ISSN (Online): 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization Volume 3, Special Issue 5, July 2014

International Conference On Innovations & Advances In Science, Engineering And Technology [IC - IASET 2014]

Organized by

Toc H Institute of Science & Technology, Arakunnam, Kerala, India during 16th - 18th July -2014

Online Tuning Based Fuzzy Logic Controller for Speed Control of BLDC Motor

George Jacob[1], Tony AbyVarkey M[2], PriyankaMukesh[3], Jisha K. R.[4]

U. G. Student, Dept of AEI, AdiShankara Institute of Engg. And Tech., Kalady, Kerala, India[1]

Assistant Professor, Dept of ECE, Faculty of Engineering, Christ University, Bangalore, India[2]

Assistant Profess or, Dept of AEI, AdiShankara Institute of Engg. And Tech., Kalady, Kerala, India[3]

Assistant Professor, Dept of AEI, AdiShankara Institute of Engg. And Tech., Kalady, Kerala, India[4]

ABSTRACT: Brushless Direct Current (BLDC) motors are one of the motor types rapidly gaining popularity. BLDC motors are widely used in industries such as Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation. BLDC motors are receiving wide attention due to their high efficiency, high dynamic response, better speed versus torque characteristics and small size. Conventional controllers are widely used to control BLDC motors. But they often fail to control the BLDC as they suffer from uncertain parameters and the non-linearity of the BLDC motors. Fuzzy control can be used to control the speed of the BLDC motors. In this paper, a fuzzy logic controller whose parameters are tuned on line is proposed to control the speed of a BLDC motor and is compared with conventional controllers like PI and PID.

KEYWORDS: BLDC, FLC, PI, PID

I. INTRODUCTION

Brushless DC motors are reliable, easy to control and inexpensive. Due to their favorable electrical and mechanical properties, high starting torque and high efficiency, the BLDC motors are widely used in most servo application as actuation, robotics, machine tools and so on. The design of the BLDCM servo system usually requires time consuming trial and error process, and fail to optimize the performance. In practice, the design of the BLDCM drive involves a complex process such as model, devise of control scheme, simulation and parameters tuning. Usually, the parameters tuning for a servo system involves a sophisticated and tedious process and requires an experienced engineer in doing so. The PI controller is suitable for the linear motor control. However, in practice, the driver and load impose many non-linear factors. The PI controller cannot be suitable for non-linear system. Fuzzy control is a versatile and effective approach to deal with the non-linear and uncertain system. Even if a fuzzy controller (FLC) can produce arbitrary non-linear control law, the lack of systematic procedure for the configuration of its parameters remains the main obstacle in practical applications.

II. BLDC MOTORS

BLDC motor is a synchronous machine. The Permanent Magnet synchronous motors are classified on the basis of the wave shape of their induced emf, i.e., sinusoidal or trapezoidal. The sinusoidal type is known as PM synchronous motor; the trapezoidal type goes under the name of Permanent Magnet Brushless DC (PMBLDC) machine. In this paper a PM Brushless DC motor is used.

ISSN (Online): 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization   Volume 3, Special Issue 5, July 2014

International Conference On Innovations & Advances In Science, Engineering And Technology [IC - IASET 2014]

Organized by

Toc H Institute of Science & Technology, Arakunnam, Kerala, India during 16th - 18th July -2014

A. ***Modeling of PMBLDC Motor***

The state space model of a PM Brushless Dc motor is developed as

$$\lambda_P = NBlr$$

$$\dot{x} = Ax + Bu$$

where

$$x = [i_{as} \quad i_{bs} \quad i_{cs} \quad \omega_m \quad \theta_r]^T$$

$$A = \begin{bmatrix} -\frac{R_s}{L_1} & 0 & 0 & -\frac{\lambda_p}{L_1} f_{as}\theta_r & 0 \\ 0 & -\frac{R_s}{L_1} & 0 & -\frac{\lambda_p}{L_1} f_{bs}\theta_r & 0 \\ 0 & 0 & -\frac{R_s}{L_1} & -\frac{\lambda_p}{L_1} f_{cs}\theta_r & 0 \\ \frac{\lambda_p}{J} f_{as}(\theta_r) & \frac{\lambda_p}{J} f_{bs}(\theta_r) & \frac{\lambda_p}{J} f_{cs}(\theta_r) & -\frac{B}{J} & 0 \\ 0 & 0 & 0 & \frac{P}{2} & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{1}{L_1} & 0 & 0 & 0 \\ 0 & \frac{1}{L_1} & 0 & 0 \\ 0 & 0 & \frac{1}{L_1} & 0 \\ 0 & 0 & 0 & -\frac{1}{J} \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$L_1 = L - M$$

$$u = [v_{as} \quad v_{bs} \quad v_{cs} \quad T_l]^T$$

where

R_s = stator resistance per phase
L = stator inductance per phase
M = mutual inductance.
i_{as}, i_{bs}, i_{cs} are the stator phase currents
ω_m is the electrical rotor speed
θr is the electrical rotor position
N is the number of conductors in series per phase
B is the flux density of the field
L is the rotor length
R is the rotor radius
f_{as}, f_{bs}, f_{cs} are functions of rotor electrical position.
J is the moment of inertia
P is the number of poles
$v_{as}v_{bs}v_{cs}$ are the individual phase voltages

ISSN (Online): 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization   Volume 3, Special Issue 5, July 2014

International Conference On Innovations & Advances In Science, Engineering And Technology [IC - IASET 2014]

Organized by

Toc H Institute of Science & Technology, Arakunnam, Kerala, India during 16th - 18th July -2014

III.CONTROL DIAGRAM

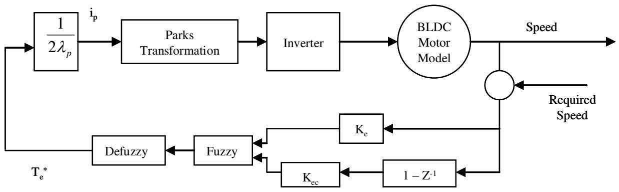


Fig. 3.1.Control Diagram for speed control of BLDC Motor

IV. TORQUE DEVELOPED

The electromagnetic torque developed is given by

$$T_e = [e_{as}i_{as} + e_{bs}i_{bs} + e_{cs}i_{cs}]\frac{1}{\omega_m}$$

The instantaneous induced emfs can be written as

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

Substituting the values of back emfs in the equation for torque, we get

$$T_e = \lambda_p[f_{as}(\theta_r)i_{as} + f_{bs}(\theta_r)i_{bs} + f_{cs}(\theta_r)i_{cs}]$$

Only two machine phases conduct current at any time, with the two phases being in series for full wave inverter operation, so the phase currents are equal in magnitude but opposite in sign. The rotor position dependent functions have the same signs as the stator phase currents in the motoring mode, but opposite signs in the regeneration mode. The result of such sign relationships is simplification of torque command as,

$$T_e = 2\lambda_p i_p^*$$

V. VECTOR CONTROL

The vector control of the PMBLDC motor is derived from its dynamic model. Considering the currents as the inputs, the three phase currents are

$$i_{as} = i_s \sin(\omega_r t + \delta)$$
$$i_{bs} = i_s \sin(\omega_r t + \delta - \frac{2\pi}{3})$$
$$i_{as} = i_s \sin(\omega_r t + \delta + \frac{2\pi}{3})$$

Where ω_r is the electrical rotor speed and δ is the angle between the rotor field and the stator phasor, known as the torque angle.

ISSN (Online): 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization Volume 3, Special Issue 5, July 2014

International Conference On Innovations & Advances In Science, Engineering And Technology [IC - IASET 2014]

Organized by

Toc H Institute of Science & Technology, Arakunnam, Kerala, India during 16th - 18th July -2014

The rotor field is traveling at a speed of ω_r rad/sec; hence the q and d axes stator currents in the rotor reference frame for a balanced three – phase operation are given by

$$\begin{bmatrix} i_{qs}^r \\ i_{ds}^r \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\omega_r t & \cos\left(\omega_r t - \frac{2\pi}{3}\right) & \cos\left(\omega_r t + \frac{2\pi}{3}\right) \\ \sin\omega_r t & \sin\left(\omega_r t - \frac{2\pi}{3}\right) & \sin\left(\omega_r t + \frac{2\pi}{3}\right) \end{bmatrix}\begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix}$$

From the above equations, the stator currents in the rotor reference frames:

$$\begin{bmatrix} i_{qs}^r \\ i_{ds}^r \end{bmatrix} = i_s \begin{bmatrix} \sin\delta \\ \cos\delta \end{bmatrix}$$

The stator – phase current commands are obtained for a balanced three phase operation as

$$\begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} = \begin{bmatrix} \cos\theta_r & \sin\theta_r \\ \cos\left(\theta_r - \frac{2\pi}{3}\right) & \sin\left(\theta_r - \frac{2\pi}{3}\right) \\ \cos\left(\theta_r + \frac{2\pi}{3}\right) & \sin\left(\theta_r + \frac{2\pi}{3}\right) \end{bmatrix}\begin{bmatrix} i_T \\ i_f \end{bmatrix} = i_s \begin{bmatrix} \sin(\theta_r + \delta) \\ \sin\left(\theta_r + \delta - \frac{2\pi}{3}\right) \\ \sin\left(\theta_r + \delta + \frac{2\pi}{3}\right) \end{bmatrix}$$

These stator – phase current commands are amplified by the inverter and its logic and fed to the PMBLDC.

VI. FUZZY CONTROL

Fuzzy logic provides an approximate effective mean of describing the behavior of some complex system. Unlike traditional logic type, fuzzy logic aims to model the imprecise modes of human reasoning and decision making, which are essential to our ability to make rational decisions in situations of uncertainty and imprecision.

The most significant variables entering the fuzzy logic speed controller have been selected as the speed error (e) and its time derivative (ec). The output this controller is U. The two input variables e(speed error) and ec(change in error) are calculated at each sampling time as

$$e(k) = s^*(k) - s(k)$$
$$ec(k) = e(k) - e(k-1)$$

where $s^*(k)$ is the reference speed at that time and s(k) is the actual speed.

The FLC consists of three stages:

1. Fuzzy
2. Rule execution and
3. Defuzzification.

A. Fuzzy Operation:

In this stage the crisp variables are converted in to fuzzy variables as:

$$e_f = K_e e$$

$$ec_f = K_{ec} ec$$

$$u_f = u / K_u$$

whereKe and Kec are the proportion coefficients which transform the input to the universe of fuzzy sets. Ku transform the fuzzy output to the actual control value. All these transformations are strictly according to the prescribed membership functions associated with the input and output variables. The membership function has been chosen to be triangular as shown in figure.

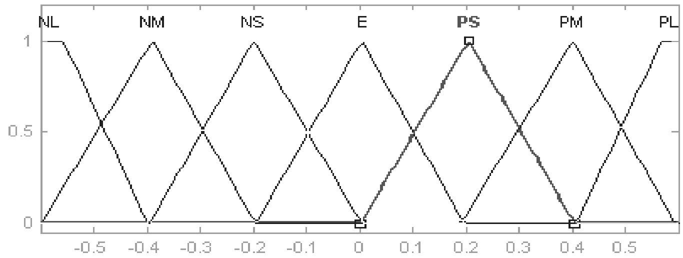


Figure 6.1. : Membership Functions

B. Rule Execution

The universe of discourse of input variables error (e) and change in error (ec)and output U are divided from –0.6 to +0.6. Each universe of discourse is divided into seven fuzzy sets: NB, NM, NS, Z, PS, PM and PB. Each fuzzy variable is a member of the subsets with a degree of between 0 (non member) and 1(full member) as

$$\mu_A(x) = \begin{cases} 1, \mu_A \in A \\ 0, \mu_A \notin A \end{cases}$$

The variables error (e_c) and change in error (e_{ce}) are processed by an inference engine which executes 49 rules. All the 49 rules are given in the table 1. Each rule is expressed in the form as

If e_c is NB and e_{ce} is Z then U is PB

If e_c is NS and e_{ce} is NM then U is PM ……. and so on

e_{ce}	e_c						
	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PM	PM	PS	PS	NM
NM	PB	PB	PM	PS	PS	Z	NM
NS	PB	PM	PS	PS	Z	NS	NB
Z	PB	PS	PS	Z	NS	NS	NB
PS	PB	PS	Z	NS	NS	NM	NB
PM	PM	Z	NS	NS	NS	NM	NB
PB	PM	NS	NS	NM	NM	NM	NB

Table 6.1: Fuzzy Linguistic Rules

C. Defuzzification

The input for the defuzzification process is a fuzzy set (the aggregate output fuzzy set) and the output is a single number. The aggregate of a fuzzy set encompasses a range of output values, and so must be defuzzified in order

IJIRSET

ISSN (Online): 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization Volume 3, Special Issue 5, July 2014

International Conference On Innovations & Advances In Science, Engineering And Technology [IC - IASET 2014]

Organized by

Toc H Institute of Science & Technology, Arakunnam, Kerala, India during 16th - 18th July -2014

to resolve a single output value from the set. The most popular defuzzification method is the centroid calculation, which returns the center of area under the curve is used here. The centroid of each output membership function for each rule is first evaluated. The final output is then calculated as the average of the individual centroid.

VII. ON-LINE TUNING

In order to improve the dynamic performance of the BLDCM servo system, the elements ofthe query table need to be adjusted according to the input variables. To do this, this paper adjuststhe coefficients (K_e, $K_{ec}$and K_u) to tuning the control system on-line.

The basic principle is the "rough adjustment" and "accurate adjustment", namely, constantlyadjusting the coefficients according to actual error and change in error. If the errorand change in errorare large, $K_e$andK_{ec} should be reduced while K_u should be increased because the main objective is diminishingthe errors. When error and change in errorare small, because the main aim is to diminish the overshoot andsteady-state error, K_e and K_{ec} should be increased to increase the resolution of errorand change in errorwhile $K_u$should be reduced to obtain small control value to reduce the overshoot andsteady-state error. The adjust functions as follows:

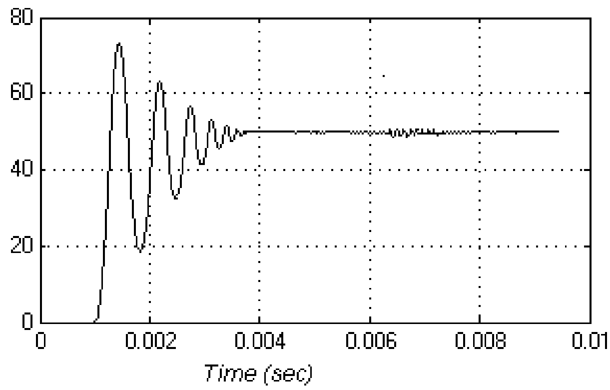
$$K_e = \begin{cases} K_{e0} + K_1 e, & |e| \le \frac{e_{\max}}{2} \\ K_{e0} + K_1 \frac{e_{\max}}{2}, & |e| > \frac{e_{\max}}{2} \end{cases}$$

$$K_{ec} = \begin{cases} K_{ec0} + K_1 e, & |e| \le \frac{e_{\max}}{2} \\ K_{ec0} + K_1 \frac{e_{\max}}{2}, & |e| > \frac{e_{\max}}{2} \end{cases}$$

$$K_u = \begin{cases} K_{u0} + K_1 e, & |e| \le \frac{e_{\max}}{2} \\ K_{u0} + K_1 \frac{e_{\max}}{2}, & |e| > \frac{e_{\max}}{2} \end{cases}$$

VIII. RESULTS

The proposed Fuzzy Logic Controller is compared with conventional controllers like the PI and the PID controller for evaluating the validity of the Fuzzy Logic Controller developed. Figure 8.1 shows the response of the system when a PI controller is used. Figure 8.2 shows the response when a PID controller is used. Figure 8.3 shows the response when the proposed Fuzzy Logic Controller is used.



ISSN (Online): 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization *Volume 3, Special Issue 5, July 2014*

International Conference On Innovations & Advances In Science, Engineering And Technology [IC - IASET 2014]

Organized by

Toc H Institute of Science & Technology, Arakunnam, Kerala, India during 16th - 18th July -2014

Figure8.1: Control using PI Controller

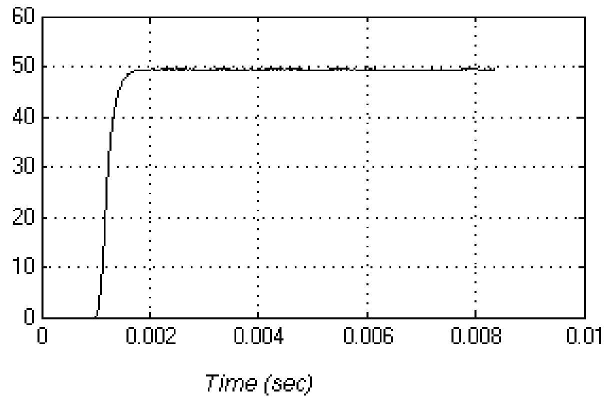


Figure8.2: Control using PID Controller

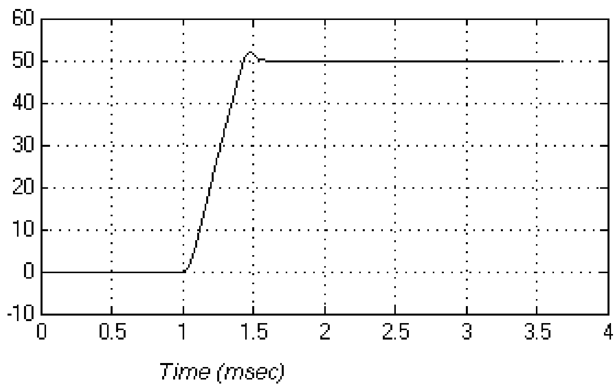


Figure 8.3: Control using Fuzzy Logic

Figure 8.1 shows that the PI controller has a larger overshoot. Figure 8.2 shows that the PID controller does not meet the required speed specifications. The response of the Fuzzy Logic Controller shown in figure 8.3 has a much lesser overshoot and a very good steady state response. The value of the settling time for 2% tolerance for the three controllers are provided in the table 8.1.

Controller	Settling Time
PI	0.038 sec
PID	0.018 sec
FLC	0.015 sec

Table 8.1: Comparison of Settling times

ISSN (Online): 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization   Volume 3, Special Issue 5, July 2014

International Conference On Innovations & Advances In Science, Engineering And Technology [IC - IASET 2014]

Organized by

Toc H Institute of Science & Technology, Arakunnam, Kerala, India during 16th - 18th July -2014

IX. CONCLUSION

The work consisted of comparing the control strategies available to control the BLDC motor. PI and PID controller fail to meet the performance specifications as both these conventional controllers does not provide a good solution for non linear systems. The Fuzzy Logic Controller offers a very good solution to control the speed of the BLDC motor as FLC are mainly used for non linear or uncertain systems.

REFERENCES

[1] R. Krishnan, "Electric Motor Drives Modeling Analysis and Control" *Pearson Education*
[2] W.S. Oh, Y.T. Kim, C.-S. Kim, T.S. Kown, and H.J. Kim, "Speed Control of Induction Motor Using Genetic Algorithm Based Fuzzy Controller," *Industrial Electronics Society Conference of IEEE*, vol. 3, no. 2, pp. 625-629, 1999
[3]D. Silva, W. Acarnley, and Finch, "Application of Genetic Algorithm to the Online Tuning of Electric Drive Speed Controllers," *Trans. Ind. Electron of IEEE*, vol. 47, no. 1, pp. 217-219, 2000.
[4] www.microchip.com
[5] Takagi T. and Sugeno M., "Fuzzy Identification of Systems and Its Applications to Modeling and Control", IEEE Transactions on Systems, Man, and Cybernetics, 15, 1, 116-132, 1985
[6] Jang J.- S. R and Sun C.-T., "Neuro-Fuzzy Modeling and Control",*Proceedings of the IEEE*, Vol. 83, 1995, pp. 378-406.
[7] G. Ron Chen, "Fuzzy PID Controllers for Industrial Applications", Lecture Notes, CityUniversity of Hong Kong