Adaptive Fuzzy PID Regulator for the Speed Control of Brushless Dc Motor

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Abstract: This paper presents an intelligent speed control system based on self tuning fuzzy PID controller for a brushless DC motor. PWM based motor current control is implemented with the help of three hall sensors placed around the motor shaft and a three phase inverter model is implemented for motor commutation. Dynamic performance of electromagnetic torque developed are analysed for this model. Traditional speed control system of BLDCM introduces conventional PI regulator in outer speed loop which debases the performance of whole system. To overcome this problem, replacement of PI controller by an intelligent controller based on fuzzy set theory is proposed. The performance of the intelligent controller has been investigated through Matlab Simulink package for different operating conditions such as sudden changes in load torque. The simulation results demonstrate that the performance of the proposed controller is better than that of conventional PI controller.

Keywords: Fuzzy Logic Controllers, BLDC, PID Controller

I. Introduction

With the rapid developments in power semiconductor technologies and manufacturing technology for high quality magnetic materials, the BLDC motors have been widely used for various industrial and servo applications. BLDC motors are reliable, easy to control and inexpensive. Due to their favourable electrical and mechanical properties, BLDC motors are widely used in applications such as automotive, aerospace, medical, instrumentation, actuation, robotics and industrial automation equipments. BLDC motors have many advantages over conventional dc servo motors such as high dynamic response, long operating life, high efficiency, long operating characteristics and high torque-weight ratio. The stator of BLDC motors have three phase windings, whereas rotor has pole magnets. The hall sensors embedded in the motor detects rotor position and decoder decodes the position of rotor and produces gate pulses to trigger the six pulse inverter to produce ac voltages that energizes the stator windings. BLDC motors have electronic commutators instead of brushes, thus they have higher efficiency, noiseless operation and long operating life. Fuzzy control provides a formal methodology for representing, manipulating and implementing a human heuristic knowledge about how to control the performance of a real dynamic system. Some simulation models based on state space equations, analysis of torque ripple due to phase commutation have been proposed for the analysis of BLDC motor drives[1],[2]. Furthermore fuzzy logic controllers are used to analyse BLDC motor drives in literature[3],[4]. The FLC technique is a model-free technique and inherently robust to load disturbances with the ease of implementation[5]. In this paper, a self tuning PID Fuzzy Logic Controller is proposed for the speed control of BLDC motor.

II. Modelling Of Permanent Magnet Brushless Dc Motor

The complete BLDC motor drive system consists of a permanent magnet motor fed by a three phase PWM inverter, hysteresis current controller, rotor position sensor and speed controller. The phase variables are used to model the BLDC motor due to its nonsinusoidal back emf and phase current. The controlled power to motor is supplied by the inverter. The magnitude and frequency of the inverter output voltage depends on the switching signals generated by the hysteresis controller. The state of these switching signals at any instant is determined by the rotor position, speed variation and winding currents. The controller facilitates the variable speed operation of the drive and also synchronizes winding currents with the rotor position. It maintains the motor speed reference value even during load and supply variations. The Fig.1 shows the configuration of Permanent Magnet Brushless DC Motor drive system.
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Fig.1 Brushless DC Motor Drive system

The mathematical model of the motor is developed based on the assumption in [4]. The terminal voltage equation of BLDC motor can be written as

$$\begin{align*}
v_a &= R_i a + L_a \frac{di_a}{dt} + e_a \\
v_b &= R_i b + L_b \frac{di_b}{dt} + e_b \\
v_c &= R_i c + L_c \frac{di_c}{dt} + e_c
\end{align*}$$

(1)

Where \(v_a, v_b, v_c\) are the phase voltages, \(i_a, i_b, i_c\) are the phase currents, \(e_a, e_b, e_c\) are the phase back emf voltages, \(R\) is the phase resistance, \(L = L_a = L_b = L_c\) is the synchronous inductance per phase and includes both leakages and armature reaction inductances.

The electromagnetic torque is given by

$$T_a = e_a i_a + e_b i_b + e_c i_c / \omega_m$$

(2)

Where \(\omega_m\) is the mechanical speed of motor.

III. Design Of Adaptive Fuzzy Pid Controller

The membership functions for controller input error and change in error are defined on the common interval \([-1 1]\). The membership function for gain updating factor is defined on \([0 1]\). The triangular membership function is selected with fifty percent overlap except at the two membership functions at the extreme end. The membership functions for error and change in error are shown in Fig. 2 and Fig.3 respectively. Their control output is shown in Fig. 4. The membership function for gain updating factor \(\alpha\) is obtained by translating Fig. 4 along the horizontal axis by an amount +1 and mapping it on \([0 1]\) using the relation \(y = 0.5(x+1)\) and it is shown in Fig. 5. The values of actual inputs \(e\) and \(\Delta e\) are mapped on to \([-1 1]\) by the input scaling factors. The fuzzy logic controller output is mapped to actual output by output scaling factor \(\alpha GU\). The actual output of adaptive FLC is obtained by using effective scaling factor \(\alpha GU\).

Fig. 2 Membership function plot for Error
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The relationship between scaling factors and input and output variables of adaptive FLC are given by Eqns. (3), (4) and (5).

\[ E = GE * e \tag{3} \]

\[ CE = GCE * \Delta e \tag{4} \]

\[ U = (\alpha GU) \ u \tag{5} \]

where GE, GCE and GU are scaling factors at the input and output of FLC. The term ‘u’ represents the fuzzy controller output and ‘U’ denotes scaled output of fuzzy logic controller. The fuzzy PD controller uses rules of the form:

\[ R_{pd}: \text{If } e \text{ is PB(Positive Big) and } \Delta e \text{ is PS (Positive Small) then } u \text{ is PB (Positive Big).} \]

The gain updating factor (\( \alpha \)) are calculated using fuzzy rules of the form:

\[ R_{\alpha}: \text{If } e \text{ is NB (Negative Big) and } \Delta e \text{ is NB (Negative Big) then } \alpha \text{ is VB (Very Big).} \]

Some of the important considerations that have been taken into account for the rule formation is to minimize the effects of delayed control action due to process dead time or measuring lag. The rules have been realized of the form: If \( e \) is PS and \( \Delta e \) is PB then \( \alpha \) is VB.(The process output is not only far away from the set point but also is moving farther away from it). 2) Using the rule ‘If \( e \) is ZE and \( \Delta e \) is PM then \( \alpha \) is B’ overshoot can be reduced. 3) When the processes are subjected to load disturbances in order to improve the control performance, the gain should be sufficiently large during the steady state condition.
The fuzzy rules for computation of control input ‘u’ are shown in Table 1 and the fuzzy rules for computation of $\alpha$ are shown in Table 2.

**Table 1 Fuzzy rules for computation of control input ‘u’**

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**Table 2 Fuzzy rules for computation of $\alpha$**

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To make controller produce lower overshoot and settling time the controller gain is set at a small value when error is big. If $e$ is NB and $\Delta e$ is PS then $\alpha$ is VS. In order to prevent excessive oscillation, the rule for $\alpha$ is selected as ‘if $e$ is PS and $\Delta e$ is NS then $\alpha$ is ‘S’. This type of gain variation will also result in the convergence rate of process to the set point. To improve control performance under load disturbance gain should be sufficiently large around steady state condition. Immediately after a large load disturbance, $e$ may be small but $\Delta e$ will be sufficiently large and in this case $\alpha$ is needed to be large to increase the gain. Fig. 6 shows the simulation diagram of BLDC motor control system and Fig. 7 demonstrates the fuzzy PID regulator simulation.

![Fig.6 Simulation diagram of BLDC motor system](image-url)
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IV. Simulation Results

Simulation results include variations of different parameters of BLDC motor like electromagnetic torque, rotor speed, line-line motor terminal voltages w.r.t time. Fig.8(a) and Fig.8(b) show dynamic responses of the rotor speed using conventional PID Controller and Adaptive fuzzy PID Controller, and Fig.9(a) and Fig.9(b) show dynamic responses of the electromagnetic torque developed using fuzzy PID controller and conventional PID controller. From the torque response curve it can be observed that for the system with fuzzy PID Controller torque ripple is minimized under variable load conditions.
With adaptive fuzzy PID controller percentage overshoot is found to be zero compared to the response of conventional PID Controller. The produced line-to-line voltage Vab, Vbc and Vca according to the conduction modes is demonstrated in Fig.10, 11 and 12 respectively.

![Fig.9 (a) Torque response curve with fuzzy PID Controller](image1)

![Fig.9(b) Torque response curve with conventional PID Controller](image2)

![Fig.10 line-line voltage Vab](image3)
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Fig. 11 line-line voltage Vbc

Fig. 12 line-line voltage VAC

V. Conclusions

A performance comparison of PID Controller and Adaptive fuzzy Logic controller has been carried out by several simulations. The results have shown that Adaptive fuzzy logic regulator is better than conventional PID controller under variable operating conditions such as sudden variation in load conditions. The performance of AFLC is excellent for reducing torque ripples. The conclusion is that Adaptive fuzzy regulator is found to be more robust, stable flexible and insensitive to parameter variations as compared with conventional PID Controllers.

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