Simulation and Modelling of Adaptive Fuzzy Logic Speed Controller for BLDC Motor

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Abstract:*The paper presents the analysis and modelling of BLDC motor with adaptive fuzzy logic controller for achieving improved performance of BLDC servomotor drive. For designing controllers it is necessary to know the exact model of the system. Here it has to be assumed that the system parameters never change during operating conditions, but practically the mechanical load parameters like inertia and friction may change due to change in load.. In this paper, adaptive fuzzy logic controller for BLDC motor has been proposed. The controller consists of two structures, one is fuzzy PI controller and the other is fuzzy PD controller. Based on the speed error signal received, switching takes place between these two controllers. Comparison is made between P, PI and the proposed adaptive fuzzy logic controller. In order to improve the performance during transient and steady state phase adaptive fuzzy logic controller has been developed.*

Keywords: *BLDC Motor, Adaptive Fuzzy logic controller, PI controller, PD controller , P controller*

I. Introduction

The BLDC motors which are replacing the brushed dc motors are more frequently finding their way into an increasing number of medical, servo control and drive system applications. The operating characteristics of BLDC motor resemble that of a dc motor, hence its name BLDC motor[1]. BLDC motors are predominantly surface-magnet machines with wide permanent magnet pole-arcs and concentrated stator windings. The design is based on a square waveform distribution of the air-gap flux density waveform as well as the winding density of the stator phases in order to match the operational characteristics of the self-controlled inverter .Having the armature windings on the stator helps the conduction of heat from the windings. Since there are no windings on the rotor, electrical losses in the rotor are minimal. There are three classifications of the BLDC motor: single-phase, two-phase and three-phase. The single-phase and three-phase motors are the most widely used. There are two types of stator windings: trapezoidal and sinusoidal, which refers to the shape of the back electromotive force (BEMF) signal[3]. The shape of the BEMF is determined by different coil interconnections and the distance of the air gap. In addition to the BEMF, the phase current also follows a trapezoidal and sinusoidal shape. A sinusoidal motor produces smoother electromagnetic torque than a paper. trapezoidal motor, though at a higher cost due to their use of extra copper windings. A BLDC motor uses a simplified structure with trapezoidal stator windings . Another advantage of using BLDC motor they have low electric noise and long lifetime since there are no brushes and commutator therefore no arcs from brushes to generate noise, which cause EMI problem[3].

The primary disadvantage of BLDC is cost, though this is no inherent reason due to the motor itself; the construction of a BLDC motor is actually simpler than that of brushed DC motor or AC induction motor. The higher cost of BLDC motor is caused by the additional driver circuit for BLDC motor[5]. However if the application requires adjustable speed, accurate position control, or requires a driver circuit, then BLDC motor is not only advantageous but also less expensive overall. Brushless DC motors use electric switches to realize current commutation, and thus continuously rotate the motor. These electric switches are usually connected in an H-bridge structure for a single-phase BLDC motor. Usually the high-side switches are controlled using pulse-width modulation (PWM), which converts a DC voltage into a modulated voltage, which easily and efficiently limits the startup current, control speed and torque. Generally, raising the switching frequency increases PWM losses, though lowering the switching frequency limits the system's bandwidth and can raise the ripple current pulses to the points where they become destructive or shut down the BLDC motor driver[4].

For designing controllers it is necessary to know the exact model of the system. Here it has to be assumed that the system parameters never change during operating conditions, but practically the mechanical load parameters like inertia and friction may change due to change in load .The main disadvantage of the conventional controllers is that they can provide better transient and steady state responses only when they are designed remain unchanged. But practically the parameters may change during operation. If PI controller is used, when the motor is disturbed, it requires fine tuning of proportional gain (Kp) and integral time constant (Ti). In this paper, the controller consists of two structures , one is fuzzy PI controller and the other is fuzzy PD controller.

II.   Modelling Of Bldc Motor

The BLDCM has three stator windings and a permanent magnet rotor on the rotor. Rotor induced currents can be neglected due to the high resistivity of both magnets and stainless steel. No damper winding are modeled the circuit equation of the three windings in phase variables are obtained[5].
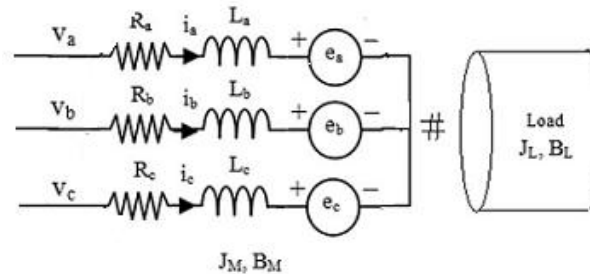

Fig:1 BLDC motor drive system

The electrical part of DC brushless motor and relationship between currents, voltage, and back electromotive force and rotor velocity is derived using Kirchhoff's voltage law. The equations involved inthe modeling of PMBLDC motor shown in Fig. 1 arederived as

$$V_{ab} = R(i_a - i_b) + L d/dt(i_a - i_b) + E_a - E_b \qquad (1)$$

$$V_{bc} = R(i_b - i_c) + L d/dt(i_b - i_c) + E_b - E_c \qquad (2)$$

$$V_{ca} = R(i_c - i_a) + L d/dt(i_c - i_a) + E_c - E_a \qquad (3)$$

Where:
R : per phase Stator resistance
L : per phase Stator inductance

The instantaneous stator phase currents are represented by ia, iband ic as. The instantaneous stator line voltages are represented by Vab, Vbcand Vcawhereas Ea, Eb and Ec represent the instantaneous back emf's. The relationship between the phase current is given by

$$i_a + i_b + i_c = 0 \qquad (4)$$

From the above equation,

$$i_c = -(i_a + i_b) \qquad (5)$$

Using Eq(5) the line voltage Eq(1)and (2) can be rewritten as ,

$$V_{ab} = R(i_a - i_b) + L d/dt(i_a - i_b) + E_a - E_b \qquad (6)$$

$$V_{bc} = R(i_a + 2i_b) + L d/dt(i_a + 2i_b) + E_a - E_b \qquad (7)$$

The electromagnetic torque developed by the motor can be expressed as

$$T_e = (E_a i_a + E_b i_b + E_c i_c)/\omega \qquad (8)$$

Since this electromagnetic torque is utilized to overcome the opposing torques of inertia and load, it can be written as

$$T_e = T_L + J_M d\omega/dt + B_M \omega \qquad (9)$$

Where $T_L$is the load torque, J_M is the inertia, and B_M is the frictional constant of the BLDC servomotor. The load torque can be expressed in terms of load inertia J_L and friction BL components as

$$T_L = J_L d\omega/dt + B_L \omega \qquad (10)$$

The output power developed by the motor is

$P = T_e \, \omega$ (11)

$E = E_a = E_b = E_c = K_b \, \omega$ (12)

The parameters that are likely to vary during the working conditions are R, JM, JL, BM, and BL. Increase in the value of energy storage inertia elements JMand JLwill increase the settling time of the speed response or vice versa. The decrease in the values of power consuming friction components BM and BL will increase the deceleration time of the speed response or vice versa[7].

Table: Selected Specifications For Bldc Motor Drive

Specifications	Value
Stator phase resistance (Ω)	1
Stator phase inductance (H)	0.001
Flux Linkage established b:ja3y magnets	0.175
Voltage constant	0.1466
Torque constant	1.4
Moment of inertia (JM)	0.0008
Friction Factor (BM)	0.001
Pole pairs	4
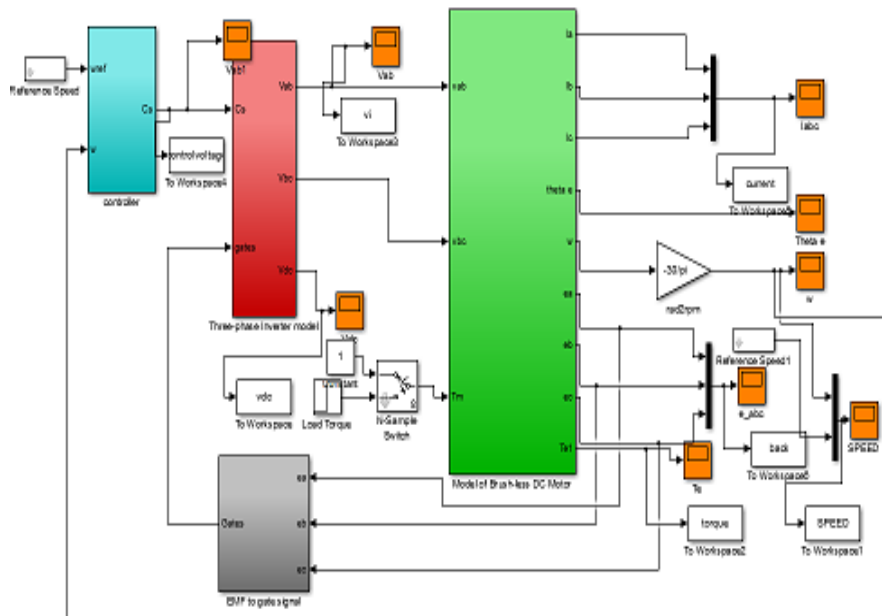
Fig: 2 Modelling of BLDC motor

III. Adaptive Fuzzy Logic Controller For Bldc Motor

Several studies show, both in simulations and experimental results, that Fuzzy Logic control yields superior results with respect to those obtained by conventional control algorithms thus, in industrial electronics the FLC control has become an attractive solution in controlling the electrical motor drives with large parameter variations like machine tools and robots. However, the FL Controllers design and tuning process is often complex because several quantities, such as membership functions, control rules, input and output gains, etc must be adjusted[4-6].Fuzzy logic has rapidly become one of the most successful of today's technology for developing sophisticated control system.. The past few years have witnessed a rapid growth in number and variety of application of fuzzy logic. The application range from consumer products such as cameras, camcorder and washing machines [8].

In the proposed system, the controller consists of two controller, fuzzy PD and fuzzy PI controller inorder to improve the performance during transient and steady state. Based on the error signal received, switching takes place between these controllers accordingly. The first step while designing the controller will be to decide the state variables of the drive system which will be taken as the input signals to the controller. Here both speed and change in speed error are used as inputs to the controller. The output of the controller, the control signal will be given to the inverter section where the voltage will be controlled, thereby controlling the speed. After specifying the fuzzy sets and the membership function for seven sets, the triangular membership functions are used to define the degree of membership [10].
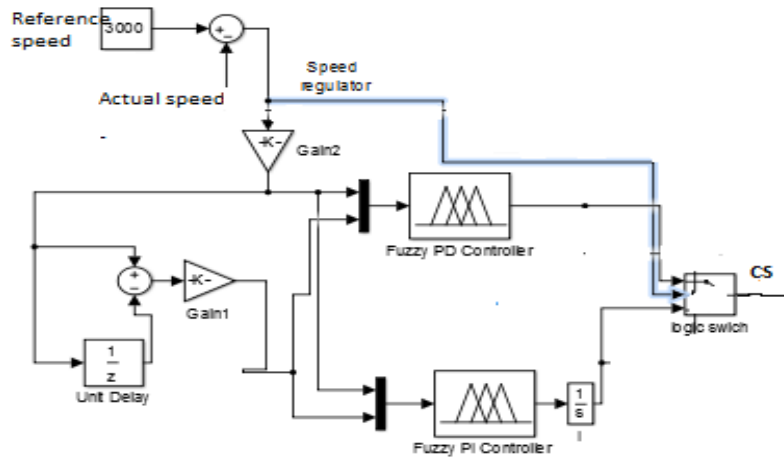
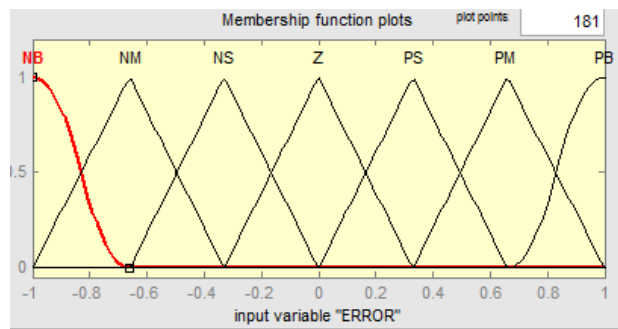**Fig: 3** Simulink Diagram of proposed fuzzy PI-PD   controller

Fig: 4 Membership function used for fuzzy controller

IV.   Simulation Results

        The BLDC parameters are shown in Table 1 and its performance is obtained by simulation using MATLAB. The simulation was run for 2 seconds. Substituting the values of the motor parameters and using Ziegler Nichols method, the tuning parameters of PI controller are determined as $Kp = 0.15$ and $Ki = 7.5$. The electromagnetic torque and speed response curves obtained for P, PI and the proposed method are given here.
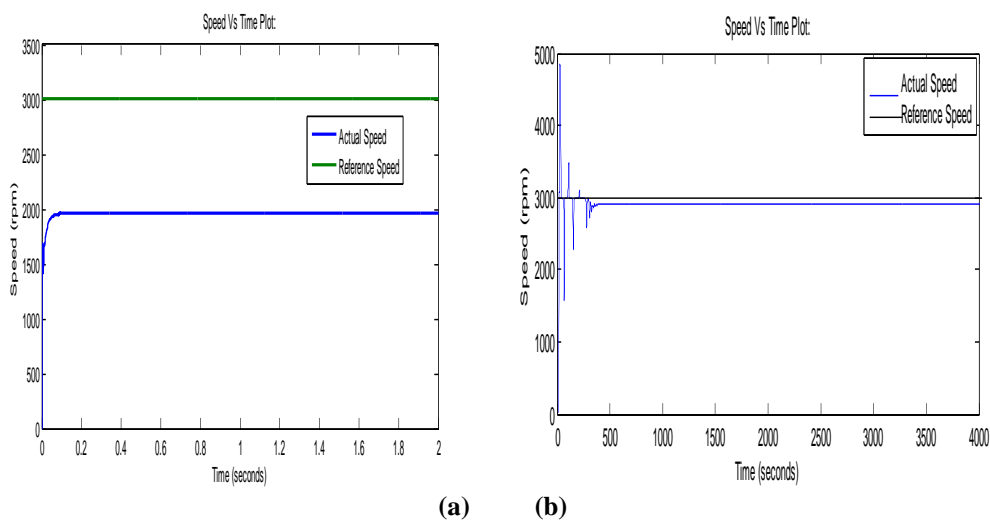

(a)   (b)
Fig 5:(a) Speed response of P controller at 3000 rpm at Kp= 0.15
(b) Speed response of P controller at 3000rpm at Kp = 5

In a proportional controller the output signal is proportional to the error signal. It amplifies the error signal and increases the loop gain. Fig 5(a) represents the speed response of BLDC motor when P controller withKp = 0.15 is used . From Fig 5 (a) it is clear that the steady state error is large, where the reference speed is 3000 rpm. Also in a P controller the steady state error tends to depend inversely upon the proportional gain, so if the gain is made larger the error goes down. But as the gain increases the system eventually becomes unstable and this unstability can be clearly observed from Fig 5 (b).
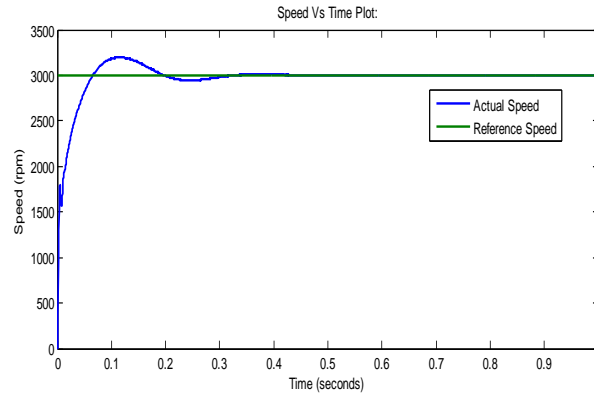
Fig6: Speed responseof PI controller at 3000rpm

Fig 6 represents speed response of the system,when PI controller is used. The PI controller consists of both proportional and integral controllers where the proportional controller will have the effect of reducing rise time but it will never eliminate the steady state error while, the integral controller eliminates the steady stste error but may make the transient response worse. Thus in Fig 6 it can be noticed that the steady state error is eliminated. But it causes an overshoot which may create problems in the system[9].
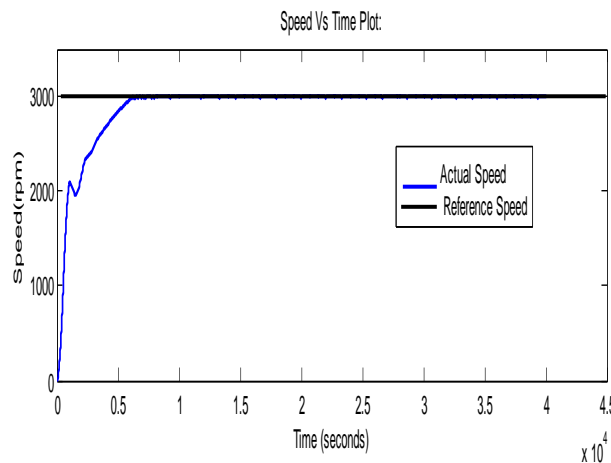
Fig 7:speed response at 3000 rpm when proposed controller is used.

The response of the system when the proposed controller is used is given in Fig 7. The proposed controller consists of a fuzzy PI and fuzzy PD block as discussed above. The speed responses are given in Fig 7 where 3000rpm is taken as the reference speed. From the graph above it can be noticed that the proposed controller eliminates all the problems that a simple PI controller had. With the newly developed proposed controller, the drive system will have superior rise time and settling time characteristics.
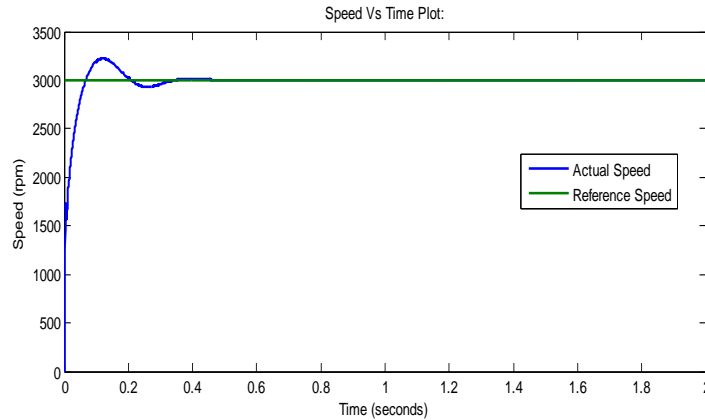
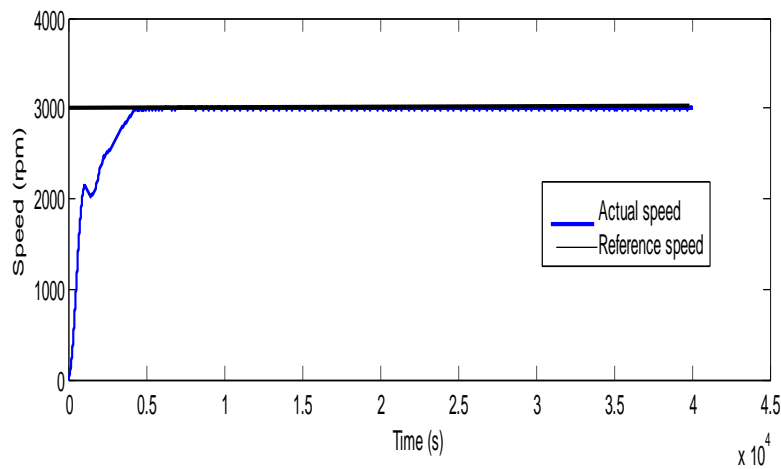**Fig 8:** Speed response of PI controller when T=2Nm

Fig 9: Speed response of proposed controller when T= 2Nm

It is to be noticed from Fig (8) that speed response of proposed controller changes when the load changes due to change in the system parameters thus we have to fine tune the propotional gain constant and integral time constant with respect to the load change, which is a tedious task. But from Fig (7) and (9) we can notice that the response of the proposed controller response does not change even if there is a change in load i.e., it is self tuned, which makes the task easier.

V. Conclusion

A fuzzy logic controller (FLC) has been employed for the speed control of PMBLDC motor drive and analysis of results of the performance of a fuzzy controller is presented. The modelling and simulation of the complete drive system is described in this thesis. Effectiveness of the model is established by performance prediction over a wide range of operating conditions. A performance comparison between the fuzzy logic controller and the conventional PI and P controller has been carried out by simulation runs confirming the validity and superiority of the fuzzy logic controller for implementing the fuzzy logic controller to be adjusted such that manual tuning time of the classical controller is significantly reduced. Fuzzy logic speed controller improved the performance of PMBLDC drive of the fuzzy logic speed controller.

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