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Design of self-tuning PID controller using fuzzy logic for DC motor speed

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Abstract:
High performance motor drives are very important in industrial as well as other purpose applications, a high-performance motor drive system must have good dynamic speed command tracking and load-regulating response to perform task, PID controller can be used to minimize speed error in DC motor, PID controller need to adjust the three gain parameters during system run. The best way is to design of self-tuning PID controller using fuzzy logic for DC motor speed, use fuzzy logic controllers to improve parameter of PID controller ability to handle disturbances.

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I. Introduction

Several conventional and numeric controller types, the controllers can be: Proportional integral (PI), proportional integral derivative (PID), Fuzzy Logic Controller (FLC) or the combination between them: Fuzzy-Neural Networks, Fuzzy-Genetic Algorithm, Fuzzy-AntsColony, Fuzzy-PID.PID controllers provide robust and reliable performance for most systems if the PID parameters are tuned properly.Implementation of self-tuned PID controller (Fuzzy-PID) for speed control of DC motor based on MATLAB. The basic property of DC motor is that speed of DC motor can be adjusted by varying its terminal voltage. It can easily be deduced that Fuzzy-PID can maintain the speed at desired values irrespective of change of load. The self-tuning PID-typefuzzy controller is an auto-adaptive PID controller that designed by using an incremental fuzzy logic controller in place of the proportional term in the conventional PID controller to tune the parameters of PID controller on line by fuzzy control rules.The advantage of fuzzy logic for online tuning of PID controller has been used to obtain robust speed control of a dc motor with an accurately modeled.The model and simulation methods for analyzing, testing and developing of dc motor using MATLAB/SIMULINK and PID parameters were obtained by using Fuzzy sets.Fuzzy logic is an extension of Boolean logic by LotfiZadeh in 1965 based on the mathematical theory of fuzzy sets, which is a generalization of the classicalsettheory[4]. Fuzzy logic is determined as a set of mathematical principles for knowledge. Representation based on degrees of membership rather than on crisp membership of classical binary logic.Unlike two-valued Boolean logic, fuzzy logic is multi-valued. It deals with degrees of membership and degrees of truth. Fuzzy logic uses the continuum of logical values between 0 (completely false) and 1 (completely true) [5]. A fuzzy set can be simply defined as a set with fuzzy boundaries while a*membership function* (MF) is a curve that defines how each point in the input space is mapped to a membership value (degree of membership) between 0 and 1. The function itself can be an arbitrary curve the shape can define as a function that suits from the point of view of simplicity, convenience, speed, and efficiency. [5]

2.6.4 DC Motor Transfer Function and Block Diagram

A block diagram for the system can be developed from the differential equations given in eqns. (2.26) and (2.27). Taking the Laplace transform of each equation gives

$$s\Omega_a(s) - \omega_a(0)$$

$$sI_a(s) - i_a(0) = -\frac{R_a}{L_a}I_a(s) - \frac{k_v}{L_a}\Omega_a(s) + \frac{1}{L_a}V_a(s)$$

The initial conditions go to zero and all the variables become some change around a reference state as follows:

$$I_a(s) = \frac{-k_v \Omega_a(s) + V_a(s)}{L_a s + R_a} \qquad \Omega_a(s) = \frac{-k_t I_a(s) - T_L(s)}{Js + B}$$

The block diagram obtained from these equations for a permanent magnet dc motor is shown in block diagram as in Figure 1.

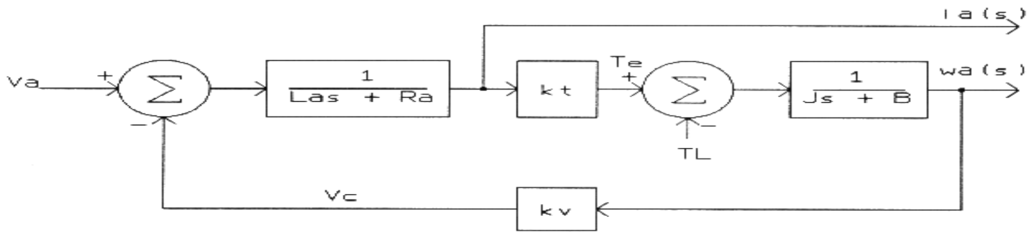

Figure 1: Block Diagram Representation of Eqns. (2.34) and (2.35).

This block diagram is reduced by block diagram algebra to an overall transfer function. Several steps in this process are shown in Figure2, with the overall transfer function between the output angular velocity and input applied voltage given within the last block in Figure2.

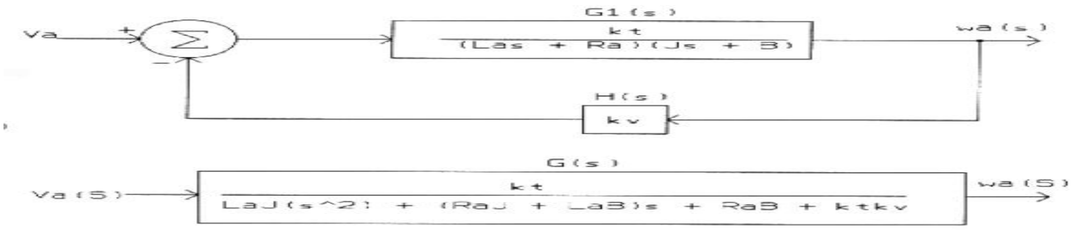

Figure 2: Overall Transfer Function for the DC Motor.

TheSimulink model of a DC motor armature voltage control system is shown in figure (3)

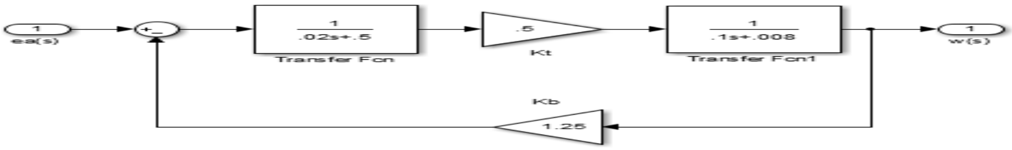

Figure 3Simulink Model of DC Motor

3.3 Fuzzy Logic Controller Design

Fuzzy logic is express by means of the human language. Based on fuzzy logic, a fuzzy controller converts a linguistic control strategy into automatic control strategy, and fuzzy rules are constructed by expert experience or knowledge database. Block diagram for speed control of DC motor using fuzzy logic controller is shown in figure 4.

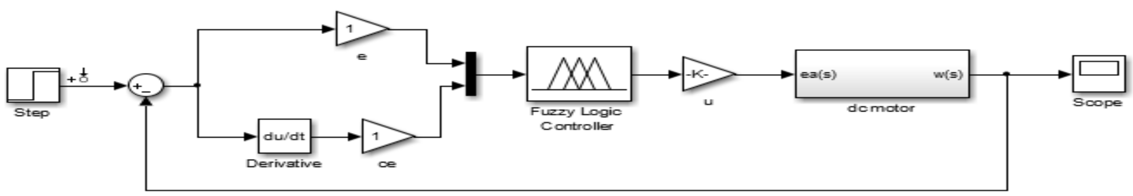

Figure 4:Simulink Model of the System Using Fuzzy Logic Controller

The linguistic variables in the Fuzzy inference are defined as {el, em, eh, ecl, ecm, ech, ol, om, oh}, where el means error low, em means error medium, eh means error high, ecl means error change low, ecm means error change medium, ech means error change high, ol means output low, om means output medium and oh means output high.That shown in membership functions in figure5for error input andchange of error inputs and for output.

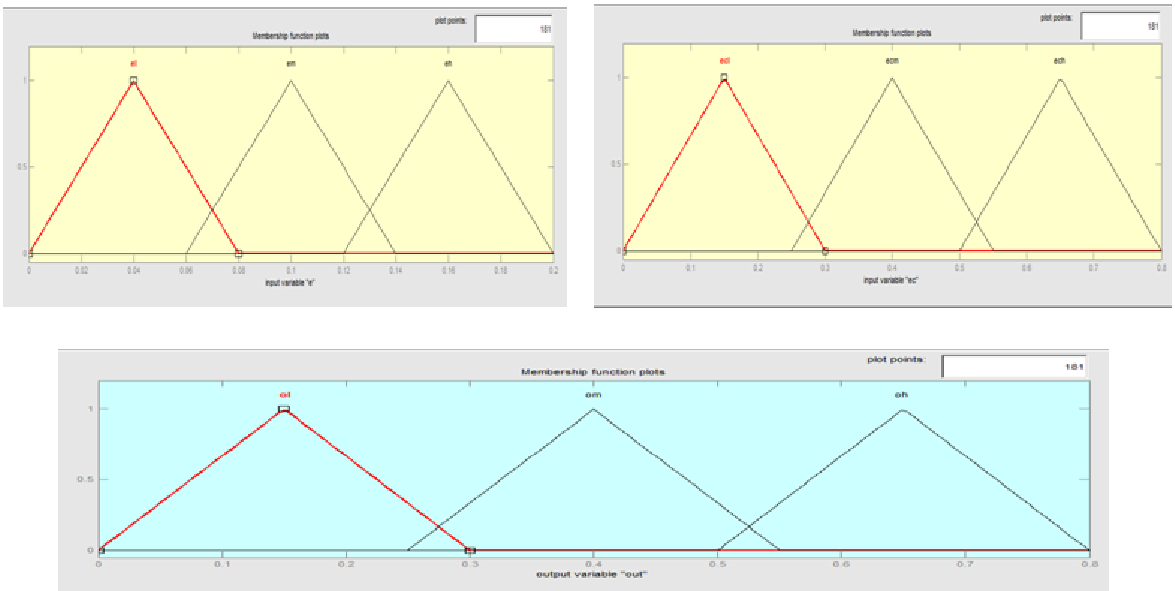

Figure 5:Membership Functions for Error Input,Change of Error Input and Output.

The fuzzy rules are summarized in Table 1. the type of fuzzy inference engine is Mamadani.

Table1:Fuzzy Rules

e\ce	*ecl*	*ecm*	*ech*
el	*ol*	*om*	*om*
em	*ol*	*om*	*oh*
eh	*om*	*om*	*oh*

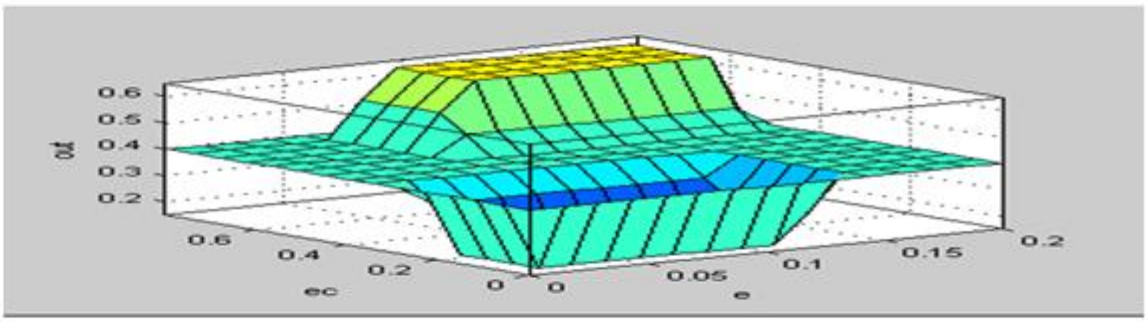

Figure 6: Input and Output Relation for Fuzzy Controller.

3.4Fuzzy-PID Controller Design

The structure of the fuzzy auto tuning PID controller designed for control speed of dc motor is shown in figure 7. its inputs are control error *(e)* and the change of control error *(ce)*.the fuzzy auto tuner block adjusts the parameter of the incremental PID controller,and the incremental PID controller calculates the control output.

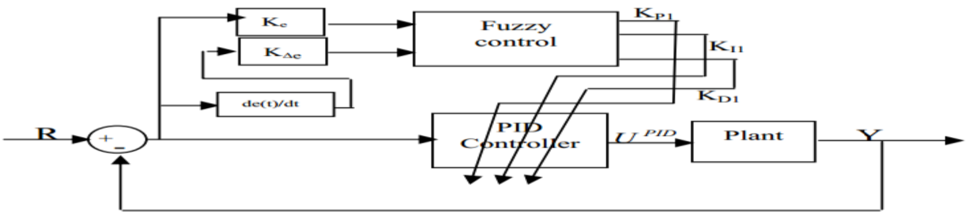

Figure7:The Structure of Self-Tuning Fuzzy-PID Controller

The fuzzy auto-tuning of PID controller is to find the fuzzy logic relationship between three parameters of PID with error *(e)*and change of error *(ce)*, calculate*(e)*and *(ce)*in cycle in the operation of control system and adjust *(kp)*,*(ki)*and *(kd)*on-line according to the fuzzy logic control principle .

The fuzzy variable sets including speed control error *(e)*, error change *(ce)*,*(Δkp)*, *(Δki)* and *(Δkd)* are defined as follows:

***e* = { -20, 40, 70, 100,160}*ce* = { -1300, -800, -550, -300, 200}**

Δ*kp*={0, 5, 10, 15, 20, 25, 30}Δ*ki*= {0, 10, 20, 30, 40, 50, 60}Δ*kd* = {0, 1, 2, 3, 4, 5,6}

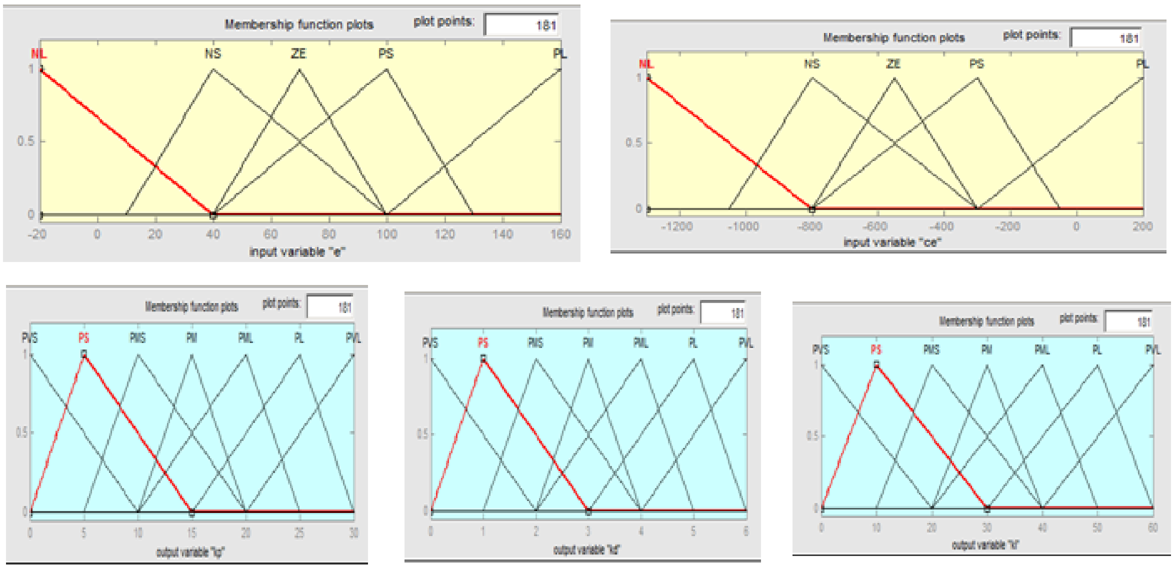

Figure 8:Degree of Memberships of Speed Control Error (e), Change Speed Error (ce),Change k_p (Δk_p), Change k_i(Δk_i) andChange k_d(Δk_d).

The fuzzy tuning rule sets of *(Δkp)*, *(Δki)* and *(Δkd)*are designed as illustrated in table 2, 3and 4

Table 2: Fuzzy Tuning Rule of (Δk_p).

ce/e	*NL*	*NS*	*ZE*	*PS*	*PL*
NL	*PVL*	*PVL*	*PVL*	*PVL*	*PVL*
NS	*PML*	*PML*	*PML*	*PL*	*PVL*
ZE	*PVS*	*PVS*	*PS*	*PMS*	*PMS*
PS	*PML*	*PML*	*PML*	*PL*	*PVL*
PL	*PVL*	*PVL*	*PVL*	*PVL*	*PVL*

Table 3: Fuzzy Tuning Rule of (Δk_i).

ce/e	*NL*	*NS*	*ZE*	*PS*	*PL*
NL	*PM*	*PM*	*PM*	*PM*	*PM*
NS	*PMS*	*PMS*	*PMS*	*PMS*	*PMS*
ZE	*PS*	*PS*	*PVS*	*PS*	*PS*
PS	*PMS*	*PMS*	*PMS*	*PMS*	*PMS*
PL	*PM*	*PM*	*PM*	*PM*	*PM*

Table 4: Fuzzy Tuning Rule of (Δk_d).

ce/e	*NL*	*NS*	*ZE*	*PS*	*PL*
NL	*PVS*	*PMS*	*PM*	*PL*	*PVL*
NS	*PMS*	*PML*	*PL*	*PVL*	*PVL*
ZE	*PM*	*PL*	*PL*	*PVL*	*PVL*
PS	*PML*	*PVL*	*PVL*	*PVL*	*PVL*
PL	*PVL*	*PVL*	*PVL*	*PVL*	*PVL*

Where NL : negative large, NS : negative small, ZE : zero, PS : positive small, PL : positive large, PVS : positive very small, PMS : positive medium small, PM : positive medium, PML : positive medium large, PVL means positive very large.Fuzzy if-then rules are shown total 25 rules outputs variable and in figure 9 show relation between inputs and outputs for fuzzy controller.

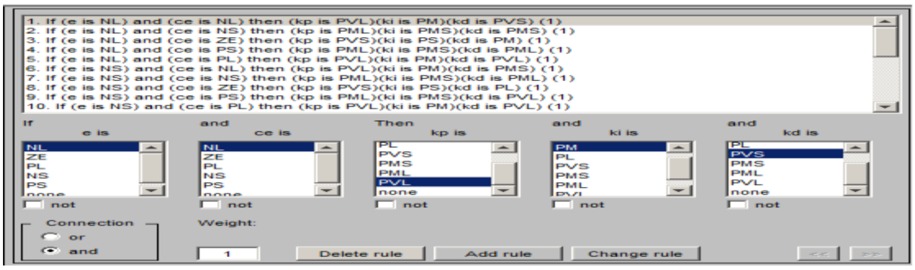

Figure 9: Fuzzy IF-Then Rules.

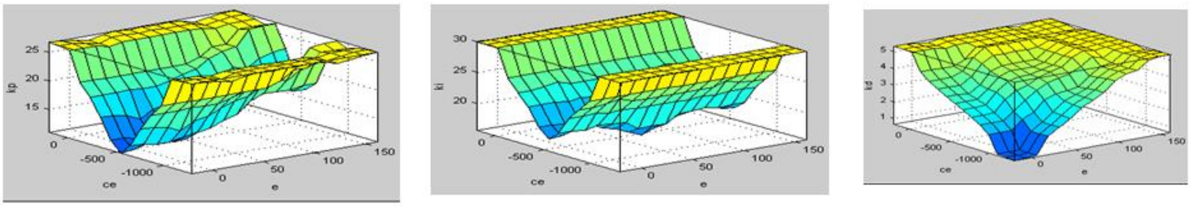

Figure 10: Relation Between Inputs and Outputs

According to the membership degree calculation table of all fuzzy variable sets, and the fuzzy tuning rule sets and algorithms of all control parameters, the mamdani-type inference system Fuzzy-PID is developed using the fuzzy control simulation toolbox" fuzzy "ofmat lab. The simulation model for Fuzzy-PID self-tuning controlleris shown in figure 11, it contains 2 input *(e,ce)*,3outputs (Δk_p,Δk_i *and* Δk_d) and 25 fuzzy inference rules.

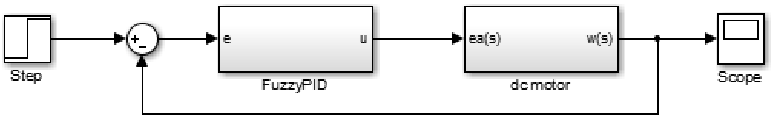

Figure 11: Simulink Modelfor Fuzzy-PID Self-Tuning Controller

Self-tuning fuzzy-PID regulator subsystem block is shown in figure 12Consists of fuzzy and PID block with some modification refers to the formula which is applied to calibrate the value of *(Δkp)*,*(Δki)* and *(Δkd)* from fuzzy block to obtain the value of *(kp)*, *(ki)* and *(kd)*. Each parameter has it is own calibration.

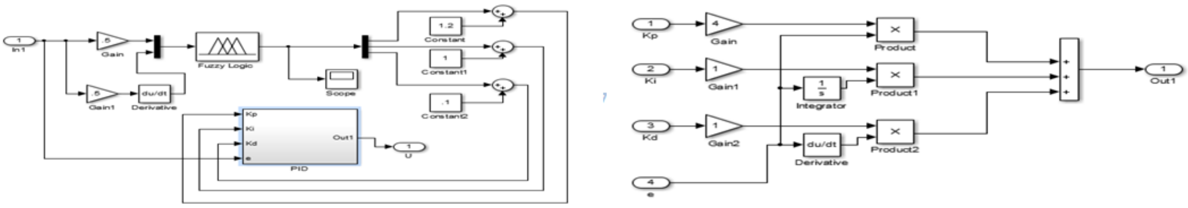

Figure 12: Simulation Block of Fuzzy PIDSelf-Tuning.

After run the Simulink block automatically to carry out the fuzzy auto tuning of PID parameters, through looking up the fuzzy tuning rule tables. Then fuzzy PID will calculate the tuned new values of *kp*, *ki*and *kd*, using the following algorithm:

$K_p = k_p0 + \Delta k_p K_i = k_i0 + \Delta k_i K_d = k_d0 + \Delta k_d$Where *kp0*,*ki0* and *kd0* are constants.

II. Result and Discussion

After simulating the process control of speed control system models by using MATLAB/SIMULINK.the performance of the controllers was analyzed by comparing the output signal represented by the graph.Figures13show performance of the PID controller. Using Zigler_Nichols method to tune PID controller parameters.Figure 14 show Error of the closed loop system using PID controller.

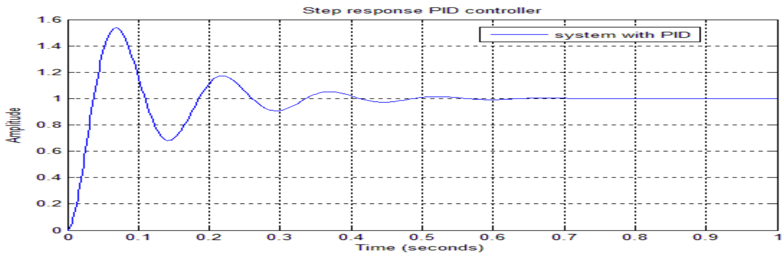

Figure13:Step Response of the System with PID Controller.

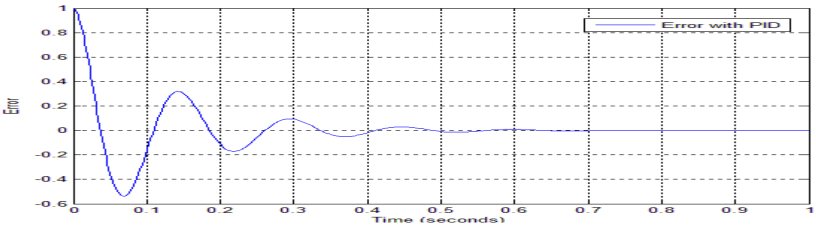

Figure 14: Error of the Closed Loop System Using PID Controller

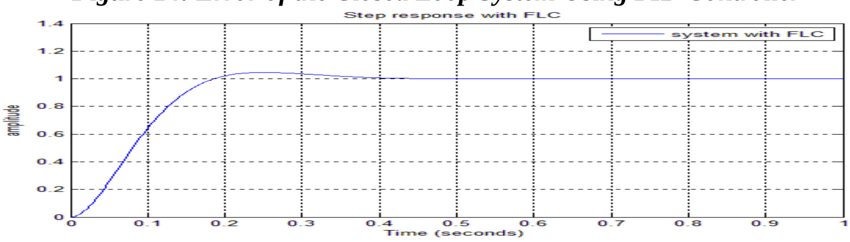

Figure 15: Step Response of the System with Fuzzy Controller.

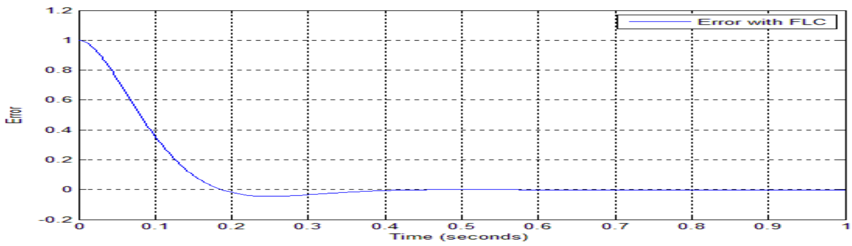

Figure 16: Error of the Closed Loop System Using Fuzzy Controller

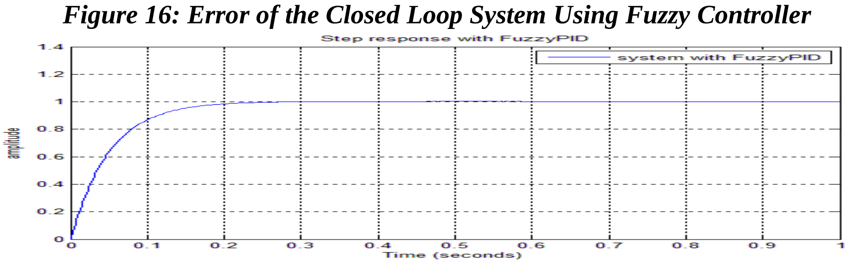

Figure 17: Step Response of System Using Fuzzy-PID Controller

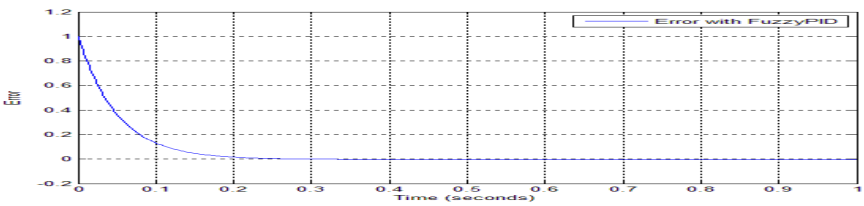

Figure 18: Error of the Closed Loop System Using Fuzzy-PID Controller

Comparison between PID, Fuzzy and Fuzzy plus PID controller step response specification as shown in figure 19 and table 5.

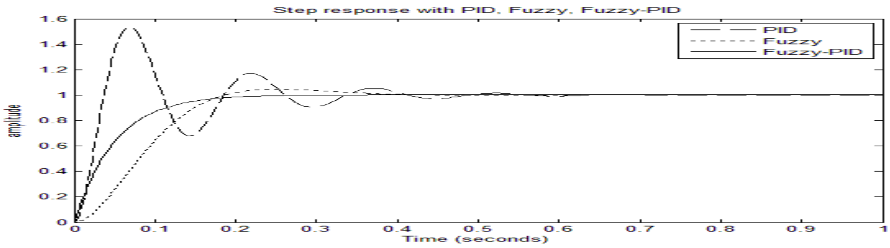

Figure 19: Step Response of System.

Table 5: Comparison Between the Output Responses for Controller

Title	PID controller	Fuzzy controller	Fuzzy-PID controller
Peak amplitude	*1.48*	*1.045*	*1*
Peak time (sec)	*0.0742*	*0.25*	*0.29*
% Overshoot	*48.3*	*4.5*	*0*
Settling time (sec)	*0.571*	*0.36*	*0.2*
Rise time (sec)	*0.03*	*0.15*	*0.11*

From the simulation results it is concluded that, compared with the conventional PID controller, Fuzzy controller and self-tuning PID controller. Fuzzy-PID controller has a better performance in both transient and steady state response. Theself-tuning Fuzzy-PID has better dynamic response curve, short response time, smaller overshoot, less peak amplitude, minimum settling time, small steady state error (SSE), high steady precision compared to the conventional PID controller and Fuzzy controller.

5.1 Conclusion

In this paper designed a DC motor whose speed can be controlled using PID controller. The proportional, integral and derivate *(KP, KI, KD)* gains of the PID controller are adjusted according to FUZZY LOGIC. First, the fuzzy logic controller is designed according to fuzzy rules so that the systems are fundamentally robust. There are 25 fuzzy rules for self-tuning of each parameter of PID controller. The FLC has two inputs. One is the motor speed error between the reference and actual speed and the second is change in speed error (speed error derivative).Secondly, the output of the FLC i.e. the parameters of PID controller are used to control the speed of DC Motor. The study shows that both characters of PID controllers and characters of fuzzy controller are present in fuzzy self-tuning PID controller. The fuzzy self-tuning approach implemented on a conventional PID structure was able to improve the dynamic as well as the static response of the system. Comparison between the conventional output and the fuzzy self-tuning output was donebased on the simulation result obtained by MATLAB. The simulation results demonstrate that the designed self-tuned PID controller realize a good dynamic behavior of the DC motor, a perfect speed tracking with less rise and settling time, minimum overshoot, minimum steady state error and give better performance compared to conventional PID controller.

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