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Design of Brushless DC Motor with Fuzzy Logic Controller

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Abstract **- Actually brushless DC motor is the alternate motor for traditional motors and also comparatively brushless DC motor has improved performance in speed, torque, efficiency and electromagnetic torque. In this paper the three phase brushless DC motor model is designed with fuzzy logic controller and tested in MATLAB software. The Fuzzy logic controller is used to control the speed of the brushless DC motor. On the other hand parameters like Back EMF, current, speed and torque are evaluated for the designed models of BLDC motor.**
Keywords **- Brushless DC motor, Fuzzy logic controller, PMBLDC.**

I. INTRODUCTION

The replacement for conventional DC motor is BLDC motor in many cases. The characteristic of DC motor is retained by BLDC motor except brushes and commutator. To provide large amount of torque for a wide range of speed BLDC motor suits the most with high performance. Actually for applications that require high power, high reliability and high efficiency BLDC motor is the ideal choice.

A small BLDC motor is used in hard disk drives and large BLDC motor is used in electric vehicles. In BLDC motor physical commutator is not necessary because the electric current powers the permanent magnet that causes rotation in motor. So current commutation takes place because of solid state switches. In this case commutation happens electronically. Most commonly used BLDC motors are three phases rather than two phase BLDC motor.

Due to the rotor rotation voltage is induced in the stator winding called back-EMF of BLDC motor. So torque is primarily influenced by back-EMF of BLDC motor. In case size of the motor and torque delivered ratio is higher so the critical factors are space and weights in certain application to make it useful. When practical speaking the torque ripple exit mainly due to imperfection emf, ripple current and phase current commutation. Due to the magnet size and shape of the BLDC motor the imperfection emf is occurred. On the other side hysteresis and PWM control generates ripple in current. The Bimbra [1] has explained the generalized machine theory.

II. BLOCKING DIAGRAM OF PROPOSED METHOD

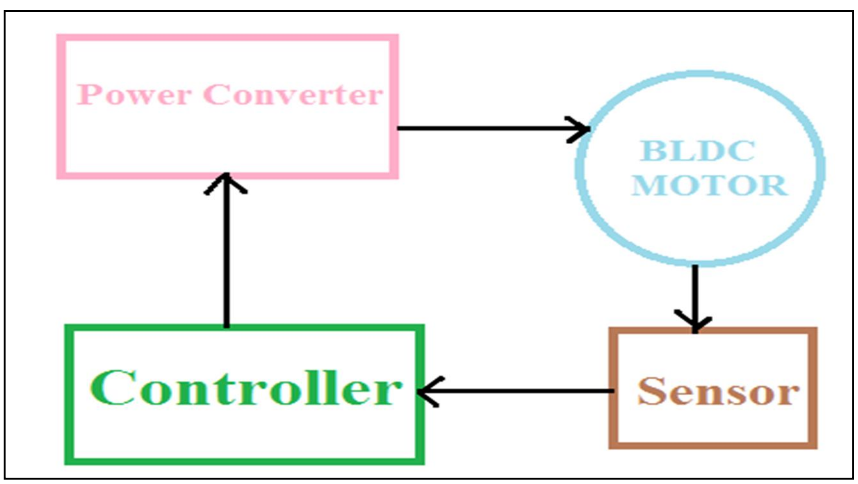

Figure 1: Block diagram of BLDC motor's Speed control

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The block diagram of brushless dc motor with its speed controller is shown in [Figure.1].It consist of four main parts they are BLDC motor, sensors, controller and power converters. The power is transformed from source to BLDC motor through converter. So the BLDC motor in turn converts electrical energy in to mechanical energy. To the power converter gate signal is applied on the basis of rotor position.

III. WORKING PRINCIPLE OF BLDC MOTOR

One after another the BLDC motor's electronic commutator energizes the stator coils and generates a rotating electric field that 'drags' the rotor around with it. N "electrical rotations" equates to one mechanical rotation, where N is the number of magnet pairs. To indicate the relative position of stator and rotor to the controller three phase effect sensors are embedded in the stator of the three phase brushless DC motor. The hall sensor helps brushless DC motor to energize the winding in a correct sequence and at the correct time.Constructionally the all sensor is mounted on the non driving side of the system [Figure.2].

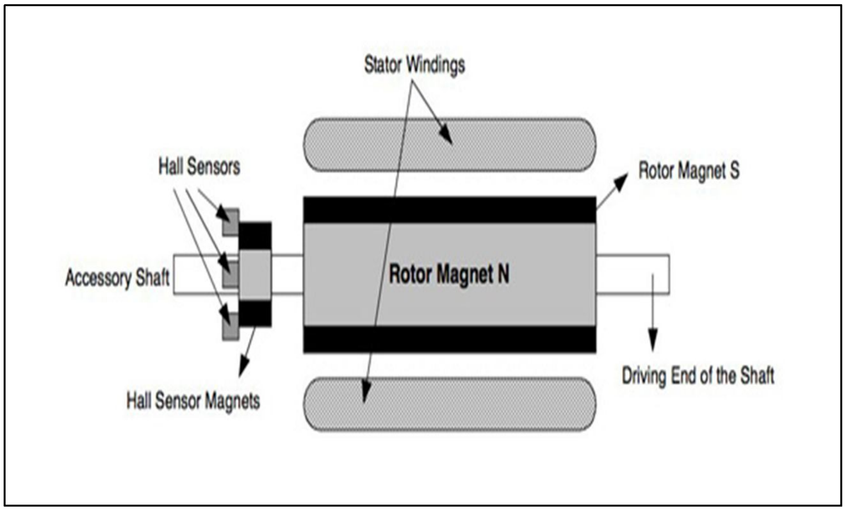


Figure 2: Hall sensors are embedded in the stator of a BLDC motor

The high or low signal is generated during the rotor magnetic poles passes the hall sensors by combining the signals from the three sensors. Due to the movement of the winding through the associated magnetic field the potential voltage is generated by the electrical motors and it can be called as electromotive force. As per Lenz's law the magnetic field which opposes original change in flux will give rise in winding current. In general this means electromotive force tends to resist the rotation of the motor and referred as back electromotive force.

The Baldursson [2] has developed brushless DC motor modelling and control. Padmaraja [3] has developed the fundamentals of brushless DC motor. A new simulation model is developed by Jeon [4].For complete MATLAB modelling Simulink user's guide is helpful [5].

IV. BLOCK DIAGRAM OF FUZZY LOGIC CONTROLLER AND ITS WORKING

In developing sophisticated control system fuzzy logic has become one of the most successful technologies. The variety and number of fuzzy logics are continuously improving in the recent years due to implementation is simple and inexpensive controllers. The Fuzzy logic controller techniques are presented in detail by Elmas, Silva and KO [6], [7], [8]. In 1960's lotfi zadeh has introduced the fuzzy set theory. The fuzzy set theory is an approximately reasoning, approximate information and uncertainty to generate decision. There are two main reasons for selecting fuzzy logic controller. They are as follows;

Modelling can be developed for non-linear system

It has adaptive characteristics

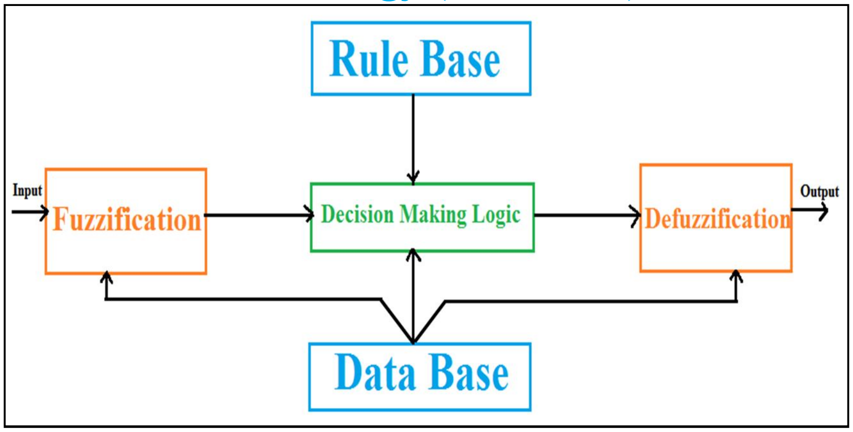


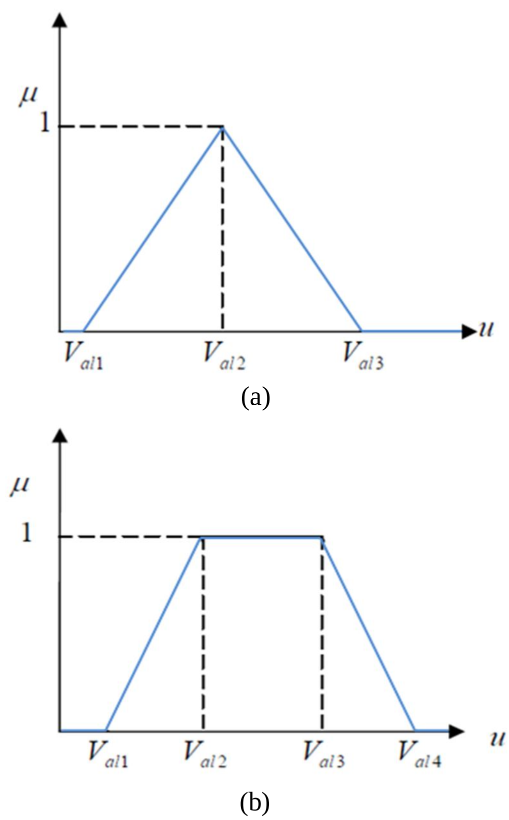
Figure.3. Block diagram of fuzzy logic controller

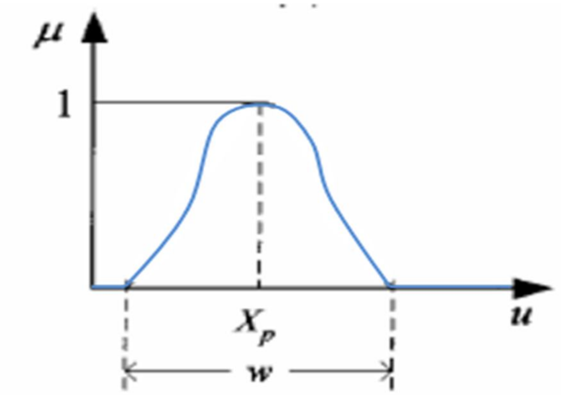
The traditional methods are complex to model accurately for complex mathematical equations and also this type of traditional system becomes infeasible. But fuzzy logic provides a feasible method. Therefore defining the operational characteristics of such system is simple. The fuzzy logic controller configuration is shown in [Figure.3]. The main components of fuzzy logic controllers are as follows:

Fuzzification
Fuzzy inference
Defuzzification

A. Fuzzification

Fuzzification has the process of mapping the multiple measured crisp inputs with fuzzy membership function. Fuzzification is to converts input data in to suitable value .This value can be considered as label of fuzzy sets. Fuzzification performs a scale mapping which transfers the input variables in to corresponding universe of discourse. The [Figure.4] shows the fuzzy membership functions in the form of trapezoidal, triangle and bell membership functions.





(c)

Figure.4 Triangle (a), Trapezoidal (b) and Bell membership function (c)

Triangle membership function is defined as,

$$\mu(u_i)=\begin{pmatrix} \dfrac{u_i-V_{a/1}}{V_{a/2}-V_{a/1}} & , & V_{a/1}\le u_i\le V_{a/1} \\ \dfrac{V_{a/3}-u_i}{V_{a/3}-V_{a/2}} & , & V_{a/2}\le u_i\le V_{a/2} \\ 0 & , & otherwise \end{pmatrix}\rightarrow Eq.\{1\}$$

Limits $[V_{a/1},V_{a/2},V_{a/3}]$

Trapezoidal membership function is defined as,

$$\mu(u_i)=\begin{pmatrix} \dfrac{u_i-V_{a/1}}{V_{a/2}-V_{a/1}} & V_{a/1}\le u_i\le V_{a/2} \\ 1 & V_{a/2}\le u_i\le V_{a/3} \\ \dfrac{V_{a/4}-u_i}{V_{a/4}-V_{a/3}} & V_{a/3}\le u_i\le V_{a/4} \\ 0 & otherwise \end{pmatrix}\rightarrow Eq.\{2\}$$

Limits $[V_{a/1},V_{a/2},V_{a/3},V_{a/4}]$

Bell membership function is defined as,

$$\mu(u_i)=\frac{1}{\left(1+\left(\dfrac{|u_i-X_p|}{w}\right)^{2m}\right)}\rightarrow Eq.\{3\}$$

Xp-Mid Point

W-Width of bell membership function

$M\ge 1$-Convexity of bell membership function

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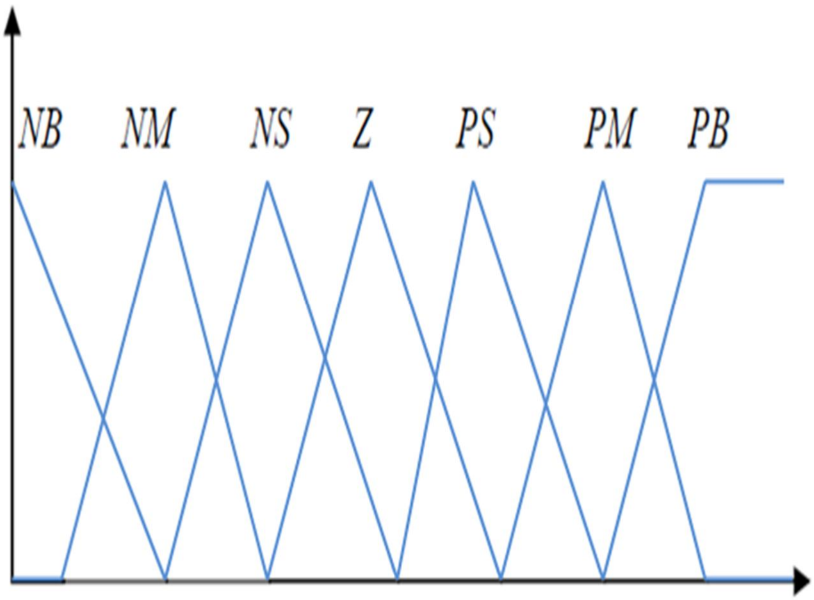

Figure.5 Fuzzy membership functions for seven levels.

B. Fuzzy Inference

Fuzzy inference is nothing but by using fuzzy logic there is a process of mapping the given input to the output and on the basis of this mapping decision are made or pattern discerned.

C. Defuzzification

The output variables are the output of the interference mechanism. The internal fuzzy output variables are converted in to crisp values by the fuzzy logic controller so that system can use these variables. Hence it is called as defuzzification.

V. FLC SPEED CONTROL ALGORITHM

Step 1: The brushless DC motor speed signal is sampled.
Step 2: Calculate speed error.
Step 3: Calculate change in speed error.
Step 4: Determine fuzzy sets and membership for speed error.
Step 5: Determine fuzzy sets and membership for change in speed error.
Step 6: Finding control action as per fuzzy rule.
Step 7: Calculate Δ_{iqs}
Step 8: Sending control command to the system after calculation of Δ_{iqs} .

Input and output variables of fuzzy membership function are selected as follows,
PB-Positive Big
PM-Positive Medium
PS-Positive Small
NB-Negative Big
NM-Negative Medium
NS-Negative Small
Z-Zero
Input variables:
Value of speed error, $-1 \le \omega_e \le +1$

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Value of change in speed error, $-1 \le \omega_{ce} \le +1$

Output variables:

Change in torque reference current, $-1 \le \Delta_{iqs} \le +1$

Because of the best control performance and simplicity the triangular shaped function are chosen as membership functions.

TABLE I

E/CE	NB	NM	NS	ZO	PS	PS	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

Table.1.Rule based table

VI. MATHEMATICAL MODELLING OF THE BLDC MOTOR

$$V_a = i_a R_a + L_a \frac{di_a}{d_t} + M_{ab} \frac{di_b}{d_t} + M_{ac} \frac{di_c}{dt} + e_a \rightarrow Eq.(1)$$

$$V_b = i_b R_b + L_b \frac{di_b}{d_t} + M_{ba} \frac{di_a}{d_t} + M_{bc} \frac{di_c}{dt} + e_b \rightarrow Eq.(2)$$

$$V_c = i_c R_c + L_c \frac{di_c}{d_t} + M_{cb} \frac{di_b}{d_t} + M_{ca} \frac{di_a}{dt} + e_c \rightarrow Eq.(3)$$

Where, R_a, R_b, R_c - Stator resistance of phase a, b and c.

L_a, L_b, L_c - Stator inductance of phase a, b and c.

i_a, i_b, i_c -Stator current of phase a, b and c.

V_a, V_b, V_c -Voltages of phase a, b and c.

$R_a = R_b = R_c = R$ -Mutual inductance between phases

L_a, L_b, L_c -Stator self inductance of phase a, b and c.

In this case, $L_a = L_b = L_c = L$

$M_{ab} = M_{ac} = M_{bc} = M_{ba} = M_{ca} = M_{cb} = M$

Assuming three phase balanced system, all phase resistance are equal.

$R_a = R_b = R_c = R$

Let us rearrange the above equations 1, 2 and 3. We get,

$$V_a = i_a R + L \frac{di_a}{d_t} + M \frac{di_b}{d_t} + M \frac{di_c}{dt} + e_a \rightarrow Eq.(4)$$

$$V_b = i_b R + L \frac{di_b}{d_t} + M \frac{di_a}{d_t} + M \frac{di_c}{dt} + e_b \rightarrow Eq.(5)$$

$$V_c = i_c R + L \frac{di_c}{d_t} + M \frac{di_b}{d_t} + M \frac{di_a}{dt} + e_c \rightarrow Eq.(6)$$

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Let us neglect mutual inductance in equations 4, 5 and 6. We get,

$$V_a = i_a R + L\frac{di_a}{d_t} + e_a \rightarrow Eq.(7)$$

$$V_b = i_b R + L\frac{di_b}{d_t} + e_b \rightarrow Eq.(8)$$

$$V_c = i_c R + L\frac{di_c}{d_t} + e_c \rightarrow Eq.(9)$$

VII. TORQUE GENERATION

Theoretical motor constant ‘K_t’ is the product of torque and supply current ‘I’.

$$T_a + T_b + T_c$$

$$K_{t(motor)} = K_{t(a)} + K_{t(b)} + K_{t(c)}$$

$$i_{motor} = i_a = i_b = i_c$$

θ-Angle

T_a, T_b, T_c-Total torques

$$\frac{d\theta}{dt} = \left(\frac{P}{2}\right) * \omega$$

The generated electromagnetic torque is given by,

$$T_e = \frac{[e_a i_a + e_b i_b + e_c i_c]}{\omega} \text{ in N-M}$$

$$T_e = K_t\{ f_a(\theta)i_a + f_b(\theta)i_b + f_c(\theta)i_c$$

$$J\left(\frac{d\omega}{dt}\right) + B\omega = T_e - T_1$$

The relation between angular velocity and angular position is given by,

$$\frac{d\theta}{dt} = \left(\frac{P}{2}\right) * \omega$$

T_1-load torque

ω -Motor inertia

B-Damping Constant

P-Number of poles

VIII. SIMULATION MODEL OF THE BLDC MOTOR

TABLE II

Voltage (V_{dc})	160 volts
Damping constant (T_{load})	0.02 N-M/rad/sec
Resistance (R)	0.7 ohms
Inductance (L)	2.72 mH
Moment of inertia (J)	0.000284Kg-m/sec^2
Number of poles	4
Number of phases	3

Table.2. Specification of BLDC motor

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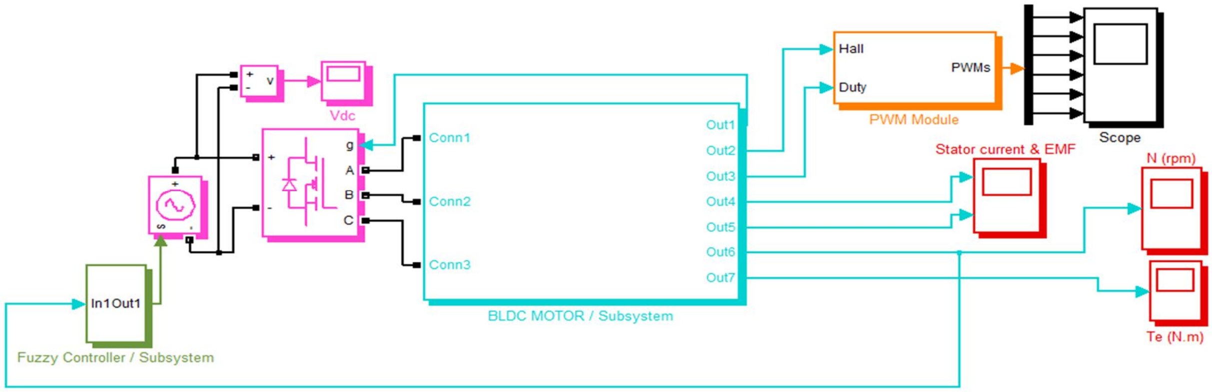

Figure 6: MATLAB Simulink model of BLDC motor

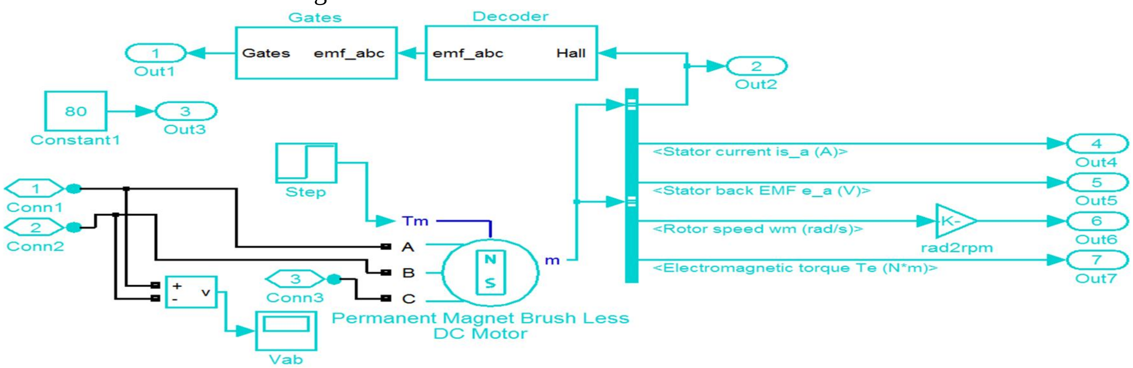

Figure 7: MATLAB Simulink Sub system model of BLDC motor

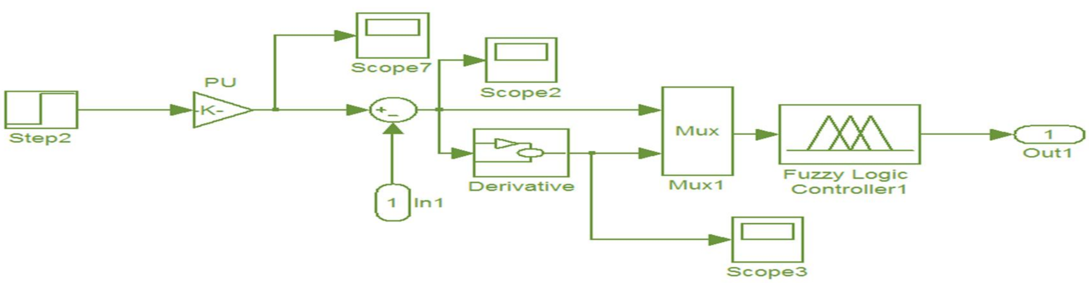

Figure 8: MATLAB Simulink Sub system model of Fuzzy controller.

IX. SIMULATION RESULTS

A. Current

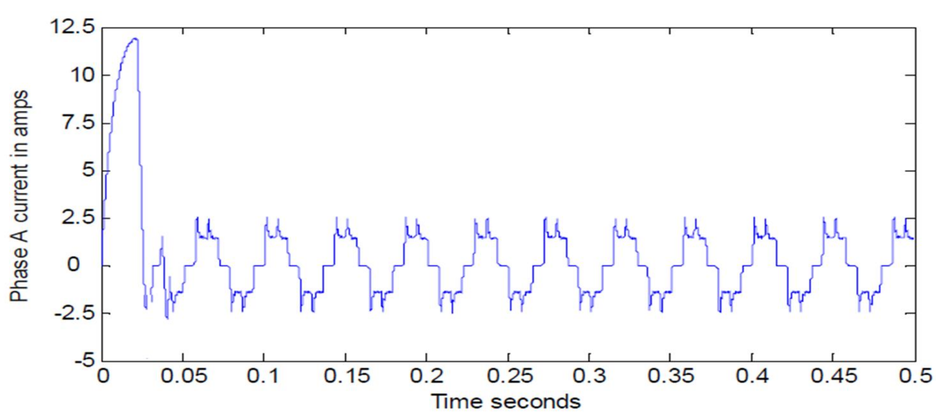

Figure 9: Current Phase A in amperes

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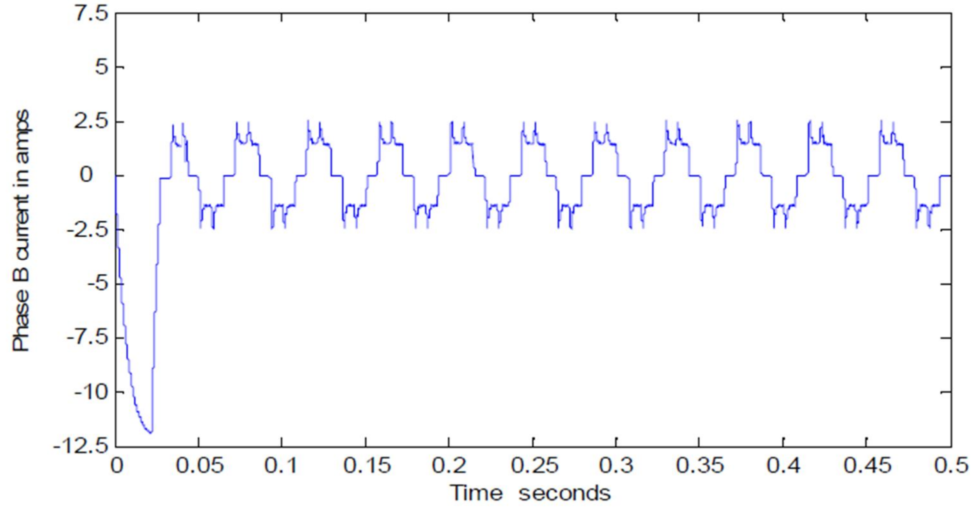

Figure 10: Current Phase B in amperes

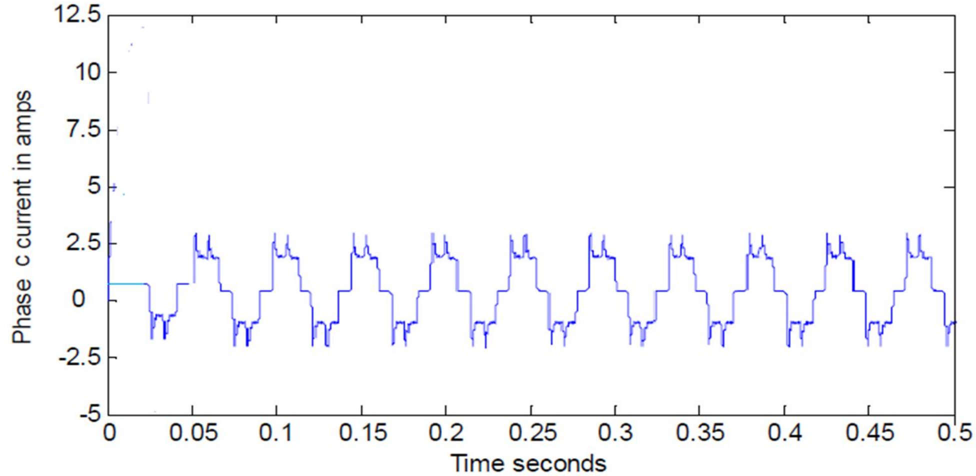

Figure 11: Current Phase C in amperes

B. Back EMF

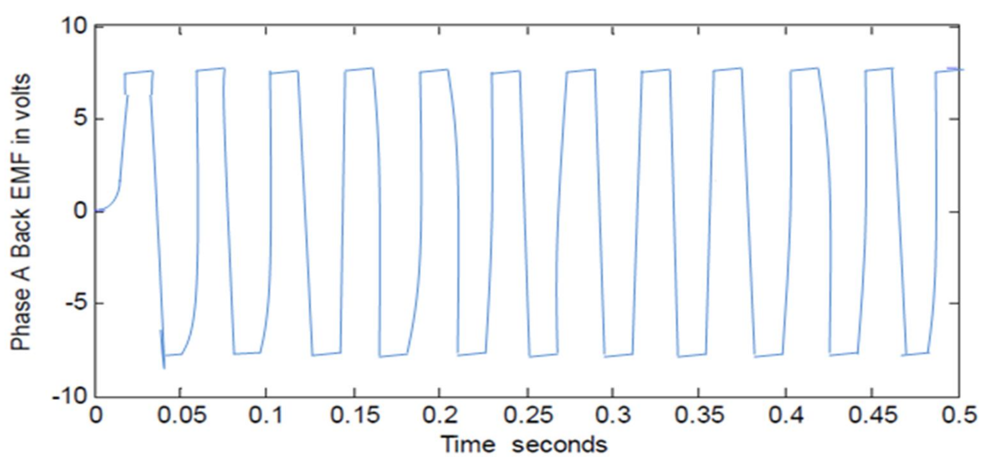

Figure 12: Back EMF Phase A in Voltages

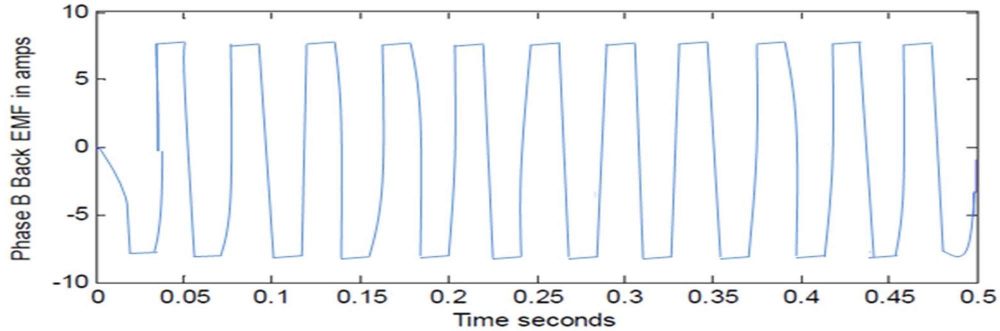

Figure 13: Back EMF Phase B in Voltages

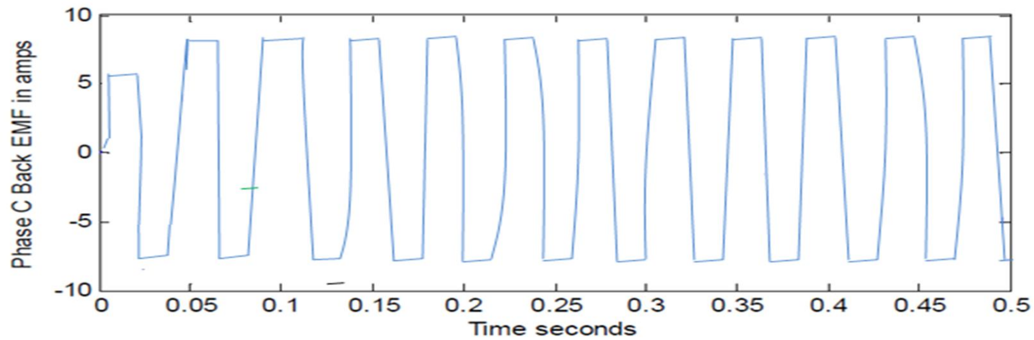

Figure 14: Back EMF Phase c in Voltages

C. Speed

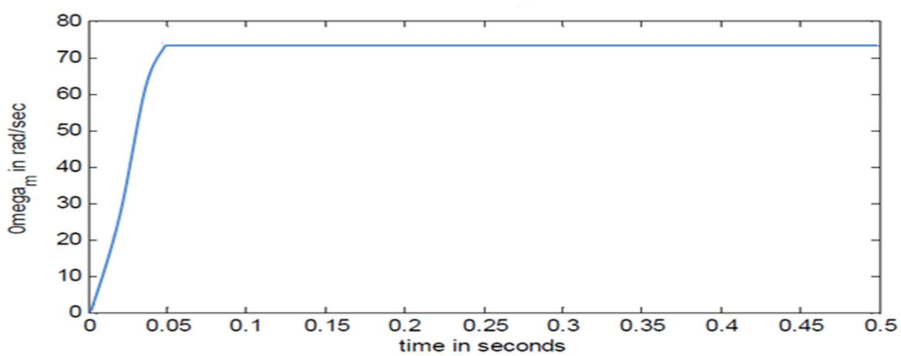

Figure 15: Speed in radian / second

D. Torque

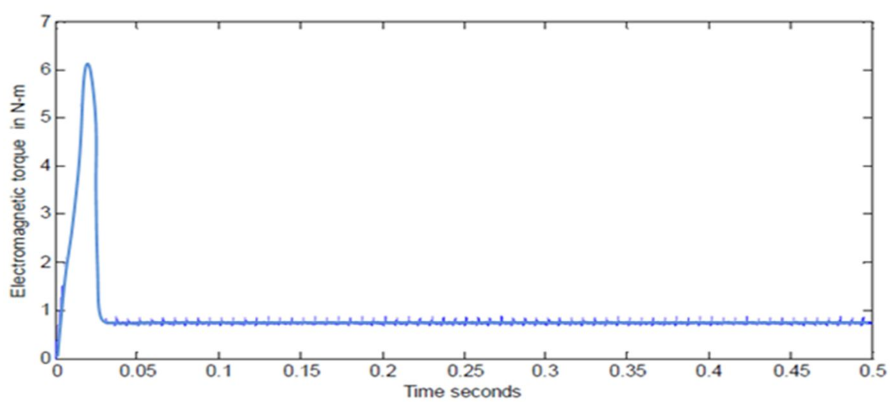

Figure 16: Torque in Newton meter

X. CONCLUSION

The speed control of fuzzy controller is shown in [Figure.15]. Actually brushless DC motor is the alternate motor for traditional motors and also comparatively fuzzy controller has improved performance in speed, torque, efficiency and electromagnetic torque with other methods of speed control. In this mission speed control of permanent magnet brushless DC motor is achieved using fuzzy controller in MATLAB software and also tested successfully by evaluating the parameters like back EMF, current, torque and speed.

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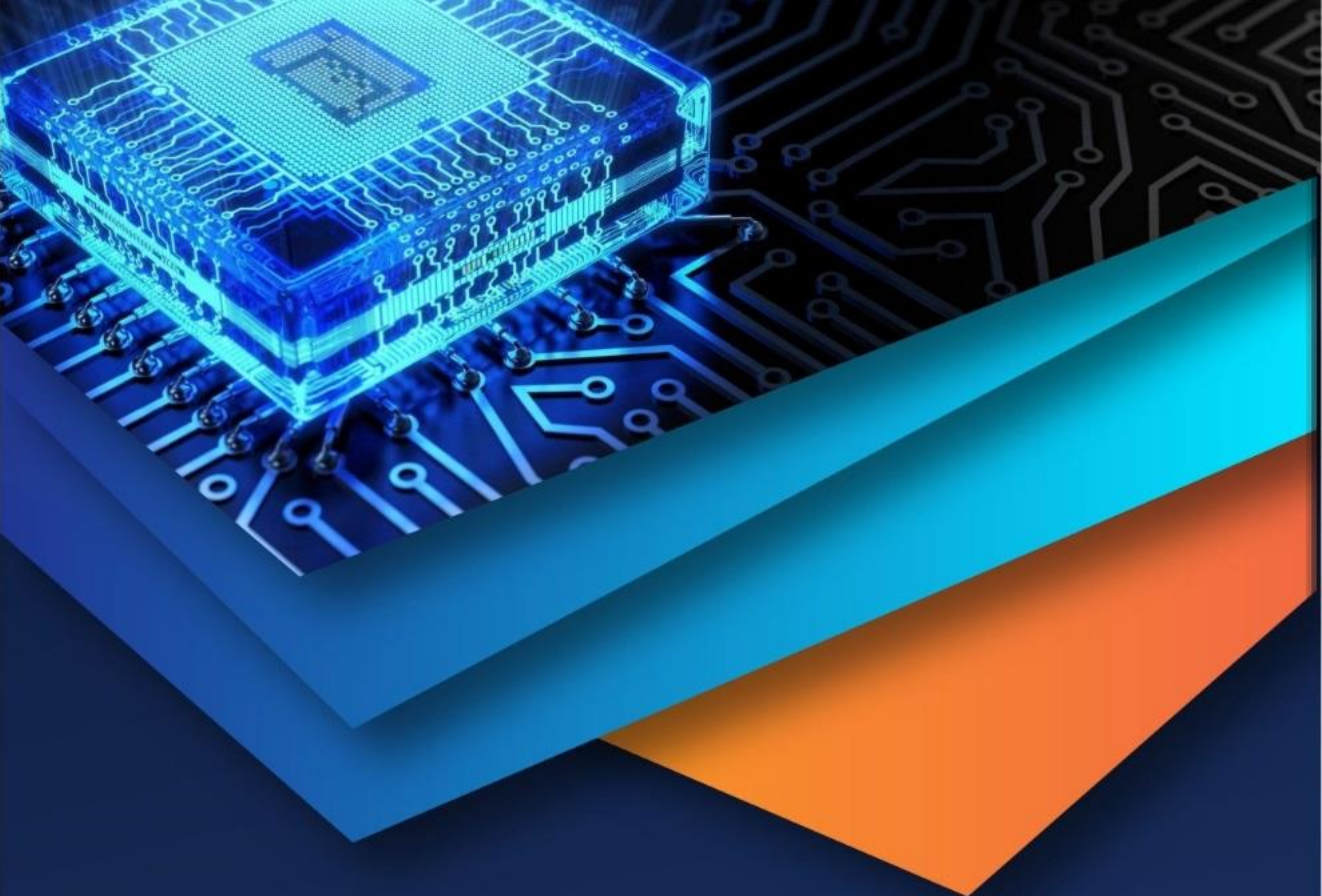
BIOGRAPHY

Mr.J.Vikramarajan received his Master degree in Power Electronics and Drives and Bachelor degree in Electrical and Electronics Engineering from VIT University, India. He has published several international research books and journals. His research interests are electrical machines, power electronic applications, power quality, power electronic converters and power electronic controllers for renewable energy systems.



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