Switching losses minimization by using direct torque control of induction motor

Suraj Karpe *, Sanjay A. Deokar, Arati M. Dixit

Department of Technology, SPPU, India

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Abstract

Direct torque control is becoming the industrial standards for induction motor torque control. This paper presents switching loss minimization technique of improved direct torque control (DTC) of induction motor. Direct torque control (DTC) of an induction motor supplied by a voltage source inverter is a simple scheme that does not need long computation time, can be implanted without speed sensors and is insensitive to parameter variations. In principle, the motor terminal voltages and currents are used to estimate the motor flux and torque. Based on the instantaneous errors in torque and stator flux magnitude and estimates of the flux position, a voltage vector is selected to limit the flux and torque errors within their flux and torque hysteresis bands. In the conventional DTC, the selected voltage vector applies for the whole switching period, irrespective of the magnitude of the torque error. DTC drive gives variable switching frequency and high torque ripple. DTC gives torque and flux ripples because no any VSI states are capable to generate the exact voltage vector from switching table required to make zero both the torque electromagnetic error and the stator flux error. To minimize this problem, a torque hysteresis band with variable amplitude fuzzy logic controller is proposed. The fuzzy logic controller is used to reduce the flux and torque ripples and it improves performance DTC especially at low speed. A duty ratio control scheme for an inverter-fed induction machine using DTC method is presented in this article. The use of the duty ratio control gives improved steady state torque response, with less torque ripple than the conventional DTC. Fuzzy logic control (FLC) used to implement the duty ratio controller. Total harmonic distortion (THD) calculation of electromagnetic torque, rotor speed and stator current of DTC and DTC with fuzzy has done successfully in this article. With the help of FLC with duty ratio, 8% THD in torque, speed and stator current have minimized compared with DTC (Uddin and Hafeez, 2012). In this paper, switching losses minimization technique through THD minimization. Switching losses are minimized because the transistors are only switched when it is needed to keep torque and flux within their hysteresis bounds, improve efficiency & reduced losses. Direct torque control with the fuzzy logic controller has verified by MATLAB SIMULINK and experimentally.

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Keywords: Direct torque control; Induction motor; Fuzzy logic; Torque ripple minimization; Fuzzy logic controller

* Corresponding author.

E-mail addresses: surajkarpe42@gmail.com, karpe_suraj@yahoo.in (S. Karpe).

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1. Introduction

The machine can be driven at variable speed, with variable frequency, sinusoidal voltage. In power electronics, the inverter gives such voltage by switching. The inverter may generate a considerable amount of voltage & current harmonics. These harmonics cause additional power losses in motor winding & magnetic core, which reduces the life of the motor. Distorted current waveform also gives rise to torque pulsation, and may damage to shaft, coupling & other mechanical component. By increasing switching frequency, total harmonic distortion (THD) of motor current & torque reduces. Switching losses in inverter gives amount of power losses in drives. Switching losses minimization reduces the manufacturing & maintenance cost of drives in Takahashi and Nouguchi (1986).

Direct torque control (DTC) has been actively investigated during the last decade in the area of AC drives for induction motors. This control strategy was first introduced by Takahashi in 1986 (Takahashi and Nouguchi, 1986) and at the same time Depenbrock developed in 1988 under the name of direct self control (Tang et al., 2003). Nevertheless, just one major manufacturer has an industrial application based on DTC, which was launched in 1995 (Kang and Sul, 2003). The main advantage of DTC is the high performance achieved (decoupled control stator flux and torque, fast torque response and robustness) together with the simplicity of the scheme (coordinate transformation, modulation block and current regulation block not require). Traditionally, the standard voltage source inverter (VSI) used in AC drives is composed of two switches per leg, where the load can be connected either to the upper or lower line of the DC-link. This is known as a two-level VSI. However, fast semiconductors have a limitation in the maximum voltage that can be handled. Series connection is necessary for high power and voltage applications, and therefore a voltage balance is required. Moreover, very high dV/dt is generated leading to important electromagnetic interference (EMI) and high windings insulation stress. Multilevel inverters are an emerging technology that can overcome the limitations associated with the standard low cost two-level VSI (Lai and Lin, 2003). DTC drive becomes one of the possible alternatives to the well-known vector control of Induction Machines over the last decade. Its main characteristic is it gives good performance, obtaining results has more accuracy as good as compare with classical but with several advantages based on its simpler control diagram. DTC (direct torque control) is characterized, as deduced from the name, by directly controlled flux and torque means indirectly controlled stator voltage and current. The DTC has some advantages comparison with the conventional vector-controlled drives, like approximately sinusoidal stator currents and stator fluxes, high dynamic performance even at locked rotor and standstill, Absences of co-ordinates transform, absences of mechanical transducers, current regulators, PWM pulse generation, PI control of flux and torque and co-ordinate transformation are not required, very simple control scheme and low computation time, reduced parameters sensitivity, superior dynamic properties. Conventional DTC has also some pitfall are possible problems during starting and low speed operation, variable switching frequency; these are disadvantages that we want to remove by using fuzzy logic controller. In the following, we will describe the application of fuzzy logic in DTC control (Kang and Sul, 1999; Rumzi et al., 2004; Abdalla, 2005).

Two different control methods are designed in this paper. The first is based on the conventional DTC scheme adapted for a two level inverter. The second is based on a fuzzy logic controller used to replace the conventional table used in DTC for the inverter state selection. A direct torque control (DTC) is a simplified variation of field orientation was developed by Takahashi (Kang and Sul, 1999) and Depenbrock (Tang et al., 2003). Fig. 1 shows a DTC of an induction motor. In DTC drives, with the help of selection of an optimum inverter switching state, it is possible to control directly the stator flux linkage and the electromagnetic torque. Switching state is used to regulate the flux and the torque errors within their respective hysteresis bands and to obtain the fastest torque response and highest efficiency at every instant. DTC is more straightforward than field-oriented control and less dependent on the motor model, since the stator resistance value is the only machine parameter used to estimate the stator flux. High torque ripple is one of the disadvantages of DTC given in Kang et al. (2005). Under constant load in steady state, an active switching state originate the torque to continue to increase past its reference value until the end of the switching period; then a zero voltage vector is applied for the next switching period causing the torque to continue to decrease below its reference value until the end of the switching period. A possible solution to reduce the torque ripple is to use a high switching frequency; however, that requires expensive processors and switching devices. A less expensive solution is to use fuzzy logic duty ratio controller. In DTC with duty ratio control, the selected voltage vector is applied for a part of the switching period rather than the complete switching period as in conventional DTC.
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