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Speed Control of BLDC Motor Using Fuzzy Logic Controller and Comparing It with PID Controller

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Abstract – Brushless DC motor is suitable for wide range of application in battery-powered vehicles, machine tools, robots, automatic wheelchairs, aerospace, temperature controllers and in many engineering, applications owing to their mechanical and electrical characteristics. Though, the non-linearity features of this motor drive make it problematic to operate it with a conventional Proportional integral derivative (PID) controller. To eliminate this problem, a Fuzzy Logic Controller with Gaussian membership function was designed. The controller is planned to record changes in speed references and steadies the output speed during load fluctuations. The usefulness of the projected technique is verified in this paper by developing mathematical simulation model in MATLAB/ Simulink software. The simulation results demonstrate that the proposed Fuzzy-Logic controller (FLC) illustrations a significant improvement of the control performance in comparison to the PID controller for both speed and load disturbance fluctuations.

Index Terms— Brushless DC Motor (BLDC), Inverter, PID Controller, the Fuzzy Logic Controller (FLC), Closed-Loop Speed Control

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1. INTRODUCTION

Nowadays, Brushless Direct Current (BLDC) motors are substituting ac motors and dc motors due to their high operational speed, less maintenance, high efficiency, outstanding speed-torque characteristics, and small size. BLDC motor is used in machine tools, robotics, battery-powered application, computer disk drives and electric vehicles (Pillay and Krishnan, 1989, Suganya Devi and Sathiskumar, 2015)

The BLDC motor is a synchronous AC motor. Current carrying stator windings generate electromagnetic poles. The stator phase, which is supplied with electricity, attracts rotor. In order to generate and maintain a rotating field on the stator, the corresponding phase sequence is fed to the stator. The traditional control techniques such as P, PI, PID are used for speed controlling. However, these controllers require a precise model and can only be applied to high linear systems. If the system is non-linear, these controllers will not provide better performance (Pillay and Krishnan, 1989). In addition, the tuning of these controllers is a difficult process. Practically, BLDC motors have variations in their parameters and varying load. As a result, their control system characteristics are non-linear and therefore conventional control method are not useful to them (Suganya Devi and Sathiskumar, 2015). The fuzzy logic controller is more suitable for BLDC motor due to its characteristics.

2. LITERATURE REVIEW

By adjusting a speed of DC motor, we can have high performance and easy controllability. Nowadays BLDC motors are used in electric vehicles, rolling mills, electric cranes, electric train and robotics. Speed Control of DC motor by means of voltage control is carried out firstly by Ward Leonard in 1981. IGBT, MOSFET, GTO and other semiconductor components have been used as electric switching devices for voltage regulation. To conclude, the control of the system is difficult due to their nonlinear characteristics. To overwhelm this problem fuzzy logic controller can be developed.

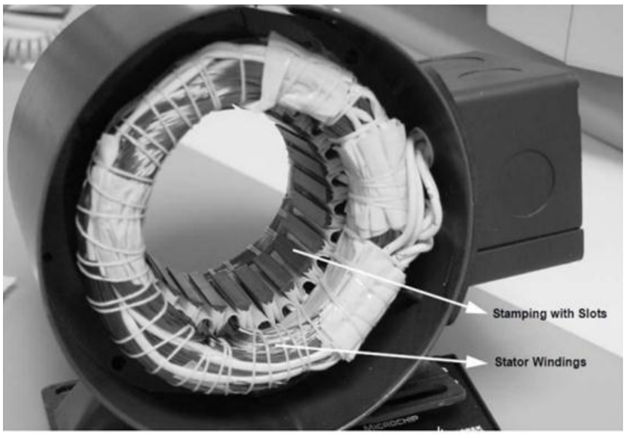
Balogh Tiber [3] has developed a mathematical model to control communication of BLDC motor by using electrical and mechanical equation. Another scheme based on trapezoidal characteristics of back emf was developed by E. Kalliappan [4].

Many designs use controllers like FPGA based control (Albert, et. al., 2010) and DSPIC based control (Rao, 2008) for BLDC has been defined. Digital implementation of BLDC for a wide range of speed control (Shanmugasundram, et. al., 2009) using fuzzy has already been implemented. Adaptive neural-fuzzy based emotional learning algorithm is also developed for speed control of BLDC motor (Li, et. al., 2016)

3. CONSTRUCTION AND WORKING OF BLDC MOTOR

BLDC motor is an electronically commuted motor. In BLDC motor brushes are eliminated compared to DC motor. Here, the rotor and stator generated magnetic field rotate at the same frequency. The stator circuit is made of magnetic steel (Milivojevic, et. al., 2012). The windings of the stator phase are inserted into slots (a distributed winding) or are wound on the poles as a single coil. The magnetization and displacement of the permanent magnets are selected in such a way that we get back emf in the trapezoidal shape.

The commutators and the brushes reverse the polarity of the current in the DC commutator motor, but in the BLDC motor, the polarity is reversed by semiconductor switches (Milivojevic, et. al., 2012). The commutator has some limitations related to the maximum speed of a DC motor. Replacing a Direct Current motor with a Brushless DC motor places a higher demand on the control circuit and the control algorithm. BLDC motor is a 3-phase motor. So, it requires 3 phase supply. In BLDC motor hall sensor is placed on the rotor shaft for sensing its position (Hyun-Soo, et. al., 2017). Motor performs as a DC motor and runs at its best speed. But the disadvantage of this motor is that it required power converter so due to this it's cost increases.



The stator of BLDC motor

Fig 1. Construction of BLDC Motor

4. CONTROLLER DESIGN

Here we are going to use PID and Fuzzy logic controller to control the speed of BLDC motor. And then we are going to compare the performance of both controllers which can be seen in below sections.

4.1 PID Speed Controller

The Proportional integral derivative controller is the closed loop mechanism which is used in the control system in industries and for many other applications. The PID controller continuously calculates error signal which is given by error detector where two values are compared, and an error signal is produced that is it compares the actual speed and reference speed. So PID controller then generates reference torque or a signal which is further given to the inverter. (Madhusudan, 2012) Below fig.3 shows the reference block diagram of the PID controller.

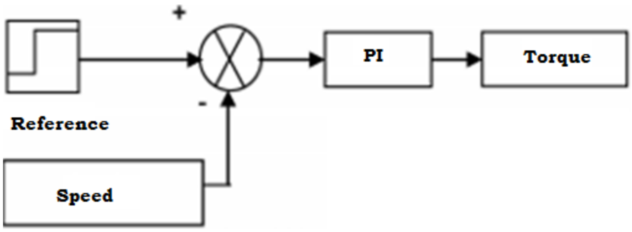


Fig 2. PID speed controller implementation

4.2 Fussy Logic Controller

Fuzzy logic is widely used in machines for control purpose. The term fuzzy means the logic which deals with the concept that expresses that whether the value is true or false. Fuzzy logic has many advantages like it gives a solution to a problem in such a way that a human operator can easily understand it and can use this for designing better controller (Zadeh, 1973). Design of such controller make the process faster and it became easy to implement it in the system.

4.2.1 Fuzzification

Fuzzy logic is divided into two parts and fuzzification is the first block in it. Fuzzification gives fuzzy value at the output. This is achieved by using membership function. Its range is 0 to 1. (Shanmugasundram, et. al., 2009).

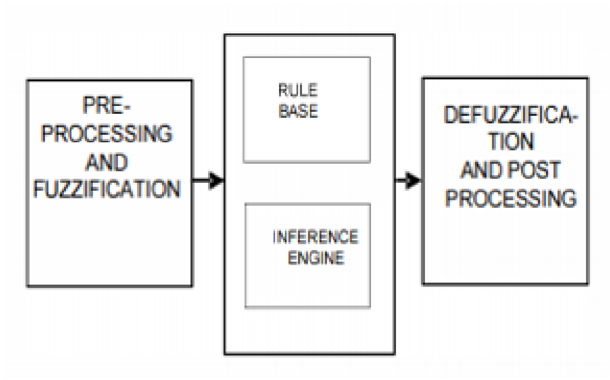


Fig 3. Fuzzy Logic Controller

4.2.2 Rules base

Fuzzy rules are a linguistic function which uses IF-THEN function. For example, it is given that "IF A THEN B" which means that if the input value is A then the output should be B else zero. The fuzzy logic rule is shown in Table I. Here PE- positive error, NE- negative error, ZE- zero error. Same way for CE. So, it makes a 3x3 matrix. Now the two-input value is in the range of NE and NCE then from the matrix or fuzzy rule the output is N which is a Negative region, so we get some value in output which lies in this N region (Madhusudan, 2012).

4.2.3 Defuzzification

Defuzzification is the reverse of fuzzification. It is the process of producing logic of a given fuzzy set and of the membership function. By using centroid defuzzification method crisp output can be obtained. Further its output is given to the inverter (Albert, et. al., 2010).

E CE	NE	ZE	PE
NCE	N	N	P
ZCE	N	NC	P
PCE	N	P	P

Fig 4. 3X3 FLC Matrix

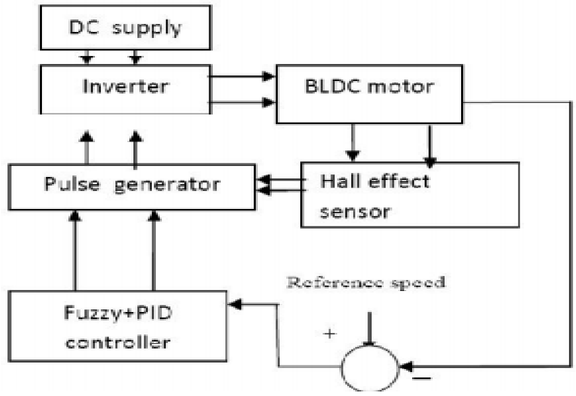


Fig 5. Block diagram for speed control of BLDC motor using FLC and PID controller

5. MODELING OF BLDC MOTOR

The mathematical modeling of BLDC motor is done by using many simultaneous equations, where this equation depends on input and on some constant values. This constant value includes the value of phase inductance, resistance, etc. which remains constant throughout the process because motor parameters do not change. However, during the process, if we want to change any parameters then in Simulink provides a dialogue box to change this parameter. Here we have assumed star wound rotor. Here we have done state space modeling of BLDC motor by using different equations. While doing this project many different approaches where tried and it could be found that state space is the best approach to do modeling of the motor and an accurate one.

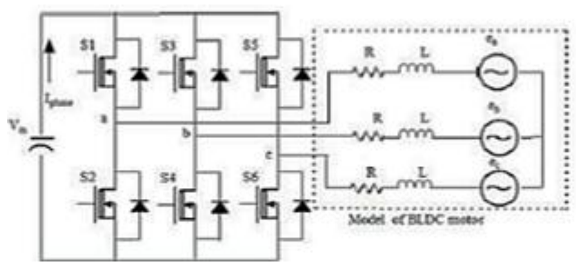


Fig 6. A mathematical model of BLDC motor

So, the stator winding equation can be given by, The coupled circuit equations of the stator windings in terms of motor electrical constants are

$$\begin{bmatrix} V_{as}-v_n \\ V_{bs}-v_n \\ V_{cs}-v_n \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + p\begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix}$$

--(1)

where:

R_s : Stator resistance per phase

I_a, I_b, I_c : Stator phase currents

p : $\frac{d}{dt}$ is the time derivative operator

E_a, E_b, E_c represent the back emfs in the respective phases in (1)

v_n : is the neutral point node voltage given by[2]:

$$v_n = \frac{1}{3}[V_{as} + V_{bs} + V_{cs}] - \sum BEMFs \quad \text{--(2)}$$

Σ B EMF means summing of all EMFs.

The peak value of trapezoidal emf is given by,

Ep = (BLv)N = N (Blrω) = NΦω =λ ω --(3)

Where:

λ = total flux linkage given as the

N = number of turns per phase

L = rotor length

Φ = flux linkage

B = flux density of the field in Weber

ω = electrical angular speed in rad/sec

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = R_s * \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + p\begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} \quad \text{-(4)}$$

Simplifying (3) further we get equation (4)

$$\begin{bmatrix} Vas \\ Vbs \\ Vcs \end{bmatrix} = R_s * \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + p\begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} \quad \text{-(5)}$$

The generated electromagnetic torque is given by

$$T_e = [E_a I_a + E_b I_b + E_c I_c]/\omega \text{ (in N.m)} \quad \text{- (6)}$$

The induced emfs can be written as

$$\begin{aligned} E_a &= \text{fa}(\theta)\lambda\ \omega. \\ E_b &= \text{fb}(\theta)\lambda\ \omega. \\ E_c &= \text{fc}(\theta)\lambda\ \omega. \end{aligned} \quad \text{-(7)}$$

Now,

J(dω /dt) + Bω = *Te*- *Tl*-(8)

Where:

B = friction coefficient

J = moment of inertia

Tl = load torque (Krishnan, 2001).

6. SIMULATION AND RESULTS

6.1 Speed control of BLDC motor using PID controller (State space modeling)

Here we are using MATLAB/Simulink environment for implementation of the mathematical model of BLDC motor with PID controller.

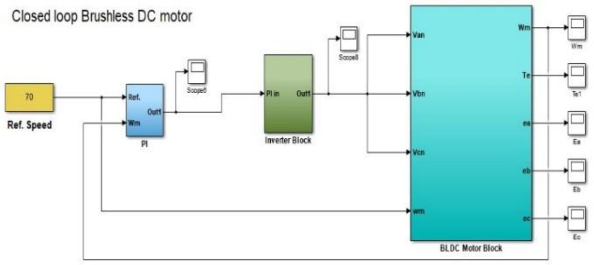


Fig 7. State space model of closed-loop speed control of BLDC motor using PID controller

This BLDC motor takes voltage values depends upon torque, emf, and on many other factors. The output is calculated by solving differential equations and then this value is put in the Simulink model. The Simulink model of closed-loop control of BLDC motor developed based on the mathematical equations. This closed-loop model consists of many blocks which include- inverter block, BLDC motor block, controller block, feedback loop.

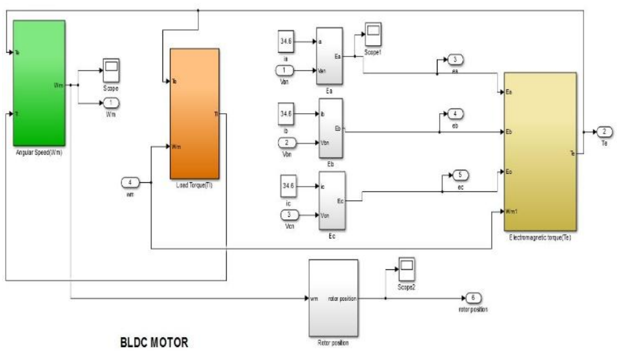


Fig 8. BLDC Motor block diagram (Simulink)

Result: -

Input speed= 500 rpm

Output speed= 498.8 rpm

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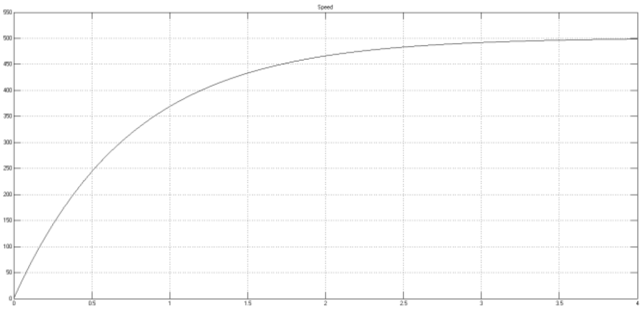

Fig 9. Speed output of the motor

6.2 Speed control of BLDC motor using a fuzzy logic controller (State space modeling)

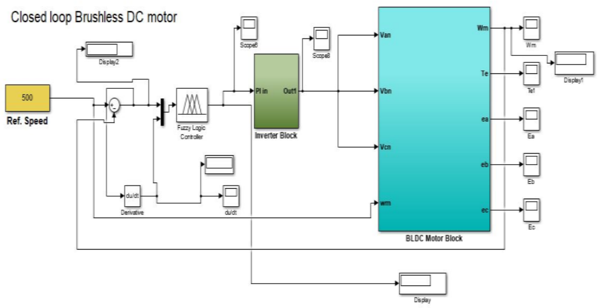

Fig 10. State space model of closed-loop speed control of BLDC motor using the Fuzzy logic controller

Fuzzy Logic Controller:

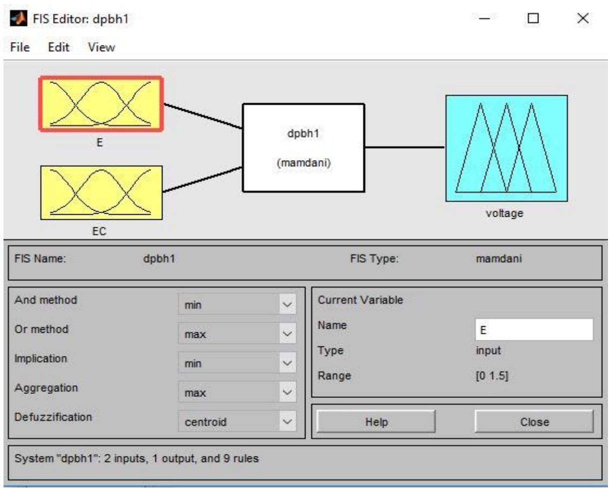

Fig 11. Fuzzy toolbox in MATLAB

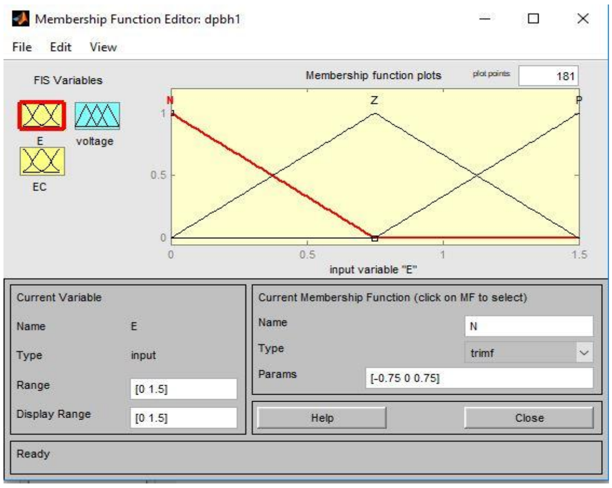

Fig 12. The error signal (E)

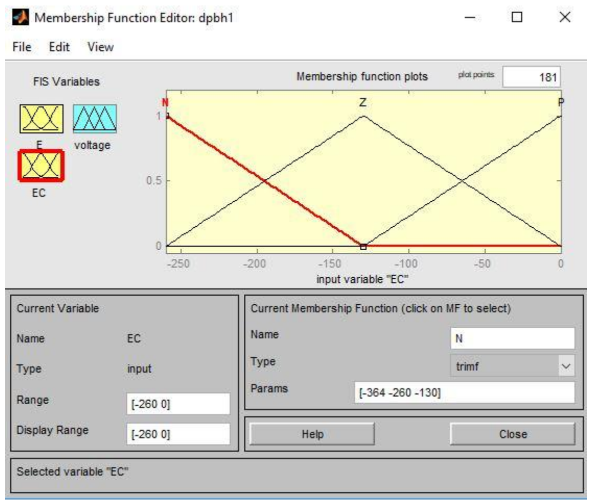

Fig 13. The rate of change in error signal (Ec)

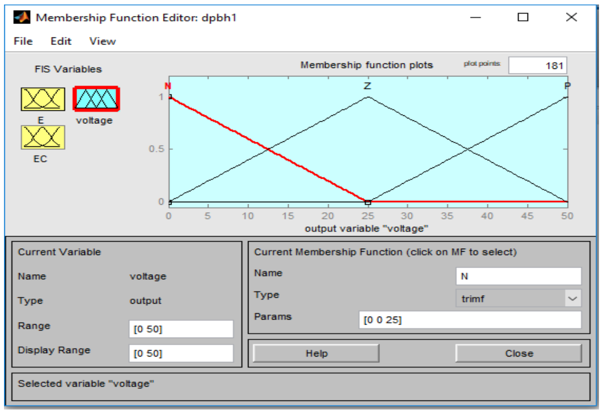

Fig 14. The output signal of FLC

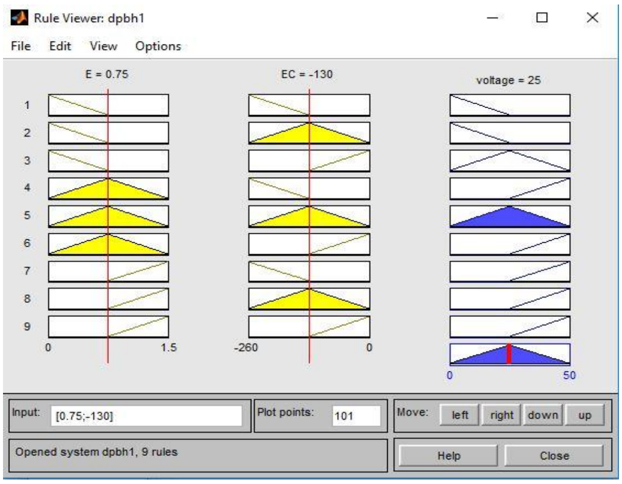

Fig 15. Fuzzy Rules

Result: -

Input speed= 500 rpm

Output speed= 499.1 rpm

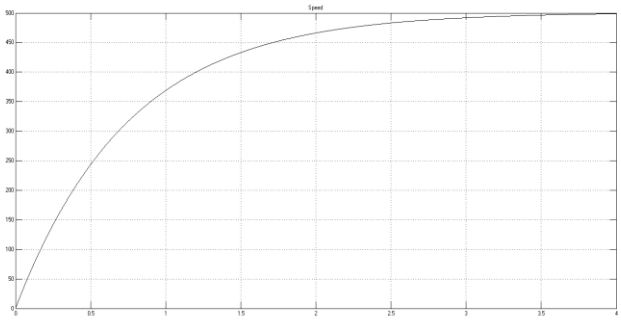

Fig 16. Speed Output of motor

6.3 Speed control of BLDC motor using PID controller (Dynamic modelling)

Here, we are going to develop a dynamic model for controlling the speed of BLDC motor by using FLC and PID. In this, we have used a physical model of BLDC motor, PID controller, and inverter available in MATLAB/Simulink. By using this block, we develop a closed loop system and saw that what will be the actual speed response we will get when this is actually implemented in hardware or in physical form.

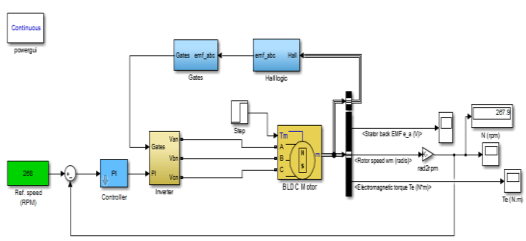

Fig 17. A dynamic model of closed-loop speed control of BLDC motor using PID controller

Result: -

Input speed= 268 rpm

Output speed= 266.9 rpm

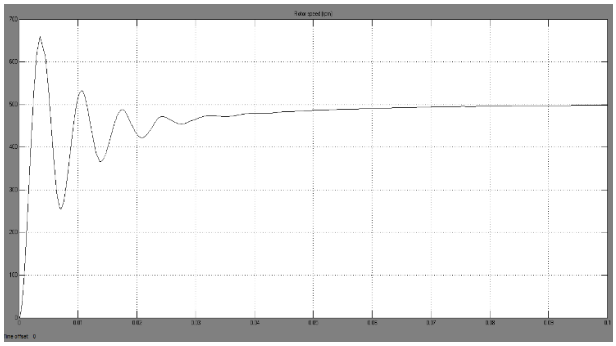

Fig 18. Output speed of a motor

6.4 Speed control of BLDC motor using a Fuzzy logic controller (Dynamic modeling)

Here, we are replacing the PID controller with a fuzzy logic controller in the system.

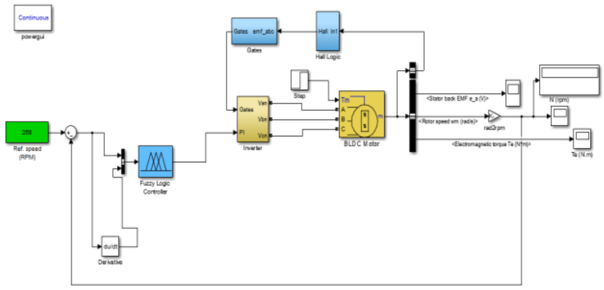

Fig 19. A dynamic model of closed-loop speed control of BLDC motor using FLC

Result: -

Input speed= 268 rpm

Output speed= 267.55 rpm

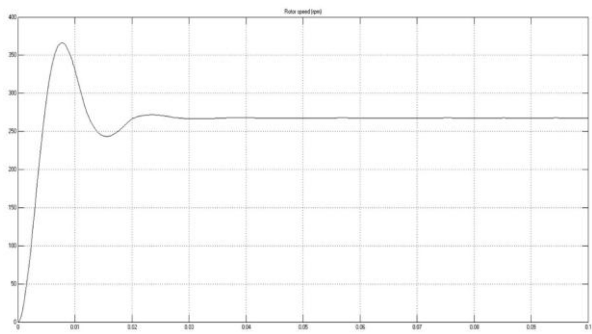

Fig 20. Output speed of a motor

7. CONCLUSION

Overall from this project, the main aim was to control the speed of the BLDC motor. Here reference speed is given to the closed loop system where the error detector compares this with the actual speed and it generates the error signal. Further, this signal is given to the controller which generates a voltage signal which further given to the inverter. Here we get 3 phase output from the inverter which is given to the motor and the gate circuit of the inverter accordingly operates or fires the phases of the motor. Here we used two controller that is PID and FLC. When we compare the results of this two we found that we get output speed nearer to reference speed in FLC compared to PID. And in FLC signal take less time to get stable which is shown in fig. 18 and fig. 20. Now when we implemented this model in dynamic form than from the result of it, we found that in PID generated more distortion at the starting of motor compare to FLC which can affect the performance of the motor. And if we increase the speed range of the motor or we if we replace the motor with high-speed motor then again, we must change gains in the PID controller to reduce the error between actual speed and reference speed whereas in FLC it is not needed. So, to overcome this disadvantages Fuzzy logic controller is more preferred.

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