International Journal of Research
Available at https://edupediapublications.org/journals
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 17
November 2016

Analysis of speed control of Brushless D.C Motor using Hybrid Fuzzy Controller

Mohammad Mohiuddin Shah Khan
M-tech Scholar
Department of Electrical & Electronics Engineering,
Lords Institute of Engineering and Technology, Himayathsagar;
Ranga Reddy (Dt); Telangana, India.
Email: mohiuddin_shahkhan@yahoo.com

MUHAMMAD SHAKEEL M
Assistant Professor
Department of Electrical & Electronics Engineering,
Lords Institute of Engineering and Technology,Himayathsagar;
Ranga Reddy (Dt); Telangana, India.
Email: shakeel.abd@gmail.com

Abstract- Brushless DC (BLDC) motors are one of the most interesting motors, not only because of their efficiency, and torque characteristics, but also because they have the advantages of being a direct current (DC) supplied, but eliminating the disadvantages of using Brushes. BLDC motors have a very wide range of speed, so speed control is a very important issue for it. There are a lot of parameters which need to be in focus while talking about a speed controller performance like starting current, starting torque, rise time, etc. There are two main methods for controlling the speed, PID Controllers, and Fuzzy PI controllers. Both are different in complexity and performance. In this paper, the PI and Fuzzy PI speed controllers for the BLDC motors will be proposed. A simulation study is conducted to evaluate the efficiency of the proposed speed controllers. Further, a comparative study is performed to validate the system effectiveness. The proposed concept can be implemented to Hybrid fuzzy controller using Matlab/simulation software

I INTRODUCTION:

Modern speed control techniques for variable speed drives have been changed drastically as compared to their conventional counterparts. Before evolution of power electronics, conventional (e.g. field and armature flux) control methods were being used in DC motor drives. Then power electronics based drives gained popularity. For industrial drive applications, closed loop control techniques were introduced and PI, PID controllers were used along with power electronic converters. Now a days for more sophisticated applications such as space craft and aeronautical engineering, biomedical instrumentation, robotic application etc; the performance of these conventional techniques are not up to the mark. So more accurate control techniques like space vector modulation (SVM), field oriented control, direct torque control, fuzzy logic and adaptive neuro fuzzy logic control technique, etc are being used. So implementing a particular speed control strategy for a particular motor and getting the satisfactory result is the prime concern for the researchers. Here we have selected BLDC motors because of their advantages over the other type of motors for these sophisticated applications. As a BLDC motor does not require a commutator-brush segment so it is compact, more efficient, and generate very less noise when in operation[4]. It exhibits excellent dynamic characteristics on load variation. Our aim is to apply fuzzy logic control scheme to this motor for better performance and experimental results will be verified in the last section. Before discussing the control scheme in detail, first we will accumulate some knowledge about basics of a BLDC motor, its construction and operation in the following sections.

II BRUSHLESS DC MOTOR:

A. Basics

Although the BLDC motor comes under the DC motor category, it can be treated as a variable frequency (or variable speed) synchronous motor [1]. The three phase inverter supplies a three phase voltage to the star connected starter. The DC fed rotor is replaced by permanent magnet. The supply voltage frequency is directly related to the ON- OFF frequency of the power electronic switches which again depends upon the reference speed. It exhibits similar torquespeed characteristics as DC motor. Unlike a synchronous motor it is self starting in nature and the speed can be varied smoothly.

B. Construction:

A sensor based three phase BLDC motor mainly consists of a star connected stator, a permanent magnet type rotor, hall sensors for position detection, a DC to AC(3-phase) converter for electronic commutation, speed controller and some other sub-circuits like reference current generator, PWM modulator, etc. The position sensors also measure speed indirectly with the help of a timer from the microcontroller. These sensors are placed either in 600 or 1200 (electrical) to each other and fixed to the yoke at the non-driving end.

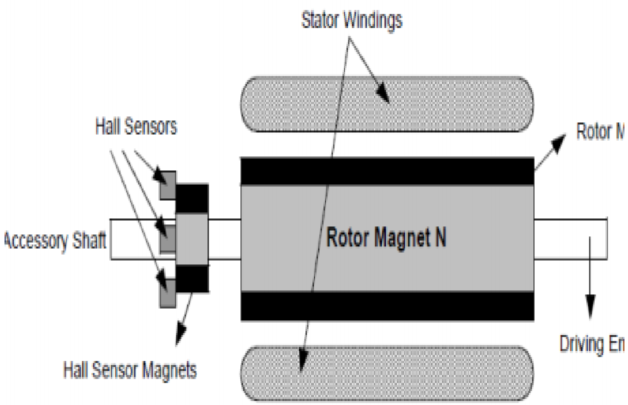

Fig.1. Transverse section of BLDC motor

C. Operation

Let the motor is in standstill position, and one has to operate it in a particular direction at a specific speed. When switched on the hall sensors provide the initial position. Hence the controller switches on appropriate IGBT pair so that the rotor starts to rotate in the required direction. After 60 degree the signal of the sensor is changed and switching combination also. In this fashion the rotor continues to rotate and speed error decreases exponentially. During the running condition if the load changes, speed also changes. To achieve the required speed controller changes the switching frequency. The complete block diagram for BLDC motor drive is shown in figure-2[3].

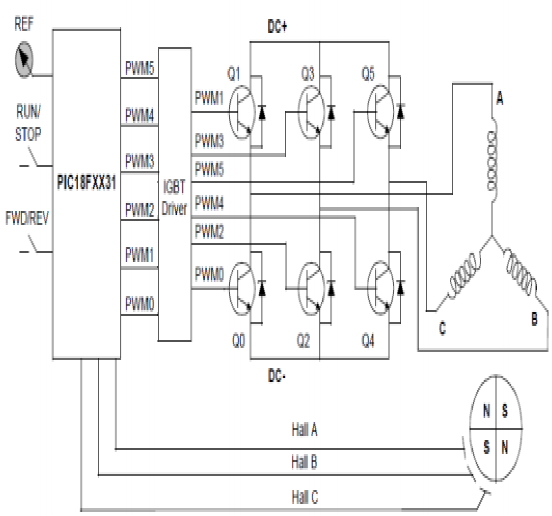

Fig.2. Overall block diagram of BLDCM drive

As signal from the sensor is changed in every 60 degrees, so six steps are required to complete an electrical cycle. According to the placement of position sensors (600 or 1200 phase difference) the manufacturer provides the sequence table to operate the motor in clockwise and anticlockwise directions. For 600 sensor placement the sequence table for clockwise direction is shown in table-1. Fig.3 represents the waveform for hall signal, back EMF, line current and torque produced.

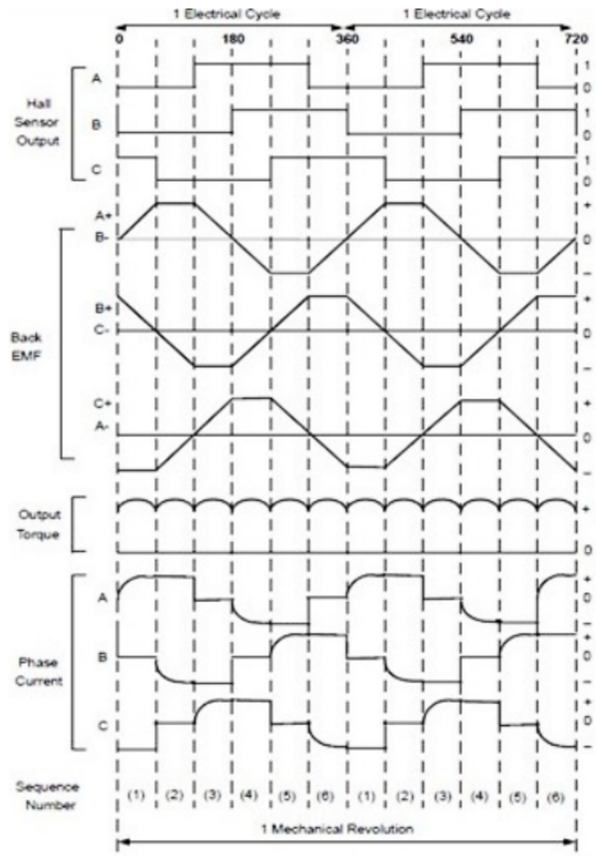

Fig.3. Hall sensor, back EMF, torque and phase current signal for 60 degree mode

TABLE I. SWITCHING SEQUENCE FOR CLOCKWISE MODE (600)

sequence	Hall input			Active switches		Phase voltage		
	A	B	C			A	B	C
1	0	0	1	Q1	Q4	dc+	0	dc-
2	0	0	0	Q1	Q2	dc+	dc-	0
3	1	0	0	Q5	Q2	0	dc-	dc+
4	1	1	0	Q5	Q0	dc-	0	dc+
5	1	1	1	Q3	Q0	dc-	dc+	0
6	0	1	1	Q3	Q4	0	dc+	0

III MATHEMATICAL MODELLING:

Assuming the resistances of all the phase windings of a BLDC motor are equal, the phase voltages can be represented by equation-1[11].

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 17
November 2016

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{1}$$

Assume that all the self inductance of each phase windings are equal. Similarly all the mutual inductance are equal.

$$L_{aa} = L_{bb} = L_{cc} = L \tag{2}$$

$$L_{ab} = L_{ba} = L_{cb} = L_{bc} = L_{ca} = L_{ac} = M \tag{3}$$

Substituting (2) and (3) in (1) :

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

For a balanced three phase stator winding, at any time summation of all phase currents is zero[13].

Ia+ ib+ ic=0

So

$$Mi_b + Mi_c = -Mi_a \tag{5}$$

Substituting (5) in (4) the state space form of BLDC motor can be obtained.

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{6}$$

IV: CONTROL STRATEGY:

To control the speed of a BLDC motor the switching frequency should be controlled. Six control signals are generated by a PWM modulator and fed to the base/gate terminal of the six switches. A controller is required to process the speed error and the output is fed to the PWM modulator. Conventionally proportional-integral control algorithm is being used for this purpose.

A. PI-Control Scheme:

A PI-controller processes the speed error and generates the reference current value. The proportional mode controls the instant speed error and integral mode determines the reaction based recent error. The two modes collectively control the speed[6].

$$Output(t) = K_P e(t) + K_I \int_0^t e(\tau) d\tau \tag{7}$$

$$e(t) = \omega_{ref} - \omega_m(t) \tag{8}$$

A reference current generator derives reference current for each phase. Then the actual line current is compared with the reference value and current error is fed to the PWM modulator, which generates the final control (gate) signal. The basic block diagram for a PI controlled BLDC motor drive is shown in Fig.4.

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 17
November 2016

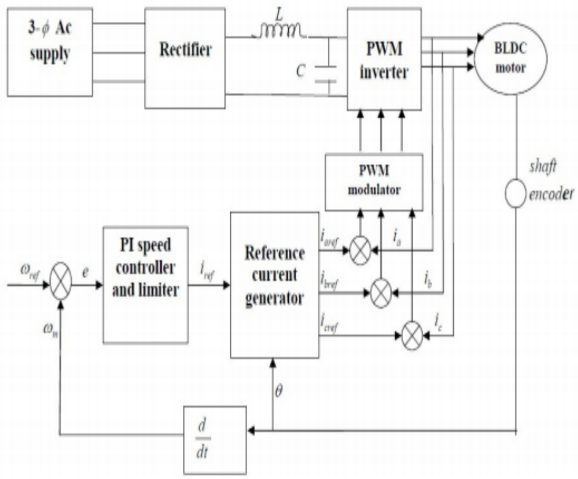

Fig.4. Block diagram for speed control of BLDCM using PI controller.

B. PI-Controller Design

The closed loop control block diagram is shown in Fig.5. The transfer function for PI controller is given by (9).

$$G(S) = K_P + \frac{K_I}{S} \tag{9}$$

Where
KP and *KI* are proportional and integral gains respectively. Ziegler Nichols method is used to tune these parameters which ensure stability of the system. The motor transfer function is given by (10).

$$M(S) = \frac{1}{JS + B} \tag{10}$$

Where
J =Moment of inertia.
B =Coefficient of friction.

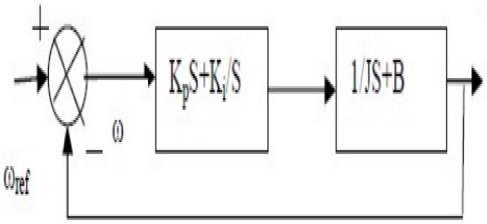

Fig.5. Closed loop transfer function of a PI controlled BLDC motor drive.

The overall transfer function of the system is given by (11).

$$T(S) = \frac{(K_P S + K_I)/J}{S^2 + \{(B + K_P)S + K\}/J} \tag{11}$$

Comparing the above transfer function with a standard second order system, *KP* and *KI* can be found out.

$$K_P = 2\xi\omega_n J - B \tag{12}$$

$$K_I = J\omega_n \tag{13}$$

C. Limitations of PI Control Scheme:

A PI controller is a good choice for industrial drives. But very accurate speed cannot be achieved by using this scheme. During the starting some speed oscillations occur, which damps out with time. At steady state condition if the load changes then some speed fluctuations can be observed. Because of these limitations a PI control scheme is not sufficient for the applications where accuracy is an issue. So a fuzzy logic control scheme is incorporated.

V FUZZY LOGIC CONTROL:

Generally the computer works with crisp logic. But the human interpretations like hot, cold, medium, very high, very low etc can be implemented by a computer with some changes in representation of input data. Fuzzy logic is a tool to represent the input data such that a computer can process them. For this purpose the input data are classified to some sets which stand for the human interpretations like hot, medium, short etc. These sets consist of a range of values called members. Each member is associated with a membership value which means percentage of that nature. The graphical representation of these sets with respect to the percentage value is called membership function[7][10]. Some general membership functions are shown in Fig.6. The speed control of a BLDC motor using fuzzy logic involves three steps; fuzzification, inference and defuzzification.

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 17
November 2016

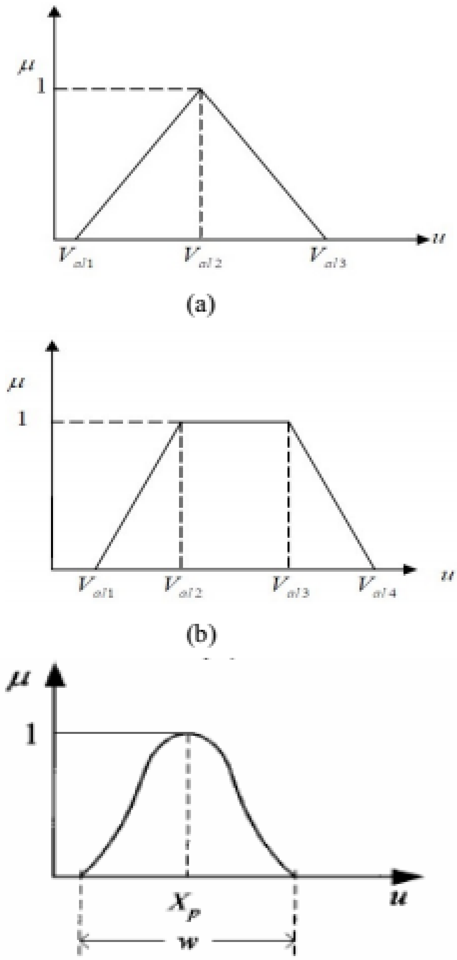

Fig.6. (a) triangular, (b) trapezoidal, (c) bell shaped membership function

A. Fuzzification:

This is the process to convert an input crisp set to a fuzzy set by using a membership function. Here a triangular membership function is chosen. The input to the controller are "speed error(E)" and "change in speed error(CE)". These two inputs are fed to the controller which gives the output in form of reference current. The fuzzified E and CE signals consists of 7 logic sets(levels) such as NB, NM, NS, ZE, PS, PM, PB. The seven-level membership function is illustrated in Fig.7.

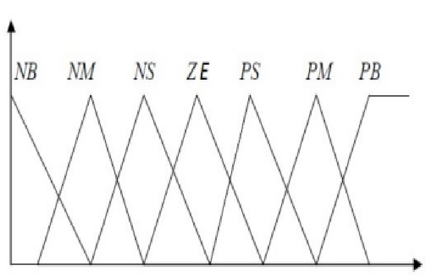

Fig.7. Seven leveled fuzzy membership function.

B. Fuzzy Inference

The programmer defines the rules (inferences) for how much to react for which level of input. Here the rules define the level of reference current(Iqc) for the corresponding speed error(E) and change in error(CE) values. As both the input sets are of seven levels so a 7x7 rule table(look up table) is formed. The rules are defined as follows[5].

- If E is PB and CE is any, then Iqc is PB.
- If E is PS and CE is PS or ZE, then Iqc is PS.
- If E is ZE and CE is PS, then Iqc is PS.
- If E is ZE and CE is NS, then Iqc is NS.
- If E is NS and CE is NS, then Iqc is NS.
- If E is NB and CE is any, then Iqc is NB.

TABLE-II. RULE TABLE

		Change in error						
		NB	***NM***	***NS***	***ZE***	***PS***	***PM***	***PB***
error	***NB***	NB	NB	NB	NB	NM	NS	ZE
	NM	NB	NM	NM	NM	NS	ZE	PS
	PS	NB	NM	NS	NS	ZE	PS	PM
	ZE	NB	NM	NS	ZE	PS	PM	PB
	PS	NM	NS	ZE	PS	PM	PM	PB
	PM	NS	ZE	PS	PM	PM	PB	PB
	PB	ZE	PS	PM	PB	PB	PB	PB

C. Defuzzification:

Now the reference current levels can be obtained from the lookup table. But it is in fuzzified state. To use these data it should be converted to crisp set. To obtain the crisp set we use the following methods[7].

1) The max criterion method:

It produces a point at which membership function reaches maximum value.

$$x = \frac{\sum_{u \in T} u'}{T} \quad \textbf{(14)}$$

2) The height method:

The centroid of each membership function for each rule is first evaluated. The final output is then calculated as the average of the individual centroids.

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 17
November 2016

$$x = \frac{\sum_{i=1}^{M} w_i f_i}{\sum_{i=1}^{M} w_i} \quad (15)$$

3) Centre of gravity method:

It generate the centre of gravity of the area by membership function.

$$x = \frac{\sum_{1}^{n} m(u).u}{\sum_{1}^{n} m(u)} \quad (16)$$

The overall fuzzy logic controlled BLDC motor block diagram is shown in Fig.8.

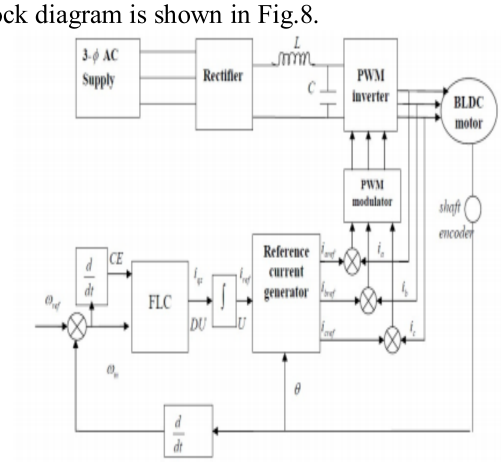

Fig.8. Block diagram of a fuzzy logic controlled BLDC motor drive.

HYBRID FUZZY:

This paper investigates two fuzzy logic controllers that use simplified design schemes. Fuzzy logic PD and PI controllers are effective for many control problems but lack the advantages of the fuzzy controller. Design methodologies are in their infancy and still somewhat intuitive. Fuzzy controllers use a rule base to describe relationships between the input variables. Implementation of a detailed rule base increases in complexity as the number of input variables grow and the ranges of operation for the variables become more defined. We propose a hybrid fuzzy controller which takes advantage of the properties of the fuzzy PI and PD controllers and a second method which adds the fuzzy PD control action to the integral control action.

The effectiveness of the two PID fuzzy controller implementations,PD and PI fuzzy controllers have the same design disadvantages as their classical counterparts. Therefore, in some cases a fuzzy PID controller maybe required. The fuzzy PID controller entails a large rule basewhich presents design and implementation problems. First, a reduced rule fuzzy PID scheme was implemented to take advantage of both PD and PI control actions. Some further research is required for the processof switching between the control actions. The second fuzzy PID control scheme used only the PD portion with an integral term added to eliminate steady-state error. Results from simulations of both control schemes demonstrate the effectiveness of the PID controllers.

VI MATLAB/SIMULATION RESULTS

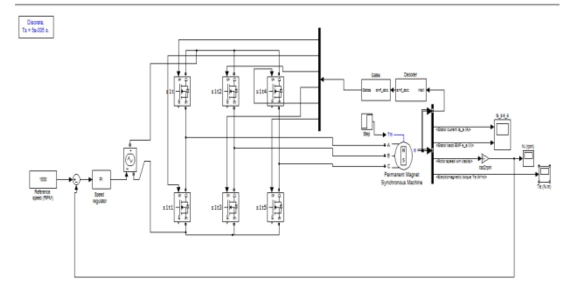

Fig 9 Matlab/simulation circuit of for speed control of BLDCM using PI controller.

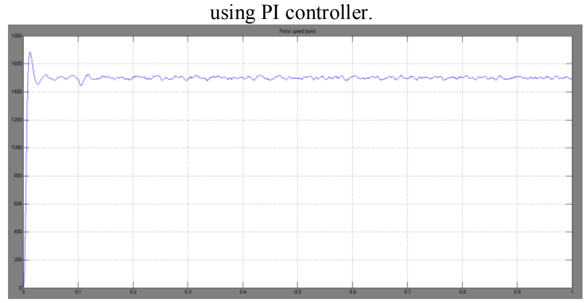

Fig 10 simulation wave form of BLDC motor speed with PI controller

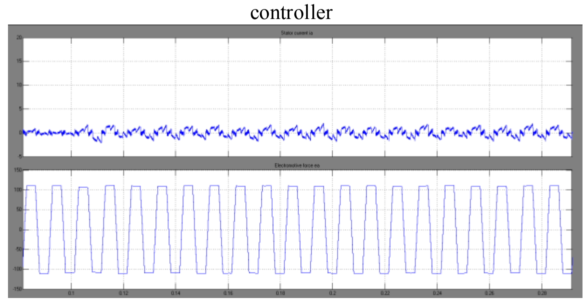

Fig 11 simulation wave form of stator current and electromagnetic force with PI controller

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 17
November 2016

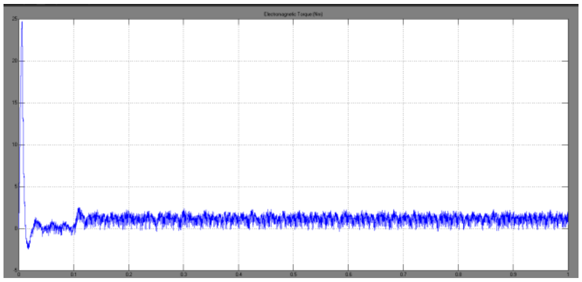

Fig 12 simulation wave form of BLDC motor electromagnetic torque with PI controller

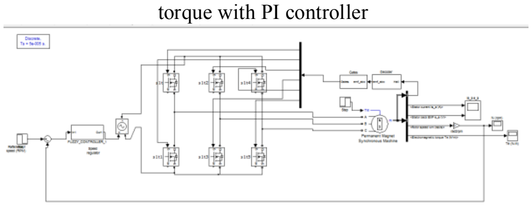

Fig 13 Matlab/simulation circuit of for speed control of BLDCM using fuzzy logic controller.

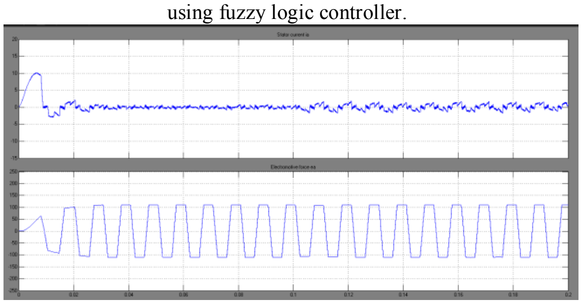

Fig 14 simulation wave form of stator current and electromagnetic force with fuzzy logic controller

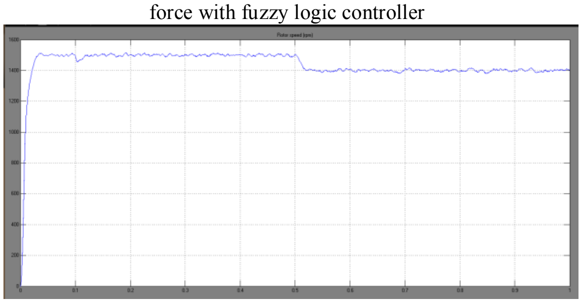

Fig 15 simulation wave form of BLDC motor speed with fuzzy logic controller

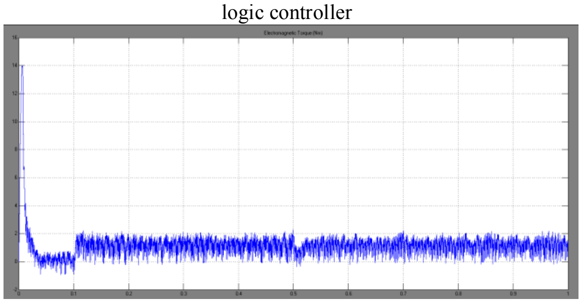

Fig 16 simulation wave form of BLDC motor electromagnetic torque with fuzzy logic controller

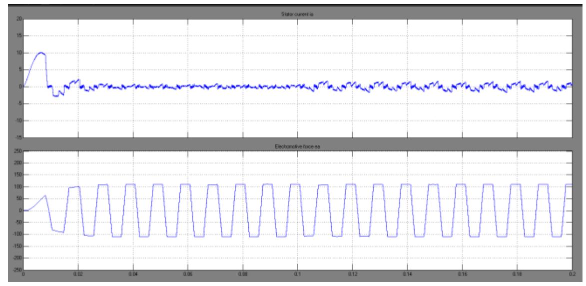

Fig 17 simulation wave form of stator current and electromagnetic force with hybrid fuzzy logic controller

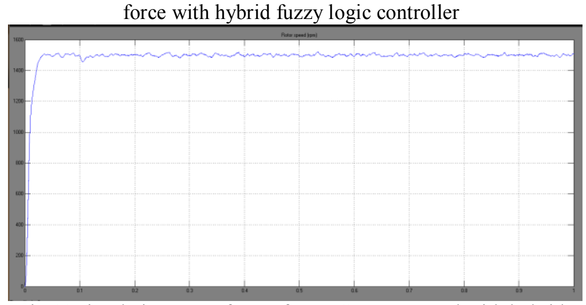

Fig 18 simulation wave form of BLDC motor speed with hybrid fuzzy logic controller

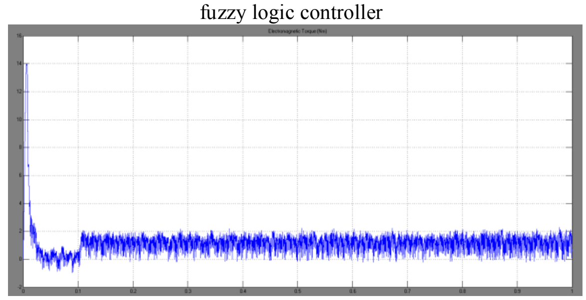

Fig 19 simulation wave form of BLDC motor electromagnetic torque with fuzzy logic controller

CONCLUSION:

In this paper we discussed the BLDC motor speed control using a hybrid fuzzy logic controller. A detailed analysis was done on fuzzification, fuzzy rules and defuzzification methods and lookup table was obtained by using fuzzy algorithm. The PI control scheme and fuzzy based PI and hybrid fuzzy controller scheme were simulated using MATLAB and compared. The dynamic response of speed in using FLC was better than only PI and fuzzy scheme. These results show that a PI based FLC technique is a better choice for BLDC motor drive and favors to widen its area of application in near future.

REFERENCES:

[1] Paul C. Krause, "Analysis of electric machinary", McGraw-Hill, 1984.
[2] P.S. Bimbhra, " Generalized Theory of Electrical Machines", Khanna Publishers.
[3] P. Yedamale, Brushless DC (BLDC) Motor Fundamentals. Application Note 885, Microchip Technology Inc., Chandler, AZ,2003.

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 17
November 2016

[4] Dutta, P.; Mahato, S.N., "Design of mathematical model and performance analysis of BLBLDC motor," Control, Instrumentation, Energy and Communication (CIEC), 2014 International Conference on , vol., no., pp.457,461, Jan. 31 2014-Feb. 2 2014

[5] Ko, J.S.; Jae Gyu Hwang; Myung-JoongYoun, "Robust position control of BLDD motors using integral-proportional plus fuzzy logic controller," Industrial Electronics, Control, and Instrumentation, 1993. Proceedings of the IECON '93., International Conference on , vol., no., pp.213,218 vol.1, 15-19 Nov 1993

[6] P.N. Reddy, Modeling and Analysis of PI Controller Based Speed Control of Brushless DC Motor Drive. International Journal of Engineering Sciences & Research Technology,2013[2226-2231].

[7] Y. Bai, H. Zhuang and D. Wang, Advanced fuzzy logic technologies in industrial applications, Springer-Verlag London Limited 2006.

[8] C.C. Lee, "Fuzzy Logic in Control Systems: Fuzzy Logic Controller, Parts I and II."IEEE Transactions on Systems, Man and Cybernetics, 20, 2 (March/April, 1990) 404-435.

[9] Devendra Rai, Brushless DC Motor Simulink Simulator, Department of Electronics and Communication Engineering, National Institute of Technology Karnataka, Surathkal 575 025, INDIA.

[10] ToshinoriMunakata, Fundamentals of the new artificial intelligence, neural, evolutionary, fuzzy and more, Second Edition, Springer-Verlag London Limited 2006.

[11] Shyam, A.; Daya, F.J.L., "A comparative study on the speed response of BLDC motor using conventional PI controller, anti-windup PI controller and fuzzy controller," Control Communication and Computing (ICCC), 2013 International Conference on , vol., no., pp.68,73, 13-15 Dec. 2013

[12] Tan Chee Siong; Ismail, B.; Mohammed, M.F.; Tajuddin, M.F.N.; Rafidah, S.; Rahim, A.; Isa, Z.M., "Study of Fuzzy and PI controller for Permanent-Magnet Brushless DC motor drive," Power Engineering and Optimization Conference (PEOCO), 2010 4th International , vol., no., pp.517,521, 23-24 June 2010

[13] N. Bianchi, S. Bolognani, J. H. Jang, S. K. Sul, “Comparison of PM Motor structures and sensor less Control Techniques for zero-speed Rotor position detection” IEEE transactions on power Electronics, Vol 22, No.6, Nov 2006

.