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Contribution to the Fuzzy Direct Control of Torque Application Utilising Double Stars Induction Motor.

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Abstract: This paper concerns the study of a control strategy known as fuzzy direct control for the study of the control of torque when using speed loop regulation of double start induction motor. Thus hysteresis comparators used on the classical method of direct control of torque has been replaced with fuzzy blocs. As results we achieved can be summarised as follows:
1-amelioration the responding time of the system
2-Minimization of the torque ripples.

Key words: the double start asynchronous motor, the fuzzy logic, 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.

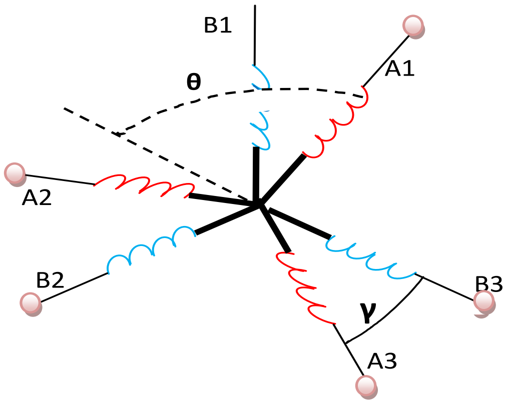

Fig.01.shows the winding of DSIM

The control of the double star asynchronous machine has progressed significantly in recent times, in particular 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 (regardless of whether they are large or small are very large or very little) to determine the states of the switches, and with the meaning of the terms “high" or "very small" are being vague and imprecise, hence the name of the concept contain a makes reference to the notion of being ‘fuzzy’. It seems natural to think of using other nomenclature **so in our paper we have used ‘fuzzy logic’ for this control method.**Today, Fuzzy logic 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:

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

For the rotative part:

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

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

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

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, in this case is represented by the tension vector

$$U = \left[V_{Salph1} \quad V_{Sbeta1} \quad V_{Sa\,lph2} \quad V_{Sabeta2}\ \right] \qquad (2.\ 8)$$

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.

$$\begin{cases} \overline{Vs_{alph_1}} = Rs_1\overline{Is_{alph_1}} + \dfrac{d\overline{\varphi_{s\,alph_1}}}{dt} \\ \overline{Vr} = \overline{0} = Rr\overline{Ir} + \dfrac{d\overline{\varphi r}}{dt} - \mathrm{j}\omega\overline{\varphi_\mathrm{r}} \end{cases} \qquad (3.\ 1)$$

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

$$\begin{cases} \overline{V_{s\ alpha_1}} = Rs_1\overline{I_{s\,alph_1}} + \dfrac{d\overline{\varphi_{s\,alph_1}}}{dt} \\ \dfrac{d\overline{\varphi_r}}{dt} + \left(\dfrac{1}{\sigma\tau_r} - \mathrm{j}\omega\right)\overline{\varphi_\mathrm{r}} = \dfrac{Lm}{Ls}\dfrac{1}{\sigma\tau_r}\overline{\varphi_{s\,alph_1}} \end{cases} \qquad (3.3)$$

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 $\gamma = \left(\overline{\varphi_s\varphi_r}\right)$ 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 fuzzy control of torque.

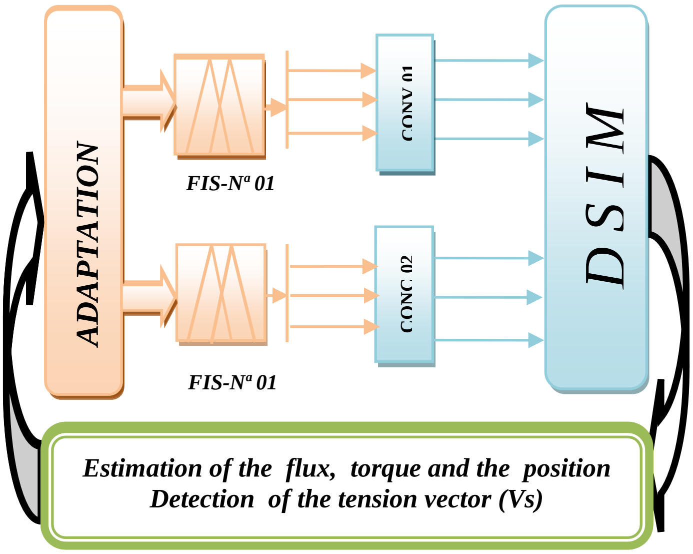

Fig.2.1. Block diagram of the fuzzy direct control of torque Application on the DSIM

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

$$\varphi sj = \int_0^t (Vsj + RsjIsj)dt \qquad j=1,2 \qquad (3.1.1)$$

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:

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

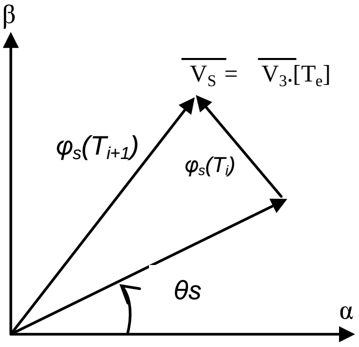

Fig.3.1.Evolution of the end of the flux ie(Vs=V3)

With φ_{S0} being the flow 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 ;

$$\overline{\varphi_S} = \varphi_{S_0} e^{j\theta_{S_0}}$$

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

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 Δωs1 as rotational speed and Immediately after t_0, we can note a modification in the value on the terms of stator and rotor flux:

$$\varphi_s = \varphi_{s_0} e^{j(\theta_{s0}+\Delta\theta_s)} \qquad (3.2.3)$$

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

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

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 Flow 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.

III.4.DEVELOPMENT OF FUZZY SWITCHING TABLE

Errors of both torque and the flux are directly used to select the inverter voltage switche’s state with no distinction between a **very big** error or relatively **small** in the classical direct control of torque, also the switching state selected in case an **important error** occurs while starting or with different consigns of torque or flux is the same as during the normal operation.

As consequence in a transient regime response of the system is slower, however the voltage vector is selected, and by taking into account the magnitude (amplitude) and signs of the errors of torque and flux and not just their signs, then the responses of the system during starting and when changing the flux control or torque can be greatly improved.

We propose in this paper a study of direct control of torque application on the double star asynchronous machine based on fuzzy logic. The hysteresis controllers and switching table of conventional DTC are replaced by a fuzzy controller. The fuzzy controller has three variable state. inputs and a fuzzy control variable as output to produce a constant control of torque and flux. As is shown in Figure(3.4.1) the first fuzzy variable, consisting of three fuzzy sets, is a difference between the amplitude of the flow reference and the estimated flux. The second fuzzy variableis slower consisting of five fuzzy sets figure(3.4.2) is the difference between the reference torque and estimated torque,The third fuzzy variable is the angle between the flow stator and the reference axis "angle of the stator flux" As show figure(3.4.3).

The discourse universe of the first fuzzy variable is divided into three fuzzy sets; positive error of the flow (P), flow error close to zero (Z) and the error flow negative (N). The membership functions with a triangular type of fuzzy sets as represented.

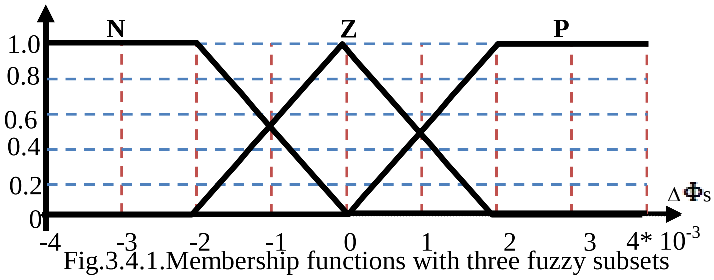

Fig.3.4.1.Membership functions with three fuzzy subsets for the error flux

To account for the slight variations in torque, the discourse universe of the second fuzzy variable is divided into five fuzzy sets; Large positive error(PL), small positive error (PS), error close to zero (Z), small negative error (NS) and large negative error (NL). The distribution of membership functions is shown in Figure (3.4.2)

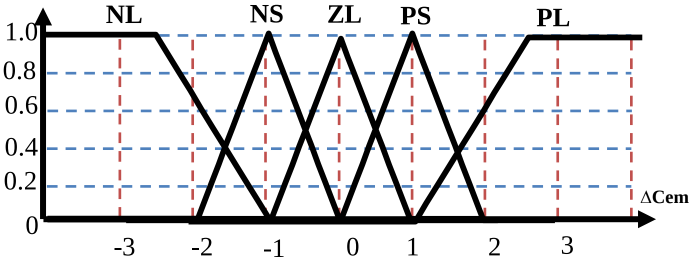

Fig.3.4.2.Membership functions with five the fuzzy sets

The universe of discourse of the third fuzzy variable is divided into twelve fuzzy symmetrical sets. The distribution function of these membership functions is shown in Figure(3.4.3).

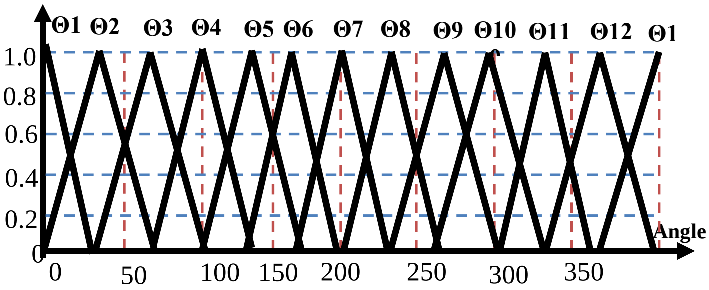

Fig.3.4.3.Membership functions for the position of the stator flux.

The output of fuzzy controller is the proper voltage vector. These voltage vectors are discrete values, they are represented by singletons as in Figure(3.4.4).

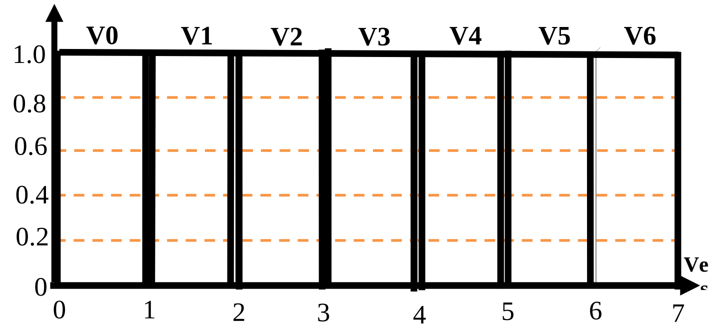

Fig.3.4.4.Membership functions of the fuzzy sets with two Sub For vectors tensions.

III.5.SELECTION TABLE FOR THE VOLTAGE VECTORS

Tables 01& 02 shows the order of voltage vectors used in the fuzzy direct control method of torque according to voltage vector position and the variation of the torque and flux errors

Tab.01.

	Θ1.5.9				*Θ2.6.10*					
ΔΓ* / *Δφ	*PL*	*PS*	*Z*	*NS*	*NL*	*PL*	*PS*	*Z*	*NS*	***NL***
P	*V5*	*V6*	*V0*	*V1*	*V1*	*V5*	*V5*	*V0*	*V6*	***V1***
Z	*V5*	*V5*	*V0*	*V0*	*V2*	*V4*	*V4*	*V0*	*V0*	***V1***
N	*V4*	*V4*	*V0*	*V3*	*V2*	*V4*	*V3*	*V0*	*V2*	***V2***
P	*V3*	*V4*	*V0*	*V5*	*V5*	*V3*	*V3*	*V0*	*V4*	***V5***
Z	*V2*	*V2*	*V0*	*V0*	*V6*	*V2*	*V2*	*V0*	*V0*	***V5***
N	*V2*	*V2*	*V0*	*V1*	*V6*	*V2*	*V1*	*V0*	*V6*	***V6***
P	*V1*	*V2*	*V0*	*V3*	*V3*	*V1*	*V1*	*V0*	*V2*	***V3***
Z	*V1*	*V1*	*V0*	*V0*	*V4*	*V6*	*V6*	*V0*	*V0*	***V3***
P	*N*	*V6*	*V6*	*V0*	*V5*	*V4*	*V6*	*V5*	*V0*	***V4***

Tab.02.

	Θ1.5.9				Θ2.6.10					
Δr Δφ	*PL*	*PS*	*Z*	*NS*	*NL*	*PL*	*PS*	*Z*	*NS*	*NL*
P	*V5*	*V6*	*V0*	*V1*	*V1*	*V5*	*V5*	*V0*	*V6*	*V1*
Z	*V5*	*V5*	*V0*	*V0*	*V2*	*V4*	*V4*	*V0*	*V0*	*V1*
N	*V4*	*V4*	*V0*	*V3*	*V2*	*V4*	*V3*	*V0*	*V2*	*V2*
P	*V3*	*V4*	*V0*	*V5*	*V5*	*V3*	*V3*	*V0*	*V4*	*V5*
Z	*V2*	*V2*	*V0*	*V0*	*V6*	*V2*	*V2*	*V0*	*V0*	*V5*
N	*V2*	*V2*	*V0*	*V1*	*V6*	*V2*	*V1*	*V0*	*V6*	*V6*
P	*V1*	*V2*	*V0*	*V3*	*V3*	*V1*	*V1*	*V0*	*V2*	*V3*
Z	*V1*	*V1*	*V0*	*V0*	*V4*	*V6*	*V6*	*V0*	*V0*	*V3*
P	*N*	*V6*	*V6*	*V0*	*V5*	*V4*	*V6*	*V5*	*V0*	*V4*

IV.FIS ALGORITHEM USED

The fis that we used, is fuzzy inference system is a system that uses fuzzy set theory to map inputs&outputs.

IV.1.FIS INPUTS,OUTPUTS

we have put all our input; flux errors cf[N Z P],torque error cpl[NS NL ZE PS PL], and the location of the tension vector N[θ1 θ2 θ3 θ4 θ5 θ6 θ7 θ8 θ9 θ10 θ11 θ12] then as output variables we have put six membership singleton S[E1 E2 E3 E4 E5 E6].

the fis type we used in our paper is Mamdani with if –and –and-then rule structure.

i.e rule Number 01 **[**if cf is P and cpl is PL and N is O1 then Etat is E1**]**.

IV.2.FIS RULS

We create the rules by using the list box and check box choices for input and output variables, connections, and weights.

IV.3.CHARACTERISTIC SURFACE

The figure(04) shows the characteristic surface of the fuzzy table used in model of FDCT

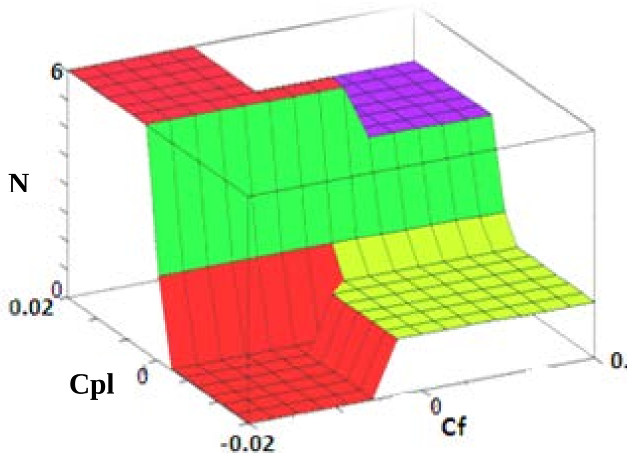

Fig.04. Fis characteristic surface

V.SIMULATION RESULTS

Figure (5.1) Demonstrates the dynamic performance of the PI controller at starting and in the event of load disturbance. The starting type is characterized by an excess of 0.06% and a response time of 0.66secondes. at t = 1.5s we apply 10N.m as load on the motor, the classical controller PI rejects the disturbance with a speed drop of 0.015% and a rejection time 0.002s.

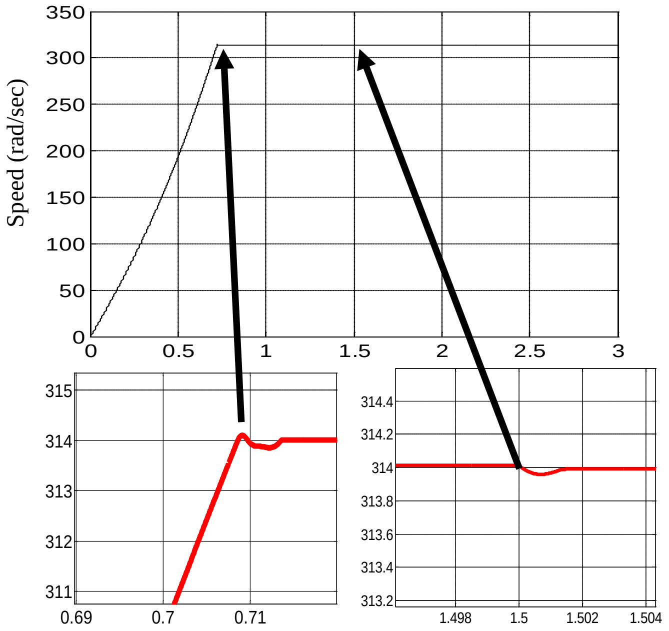

Fig.5. 1. PI Dynamic performance of FDTC on DSIM

The figure (5.2) 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 50% compared with the calissical method of direct control of torque

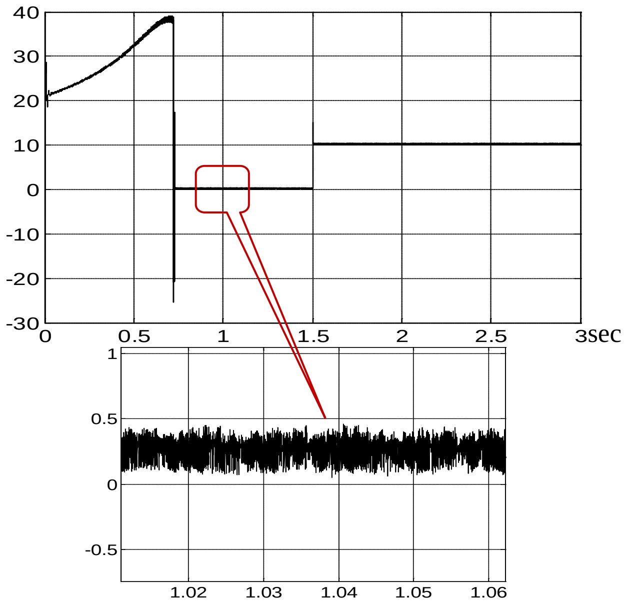

Fig.5.2.Enlarged view of resultant torque ripple

Figure (5.3) shows the form of the electromagnetic flux when using the direct method of torque control, also the perfect uncoupling between flux and torque, it also shown the flux reaching the reference value with a ripple rate of 0.41%. In the same figure we can see the evolution of the component flow $(\varphi_{s1\beta})$ versus the other component $(\varphi_{s1\alpha})$ with a uniform test flux.

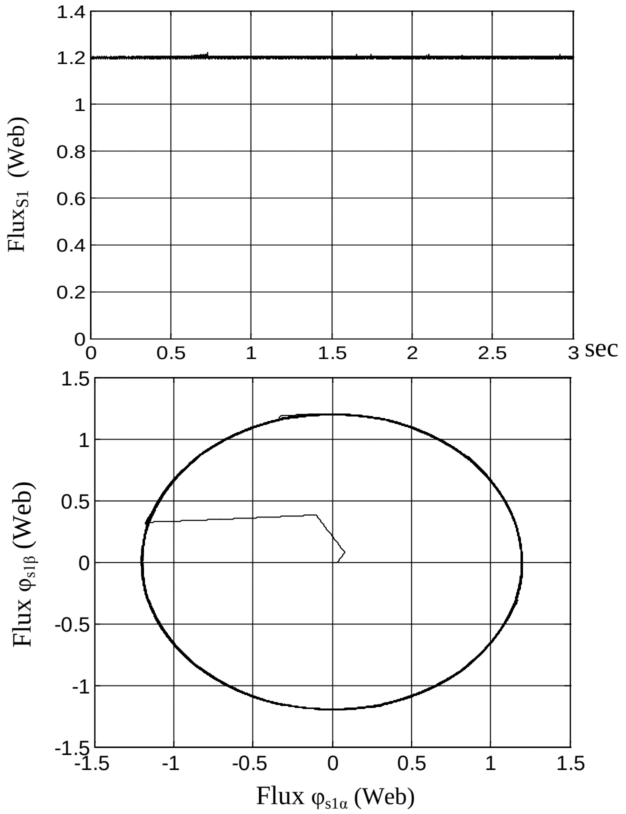

Fig.5.3.Electromagnetic flux behavior

VI.CONCLUSION.

First we did developed the theory of the direct fuzzy method of torque 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 direct fuzzy control of torque as a control method.

The speed simulation of the double star induction motor using direct fuzzy control of torque showed superior performance of fuzzy direct torque control 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 (5.2) by simulation we improved the direct fuzzy method of torque control 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 an optimal choice of parameters of the memberships functions associated..

VII.REFERENCE

[1] I. Takahashi, T.Noguchi " new quickresponse and high-efficiency control" strategy of induction motor″, IEEE Trans. On IA, Vol.22, N°.5, PP.820-827.

[2] J.Paul Louis, "Commandes d'actionneurs électriques synchrones et spéciaux" EGEM 2012

[3] J.sury, I.sic youni, K.sang lee & S.chan hong, "Direct Torque Control of Induction Motors Using Fuzzy Variables witching Sector" Industrial Electronics [2001. Proceedings. ISIE 2001. IEEE] International Symposium on Volume 2

[4] J.poul Louis,"Commande classique et avancées des actionneurs synchrones" EGEM 2010

[5] R.Abdessemed, "Modélisation et simulation des machines électriques"[Ellipses Édition Marketing S.A 2011]

[6] E. Monmasson, "Commande rapprochée de convertisseur statique 01" EGEM 2009.

[7] G. Grellet , G. Clerc, " Principe /modèle / commande" D.I.S.T.N.B Actionneurs électriques.

[8] M. Bellier, A.Galichon, " Électricité industriel: Machines Electriques."

[9] K. Marouani, A.Kheloui, " Implantation Numérique de la Commande Directe du Couple d'une Machine Asynchrone" ICEL 2000 U.S.T.O ALGERIE.

[10] L. Loron, "Commande du système électrique" Lavoisier 2003 paris.

[11] L. Dor londan, "Commande des systems" Lavoisier 2002 Paris.

[12] C. Canulas de wir, "Modélisation contrôle vectoriel et DTC" commande des moteurs asynchrones 1 MERMES science Europe.

[13] M. Depenbrock, "Direct self –control (DSC) of inverter–fed induction machine" , IEEE Trans. Power Elec.

[15] Rahman MF,Haque MDF, T. Lixin, "all. Problems associated with the direct torque control of an interior permanent magnet synchronous motor drive and their remedies" [IEEE Trans. on Industrial Electronics, 2004, 51(4).799–809]