OPEN ACCESS

International Journal Of Modern Engineering Research (IJMER)

Fuzzy logic Technique Based Speed Control of a Permanent Magnet Brushless DC Motor Drive

Shantanu Kumar Lakhanwal[1], Amandeep Gill[2]

[1]Department of Electrical Engg.,SKIT Jaipur, INDIA)

[2] Department of Electrical Engg.,JECREC University, India

Abstract: *This paper presents an analysis by which the dynamic performances of a permanent magnet brushless dc (PMBLDC) motor drive with different speed controllers can be successfully predicted. The control structure of the proposed drive system is described. The dynamics of the drive system with a classical proportional-integral-derivative (PID) and Fuzzy-Logic (FL) speed controllers are presented. The simulation results for different parameters and operation modes of the drive system are investigated and compared. The results with FL speed controller show improvement in transient response of the PMBLDC drive over conventional PID controller. Moreover, useful conclusions stemmed from such a study which is thought of good use and valuable for users of these controllers*

Keywords: *Brushless motor, derivative controller, fuzzy logic controller, integral controller,proportional controller.*

I. Introduction

Brushless dc motors (BLDCM) provide high efficiency, reliability, ruggedness and high precision of control when compared to conventional motors. It has the best torque vs. weight or efficiency characteristics. They are used in military, grinding, aircraft, automotive applications, communications equipment etc. Brushless dc motors (BLDCM) have been desired for small horsepower control motors such as: heating, ventilation, and air conditioning systems to achieve great energy saving effects for partial loads by lowering motor speeds. In addition, BLDCM have been used as variable speed drives in wide array of applications due to their high efficiency, silent operation, compact form, reliability, and low maintenance [1]. BLDCM drives were widely employed in industry due to their intrinsic robustness and high torque-to-weight ratio. The availability of cheap embedded processing power in recent years paved the way for the widespread use of sensor less control techniques; the removal of speed and position sensors leads to substantial increase of robustness and cost savings [2]. Due to the high torque to volume ratio of BLDCM, it dominates for High Performance Drives (HPD) applications, such as robotics, guided manipulation and dynamic actuation, the precise rotor movement over a period of time must be achieved. A multi-robot system performing a complementing function must have the end effectors move about the space of operation according to a pre- selected time tagged trajectory. Also, the Brushless dc motor, as the name implies, has no brushes. This is an essential requirement for several industrial applications such as airplane actuation, food and chemical industries. This must be achieved even when the system loads, inertia and parameters are varying. To do this, the speed control strategy must be adaptive, robust, accurate, and simple to implement [3].Conventional feedback controllers, such as the PID or the linear quadratic, need accurate mathematical models describing the dynamics of the system under control. This can be a major limiting factor for systems with unknown varying dynamics. Even if a model can be obtained for the system under control, unknown conditions such as saturation, disturbances, parameter drifts, and noise may be impossible to model with acceptable accuracy. For most of the basic electric drives applications, these unknown conditions in addition to the system nonlinearities can be ignored, but it may lead to unacceptable tracking performance. High accuracy is not usually imperative [4]. Some adaptive control techniques, such as the variable structure and the self-tuning, do not need a model for system dynamics. The dynamic model is, rather, developed based on the on-line input/output response of the system under control [5]**.**The F L C (Fuzzy Logic Controller) has several key features like its robustness, fault tolerant, noise free and capability of generating a nonlinear mapping between the inputs and outputs of an electric drive system without the need for a predetermined model makes it suitable for speed control of BLDC motors under varying load torque.

II. Analysis Of P MBLDC Drive

The flux distribution in PM brushless dc motor is trapezoidal; therefore, the d-q rotor reference frames model developed for the PM synchronous motor is not applicable. Given the non sinusoidal flux distribution, it is prudent to derive a model of the PMBDCM in phase variables. The derivation of this model is based on the assumptions the induced current in the rotor due to stator harmonics fields are neglected and iron and stray losses are also neglected .Damper winding are not usually a part of the PMBDCM[4].Damping is provided by the inverter control. The motor is considered to have three phase, even thought the derivation procedure is valid for any number of phases.

The coupled circuit equation of the stator winding in terms of motor electrical constant are

$$\begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} + p \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \begin{matrix} i_a \\ i_b \\ i_c \end{matrix} + \begin{bmatrix} e_{as} \\ e_{bs} \\ e_{cs} \end{bmatrix} \quad (1)$$

Where R_s is the stator resistance per phase, acquired to be equal for all three phases. The induced emf $e_{as,}\, e_{bs}$ and e_{cs} are all assumed to be in geometric shape of trapezoidal, as shown in fig.
Where E_p is the peak value, derived as

E_p= (B*l*v) N=n (B1rω_m) =N$\phi_a\,\omega_m$=$\lambda_p\ \omega_m$ (2)

The instantaneous induced emfs can be written from equation (2.2)

$$e_{as} = f_{as}(\theta_r)\,\lambda_p\,\omega_m \quad (3)$$
$$e_{bs} = f_{bs}(\theta_r)\,\lambda_p\,\omega_m \quad (4)$$
$$e_{cs} = f_{cs}(\theta_r)\,\lambda_p\,\omega_m \quad (5)$$

Where the functions $f_{as}(\theta_r)$, $f_{bs}(\theta_r)$ and $f_{cs}(\theta_r)$ have the same shape as $e_{as,}\, e_{bs}$ and e_{cs}
With a maximum magnitude of ±1.The induced emfs do not have sharp edged corners, as is shown in trapezoidal functions, but rounded edges. The emfs the result of the flux-linkages derivatives and the flux linkage are continuous functions. Fringing also makes flux density functions smooth with no abrupt edges. The electromagnetic torque then is

T_e= λ_p[$f_{as}(\theta_r)\, i_{as}$+ $(\theta_r) i_{bs}$+$f_{cs}(\theta_r) i_{cs}$](N.m) (6)

the same signs as the stator phase current in the motoring mode ,but opposite sign in the regeneration mode .The result of such sigh relationship is simplification of torque command as,

T_e^*=2$\lambda_p\ i_p^*$ (7)

The individual stator-phase current commands are generated from the current magnitude command and absolute rotor position. These commands are amplifier through the inverter by comparing them with their respective current in the stator phases. Only two phase current are necessary in the balanced three-phase system to obtain the third phase current, since the sum of the three-phase current is zero

III. Speed Control

This section explores the controller schemes applied to a PMBLDC motor with a trapezoidal back emf for providing a satisfactory speed control performance. It will examine the PMBLDC motor with PID and FL controllers.

3.1 PID Controller

The PID controller calculation algorithm involves three separate constant parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values are denoted by P, I, and D. By putting these values can be interpreted in terms of time: P depends on the present error, I on the collection of past errors, and D is a anticipation of future errors, grounded on current rate of change [7]. The weighted down sum of these three actions is used to adjust the process via a control element such as the position of a control assess, a damper, or the power furnished to a heating element. The response of the controller can be described in terms of the responsiveness of the controller to an error, the stage to which the controller overshoots the set point, and the stage of system oscillation. Some applications may involve using only one or two actions to provide the appropriate system control. This is accomplished by setting the other parameters to zero. PID controller will be called by PI, PD, P or I controller in the absence of the various control actions [16]. PI controllers are reasonably common, since derivative action is sore to measurement noise, whereas the absence of an integral term may prevent the system from reaching its target value due to the control action.

The PID controller is calculated using the transfer function

$$G_c\ s = k_p\left(1 + \frac{1}{T_{i\ s}} + T_d s\right) \qquad (8)$$

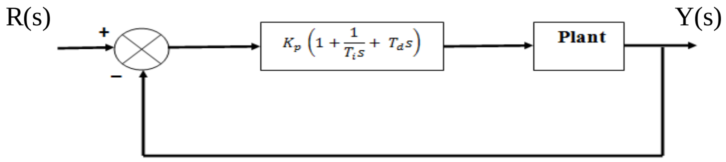

Fig.1 Schematic Block Diagram of Speed Controller

3.2. Fuzzy Logic Controller Theory

Fuzzy logic is a mathematical environment, based on fuzzy set theory, which admits for degrees of truth or falsehood". As opposition to "binary logic" which gives a confirmation that must be either true or false. 'Fuzzy logic' conciliates the possibility that the logic can be exactly false. The degree of truth or falsehood in the affirmation can be both qualitatively and quantitatively explained. As given above fuzzy logic deals with dubiety, ambiguity and imprecision, which exists in difficult real world troubles specifically in engineering [22]. Fuzzy logic is multi-valued logic basically dealing with uncertainty and approximate reasoning.

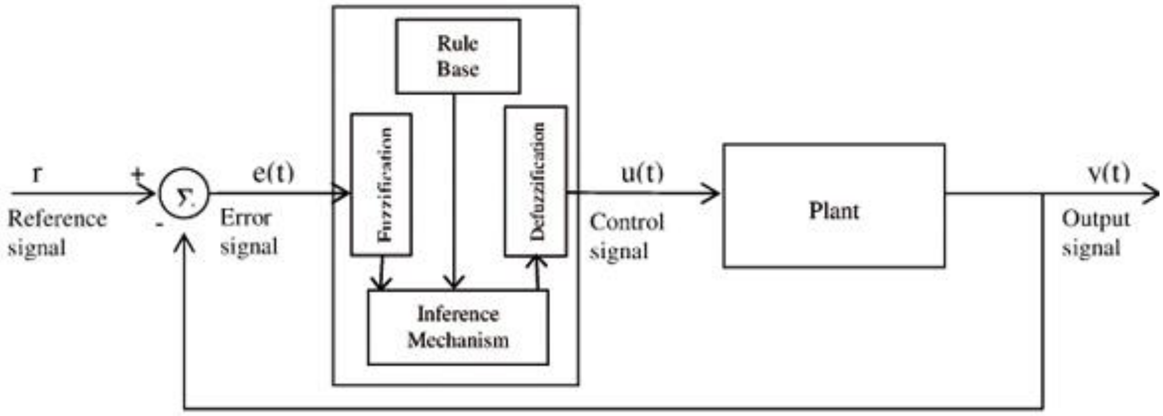

Fig.2Block diagram of fuzzy logic controller

The fuzzy membership function for the input variable and output variable are described as follows: Positive: PB, Negative Big: NB Positive Medium: PM, Negative Medium: NM Positive Small: PS, Negative Small: NS and Zero: ZE

The triangular shaped functions are picked out as the membership functions due to the output best control performance and simplicity The membership function for the speed error and the change in speed error and the change in torque reference current are shown in Fig. 4.5 .For all variables seven levels of fuzzy membership function are used. TABLE 1 shows the 7×7 rule base table that is used in the system.

The processing stage is based on a collection of logic rule in the form of IF-THEN statements. In practice, the fuzzy rule sets usually have several antecedents that are combined using fuzzy operators, such as AND, OR, and NOT. For example: IF e = ZE AND delta = ZE THEN output = ZE. The results of all the rules that have fired are "defuzzified" to a crisp value by one of several methods. There are dozens in theory, each with various advantages and drawbacks.

The "centroid method" is very popular, in which the "center of mass" of the result provides the crisp value. Another approach is the "height" method, which takes the value of the biggest contributor. The centroid method favors the rule with the output of greatest area, while the height method obviously favors the rule with the greatest output value.

Table 1

E/ΔE	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NS	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

IV. Simulation And Results

Several results were simulated to evaluate the performance of the proposed FLC-based PMBLDC drive system. The effectiveness of the proposed FL controller is investigated and compared to the conventional PI controller through the following results. The speed, stator current, and torque responses are observed under different operating conditions such as change in command speed, step change in load, etc.

The motor speed, current, and torque responses of the PMBLDC drive with PI and FL controllers are shown in Fig. The results show the starting performance as well as the response with a step change in reference speed. The drive system was unloaded with a speed reference set at 3000 rpm. Consequently, the reference speed is increased to 8000 rpm motor speed with FL controller converges to the reference value within 0.2 s without any overshoot/undershoot and with zero steady- state error. Fig.3-12 shows the speed, current, and torque responses of the PMBLDC drive under loading conditions with PI and FL controllers. It is shown that the proposed drive with FL controller is also capable of following the reference speed very quickly with zero steady-state error and almost without any overshoot/undershoot when the motor is loaded. From these results it is concluded that the FL controller ensures better damping of speed, current, and torque.

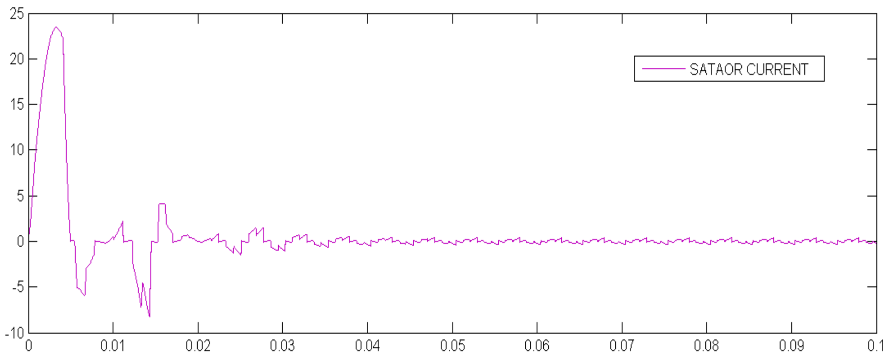

Fig. 3 Waveform of the stator current (phase a) of BLDCM

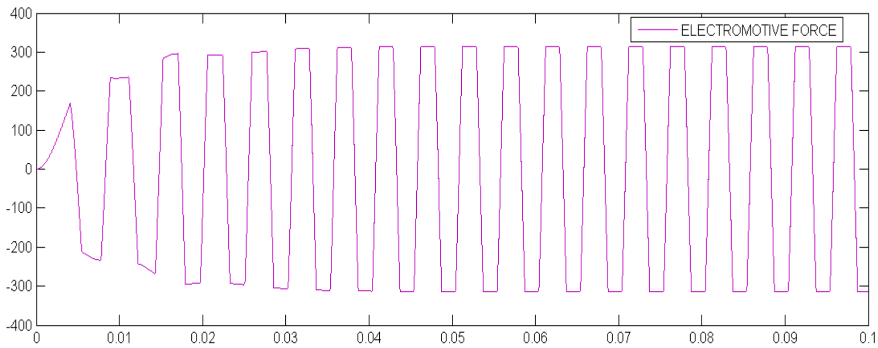

Fig.4 Waveform of Stator back EMF

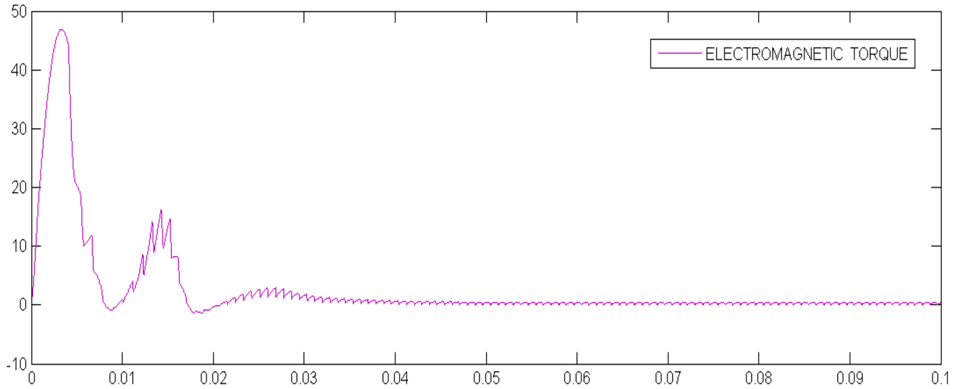

Fig.5 Waveform of the Electromagnetic Torque Te (Nm) of BLDCM

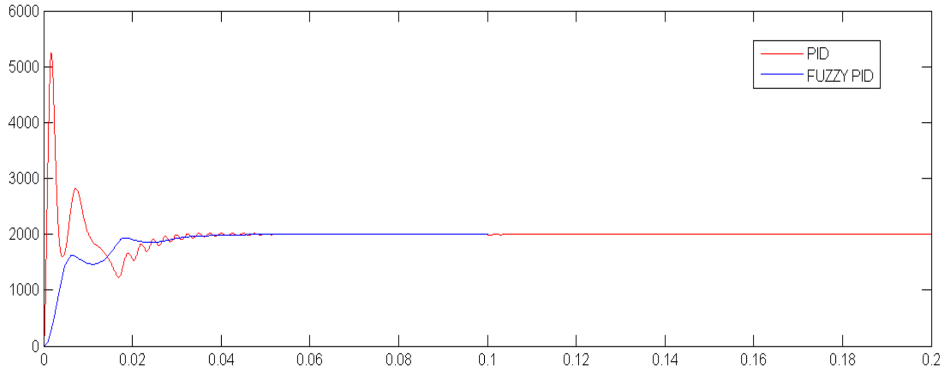

Fig. 6 Waveform of the BLDCM at 2000 rpm

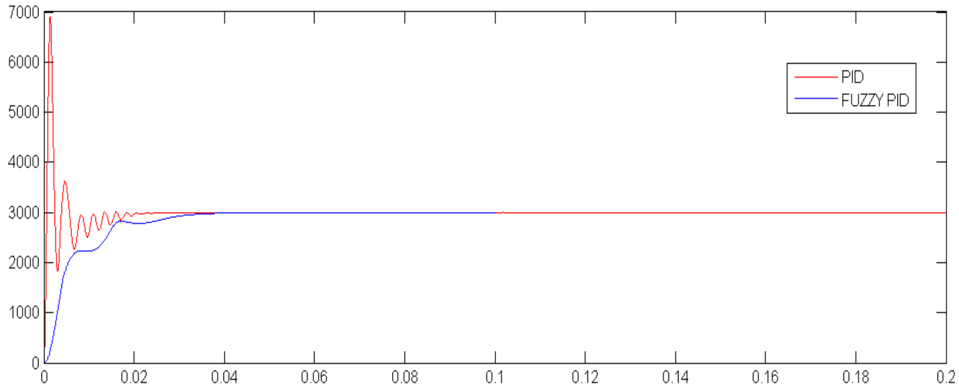

Fig.7 Waveform of the BLDCM at 3000 rpm

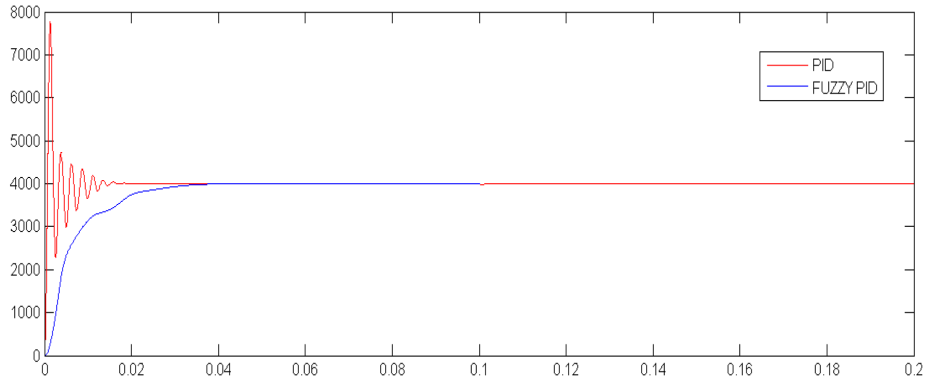

Fig. 8 Waveform of the BLDCM at 4000 rpm

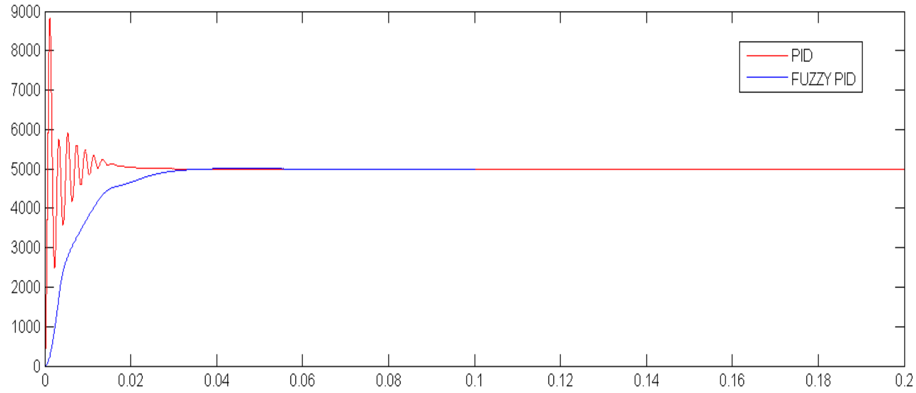

Fig.9 Waveform of the BLDCM at 5000 rpm

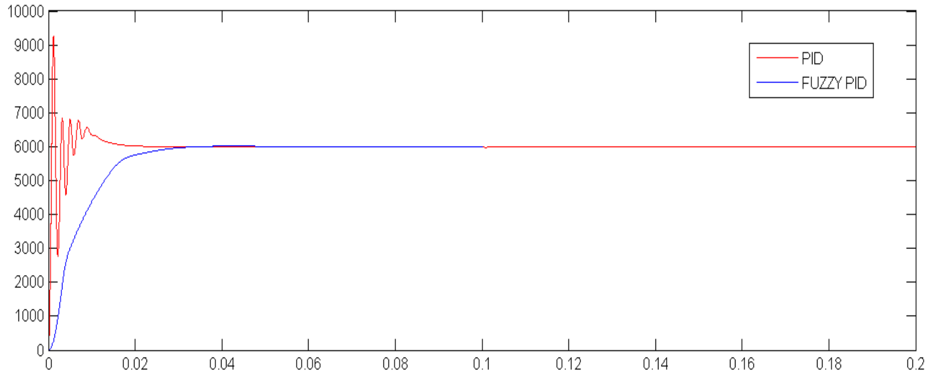

Fig. 10 Waveform of the BLDCM at 6000 rpm

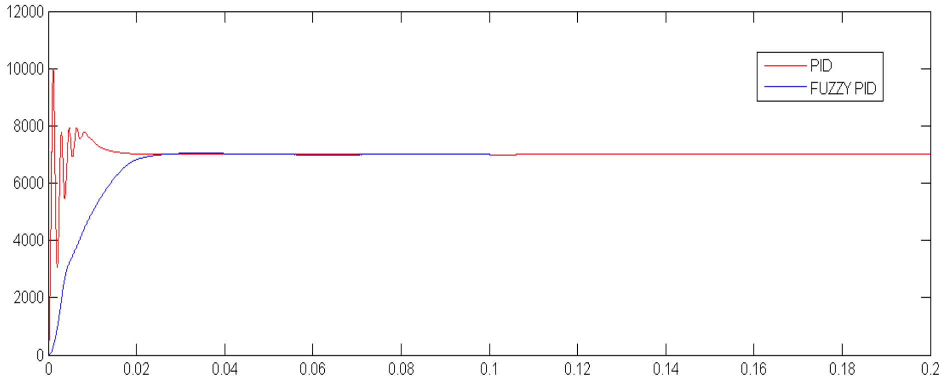

Fig. 11Waveform of the BLDCM at 7000 rpm

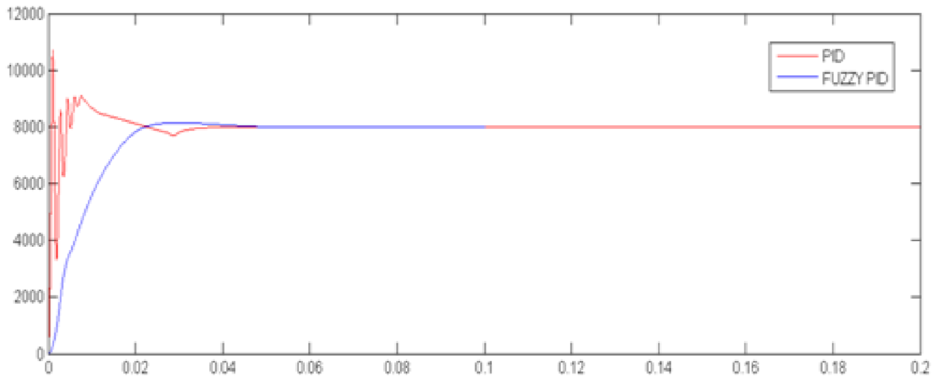

Fig. 12 waveform of the BLDCM at 8000 rpm

Oscillations over the whole speed range. This feature is valid for various operating conditions of the drive system, for speed reference changes as well as for load torque changes. It confirms that the FL controller is more robust to changes of operating condition of the drive system.

V. CONCLUSION

A fuzzy logic controller (FLC) has been used for the speed control of PMBLDC motor drive and outcome of a fuzzy controller is presented. The modeling and simulation of the complete drive system is explained in this paper. Effectiveness of the model is established by performance prediction over a wide range of operating conditions. A performance comparison between the fuzzy logic controller and the conventional PID controller has been analyzed out by simulation runs confirming the validity and superiority of the fuzzy logic controller. For implementing the fuzzy logic controller, tuning of gains to be adjusted such that manual tuning time of the classical controller is significantly reduced. The performance of the PMBLDCM drive with reference to PI controller and FLC controller have been experimentally verified with conventional PID controller using DSP processor. Fuzzy logic speed controller improves the performance of PMBLDC Drive.

Acknowledgements

I would like to articulate my profound gratitude and indebtedness to my guide Mrs. Suman Sharma as well as co-guide Mr.Amandeep Gill, who have always been a source of constant motivation and guiding factor throughout the complete work. They have been a guiding factor and great opportunity to work under them to complete the work successfully.

I wish to extend my sincere thanks to Dr. Ramesh Pachar, Vice-Principal and Head of the Deptt.(Electrical Engg.).

An undertaking for the work of this nature could never have been attempted with our reference to and inspiration from the works of others whose details are mentioned in reference section. I admit my obligation to all of them. I would also like to take this opportunity to thank my batch mates because without the help and support that we shared among us, it could not have been able to shape out the report.

REFERENCES

Journal Papers:

[1] Tolliver.C.L, Shieh.L.S, Ali.W.H, Zhang.Y,and, Akujuobi.C.M ,"Load disturbance resistance speed controller design for permanent magnet synchronous motor(BLDC)," IEEE Transition. Ind. Electron., vol. 53, no. 4, pp. 1198– 1207, August. 2006.

[3] Rahman.M.A,"Special section on Permanent magnet motor drives; Guest editorial," IEEE, Trans. on Ind. Electronics, vol. 43, no. 2, pp. 245,1996.

[5] Wang.X.Y, Chau.K.T Jiang.J.Z. Chen.G.H, and Chan.C.C, "A novel poly phase multi pole square wave permanent magnet motor drive for electric vehicles", IEEE, Transactions on Industry App., vol. 30, no. 5, pp.1258-1266, 1994.

[8] Pillay. P and Krishnan. R, "Application Characteristics of Permanent Magnet Synchronous and Brushless dc Motors BLDCM for Servo Drives," IEEE Trans. Industrial. Application., vol. 27, no.5, pp. 986-996 September./October. 1991.

[9] Chan. C. and Cheng. M, "Design and analysis of a new doubly salient permanent magnet motor," IEEE Trans. Magazine., vol. 37, pp. 3012–3020, July 2001.

Proceedings Papers:

[2] Concari.C, Torni.F ,"Sensor less control of BLDC motor at Lower Speed based on differential back emf measurement ",IEEE, Conference on energy conversion congress & exposition, pp. 1772-1777, sept.2010.

[4] Hwang.R.C, Yu.G.R, "Optimal PID Speed control of BLDC motor Iqr approach", IEEE, Conference on system, man & cybernetics, vol.1, pp. 473-478, Oct.2004.

[6] Bakly.A.E,Fouda.A and Sabry.W. , "A Proposed DC Motor Sliding Mode Position Controller Design using Fuzzy Logic and PID Techniques," ASAT, 13th International Conf. on Aerospace Sciences & Aviation Technology, pp 13-14May 2009.

[7] Baek.S and Kuc.T., " An Adaptive PID Learning Control of DC Motors" IEEE, Conference on System, Man, and Cybernetics, vol. 3,pp 2877 – 2882, Oct 1997.

[10] Fallahi.M and Azadi.S.," Fuzzy PID Sliding Mode Controller Design for the position control of a DC Motor",IEEE, International Conf. on Education Technology and Computer, pp 73-77, April 2009.

I. FIGURES AND TABLES

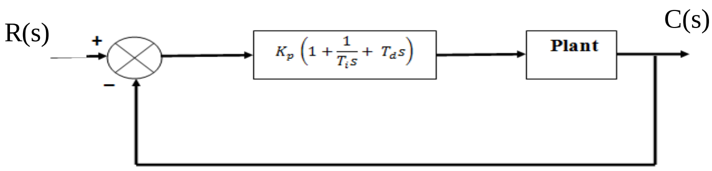

Fig.1 Schematic Block Diagram of Speed Controller

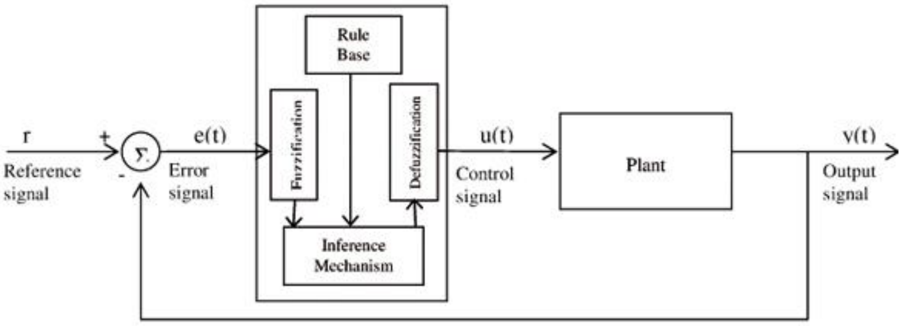

Fig.2Block diagram of fuzzy logic controller

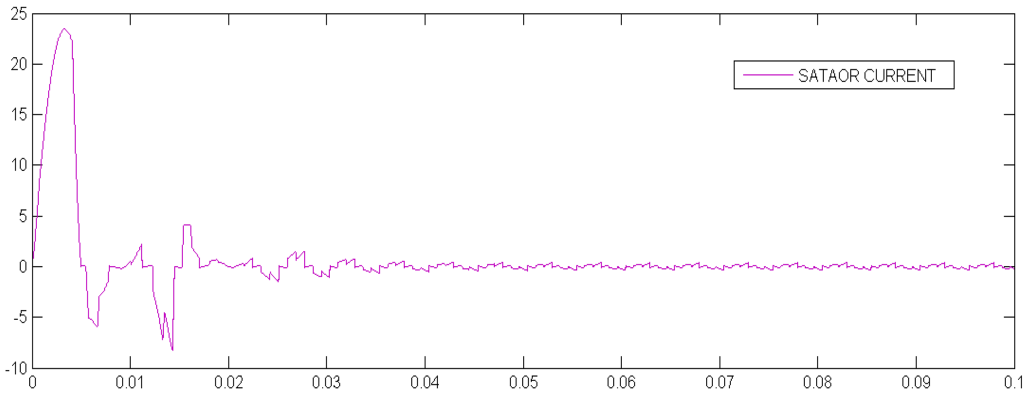

Fig. 3 Waveform of the stator current (phase a) of BLDCM

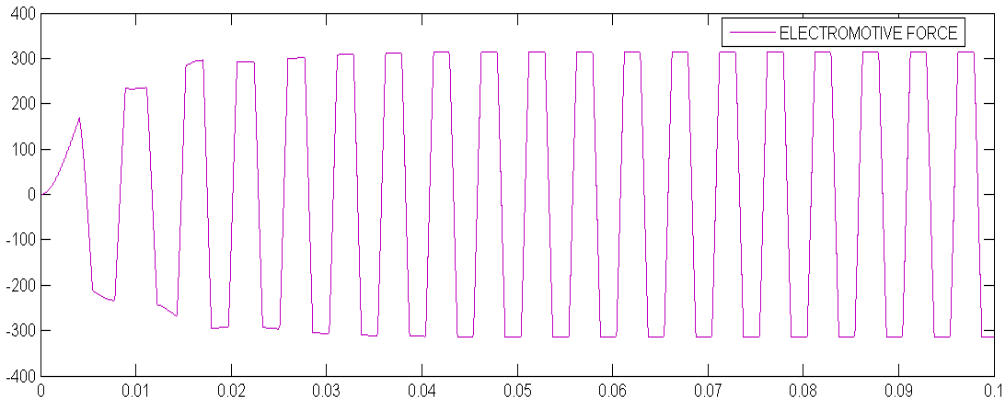

Fig.4 Waveform of Stator back EMF

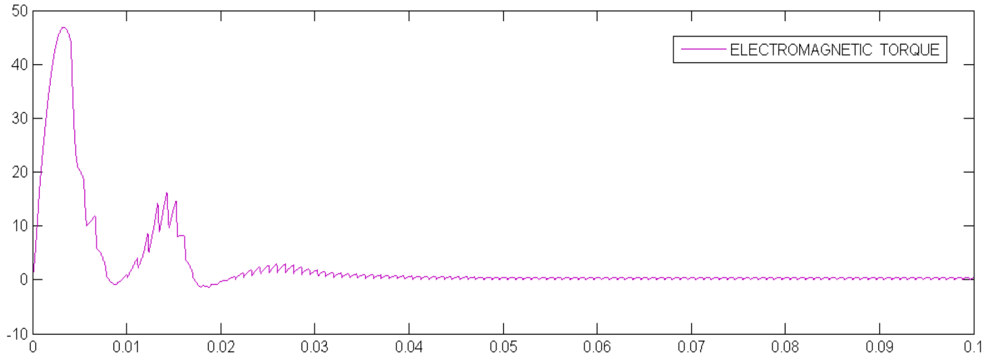

Fig.5 Waveform of the Electromagnetic Torque Te (Nm) of BLDCM

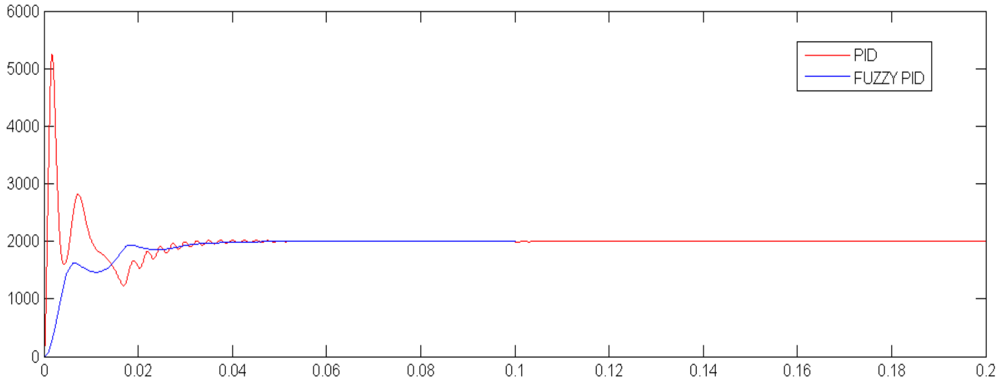

Fig. 6 Waveform of the BLDCM at 2000 rpm

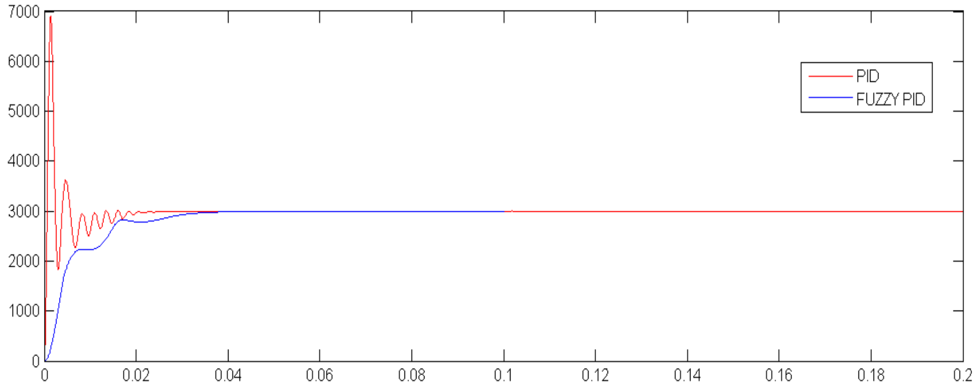

Fig.7 Waveform of the BLDCM at 3000 rpm

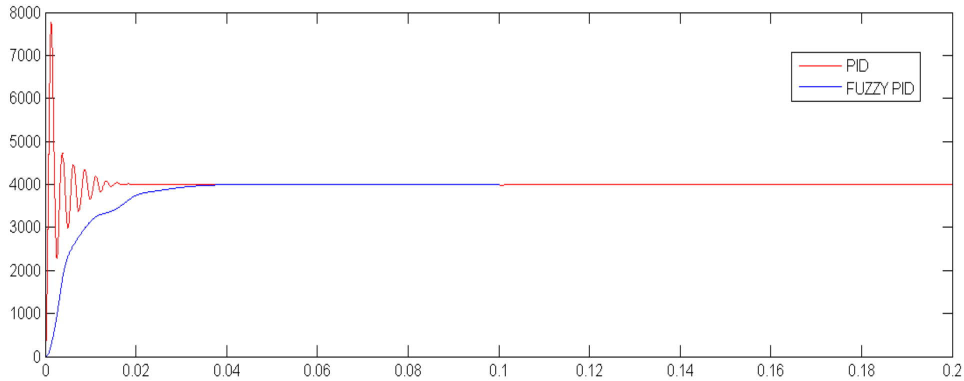

Fig. 8 Waveform of the BLDCM at 4000 rpm

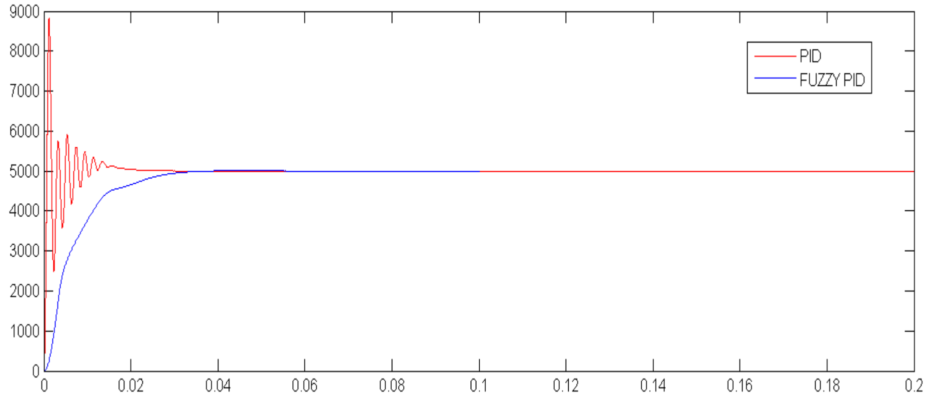

Fig.9 Waveform of the BLDCM at 5000 rpm

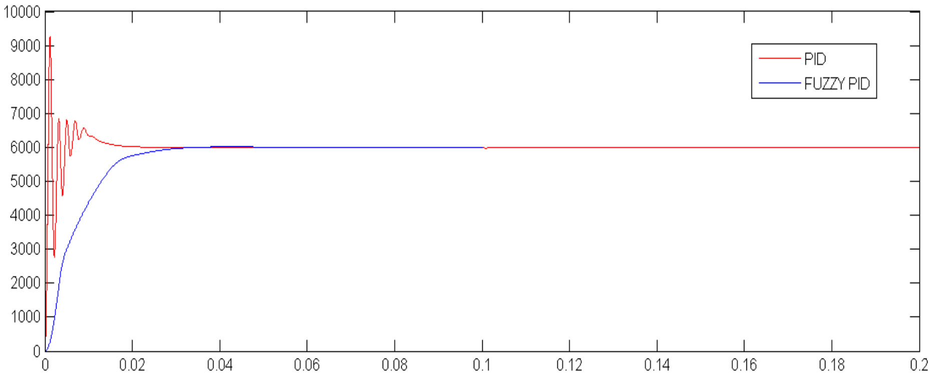

Fig. 10 Waveform of the BLDCM at 6000 rpm

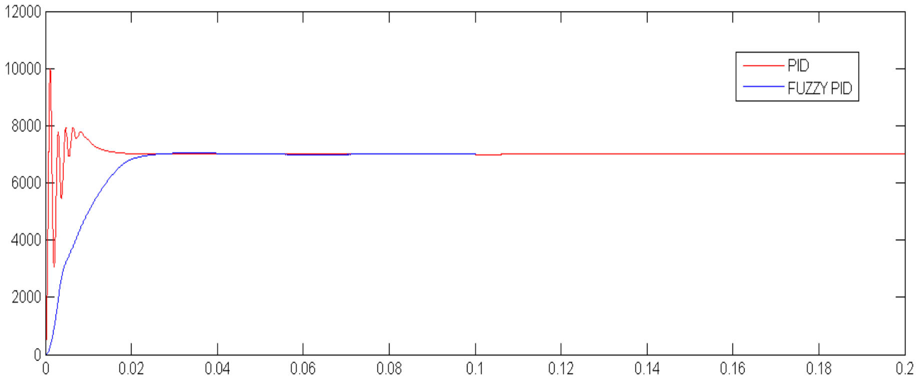

Fig. 11Waveform of the BLDCM at 7000 rpm

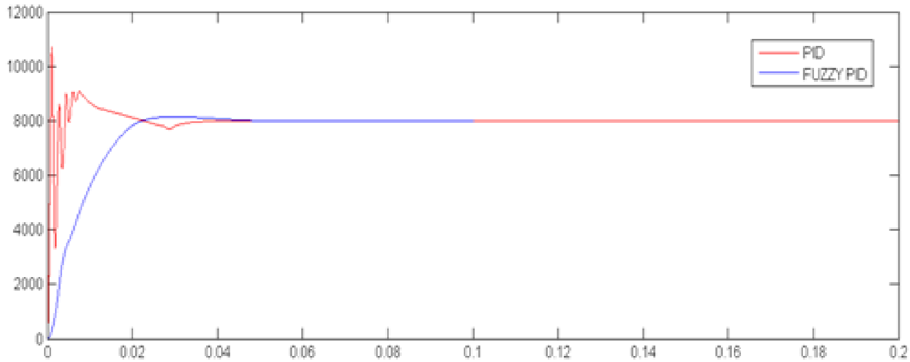

Fig. 12 waveform of the BLDCM at 8000 rpm

Table 1

7×7 Rule base table for Fuzzy Logic Controller

E/CE	NB	NM	NS	ZE	P	P	PL
NB	NB	NM	NS	NS	NS	NS	ZE
NM	NM	NM	NS	NS	NS	ZE	ZE
NS	NS	NS	NS	NS	ZE	NS	PM
ZE	NS	NS	NS	ZE	PS	PM	PM
PS	NS	NS	ZE	PS	PS	PS	PS
PM	NS	ZE	NS	PM	PS	PL	PL
PL	ZE	PS	PM	PL	PL	PL	PL

Table 2
Comparison between Rise time and maximum peak overshoot of FLC and PID controller

controllers	**Speed (rpm)**	**Rise Time (sec)**	**rcentage ershoot**
gler- Nicholus based PID Controller	2000	4.03e-4	162.50
	3000	4.05e-4	130.49
	4000	4.44e-4	94.03
	5000	4.35e-4	76.40
	6000	4.70e-4	56.85
	7000	4.90e-4	42.85
	8000	4.90e-4	33.75
tuned Fuzzy logic PID controller	2000	.01484	0.00556
	3000	.01365	.02366
	4000	.01628	0.05862
	5000	.01373	0.1736
	6000	.01366	0.2720
	7000	.01403	0.6165
	8000	.01431	1.7975

Table 3
Ziegler & Nichols tuning parameters

Type of Controller	k_p	T_i	T_d
P	**T/L**	□	**0**
PI	**0.9 T/L**	**L/0.3**	**0**
PID	**1.2 T/L**	**2L**	**0.L**

Table 4
Brushless DC motor Parameters

Power input	1 KW
No. of Poles	4
No. of Phases	3
Type of connection	star -delta
Supply voltage (V_{dc})	500volt
Rated speed	3000 RPM
Stator phase resistance	2 .8750ohm
Stator phase Inductance	8.5×10^{-3}Henry
Flux linkage established by magnet	250V.s
Inertia	$.8\times10^{-3}$(Kg.m^2)
Friction factor	0.3(N.m.s)

Table 5
FLC(Fuzzy Logic Controller) Parameters

FLC Type	Mamdani
Number of Inputs	2
Number of outputs	3
Number of Rules	49
AND Method	Min.
OR Method	Max.
Defuzzification Method	Height Defuzzification

INDENTATIONS AND EQUATIONS

$$\begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} + p \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \begin{matrix} i_a \\ i_b \\ i_c \end{matrix} + \begin{bmatrix} e_{as} \\ e_{bs} \\ e_{cs} \end{bmatrix}$$
(1)

E_p= (B*l*v) N=n (B1rω_m) =N$\phi_a \omega_m = \lambda_p \ \omega_m$ (2)

$e_{as} = f_{as} \ (\theta_r) \ \lambda_p \ \omega_m$ (3)

$e_{bs} = f_{bs}(\theta_r) \ \lambda_p \ \omega_m$ (4)

$e_{cs} \ = f_{cs} \ (\theta_r\,) \ \lambda_p \ \omega_m$ (5)

$T_e = \lambda_p[f_{as}(\theta_r)\, i_{as} + (\theta_r) i_{bs} + f_{cs}(\theta_r) i_{cs}]$ (N.m) (6)

$T_e^* = 2\lambda_p \ i_p^*$ (7)

$$G_c \ s = k_p(1 + \frac{1}{T_{i\,s}} + T_d s)$$

(8)