FUZZY LOGIC BASED DIRECT TORQUE CONTROL OF INDUCTION MOTOR

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Abstract:

This paper presents an improved Direct Torque Control (DTC) based on fuzzy logic technique. The major problem that is usually associated with DTC drive is the high torque ripple. To overcome this problem a torque hysteresis band with variable amplitude is proposed based on fuzzy logic. The fuzzy proposed controller is shown to be able to reducing the torque and flux ripples and to improve performance DTC especially at low speed.

Keywords: ***Direct torque control, induction motor, fuzzy logic, torque ripple minimization***

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1. INTRODUCTION

DTC (Direct Torque Control) is characterized, as deduced from the name, by directly controlled torque and flux and indirectly controlled stator current and voltage. It is an alternative dynamic control for vector control. The big interest in DTC is caused by some advantages in comparison with the conventional vector-controlled drives, like:

- The control is without using current loops.
- The drive does not require coordinate transformation between the stationary frame and synchronous frame. - A pulse-width modulation (PWM) modulator is not required.

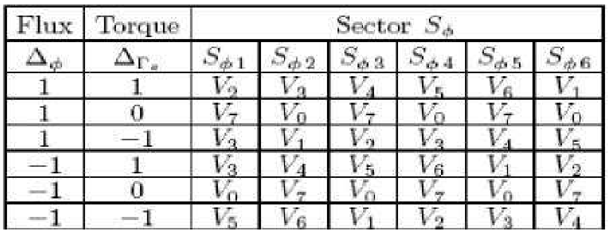
Conventional DTC has also some disadvantages:

- Possible problems during starting and low speed operation.
- High requirements upon flux and torque estimation. - Variable switching frequency.

These are disadvantages that we want to remove by using and implementing modern resources of artificial intelligence like neural networks, fuzzy logic, genetic algorithms etc. In the following, we will describe the application of fuzzy logic in DTC control.

2. DTC PRINCIPLES

The DTC scheme is given in Fig. 1, the ε_ϕ and ε_τ signals are delivered to two hysteresis comparators. The corresponding digitized output variables: change of magnetic flux $\Delta\phi$, of mechanical torque $\Delta\tau$ and the Stator flux position sector S_N created a digital word, which selects the appropriate voltage vector from the switching table? The selection table generates pulses S_a, S_b, S_c, to control the power switches in the inverter. Three-level torque and two level flux hysteresis controllers are used according to the outputs of the torque controller and the sector information of appropriate voltage vectors for both the inverters are selected from a switching table as it is shown in fig.1.Figure.2 shows the voltage vectors which are usually employed in DTC scheme when the stator flux vector is lying sector I. The selection of a voltage vector at each cycle period is made in order to maintain the torque and the stator flux within the limits of two hysteresis bands. This simple approach allows a quick torque response to be achieved, but the steady state performance is characterized by undesirable ripple in current, flux and torque. Torque and rotor speed values in the voltage selection algorithm.



Flux	Torque	Sector S_ϕ					
Δ_ϕ	Δ_{Γ_e}	$S_{\phi 1}$	$S_{\phi 2}$	$S_{\phi 3}$	$S_{\phi 4}$	$S_{\phi 5}$	$S_{\phi 6}$
1	1	V_2	V_3	V_4	V_5	V_6	V_1
1	0	V_7	V_0	V_7	V_0	V_7	V_0
1	−1	V_3	V_1	V_2	V_3	V_4	V_5
−1	1	V_3	V_4	V_5	V_6	V_1	V_2
−1	0	V_0	V_7	V_0	V_7	V_0	V_7
−1	−1	V_5	V_6	V_1	V_2	V_3	V_4

Table 1. DTC switching table

3. TORQUE RIPPLE ANALYSIS

Since none of the inverter switching vectors is able to generate the exact stator voltage required to produce the desired changes in torque and flux, torque and flux ripples compose a real problem in DTC induction motor drive. According to the principle of operation of DTC, the torque presents a pulsation that is directly related to the Amplitude of its hysteresis band. The torque pulsation is required to be as small as possible because it causes vibration and acoustic noise

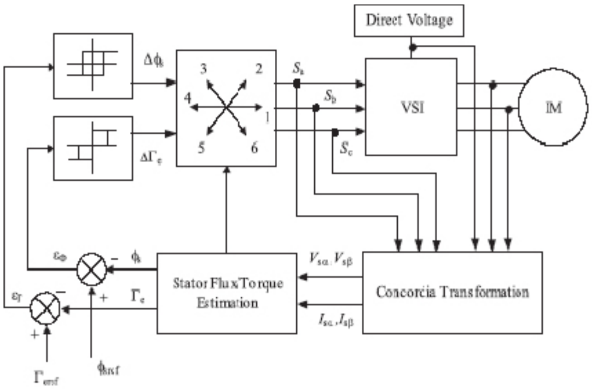


Fig.1 Block diagram of the induction motor drive system based on DTC scheme

A small flux hysteresis bands should be preferred when high-switching speed semi-conductor devices are utilized because their switching losses are usually negligible with respect on state losses. In this way the output current harmonic can be strongly reduced.

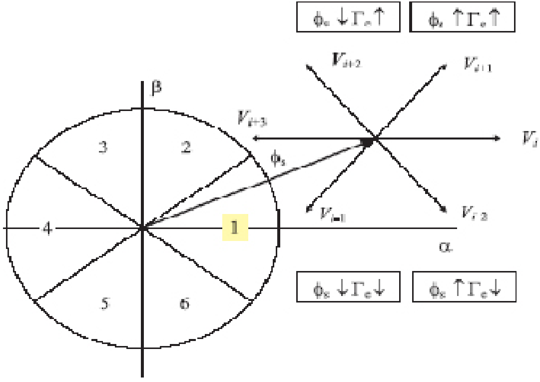


Fig. 2 Stator flux variation (Φs is in section 1)

The hysteresis band has to be set large enough to limit the inverter switching frequency below a certain level that is usually determined by thermal restriction of power devices. Since the hysteresis bands are set to cope with the worst case, the system performance is inevitably degraded in a certain operating range, especially in a low speed region. In torque hysteresis controller, an elapsing time to move from lower to upper limit, and vice versa can be changed according to operating condition.

4. FUZZY LOGIC WITH DTC

To obtain improved performance of DTC drive during changes in the reference torque, it is possible to use a fuzzy-logic-based switching vector selection process. For this purpose a Mamdani-type fuzzy logic system will be used. The different output voltage states (active and zero states) are selected by using three inputs: flux $e_{ö}$ and torque $e_{ô}$ errors and also the position of the stator flux linkage space vector u_s .

For this purpose it is assumed that the stator flux linkage space vector can be located in any of twelve sectors, each spanning over a 60° wide region. For every sector there are 15 rules. The stator flux error ($e\tau$) has three fuzzy sets: stator error can be positive P, zero ZE, and negative N. For the torque error, there are five fuzzy sets: the torque error($e_{ô}$) can be positive large PL, positive small PS, zero ZE, negative small NS and negative large NL (Figs. 5,6,7,8). Since there are 12 sectors, for each sector 15 rules, the total number of rules is 180.

Example:
Rule 1: if $e\phi$ is P and eτ is PL and u is $S1$ then n is 1
Rule 2: if $e\phi$ is P and eτ is PS and u is $S2$ then n is1
Rule 3: if $e\phi$ is P and eτ is ZE and u is $S3$ then n is 1
Where $S1$, $S2$ *and* $S3$ are fuzzy labels ($S1$ is the label for those stator flux angles which correspond to stator Fluxes in sector 1, etc).
i -th rule: if $e\phi$ is *A i* and □□*e* is *B i* and *s u* is *C i* then *n*
Thus by using the minimum operation for the fuzzy
AND operation, the firing strength of the rule (where if=1, 2, 180),
αi can be obtained by considering
αi = min [μ *A i(eϕ),μBi(*eτ),μCi(μs)]……………[1]
Membership functions of the fuzzy
Sets *A i*, *Bi* and *Ci* of the flux error, torque error and
Flux position and is *n* the switching state. Where ìN_i (*n*), is the the membership function of fuzzy set N_i of variable *n* .The outputs from the fuzzy system are
μN (*n*) =max [ì*N*(*n*)] ....i=1,2,...,180. [2]
The fuzzy logic has been proved powerful and able to resolve many problems. A fuzzy controller seems to be a reasonable choice to evaluate the amplitude of torque hysteresis band according to the torque ripple level. In this paper, the amplitude of torque hysteresis band is not prefixed but it is determinate by a fuzzy controller. Based on the analysis given in section (B), two inputs are chosen, speed error variation and stator current variation. The fuzzy controller design is based on intuition and simulation. For different values of motor speed and current, the values reducing torque and flux ripple were found. These values composed a training set which is used to extract the table rule. The shapes of membership functions are refined trough simulation and testing. The membership functions of input and

output variables. The rules were formulated using analysis data obtained from the simulation of the system using different values of torque hysteresis band. If the amplitude b□ is set too small, the overshoot may touch the upper band which will cause a reverse voltage vector to be selected. This voltage will reduce rapidly the torque causing undershoot in torque response consequently the torque ripple will remain high.

5. SIMULATION RESULT

The simulations of the DTC induction motor drive were carried out using the Matlab/Simulink simulation package. We get speed fuzzy DTC control of the induction machine (Figs. 3,4). Figures. 9,12,14 and 10,11,13,15,16 show the Vab, Iab, Speed, Torque characteristics with Conventional DTC and Fuzzy DTC ,see Figs the torque ripple is significantly reduced when fuzzy controller is in use. The fuzzy controller provides the desired amplitude according to the torque ripple level and operating condition, as it is shown in paper. It is seen that the steady state performance of the DTC-with fuzzy controller is much better than of the DTC-without fuzzy controller. For dynamic performance, the modified DTC is almost as good as the conventional DTC [9,10].

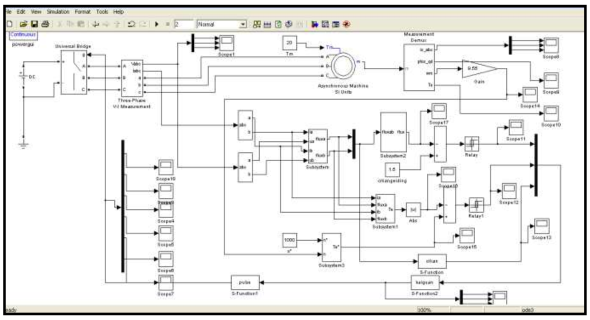


Fig. 3 Block diagram of the IM drive system based on DTC with FLC

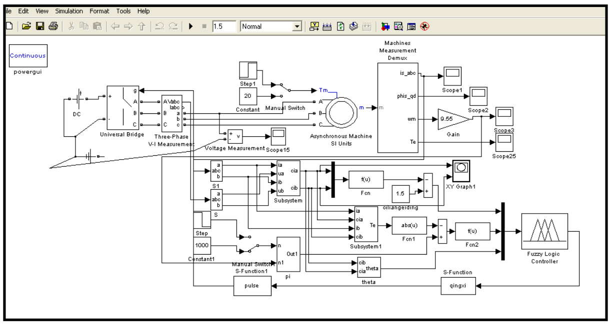


Fig. 4 Block diagram of the IM drive system based on DTC with FLC

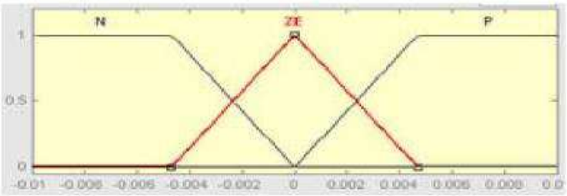


Fig. 5 Triangular membership functions for input variable (e_ϕ)

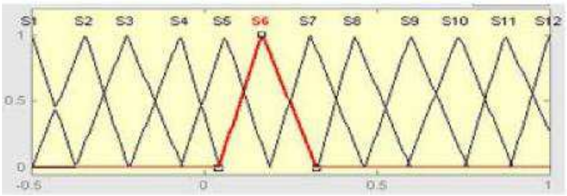


Fig. 6 Triangular membership functions for input variable (e_τ)

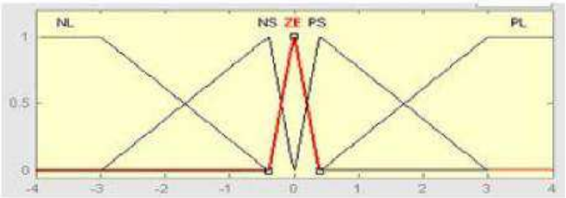


Fig. 7 Triangular membership functions for input

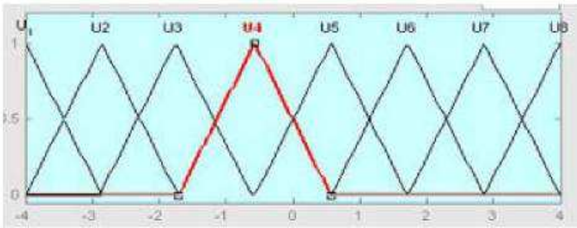


Fig. 8 Triangular membership function for variable (n)

CONCLUSION

The present paper has presented a speed DTC drive with fuzzy controller. This controller determinates the desired amplitude of torque hysteresis band. It is shown that the proposed scheme results in improved stator flux and torque responses under steady state condition. The main advantage is the improvement of torque and flux ripple characteristics at low speed region; this provides an opportunity for motor operation under minimum switching loss and noise. This controller determinates the desired amplitude of torque hysteresis band. It is shown that the proposed scheme results in improved stator flux and torque responses under steady state condition The main advantage is the improvement of torque and flux ripple characteristics at low speed region, this provides an opportunity for motor operation under minimum switching loss and noise.

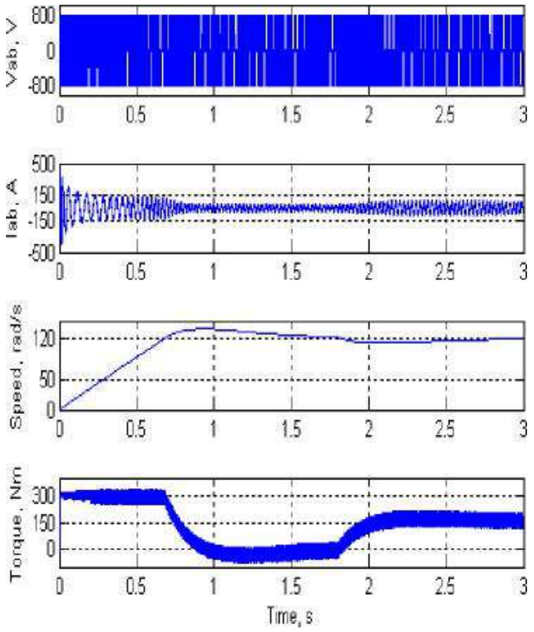


Fig. 9 Vab, Iab, Speed, Torque characteristics with Conventional DTC

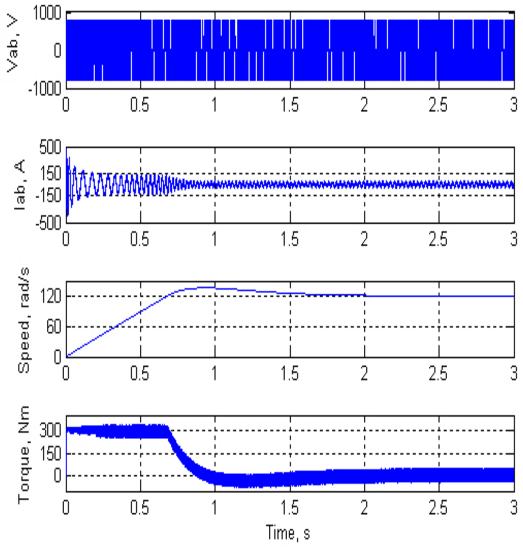


Fig. 10 Vab, Iab, Speed, Torque characteristics with Fuzzy DTC

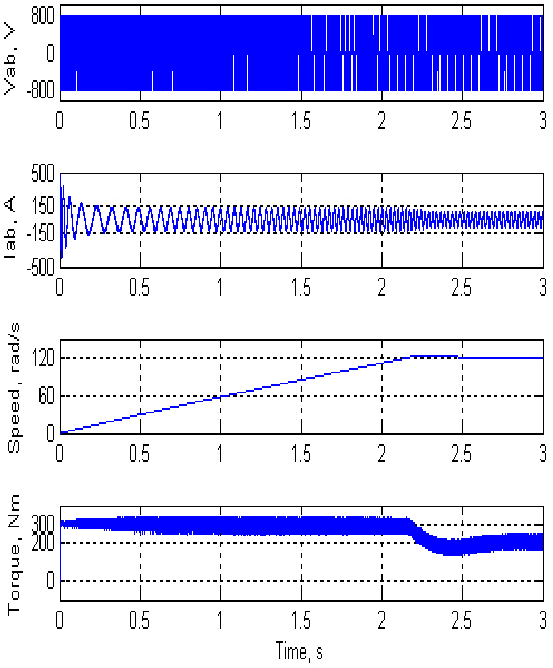


Fig. 11 Vab, Iab, Speed, Torque characteristics with Fuzzy DTC

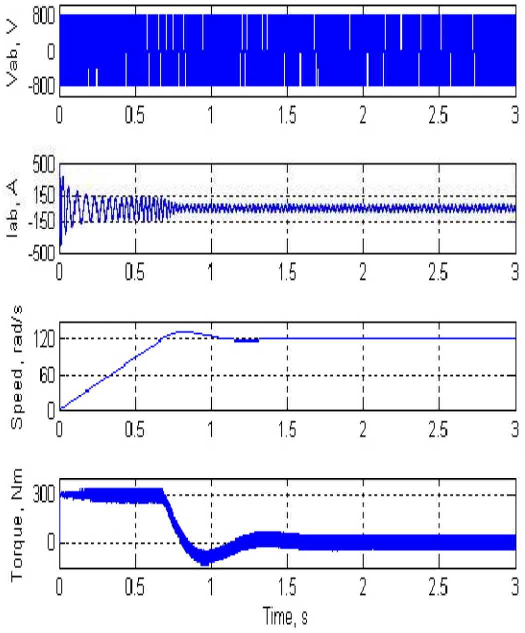


Fig. 12 Vab, Iab, Speed, Torque characteristics with Conventional DTC

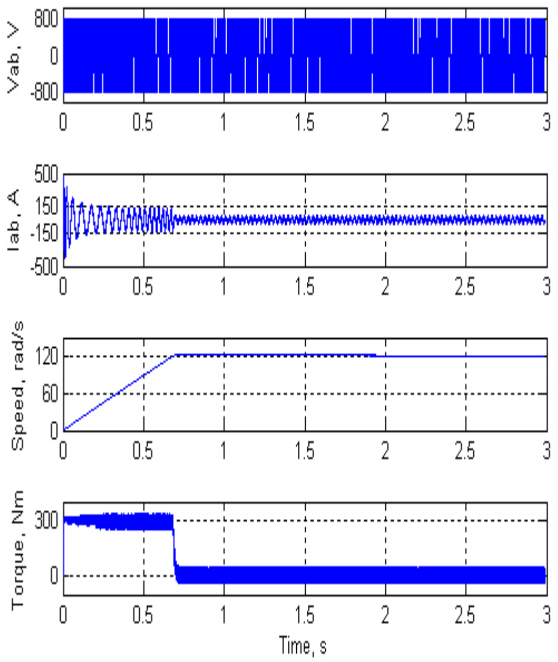


Fig. 13 Vab, Iab, Speed, Torque characteristics with Fuzzy DTC

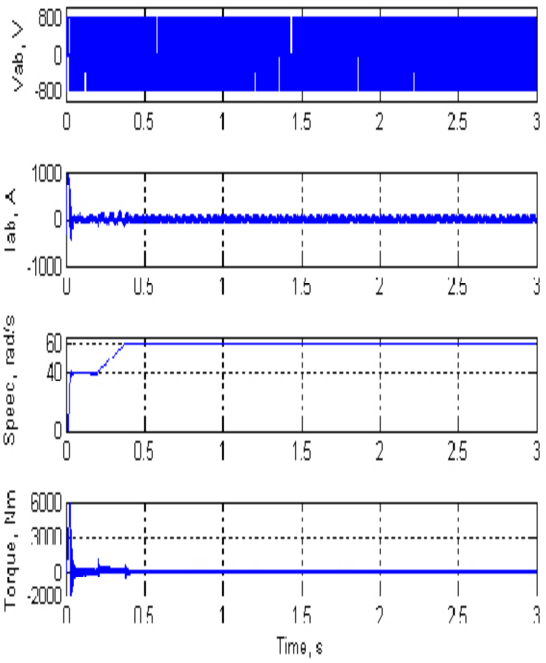


Fig. 15 Vab, Iab, Speed,Torque characteristics with Fuzzy DTC

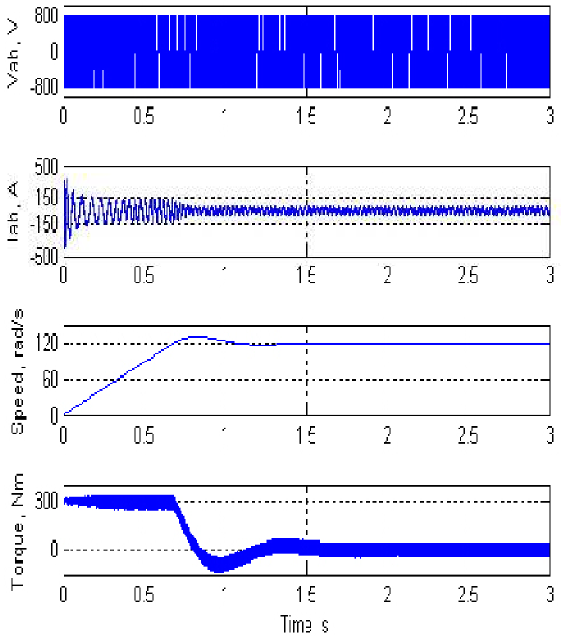


Fig. 14 Vab, Iab, Speed, Torque characteristics with Conventional DTC

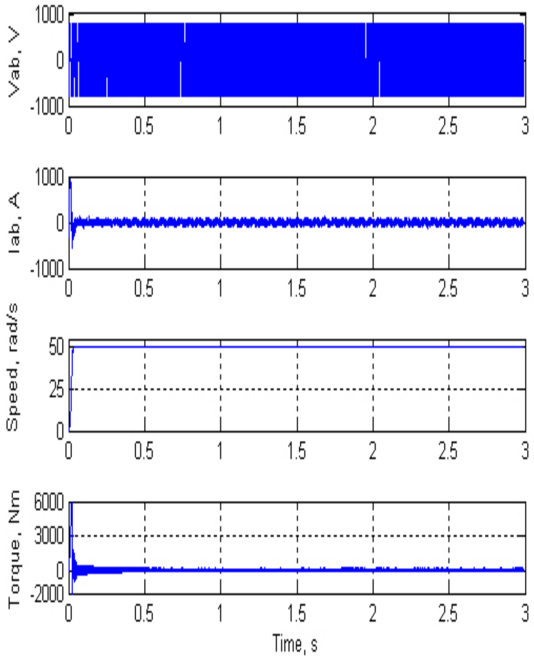


Fig. 16 Vab, Iab, Speed,Torque characteristics with Fuzzy DTC

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