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MODELING AND SIMULATION OF CONTROL ACTUATION SYSTEM

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ABSTRACT

In this paper a dynamic simulation model is implemented using Fuzzy logic controlled Brushless direct current motor drives for fin control actuation. The Brushless direct current (BLDC) motor is modeled using MATLAB-SIMULINK models and controlled by fuzzy logic controller. In addition to this, current hysterias controller block, inverter block and speed estimated block, entire blocks are modeled in SIMULINK environment and resulted are compared with conventional methods. In order to validate the models, the models are loaded with different loads conditions and a simulation output during loaded conditions has satisfactory results.

Keywords: BLDC, fuzzy control, Control Actuation, MATLAB, Controller, inverters.

1. INTRODUCTION

Brushless DC (BLDC) motor is increasing its applications day-by-day in areas of Industrial Automotive, aerospace, defence and Appliance. BLDC motor is a type of DC motor which has electronic commutation replacing brushes. The BLDC has better dynamic response, torque-speed characteristics; higher speed ranges compared to conventional DC motors.

The Control Schemes are developed to drive the BLDC motor according to desired applications. The Proportional Integral Derivative controller is conventional technique scheme to control BLDC for better dynamic performance and smooth operation.

The Control and tuning of BLDC motor for specified application with particular rise time is a challenging work which is carried out this paper. The main advantage of BLDC motor is built in microprocessor allows for programmability, better control over airflow and serial communication.

The Speed of BLDC motor can be controlled using PID, Fuzzy and ANFIS controller in SIMULINK environment. In BLDC motor has permanent which rotate and a fixed armature, eliminating problems in conventional dc motor.

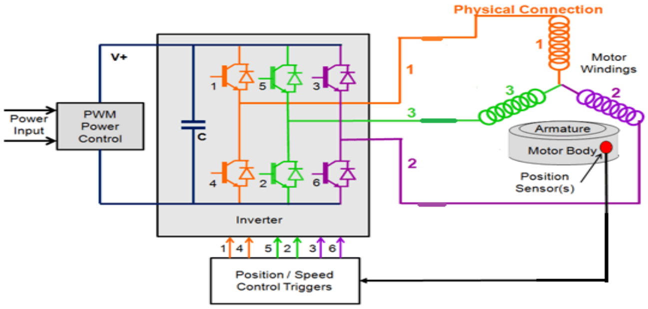

Figure-1. Configuration of BLDC motor drive system.

The BLDC motor Configuration is shown in Figure-1 consists of three MOSFET driver circuit tuned by PWM controller. The three phases in BLDC motor produce trapezoidal back EMF with 120 degree phase difference. For the last three decades, many researches are shown enormous interest in control techniques of BLDC motor. A closed loop position control of BLDC Motor by Fuzzy controller is simulated with above BLDC model. According to velocity error, controller generates reference current which is sent to PWM current Controller for generation of inverter switching signals [1]. The main objective of this paper is to model fuzzy logic controller to control position and speed of the BLDC motor to attain optimum efficiency.

2. BRUSHLESS DC (BLDC) MOTOR CONTROL

BLDC motor commutation performs as motor change its phase current by driver circuit to produce a traditional torque which is performed mechanically in brushed DC motor. The equivalent circuit of BLDC motor with corresponding back EMF is shown in figure. The Hall sensor placed in rotor generates position information of the rotor for generation of back EMF through which gates of MOSFET driver is controlled [2].

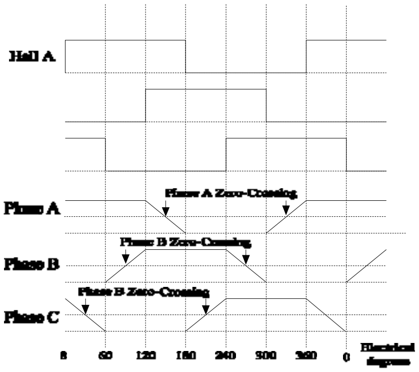

Figure-2. Waveform of Hall sensors versus Back-EMF voltages.

Table-I. Six step switching sequence for commutation.

Rotor position (q)(deg)	Hall sensors			Switch closed		Phase Current		
	H1H2H3					A	B	C
0-60	1	0	0	Q1	Q4	+	-	off
60-120	1	1	0	Q1	Q6	+	off	-
120-180	0	1	0	Q3	Q6	Off	+	-
180-240	0	1	1	Q3	Q2	-	+	off
240-300	0	0	1	Q5	Q2	-	off	+
300-360	1	0	1	Q5	Q4	Off	-	+

BLDC Motor Driver part is MOSFET based device which includes all the switching circuitry needed to drive a BLDC motor. In this configuration, three hall sensors are placed at 120 electrical degrees apart around the motor shaft, detects the rotor position in three phase motor [4]. The general equation of BLDC motor is given as

$$Va = RaIa + Ladia\backslash dt + Macdib\backslash dt + Mbcdic\backslash dt + ea \tag{1}$$

$$Vb = RbIb + Lbdib\backslash dt + Macdia\backslash dt + Mbcdic\backslash dt + eb \tag{2}$$

$$Vb = RcIc + Lcdic\backslash dt + Macdib\backslash dt + Mbcdia\backslash dt + ec \tag{3}$$

R: Stator resistance per phase, assumed to be equal for all phases

L: Stator inductance per phase, assumed to be equal for all phases.

M: Mutual inductance between the phases.

i_a, i_b, i_c: Stator current/phase.

Va, Vb, Vc: are the respective phase voltage of the winding and the instant aneous back EMF in BLDC were written as:

$$e_a=f_a(\theta)Ke\omega \tag{4}$$

$$e_b=f_b(\theta Ke\omega \tag{5}$$

$$e_c=f_c(\theta)Ke\omega \tag{6}$$

Where ea, eb, ecare back-emf generating function and back EMF constant Ke is derived from motor parameters.

In Figure-3. Shows back EMF generation which sense the on time and Off time by dividing power voltage theory. The Zero crossing points of back-EMF signal have 30 electrical degrees offset to required command positions.

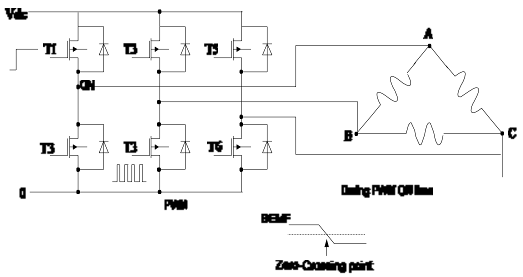

Figure-3. Back-EMF generation and sensing voltage.

There are eight possible combinations for three hall sensors inputs out of which six combinations are valid with 120 electrical degree sensor phasing. For any Hall sensor input combination logic there is one output configuration used to drive the motor. Rate of variation for three phase switching signals depends on the average output voltage of PWM signal. Higher magnitude of PWM signal allows higher current to flow through the motor which increases the speed of motor[5]. The mathematical equation based model for BLDC motor is derived as shown in Figure-4.

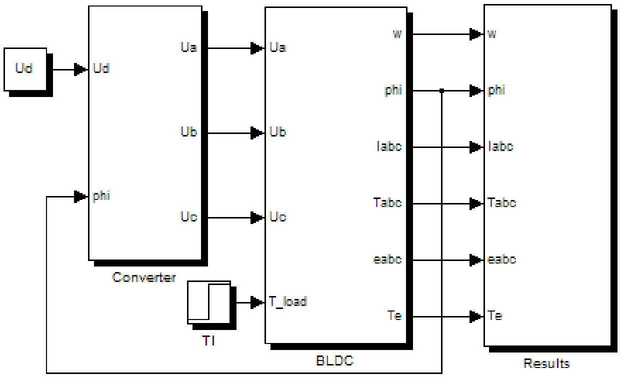

Figure-4. Mathematical model of BLDC motor.

3. PROPOSED FUZZY LOGIC CONTROLLER

Fuzzy PID controller used in this paper is based on two inputs and one output. The overall structure of used controller is shown in Fig. 1. In Fuzzy PID controller only one output which are connected to Kp, Ki and Kd. Real interval of variables is obtained by using scaling factors which are Se, Sde and Su [6].

The fuzzy control rule is in the form of: IF e=E_i and ce=dE_j THAN U_{PD}=U_{PD}(i,j). These rules are written in a rule base look-up table which is shown in Figure-5. The rule base structure is Mamdani type [7].

FLC has two inputs and one output. These are error (e), error change (de) and control signal, respectively. A linguistic variable which implies inputs and output have been classified as: NB, NM, NS, Z, PS, PM, PB. Inputs and output are all normalized in the interval of [-3,3] as shown in Figure-5.

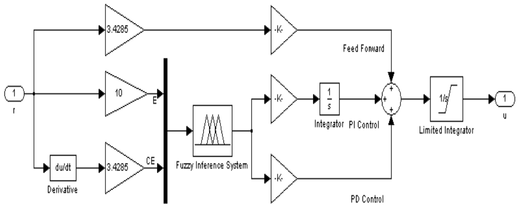

Figure-5. Simulation of Fuzzy PID Controller.

The linguistic labels used to describe the Fuzzy sets were ‘Negative Big’ (NB), ‘Negative Medium’ (NM), ‘Negative Small’ (NS), ‘Zero’ (Z), ‘Positive Small’ (PS), ‘Positive Medium’ (PM), ‘Positive Big’ (PB). It is possible to assign the set of decision rules as shown in Table-II. The fuzzy rules are extracted from fundamental knowledge and human experience about the process [9]. These rules contain the input/the output relationships that define the control strategy. Each control input has seven fuzzy sets so that there are at most 49 fuzzy rules.

Table-2. Fuzzy rule.

E CE	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

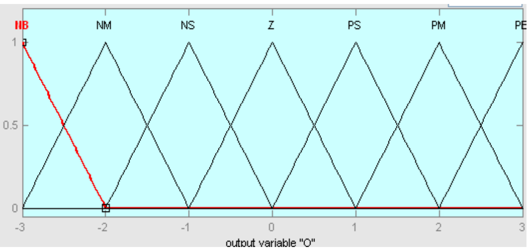

Figure-6. Membership functions of output.

The overall structure of used controller is shown in Figure-6. In Fuzzy PID controller have three outputs which are Kp, Ki and Kd.Error speed (E) and Change in error speed (CE) as fuzzy control input and fuzzy outputs are ΔKp, ΔKi, Δkd.

$$\Delta Kp = Kp.\Delta Kp^1 \quad (6)$$

$$\Delta Ki = Ki.\Delta Kp^1 \quad (7)$$

$$\Delta Kd = Kd.\Delta Kp^1 \quad (8)$$

A linguistic variable which implies inputs and output have been classified as: NB, NM, NS, Z, PS, PM, PB. Inputs normalized in the interval of [-3,3] and output ΔKp interval [-1,1], ΔKp interval[-1,1] and ΔKp interval[-0.005,0.005]. The output membership of ΔKp fuzzy set is shown fig.7.

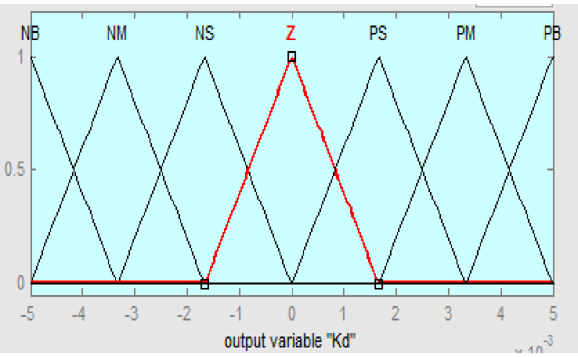

Figure-7. Membership function of Kd output.

Table-3. Fuzzy rule for ΔKP.

E CE	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PM	PM	PS	PS	Z
NM	PB	PB	PM	PS	PS	Z	NS
NS	PB	PM	PM	PS	Z	NS	NS
Z	PM	PM	PS	Z	NS	NM	NM
PS	PS	PS	Z	NS	NS	NM	NM
PM	PS	Z	NS	NM	NM	NM	NB
PB	Z	NS	NS	NM	NM	NB	NB

4. SIMULATION OF CONTROL ACTUATION SYSTEM

The practical results are verified by designing Faulhaber Motor K 3564 series. Inth is model, the trap ezoidal back EMF wave forms are modeled as a function of rotor position. The three phase currents are controlled to take a type of quasisquare wave form in order to synchronize with the trap ezoidal back EMF to produce the constant torque according to the rotor position. Byvarying the current flow through the coils, the speed and torque of the motor can be adjusted. The most common way to control the current flow is to control the average current flow through the coils. Planetary gear is implemented to drive motor shaft to actuation motion system.

Table-4. Parameters of Motor.

Terminal Voltage	28 Volts
Terminal Resistance	1.2 ohms
Inductance	97microfarad
Rotor Speed	11000 rpm
Rotor Inertia	34 Kg/m^2
Stall Torque	0.12 N-m

5. RESULTS AND JUSFICATION

The Control Actuation System builds with inner loop current control and outer loop speed/position control. Current Idc is controlled through fixed PWM of 10 KHz and it's limited up to 6A to -6A peak. Necessary hall signal decoding logic is build in with. Feedback controller for both current and speed/position was developed with conventional PID as well as fuzzy PID controller. Fig.5 shows fuzzy PID controller with anti-wind up feature.

A. Speed control performance

Bellow results show the speed control of motor with inner loop current control for both conventional PID and Fuzzy PID. Figure-8 show the closed loop speed with 10000rpm of set speed (Green Line) both conventional PID starting response (Red Line) and Fuzzy PID starting response (Blue Line) in same single figure. From the figure fuzzy rising is better and quick settle the desired speed.

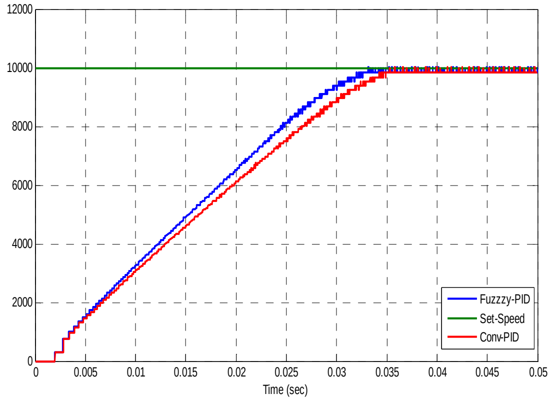

Figure-8. Speed control for 10000rpm.

B. Position control performance

Figure-8 show the position control of motor with inner loop current control for both conventional PID and Fuzzy PID. Unit step change of fine for 1 degree required 2100 pulse counts from motor shaft, so the results taken for desired 2100 pulse counts (Green Line) and their corresponding response of conventional PID (Red Line) Fuzzy PID (Blue Line) are show in same single Figure-9.

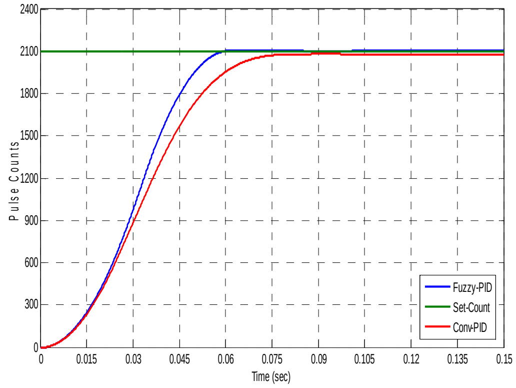

Figure-9. Position control of BLDC motor.

6. CONCLUSIONS

This paper presents the complete Speed Control of BLDC Motor in Matlab/Simulink environment. Here BLDC motor modeled in State-Space is very efficiently controlled by Fuzzy-PID Controller. Besides, Fuzzy-PID reasoning algorithm designed to control BLDC to getthe optimum performance under the unstable rotor turning situation or sudden load change, the proposed Fuzzy-PID controller has good adaptability and strong robustness when ever the system is disturbed. It can be said that Matlab/Simulink is a good tool for modeling and simulation of position control of logic controlled Brushless DC motor. The presented model can be made equivalent to actual system model by in corporating more details of motor and Drivers parameters. By adopting new Fuzzy controller for rise time of BLDC Motor can be improved.

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