TORQUE AND FLUX RIPPLE MINIMIZATION OF DTC CONTROLLED IM BY USING FUZZY LOGIC DUTY-RATIO ESTIMATOR AND HYBRID FLUX OBSERVER

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Abstract: Direct Torque Control (DTC) drive allows direct and independent control of flux linkage and electromagnetic torque by the selection of optimum inverter switching tables. There is no need for any complex transformation of current or voltage. However in the conventional DTC induction motor drive there are torque and flux ripples, since none of the inverter switching vectors is able to generate the exact stator voltage required to produce the desired chances in the electromagnetic torque and stator flux linkage. In this study, we propose a method to reduce torque and flux ripples. Two steps were carry out for this purpose. The first step is to use duty-ratio. A selected inverter switching vector not for the entire switching period as in conventional DTC, but only for a part of the switching period which is defined as the duty ratio, δ and by using zero switching vector for the rest of period. The duty ratio determines the average input voltage to the induction motor during the application of each switching vector as δVdc. The duty ratio of each switching state is a non-linear function of the electromagnetic torque error, stator flux-linkage error and a function of the position of the stator flux-linkage space vector. In that case fuzzy-logic based duty-ratio control can be used because of it is difficult to model its non-linear structure. The second step is to use hybrid flux observers. The hybrid flux observer uses two model for high and low speeds. Accurate stator flux estimation is obtained by using the stator voltage equation at high speeds, but low speeds accurate stator flux estimation is obtained by the rotor voltage equation. The proposed method is simulated via using MATLAB Simulink and compared to conventional DTC results. Comparing results suggest that the proposed method reduced the ripples in electromagnetic torque, stator flux linkage, stator currents and speed. Motor parameters, reference flux and torque values of motor and load torque value of conventional and proposed methods are arranged to be same for the comparison.

Keywords: Induction Motor, Direct Torque Control, Duty-Ratio Control, Hybrid Flux Observer, Torque and Flux ripple.

Introduction

Direct torque control method (DTC) is a vector control system because it allows calculating motor's flux and torque with the help of measurable magnitudes by motor parameters. The method is based on applying a switching series, which shall directly eliminate errors, which shall occur in torque, through the reference given as value and the calculated flux, to the power switching elements in the inverter (Vasudevan, 2004).

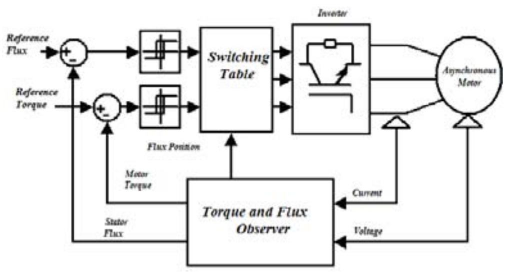


Fig. 1. DTC method block diagram

$$v_{s\beta} = R_s i_{s\beta} + \frac{d\psi_{s\beta}}{dt}, \quad v_{s\alpha} = R_s i_{s\alpha} + \frac{d\psi_{s\alpha}}{dt} \tag{1}$$

$$\psi_{s\alpha} = \int (v_{s\alpha} - R_s i_{s\alpha})dt, \quad \psi_{s\beta} = \int (v_{s\beta} - R_s i_{s\beta})dt \tag{2}$$

$$M_e = p\left(i_{s\alpha} i_{s\beta} - i_{s\beta} i_{s\alpha}\right), \ \left|\vec{\psi}_s\right| = \sqrt{\left(\psi_{s\alpha}^2 + \psi_{s\beta}^2\right)} \quad (3)$$

This may be realized by using motor model on the α-β axis set. Stator flux, torque and stator flux sector zone may be calculated with the help of currents and voltages measured in the motor's stator as mentioned above equations (Depenbrock, 1988).
To accomplish switching process, one of the 8 different voltage vectors consisting of 8 different switching is selected as seen in Figure 2. Vi (Sa, Sb, Sc) (i=0,1,2…7) Besides 6 switching levels, there are V0(0,0,0) and V7(1,1,1) levels not producing a voltage at the output when they are applied. Table 1 may be useful to determine that the flux in which zone.

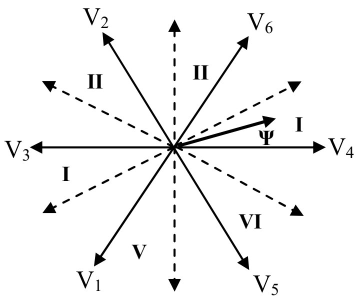


Fig.2 Switching Positions of DTC

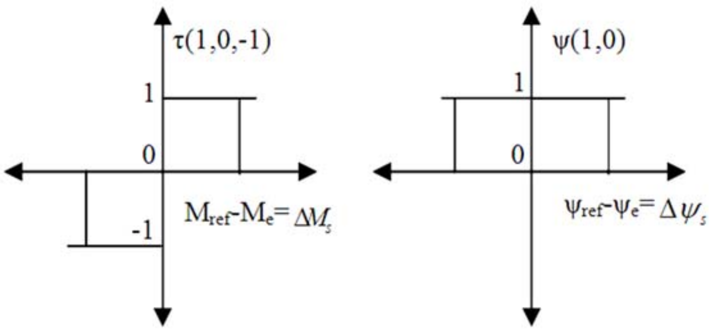


Fig.3 Hysteresis blocks which are Flux and torque error

Figure 3 is hysteresis block schema on which flux and torque errors are applied. Flux and torque errors are applied on hysteresis blocks and the signs produced by these blocks are used in addressing switching board. Hysteresis band widths are symbolized with and for flux and torque respectively. Table 1, which is seen below, shows switching logics when the motor is desired to rotate clockwise and counter-clockwise (Sarioglu, 2003).

Table 1: Optimal Switching Logics For Motor Rotating

		θ(1)	θ(2)	θ(3)	θ(4)	θ(5)	θ(6)
ψ =0	τ =1	V_5	V_1	V_3	V_2	V_6	V_4
	τ =0	V_7	V_0	V_7	V_0	V_7	V_0
	τ=-1	V_6	V_4	V_5	V_1	V_3	V_2
ψ =1	τ =1	V_1	V_3	V_2	V_6	V_4	V_5
	τ =0	V_0	V_7	V_0	V_7	V_0	V_7
	τ=-1	V_2	V_6	V_4	V_5	V_1	V_3

Material and Methods

In the conventional DTC induction motor drive a voltage vector is applied for the entire switching period and this causes the stator current and electromagnetic torque to increase over the whole switching period. Thus for small errors, the electromagnetic torque exceeds its reference value early during the cycle, and continues to increase, causing a high torque ripple. A solution can be obtained where the ripples in the torque and flux can be reduced by employing a selected inverter switching vector not for the entire switching period, as in the conventional DTC induction motor drive, but only for a part of the switching period (which is defined as the duty ratio, δ) and by using the zero switching vector for the rest of the period. The duty ratio is selected to give a voltage vector whose average over the switching cycle gives the desired torque change, thus resulting in reduced torque ripples(Vas, 1989).

The duty ratio of each switching state is a non-linear function of the electromagnetic torque error and stator flux-linkage error, and it is also a function of the position of the stator flux-linkage space vector. Thus it is difficult to model this non-linear function. However, by using a fuzzy logic based DTC system, it is possible to perform fuzzy logic based duty-ratio control, where the duty ratio is determined during every switching cycle. In such a fuzzy-logic system, there are two inputs, the electromagnetic torque error ete=teref - te and the stator flux linkage position ρs . The output of the fuzzy-logic controller is the duty ratio(δ). The fuzzy-logic duty-ratio estimator is shown in Fig.4. The fuzzy logic controller is a Mamdani-type of controller and contains a rule base. As shown Table II There are 18 simple rules and there are only a minimal number (three) fuzzy sets used for two input variables and also for the three output variables; these are small, medium and large.

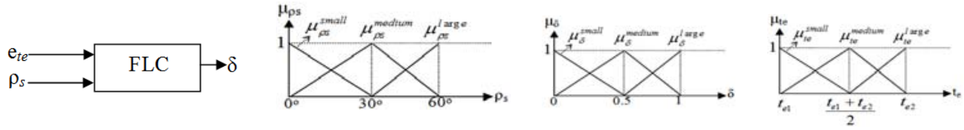


Fig. 4. Fuzzy-logic duty-ratio estimator, and membership functions

The hybrid flux estimator uses two models; a stator-voltage-equation-based model and also a rotor-voltage-equation-based model. Such an estimator utilizes the fact that at high speeds, accurate stator flux estimation can be obtained by using the stator voltage equation, but at low speeds accurate stator flux estimation can be obtained by using the rotor voltage equation. it is also possible to improve the estimation of the stator flux linkages with this method (Vas, 1989).

Designing Of The Simulink Model And Simulation Results

Both of control systems are realized in Matlab/Simulink. Fuzzy Logic Duty-Ratio Estimator and Hybrid Flux Observer based direct torque control Simulink schema of induction machine in Matlab/Simulink is shown in the Figure 5. Figure 6 and Figure 7 show us comparing torque, flux loop, and current respectively.

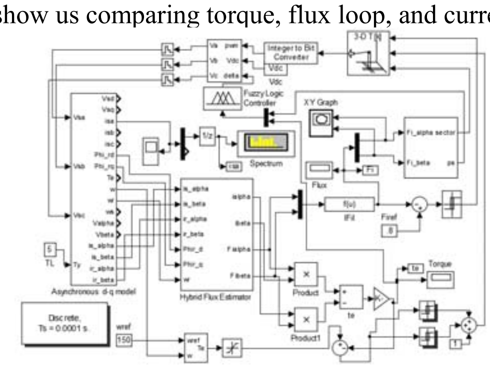
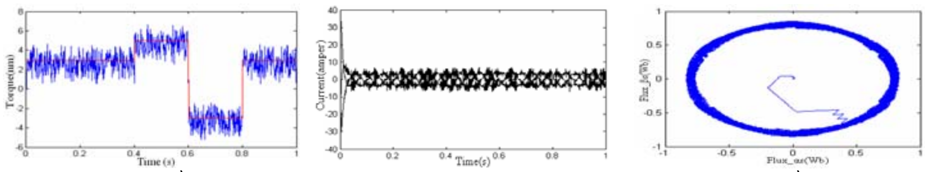
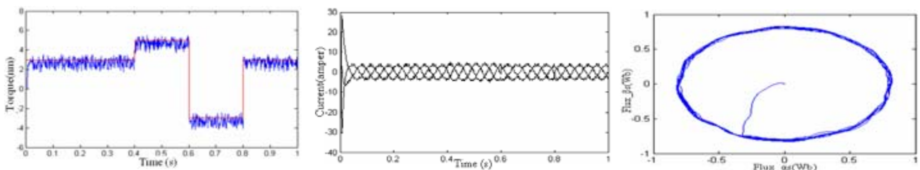


Fig. 5. Proposed DTC Matlab/Simulink Schema



a) b) c)

Fig.6 Conventional DTC a)Torque b)Current c)Flux Loop



a) b) c)

Fig.7 Proposed DTC a)Torque b)Current c)Flux Loop

Conclusion

Fuzzy Logic Duty-Ratio Estimator and Hybrid Flux Observer based direct torque control method is compared to conventional direct torque control. The DTC and the Fuzzy Logic Duty-Ratio Estimator and Hybrid Flux Observer based DTC method are simulated and the comparison of their performances is presented. The ripples in electromagnetic torque, stator flux and stator currents reduced by the duty-ratio-controlled DTC.

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