Direct Torque Control of Induction Motors with Fuzzy Minimization Torque Ripple

L. YOUB , A. CRACIUNESCU

***Abstract* — Direct torque control (DTC) is a new method of induction motor control. The key issue of the DTC is the strategy of selecting proper stator voltage vectors to force stator flux and developed torque within a prescribed band. Due to the nature of hysteresis control adopted in DTC, there is no difference in control action between a larger torque error and a small one. It is better to divide the torque error into different intervals and give different control voltages for each of them. To deal with this issue a fuzzy controller has been introduced. But, because the number of rules is too high some problems arise and the speed of fuzzy reasoning will be affected. In this paper, a comparison between a new fuzzy direct-torque control (DTFC) with space vector modulation (SVM) is made. The principle and a tuning procedure of the fuzzy direct torque control scheme are discussed. The simulation results, which illustrate the performance of the proposed control scheme in comparison with the fuzzy hysteresis connected of DTC scheme are given.**

***Key words*— Induction machine, Direct torque control, Fuzzy logic, Space vector modulation**.

I. INTRODUCTION

In applications of high-performance induction motor drives such as motion control, it is usually desirable that the motor can provide good dynamic torque response as it is obtained from dc motor drives. Many control schemes have been proposed for this goal, among which the vector control or sometimes called oriented field control has been recognized as one of the most effective methods [1, 2, 3]. It is well known that vector control needs quite complicated to on line coordinate transforms to decouple the interaction between flux control and torque control in order to provide a fast torque control of an induction motor.

The appropriate computation algorithms are time consuming and their implementation requires high performance DSP chips. In recent years an innovative control method, called direct torque control has gained the attraction of researchers, due to its capability to produce fast torque control of the induction motor without to use many on-line computation as for vector control.

Classical (DTC) uses two hysteresis controllers for stator flux and developed torque, respectively. The key issue of design of the DTC is the strategy used for selection of the proper stator voltage vectors to force stator flux and developed torque values to maintain into their prescribed bands. Usually, the hysteresis controller is a two-value bang-bang controller, which has the same outputs both for the big torque errors as for the small torque errors. Therefore, big torque ripples are produced. In order to reduce the torque ripples, the torque errors have to be dividing into several intervals on which operate different control action. As the DTC control strategy is not based on mathematical analysis, it is not easy to give an apparent boundary to the division of torque error. Fuzzy control is a way for controlling a system without the need of knowing the plant mathematic model. It uses the experience of people's knowledge to form its control rule base [3, 4].

In this paper, the fuzzy direct torque control associated with the space vector modulation technique is analyzed. The space vectors are generated by two fuzzy logic controllers. The first one is for flux control and the second one is for torque control. The uses of fuzzy controllers instead of PI controllers permit a faster response and more robustness. The use of SVM technique which provide a constant inverter switching frequency has as results small torque ripples and current distortion.

II. FUZZY DIRECT TORQUE CONTROL

In order to improve the DTC performances a complimentary use of fuzzy regulators is proposed. The two hysteresis controllers of classical DTC will be complimented with two fuzzy regulators as it is shown in figure. 1

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L.Youb is with University of Batna (Algeria), Science Engineering Faculty (e-mail: youblamia@yahoo.fr).
A.Craciunescu is with University of Bucharest (Romania), Electrical Engineering Faculty (e-mail: aureliancraciunescu@yahoo.com).

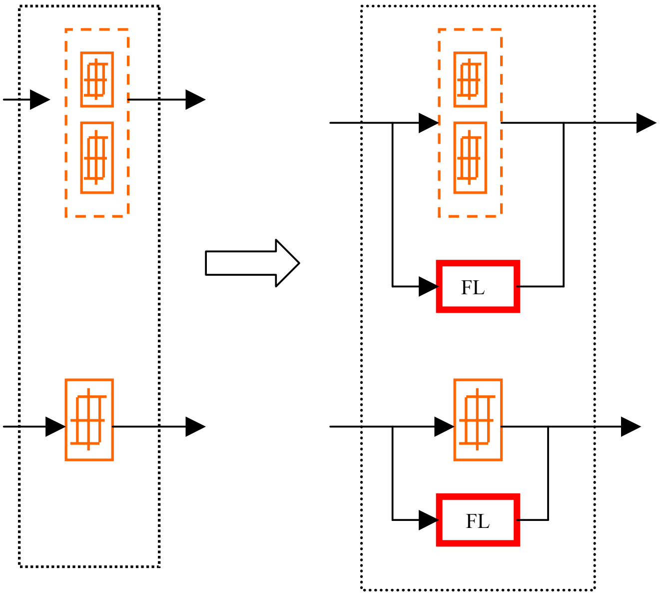

Fig. 1 The improvement of DTC performances by adding fuzzy controllers

It follows from the previous section that the controller adopting DTC strategy has the property of hysteresis, which only takes two value controls for the very big or small error of the torque. That means the control action will be the same in the whole error range. To get better control performance a fuzzy logic controller has been introduced to be a compliment to the hysteresis controller. The wide of hysteresis cycle will be fuzzy variables: b_ϕ for flux controller and b_T for torque controller. The fuzzy controller design is based on intuition and simulation. These values compose a training set which is used to obtain the table of rules. The fuzzy rules' sets are shown in Table 1. In Fig. 2 it is shown the membership functions of input and output variables in Fig.3. The rules were formulated using analysis data obtained from the simulation of the system using different values of the torque hysteresis band.

TABLE. I
FUZZY RULES OF TORQUE AND FLUX HYSTERESIS CONTROLLER

e1 e2 Δb_Γ or Δb_φ	NH	NM	NS	ZE	PS	PM	PH
N	N	N	NS	ZE	PS	PS	P
ZE	N	N	NS	ZE	PS	PS	P
P	N	NS	NS	ZE	PS	P	P

PH: positive high, NH: negative high,
PM: positive medium, NM: negative medium,

PS: positive small, NS: negative small, ZE: zeThe linguistic rules can be expressed by the following example:

- If (e1 is NH or NM and e2 is N) then (Δb_Γ or Δb_φ is N):

This case corresponds to a big overshoot in torque error, consequently high torque ripple. To reduce the torque ripple, the value Δb_Γ should be reduced. In this case, the overshoot in torque error can touch the upper band which will cause a reverse voltage vector to be selected. This one will result in a torque to be reduced rapidly and causes undershoot in the torque response below the hysteresis band. Thus, Δb_Γ should not be too small; Δb_Γ is set positive in order to avoid this situation.

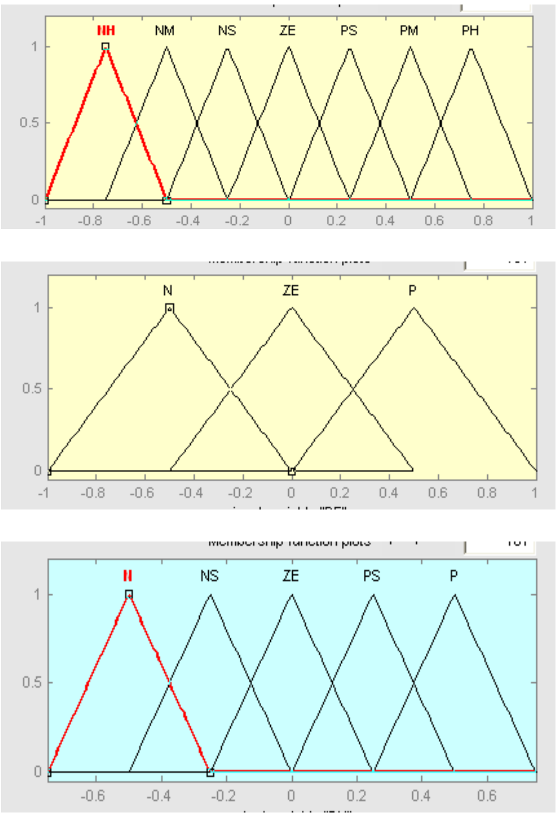

Fig. 2 input/output variables membership functions

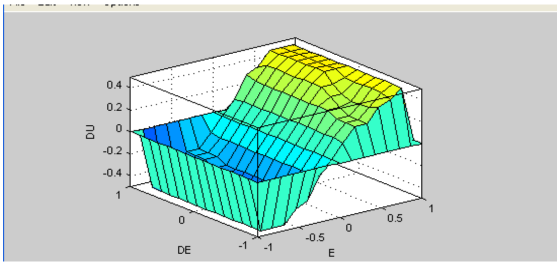

Fig. 3 Control surface

III. SPACE VECTOR MODULATION

The aim of SVM is to minimize harmonic distortion in the current by selecting the appropriate switching vectors and determining their corresponding dwelling widths [5]. As depicted in Fig. 4 there are eight states available for voltage space vector according to eight switching positions of the inverter. SVM is based on time averaging techniques during sampling period T_s. If the reference vector Vs ($V_{ref} = V_1 + V_2$), is located in sector I (Fig.4), then it is composed of voltage vector $V1$ and $V2$ and zero vectors $V0$ and $V7$, one finds [6]:

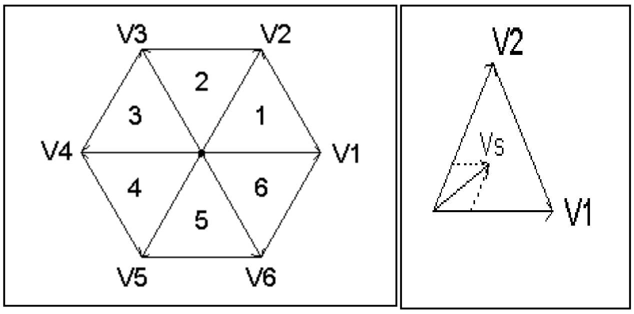

Fig. 4 decomposition of voltage vector

All techniques SVM use to synthesize the reference voltage standard the following equations

$$T_0 = T_7 = \frac{1}{2}(T_s - T_1 - T_2) \qquad (1)$$

$$T_1 = \frac{T_s}{2} a \frac{\sin(\pi - \theta)}{\sin\left(\frac{\pi}{3}\right)} \qquad (2)$$

Several strategies SVM can be used for the piloting of the inverter only difference between these strategies is the choice of the null vector and the sequence of application of the vectors tension during the period of sampling.

$$T_1 Vs = T_1 V_1 + T_2 V_2 \qquad (3)$$

$$T_1 = \frac{T_s}{2} a \frac{\sin(\theta)}{\sin\left(\frac{\pi}{3}\right)} \qquad (4)$$

Where:

$T1$ and $T2$ are the active pulse times of voltage vectors $V1$ and $V2$.

$$a = \frac{V_s}{\left(\sqrt{\frac{2}{3}} V_{dc}\right)}$$

V_{dc} : d-c link voltage. $T0$, $T7$ are a null vector times.

The Fig.5. shown the novel direct torque control scheme for ac motor drives (DTC) with fuzzy hysteresis and space vector modulation.

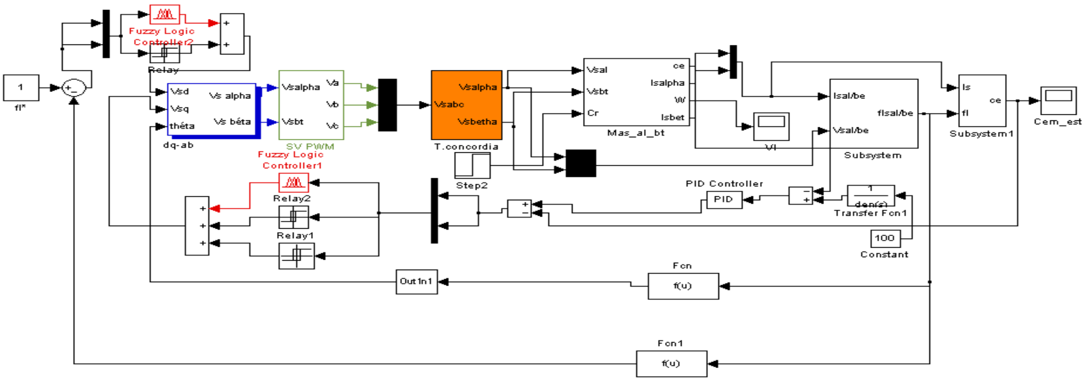

Fig. 5. A novel direct torque control scheme for ac motor drives (DTC) with fuzzy hysteresis and space vector modulation

IV. SIMULATION RESULTS

To study the performance of the fuzzy logic controller with direct torque control strategy, the simulation of the system was conducted by using MATLAB /SIMULINK and fuzzy logic tools. The problem of how to make the flux rapidly reaching its given value, when system started with direct torque control was experienced. In the case of combined control strategy, where the hysteresis regulators are associated with fuzzy regulators and space vector modulation, the same membership functions were used as in paragraph II. The comparative results obtained by simulation for an induction motor are given in figures (6-7).

Interesting results are, as it is shown in figure (7), the torque pulsations in the case of fuzzy DTC with space vector modulation are smaller than in the case of classical DTC with fuzzy hysteresis in (figure.6), but the stator current is bigger. The figures which are presented show the dynamics of the flux and the torque of the induction motor. The trajectory of stator flux has a reduction of the ripples (figure.7), and trajectory of stator flux is circular. Fast torque response and good establishment time, and this while the comparators hysteresis is complimented by fuzzy regulators in (Figure.6). The results of simulation obtained shown well the performances of the combined fuzzy- hysteresis direct torque control of the induction motor.

In the case of space vector modulation as we can see from figure. 7 the torque ripples are drastically reduced. These results are obtained in spite of using larger sampling period for the DTFC. The simulation results given in Fig. 7 show a good tracking of electromagnetic torque using DTFC -SVM and prove that this technique allows a good dynamic performance similar to the basic DTC schemes. Moreover, it can be noted that the effects due to the crossing of sector boundaries, typical of basic DTC schemes, are avoided using the DTFC-hysteresis scheme.

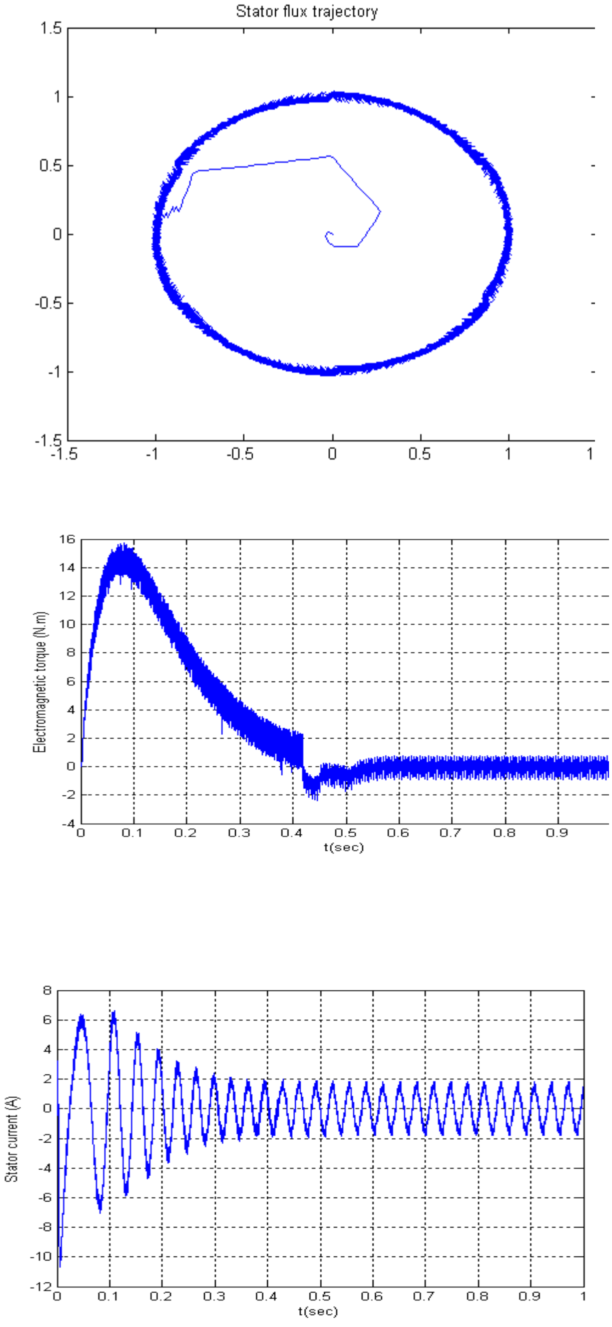

Fig.6 response of trajectory of flux, electromagnetic torque and stator current for scheme of simulation results of fuzzy-hysteresis regulators connected

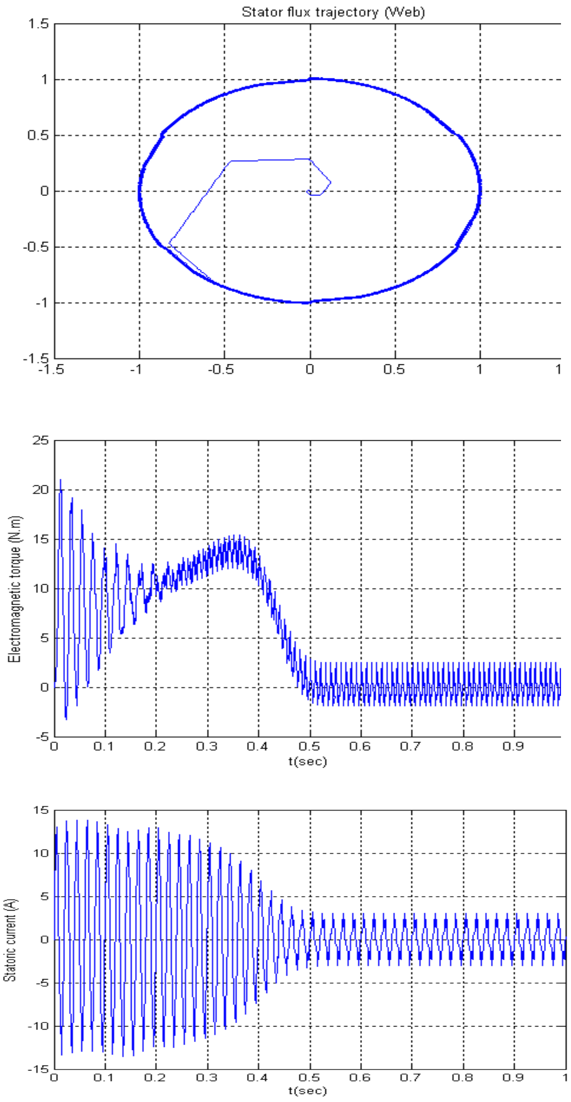

Fig. 7 response of trajectory of flux, electromagnetic torque and stator current for scheme of DTC- fuzzy hysteresis with SVM

V. CONCLUSION

In this paper, a fuzzy direct torque control with space vector modulation is analyzed in comparison to fuzzy hysteresis connected of DTC. The results obtained by numerical simulation are given. In short, the advantages of proposed fuzzy direct torque control using space vector modulation technique in comparison with a fuzzy hysteresis of DTC are the following:

– Reduced torque and flux distortion;
– Constant switching frequency thanks to apply SVM;
– Fast torque response because of the use of fuzzy controller;
– Lower sampling time;
– No problems during Low-speed operation;
– No current and torque distortion caused by sector changes.

APPENDIX

INDUCTION MOTOR PARAMETRS

Power rating	4 kW
Stator voltage	220/380 V
Stator resistance	10 Ω
Stator leakage inductance	0.6550 H
Rotor resistance	6.3 Ω
Rotor leakage inductance	0.6520 H
Mutual inductance	0.612 H
Inertia	0.03kg.m^2
Number of poles	2
TORQUE RATING	25 N.M

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