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Performance Comparison of Fuzzy Logic and PID Controller for Speed Control of DC Motor in Distribution Grid

Didem ALTUN[1]

[1]*Res.Assist., Department of EEE, Sivas Cumhuriyet University, Sivas, Turkey*

Abstract - *This paper presents comparison between fuzzy logic controller and PID controller over a speed control of separately excited DC motor implementation in MATLAB/SIMULINK. The paper defines the setting steps of a fuzzy logic controller and PID controller to retain constant speed. Nine rules are planned for fuzzy logic controller using membership functions, and the gains of the PID controller are tuned by using Simulink Tuning Tool. Finally, the performance of fuzzy logic controller and PID controller is compared and examined for step input in terms of overshoot, rise time, peak time and settling time.*

Key Words: DC Motor Speed Control, PID Controller, Fuzzy Logic Controller, Ziegler-Nichols Method.

1. INTRODUCTION

DC motors have been commonly used in many industrial applications namely electric cranes, electric vehicles, robotic manipulators, and medical tools [1]. In terms of wide, simple, precise, and continuous control characteristic, DC machines such as step motors, DC series connected, DC shunt connected and DC brushless motors are more appropriate than asynchronous machines. However, collector and brush equipment of the dc motors restricts the usage area of these machines.

Electrical connections of the armature winding and the field windings is main classification criteria of the DC machines. In separately excited DC machines, the armature and field winding are electrically separate from each other, and the field winding is excited by a separate DC source [4].

Separately excited motor generally is used in train and automotive traction applications.

In order to control the speed of DC motors, adaptive, proportional (P), proportional integral (PI), proportional derivation integral (PID), neural network controller (NNC) and fuzzy logic controller (FLC) have been developed. The performance of conventional controllers could be degraded due to non-linear characteristics of DC motors such as saturation and friction. Usually, obtaining a better performance for controller depends on more accurate models and tuning parameters of a system [2].

FLC techniques are preferred to control speed of the DC motors, since fuzzy logic controllers are not sensitive to the accuracy of model of the DC motor, which is difficult to obtain.

DC motor speed control techniques;

- Under constant torque region, varying the armature voltage.
- Decreasing field flux in order to achieve speed above the rated speed in the constant power region [5].

DC Motor speed control methods;

- Controlling the rheostat armature, conventionally.
- PID controllers.
- Weakening field with constant power controllers
- Neural network controllers.
- Pulse width modulation using AC-DC step-up and step down converters to control armature voltage.
- Under constant torque region, moving average controllers which is non-linear auto regressive [6].

In this paper, after giving dynamical model of the separately excited DC motor and providing basic information about fuzzy logic process, DC motor speed control is carried out by using PID controller and fuzzy logic controller. In order to maintain constant speed under various shaft load, the rules and sets of the fuzzy logic controllers are used and developed by using 'IF-THEN' rules, the speed errors are decreased in acceptable values. On the other hand, the gains of the PID controller tuned by using Simulink Tuning Tool. In the last part of the paper, the efficiency of both FLC and PID are compared in terms of settling time and overshoot percentage.

2. MODEL OF SEPARATELY EXCITED DC MOTOR

DC motors are electrical machines that generate mechanical torque and consume DC electrical power. DC machines usually categorized according to the connection configuration of the field circuit with respect to the armature circuit [7]. In this study, separately excited DC motor whose model is given below will be used,

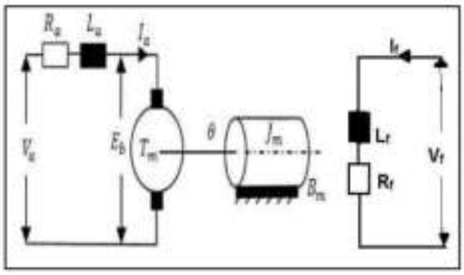

Figure-1: Model of the Separately Excited DC Motor

The mathematical model of the separately excited DC motor is as follows;

$$V_a = E_b + I_a.R_a + L_a\left(\frac{dI_a}{dt}\right) \quad (1)$$

$$T_m = J_m\left(\frac{d\omega}{dt}\right) + B_m\omega + T_L \quad (2)$$

Friction in rotor can be neglected since it is very small, in this study $B_m = 0.008\ N.\frac{m}{rad}/sec$

$$T_m = J_m\left(\frac{d\omega}{dt}\right) + T_L \quad (3)$$

$$E_b = K\varphi \quad (4)$$

$$T_m = K\varphi I_a \quad (5)$$

Taking Laplace transform of the armature voltage

$$I_a(S) = (V_a - E_b)/(R_a + L_a S \quad (6)$$

$$I_a(S) = (V_a - K\varphi\omega)/R_a(1 + L_a\frac{S}{R_a} \quad (7)$$

$$\omega(S) = \frac{T_m - T_L}{J_s} = \frac{K\varphi I_a - T_L}{J_m S} \quad (8)$$

$$T_a = \frac{L_a}{R_a} \quad (9)$$

After substitution all equation to simplify the motor model, the general transfer function is

$$\frac{\theta(s)}{V_a(s)} = \frac{K\varphi}{L_a J_m s^2 + R_a J_m s + k^2\varphi^2} \quad (10)$$

For the overall transfer function of DC motor which is used in this paper is given as;

$$\frac{\theta(s)}{V_a(s)} = \frac{0.5}{0.002s^2 + 0.05s + 0.625} \quad (11)$$

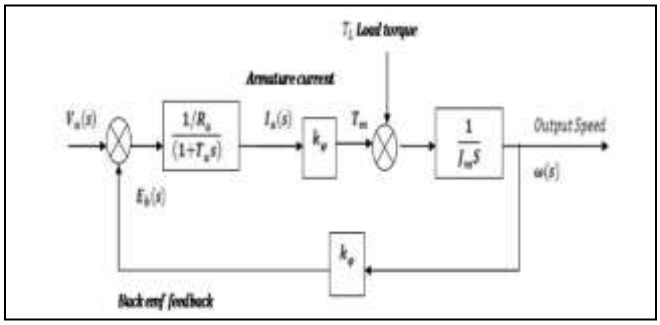

Figure-2: Separately Excited DC Motor Block Diagram

DC motor parameters is given in Part IV which is simulation and analysis.

3. CONCLUSIONS

Fuzzy logic method is a mathematical theory which can define a state and direct it to fuzzy logic system.

A fuzzy set A which is nonempty set, in X is described by its membership function

$$\mu_a : X \rightarrow [0,1] \quad (12)$$

In fuzzy set A for each x ∈ X, $\mu_A(x)$ is the degree of membership of element x.

Then A is

$$A = \{(x, \mu_A(x)), x \in X\} \quad (13)$$

The union of two fuzzy sets (A ∪ B) is defined with logic OR operator. If a ≥ b, max (a, b) = a, and if b>a, max (a, b) = b

$$\mu_{AUB(x)} = \max(\mu_{A(x)}, \mu_{B(x)}), x \in X \quad (14)$$

The intersection of the two fuzzy sets (A ∩ B) is defined with logic AND operator. If a ≤ b, min (a, b) = a, and if a>b, min (a, b) = b

$$\mu_{A \cap B(x)} = \min(\mu_{A(x)}, \mu_{B(x)}), x \in X \quad (15)$$

After describing fuzzy variables, membership functions are assigned to that variables and the rules are adjusted according to each combination of the control variable. These rules are determined by using "If-Then" states, which correlate with input and output variables. Each "If" condition is a suggestion for "Then" as a conclusion.

However, to obtain exact relation between input and output variables is difficult due to mathematical model complexity uncertain or approximate reasoning, especially in this kind of case fuzzy systems are suitable. Fuzzy logic allows decision making with estimated values under incomplete or uncertain information [3].

Although fuzzy logic controller is based on linguistic fuzzy variables, these linguistic variables have to be classified and summarized.

The inputs are generally hard or crisp measurement from some measuring equipment rather than linguistic. A preprocessor shows the conditions the measurements before enter the controller [9].

Each input data is converted to degrees of membership searching in one or several MFs by Fuzzification block. The conditions of the rules are determined matching the input data by fuzzification block. Degree of membership is corresponded for each linguistic term which applies to the input variable [13].

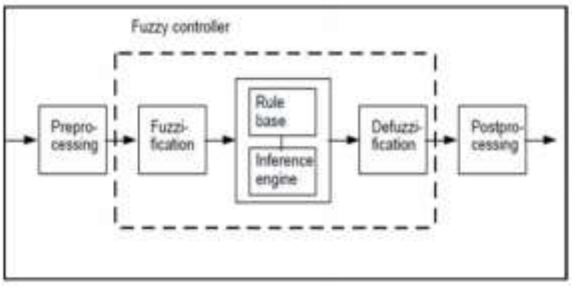

Figure-3: Structure of fuzzy logic controller

Rule base can be defined as collection of rules. The rules are composed of "If Then", "If" can be defined as conditions and "Then" can be defined as conclusion. The rules are implemented, and control signal which depends on the inputs error and change in error which already measured are calculated by computer program.

Control signal of the system which is also non-fuzzy output signal is converted by Defuzzification block from fuzzy signal. The output signal depends on the rules and nonlinearity of the system [6].

The post processing block can be used as an integrator that contains output gain.

The performance of PID controller that based on accuracy of mathematical model of the system, however, a FLC typically inserts the insight and knowledge of a human operator. The process input based on error and change in error can be manipulated by human operator within the shortest possible time. The output of the system (u (t)) is controlled variable of fuzzy controller [2].

4. SIMULATION AND ANALYSIS

In this paper, simulation for DC motor is implemented for parameters as follows; armature inductance (L_a = 0.02 H), armature voltage (V_a = 200 V), armature resistance (R_a = 0.5 Ω), mechanical inertia (J_m = 0.1 kg.m^2), friction coefficient (B_m = 0.008 N.m/rad/sec), motor torque constant (k = 0.5 N.m/A), back emf constant (k = 1.25 V/rad/sec).

The aim of the FLC and PID controller is try to keep speed of the motor constant when the load changes. The step function input, in this study, is used for both of the controller types to observe their response.

After choosing input and output, membership functions (MFs) are defined as seen in Figure 4 and Figure 5, respectively. In this study, symmetric triangles are used for MFs.

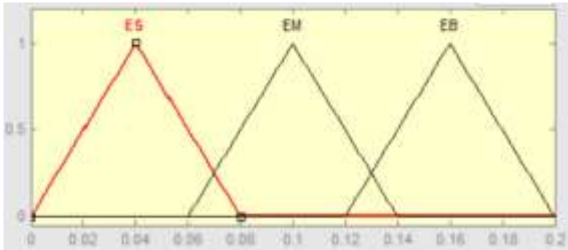

Figure-4: MFs for input-1

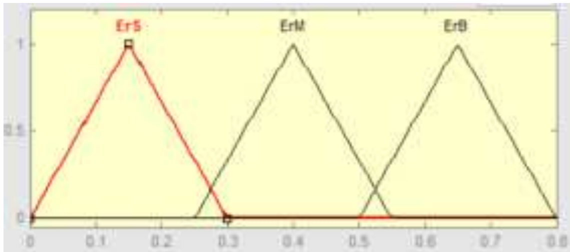

Figure-5: MFs for input-2

ES - ***e*** Small, EM - ***e*** Medium, EB - ***e*** Big, ErS - $\dot{e}$ Small, ErM - $\dot{e}$ Medium, ErB - $\dot{e}$ Big, OS - u(t) Small, OM - u(t) Medium, OB- u(t) Big.

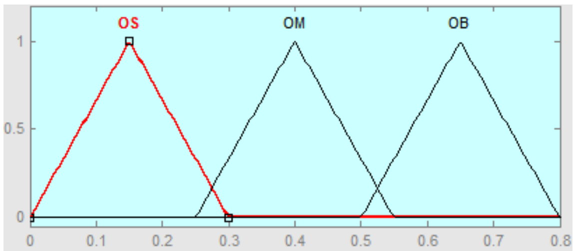

Figure-6: MFs for output

Figure 6 shows the membership functions of the output which can be defined as conclusion of the system.

The relationship between inputs and output is adjusted using toolbox rule editor as seen in Figure 7. The number of rules is equal to 9 which is square power of the number of MFs for input.

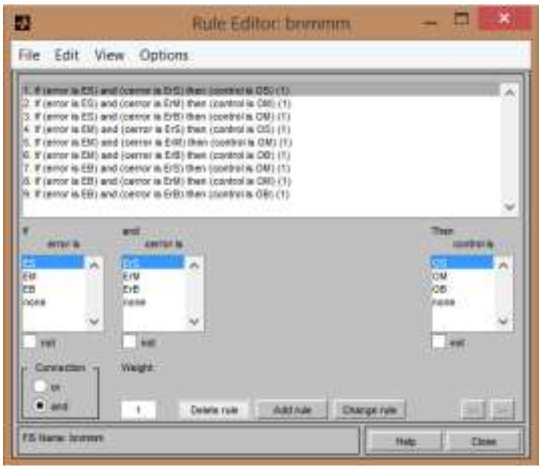

Figure-7: Fuzzy rules of the system

The number of the rules are equal to square power of the number of MFs for input (Table 1). In this study, Mamdani method is used for developing fuzzy inference system. Rule base is needed for developing rules and its relation between input MFs as seen above.

Table -1: Rule Base

e/Δe	ErS	ErM	ErB
ES	OS	OM	OM
EM	OS	OM	OB
EB	OS	OM	OB

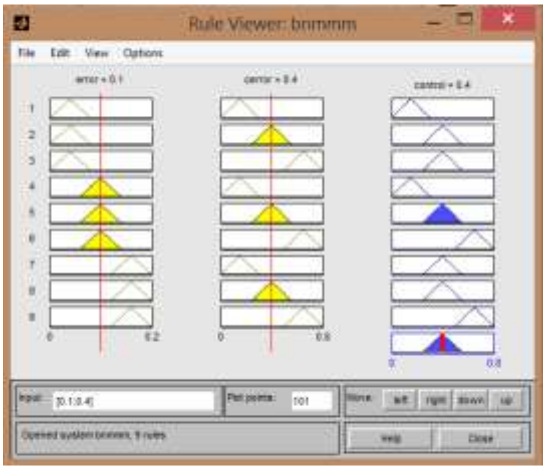

Figure-8: Rule viewer

Three dimensional behavior of the controller is depicted in Figure 9.

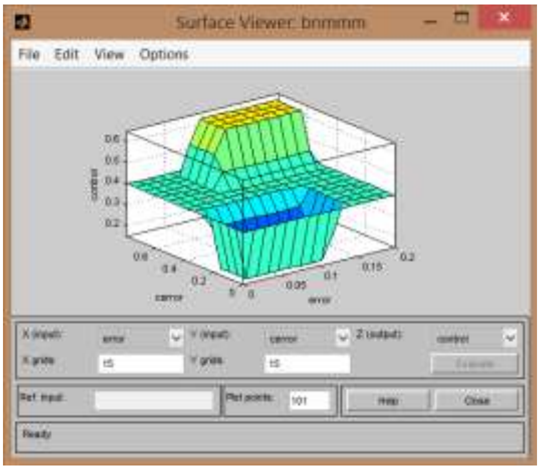

Figure-9: 3-D view of the FLC response

The 2-D relationship between error (input-1) and control (output) is shown below,

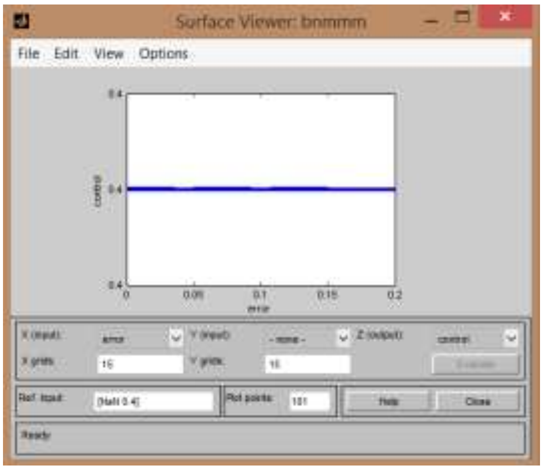

Figure-10: 2-D view of the error-control

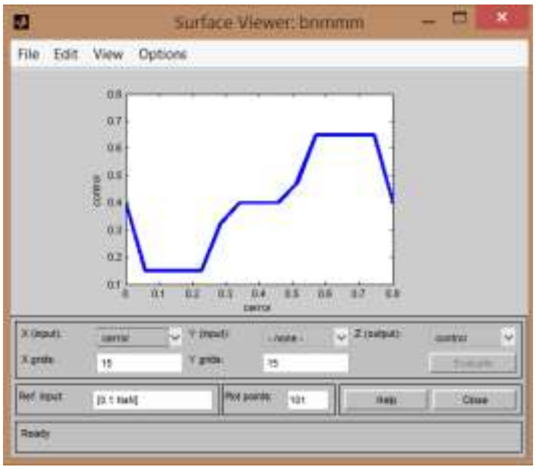

Figure-11: 2-D view of the change in error and control

As seen in Figure 12, PID controller was designed in MATLAB/SIMULINK. The parameters of PID controller are tuned using Simulink Tuning Tool. Although Ziegler-Nichols method usually is preferred to tune contoroller parameters, Simulink Tuning Tool give better tuned PID controller parameters [8].

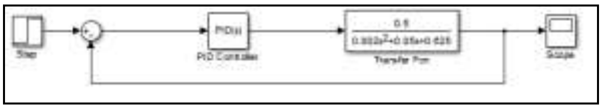

Figure-12: PID model of the system

The PID controller output for second order system is depicted below,

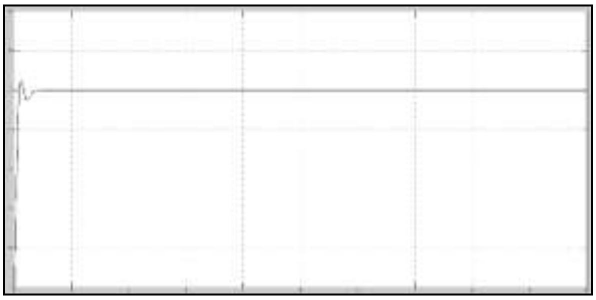

Figure-13: PID controller response for Step function input

As seen in Figure 14, FLC system was designed in MATLAB/SIMULINK. FLC parameters are carried out by using Fuzzy Logic Toolbox with nine fuzzy rules.

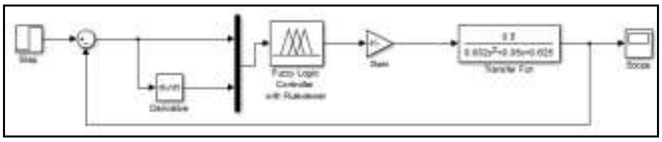

Figure-14: FLC model of the system

FLC response for simulation output of the for second order system is depicted below,

Figure-15: FLC response for Step function input

```
>> stepinfo(ScopeData(:,2))

ans =

        RiseTime: 4.5973
    SettlingTime: 17.9203
     SettlingMin: 0.9509
     SettlingMax: 1.0493
       Overshoot: 4.9408
      Undershoot: 0
            Peak: 1.0493
        PeakTime: 13
```

Figure-16: PID controller step response characteristic

```
>> stepinfo(ScopeData(:,2))

ans =

        RiseTime: 2.8386
    SettlingTime: 12.1929
     SettlingMin: 0.9226
     SettlingMax: 1.0437
       Overshoot: 4.2030
      Undershoot: 0
            Peak: 1.0437
        PeakTime: 11
```

Figure-17: Fuzzy controller step response characteristic

The parameters of PID controller, tuned using Ziegler Nichols method, simulated and the performance of controller can be seen in below, worse than controller which tuned using Simulink Tuning Tool.

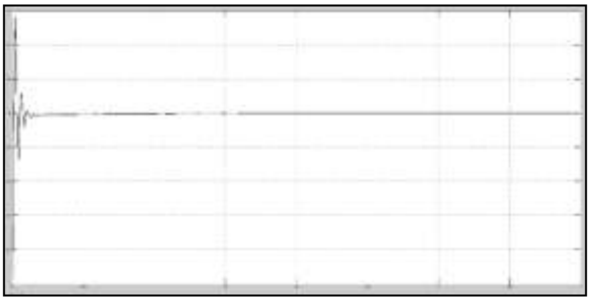

Figure-18: Step response of the system with PID controller tuned using Ziegler Nichols Method

```
>> stepinfo(ScopeData(:,2))

ans =

        RiseTime: 1.8017
    SettlingTime: 24.6962
     SettlingMin: 0.7210
     SettlingMax: 1.5601
       Overshoot: 55.9766
      Undershoot: 0
            Peak: 1.5601
        PeakTime: 10
```

Figure-19: PID controller tuned using Ziegler Nichols step response characteristic

As it is seen in Figure 16 and Figure 17, performance of the PID controller depends on tuning the controller parameters which depends on more accurate mathematical model of the system. Performance of the FLC just depends on the fuzzy rules

5. CONCLUSION

In this paper, performance of the FLC and PID controller is observed for separately excited DC motor speed control, when input function is step. A system should be designed for less rising time and less overshoot percentage. The performance comparison study between FLC and PID controller whose parameters adjusted using Simulink Tuning Tool which gives better parameters than other tuning methods is carried out. Even though, better tuned PID controller may be provide better performance, the recommended FLC has more benefits, such as better static and dynamic performance, higher flexibility, control, compared with PID controller. Furthermore, it can be seen in Figure 10-11, FLC have provided less overshoot percentage of 4.2 % and lower rising time 2.8386 second, which means FLC has better performance in terms of overshoot percentage, settling time, control performance, and rise time, therefore, FLC design was recommended and implemented.

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