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Fuzzy logic speed controller optimization approach for induction motor drive using backtracking search algorithm

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ABSTRACT

This paper presents an adaptive fuzzy logic controller (FLC) design technique for controlling an induction motor speed drive using backtracking search algorithm (BSA). This technique avoids the exhaustive traditional trial-and-error procedure for obtaining membership functions (MFs). The generated adaptive MFs are implemented in speed controller design for input and output based on the evaluation results of the fitness function formulated by the BSA. In this paper, the mean absolute error (MAE) of the rotor speed response for three phase induction motor (TIM) is used as a fitness function. An optimal BSA-based FLC (BSAF) fitness function is also employed to tune and minimize the MAE to improve the performance of the TIM in terms of changes in speed and torque. Moreover, the measurement of the real TIM parameters via three practical tests is used for simulation the TIM. Results obtained from the BSAF are compared with those obtained through gravitational search algorithm (GSA) and particle swarm optimization (PSO) to validate the developed controller. Design procedure and accuracy of the develop FLC are illustrated and investigated via simulation tests for TIM in a MATLAB/Simulink environment. Results show that the BSAF controller is better than the GSA and PSO controllers in all tested cases in terms of damping capability, and transient response under different mechanical loads and speeds.

1. Introduction

Three-phase induction motors (TIMs) are widely used for industrial applications because of their simple structure, easy maintenance, ruggedness, low cost, robustness, and a high degree of reliability [1,2]. TIM dynamical system is nonlinear and it is not easy to explain theoretically because of its sudden changes in mechanical load or speed variation in most of the applications [3]. The variable voltage and frequency of TIMs are usually always employed to control the speed and torque of the TIM drives [4]. Voltage/frequency (V/f) scalar control strategy is applied to TIM drives to develop the performance and dynamic response of the TIM. This method has a few advantages such as simple structure, low cost, easy design, and low steady-state error [5]. Voltage source inverter (VSI) is an important part to control variable high-speed induction motor derives such as for fans and pumps. Such inverter is generally controlled by pulse width modulation (PWM) techniques. Several PWM techniques are employed to control three-phase inverters. Space vector PWM (SVPWM) method is one of the best methods because of its capability to minimize

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harmonic distortion [6]. SVPWM control is utilized in TIMs to specify each switching vector as a point in a complex space [7].

Several TIM speed controllers have been studied recently. For example, the proportional-integral-derivative (PID) controller is widely utilized in industrial applications because of its smooth design and structure [8,9]. In [8], this controller is used with indirect field oriented controller to control the TIM. In [10], a traditional PI controller is proposed to control a boost converter. However, PI controllers require mathematical modeling as well as to trial-and-error method to find the controller parameters for designing [8,11].

Artificial intelligence (AI) based controllers have been used in various applications. For example, an artificial neural network (ANN) is used to control DC series motor by buck converter [12]. In addition, ANN is utilized to identify TIM parameters [13]. Adaptive neuro-fuzzy inference systems are merged between ANN with fuzzy logic controller (FLC) and applied to a new vector control in TIM [14]. In [15], ANN is used to estimate rotor speed of a DC motor for closed-loop control. In [16], the aging process of an electric motor is accomplished by ANFIS using vibration signals. In [17], ANFIS is used to detect the contact position of a new tactile sensing structure. However, the above mentioned controllers encounter problems because of their massive data requirement and long training and learning time.

Many researchers have proven that FLC controller is simple to implement; this controller does not require a mathematical model of the controlled system [8,10]. FLC controllers have replaced other controllers owing to the former's improved control of the speed and mechanical load, which allows such controllers to exhibit excellent performance in terms of transient reduction and control [8,18]. Thus, several applications are implemented to enhance the performance of the temperature control precision and robustness of the chamber cooling system [19]. In [20], FLC is used to optimize multiple performance characteristics in drilling of bone. However, the performance of FLCs depends on the membership functions (MFs), the number of rules and rule basis. These variables are determined by a trial and error procedure, which is time consuming [18,21]. Therefore, to overcome these limitations, FLC design optimization techniques uses differential search algorithm to develop FLC and control of photovoltaic inverters [18]. In [22], particle swarm optimization (PSO) is proposed to enhance FLC for maximum power point tracking (MPPT) in a grid-connected photovoltaic inverter.

In the present study, the backtracking search algorithm (BSA) optimization is developed to improve the performance of the TIM speed controller by tuning the free parameters and selecting the limits and best values for input and output MFs. Obtained results from the developed BSA-based FLC (BSAF) speed controller are compared with those of gravitational search algorithm (GSA) and PSO algorithm under sudden change conditions in speed and mechanical load. High performance of MFs is also obtained by minimizing the error function using the mean absolute error (MAE) of the system. Moreover, SVPWM switching algorithm is employed with BSAF speed controller for TIM drives.

2. Modeling of induction motor drive

A mathematical model is an approximation of a real physical system. To achieve the mathematical model for the TIM drive controller, a detailed definition of the parameters employed in TIM is required [1,5]. The TIM simulation model in this study includes a dynamic model of TIM, fuzzy speed control, *V*/*f* control, SVPWM switching technique, a three-phase inverter, and TIM control parameters. Fig. 1 shows the open-loop scalar control structure of the TIM with SVPWM.

2.1. Measurement of the TIM parameters

Parameter values of the TIM must be realistic to be simulated in MATLAB and to represent the actual TIM. These parameters were obtained experimentally by executing three tests, namely, DC test, no-load test, and break test, on the TIM. In this paper, TIM by WEG Company has been used to fulfill the tests. A few parameters were taken from the TIM datasheet available in the website [23]. The other parameters have been obtained by measuring through the three practical tests. First, DC test is conducted to measure stator resistance (r_s). DC power supply is applied to two phases to measure DC voltage and current on the stator terminal. The DC resistance is then calculated and the stator resistance is computed. Fig. 2a illustrates the block diagram of DC test measurement, and Fig. 2b shows the real image of the DC test. Second, no-load (open circuit) test is performed to obtain mutual reactance (X_m) by measuring power, voltage, and current for each phase. Fig. 3a shows the connection of the no-load test. Fig. 3b describes the real image of the no-load test and shows the power quality analyzer (FLUKE type) connection. Third and last, breaker (short circuit) test is used to obtain rotor resistance (r_r') and stator and rotor reactance (X_s, X_r) by measuring power, voltage, and current for each phase during the breaking of rotor shift. Fig. 4a shows the connection for break test, and Fig. 4b shows the actual image of the connection together with the power quality analyzer (FLUKE type). The detailed measurements of the TIM control parameter ratings are shown in Table 1.

2.2. Dynamic model of TIM

The dynamic model of squirrel-cage TIM can be represented by a mathematical model consisting of a set of parameters. The *d*–*q* axis stator voltage and rotor voltage state equations of TIM in the stationary frame are shown in the equations below [1,8,24].

$$v_{ds}^s = r_s i_{ds}^s + \frac{d\lambda_{ds}^s}{dt} \tag{1}$$

$$v_{qs}^s = r_s i_{qs}^s + \frac{d\lambda_{qs}^s}{dt} \tag{2}$$