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Energy Procedia 75 (2015) 1529 – 1535

Energy Procedia

The 7th International Conference on Applied Energy – ICAE2015

Efficiency improvement of induction motor variable speed drive using a hybrid fuzzy-fuzzy controller

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Abstract

Induction motor (IM) variable speed drive efficiency is essential for a few reasons as energy conservation, economic saving and lessening of ecological contamination. This research represents a study of the efficiency improvement for the developed hybrid fuzzy-fuzzy controller (HFFC) scheme to gain control over the speed of an induction motor's variable speed drive (VSD). In order to overcome drawback of field oriented control (FOC) method, the principle of HFFC is based on set of rules to control speed of a rotor by utilizing fuzzy frequency controller during the accelerate-decelerate stage. Alternatively, a fuzzy stator current magnitude controller is used during steady-state stage. The two aspects (current and frequency) of FOC are engaged to design a scalar controller. The performance of the controller is observed by conducting a series of tests, and it can be concluded that the controller is efficient, reliable and insensitive towards the parameter variation in the system and motor robustness to load and noise disturbances.

Peer-review under responsibility of Applied Energy Innovation Institute

Keywords: Indirect field-oriented control (IFOC); Hybrid fuzzy-fuzzy control (HFFC); Disturbances; Efficiency improvement.

1. Introduction

Induction motor VSD efficiency is essential for energy conservation, economic saving and lessening of ecological contamination [1]. During the last forty years the induction motors have been largely utilized in the applications that use variable speed. In industry, the term 'workhorse' is used to refer to the induction motor [2,3]. The FOC or the vector control was considered as the most significant inventions in the AC motor drives [3]. Also, Fuzzy Logic was presented in 1965 as a novel kind of mathematical set approached by Zadah [4]. As the continuous improvement on the control aspects of variable speed drive (VSD), several research studies exist that are based on the control techniques and commercially available tools which yield a high degree of performance and reliability. For example in [5] the PLC based hybrid-

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Peer-review under responsibility of Applied Energy Innovation Institute
doi:10.1016/j.egypro.2015.07.309

fuzzy control for PWM-driven VSD was examined that depends upon the s-domain transfer function in a scientifically presented model of an original plant, by keeping the V/f ratio at a constant value. However in [5], the optimizations of the controller's performance, against the parameter variation, and external disturbances were not fully considered. Consequently, the disadvantages of FOC method and the results gained from the simulation have been overcome by an implementation of the two stage controllers in [6–8], though all the practical implementations were quite satisfactory. Moreover, the satisfactory results have been gained by applying suitable controller algorithms on controlling the speed of an IM [9,10]. The primary emphasis of this study is on the implementation of a fuzzy current amplitude controller on the induction motor model, which makes this work unique. This controller possesses the same supply features as FOC [6] and is insensitive to the parameter variation of the motor, with system robustness to noise and load disturbances is one of the advantages of this controller. Due to the fact that it provides better performance, the fuzzy current amplitude controller has been selected.

Nomenclature

i_{ds}, i_{qs}	*d*- and *q*-axis stator current modules, respectively and expressed in a stationary reference frame
L_M	Magnetizing inductance
L_s, L_r	Self-inductance of the rotor and stator respectively
r_s, r_r	The resistance of a rotor and stator phase winding respectively
T_e, T_l	Load torque and Electromagnetic torque replicated on the motor shaft respectively
$\lambda_{ds}, \lambda_{qs}$	*d*- and *q*-axis stator flux components, respectively and expressed in a stationary reference frame
$\lambda_{dr}, \lambda_{qr}$	*d*- and *q*-axis rotor flux components, respectively and expressed in a stationary reference frame
ω_m, ω_r	Mechanical and electrical angular rotor speed respectively
ω	Synchronous speed or dominant frequency
P, J, B	Number of pairs of poles, the inertia of the rotor (kgm^2), and the damping constant respectively

2. Mathematical Modeling

The equations (1)-(3) provide the state-space model of an induction motor in a stationary frame with a controlled stator current [11,12].

$$\frac{d\lambda_{dr}^s}{dt} = -\frac{r_r}{L_r}\lambda_{dr}^s - \frac{P}{2}\omega_m\lambda_{qr}^s + \frac{r_r L_M}{L_r} i_{ds}^s \quad (1)$$

$$\frac{d\lambda_{qr}^s}{dt} = -\frac{r_r}{L_r}\lambda_{qr}^s + \frac{P}{2}\omega_m\lambda_{dr}^s + \frac{r_r L_M}{L_r} i_{qs}^s \quad (2)$$

$$\frac{d\omega_m}{dt} = \left[\frac{3}{2}\right]\left[\frac{P}{2}\right]\frac{L_M}{JL_r}\left(i_{qs}^s\lambda_{dr}^s - i_{ds}^s\lambda_{qr}^s\right) - \frac{T_l}{J} \quad (3)$$

The two features for the FOC that have been used in this study are shown in Eq. (1) to (3). The first aspect is that the supply frequency changes with the speed of the rotor, [11], is given by Eq. (4).

$$\omega = \omega_r + \frac{P}{2}\omega_m \qquad \text{where,} \qquad \omega_r = \frac{3 r_r T_l^*}{P {\lambda_{dr}^{e*}}^2} \quad (4)$$