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Speed control of permanent magnet synchronous motors using fuzzy controller based on genetic algorithms

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ABSTRACT

In this study, speed control of a permanent magnet synchronous motor (PMSM) with genetic based fuzzy controller has been simulated. Earlier studies have focused on different components of fuzzy controllers such as rule base or data base in the literature. However, in this study, the whole knowledge base is parameterized and optimized to obtain an optimal fuzzy controller without expert knowledge. In the developed control scheme, there are three closed loops. The two inner loops are the current and the velocity feedbacks, respectively. The other outer feedback is the genetic algorithm (GA) which optimizes the rule base and data base of the fuzzy controller simultaneously. This outer loop is an iterative process. To make comparisons, a conventional fuzzy controller also has been designed and the PMSM speed control has been simulated for both the proposed and conventional fuzzy controller. The comparative results have proved that the proposed controller has a better dynamic response than that of the conventional one.

1. Introduction

In recent years, advancements in magnetic materials, semiconductor power devices and control theories have made permanent magnet synchronous motor (PMSM) drives play a vitally important role in motion-control applications [1]. They have superior features such as compact size, high torque/weight ratio and absence of rotor losses. Furthermore, advanced magnetic materials having even higher power lead to wider applications of PMSM [2–6]. However, the performance of the PMSM is very sensitive to external load disturbances and parameter variations in the plant. Some control techniques such as nonlinear control, sliding mode control and intelligent control have been developed to overcome these problems for speed and position control of PMSMs [7].

The operation of a fuzzy logic controller (FLC) is based on heuristic knowledge and linguistic description to perform a task. The effects from inaccurate parameters and models are reduced because a FLC does not require a system model [5]. During fuzzy control, the behavior of controlled system could be described using a set of linguistic fuzzy rules, reducing the complexity of design control system. However, the disadvantage of this technique is the difficulty in designing an efficient inference engine from much of the knowledge [8].

Nonlinear controllers can ensure the stability of power systems in large operating regions and in the presence of large disturbances [9]. In the literature, it has been shown that FLCs with nonlinear structure are one of the control techniques that provide high performance, are robust against parameter variations and are less affected by the disturbances when their design parameters are well adjusted. However, as the design process of conventional FLC is carried out in accordance with expert knowledge, accuracy and correct application of the provided knowledge are significant problems encountered during the design of FLC. Therefore, the knowledge provided by the expert has important impact on the controller performance. In addition, in such conventional design approaches, the design process takes a long time and optimal control cannot be guaranteed. These disadvantages limit the application areas of FLCs. To deal with these problems, the key point is to employ an evolutionary learning process to automate the fuzzy controller design. The automatic definition of the fuzzy controller parameters can be seen as an optimization or search problem, and genetic algorithms are a well known, widely used global search technique with the ability to explore a large search space for suitable solutions only requiring a simple scalar performance measure [10]. As a result, a genetic fuzzy system (GFS) is basically a fuzzy system augmented by a learning process based on a GA [11].

In the related literature, there are lots of studies regarding genetic fuzzy systems. Overview of the studies on genetic fuzzy systems can be found in Cordon et al. [10] studies.

Gürocak [12], in his study, proposed a method based on GA for generating rule base of a FLC. Shi and Eberhart [13] added types of membership functions into the used GA chromosome structure in

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Nomenclature

B	friction torque (Nm s/rad)
c_p	parameter adjusted by GA for optimizing membership functions
de_ω	time derivative of speed error
d/dt	derivative operator
e_a, e_b, e_c	electromotive forces (EMFs) of phase windings (V)
e_ω	speed error
F	multi-objective performance index
T	sampling period
i_a, i_b, i_c	phase currents (A)
$i^*_{a,b,c}$	reference phase currents (A)
i_{dc}	inverter supply current (A)
I^*	control current (A)
J	inertia torque (Nm s^2)
K_e	scaling factor of the input error variable
K_{de}	scaling factor of the input error derivative variable
K_u	scaling factor of the controller output variable
L_{ss}	total phase inductance (H)
L_l	leakage inductance (H)
L_{ms}	self inductance (H)
m	number of membership functions defined for input/output variables
M	mutual inductance (H)
ε	maximum overshoot value of the system response
p	motor number of poles
p_m	mutation rate
p_d	discard rate
p_e	elitism rate
R_s	motor's stator resistance (Ω)
$S_{1,\ldots,6}$	power switches
$s_{1,\ldots,9}$	parameters used in the rule base plane
T_L	load torque (Nm)
T_e	generated electrical torque (Nm)
V_a, V_b, V_c	phase voltages (V)
v_{dc}	inverter suppy voltage (V)
θ_r	rotor position (rad)
ω_r	actual speed (rad/s)
ω_{ref}	reference speed (rad/s)
μ	fuzzy membership degree
λ_f	flux due to the permanent magnet rotor (V s/rad)
Δi^*	change of control current

addition to fuzzy membership function and rule base and hence, they formed a different chromosome structure. Homafiar ve McCormick [14] focused on the design of FLC membership functions and rule base using GAs. In the study, the fuzzy rules and membership functions were encoded into a single string. Arslan and Kaya [15], in their study, benefited from GAs to determine the fuzzy membership functions. Bulut et al. [16] designed a genetic fuzzy controller and they applied it to the speed control of a DC motor. In the study, the rule table of the FLC was placed into a long string and it was learned automatically by GAs. Li and Shieh [17] investigated a fuzzy PID controller on the basis of GAs to eliminate the undershoot of a nonminimum-phase (NMP) system and to improve the transient response at the same time. It was demonstrated by the computer simulations that the obtained FLC, which was optimized offline, provided satisfactory performance.

In this paper, in order to evaluate the proposed method, an optimal fuzzy controller based on GA and a conventional fuzzy controller depending on the knowledge of a human expert have been designed for the speed control of PMSM. In GA based fuzzy controller, all the controller parameters have been determined simultaneously with a different approach according to a multi-objective performance index related to integral error and maximum overshoot measures. The main goal is to obtain an optimal fuzzy controller without expert knowledge and to increase the controller performance including overshoot, rise time, steady-state error.

2. Mathematical equations of pmsm

Fig. 1 shows the block diagram of the configuration for PMSM speed drive system. The drive system consists of speed controller (conventional fuzzy controller or genetic based fuzzy controller), a reference current regulator, a hysteresis band current controller, a three phase PWM inverter and a position encoder.

In Fig. 1, ω_r is actual speed, θ_r is rotor position, i^*_a, i^*_b, i^*_c and i_a, i_b, i_c are reference and actual phase currents with a spacing of 120°. e_ω is the speed error, de_ω is its time derivative and using these input

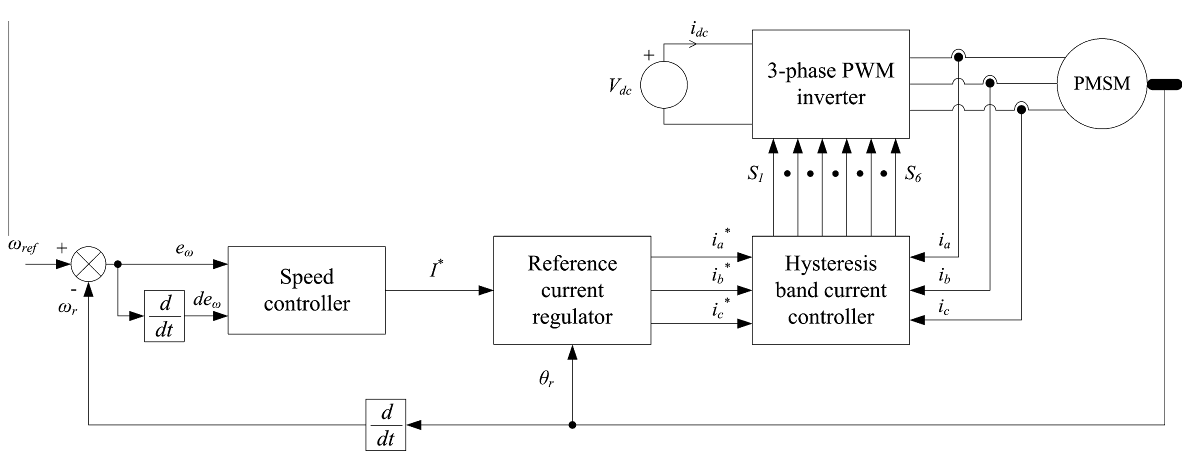

Fig. 1. Block diagram of the configuration for PMSM speed drive system.