Direct Torque Control-Fuzzy Logic Controller (DTC-FLC)of Doubly Fed Induction Machine (DFIM)

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Abstract.

This paper presents a new advanced Direct Torque Control of doubly fed induction motor using Fuzzy logic controller, which the classic integral proportional (IP) controller have been replaced by new fuzzy logic controller (FLC) of speed to overcome the most drawbacks and limitations of classical DTC control, accuracy and the convergence speed under sudden changing torque reference and/or speed reference. The fuzzy logic controller parameter that optimize the performances of conventional Direct Torque Control of doubly fed induction motor. The proposed fuzzy logique controller have shown is better than the conventional controller.

Keywords: Fuzzy logic FL, Double Feed Induction Machine DFIM, Direct Torque Control DTC, Speed Control.

1. INTRODUCTION

The Doubly Fed Induction Machine (DFIM) is an attractive alternative to cage rotor induction and synchronous machines in high power applications. The interest occurs mainly in applications such as: generator for renewable energy and motor for variable speed application, railway traction, marine propulsion, and hydroelectric power stations [1-5].

The widespread use of doubly fed induction machines is justified by following advantages:

- DFIMs can generate reactive current and produce constant-frequency electric power at variable speed operation.
- DFIM can be fed and controlled stator or rotor by various possible combinations;
- The power flow can be modulated;
- DFIM can be operate in wide range of speed variation around the synchronous speed (until ± 30%), so, it The active and reactive power can be control separately;
- the stator and rotor currents are measurable;
- Many DFIMs parameters can be controlled independently (torque, flux, and power factor).

Although, the previous advantages of DFIM, its brushes and slip rings structure are the most drawbacks, which it require permanent maintenance.

The growing interest of the doubly fed induction machine (DFIM) has motivates many researchers to develop and improve it continuously, which they study the including different parts such as converter parts, conception machine, materials and the control of DFIM. In last point, a large number of techniques have been proposed since it can exhibits many merits, the field oriented control (FOC) techniques are developed firstly, However, it highly dependent on the parameters of the induction machine and constant gains PI controllers may become unable to provide the required control performance. Hence PI controller limitations and its complexity of implementation are the most drawbacks [5-9]. Moreover, Direct torque control (DTC) was proposed in 1980s and then it was well developed in power electronics and drives application for its excellent steady state and transient performance [7], and Direct Self Control (DSC) by Depenbrock [8] have provided better steadystate and transient torque control conditions rather than FOC techniques. In addition, Direct Control techniques do not require current regulators, nor coordinate transformations or specific modulations like PWM or SVM for pulse generation. However Direct Control techniques present some many drawbacks compared to the FOC such as difficulties of torque control at very low speeds, variable switching frequency, and the lack of direct current control.

In recent years , many improvements have introduced to Direct Control techniques to reduce torque ripple [3] and achieved constant switching frequency such as Direct Mean Torque Control (DMTC) [2], Direct Torque Control using Artificial Neural Network (DTC-ANN) [1]. In addition, many intelligent control strategies have been proposed such as fuzzy logic control (FLC) [6], sliding mode control (SMC) [19], backstepping control , Fuzzy-SVM , adaptive fuzzy vector controller (AFVC) [10].

In this paper, to reduce the dip in the speed, New Fuzzy controller for DTC of doubly fed induction machine DFIM has been developed. Modelling of DFIM and details of proposed control strategy have been presented, The performances in terms of torque and speed tracking, and accuracy have been demonstrated.

2. DOUBLY FED INDUCTION MACHINE MODEL

The state-all-flux DFIM dynamic model expressed in (α,β) axes rotational reference frame is given by the following equations:

$$\begin{cases} V_{s\alpha} = R_s I_{s\alpha} + \dfrac{d}{dt}\Phi_{s\alpha} \\ V_{s\beta} = R_s I_{s\beta} + \dfrac{d}{dt}\Phi_{s\beta} \\ V_{r\alpha} = R_r I_{r\alpha} + \dfrac{d}{dt}\Phi_{r\alpha} + \omega\Phi_{r\beta} \\ V_{r\beta} = R_r I_{r\beta} + \dfrac{d}{dt}\Phi_{r\beta} - \omega\Phi_{r\alpha} \end{cases} \qquad (1)$$

$$\begin{cases} \Phi_{s\alpha} = l_s I_{s\alpha} + M I_{r\alpha} \\ \Phi_{s\beta} = l_s I_{s\beta} + M I_{r\beta} \\ \Phi_{r\alpha} = l_r I_{r\alpha} + M I_{s\alpha} \\ \Phi_{r\beta} = l_r I_{r\beta} + M I_{s\beta} \end{cases} \qquad (2)$$

The electromagnetic torque is given by :

$$C_{em} = \frac{3pM}{2L_s}(\Phi_{s\alpha} I_{r\beta} - \Phi_{s\beta} I_{r\alpha}) \qquad (3)$$

3. DIRECT TORQUE CONTROL OF DFIM

DTC is an advanced control method involving direct control of the electromagnetic torque and the flux developed in the double feed Induction machine. At the heart of the control system in the DTC are the flux and torque hysteresis controllers and an optimal switching state logic block. An appropriate DFIM model is essential for the correct estimation of the electromagnetic torque and stator flux. The estimation of these quantities is carried out by measurements of the DFIM currents, flux linkages and the DC voltage. The estimated values of the motor torque and flux are input to the two hysteresis controllers wherein, a comparison between the estimated and the actual values of the quantitates is performed [4],[8].

Direct torque control is based on the flux orientation, using the instantaneous values of voltage vector. An inverter provides eight voltage vectors, among which two are zeros.

These vectors are errors as well as the stator flux vector chosen from a switching table according to the flux and torque position. In this technique, we don't need the rotor position in order to choose the voltage vector. This particularity defines the DTC as an adapted control technique of AC machines and is inherently a motion sensorless control method [2-6].

As shown in Fig. 1, the position vectors and Status of the flux and tourque , the stator flux is divided into six sectors. There are also 8 voltage vectors which correspond to possible inverter states.

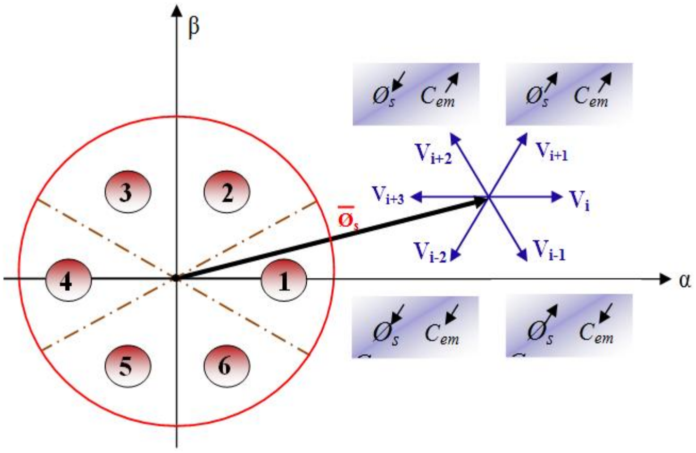


Fig.1. Vectors and Status of the flux and tourque.

The flux estimator can be obtained by the following equation:

$$\overline{\phi_s}(t) = \int_0^t (\overline{V_s} - R_s\,\overline{I_s})\,dt \qquad (4)$$

The stator flux $Ø_{sref}$ and the torque Cem_{ref} are compared with respective estimated values, and errors are processed through hysteresis-band controllers. The digital outputs from the hysteresis comparators along with the sector number are shown in Table 1. The correct voltage vector is then selected. The corresponding switch position for the inverter, to achieve the selected voltage vector is shown in Table 2.

Flux	Torque	N = 1	N = 2	N = 3	N = 4	N = 5	N = 6	corrector
Cflx=0	Ccpl=1	V_3	V_4	V_5	V_6	V_1	V_2	2 levels
	Ccpl=0	V_0	V_7	V_0	V_7	V_0	V_7	
	Ccpl=-1	V_5	V_6	V_1	V_2	V_3	V_4	3 levels
Cflx=1	Ccpl=1	V_2	V_3	V_4	V_5	V_6	V_1	2 levels
	Ccpl=0	V_7	V_0	V_7	V_0	V_7	V_0	
	Ccpl=-1	V_6	V_1	V_2	V_3	V_4	V_5	3 levels

Table. 1. Switching table for voltage vectors.

	V_0	V_1	V_2	V_3	V_4	V_5	V_6	V_7
S_a	0	1	1	0	0	0	1	1
S_b	0	0	1	1	1	0	0	1
S_c	0	0	0	0	1	1	1	1

Table .2. Switch positions and their voltage vectors.

The choice of the zero vectors (V_0, V_7) produces a smaller torque and flux variations compared with the active vectors. Then, the zero vectors are not really needed to keep the torque and flux controlled; however, it is used to reduce the torque and flux ripples at steady state operation. For almost every application of DTC, it is advantageous if the torque and flux ripples are minimized as much as possible [9].

4. Fuzzy Speed Controller

With the aim of eliminate the static error and reduce the response time, while keeping the system is stable, the motor speed can be controlled indirectly by controlling the torque with a Fuzzy Controller.

The Fuzzy Logic is based on the theory of fuzzy sets developed by Zadeh [17-18]. The proposed fuzzy controller has two inputs and one output as described in Fig. 2.

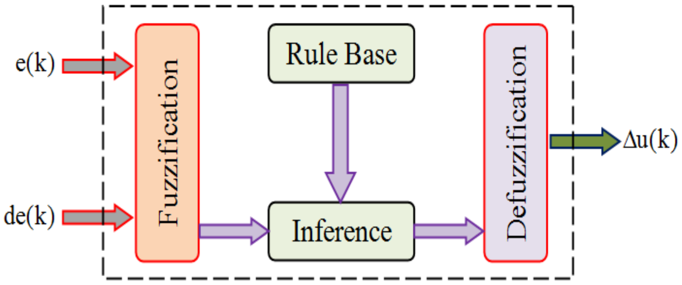


Fig. 2. Structure of the fuzzy controller.

Where e is the error, expressed by:

$$e(k)=\omega^{*}(k)-\omega(k-1) \qquad (5)$$

de: is derived from the error approximated by:

$$de=\frac{e(k)-e(k-1)}{T} \qquad (6)$$

With: T is the sampling period.

The output of the regulator is given by:

$$C_{ref}(k)=C_{ref}(k-1)+\Delta u(k) \qquad (7)$$

The fuzzy controller is composed of three blocks: fuzzification, rule bases, and defuzzification. Fig. 3 shows the function of membership of each input signals (e, de).

The fuzzy subsets are as follows: NB (Negative Big), Nm (Negative Medium), NS (Negative Small), Z (Zero), PS (Positive Small), PM (Positive Medium), PB (Positive Big).

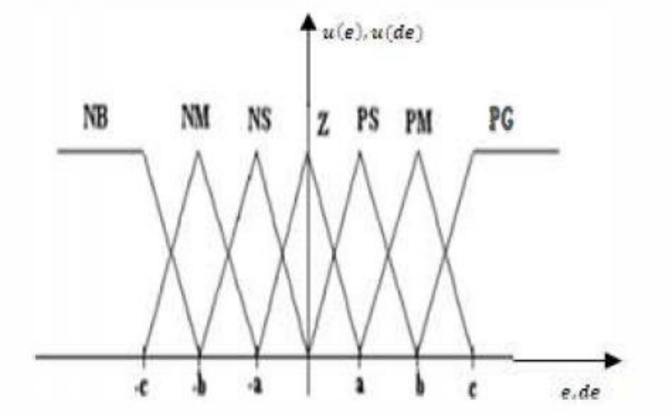


Fig. 3. The Membership function.

There are 7 fuzzy subsets for each variable, which gives 7* 7 = 49 possible rules, where a typical rule is:

"If ***e*** is PS and **de** is PM Then Δu is PB"

The rules base is shown in Table 3.

e de	NB	NM	NS	Z	PS	PM	PB
PB	Z	PS	PM	PB	PB	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PS	NM	NS	Z	PS	PM	PB	PB
Z	NB	NM	NS	Z	PS	PM	PB
NS	NB	NB	NM	NS	Z	PS	PM
NM	NB	NB	NB	NM	NS	Z	PS
NB	NB	NB	NB	NB	NM	NS	Z

Table .3. Rules base.

The proposed FLC Speed controller is shown in Fig. 4. The weights are determined by training algorithm.

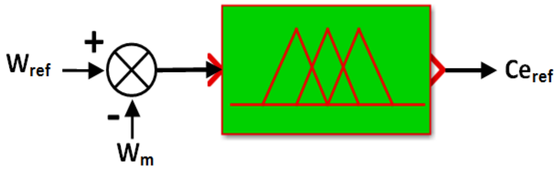


Fig. 4. The fuzzy logic Speed Controller.

The proposed DTC-FLC scheme including both Fuzzy logique speed controller is illustrated in the Fig.5.

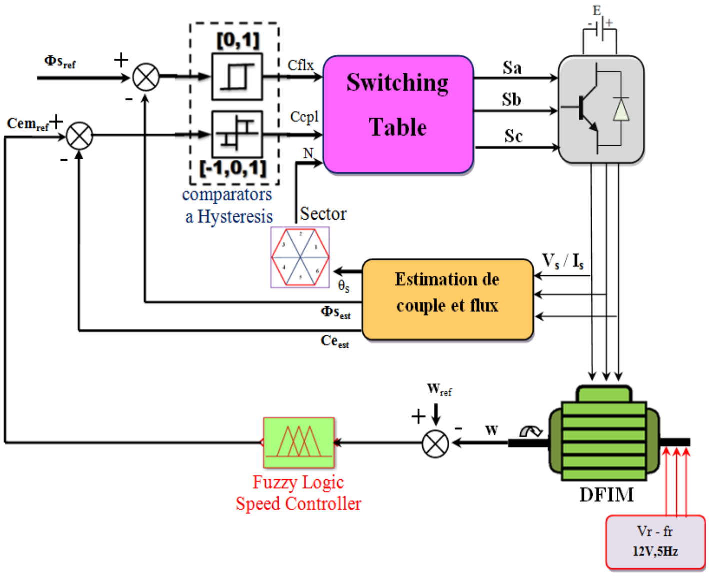


Fig. 5. DTC-FLC scheme .

5. SIMULATION RESULTS

To demonstrate the efficiency of the proposed DTC-FLC strategy, has been carried out using 0.8kW DFIM [4], which many performance parameters have been studied.

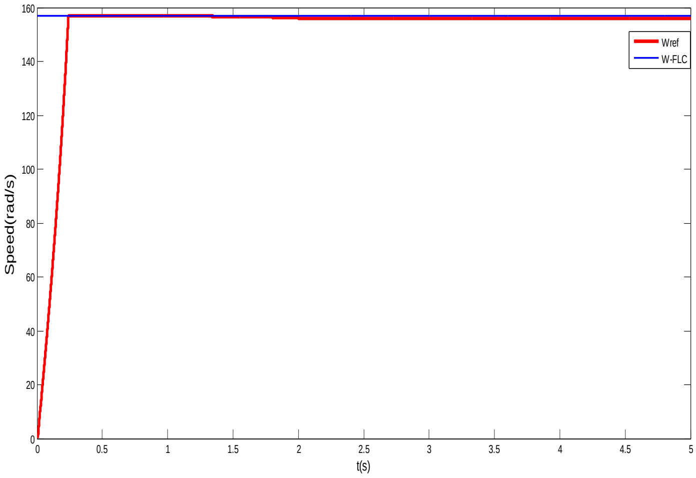
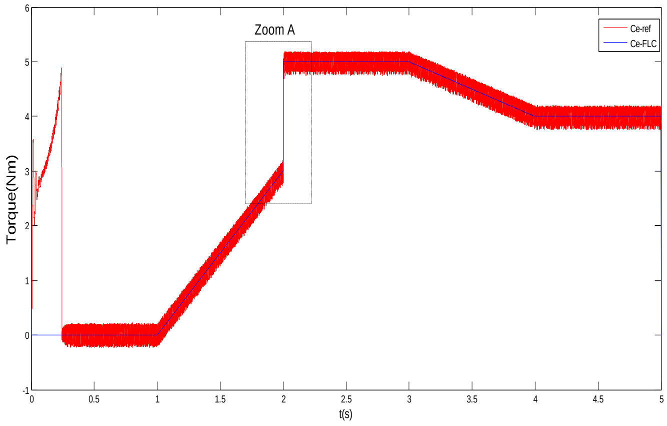


Fig. 6. DTC-FLC under speed variation.

The simulation results obtained with no load as starting up condition and connecting the nominal load as normal operating condition are presented in following figures.



a) Zoom A

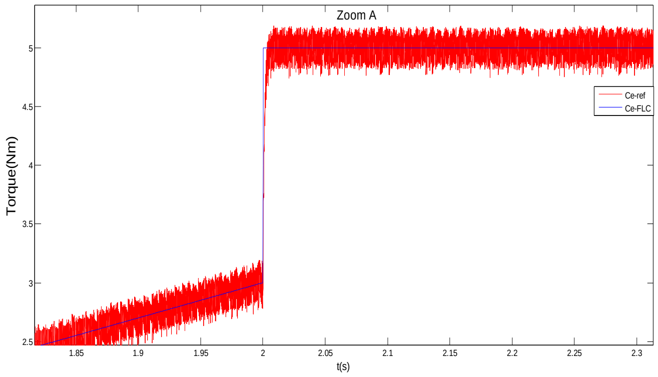


Fig.7.DTC-FLC under variable load.

The Fig.6 and Fig.7 illustrate the speed, electromagnetic torque respectively, while Fig.8 shows the flux .

From Fig.6, we can see that at starting up with no load or in case of nominal load, the DTC-FLC controller reaches its speed reference rapidly without overshoot. so the excellent dynamic performance of torque and flux control is evident.

From Fig.7, its clear that the electromagnetic torque obtained by proposed DTC-FLC better performances characterised by less response time and low overshoot.

The stator flux cercle is shown in Fig. 8.

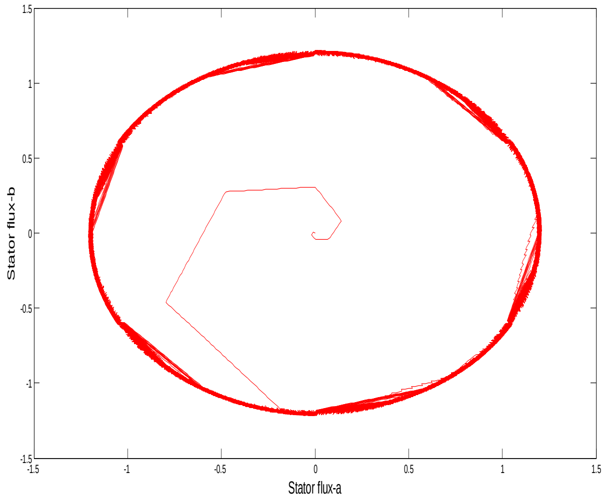


Fig. 8. Stator flux cercle.

Fig.9. shows the statorique courant de phase signals issued by DTC-FLC of DFIM

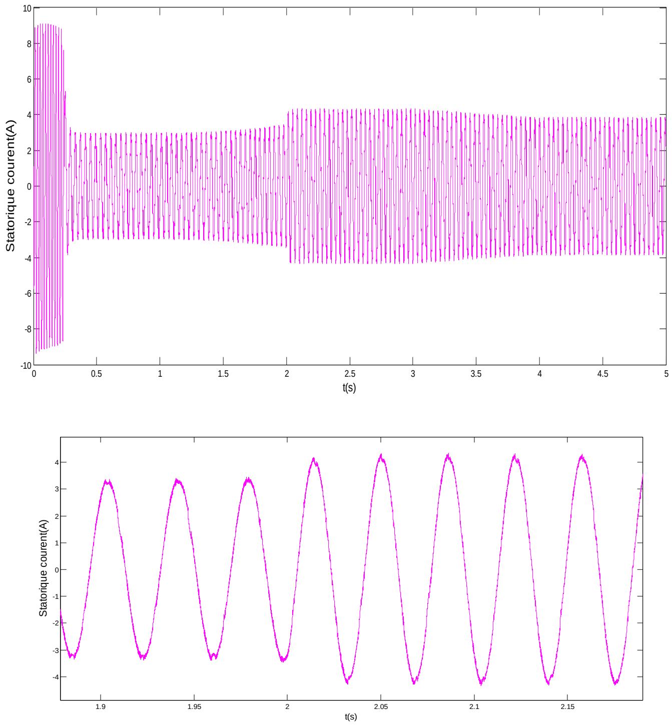


Fig. 9. Stator current of DFIM using DTC-FLC.

From Figures 6 to 9, The control performances are very satisfactory. The dynamics of continuation is not affected during the variation of the load torque. The rejection of disturbance is very efficient. One notices, for speed, a fast starting without an overshoot and static error. The figure of stator flux vector locations is describes the stator flux vector trajectory which is circular.

6. CONCLUSION

In this paper, direct torque control strategy using fuzzy logic speed controller for DFIM (DTC-FLC) has been proposed and investigated. In which, modelling of DFIM and proposed DTC-FC strategy have been discussed in detail. In addition, the development of fuzzy logic controller has been explained (structure, function, rules). Simulation results demonstrate the effectiveness and the robustness of the proposed DTC-FLC in term of faster converging speed.The proposed DTC-FLC is more suitable for the speed regulation of DFIM control.

APPENDIX:

Double Feed Induction Machine parameters:
P_n = 0.8 kW ;U_n= 220/380 V ;F=50 Hz ;I= 3.8/2.2 A
Vr= 3×120 V; 4.1 A ;Ω =1420 tr/min ;Rs = 11.98 Ω ;Rr = 0.904 Ω
Ls = 0.414 H ;Lr = 0.0556 H ;M = 0.126 H ;P = 2 ;J = 0.01 kg.m^2
f = 0.001

REFERENCES

[1] ZEMMIT, Abderrahim, MESSALTI, Sabir, et HARRAG, Abdelghani. Innovative improved Direct Torque Control of Doubly Fed Induction Machine (DFIM) using Artificial Neural Network (ANN-DTC). International Journal of Applied Engineering Research, 2016, vol. 11, no 16, p. 9099-9105.

[2] JACOMINI, R. V., ROCHA, C. M., ALTUNA, J. A. T., et al. Implementation of a neuro-fuzzy direct torque and reactive power control for DFIM. In : IECON 2014-40th Annual Conference of the IEEE Industrial Electronics Society. IEEE, 2014. p. 648-654.

[3] S. Messalti, A. Gherbi, and S. Belkhiat," Improvement of Power System Transient of Stability using wind farms based on doubly fed induction generator (DFIG)", Journal of Electrical Engineering : Volume 13 (3), 2013

[4] Abderrahim ZEMMIT, Sabir MESSALTI, "Modeling and Simulation of Doubly Fed Induction Motor (DFIM) Control using DTC and DFOC: A comparative study", International Journal of Applied Engineering Research ISSN 0973-4562 Volume 11, Number 8 (2016) pp 5623-5628.

[5] Ouledali, O., et al. "Direct Torque Fuzzy Control of PMSM based on SVM." Energy Procedia 74 (2015): 1314-1322.

[6] Bennassar Abderrahim, Ahmed Abbou and Mohammed Akherraz Akherraz. A comparative study of IP, fuzzy logic and sliding mode controllers in a speed vector control of induction motor. International Review on Modelling and Simulations (IREMOS) 6, no. 6 (2013): 1865-1871.

[7] Yuan Li, Feng-You He, Zong-Bin Ye, Study on Sliding Mode Speed Control with Fuzzy Approch for Doubly-Fed Induction Motor, IEEE.Intrnational Conference on Conference on Control and Automation, Christchurch, New Zealand, December 9-11, p.2171-2175.

[8] LAI, Yen-Shin et LIN, Juo-Chiun. New hybrid fuzzy controller for direct torque control induction motor drives. IEEE Transactions on Power Electronics, 2003, vol. 18, no 5, p. 1211-1219.

[9] WANG, Shun Yuan, TSENG, Chwan Lu, LIN, Shou Chuang, et al. Design of Fuzzy Controllers for Direct Torque Control Systems. In : Computer, Consumer and Control (IS3C), 2014 International Symposium on. IEEE, 2014. p. 994-997.

[10] Aissa, O., Moulahoum, S., Kabache, N., & Houassine, H. (2014, June). Improvement of DTC of induction motors by using a three-level inverter and fuzzy speed controller. In Control and Automation (MED), 2014 22nd Mediterranean Conference of (pp. 73-78). IEEE.