A Robust Fuzzy Torque Control System for Electric Vehicles Application

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Abstract: Motor parameter variations in Electric Vehicles(EV) induction motor drive system are larger than in industrial drive systems[6]. In this paper, a robust fuzzy torque control system using the Takagi-Sugeno approach(TSA) which provide simplicity and performance. The block diagram of this system and the membership functions of every fuzzy variable are also given in this paper. The simulation results show that the fuzzy torque control (FTC) has better dynamic torque performances that torque control (OFC). In addition, The sturdiness of the fuzzy control is proved.

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1. Introduction

Confronted to increasingly complex systems such as non-linear ones, the researchers have rapidly rendered account that using conventional methods did not allow them to satisfy the wished performance indices. The fuzzy logic gives good solutions and includes human descriptions or intuitive thinks. The fuzzy logic is also very useful in imprecise decisions[1].

Another complex environment system search solutions so a kind of zero air pollution transports Electric Vehicles (EV) have been paid great attention by the world relative sector, meanwhile automobile manufactures are actively studying possibilities of EVs for widespread practical use[3]. However there are varieties of problems that must be solved for EVs, among which the performance of electric drive system is one of key problems. Although the requirements of various EVs drive system are different, all these drive systems are kinds of torque control system. In the course of vehicles running, a series of operations, such as starting up, accelerating and decelerating, was finished by driver controlling the torque of motors. So a fast, accurate and stable torque control for electric vehicle is necessary.

Now, the mostly drive system is the Oriented Field Control (OFC), decoupling the interaction between flux current and the torque current. This kind is sensitive to the change of the parameters of the motor and the response of this system during start up is slower, so the power performance of Evs is bad. This paper presents a fuzzy control (FTC) of an induction motor for Evs, as the control rule can be adjusted on line depending on the input of fuzzy controller, the torque response of system is improved.

2. The principle of Fuzzy Torque Control

For an induction motor the rotor current is produced by the transformor effect which is the flux. So the flux control is an important parameter of the machine.

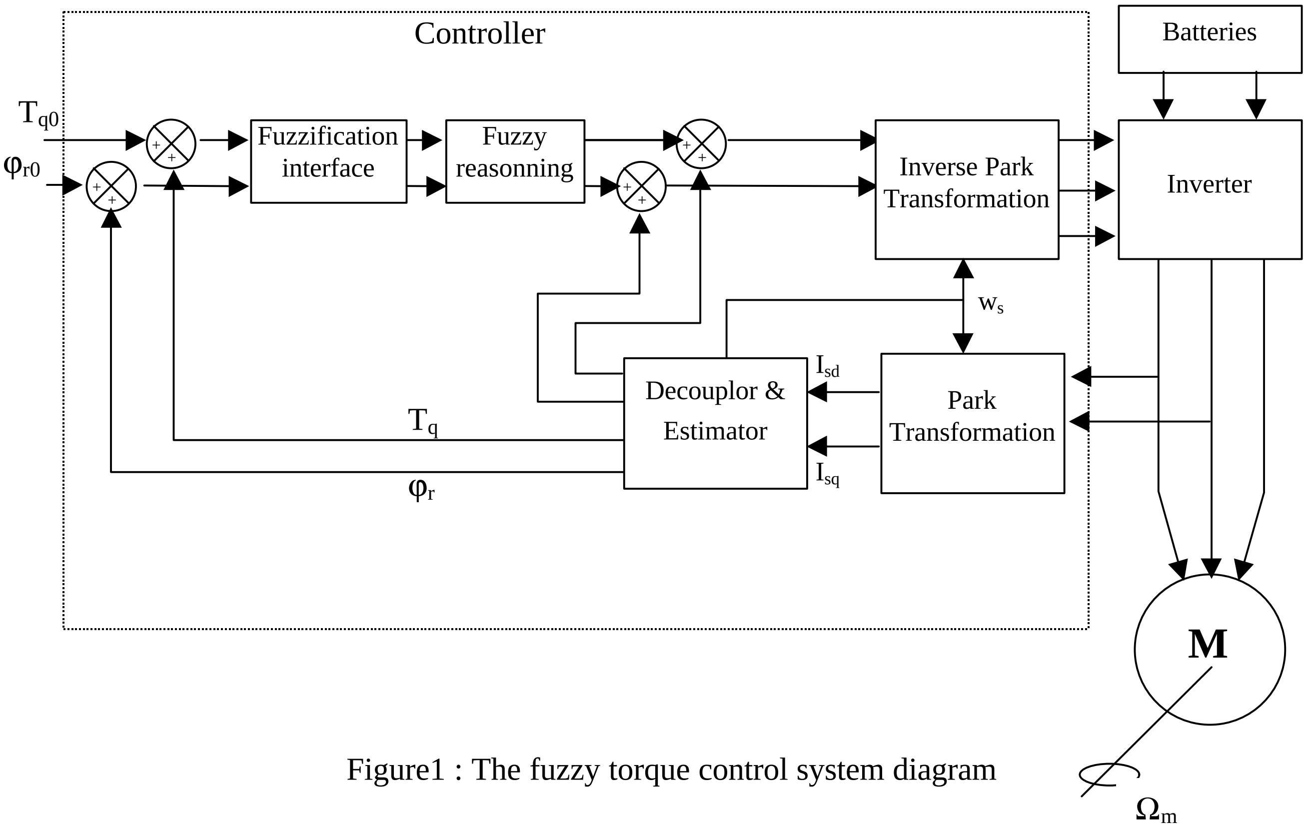


Figure1 : The fuzzy torque control system diagram

The key point of the well Known Field oriented control approach is to keep constant the rotor flux amplitude in order to obtain an independent torque control allowing to obtain the best dynamic performance [4].

The presented FTC modifies the conventional OFC by incorporating fuzzy logic into OFC. The whole system consists of these main parts :

Torque and flux estimator, fuzzification interface, fuzzy reasoning and Park and Inverse Park transformation. This system block diagram is shown on figure1.

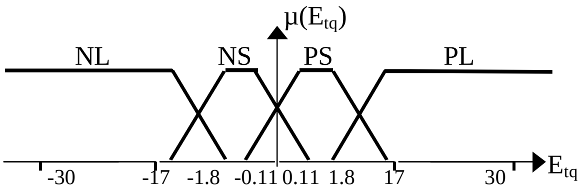
3. Fuzzy variables and membership

The fuzzy torque control (FTC) in figure1 must realise the torque and flux close-loop control in order to satisfy to EV to get a fast, accurate and stable control. Thus in this presented system the rotor flux magnitude error and the torque error which have relationship with EV performances are used as input variable of fuzzy controller. The two fuzzy variables are:

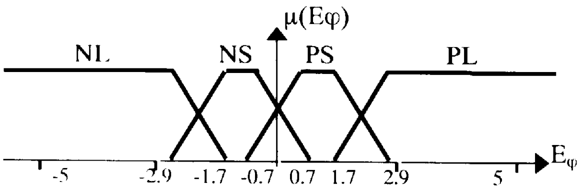
Etq : Error between the command torque and the estimated torque (figure2(a)).

Eφ : Error between the command rotor flux magnitude and the estimated rotor flux magnitude (figure2(b)).

The universe of discourse of each variable is divided on four fuzzy sets (figure2): Negative Large(NL), Negative Small(NS), Positive Large(PL), Positive Small(PS).



(a): Membership distribution of E_{tq}



(b) : Membership distribution of E_φ

Figure2 : Membership distribution of fuzzy variables

4. Fuzzy torque control and fuzzy reasoning

Fuzzy control rules

The fuzzy controller is designed to have the error on torque and flux at zero on minimum time so the rules are obtained from the data base of the motor (Table1).

$E_{tq}E_{\varphi}$	NL	NS	PS	PL
NL	-1500	-441	441	1500
NS	-795	-617	617	795
PS	-795	-617	617	795
PL	-1500	-441	441	1500

(a) V_{sd} fuzzy control rules

$E_{tq}E_{\varphi}$	NL	NS	PS	PL
NL	-1500	-1265	-1265	-1500
NS	-6	-1500	-1500	-6
PS	6	1500	1500	6
PL	1500	1265	1265	1500

(b) V_{sq} fuzzy control rules

Table1 : Fuzzy control rules

The V_{sd} i^{th} rule can be written as :

R_i if E_φ is A_i and E_{tq} is B_i then V_{sd} is V_i

Where A_i, B_i are the fuzzy sets and V_i is the output crisp value.

Fuzzy reasoning

The fuzzy reasoning used is Takagi-Sugeno (TSA) with the firing strength of the i^{th} rule α_i is decided with product operator :

$$\alpha_i = \mu_{Ai}(E_\varphi)*\mu_{Bi}(E_{tq})$$

where $\mu_{Ai}(E_\varphi)$, $\mu_{Bi}(E_{tq})$ are the membership factors of the variables E_φ and E_{tq} in A_i, B_i sets.

The output of the i^{th} rule

$$\mu_i = \alpha_i * V_i$$

The result is given by :

$$V_{sd} = \sum_{i=1}^{16} \mu_i$$

54. Simulation of the system

To show the particular performances of the fuzzy torque controller system, it is important to compare its results with those of classic control (OFC) using MATLAB Language.

The model of the induction motor

In both FTC and OFC systems the motor model as following is given in (d,q) axes by selecting stator current and rotor flux as state variables.

$$\frac{d}{dt}X = AX + BU \qquad Y = CX$$

$$X = \begin{bmatrix} \varphi_{ds} \\ \varphi_{qs} \\ i_{ds} \\ i_{qs} \end{bmatrix} \qquad U = \begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix}$$

$$A = \begin{bmatrix} 0 & \omega_s & -R_s & 0 \\ -\omega_s & 0 & 0 & -R_s \\ \frac{1}{\sigma L_s T_r} & \frac{\omega_r}{\sigma L_s} & \frac{-1}{\sigma}\left(\frac{1}{T_s}+\frac{1}{T_r}\right) & \omega_s - \omega_r \\ -\frac{\omega_r}{\sigma L_s} & \frac{1}{\sigma L_s T_r} & \omega_r - \omega_s & \frac{-1}{\sigma}\left(\frac{1}{T_s}+\frac{1}{T_r}\right) \end{bmatrix}$$

$$B = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ \frac{1}{\sigma L_s} & 0 \\ 0 & \frac{1}{\sigma L_s} \end{bmatrix} \qquad C = I_{(4*4)}$$

where R_s, R_r are stator and rotor resistance, L_s, L_r are stator and rotor self-inductance, L_m is mutual inductance, ω_r is the rotor angular speed and ω_s is the pulsation.

$$\sigma = \frac{L_m^2}{L_s L_r} - 1,\ T_r = \frac{L_r}{R_r},\ T_s = \frac{L_s}{R_s}.$$

However the above equations are not completed to build the motor model, another equation reflecting the mechanical dynamics should be added.

$$\frac{d\omega_r}{dt} = \frac{n_p}{J}(n_p.\varphi_{ds}.i_{qs} - n_p.\varphi_{qs}.i_{ds} - T_l - \frac{f}{n_p}\omega_r)$$

$$T_q = n_p.\varphi_{ds}.i_{qs} - n_p.\varphi_{qs}.i_{ds}$$

where n_p is pole pair number, J is the initial moment of motor, f is the friction coefficient and T_l is load torque.

Simulation results

To simulate FTC and OFC systems we have used Matlab language. Figure3(a) shows the torque responses of the system for the two types of control with the same flux command. The response of the fuzzy controller is faster than the OFC.

In the high performance induction motor drive systems, vector control is a commonly used method because the decoupling control of torque and rotor flux can be realised by it. However, this method suffers from sensitivity to motor parameter variations, especially the variations of rotor time constant L_r/R_r[5]. Unfortunately, the variation of rotor time constant is larger in EV drive systems than in industrial situation[6]. On figure4 the FTC gives a robust control for the induction motor for a variation of the rotor time constant with a ratio of 20%.

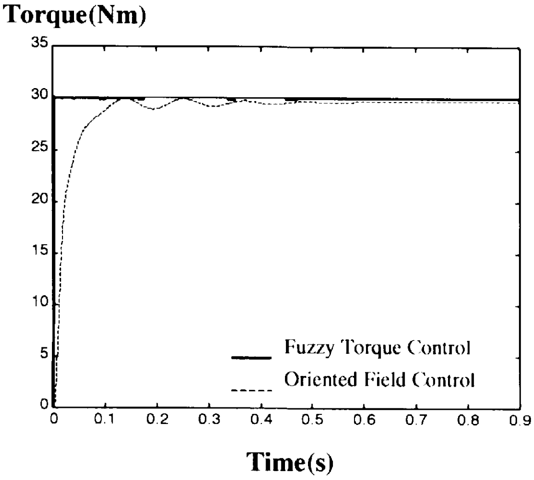


Figure3: Torque responses.

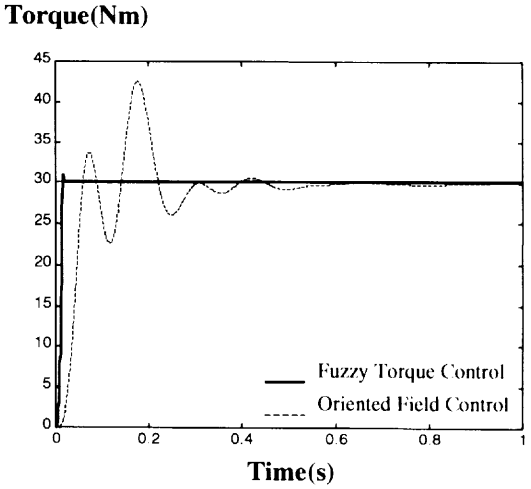


Figure4: Fuzzy and direct response comparison for parameter variation.

6. Full-digital control system

A full-digital controller for Evs with a 32-bit high-speed digital signal processor (DSP) TMS320C50 operated at 40 MHz is used in this system. The block diagram of the controller of induction motor is shown in figure 5. The processing program of fuzzy control is executed with the software of DSP. The torque command and the current i_1,i_2 of the motor are inputted after A/D converting respectively.

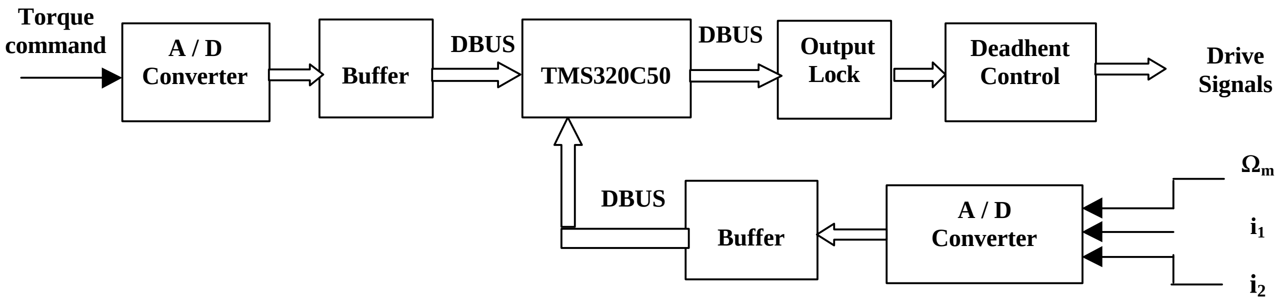


Figure 5: Hardware construction of the controller

The electromagnetic torque and stator flux estimators need the stator direct current, the quadratic current and the speed.

I_{sd} and I_{sq} can be calculated by i_1 and i_2 with the park transformation.

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{4\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta - \frac{4\pi}{3}\right) \end{bmatrix} * \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix}$$

The following current relation can be satisfied in a three phase motor:

$$i_1 + i_2 + i_3 = 0$$

So i_3 can be calculated when i_1 , i_2 are observed.

The main function of hardware interface circuit is converting and collecting the command and feed signals and outputting the drive signals. As TMS320C50 has high speed and rich assembly language functions, and the system doesn't need the motor speed detection, the hardware of the controller can be minimally designed for Evs drive system.

5. Conclusion

A robust fuzzy torque control system for EV has been proposed. The membership functions and the inference mechanism of the TSA are represented on this paper. From the simulation curves we conclude that the FTC system makes it possible to generate the motor torque stably, accurately and efficiently. It has been proved that under the control of fuzzy method, when motor parameter change, the direct control is more affected than the fuzzy control. Therefore, the fuzzy method is robust. As a perspective of this study we prepare the conception of this controller with the integration on DSP to compare the performances with devices already realised.

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