International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 10 Issue: 1 | Jan- 2023 www.irjet.net p-ISSN: 2395-0072

A Fuzzy-PI based Gain Optimizing Approach for Speed Controlling of DC Motor

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Abstract - *In areas demanding flexible and smooth speed torque characteristic, DC motor drives are very popular. Its small size (in comparison with other motors of same rating), high torque density and better efficiency makes it more prevalent. This variation is speed is according to the demand of load connected. Thus, this requires a system, which automatically adapts to this point in short making system very vital for engineering and science. In this work, the focus will be to develop a model based on two techniques called PID controller and Fuzzy logic based intelligent controller. The fuzzy controller is comprised of a human-like intuition strategy with the help of membership function and rule base. The design and implementation are done on MATLAB platform. In this work, the comparison is done over the performance of two controllers for DC motor based on settling time, rise time, peak time, and percent overshoot. The inputs taken for modeling the fuzzy logic model are error and change in error and the single output to the model will be required signal for motor speed control. Based on the signal, the input supply is regulated for speed control of DC motor.*

Keywords– Speed Control of DC Motor, Fuzzy logic controller, PID Controller Tuning, rise time, Peak overshoot, Peak time.

1. INTRODUCTION

In the past century, the electric motor has played a major role in industrial development. Several types of motor are developed based on the requirement. Even in the domestic application, motors have a big role to play. Several types of appliances like AC, Refrigerators, fans, etc. uses electric motors only. Every industrial process demands a variable speed operation from the motor based on the requirement from the load. Hence, to fulfill that demand a circuit is to be designed to control the speed of the motor, known as an electric drive. Out of all type drives, the DC motor is very popular due to its simple and efficient operation along with good control characteristics compare to the induction motor.

In the present electrical framework pressure from government regulations and reduction in operational costs are high. The system demand that the framework is independent of electromagnetic obstruction and good productivity. One such activity is speed control in DC motor. Any DC motor drive needs to have minimum possible transients' generation which controlling speed. Usually, the armature voltage of the DC motor is controlled for varying speeds. In any DC motor speed control drive, a reference speed is chosen to have a benchmark to achieve. It is also provided with the current speed of the motor in reference to current armature voltage. The difference between both signals is calculated to generate a control signal to change armature voltage and thus motor speed.

This work has utilized two techniques to generate the required signal for controlling the voltage of DC motor armature. First is the conventional PID controller, having constant gain throughout the operation. Second is the Fuzzy logic controller, which works on the principle of the Fuzzy logic hypothesis, which unlike Boolean rule with only true or false state utilizes the entire framework between true and false. Fuzzy logic controller optimizes gain for the PID controller at every time step

DC motor is known to have a good speed-torque characteristic to the framework as compared to other motors of the same rating, hence is more popular is the area where variable speed is demand. The issue comes with a good controller with a DC motor to control its speed with good accuracy.

2. DC MOTOR AND PID CONTROLLER OVERVIEW

The electric motor is a motor that changes over electrical vitality into mechanical vitality. There are two kinds of the motor which are AC motor, and DC motor. A straightforward DC motor uses power and an attractive field for delivering force that pivots the motor. DC motor beats to AC motor since it gives better speed control on high force loads and uses in wide mechanical applications. DC motors are increasingly used as it intended to use with batteries and solar cells vitality sources, which give convey ability where we required it and in this manner give a financially savvy arrangement, since it is absurd to expect to have an AC power supply in each spot, DC motor show its reaction at both voltage and current. The applied voltage portrays the speed of the motor while the current in the armature windings shows the force. Whenever the applied burden expanded in the pole of the motor, at that point to continue its speed motor draws progressively current from the supply, and in the event that the supply can't give enough current, at that point motor speed will be influenced.

By and large, it tends to be said that applied voltage influences speed while force is controlled by the current. DC motors give progressively compelling outcomes if the cleaving circuit is utilized. Low power DC motor ordinarily use in lifting and transportation purposes as low power AC motors don't have great force ability. DC motor is utilized in railroad motors, electric vehicles, lifts, automated applications, vehicle windows, and a wide verity of little machines and complex modern blending forms where force can't be undermined.

There are a few kinds of DC motor however most normal are brushed DC motor, brushless DC motor, stepper motor, and servo motor. These DC motors have three winding procedures, for example, shunt DC motor, arrangement DC motor, and compound DC motor.

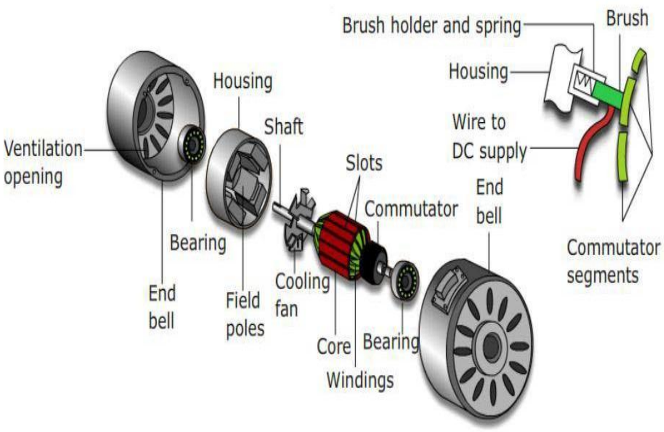

Fig-1: DC motor parts

2.1 DC MOTOR MATHEMATICAL MODELLING

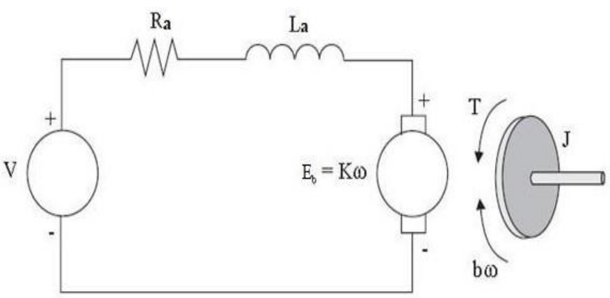

Fig-2: Schematic representation of the considered DC motor

Equation for the DC motor

$$Js^2\theta(s) + bs\ \theta(s) = K_t\ \frac{V(s) - K_e s\ \theta(s)}{L_a s + R_a}$$

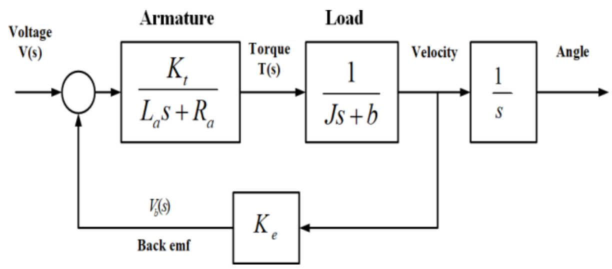

Fig-3: DC Motor block diagram

It has been developed in MATLAB/Simulink as shown

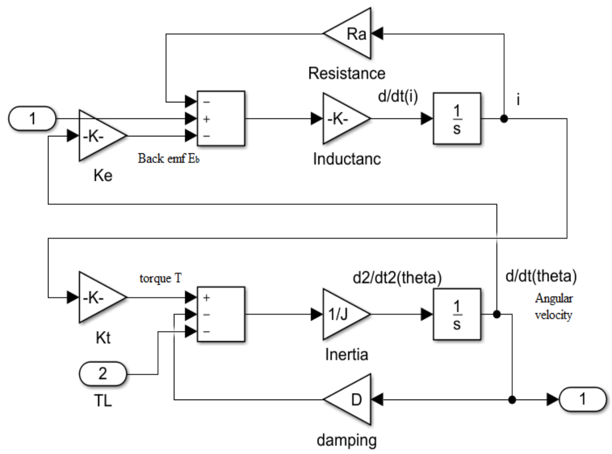

Fig-4: DC Motor Modelling

2.2 PID CONTROLLER DESIGN

Every machine is prompt towards dynamic systems. Having a controller is very important for maintaining stability. Several conventional methods proposed in past, some of which are listed 1)Classical control methods like root locus design, lead-lag compensator, etc 2) Nonlinear methods like back-stepping, Lyapunov redesign, etc 3) Control methods having an adaptive property like self-tuning regulators, dynamic programming, etc

All such controllers have a property to utilize the data mathematical model of the provided system. Each controller is required to have a self-tuning capability of the system. Such a method is more important because of the fact that the mathematical model designed is not always accurate as depends upon the parameters chosen to design it. Heuristics is one such problem arises with all conventional technique and it doesn’t fit into the proper mathematical framework which might help in proper controlling.

Out of conventional methods PID controllers find application in speed controlling of DC motor. PID stands for Proportional, Integral, and derivative modes of control. A combination of these three different modes is utilized in many systems. In the following section discusses three modes in detail

The proportional controller mode is usually useful under conditions when suddenly change in the system happened. "P" controller is linear in nature hence its response is very fast. This controller finds difficulty in stabilizing the higher-order process hence can be effectively used for single order processes only. Such a process system is comprised of only one energy store element. Hence the system can withstand large gain increment which further leads to low steady-state error. A low steady-state error means the system is following the output pattern of the process efficiently. Also, large gain gives a fast response, as discussed earlier means process control will be very sensitive in a closed-loop system. Also, proportional gain helps in attaining smaller amplitudes and phase margin

Integral controller mode comes handy when the present state of the dynamic process somehow depends on the value of the past state of the system.

Hence a combination of P& I called PI controller to finds the better application. The benefit of PI is that it will remove forced oscillation in the system that occurred due to switching in the system. Although there is also a certain drawback of the PI system, one major one is compromised with speed. The response speed of PI bis slower than that of P and also have a negative effect on overall stability.

Both integral and proportional modes of the controller have no ability to predict the nature of the error in the near future. This led to the requirement of a controller which can provide information regarding values of error in the future for a dynamic system, which is fulfilled by the derivative controller. Derivative modes have the ability to find the solution to gain whose value is dependent on the future error value. Again, in order to avoid sudden variation in output due to sudden variation in input combination of proportional and derivative is used. Such a system finds its applicatio0n in areas like submarines, ships, flying vehicles. When all the modes are used simultaneously in any dynamic system it is called a PID controller. The controllers help in estimating control inputs of the system by adjusting gain according to system error pattern.

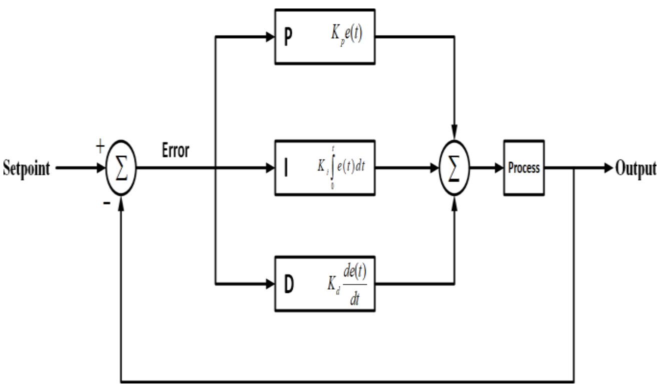

Fig-5: Block Diagram of the PID controller

PID controller can achieve quick response with the help of derivative mode. Reduction in error towards zero using integral control mode and reduction is oscillation using proportional mode. Such a controller is used with the order of the dynamic system is more than 1st order. Such a controller is used in an area where high precision is required like Autopilot in Airplanes. proportional, integral, and the derivative term is given by:

$$P = KP\ e(t)$$

$$I = Ki \int_0^t e(t)dt$$

$$D = Kd \frac{de(t)}{dt}$$

Table-1 Effects of Coefficients

Parameter	Speed of Response	Stability	Parameter
Increasing K_p	increases	deteriorate	improves
Increasing K_i	decreases	deteriorate	improves
Increasing K_d	increases	improves	no impact

2.3 PID TUNING METHODS

Every dynamic system has its own behavior and each system has its own requirement which depends on the adjustment of control parameters to the best possible value. Tuning is thus the process of finding the most optimal value of gain of 3 modes such that system controlling can happen along with maintaining stability. Different methods are there for tuning, some of them are manual tuning and PID tuning software method.

The manual tuning method as the name suggests works by changing values of Kp, Ki & Kd till the demand for control is obtained. It's like the hit & trial method. Steps to follow while finding optimal gain value is to set the value of Kp is increased until the output of the system start oscillations. The value of Kp is exactly half of the above point. After setting

Kp, the value of Ki increased until the error is settled insufficient time until the system becomes unstable. After setting Ki, the value of Kd is increased until the system steady- state error is reduced to acceptable value with having a system overshoot.

In the PID tuning software method, the gain is optimized with the help of any theoretical method implemented with the help of any software. In this work, we have used both these methods, for optimizing gain. In the software tuning method, we have used the fuzzy logic approach in MATLAB software.

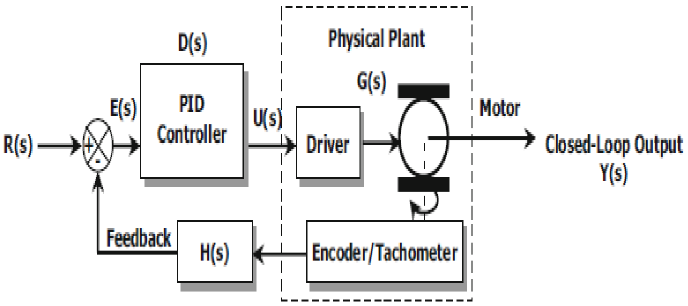

Fig-6: The block diagram of the PID closed-loop control system

2.4 STEP RESPONSE CHARACTERISTICS

In order to understand the behavior of any system, step response characteristics are used. In such an analysis, the output of the system is an observer for a change in input from 0 to 1 in a very short time

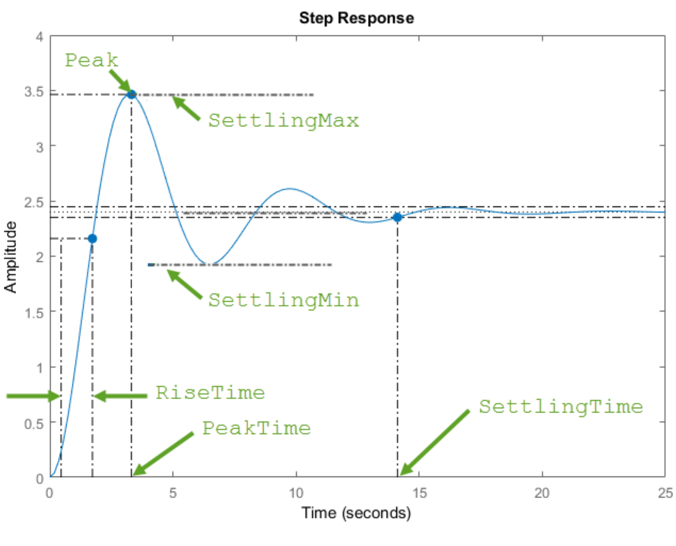

Fig-7: Step Response Characteristic

2.5 FUZZY LOGIC THEORY

Fuzzy logic is a mathematical system that takes input in form of crisp value and performs the operation using equivalent linguistic terms. Basically, fuzzy logic is based on the way the human brain behaves, where its decision is based on feelings. The way the human brain takes a decision based on past learning experiences is now replicated in fuzzy logic theory.

In the year 1965, the fuzzy logic approach was first proposed, but it was in the year 1974 when fuzzy logic was first used in any practical application. It was Dr. Mamdani (based on whom Mamdani approach of FLC is named) used Fuzzy logic in controlling of the steam engine. Since then the popularity of a fuzzy logic idea has gained pace and now it finds application in each sector of society ranging from automobiles, industrial manufacturing and hospitals, etc. in order to implement fuzzy logic three-stage operations are performed. It starts with fuzzification then fuzzy inference process & defuzzification.

Any fuzzy set can be expressed in the following way

$$\mu x(A) \in [0,1]$$

Where x is any set, A is any member of that set, $\mu_x(A)$ is the membership function. Now similar to classical set theory fuzzy also exhibit an almost similar type of operations. Let x & y are two fuzzy sets element

Union: $x \cup y = \mu x(A) \cup \mu y(A)$

$= \max(\mu x(A), \mu y(A))$

Intersection: $x \cap y = \mu x(A) \cap \mu y(A)$

$= \min(\mu x(A), \mu y(A))$

Compliment: $xc = F/x$

2.6 INTRODUCTION TO FUZZY LOGIC CONTROLLER

Any fuzzy logic controller performs three main tasks namely Fuzzification, Decision using control block, and defuzzification. The following block diagram shows the steps involved in FLC.

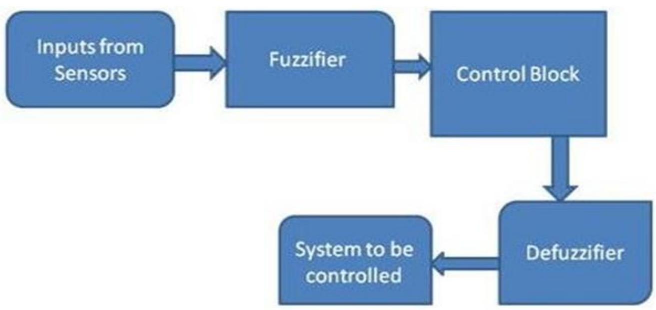

Fig-8: Block Diagram approach of FLC

2.7 FUZZY CONTROL RULES

In order to gain knowledge like a human being, rules are formed in a fuzzy interface system with the help of the expert opinion of human beings. Such rules are based on input & output with the help of the IF-THEN condition. Rules help in developing an algorithm to give output for any particular input value. These rules help FIS to calculate the degree the i/p matches the condition of a rule. The process of forming rules can be done in two ways. In the first mapping between i/p & o/p is done with linguistic terms. Whereas in a second way, logic is formed to find the relationship between i/p & o/p.

2.8 DIFUZZIFICATION

The process is the opposite of fuzzification. Post fis, the o/p generated is in the form of linguistic or vague form. In order to utilize in the application, it needs to be converted back to crisp o/p. Several methods are possible for defuzzification. some of them are discussed below.

Mean of maximum (MOM) method: in this method, the output value is equal to the average value of output with the highest degree. Taking examples of AC again if the o/p FIS is "SLOW" then the crisp value from the defuzzifier can be given by the following equation.

$$MOM(SLOW) = \sum xFg\ pxF/p$$

$$= \{x' \mid \mu SLOW(x')$$

Where p stands for a set of o/p x with a maximum value of MF for o/p SLOW.

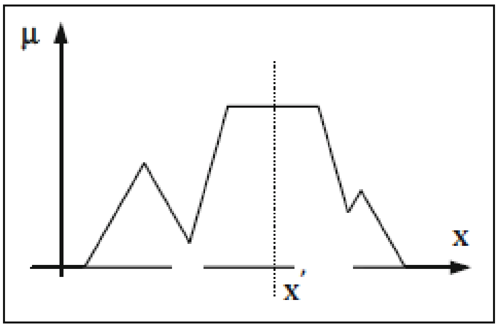

Fig-9: MOM Method

3. FUZZY PI CONTROLLER

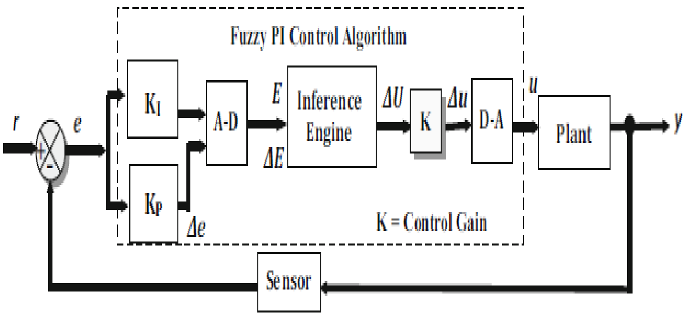

Fig-10: Fuzzy-PI control system block diagram

3.1 FLOW CHART FOR SPEED CONTROL OF DC MOTOR USING FLC

The below figure represents the steps involved in controlling the speed of the DC motor using the fuzzy logic controller. The work starts with the definition of inputs and outputs for the given problem. Now each of these inputs and outputs must be represented in the form of respective membership function with different range and different width of different categories, making each membership function unique for the particular input parameter.

After defining the membership function the next step is to develop a rule base using knowledge base by expert opinion. These rules are defined based on an if-then conditional statement. Once these rules are formed a simulation is done based on input and output data. Based on this data error is calculated on forecasted and actual value of the output parameter. After the evaluation of error, a comparison is done with the required optimum error value. If the target is reached then no further training is required and the process will end, otherwise, further tuning of the process is done to improve the result and the same steps are followed again.

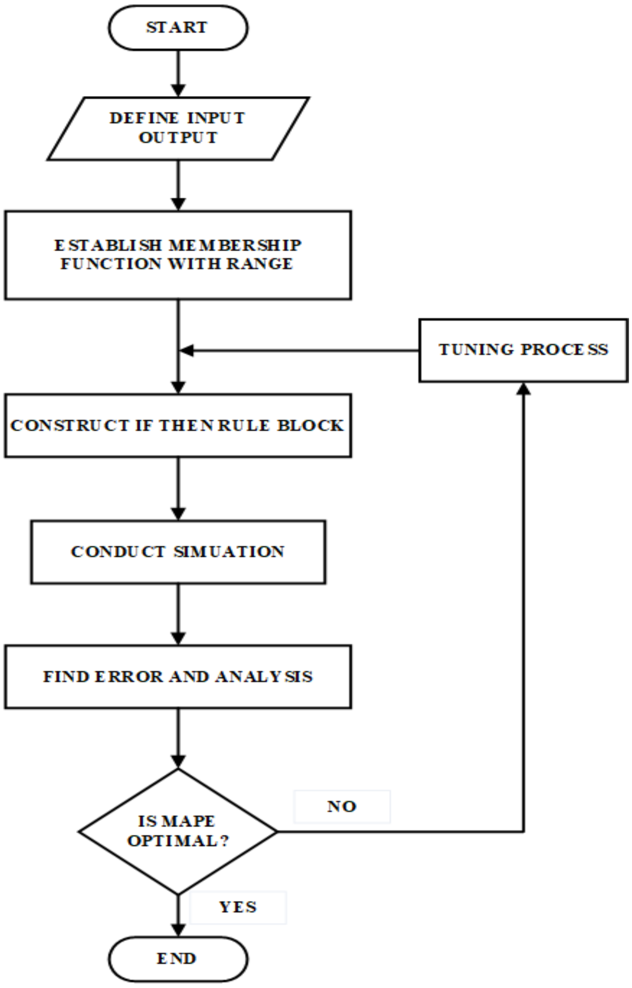

Fig-11: Flow chart for the fuzzy logic model

3.2 VARIABLES USED

The Linguistic Variables considered in the control are

Z - Zero

PM - Positive Medium

NM - Negative Medium

PL - Positive Large

NL – Negative Large

We have considered 5 Linguistic variables (NL, NM, ZE, PM, PL) for the Input 'Error' and only 2 Linguistic variables (NL, PL) for the Input 'Rate of Change in Error'. In the case of Output 'Control', we have considered 5 Linguistic variables (NL, NM, ZE, PM, and PL).

3.3 MEMBERSHIP FUNCTIONS USED

The inputs are Error is speed and Change in Error. We have studied above the Fuzzy rule base and formed the rules for 5, 2 linguistic variables of the inputs and 5 linguistic variables of the output using the Fuzzy toolbox. The membership functions used are

Error Signal – 2 trapezoidal and 3 triangular.

Change in Error signal – 2 triangular.

Control signal – 5 triangular

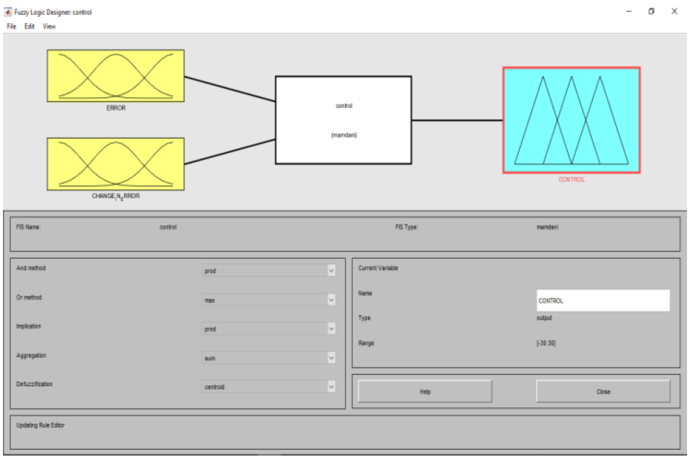

Fig-12: Fuzzy Logic Designer

3.4 FUZZY RULE BASE

General Interpretation of the control rules to be set to the Fuzzy control:

If Error = 0 and Change in error = 0, then do not change the present setting.

If Error is non-zero but Error is tending to zero at an acceptable rate, then do not change the present setting.

If Error is increasing or decreasing, then make the control signal according to the magnitude and sign of the Error and Change in Error to make the Error = zero.

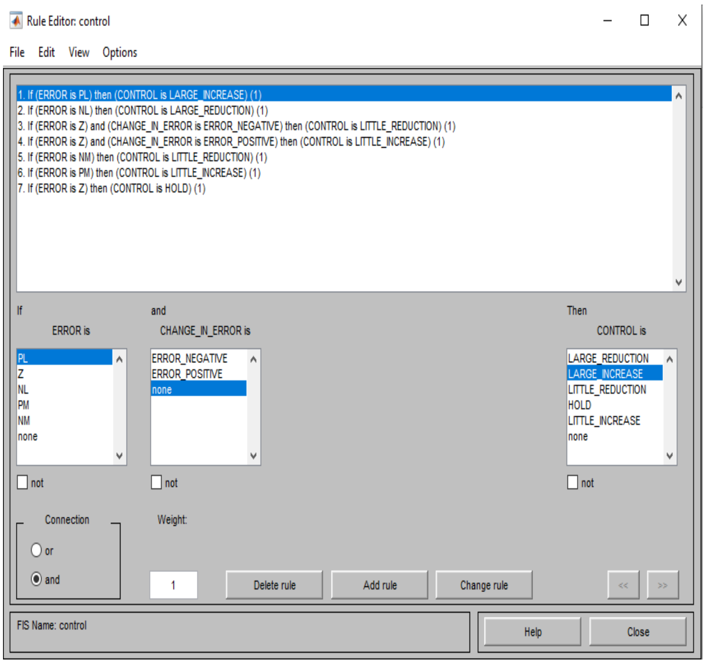

Fig-13: Fuzzy Rule Viewer

4. RESULTS

The Simulink model is prepared for two techniques, and their results obtained are shown and discussed in detail. Post mathematical modeling of DC motor, it is implemented in Simulink. The model of the DC motor remains the same for both the controllers. The controllers are then designed in Matlab/Simulink software. Both the Fuzzy and PID based model's output is displayed and compared to find the best out of two based on speed signal response parameters

4.1 PID CONTROLLER BASED SPEED CONTROL MODEL

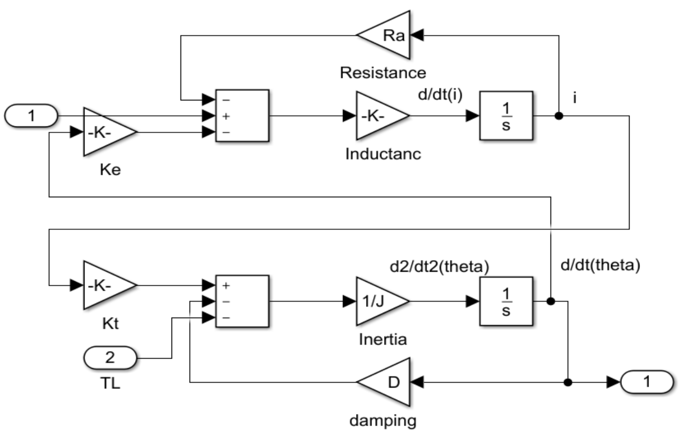

Fig-14: DC motor Simulink model

The model comprises four factors of DC motor they are Armature Resistance, Armature Inductance, Inertia, and damping coefficient.

Rated Speed = 1500 rad/sec., Back EMF constant = 0.01 V/rad/sec , Reference Speed = 1450 rad/sec. and Load Torque = 10 N-m.

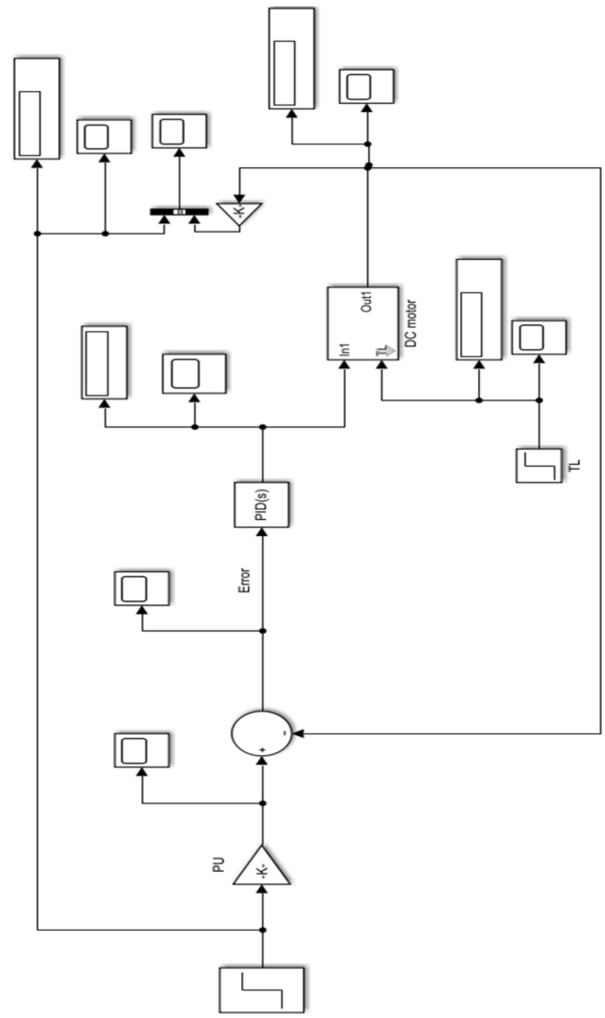

Fig-15: Simulink model of speed control of DC motor using a PID controller

The above figure 15 shows the model of the PID controller. The reference speed was set to 800 for the first 5 sec and to 1450 for the last 5 sec. The reference speed is normalized to per unit value. This value is then subtracted with the present output value of the speed of the DC motor, giving error. The value of the error is fed to the PID controller, which generated the appropriate signal to reduce the error value and control the speed of the motor. The response of the motor based on the controller is noted and shown in the following figures

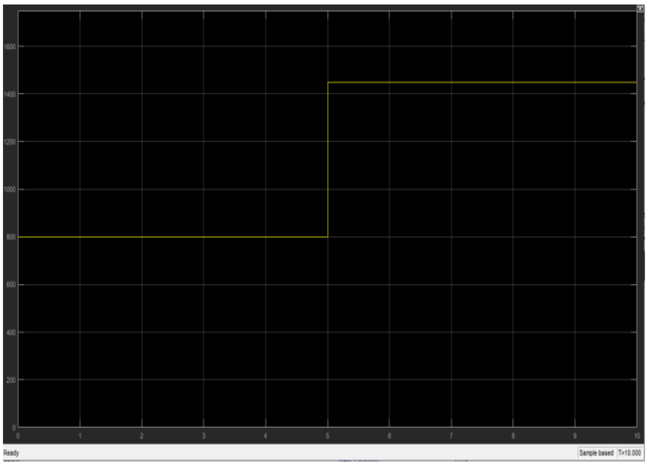

Fig-16: Reference speed signal for the PID controller

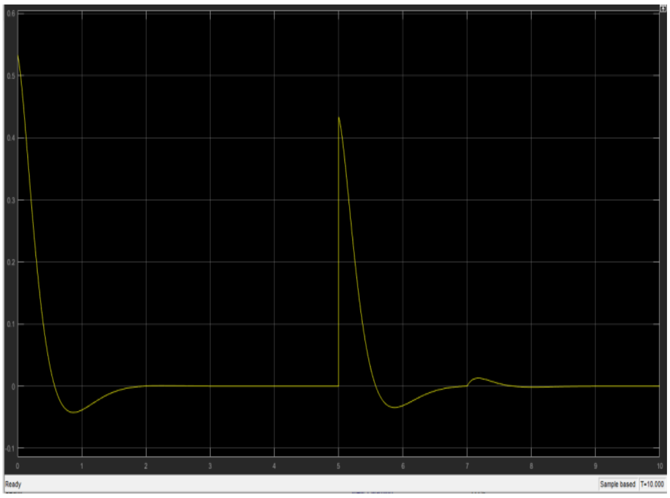

Fig-17: Error in Speed response using a PID controller

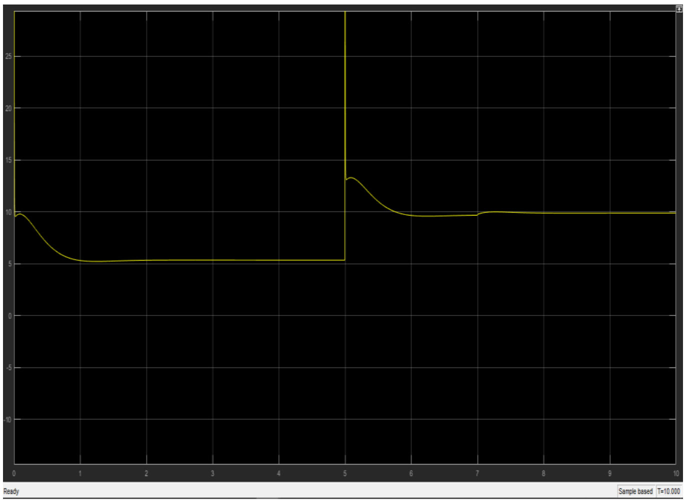

Fig-18: PID controller output signal

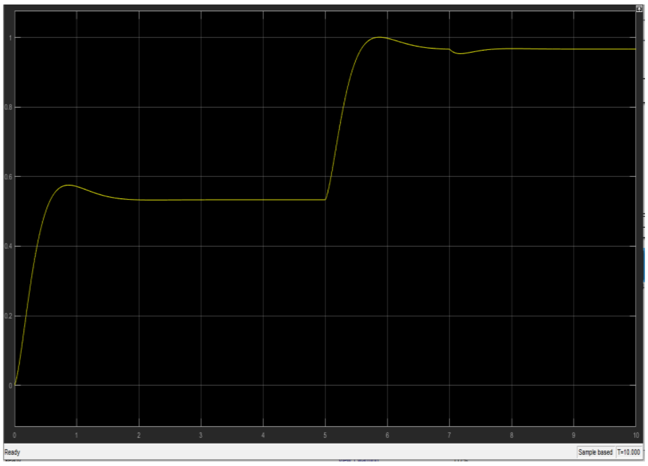

Fig-19: per unit Speed Response signal using a PID controller

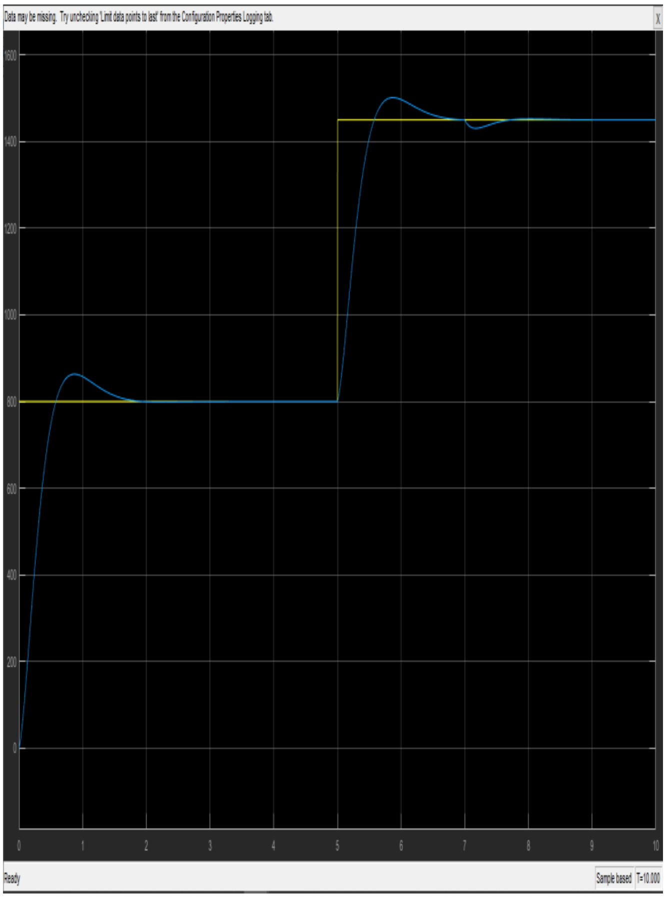

Fig-20: Speed Response signal using a PID controller

4.2 FUZZY LOGIC CONTROLLER BASED SPEED CONTROL MODEL

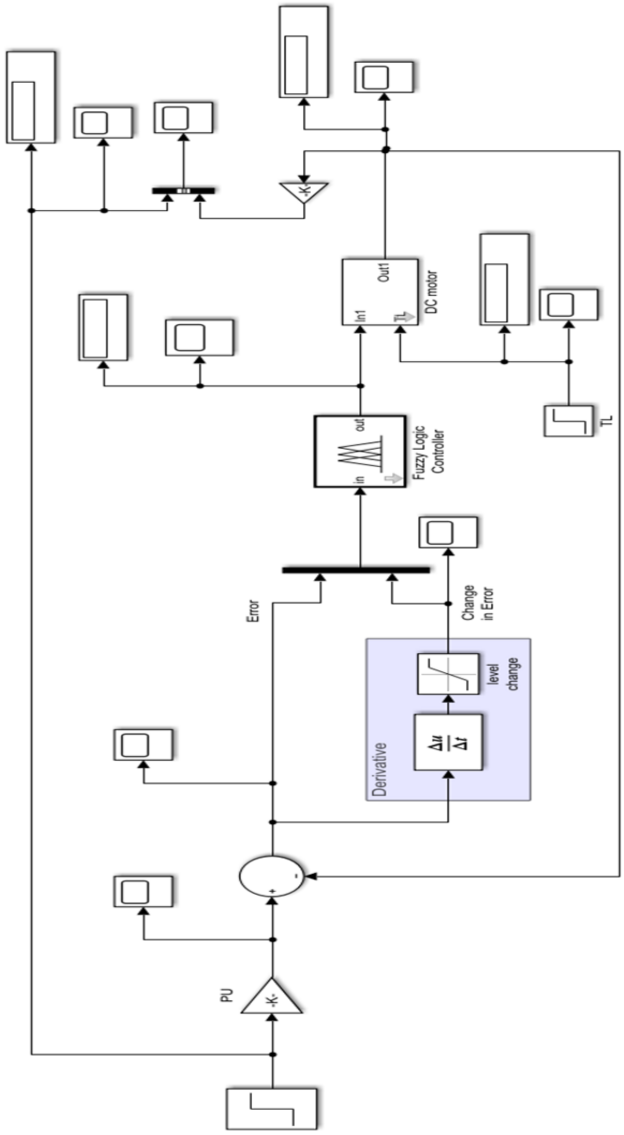

Fig-21: Simulink Model for Fuzzy Logic Control

Figure 20 shows the model of the Fuzzy logic controller. The reference speed was set to 800 for the first 5 sec and to 1450 for the last 5 sec. The reference speed is normalized to per unit value. The advantage of per-unit value is that it makes designing a range of variables for membership function in the Fuzzy logic toolbox easy. This value is then subtracted with the present output value of the speed of the DC motor, giving error. The value of error is further differentiated using a derivative block to get a change in error value. The value of error and change in error is fed to the Fuzzy controller block as inputs, which then generated the appropriate signal to reduce the error value based on the rule base. This output value is then subtracted with armature voltage to control the speed of the motor.

The response of the motor based on the controller is noted and shown in the following figures. The initial load torque (TL) taken in the present case is 0.0001 N-m and 0.002 N- m as the final value of load torque after 7 sec. The value of the fuzzy logic output signal and Load toque is fed as input to the motor model, which will give per unit value of speed. The speed is then multiplied with inverted gain as taken with reference speed gain block to get the actual value of speed.

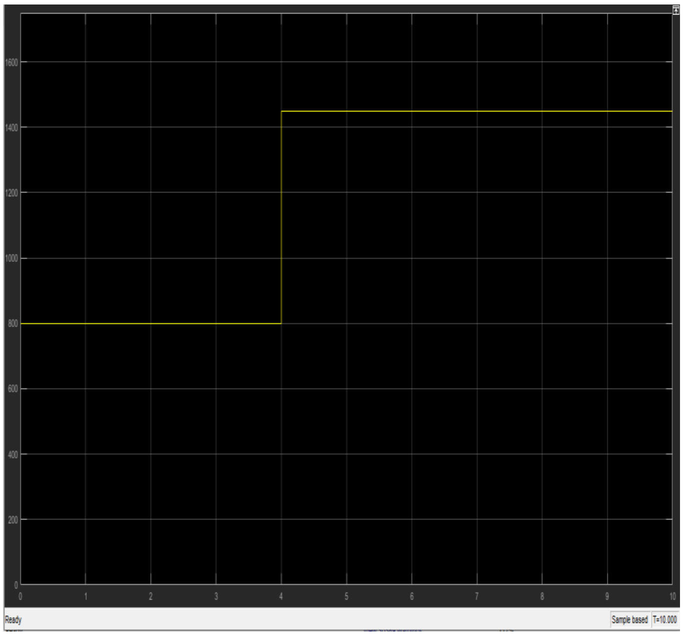

Fig-22: Reference speed for FLC

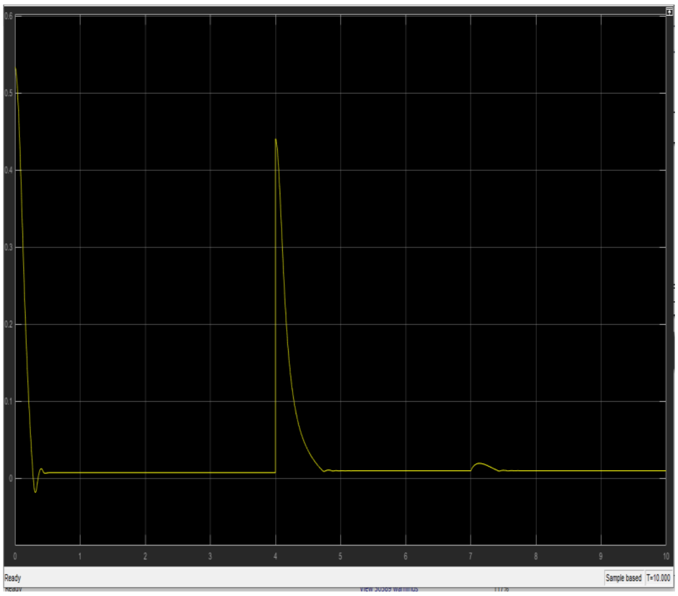

Fig-23: Error in Speed response using FLC

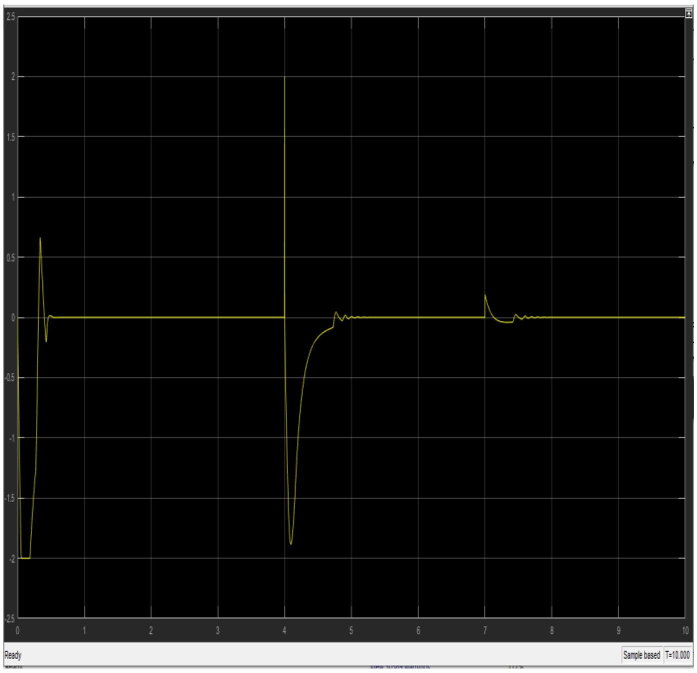

Fig-24: Change in Error in Speed response using FLC

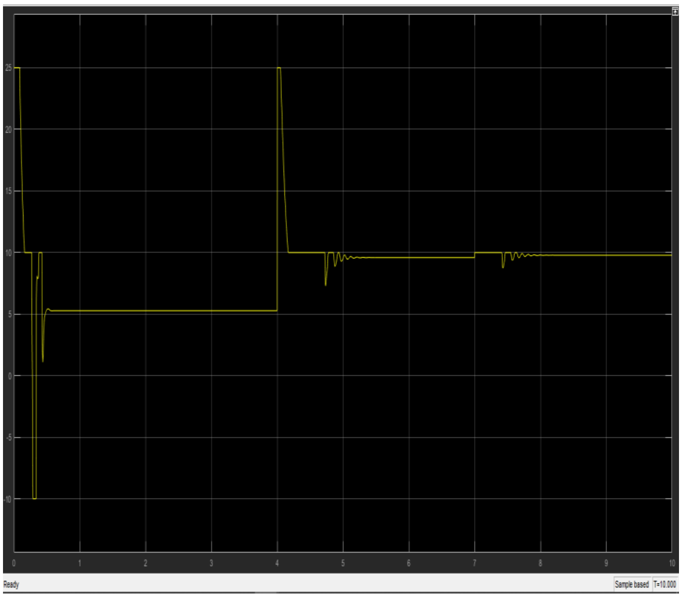

Fig-25: Fuzzy logic controller output response

evident that Fuzzy logic-based controllers are better performing than PID based controller because it has a low value of rising time, peak time and settling time and also has a small value of overshoot.

REFERENCES

[1] Tigo Wati1, Subiyanto1 and Sutarno, "Simulation model of speed control DC motor using fractional order PID controller", *Journal of Physics: Conference Series*, Volume 1444, Number 1, IOP Publishing Ltd, 2020

[2] Suresh Kumar B., Varun Raj D., Venkateshwara Rao D, "Speed Control of BLDC Motor with PI Controller and PWM Technique for Antenna's Positioner", *Emerging Trends in Computing and Expert Technology*, COMET 2019, Lecture Notes on Data Engineering and Communications Technologies, vol 35, Springer, 2019.
DOI: https://doi.org/10.1007/978-3-030-32150-5_43

[3] Farahani, G., Rahmani, K., "Speed Control of a Separately Excited DC Motor Using New Proposed Fuzzy Neural Algorithm Based on FOPID Controller", *Journal Control Autom Electrical System 30*, pp 728–740, 2019.
DOI: https://doi.org/10.1007/s40313-019-00485-8

[4] N. L. Ismail, K. A. Zakaria, N. S. Moh Nazar, M. Syaripuddin, A. S. N. Mokhtar and S. Thanakodi, "DC motor speed control using fuzzy logic controller", AIP Conference Proceedings 1930, 2018.
DOI: https://doi.org/10.1063/1.5022920

[5] Jesús U. Liceaga-Castro, Irma I. Siller-Alcalá, Jorge Jaimes-Ponce, Roberto A. Alcántara- Ramírez and Enrique Arévalo Zamudio, "Identification and Real Time Speed Control of a Series DC Motor", Hindawi Mathematical Problems in Engineering, Article ID 7348263, 11 pages, 2017.
DOI: https://doi.org/10.1155/2017/7348263

[6] E Gowthamana, V Vinodhinib Mir Yasser Hussainc S K Dhinakarand T Sabarinathane, "Speed Control of Permanent Magnet Brushless DC Motor Using Hybrid Fuzzy Proportional plus Integral plus Derivative Controller", *1st International Conference on Power Engineering, Computing and CONtrol*, PECCON-2017, 2-4 March 2017, VIT University, Chennai Campus. Energy Procedia 117, pp. 1101–1108. Elsevier, 2017

[7] AkashVarshney, Deeksha Gupta, Bharti Dwivedi. "Speed response of brushless DC motor using fuzzy PID controller under varying load condition", *Journal of Electrical Systems and Information Technology,* Volume 4, Issue 2, pp. 310-321, 2017

[8] Mohammed Alhanjouri, "Speed Control of DC Motor Using Artificial Neural Network",*International Journal of Science and Research* (IJSR), Volume 6 Issue 2, 2017.
DOI: 10.21275/ART20172035

[9] P. Sarala, S. F. Kodad and B. Sarvesh, "Analysis of closed loop current controlled BLDC motor drive," *2016 International Conference on Electrical, Electronics, and Optimization Techniques* (ICEEOT), Chennai, pp. 1464-1468, 2016.
DOI: doi: 10.1109/ICEEOT.2016.7754925

[10] S. K. Suman and V. K. Giri, "Speed control of DC motor using optimization techniques based PID Controller," *2016 IEEE International Conference on Engineering and Technology (ICETECH)*, Coimbatore, 2016, pp. 581-587, 2016.
DOI: 10.1109/ICETECH.2016.7569318.

[11] S. Xiong, G. Junguo, C. Jian and J. Biao, "Research on Speed Control System of Brushless DC Motor Based on Neural Network," *2015 8th International Conference on Intelligent Computation Technology and Automation (ICICTA)*, Nanchang, pp. 761-764, 2015.
DOI: 10.1109/ICICTA.2015.193.

[12] Osama Omer Adam Mohammed, Dr. Awadalla Taifor Ali, “Comparative Study of PID and Fuzzy Controllers for Speed Control of DC Motor”, *International Journal of Innovative Research in Science, Engineering and Technology* Vol. 3, Issue 9, 2014.

[13] Anupam Aggrawal, Akhilesh Kumar Mishra , Abdul Zeeshan, "Speed Control of DC Motor Using Particle Swarm Optimization Technique by PSO Tunned PID and FOPID", *International Journal of Engineering Trends and Technology* (IJETT), V16(2), pp 72-79, 2014.

[14] S. A. Deraz, “Genetic Tuned PID Controller Based Speed Control of DC Motor Drive”, *International Journal of Engineering Trends and Technology* (IJETT) – Volume 17 Number 2, Page 88,