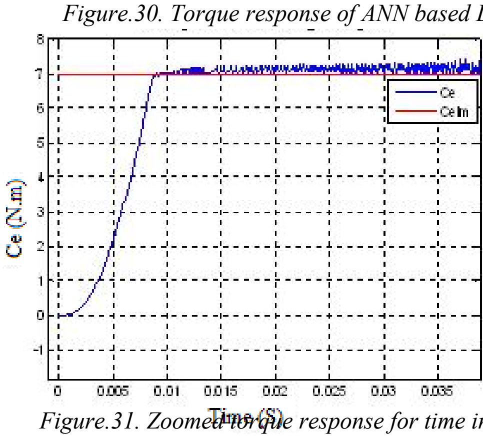

Figure.31. Zoomed torque response for time interval 0 sec to 0.035 sec

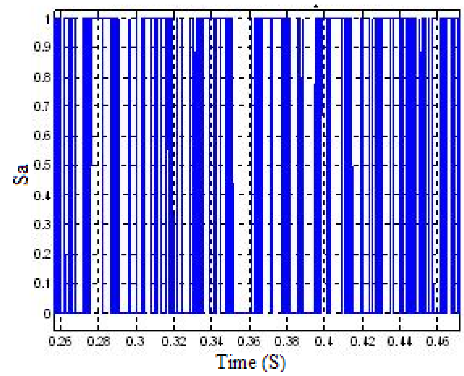

Figure.32. Impulsion control for Converter S_a

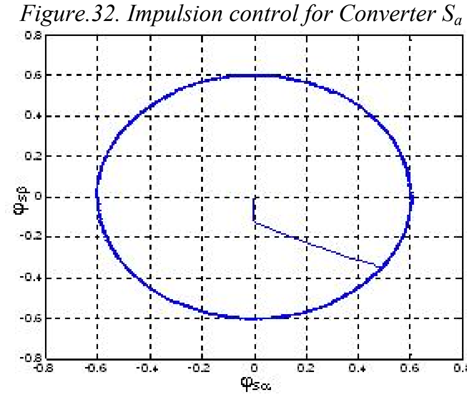

Figure.33. α-β-axis stator flux plot (NN based DTC Scheme)

The torque and flux references used in the simulation results of the neural direct torque control strategy are (+7N.m in 0Sec, +3N.m in 0.1Sec, -3N.m in 0.3Sec) and 0.6Wb respectively. The machine is running at 100rad/sec. The sampling period of the system is 50µs. All four figures are the responses to step change torque command from zero to 10 N.M, which is applied at 0 sec.

The simulation results in *Fig.28* shows that the current's stator ripples with direct torque neural networks control in steady state is significantly reduced compared to DTC classic.

The *Fig.29* illustrates the response of stator flux magnitude of the neural network *DTC* Control. The stator flux of the *DTC_ANN* has the fast response time in transient state.

The simulation results in *Fig.30* and *Fig.31* show the response of electromagnetic torque of the *DTC_ANN* neural network. It can be seen that the torque's ripples with NN direct torque control in steady state is significantly reduced compared to conventional and neural networks *DTC*. It is obvious from *Fig.14* that in *NN* direct torque control, the torque trajectory is established quickly than in the conventional.

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The *Fig.33* describes the stator flux vector trajectory which is almost circular. In this figure it can be noticed that neural network controller offers the fast transient responses.

5. CONCLUSION

The Direct Torque Control (*DTC*) is an important alternative method for the *PMSM* motor drive, with its high performance and simplicity. The *DTC* applied to *PMSM* machine fed by a 3-level diode clamped inverter presents good performance and undulations reduction. In this case, some techniques were developed in order to replace the conventional *DTC* switching table adapted for a NPC inverter.

In this paper, a new training algorithm is proposed for *DTC*. The proposed algorithm gives very fast response. From the simulation results, it can be observed that the performance of the neural network *DTC* Control scheme shows the stability and learning capability of neural networks, the proposed method can be considered as better technique.

REFERENCES

[1] B.BOSSOUFI, M.KARIM, S.IONITA, A.LAGRIOUI, "Performance Analysis of Direct Torque Control (DTC) for Synchronous Machine Permanent Magnet (PMSM) " in Proc. IEEE-SIITME'2010, pp. 275-280, 23-26 Sep 2010, Pitesti, Romania.

[2] *R.Kumar, R. A.Gupta, S.V.Bhangale, H.Gothwal, "*ARTIFICIAL NEURAL NETWORK BASED DIRECT TORQUE CONTROL OF INDUCTION MOTOR DRIVES", *IETECH Journal of Electrical Analysis,* Vol: 2, No: 3, 159 – 165, IETECH Publications, 2008

[3] R.Toufouti S.Meziane, H. Benalla, "DIRECT TORQUE CONTROL FOR INDUCTION MOTOR USING INTELLIGENT TECHNIQUES", *Journal of Theoretical and Applied Information Technology,* pp 35-44, JATIT, 2007.

[4] B.BOSSOUFI, M.KARIM, S.IONITA, A.LAGRIOUI, G.IANA "Matlab & Simulink Simulation with FPGA-Based Implementation Sliding Mode Control of a Permanent Magnet Synchronous Machine Drive." *WSEAS TRANSACTIONS on SYSTEMS and CONTROL*, pp 92-103, Issue 3 Vol.6, August 2011.

[5] B.BOSSOUFI, M.KARIM, S.IONITA, A.LAGRIOUI, "Indirect Sliding Mode Control of a Permanent Magnet Synchronous Machine: FPGA-Based Implementation with Matlab & Simulink Simulation" *Journal of Theoretical and Applied Information Technology JATIT*, pp32-42, Vol. 29 No.1, 15th July 2011.

[6] B.BOSSOUFI, M.KARIM, S.IONITA, A.LAGRIOUI, "The Optimal Direct Torque Control of a PMSM drive: FPGA-Based Implementation with Matlab & Simulink Simulation" *Journal of Theoretical and Applied Information Technology JATIT*, pp63-72, Vol. 28 No.2, 30th June 2011.

[7] Martins, A.C., Roboam, X., Meynard, T.A. & Carvaiho, "A.C. Switching Frequency Imposition and Ripple Reduction in DTC Drives by using Multilevel Converter ". IEEE *Trans, on Power Electronics*, Vol.17 N°2, March 2002.

[8] Grabowski, P.Z., Kazmierkowski, M.P., Bose, B.K. & Blaabjerg, F. "A simple Direct torque Neuro Fuzzy control of PWM Inverter fed Induction motor drive". IEEE *Trans. Electron*. 47 N° 4, pp 863-870, Aug 2000.

[9] Barbara H. K. "Stator and Rotor Flux Based Deadbeat Direct Torque Control of Induction Machines". IEEE *Industry Applications Society, Annual Meeting*, Chicago, September 30-October 4, 2001.

[10] Schibili, N., Nguyen, T. & Rufer, A. "Three-Phase Multilevel Converter for High- Power Induction Motors". IEEE *trans. On Power Elect*. Vol. 13 N°.5, 1998.

[11] Abbou A, Mahmoudi H. Performance of a sensorless speed control for induction motor using DTFC strategy and intelligent techniques. *Journal of Electrical Systems*. Volume 5, Issue 3, September 2009.

[12] B. Bose, "Power Electronics and Motor Drives, Advances and Trends", Academic Press is an imprint of Elsevier, published 2006, 935 pages.

[13] R.Toufouti S.Meziane ,H. Benalla, "Direct Torque Control for Induction Motor Using Fuzzy Logic" *ICGST Trans. on ACSE*, Vol.6, Issue 2, pp. 17-24, June, 2006.

[14] M. Aime, G. Gateau, and T. Meynard, "Implementation of a peak current control algorithm within a field programmable gate array," *IEEE Trans. Ind. Electron.*, vol. 54, no. 1, pp. 406–418, Feb. 2007.

[15] G. Gateau, A. M. Lienhardt, and T. Meynard, "Digital sliding mode observer implementation using FPGA," *IEEE Trans. Ind. Electron.*, vol. 54, no. 4, pp. 1865–1875, Aug. 2007.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

[16] X. Lin-Shi, F. Morel, A. Llor, B. Allard, and J. M. Retif, "Implementation of hybrid control for motor drives," *IEEE Trans. Ind. Electron.*, vol. 54, no. 4, pp. 1946–1952, Aug. 2007.

[17] G. Edelbaher, K. Jezernik, and E. Urlep, "Low-speed sensorless control of induction machine," *IEEE Trans. Ind. Electron.*, vol. 53, no. 1, pp. 120–129, Dec. 2005.

[18] R. Dubey, P. Agarwal, andM. K. Vasantha, "Programmable logic devices for motion control—A review," *IEEE Trans. Ind. Electron.*, vol. 54, no. 1, pp. 559–566, Feb. 2007.

[19] E. Ishii, H. Nishi, and K. Ohnishi, "Improvement of performances in bilateral teleoperation by using FPGA," *IEEE Trans. Ind. Electron.*, vol. 54, no. 4, pp. 1876–1884, Aug. 2007.

[20] J. CatalaiLopez, L. Romeral, A. Arias, and E. Aldabas, "Novel fuzzy adaptive induction motor drive," *IEEE Trans. Ind. Electron.*, vol. 53, no. 4, pp. 1170–1178, Jun. 2006.

[21] B.BOSSOUFI, M.KARIM, S.IONITA, A.LAGRIOUI, "Performance Analysis of Direct Torque Control (DTC) for Synchronous Machine Permanent Magnet (PMSM)" *2010 IEEE 16th International Symposium for Design and Technology of Electronics Packages, SIITME 2010*, art. No. 5649125, pp. 237-242.

[22] F.-J. Lin and P.-H. Shen, "Robust fuzzy neural network sliding-mode control for two-axis motion control system," *IEEE Trans. Ind. Electron.*, vol. 53, no. 4, pp. 1209–1225, Aug. 2006.

[23] N. R. N. Idris and A. H. M. Yatim, "Direct torque control of induction machines with constant switching frequency and reduced torque ripple," *IEEE Trans. Ind. Electron.*, vol. 51, no. 4, pp. 758–767, Aug. 2004.

[24] A. Dinu, "FPGA neural controller for three phase sensorless induction motor drive systems," Ph.D. dissertation, De Montfort Univ., Leicester, U.K., 2000.

[25] J. Chia-Feng and C. Jung-Shing, "Water bath temperature control by a recurrent fuzzy controller and its FPGA implementation," *IEEE Trans Ind. Electron.*, vol. 53, no. 3, pp. 941–949, Jun. 2006.