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Bat algorithm optimized fuzzy PD based speed controller for brushless direct current motor

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ABSTRACT

In this paper, design of fuzzy proportional derivative controller and fuzzy proportional derivative integral controller for speed control of brushless direct current drive has been presented. Optimization of the above controllers design is carried out using nature inspired optimization algorithms such as particle swarm, cuckoo search, and bat algorithms. Time domain specifications such as overshoot, undershoot, settling time, recovery time, and steady state error and performance indices such as root mean squared error, integral of absolute error, integral of time multiplied absolute error and integral of squared error are measured and compared for the above controllers under different operating conditions such as varying set speed and load disturbance conditions. The precise investigation through simulation is performed using simulink toolbox. From the simulation test results, it is evident that bat optimized fuzzy proportional derivative controller has superior performance than the other controllers considered. Experimental test results have also been taken and analyzed for the optimal controller identified through simulation.

1. Introduction

Brushless Direct Current (BLDC) motors are widely used in servo robotic positioning actuators, traction, fans, and blowers due to their high reliability, high efficiency, low maintenance, and many other advantages [1]. In the last decade, many number for speed controllers have been developed for the speed control of brushless dc motor. They are classified as proportional integral derivative controller, fuzzy logic based controller, Neuro fuzzy controller, etc [2–22].

Normally, Proportional Integral derivative controller is an optimum choice for controlling the speed of the BLDC motor. However, it has uncertainty problem due to load as well as in set speed variations. Also, tuning of the proportional integral and derivative (PID) controller leads to uncertainty in the control system parameters [2]. In order to overcome the above problems, precise method of control can be provided with help of intelligent system based on fuzzy logic and neural network approach. But most of the time, fuzzy logic based controller provides better results than the conventional and neural network.

Conventional proportional integral (PI) controller has been implemented for BLDC motor in [3]. Direct self control was designed for brushless dc motor with PI speed controller in [4]. Three phase brushless dc motor with proportional integral based speed controller has been presented for four quadrant operation in [5]. From the literatures [3–5], the proportional controller is the most preferable speed controller for BLDC motor, but PI controller produces sluggish response in the system, and also it produces uncertainty problem in some operating conditions of the BLDC motor. To avoid these shortcomings, the fuzzy logic controller has been developed [6–9]. In [6], adaptive fuzzy logic based speed controller has been designed for brushless dc motor. In [7], comparative analysis for PI controller, fuzzy tuned PID controller, fuzzy variable structure controller, and ANFIS controller has been developed for Brushless DC motor. In [8], adaptive fuzzy PID controller has been developed for the dc motor. In [9], fuzzy like Proportional Derivative (PD) controller was developed for non linear plant. But the non linearity of the system depends on the scaling factor of the fuzzy Proportional Derivative controller.

From [6–9], all parameters were in favor of the fuzzy logic based controller. Even though, performance of the fuzzy logic controller depends on the scaling factor of the input and output of the fuzzy logic controller, it also affects the control system performance. In order to overcome these problems, the tuning of scaling factor of the PID and fuzzy logic controller with naturally inspired algorithm such as genetic algorithm, particle swarm optimization, and cuckoo search algorithm was developed for the optimization of constant parameter in [10–13]. The design and the tuning of PID controller through the genetic algorithm approach have been presented for robotic manipulator in [10]. From the simulation result, torque of

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the manipulator has larger overshoot and larger error. In [11], tuning of PID controller gain by particle swarm optimization (PSO) was implemented for brushless dc motor, but the electromagnetic torque has high overshoot and undershoots in the starting period.

In [12], genetic algorithm has been used for tuning the scaling factor of fuzzy logic based PID controller, and it was applied for the speed control of brushless dc motor. From the experimental results it was pointed out that speed response has uncertainty problem due to load variations. In [13], the survey has been presented explaining the nature-inspired optimization algorithms for tuning the scaling factor of the fuzzy logic control. The importance of particle swarm optimization for large scale optimization was explained in [14]. In [15], comparison of particle swarm optimization and genetic algorithm for FACTS-based controller design has been explained. In [16], the comparison of Cuckoo search with standard versions of PSO and GA has been discussed. Cuckoo search algorithm was applied for tuning the parameter of two degrees of freedom controller in the automatic generation control of multi area system which has been presented in [17]. But with this algorithm also, only steady state response of the system has improved without significant transient response improvement. The comparative analysis of swarm intelligent techniques (cuckoo search, firefly algorithm, and glowworm swarm optimization) with population based algorithm (genetic algorithm) was presented in [18]. The superiority of each swarm intelligent techniques has been noticed with population based algorithm. The scaling factor of fractional order fuzzy PID controller tuning by cuckoo search algorithm has been presented in [16]. In [19,20], bat algorithm was used for tuning the parameters of the power system stabilizers, and its effectiveness was also reported. Most of the researchers only concentrated on the GA, PSO, and Cuckoo algorithm for tuning fuzzy logic controller scaling factors.

The operation of the system under fuzzy logic control not only depends on the input and output scaling factors of the fuzzy logic controller but it also depends on the position of the membership function of the input and outputs of the comptroller. Tuning of membership function of Fuzzy PWM based on Genetic Algorithm for battery charging has been outlined in [21]. Genetic fuzzy self-tuning PID controllers for antilock braking systems have been presented in [22]. Genetic algorithm has been used for tuning the antecedent part of the input membership function, and coefficients of the consequent parts of the Takagi and Sugeno fuzzy inference system. Totally, 93 parameters have been tuned for the fuzzy inference system. From this, genetic algorithm takes large computation time for getting optimal parameter for the fuzzy logic control. Although, overshoot, performance indices, i.e., integral of absolute error and integral of time multiplied absolute error was not favored for the fuzzy self tuned PID controller. There is no significant literature based on bat algorithm optimized tuning of parameters in fuzzy logic controller. Flexible job shop scheduling problem using an estimation of distribution algorithm (EDA) has been explained, and effectiveness of EDA has been addressed in [23]. But EDA has some disadvantages that are loss of diversity, insufficient use of local information of solution, and it traps into local optima.

The objective of this paper is to design the fuzzy PD and fuzzy PID controller for the speed control of brushless dc motor and optimize the input and output scaling factor, antecedent part of the input membership function, and coefficients of the consequent parts of the fuzzy inference system of the fuzzy PD controller and fuzzy PID controller with bat, PSO, and cuckoo search algorithms. The purpose of optimization is to minimize the objective function in order to improve the time domain specifications and performance indices under different operating conditions. Parameters such as overshoot, undershoot, settling time, recovery time, steady state error, root mean squared error, integral of absolute error, integral of time multiplied absolute error and integral of squared error are measured and compared for the above controllers with different operating conditions of the brushless dc motor drive. Based on the simulation results, best controller is suggested and validated. An attempt has also been made to prove experimentally the results of the optimal controller pointed out through simulation study.

The paper is organized as follows: Speed control of BLDC motor is given in brief in section 2, and design of Fuzzy PD and Fuzzy PID type speed controller is explained in section 3. Formulation of the objective function for the fuzzy PD and fuzzy PID controller is presented in the section 4. Review of nature-inspired optimization algorithms for tuning of fuzzy PD and fuzzy PID controller has been provided in section 5. Section 6 discusses the simulation results, and section 7 provides experimental verification and discussion on results. Concluding remarks are outlined in section 8.

2. The speed control of the brushless dc motor

Speed control system for BLDC motor is represented in Fig. 1. Three phase star connected brushless dc motor can be described by the following five equations (1) to (5) as,

$$v_{ab} = R(i_a - i_b) + L\frac{d}{dt}(i_a - i_b) + e_a - e_b \tag{1}$$

$$v_{bc} = R(i_b - i_c) + L\frac{d}{dt}(i_b - i_c) + e_b - e_c \tag{2}$$

$$v_{ca} = R(i_c - i_a) + L\frac{d}{dt}(i_c - i_a) + e_c - e_a \tag{3}$$

$$T_e = k_f \omega_m + J\frac{d\omega_m}{dt} + T_L \tag{4}$$

$$\omega_m = \frac{d\theta_m}{dt} \tag{5}$$

Where V_{ab}, V_{bc}, and V_{ca} are the phase to phase voltage in volts. Phase currents of the stator winding represents by i_a, i_b, and i_c in amperes. L denotes the self inductance of the motor in Henry. Back electromagnetic force is represented by e_a, e_b, and e_c in volts. T_e and T_L are the electromagnetic torque and Load torque of the motor in N-m. J is the rotor inertia, k_f is a friction constant, ω_m is the rotor speed of the motor in rad/s, and θ_m is the rotor position of the motor in rad. Fig. 1 shows the speed control system of the brushless dc motor. The system consists of two loops, such as the inner loop and the outer loop. Inner loop is used for synchronizing the inverting gate signal with back electro motive force or rotor position of the motor. The outer loop is used to sense the actual speed of the motor, and then it is compared with the reference speed to produce speed error. The speed error is then processed via controller thus provide

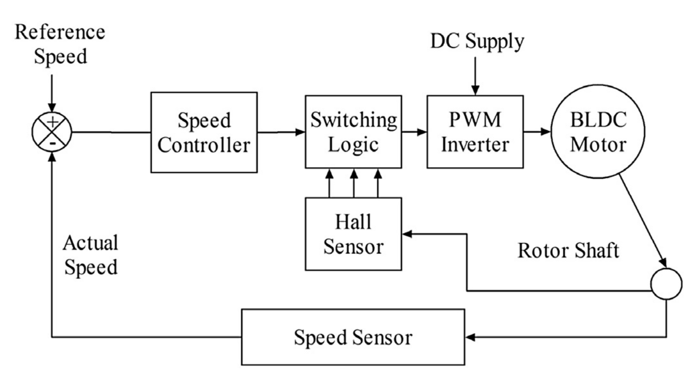

Fig. 1. Speed control system of brushless dc motor.