Using A Fuzzy Logic Controller, A Separately Excited DC Motor's Speed Can Be Controlled

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Abstract

The Fuzzy method gives a human like intuition to the control strategy and is self-tolerant to inputs which are no so precise. The Fuzzy Logic Controller contains different components like Fuzzification, Defuzzification and Fuzzy Rule inference. The Objective is to understand the Fuzzy Rule base and inference methods and employ them in controlling the speed of the motor. It is very efficient where the precision required is not too high. It is a robust, easily controllable strategy. It is capable of realizing multiple inputs and producing different numerous outputs. Here, we discuss the Fuzzy Logic Control of the speed of DC Motor. We make use of this this strategy to achieve a flexible control of the speed of the Separately Excited DC Motor. Error in speed and the derivative of Error are taken as the inputs to the Fuzzy controller and by selecting suitable membership functions we control the output of the Fuzzy controller which is subtracted from the armature supply and then supplied to the armature. In this way the speed of the DC motor is controlled by regulating the armature supply voltage.

Introduction:

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- Fuzzy Theory:
- Definitions and Basics:

The Fuzzy theory was first put forward by L.A. Zadeh in 1965. He felt that the classical theory concentrates much on precision rather than easy and efficient controlling mechanism. Unlike classical sets, the Fuzzy sets have a certain degree of membership for each element.

If-Then Rules. Fuzzy sets depend on certain rules. The rule base is the most important requirement for the fuzzy logic. The rule base generally consists of various cases of If-Then rules. First the fuzzy sets and the membership functions are declared. Then the If-Then rules for the membership functions are decided for the particular control. The output is controlled by these rules on input.

A typical If-Then rule consists of two parts. They are 1) Antecedent and 2) Consequence or Conclusion. The 'If' statement is the Antecedent and the Then statement is the Consequence.

If - (Antecedent) & Then - (Consequence). Examples:

If the fan is slow, then increase the speed.

If the temperature is high, then decrease the setting on an air conditioner.

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Sets and Operations:

Classical Set: In a classical set for a universe of discourse the elements belonging to the set must satisfy the rules specified by the set. It is represented by

$A=\{x \in U| \ x \text{ meets some conditions}\}$

It can also be denoted by

μA(x) = {1 if x ϵ A
0 if x not ϵ A}

Fuzzy set: In a fuzzy set each element has a certain degree of membership unlike the classical set, with which it belongs to the particular fuzzy set.
$A = \{(x, \mu A(x))|x\epsilon U\}$

Operations:
Consider two Fuzzy A and B sets such that A, B ∈ U. Where, U is the Universe of Discourse. Main set operations are: [4]
1. Complement,
2. Intersection,
3. Union.

Complement:
The Complement of a fuzzy set can defined as a fuzzy set with the membership function shown below:
(x) = 1 (x)

Intersection:
It can be defined as the biggest fuzzy set in both A and B which contains both the elements in A and B. It can also written as 'A ∩ B'. The membership function for Intersection is defined as:
(x) = (x) (x)
Union:
It can be defined as the smallest set which contains all the elements in 'A' or 'B'. It can be written as 'A + B' or 'A U B'. The membership function for Union is defined as:

(x) = (x) (x)

Importance of Fuzzy Logic:
Advantages of Fuzzy Control: It has certain advantages which make it preferable to the other controllers.
1. Very easy to comprehend because the concept behind the control is very simple.
2. It possesses the intuition like a human which gives it the strength to adapt to the difficulties in the control.
3. It can work well even with noisy inputs.
4. It can be worked with multiple inputs and can provide multiple outputs as it solely works on rule basis. Creating the rule base for fuzzy control is easier than optimising the parameters for PID control.
5. When any sensor stops working it can be programmed to turn off safely, instead of keep on working which could be dangerous to the plant.
6. It does not consist of complex mathematical analysis, hence very easily designed.
7. It does not require high precision sensors but compensates for the precision making use of the intuitive control which makes this method very economical.
8. It operates very well even in highly non-linear systems adapting to the situation. But designing other conventional controllers to adjust in case of non-linearity in characteristics is very difficult.
9. Very simple user interface. Easier end-user interpretation when the final user is not an expert.
10. Easy calculation. Extensively existing toolboxes and dedicated integrated circuits.
11. Ambiguousness. Fuzzy logic is a "natural" way of expressing unknown information. Tools available to the fuzzy logic helps in concluding different actions depending on the possibility or necessity of certain plant situations.

Implementation of Fuzzy Logic:
It maps the input to an output in a very efficient and the mapping can be very easily controlled without much complex knowledge about the process. Steps to be performed in Fuzzy control:
1. First, study how the rule base system and the operator can be applied to this control.
2. Understand the concept of membership functions and linguistic variables.
3. Analyse the power system to be controlled and decide the state variables to be considered as inputs to the system.
4. Form an understanding as how to control the state variables to get the required control in the plant.
5. Now form the Rule base for the linguistic variables of inputs and outputs
6. Try to optimize the membership functions to make the control more efficient.
7. Integrate the fuzzy controller into the plant and check the result.

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Mamdani Method:
Mamdani’s methods of the Fuzzy interface is the most commonly used method. It was among the first control systems built using fuzzy set theory. This inference method expects the output variable to be fuzzy sets. It is more advantageous to use a single membership function of a linguistic variable instead of number of fuzzy sets which can be tedious in some cases. This method of using a single linguistic variable in output is called as Singleton output mechanism. It enhances the Defuzzification process because it greatly simplifies the computation required by the more general Mamdani method which finds the centroid of the two dimensional function. But in the Sugeno type of inference can be used to model any inference system in which the output membership function is either linear or constant.

Sugeno Method:
The first two parts namely, fuzzifying the inputs and applying the fuzzy operator, of the Sugeno method are similar to the Mamdani method. [8]

If the first input is x and the second input is y, then the Output is of the linear form
O = Kx +Ly + M
For a zero-order Sugeno model, the output O will be a constant (K = L = M).
The output level Oi of each rule is only weighted by the weightage Wi of the rule.
Comparison: When the performances of Mamdani and Sugeno models are compared with each other, the superlative outcome is obtained from the Sugeno mode. [7]

Mamdani Advantages:
- It is instinctual. Can be trained in human intuition.
- More generally acknowledged.
- It is more effective to human input.

Sugeno Advantages:
- It is very effective in calculations and controlling.
- It is generally used to enhance the linear techniques.
- It is used to optimize the parameters and works adaptively.

4 Simulation Work:
4.1 Variables Used:
The Linguistic variables considered in the control are
- ZE - Zero
- PS - Positive Small
- NS - Negative Small
- PL - Positive Large
- NL – Negative Large

We have considered 5 Linguistic variables (NL, NS, ZE, PS, PL) for the Input ‘Error’ and only 2 Linguistic variables (NL, PL) for the Input ‘Rate of Change in Error’. In case of Output ‘Control’, we have considered 5 Linguistic variables (NL, NS, ZE, PS, and PL).
4.2Membership Functions used:
Error:
Figure 7 Error Signal Membership Functions

Change in Error:
Figure 8 Change in Error Signal Membership Functions

Control Signal:

Figure 9 Control Signal Membership Functions

7.4 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.

Figure 10 Fuzzy Rule Viewer

1. If Error (Reference speed – Observed speed) is PL and the de is neither NL nor PL, then the motor speed is very less than the reference speed. Then the armature voltage needs to be increased which can be done by setting the Control signal at PL. Similarly when Error is NL, the control signal is NL.
2. If Error is ZE, then the motor is at reference speed at that instant. But the de is NL. This shows that the speed of the motor is increasing. So, the control signal is NS. Similarly when de is PL, the control signal is PS.
3. If Error is NS, then the motor speed is close to the reference speed but greater than the reference speed. This requires a decrease in the armature voltage. So, the control signal is NS for any value of de. Similarly when the Error is PS, the control signal is PS.
4. If the Error is ZE, then the motor speed is at the reference speed. Unless de is either NL or PL, the control setting has to be ZE so as to keep the motor close to the reference speed.

Table 1: Rule base for Fuzzy control:

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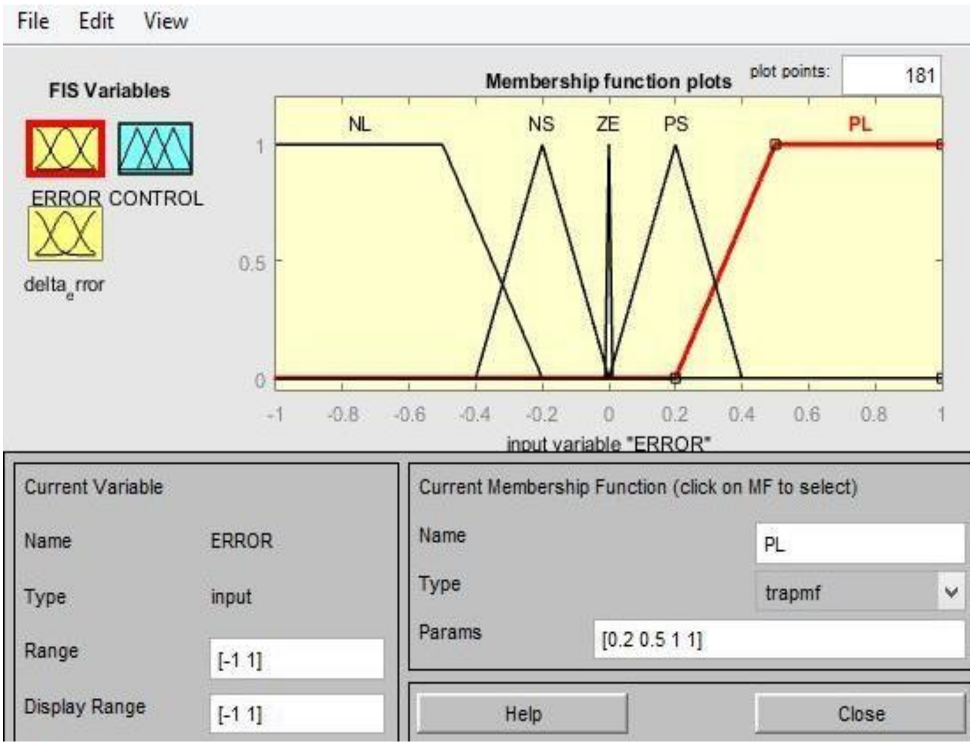

Figure 7 Error Signal Membership Functions

Change in Error:

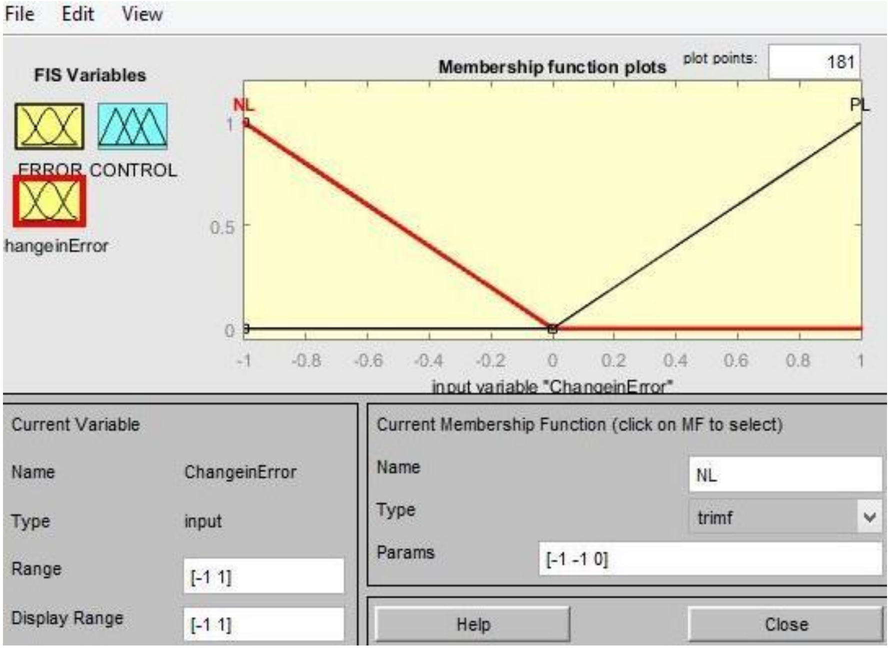

Figure 8 Change in Error Signal Membership Functions

Control Signal:

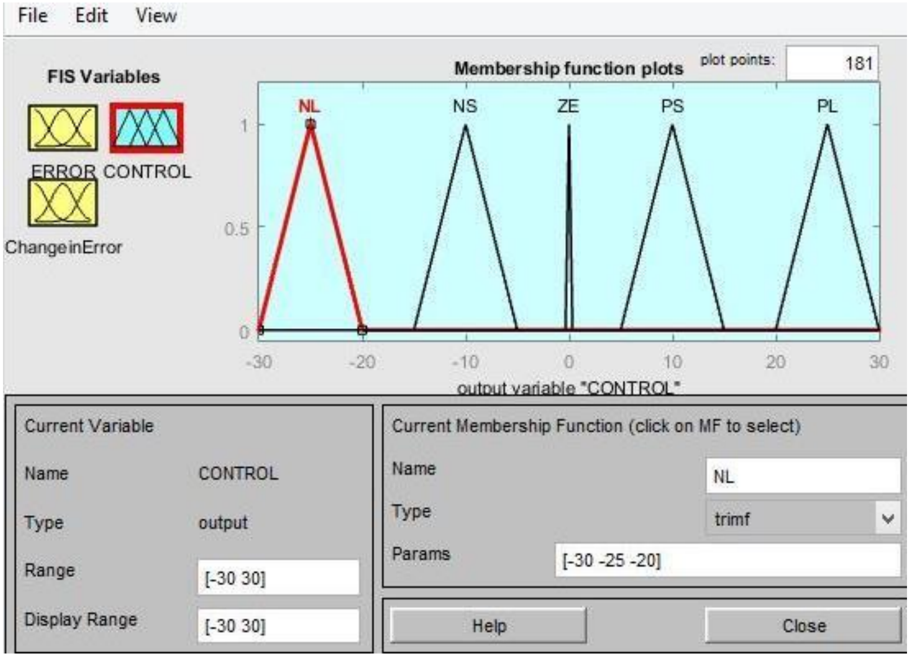

Figure 9 Control Signal Membership Functions

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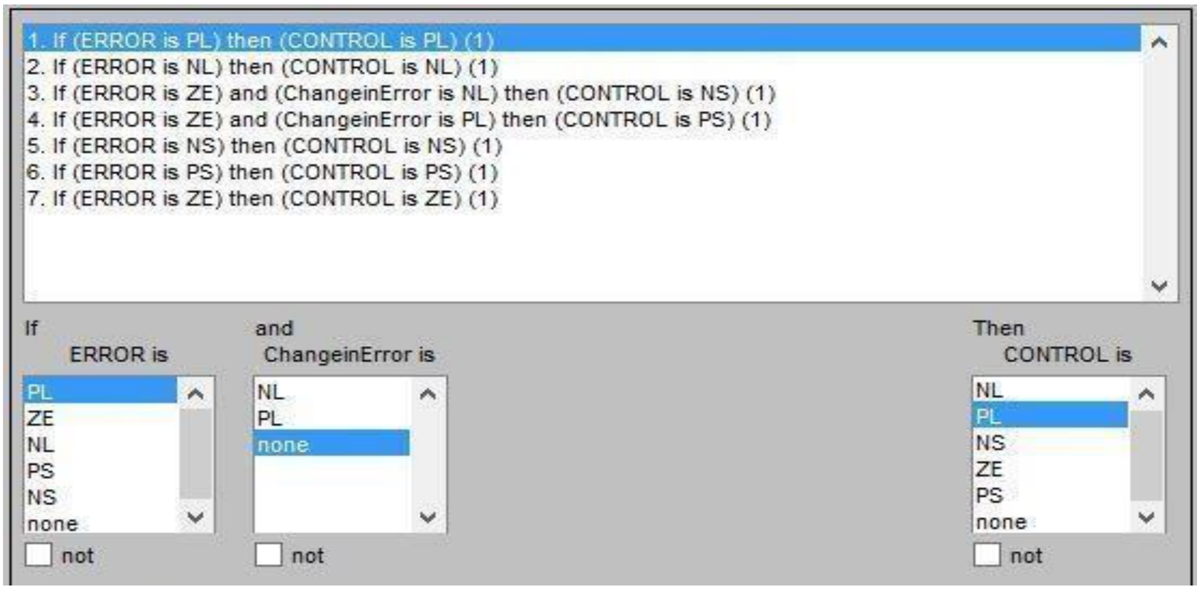

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Table 1: Rule base for Fuzzy control:

de/e	NL	NS	ZE	PS	PL
NL	NL	NS	NS	PS	PL
PL	NL	NS	PS	PS	PL

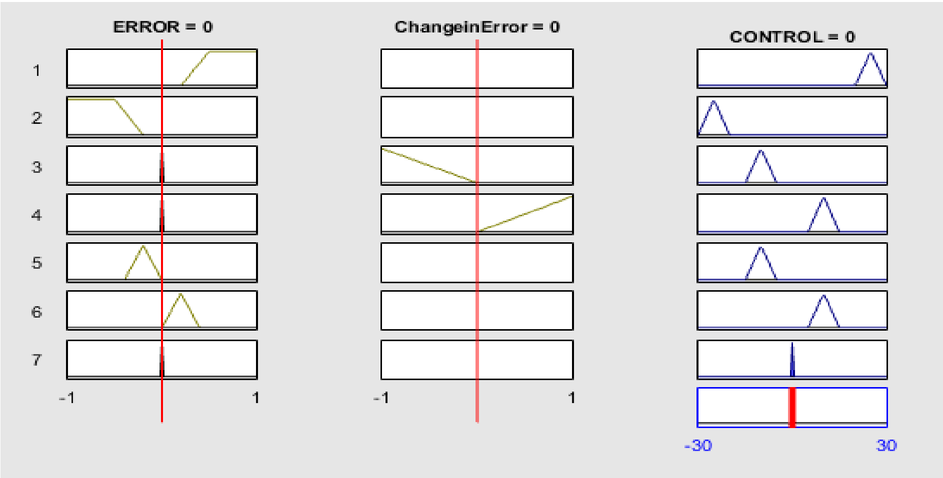

Figure 11 Rule Viewer

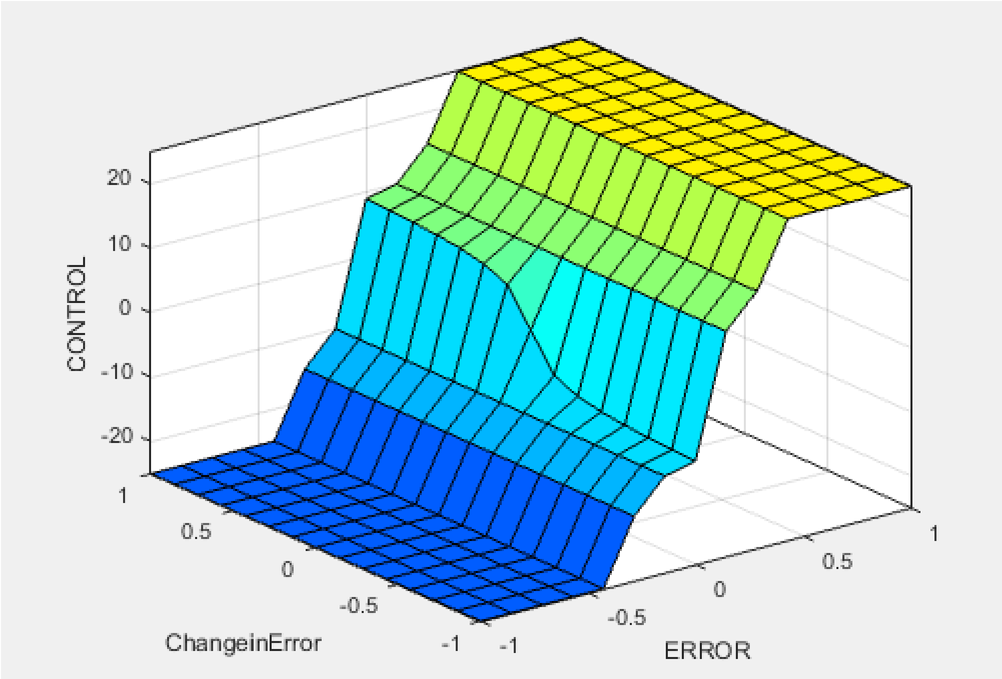

Figure 12 Fuzzy Rule Surface Viewer

7.4 Parameter specifications for Motor:

Armature Resistance = 1 Ohm. Armature Inductance = 2 mH. Moment of Inertia = 100 Kg-m^2. Viscous Friction Coefficient = 0.1 N-m/rad/sec. Back EMF constant = 0.01 V/rad/sec Rated Speed = 1500 rad/sec. Reference Speed = 1450 rad/sec. Load Torque = 10 N-m.

7.5 Modelling in SIMULINK:

Model:

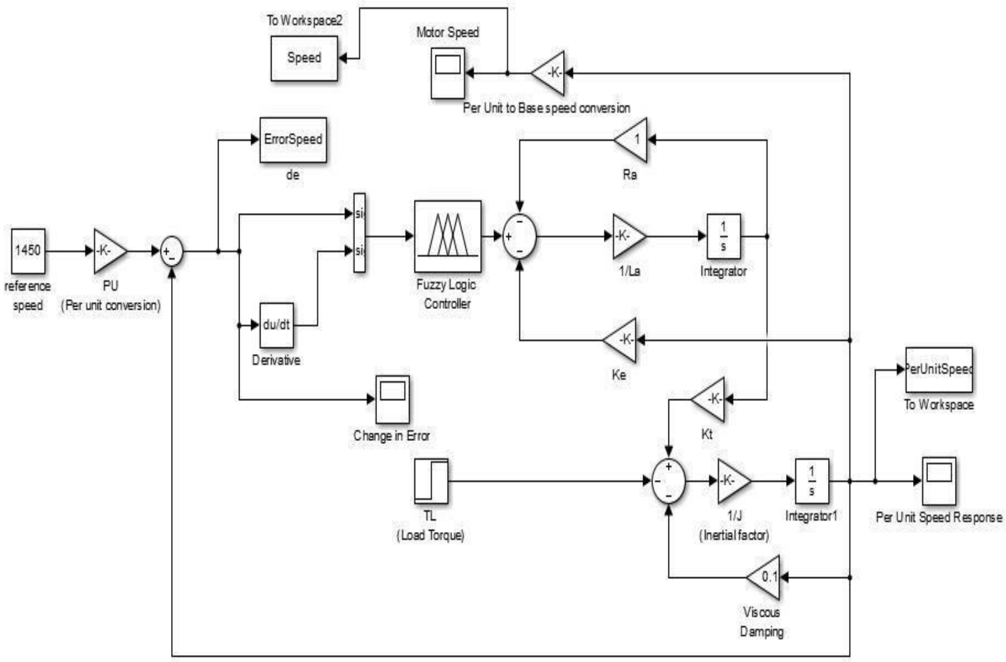

Figure 13 Simulink Model for Fuzzy Logic Control

The simulation was carried out for 2.5 sec.
The reference speed was converted into Per Unit speed for ease of designing the range of the linguistic variables in the Fuzzy tool box. Then the motor output speed at that instant is taken and subtracted from the reference speed to calculate the error signal. This Error signal is important as this is one of the inputs to the Fuzzy controller block. Now the other input is taken to fuzzy through the derivative block which gives the rate of change in Error. Now the Fuzzy controller acts according to the Rule base formed before and tries to bring the motor to the reference speed by supplying the output to the Armature. The difference of output of the Fuzzy controller and the armature supply is taken as Armature voltage and this controls the speed of the motor. The load torque is taken as a step for 10 sec with an initial value of 0.001 and Final value of 10 N-m. Now the Per Unit motor speed is obtained. To get the Speed, the per-unit speed is passed through a gain block with gain magnitude equal to the base speed taken in the per unit conversion. This gives the Speed of the motor.

7.6 Simulation Results:

Per-Unit Speed response:

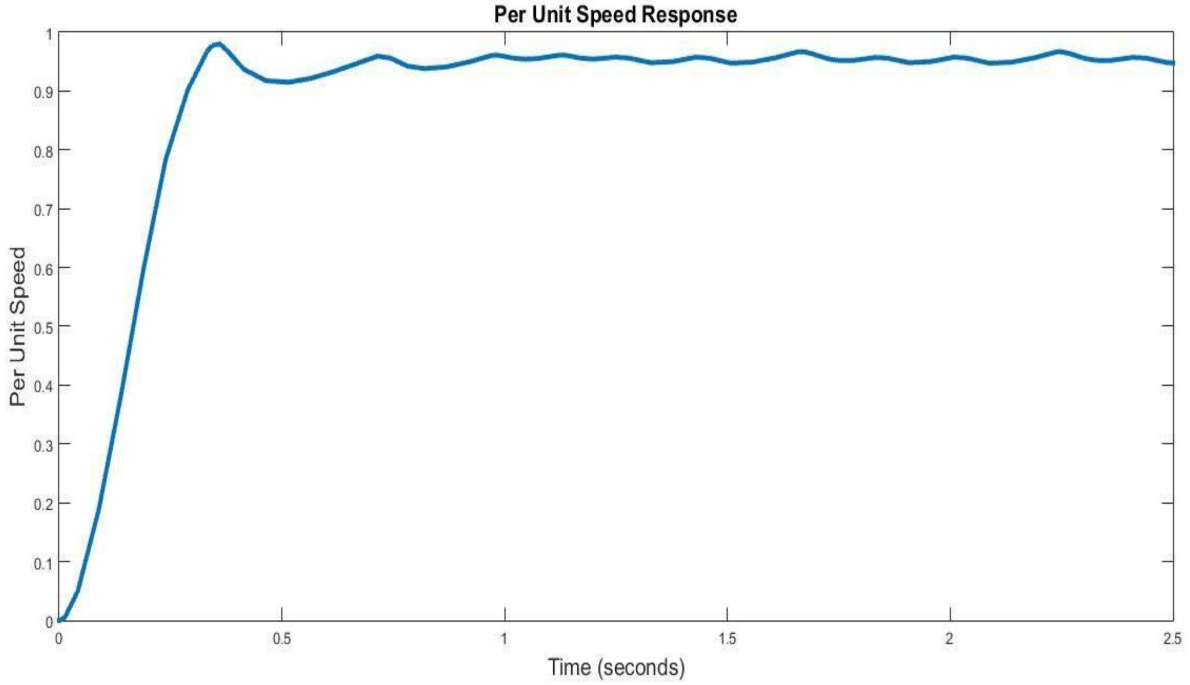

Figure 14 Per-Unit Speed Response

Speed response:

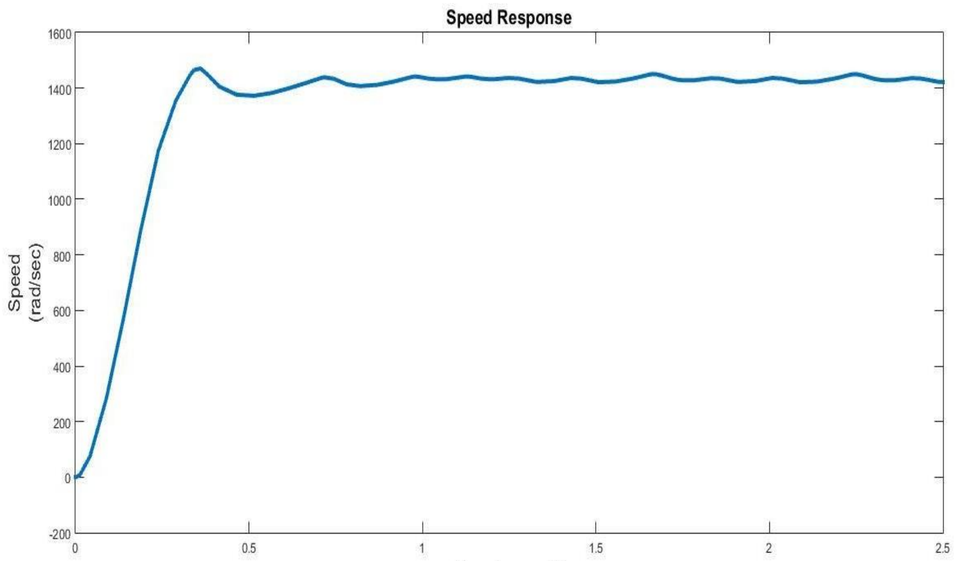

Figure 15 Speed

Error in Speed response:

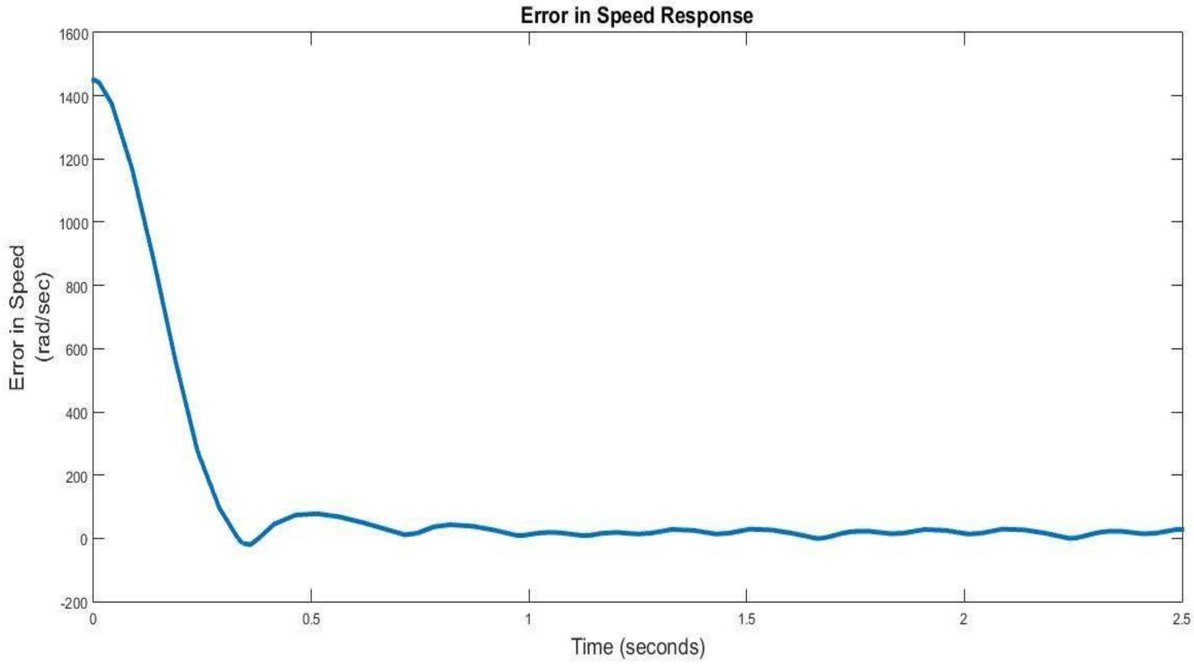

Figure 16 Error in Speed response

From the waveform of the Speed response (Fig. 14),

Table 2 Speed Response parameters

Rise time	Peak time	Peak overshoot
0.3318 sec	0.36 sec	20 rad/sec

5 Conclusion:

Here we have considered different types of speed control for a separately excited DC motor and understood the importance of Fuzzy logic in particular areas. We have also studied and understood various concepts of Fuzzy logic and Fuzzy set theory. We have also studied the Speed-Torque characteristics for the separately excited DC motor.

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 Fuzzy tool box. The membership functions used are Error Signal – 2 trapezoidal and 3 triangular. Change in Error signal – 2 triangular.
Control signal – 5 triangular.

We have modelled the Fuzzy control scheme using SIMULINK and plotted various waveforms. From the Speed response waveform we can see that the rise time is 0.3318 sec, the peak time is 0.36 sec and the peak overshoot is 20 rad/sec (1.3% of the reference speed). Thus, we have controlled the speed of the DC motor using the Fuzzy control logic.

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