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An Optimized Speed Controller for Brushless DC motor using Hybrid Genetic-Fuzzy Controller Technique

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Extended Abstract

This paper presented the hybrid auto-tuning technique for the brushless direct current motor speed control combining fuzzy logic controller and genetic algorithm (GA). Based on the combination of Genetic algorithm (GA) that belongs to the larger class of evolutionary algorithms with Fuzzy logic controller that operates based on the database rules and intelligent decision making, an optimized speed controller is proposed. In this control framework, the GA-Fuzzy controller contains current feedback loop which is to adjust the torque of the motor and the fuzzy logic controller loop whose control rules are optimized off-line and parameters are adjusted based on the genetic algorithm. The simulation results can proved that the proposed technique has better performance than conventional PID controller

Introduction

The BLDC motors are extremely used in various industrial applications due to their reliable performance in terms of high efficiency, high starting torque, long operating life, noiseless operation and excellent favorable electrical and mechanical properties [1-3]. There are several attractive characteristic pertained to BLDC motors such as smooth speed control and torque –speed characteristics. Especially, the driver of BLDC motors is incited by DC voltage, the stator voltage is the main parameter for speed regulation of BLDC motors and the characteristic of speed is a significant factor to measure the BLDC motors' operating performance [4–6].

In practice, the speed closed-loop is utilized to control the BLDC motors and the design of the BLDCM drive involves a complex process such as model identification, framework of control scheme, simulation and parameters tuning. Generally, the most conventional BLDC speed control approaches is proportional-integral-derivative (PID) widely adopted in practical application because of its simplicity, clear functionality, robustness and effectiveness [7,8]. However, conventional PID controller usually entail some deficiencies and malfunctions due to BLDC motor's nonlinearity and parameters variations and system uncertainties [9–11].

In order to make a better control of the BLDC motors, many researchers have studied and proposed some advanced control strategies. The PI controller has been proposed for BLDCM with the linearized motor dynamic model [12]. An enhanced PID controller for speed control of BLDC motors based on convex set optimization has been reported [13]. It was shown that the enhanced PID controller could achieve a better speed performance of time domain comparably with the conventional PID controller. In this regard, an anti-windup PI speed controller of BLDC motor demonstrated that the anti-windup PI controller has better anti disturbance ability, less overshoot and less settling time of the system than the conventional PI controller [14].

However, in practice, due to non-linear characteristics of BLDC motors and presence of sensors to estimate rotor position, PID controller cannot be suitable for non-linear system. Hence, application of fuzzy controllers that have non-linear processes such as fuzzification, defuzzification and fuzzy inference is suitable for BLDC motor control [15]. The advantages of FLC over the other conventional

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systems is that it does not need a detailed mathematical model; it can deal with nonlinear and uncertain system [16]. However, the conventional FLC with multiple inputs having multiple membership functions and multiple if-then rules have been facing some disadvantages due to its high computational burden so that the parameters of the FLC cannot be auto-tuning and not be suitable for difference conditions [17]. To overcome the above difficulties GA based FLC has been implemented in the proposed work.

Configuration of BLDC motor

From motor voltage equation and the electromechanical torque and angular velocity representation, the mathematical model of the BLDC motor can be characterized as follows [19]:

$$\begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} = R\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + (L-M)\begin{bmatrix} \frac{di_a}{dt} \\ \frac{di_b}{dt} \\ \frac{di_c}{dt} \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{1}$$

$$T_e - T_L = J\frac{d\omega_m}{dt} + B\omega_m \tag{2}$$

$$\frac{d\theta_r}{dt} = \frac{P}{2}\omega_m \tag{3}$$

Where Van,Vbn,Vcn are the phase voltages in volts, stator winding resistance is presented by R in ohms, ia,ib,ic denote the phase currents of the motor in amperes. Moreover, L and M in Henry denote the self-inductance of the motor winding and the mutual inductances between stator windings, respectively. ea, eb, ec represent the back electromagnetic force of each phase in volts. The number of poles in the rotor is represented by P, and θr is the rotor position of the rotor in radians. J, B, ωm and TL denote the moment of inertia, frictional coefficient, angular velocity, and load torque of the motor, respectively. Block diagram of BLDC motor control system with GA based Fuzzy controller could be described as Figure 1.

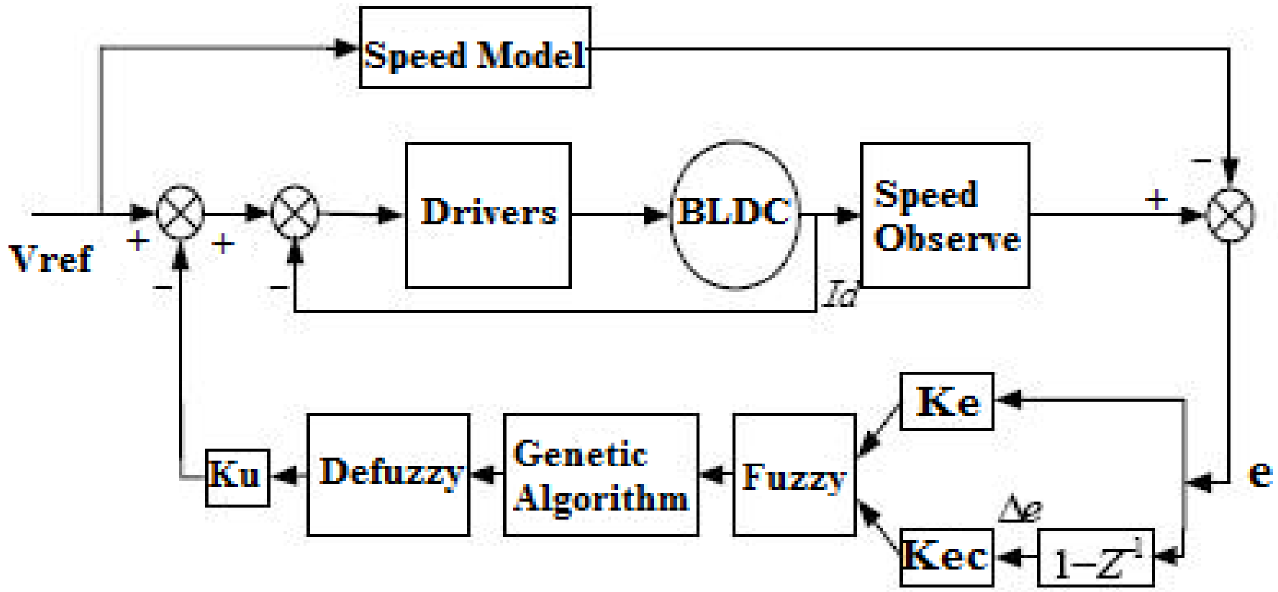

Fig.1: Configuration of BLDCM with Fuzzy-GA [18]

The block diagram consists of Drivers modules, three-phase BLDC motor, GA-based fuzzy Controller, PI and auto-tuned Gain controller, and motor measurement observers. In addition, two closed loops namely inner loop and outer loop are established based on the aforementioned blocks. Particularly, the outer loop is used for controlling the speed of the BLDC motor, and based on error and rate of change of error, the GA-optimized fuzzy controller provides the control signal to reduce rate of tracking error so as to control the speed of the motor accordingly.

Design of Proposed GA-Fuzzy Controller

A. *Fuzzy Control*

Unlike traditional logic type, fuzzy logic aims to model the imprecise modes of human reasoning and decision making, which are essential to our ability to make rational decisions in situations of uncertainty and imprecision. As shown in Figure 2, a fuzzy controller is designed which consist of fuzzifier, inference engine, rule base, and defuzzifier. Fuzzifier converts the crisp input e and △e into fuzzy linguistic variables NB, NM, NS, Z, PS, PM and PB and rule base consists of all the control rules describing the dynamic behavior of the controller. Moreover, based on the rules, inference engine completes reasoning and makes decisions. Finally, defuzzifier converts the fuzzy output of inference engine into crisp values of Ke, Kec, and Ku. Moreover, the input and output values are scaled within the corresponding range by the scaling factors.

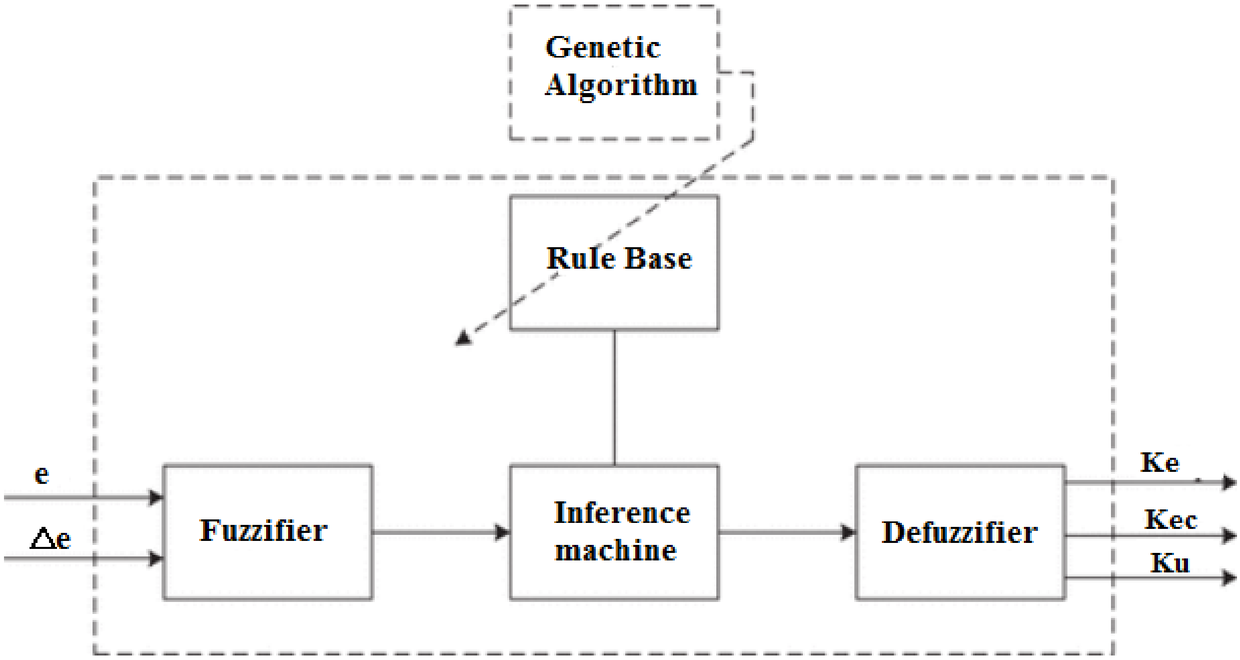

Fig. 2. The filtering process, at its most basic level [19]

The two input variables e (speed error) and ec (change in error) are calculated at each sampling time as

$$e(k) = n^*(k) - n(k) \tag{4}$$

$$ec(k) = e^*(k) - e(k-1) \tag{5}$$

Where $n^*(k)$ is the reference speed that time, and $n(k)$ is the actual rotor speed at that sampling. In fuzzifier operation, the crisp variables are converted into fuzzy variables as

$$E = K_e e$$
$$EC = K_{ec} ec$$
$$U = u / K_u \tag{6}$$

In (6), K_e, K_{ec} are the proportion coefficients. They transform the inputs to universe of fuzzy sets. And use K_u to transform the output of the fuzzy control to actual control value. These transformations are closely according to the prescribed membership functions associate with the control variables, the membership functions have been chosen with triangular shapes as shown in Figure 3.

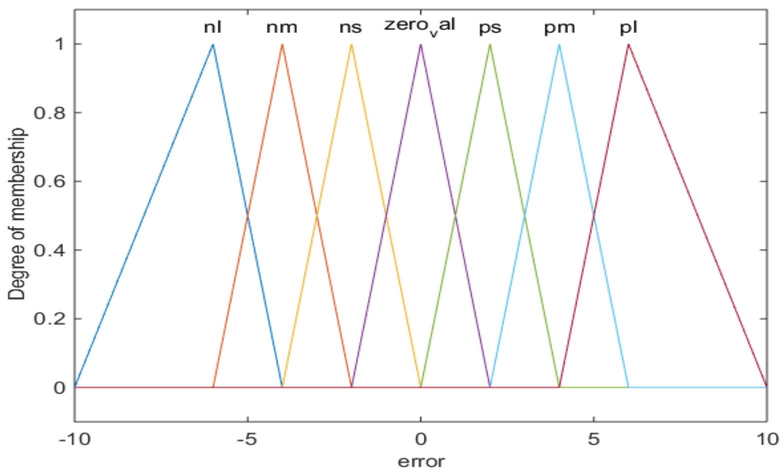

Fig. 3. Membership functions for inputs and outputs.

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The universe of discourse of input variables, e_c and output U are divided from -10 to $+10$. Each universe of discourse is divided into seven fuzzy sets: NB, NM, NS, Z, PS, PM and PB. Each fuzzy variable is a member of the subsets with a degree of between 0 (nonmember) and 1 (full member) as

$$\mu_A(x) = \begin{cases} 1 \ \ if\ \mu_A \in A \\ 0 \ \ if\ \mu_A \notin A \end{cases} \tag{7}$$

Table 1 shows the fuzzy rules. The variables are processed by an inference engine executes 49 rules (7*7).

Table 1: The fuzzy linguistic rules

E	e_c						
	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PM	PM	PS	PS	NM
NM	PB	PB	PM	PS	PS	ZE	NM
NS	PB	PM	PS	PS	ZE	NS	NB
ZE	PB	PS	PS	ZE	NS	NS	NB
PS	PB	PS	ZE	NS	NS	NM	NB
PM	PM	ZE	NS	NS	NS	NM	NB
PB	PM	NS	NS	NM	NM	NB	NB

Design of Proposed GA-Fuzzy Controller

GA is a stochastic optimization algorithm that can be provided as an effective way of searching a large and complex solution space to give close to optimal solutions and avoid local minima based on the concepts of the evolutionary theory. The basic element processed by a GA is a string formed by concatenating substrings, each of which is a binary coding (if binary GA was adopted) of a parameter. Each string represents a point in the search space. The Selection, Crossover and Mutation are the main operations of GA. The optimization step of GA is follow (Figure 4):

Code the parameter
The initialization of the population
Evaluate the fitness of each member
Selection
Crossover
Mutation

Go to step1 until find the optimum solution.

The design of the fuzzy controller is based on the GA. Figure. 5 shows the coding formulation when using GA to optimize the fuzzy controller. Here, 10 bits binary code is used to denote one fuzzy inference rule. The first binary code is the flag whether the rule is used. The 2-4, 5-7 and 8-10 refer to the error, change in error and the output variable. And 001, 010, 01 1,100,101,110 and 11 1 refer to NB, NM, NS, ZE, PS, PM and PB respectively.

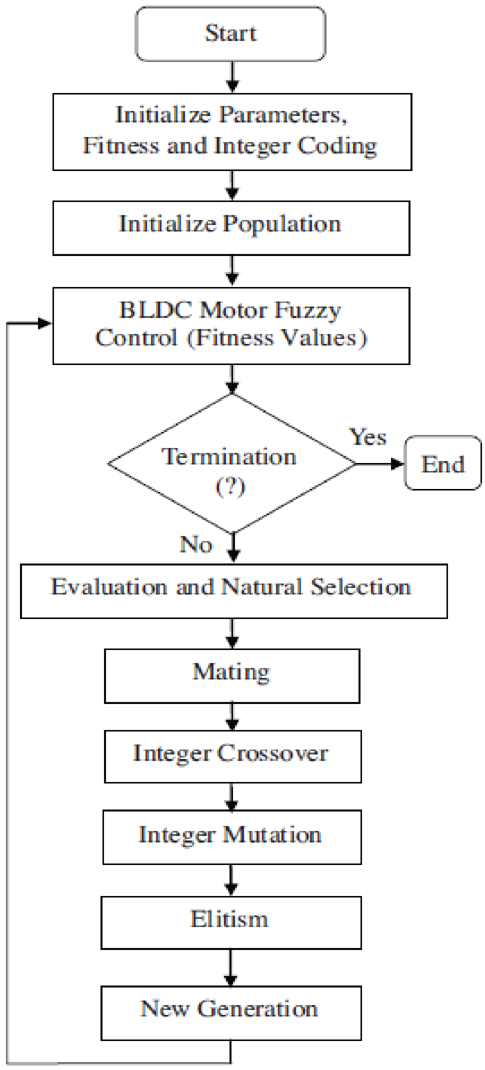

Fig. 4: Flowchart of Fuzzy-GA Controller

$$\overbrace{1\ \ 101\ \ 010\ \ 011}^{Rule1}\quad \overbrace{0\ \ 111\ \ 001\ \ 110}^{Rule2}\ ....$$

Fig. 5. Coding diagram for GA.

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Table 2: The Parameters of GA.

Crossover Possibility	**0.85**
Mutation Possibility	**0.002**
Generation Numbers	**30**

Table3:. The Parameters of GA.

E	e_c						
	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PM		PS	PS	NM
NM		PM	PS	PS	PS	ZE	NM
NS	PB	PM	PS	PS	ZE	NS	NB
ZE	PB	PS	PS	ZE	NS	NS	NB
PS		PS	ZE	NS	NS	NM	
PM	PM	ZE	ZE	NS	NS	NB	NB
PB	PM		NS		NM	NB	NB

For example, the first rule of coding diagram depicted in Figure 5 shows that if e is PB and ec is NB then U is PM, and the first bit binary code '0' indicate that this rule will be eliminated through optimization. In order to improve the speed of the optimization, 30 candidates is chosen as the initialization population and these candidates are proved to be able to make the motor run steadily. Table 2 shows the parameter of GA used and Table 3 shows the fuzzy rules intimidated through GA method. Through the optimization, 6 rules are eliminated and 4 rules are optimized.

Simulation Results

To test the performance of Fuzzy-GA, the BLDC motor speed control system is modeled using MATLAB/Simulink tool box and the specifications of the BLDC motor like in [18]. The speed respond for different conditions is measured and analyzed for the considered BLDC motor. A simulation program is designed to compare the stable and dynamic performances. Figure 5 shows the speed response curves under varying set speed condition when the set point speed is varied from 0 to 1000 r/min.

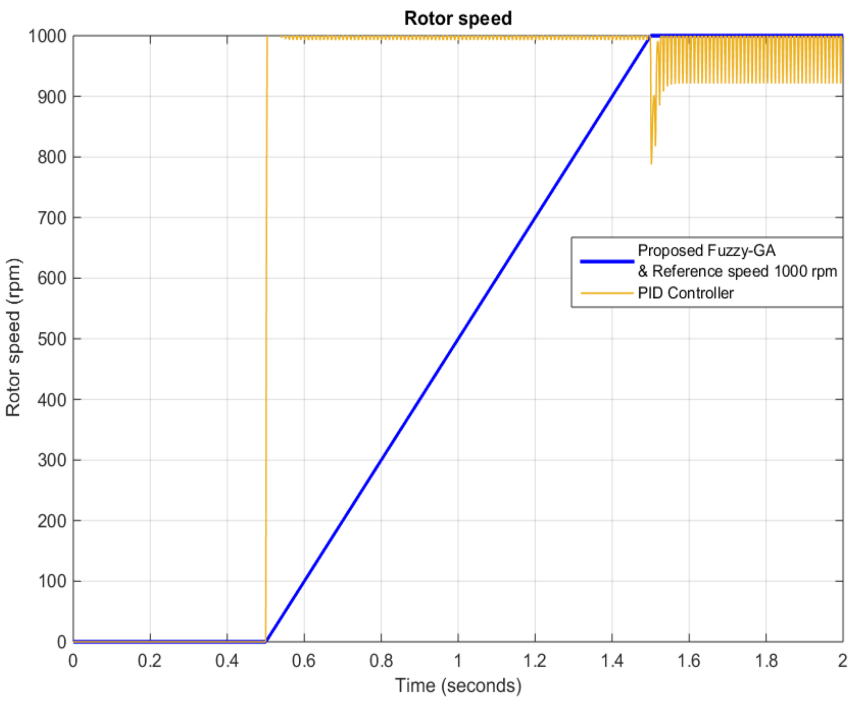

Fig. 6: Comparison of speed response under varying set speed conditions

As can be seen from Figure 5, when the set speed suddenly changes at 0.5 s, oscillation occurs for PID controller. This simulation result shows that GA-FLC performs better than the PID controller. Moreover, GA based fuzzy controller has less overshoot and more stable performance.

The waveform of electromagnetic torque with the proposed controller is sharper than that of conventional PID controller due to the shorter rising time and settling time. Figure 6 shows the electromagnetic torque response curve with the two controllers. It is clear that the GA-FLC controller has a better performance than conventional PID controller under sudden change in load.

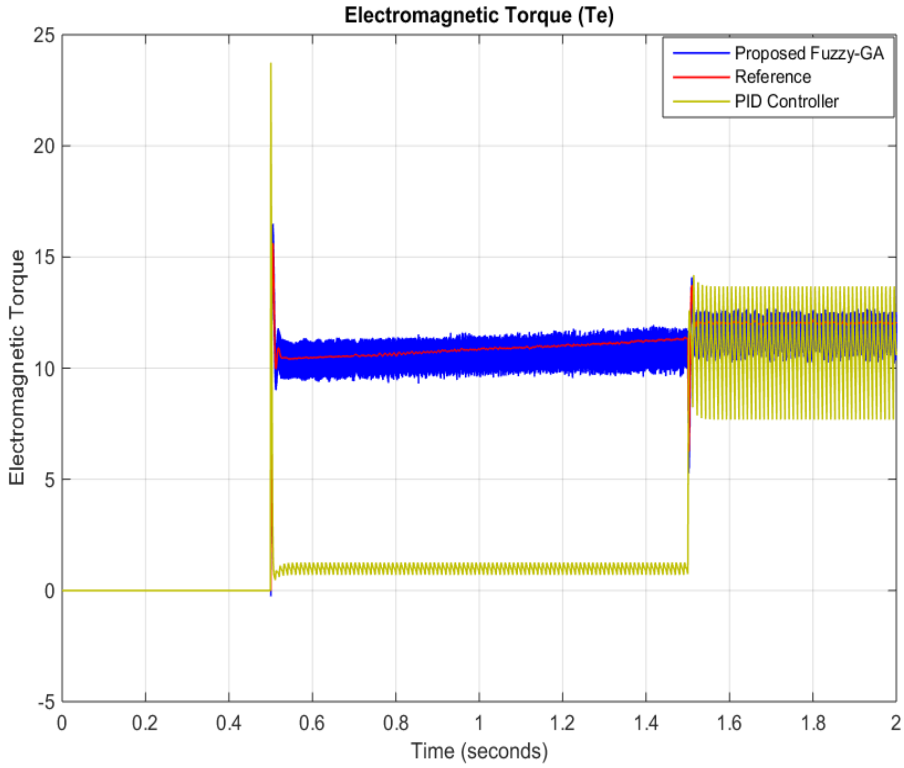

Fig. 7. Electromagnetic torque response curve of sudden change in load.

Conclusion

This paper uses the GA-Fuzzy controller as the speed controller of the BLDC motor. The gains of proportion coefficients are tuned by a fuzzy logic controller whose membership functions and control rules are optimized by an improved genetic algorithm. By comparison with PID controller, it testifies that this method is not only convincing, but also can improve dynamic performance of the system and proposed controller outperforms other controller under operation condition of the BLDC motor.

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