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Adaptive Neuro-Fuzzy Inference System based speed controller for brushless DC motor

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ABSTRACT

In this paper, a novel controller for brushless DC (BLDC) motor has been presented. The proposed controller is based on Adaptive Neuro-Fuzzy Inference System (ANFIS) and the rigorous analysis through simulation is performed using simulink tool box in MATLAB environment. The performance of the motor with proposed ANFIS controller is analyzed and compared with classical Proportional Integral (PI) controller, Fuzzy Tuned PID controller and Fuzzy Variable Structure controller. The dynamic characteristics of the brushless DC motor is observed and analyzed using the developed MATLAB/simulink model. Control system response parameters such as overshoot, undershoot, rise time, recovery time and steady state error are measured and compared for the above controllers. In order to validate the performance of the proposed controller under realistic working environment, simulation result has been obtained and analyzed for varying load and varying set speed conditions.

1. Introduction

Brushless DC (BLDC) motors are coming of age due to continuous improvement in high energy permanent magnet materials, power semiconductor and digital integrated circuits. In any application requiring an electric motor where the space and weight are at a premium, the BLDC motors becomes the ideal choice. A BLDC motor has high power to mass ratio, good dissipation characteristics and high speed capabilities. Limitations of brushed DC motors overcome by BLDC motors include lower efficiency, susceptibility of the commutator assembly to mechanical wear, consequent need for servicing, less ruggedness and requirement for more expensive control electronics. Due to their favorable electrical and mechanical properties, BLDC motors are widely used in servo applications such as automotive, aerospace, medical field, instrumentation areas, electromechanical actuation systems and industrial automation requirements [1–3]. Many control schemes have been developed for improving the performance of BLDC motor drives.

Many varieties of control schemes such as Proportional Integral Derivative (PID), Non-Adaptive Fuzzy Logic Controller (FLC) and Adaptive Fuzzy Logic Controller have been developed for the speed control of brushless DC motors. Most of the manufacturing processes still use the conventional PID controllers due to their simplicity and robust design. Conventional PID controllers are usually not efficient if the processes involved are of higher order and time delay systems, non-linear systems, complex and unclear systems without accurate mathematical models and systems with uncertainties [4,5].

Non-adaptive fuzzy logic, which is based on fuzzy set theory, was first developed by Zadeh in 1965. Control applications such as temperature control, traffic control, DC motor speed control, etc. are the most prevalent of non-adaptive fuzzy logic applications. For the most complex systems, where few numerical data exist and where only ambiguous or imprecise information is available, fuzzy reasoning provides a way to understand the system behavior by allowing interpretation between the observed input and the output relations of the system [6–9]. While non-adaptive fuzzy control has proven its value in some applications, it is sometimes difficult to state the rule base for some plants, or the need could arise to tune the rule-base parameters if the plant changes. In order to overcome these shortcomings, adaptive fuzzy logic speed controller has been developed [10–20].

In this paper, an attempt has been made to improve the performance of speed controller by proposing a novel ANFIS speed controller for BLDC motor drive. The paper is organized as follows: Literature review is given in Section 2 and mathematical model of the BLDC motor drive is presented in Section 3. Adaptive Neuro-Fuzzy Inference

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System based controller is presented in Section 4 and Section 5 discusses simulation results. Concluding remarks is outlined in Sction 6.

2. Literature review

Fuzzy Proportional Integral based speed controller designed for brushless DC motor exhibits more oscillatory speed response under load varying condition [6]. In [7], simulation results of fuzzy logic based current and speed controller for BLDC motor drive was presented and it has produced more oscillatory speed response. Fuzzy logic controller for BLDC permanent magnet motor drive has been discussed in [8]. From the simulation and experiment results, it has been observed that, during load disturbance, overshoot and undershoot were produced in the speed response. In [9], comparative evaluation between classical PID controller and hybrid fuzzy logic PID controller has been presented. The results proved that fuzzy logic controller outperforms PID controller but speed response obtained during load variations exhibited overshoot and undershoot.

In [10], modified model reference adaptive fuzzy logic speed controller was designed for BLDC motor drive. This controller needs reference plant model for training the fuzzy logic controller and also the response was more oscillatory. Adaptive fuzzy logic speed controller for brushless dc motor drive has been discussed in [11] and this controller has two structures namely fuzzy proportional derivative and fuzzy Proportional Integral controller. Adaptation is made based upon error signal received and this controller cannot be used for other plant models. Adaptive sliding mode controller, non-adaptive fuzzy controller and adaptive fuzzy based controllers have been presented for the BLDC motor drive in [12,13]. But, the simulation and experimental results have clearly indicated that the parameters like steady state error, settling time, overshoot and response time are not in favor of controller performance during load disturbance.

The combination of neural network and fuzzy system has recently become popular in engineering fields and one such structure namely Adaptive Neuro-Fuzzy Inference System was discussed in [14–20]. In [14], intelligent agent based Adaptive Neuro-Fuzzy Inference System (ANFIS) was developed to perform Non-linear Auto-Regressive Moving Average with exogenous input (NARMAX) system identification of BLDC motor. Back electromagnetic force prediction performed by ANFIS for sensorless control of brushless dc motor was presented in [15]. Gain adjustment of dead beat Proportional Integral based speed controller for BLDC motor has been designed by particle swarm with ANFIS [16]. The limitation of this controller is that, it worked only for particular operating conditions. The controller response has changed abruptly for change in operating conditions. Also, the system exhibited larger overshoot, high rise time, high settling time and increased possibility of system moving to unstable state. In [17], hybrid approach was followed for designing the speed controller. The controller incorporates Neuro fuzzy based proportional derivative controller and conventional integral controller. Neuro fuzzy controller produced more noise in the control system and tuning of the integral gain has considerable effect on the control performance such as overshoot and settling time. ANFIS based controller has been designed for brushless dc motor in [18,19], but the speed response exhibited high rise time, high settling time and larger steady state error. In [20], ANFIS controller based on emotional learning algorithm was presented. The emotional learning algorithm utilized the proportional derivative controller function and it modified the output layer gain of Neuro fuzzy controller. But, tuning of the proportional and derivative gains has resulted in large overshoot, large settling time and high steady state error in the system performance.

Fig. 1 shows the controllers considered for investigation. Fig. 1 (a) shows Proportional Integral controller [3]. It is simple and widely used in most of the industries till now but tuning of gain in the proportional and integral part has significant effect on control system performance. Also, performance uncertainty was experienced during load variations. In order to overcome this problem, Non-Adaptive Fuzzy Logic Controller, i.e., Fuzzy Tuned PID controller has been developed and it is shown in Fig. 1(b). The controller design has been carried out on trial and error basis. Also, it required more number of rules, i.e., 147 rules and performance uncertainty was observed during some operating conditions [9]. Non-adaptive controller problems have been overcome by adaptive

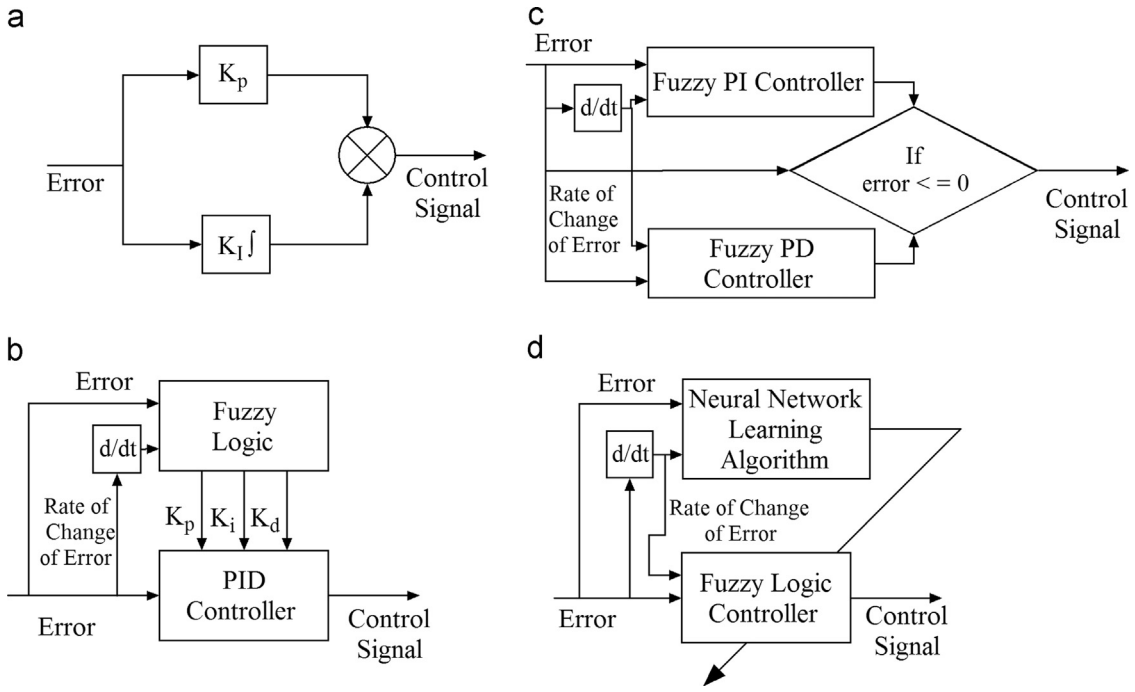

Fig. 1. (a) Proportional Integral controller, (b) Fuzzy Tuned PID controller, (c) Fuzzy Variable Structure controller, and (d) proposed ANFIS controller.