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Fuzzy Controller for Speed Control of BLDC motor using MATLAB

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Abstract – *Brushless DC Motors are used in various applications like robotic application and space application due to small volume , highe torque and low maintenance.PWM base 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. The modeling, simulation and control of BLDC Motor have been done in MATLAB\SIMULINK software.*

1. INTRODUCTION

A BLDC Motor is a permanent synchronous motor that uses position detectors and an inverter to control the armature currents. Its armature is in the stator and the magnets are on the rotor and its operating characteristic resembles those of a DC motor. Instead of using a mechanical commutator as in the conventional DC Motor, the BLDC motor employs electronic commutation which makes it a virtually maintenance free. The BLDC motor isdriven by DC voltage but current commutation is done by solid-state switches. The commutation instants are determined by the rotor position and the position of the rotor is determined either by position sensors like Hallsensor, position encoder and resolver etc. or by sensorless techniques. There are two main types of BLDC Motors:Trapezoidal type and Sinusoidal type. The trapezoidal motor is a more attractive alternative for most applications due to its simplicity, lower price and higher efficiency. Here State-Space based trapezoidal motor has been taken for modeling and simulation in MATLAB\SIMULINK. Overall block diagram is shown.

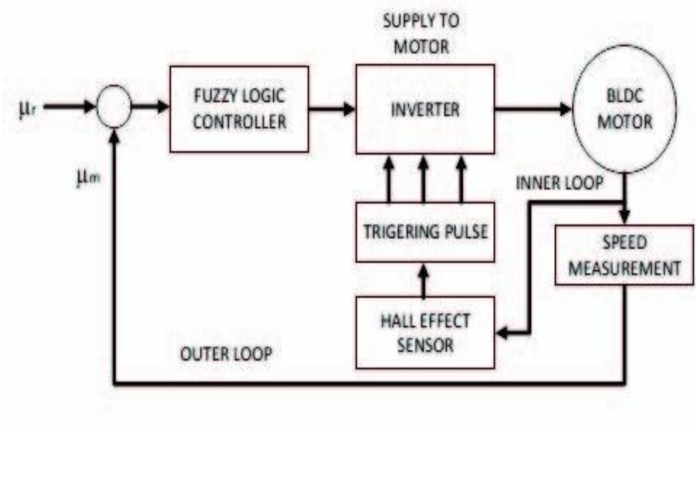

Fig -1: Block Diagram of speed control of BLDC motor

1.1. MODELLING AND SIMULATION

In this paper, a three phase connected trapezoidal back-EMF type BLDC motor is modelled. Trapezoidal back-EMF is referring that mutual inductance between stator and rotor has trapezoidal shape. The mathematical model of BLDC Motor is comprising into two parts: Electrical and Mechanical equations.

Electrical Equations

$$Va = R * ia + L * \frac{di_a}{dt} + ea \quad (1)$$

$$Vb = R * ib + L * \frac{di_b}{dt} + eb \quad (2)$$

$$Vc = R * ic + L * \frac{di_b}{dt} + ec \quad (3)$$

where, Va, Vb,Vc is the terminal voltage, R is the stator resistance, L is the stator inductance, ia, ib, ic is the stator phase current and ea, eb, ec is the induced back emf in each phase. In order to obtain the space model (1) and (2) are combined together with the fact that the sum of all phase currents will be zero, ia + ib + ic =0, which gives

$$i_a = \frac{1}{3LS}[2V_{ab} + V_{bc} - 2e_a + e_b + e_c - 3 * R\, i_a\ ] \quad (4)$$

$$i_b = \frac{1}{3LS}[2V_{ab} + V_{bc} + e_a - 2e_b + e_c - 3 * R\, i_b\ ] \quad (5)$$

This state space equation of phase current will be using in SIMULINK model of BLDC motor. The trapezoidal back-EMF in a 3-phase BLDC motor is related to a function of rotor position where each phase is 120°phase shifted and given by

$$ea = Kb * w * f(\theta) \quad (6)$$

$$eb = Kb * w * f(\theta + 2\Pi/3) \quad (7)$$

$$ec = Kb * w * f(\theta - 2\Pi/3) \quad (8)$$

Where Kb is the motor back EMF constant (V/rad/sec), w is the rotor speed, θ is the electrical rotor angle and f is the trapezoidal shape reference function with respect to rotor position.

Mechanical Equations

$$T_e = B * w + J * \frac{dw}{dt} + T_l \quad (9)$$

where, Te is the total electromagnetic torque, B is the frictional coefficient(Nm/rad/sec, J is the moment of inertia (kgm^2), $T_l$is the load at motor.

where, Te = (ea ia + eb ib + ec ic) / w (10)
Therefore, rotor speed is
w = 1/J S [Te – B w – Tl] (11)

Rotor inertia (J)	0.089 (kg.m^2)
Friction coefficient (F)	0.005 (N.m.s)

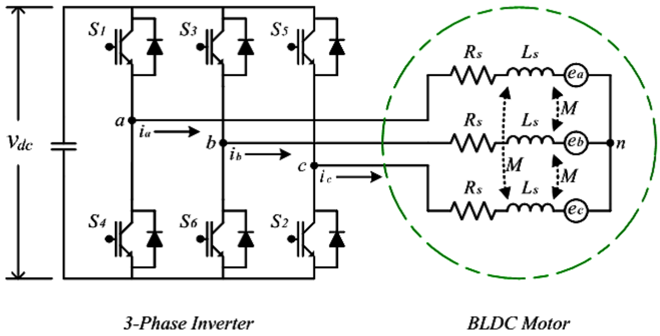

Fig -2: Brushless DC Motor with Inverter

2. MATLAB/SIMULINK MODELS

The Universal Bridge block implements a universal three-phase power inverter that consists of 3arms and six power switches connected in a bridge configuration.The Universal Bridge block allows simulation of inverter using naturally commutated power electronic devices(diodes or thyristors) and forced-commutated devices(GTO, IGBT, MOSFET). From the terminals A and B output signals Vab and Vbc are obtained for further calculations . Speed generator block is the mechanical part of BLDC motor developed this model for generating the actual speed (w) of the BLDC motor by using the mechanical and electrical equations.

Table -1: MOTOR SPECIFICATIONS FOR SIMULATION

No. of phases	3
Type of connection	Star
Pole pairs (p)	4
Back EMF waveform	Trapezoidal
Back EMF flat area	120
Back EMF constant (k)	0.25 (V/rad/sec)
Stator phase resistance	2.875 Ω
Stator phase inductance	8.5e H
Constant voltage (V)	146
Constant torque (N.m / A peak)	1.4
Rated speed (*w*)	1400 rpm

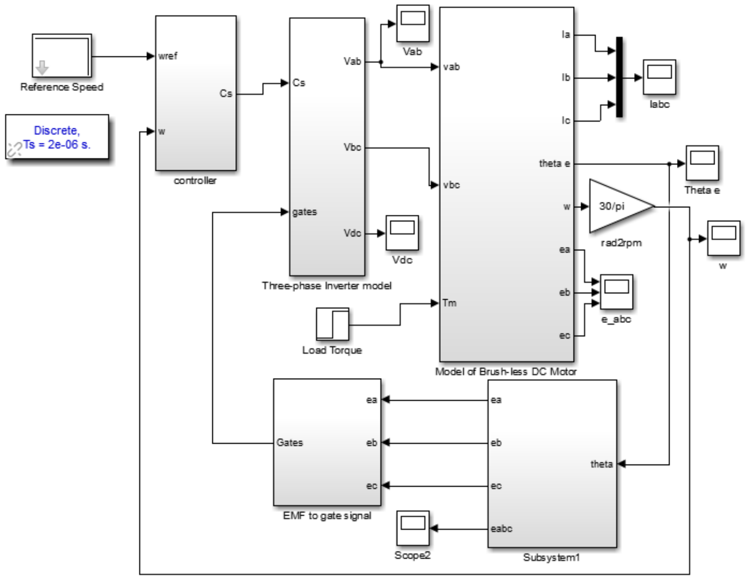

Fig -3: Simulink Model

3. FUZZY INFERENCE SYSTEM

Fuzzy logic has rapidly become one of the most successful of today's technology for developing sophisticated control system. It is a rule based controller. The most important things in fuzzy logic control system designs are the process design of membership functions for input, outputs and the process design of fuzzy if-then rule knowledge base as shown in Figure- 4.

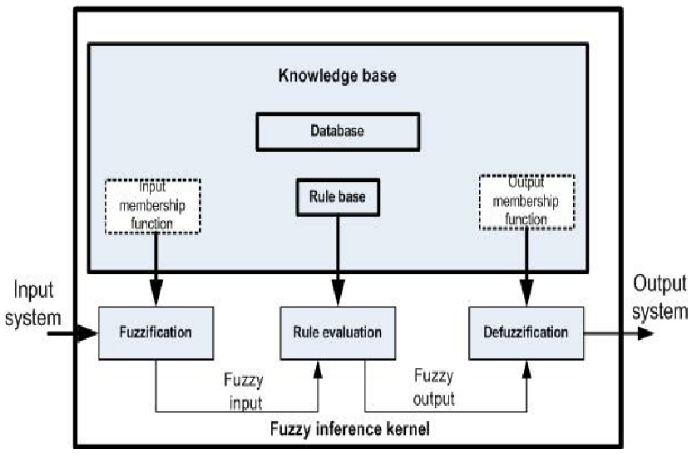

Fig-4: Fuzzy System

Fuzzy Inference system for BLDC motor has one input (rotor position angle- theta) and three outputs (phase A, phase B, phase C). Input have six membership function which ranges from -180 to +180 (representing the angle) and outputs have three membership functions -1, 0, +1 (representing ON and OFF). Fuzzy rules are made according to the Table2.

Table -2: FUZZY RULES TABLE

Rotor Position Angle (theta)	**Phase A**	**Phase B**	**Phase C**
-180 → -120 (mf1)	-1 (mf1)	0 (mf2)	1 (mf3)
-120 → -60 (mf2)	0 (mf2)	-1 (mf1)	1 (mf3)
-60 → 0 (mf3)	1 (mf3)	-1 (mf1)	0 (mf2)
0 → 60 (mf4)	1 (mf3)	0 (mf2)	-1 (mf1)
60 → 120 (mf5)	0 (mf2)	1 (mf3)	-1 (mf1)
120 → 180 (mf6)	-1 (mf1)	1 (mf3)	0 (mf2)

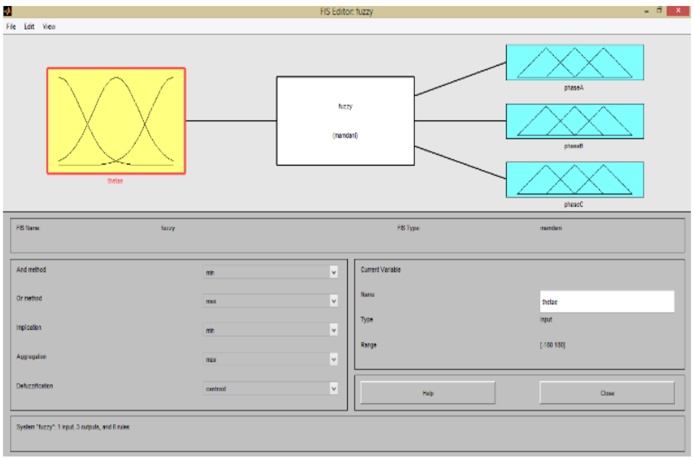

Fig- 5: Fuzzy Inference system for BLDC motor speed controlling.

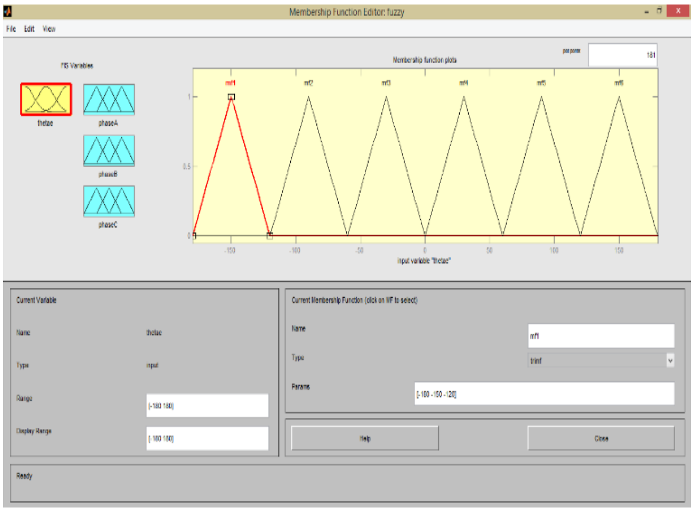

Fig-6: Input membership function (theta).

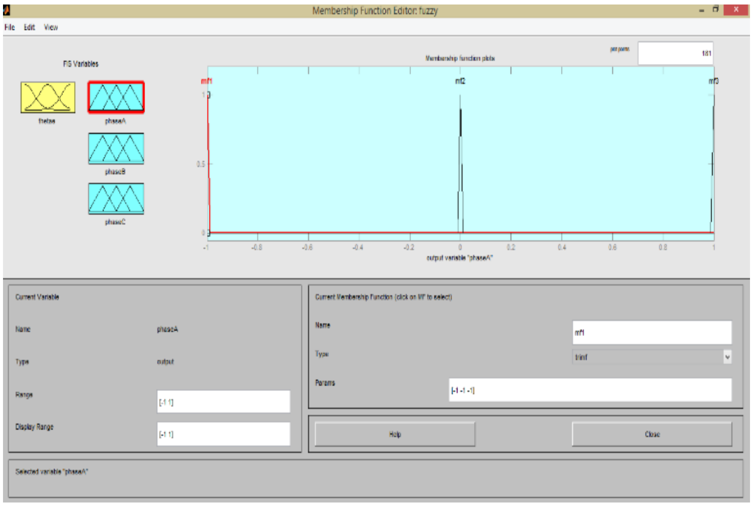

Fig- 7: Output membership function.

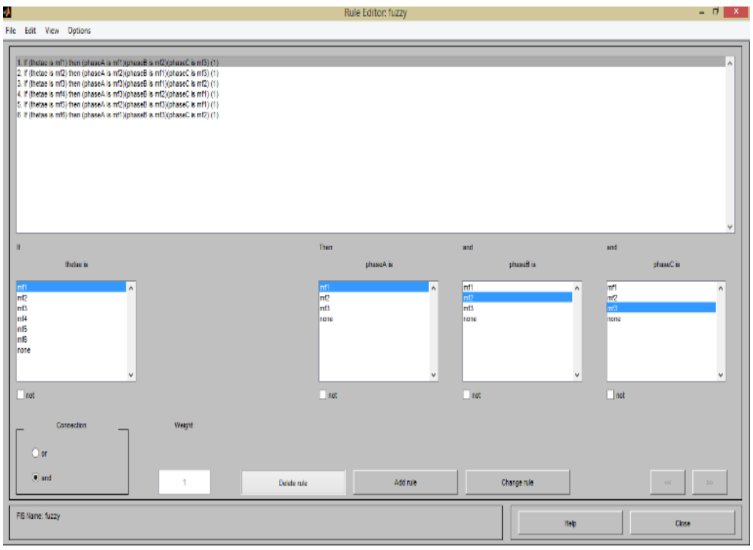

Fig-8: Fuzzy Rule

4. DISCUSSION OF RESULTS

The BLDC motor Simulink model has been simulated and the waveforms are provided below. BLDC motor reference speed was set as 2000 rpm and then reducing to1000 rpm after a time period of 0.4 seconds and applying a load torque of 2Nm after 0.2 seconds from motor start .

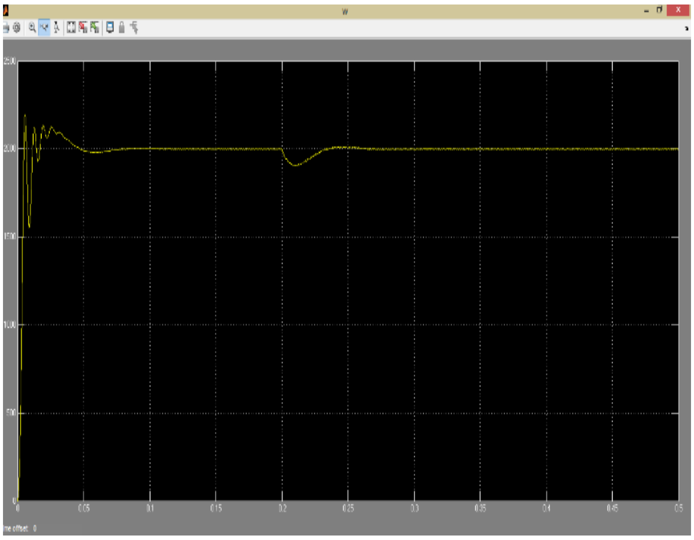

Fig-9 : Motor Speed plot in RPM

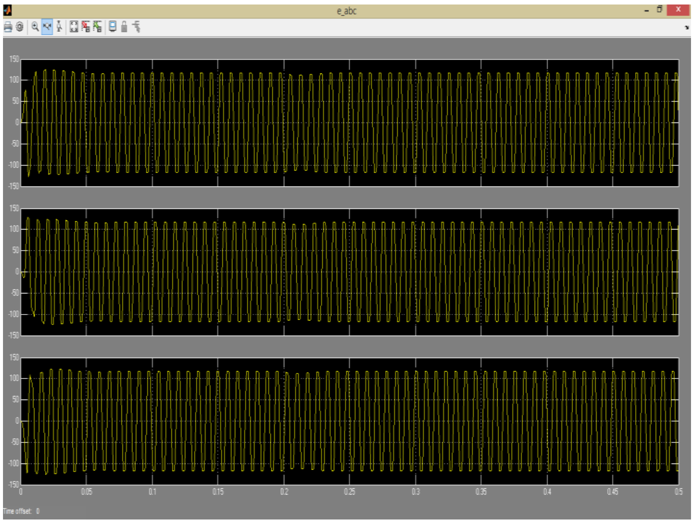

Fig-10 : Back EMF Waveform

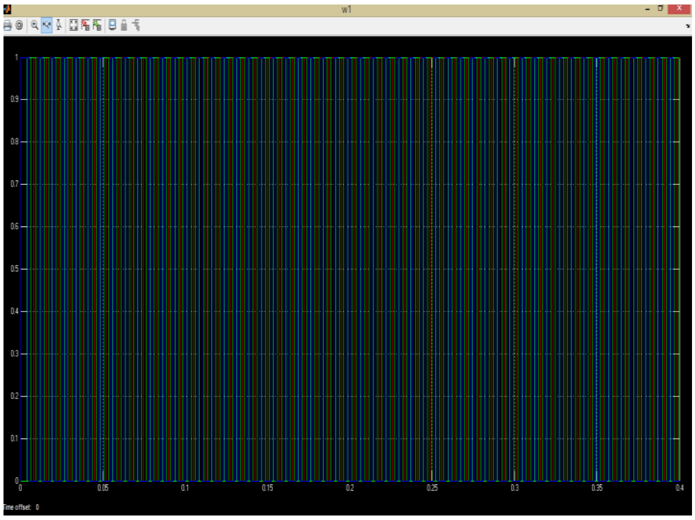

Fig-11 : Gate Signal

5. CONCLUSIONS

The speed control of the BLDC motor is studied and simulated in MATLAB/Simulink.The speed control of a BLDC Motor is presented in this paper, using both PI controller, and Fuzzy Logic Controller.The inference which can be concluded after comparison is that speed control of BLDC using Fuzzy Logic Controller has better performance than PI,PID Controllers. To add current control function to the proposed speed controller in order to keep the current within a certain range for a specific speed, could be a work for future. The proposed future work would thereby enhance the motor start-up current, reduce the motor current ripples and overall enhance the motor torque characteristics performance. Current control methodology will also reduce the speed and torque variations caused due to any sudden changes in the motor current value .

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BIOGRAPHIES

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