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Comparison of speed control of brushless DC motor using fuzzy logic controller system and closed loop system

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Abstract

This paper presents a design and implementation of speed control scheme of brushless direct current (BLDC) motor drive using Fuzzy Logic controller and performance of motor is compared with closed loop control. The brushless dc motors possess properties like, efficiency, reliability, high speed, less noise, smaller size and low maintenance. They are widely used in applications such as defence industries, robotics, tractions, computers etc. This motor cannot be controlled efficiently using conventional (PID) controller due to its nonlinear characteristics. To overcome this, we have developed Fuzzy Logic controller with a Triangular membership function. The mathematical model ofa three phase star connected BLDC motor is derived. The input to the fuzzy logic controller is Error (E) & Change in Error (first derivative of error) with respect to time. In this thesis, transient and steady state performances of BLDCM are evaluated using the controller. The effectiveness of the Fuzzy controller is verified by developing simulation model in Matlab/ Simulink software. The simulation results show that the proposed Fuzzy Logic controller (FLC) produce significant improvement in speed control performance and load disturbance variations compared to closed loop. Fuzzy logic introduced here suppresses the chattering and enhances the robustness of the control.

Keywords

BLDC, PID, BLDCM, FLC.

1.Introduction

The two types of DC motor used in the industry is the conventional dc motor and the brushless dc motor. In the first one flux is produced by the current through the field coil of stationary pole structure. Brushes are used for commutation, which requires maintenance as they wear out due to continuous rubbing on commentator segments [1]. In the brushless type the permanent magnet provides the necessary air gap flux instead of the wire wound field poles. They are electronically commutated and do not require brushes. Electronic commutation increases cost but is maintenance free as nothing to wear out. Due to high efficiency, very low noise during operation, easier cooling, small in size, reliable and low in maintenance, it can operate in hazardous condition. Brushless dc (BLDC) motors are preferred as they are available in many different power rating. The only drawback of Brushless motors are its cost since they require a controller to keep the motor running. But with continuing technology development in power semiconductors, microprocessors, adjustable speed drivers control schemes and permanent-magnet brushless electric motor production have been combined to enable reliable, cost-effective solution for a broad range of adjustable speed applications. We need high resolution position sensors to know the exact position of the rotor. Commutator and brushes are replaced by inverter and a position sensor.

BLDC motor shows non-linear characteristics as inertia and friction changes due to their decoupling inertia elements. Due to temperature changes the phase resistance of BLDC motor changes and it is easily affected by parameter variations and load disturbance during operating condition [2-4]. Traditional control methods use mathematical models which use differential equations to describe a system .At times the mathematical model may not be available or may be too expensive for processing on computers. These are some of the reasons which make conventional controllers unsuitable. However the proposed controller shows dynamic performance and there is no variation and load disturbance in the motor drive system.

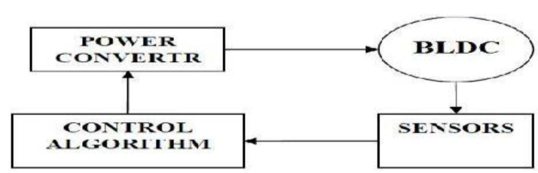

Figure 1 Block diagram of proposed model

The motor drive consists of a controller, three phase inverter, hall sensor and gate signals. The position of the motor is sensed using Hall sensors. Accordingly Hall sensors generate High and Low level signals which are fed to the decoder circuit which produces the gating signals. Motor speed is compared with the reference value and the speed error so obtained is processed in FLC speed controller, reference signal is produced by the controller [5]. Out of three phases of BLDC motor only two phases conduct at a time. Which two will conduct is determined by the switching sequence of the inverter switches. Based on the rotor position, command signals like torque command,speed command , voltage command and so on may be generated. The control algorithm determines the gate signal to each semiconductor in power electronic converter.The BLDC motor has a trapezoidal back EMF which is shown in Figure *2* and the rectangular stator currents are needed to produce a constant electric torque. Trapezoidal back EMF motors are simple, less expensive and higher in efficiency(reduce losses for the same power level) results in reduction in inverter size.

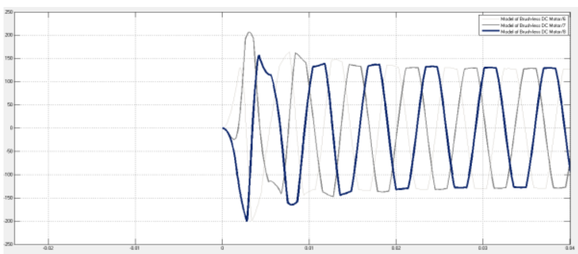

Figure 2 Back emf waveform as obtained from BLDC motor

2.Dynamic modeling of BLDC motor

3 phase BLDC motor is usedwhere armature windings are connected in star fashion.It consist of two parts. The electrical part calculates electromagnetic torque and current of the motor. The mechanical part, generates revolution of the motor.

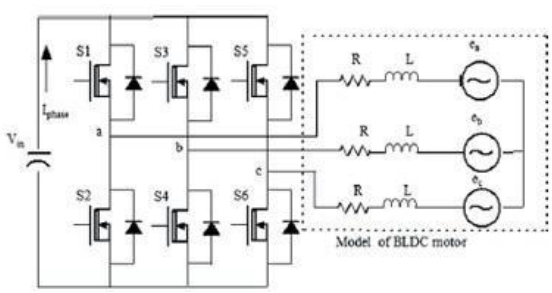

Figure 3 Mathematical model of BLDC motor

Using KVL the voltage equation from Fig. 3 can be expressed as follows:

$V_a = R*i_a + L*\frac{dia}{dt} + M*\frac{d\,ib}{d\,t} + M*\frac{d\,ic}{d\,t} + e_a$ (1)

$V_b = R*i_b + L*\frac{dib}{dt} + M*\frac{d\,ia}{d\,t} + M*\frac{d\,ic}{d\,t} + e_b$(2)

$V_c = R*i_c + L*\frac{dic}{dt} + M*\frac{d\,ib}{d\,t} + M*\frac{d\,ia}{d\,t} + e_c$(3)

where

L represents per phase armature self-inductance [H],

R represents per phase armature resistance [Ω],

V_a,$V_b$andV_c indicates per phase terminal voltage [V]

i_a ,i_b and i_c represents the motor input current [A]

e_a,$e_b$and e_c indicates the motorback-EMF developed [V] in each phase respectively.

M represents the armature mutual-inductance [H].

In case of three phase BLDC motor, we can represent the back emf as a function of rotor position and it is clear that back-EMF of each phase has 120^0 shift in phase angle. Hence the equation for each phase of back emf can be written as:

$e_a = K_w\, f(\theta_e)\, \omega$ (4)

$e_b = K_w\, f(\theta_e - 2\,\prod/3)\, \omega$ (5)

$e_c = K_w\, f(\theta_e + 2\,\prod/3)\, \omega$ (6)

where,$K_w$denotesper phase back EMF constant [V/rad.s-],

θ e represents electrical rotor angle [rad],

ω represents rotor speed [rad.s-1].

The expression for electrical rotor angle can be represented by multiplying the mechanical rotor angle with the number of pole pair’s P:

$\theta_e = \frac{P}{2} * \theta_m$ (7)

Mathematical model of BLDC motor can be represented by the following equations:

$$\begin{matrix} L & M & M \\ M & L & M \\ M & M & L \end{matrix} \frac{d}{dt} \begin{matrix} ia \\ ib \\ ic \end{matrix} = \begin{matrix} Va \\ Vb \\ Vc \end{matrix} - \begin{matrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{matrix} \begin{matrix} ia \\ ib \\ ic \end{matrix} - \begin{matrix} ea \\ eb \\ ec \end{matrix}$$

The summation of torque produced in each phase gives the total torque produced, and that is given by:

$Te = \frac{(ea*ia+eb*ib+ec*ic)}{\omega}$ (8)

Where, Te denotes total electromagnetic torque output [Nm].

Mechanical part of BLDC motor is represented as follows:

$T_e - T_l = J * \frac{d\omega}{dt} + B*\omega$ (9)

Where,

T_l denotes load torque [Nm],

J denotes of rotor and coupled shaft [kgm2], and

B represents the Friction constant [Nms.rad-1]

Transfer function of BLDC motor can be written as

$G(s) = \frac{1/Ke}{TmTe\, s2 + Tm\, s+1}$

Where T_m is the mechanical time constant and T_e is the electrical time constant.

3.Design of fuzzy logic controller

Fuzzy logic control accounts on human brain inference rather than a mathematical model .There are certain components in a fuzzy controller to support a design procedure [6-9]. Figure 4 shows a controller between the preprocessing block and post processing block. As we need to control the speed of BLDC motor, The two inputs for the controller are Error and Change in Error [first derivative of error] and Control Signal is the output variable .Error refers to difference between actual speed of motor and reference speed, while Change in Error refers to the difference between previous error and current error with respect to time and control signal output tells us what should be the speed of motor. Controller consists of three basic portions: the fuzzification unit at the input terminal, the inference engine built on fuzzy control rule base in the core and the defuzzification at the output terminal.

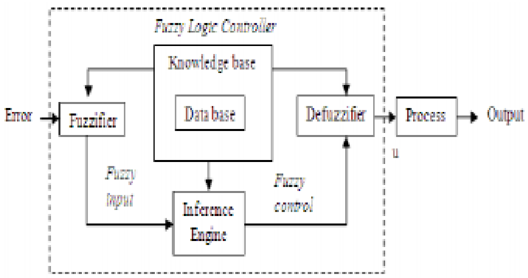

Figure 4 Structure of a fuzzy controller

4.Fuzzification

The transformation of numerical variable into a linguistic variable is called fuzzification.i.e. value of a variables are words rather than numbers.

The fuzzification converts the physical values of the speed i.e. , the error signal (input to controller) , into a normalized fuzzy subset consisting of a subset (interval) for the range of the input values which are related with a membership function which is a graphical representation of the magnitude of participation of each input. The purpose is to make the input physical signal compatible with the fuzzy control rule base in the core of the controller. There are different membership function associated with each input and output response. Quality of control improves with the increase in number of membership functions, but at the same time computational time and required memory increases. Triangular membership function is chosen here, though shape is less important than the number of curves and their placement .The fuzzy variables Error, Change in Error(first derivative of error) and Control signal are quantized using the linguistic terms NB,NM,NS,ZO,PS,PM,PB (negative big ,negative medium, negative small ,zero ,positive small, positive medium ,positive big respectively).

The range of speed of motor is 0-2500 rpm. The possible range of Error is -2500 to +2500 rpm. The possible range of Change of Error is $-2.5 * 10^{6}$ to $+2.5 * 10^{6}$. The possible range of control signal is 0-2500 rpm.

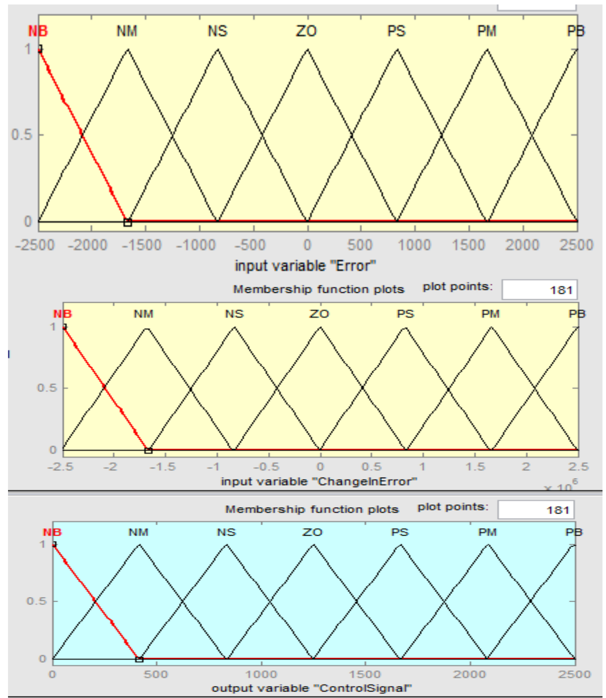

Figure 5 The membership function used for inputs and output variables

5.Fuzzy rule base

Fuzzy rules are given in the rule base, which consist of If-Then rules. These rules may be provided by knowledge of the system, experts or can be extracted from numerical data. By adjustment of rules and membership function performance of controller can be improved. We have defined 49 rules as shown in Table 1. Which we read as:-If Error is NB and Change in Error is NB then Control signal is NB.

Table 1 Rule base for fuzzy controller

E/C E	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZO
NM	NB	NB	NB	NM	NS	ZO	PS
NS	NB	NB	NM	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NM	NS	ZO	PS	PM	PB	PB
PM	NS	ZO	PS	PM	PB	PB	PB
PB	ZO	PS	PM	PB	PB	PB	PB

6.Defuzzification

Defuzzification is a process of converting a fuzzy output to a crisp value. This crisp value is needed for control action. We have chosen centroid method for defuzzification as it requires less computation times.

The FLC gives out a crisp value (i.e. speed of motor)which is fed to the inverter.

7.Simulation and result

The simulation model of BLDC motor developed based on the mathematical equations is shown in Fig. It consists of an inverter block, hall signal generation block, main BLDC model block and controller block. The main BLDC block, further consists of a current generator block, speed generator block and EMF generator block.

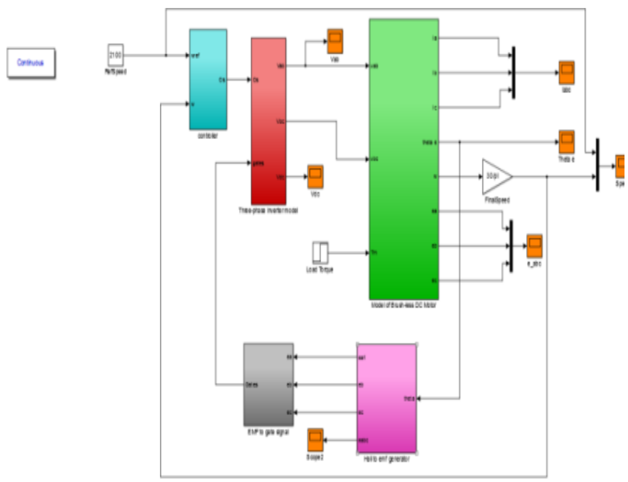

Figure 6 Simulink model of inverter fed BLDC motor

Speedresponseof BLDC motor with closed loop at no load with closed loop without any controller motor the maximum speed reaches to2800 rpm. On application of step load of 1.5 at 0.2 second, the speed of motor reaches1690rpm ,and after 0.3 second the speed of motor stabilizes at 1550-1590 rpm.

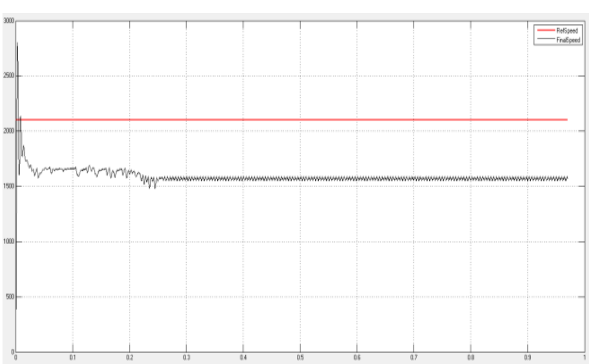

Figure 7 Shows the speed of motor with closed loop control

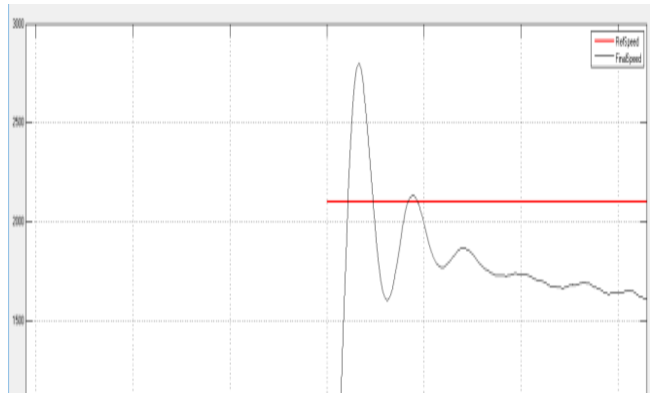

Figure 8 Transient response of motor with closed loop control

Speedresponseof BLDC motor with FLC On application of fuzzy controller the maximum speed reaches to 3522 rpm. On application of step load of 1.5 at 0.2 second, the speed of motor reaches 2277 rpm and within 20 milliseconds, speed of motor stabilizes at 2070-2110 rpm.

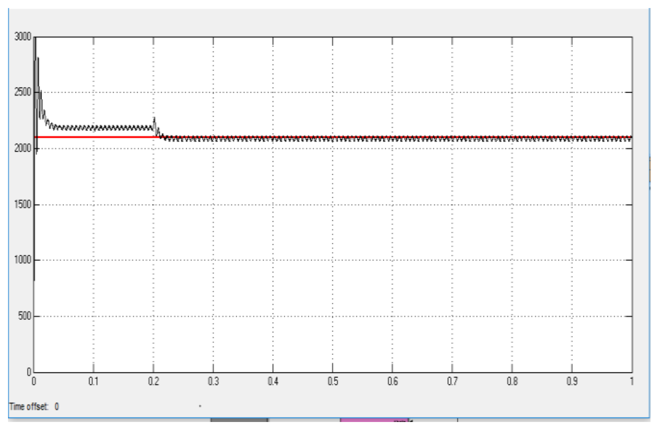

Figure 9 Speed response of BLDC motor using FLC

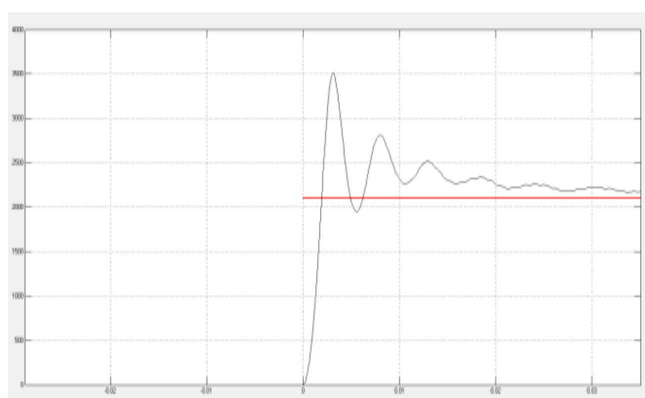

Figure 10 Transient response of motor using FLC

For evaluation of performance of BLDC motor , a number of measurements are taken. We consider the following characteristics Rise Time(t_r),Settling Time(t_s),Overshoot (Mp),Steady state error(ess) and stability.

Table 2 Fuzzy controller

Parameter	**Closed loop control**	**Fuzzy controller**
Rise time(t_r)	1.1m.sec.	1.2m. sec.
Settling Time(t_s),	0.5 sec	0.22 sec
Overshoot (Mp),	33%	67%
Steady state error(ess)	25.2%	0.48%
Stability	poor	Good

8.Conclusion

Performance of three phase BLDC motor with closed loop and fuzzy logic controller are analysed and compared on the basis of various control system parameters such as steady state error , rise time ,peak overshoot, settling time . It is found that the control concept with FLC outperforms closed loop in most of the aspects. Simulation results show that fuzzy logic controller shows better dynamic response than the closed loop.

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