FUZZY LOGIC BASED DIRECT TORQUE CONTROL OF THREE PHASE INDUCTION MOTOR

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Abstract

This paper presents the comparison between three different Direct Torque Control (DTC) strategies for the speed control of Induction Motor (IM): (i) DTC strategy with Hysteresis controllers (ii) DTC-Space Vector Modulation (SVM) with Proportional Integral (PI) controller and (iii) DTC-SVM with Fuzzy Logic controller (FLC). Dynamic behavior as well as steady state behavior of all the three methods is analyzed using MATLAB/SIMULINK. Simulation results show that, the FLC based DTC-SVM gives excellent dynamic and steady state performances. Also DTC SVM gives low torque ripples and maintains the switching frequency constant.

Keywords: Direct Torque Control, Space Vector Modulation, Fuzzy Logic Controller, Induction Motor, Torque Ripple Minimization.

1. Introduction

Squirrel cage induction motors are used in almost 75% of industrial applications, the popularity of the induction machine is due to its advantages like rugged construction, economical, less maintenance and self-protection against short circuit. Control strategies have indispensable role in high performance of induction motor applications. Predominantly, scalar control and vector control methods are used. Scalar control is simple and easy for implementation. But, the dynamic performance of the IM depends on the machine parameters [1]. DTC has simple calculation and no coordinate transformations. It requires only stator resistance for flux and torque calculation, which diminishes the machine parameter dependency [5, 6]. But conventional DTC
has some drawbacks; switching frequency of inverter varies with error band and large torque and flux ripples [7]. Torque and flux ripples can be reduced by using Multi level inverter (MLI) or DTC-SVM inverter.

In this paper three control strategies based on DTC, that can be used for the control of induction motor are described. Comparison between conventional DTC, PI controller based DTC-SVM and Fuzzy controller based DTC-SVM are presented. The fuzzy controller based DTC-SVM gives better result compared to the other methods.

2. Design of PI controller

Proportional (Kp) and Integral (Ki) are the two main parameters used for the calculation of change in angle. Proportional constant depends on the present error and Integral time constant depends on the past error. The process can be controlled using weighted sum of these two parameters. The transfer function of PI controller is synthesize as

\[ C(s) = K_c \frac{1 + T_i s}{T_i s} \]  \hspace{1cm} (26)

![Figure 1. PI controller based system model](image)

PI controller based DTC system can be modelled as shown in fig.1. The performance of PI controller depends on the parameters of \( K_c \) and \( T_i \).
3. Design of Fuzzy Logic Controller

Design of PI controller is quite complicated since it requires accurate mathematical model of the system and also has slower and poor transient responses such as overshoots during dynamic change in torque, oscillation in speed, high settling time and high torque ripple [10-13]. But FLC requires the knowledge of mapping between the inputs and output and it overcomes the drawbacks of PI controller. The Input of FLC is torque error and change in error. Each input and output consists of seven fuzzy sets. Linearized membership corresponding to inputs and output are shown in fig.6. Mamdani 'min'type fuzzy is used for implication and centroid type is used for defuzzification. Fuzzy has seven membership functions for the inputs and an output are Negative Large(NL), Negative Medium(NM), Negative Small(NS), zero(Z), Positive Small(PS), Positive Medium(PM) and Positive Large(PL). Rules used in fuzzy logic controller for the DTC-SVM scheme are listed in Table 1.

Table 1. Fuzzy Logic Control Rules

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<th>ΔTe</th>
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4. Results And Discussions

The methods proposed are modelled and simulated in MATLAB/SIMULINK. Simulations are carried out for different operating conditions such as variable speed and variable torque. The motor parameters are given in appendix.

Fig. 2 to fig. 4 present the responses for load variations of 2 Nm, 4Nm and 3Nm applied at 0.5s, 1s and 1.5s respectively. Reference torque, Electromagnetic torque and d-q axis flux and current waveforms are shown from top to bottom.

The Waveforms for the conventional DTC are presented in fig.3. Electromagnetic torque follows the reference torque but the torque ripple is nearly 2.5 Nm. The d and q axis flux waveforms are shown in fig.3d and fig.3e, both waveforms are sinusoidal and 90 degree phase shifted, but the frequency varies randomly with torque changes. Similar to the flux, d and q axis stator current and frequency varies but the current waveform gets distorted and has more ripples.
(b) Estimated torque

(c) Stator current

(d) Stator flux d axis

(e) Stator flux q axis

(f) Stator current d axis

(a) Stator current q axis
Figure 3. a) Reference torque b) Electromagnetic torque c) Three phase stator current d) Stator flux d-axis e) Stator flux q-axis f) Stator current d-axis g) Stator current q-axis

The waveforms for FLC based DTC-SVM are shown in fig.4. Torque ripples are minimized effectively and transient responses like peak overshoot and rise time also get reduced compared to PI controller based DTC-SVM. The stator current waveform is shown in fig.9c and is sinusoidal, distortion free. The stator current increases with increase in torque. Frequency and peak value of stator current and flux are almost at constant value.
Table 2 shows the rise time and settling time of the PI and Fuzzy controlled DTC-SVM. Comparing the performance of three methods, effective method of controlling of three phase squirrel cage induction motor is FLC based DTC-SVM. This method minimizes the torque ripple, improves the transient and steady state responses. Also, maintains the stator current and flux waveform sinusoidal.

TABLE 2. Performance Measures

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<tr>
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<th>Rise time</th>
<th>Settle time</th>
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<tr>
<td>PI controller based DTC-SVM</td>
<td>0.0054s</td>
<td>0.041s</td>
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<tr>
<td>Fuzzy Controller based DTC-SVM</td>
<td>0.0028s</td>
<td>0.035s</td>
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5. Conclusion

The conventional Direct Torque Control, Direct Torque Control based Space Vector Modulation using PI controller and
Fuzzy Logic Controller for three phase induction motor has been developed and analysed using MATLAB simulation. Simulations are carried out for dynamic changes in induction motor torque. The simulation results show that DTC-SVM scheme with fuzzy logic controller gives less torque and flux ripples, better transient and steady state response. Also, DTC-SVM maintains the switching frequency constant.

References