Impact Factor: 4.14 (Calculated by SJIF-2015)
e- ISSN: 2348-4470
p- ISSN: 2348-6406
International Journal of Advance Engineering and Research Development
Volume 3, Issue 4, April -2016

Effect of Fuzzy Inference Systems on PID Controlled DC Motor

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Abstract - *In this paper we have designed a PID Controlled DC motor whose speed is controlled using Mamdani fuzzy Inference system and Sugeno Fuzzy Inference system. First Mamdani FIS is designed according to various rules. In Sugeno FIS system three FLC's are used. The Sugeno FIS system was able to improve the speed response of PID controlled DC motor. Comparison between the outputs of two fuzzy inference systems is done. The result shows that the Sugeno system having better response than Mamdani FIS system.*

Keywords: *DC Motor, Mamdani FIS, PID Controlled DC Motor, Seed Control, Sugeno FIS.*

I. INTRODUCTION

DC motor is a machine which converts electric energy into mechanical energy. They are widely used in many applications like electric vehicles, electric trains, lifts and in many other industrial applications because of their high reliability and low cost [7]. They require speed control to perform their specific tasks. PID is one of the most widely used controller for various control system because they provide robust performance if its parameter are tuned properly. At the same time the PID controller have some disadvantages too like undesirable overshoot and sensitivity to control gains [1]. PID's disadvantages can be overcome by using FLC.

FLC has become one of the rapidly used techniques in control systems. FLC's used two type of inference system one is Mamdani inference system and the other one is Sugeno inference system. They represent an important part of fuzzy logic. In most of control applications they perform crisp non-linear mapping. Basically collection of fuzzy rules specifying input to output map refer as inference system[2]. They allow effective utilization and representation of human knowledge about the system.

II. DC MOTOR MODEL

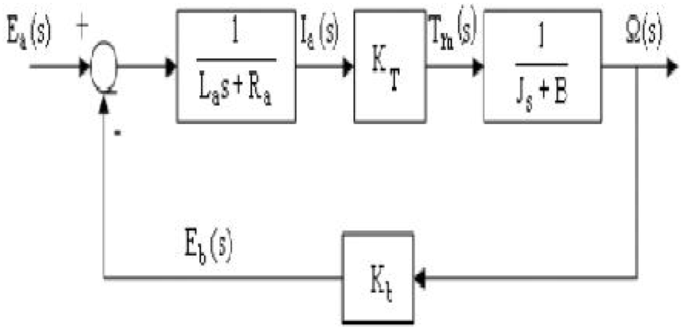

Figure1: Block Diagram of DC Motor

A linear model of a simple DC motor consists of an electrical equation and mechanical equation as determined in the following equations (1) and (2). [1], [3]

$$Va = E_b + IaRa + La\,(dIa/dt) \quad (1)$$

$$Tm = Jm^* \,d\omega /dt + B_m w + T_l \quad (2)$$

Where,

R_a: armature resistance (Ω)

L_a: armature inductance (H)

I_a: armature current (A)

E_a: input voltage (V)

E_b: back electromotive force (V)

T_m: motor torque (Nm)

ω : angular velocity of rotor (rad/s)

J : rotor inertia (kgm2)

B: friction constant (Nms/rad)

K_b: EMF constant (Vs/rad)

K_T: torque constant (Nm/A)

III. PID CONTROLLED DC MOTOR MODEL

Figure1 shows the simulink model of PID controlled DC motor. In this model 140 is the reference speed input given to pid. Here PID controller is tunned through Kp K_i and K_d using values 7.5, 8 , 1.8 respectively. Step response is given in order to provide some disturbances.

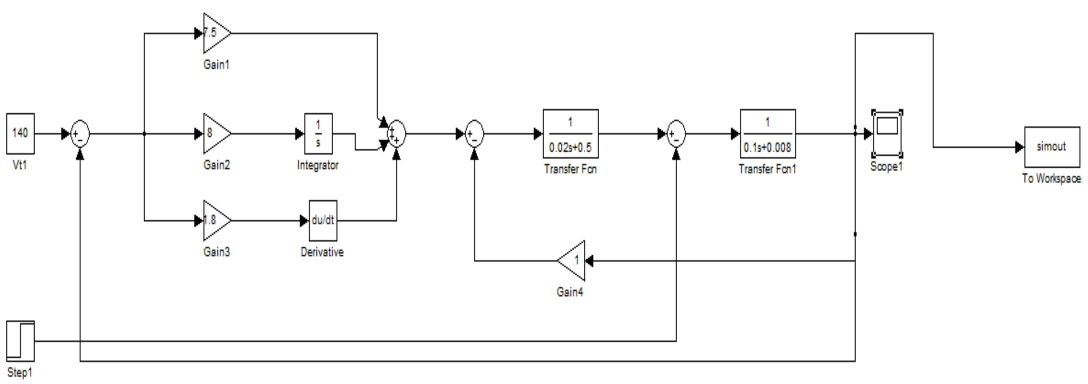

Figure 2: Simulink Block Diagram of PID Controlled DC Motor

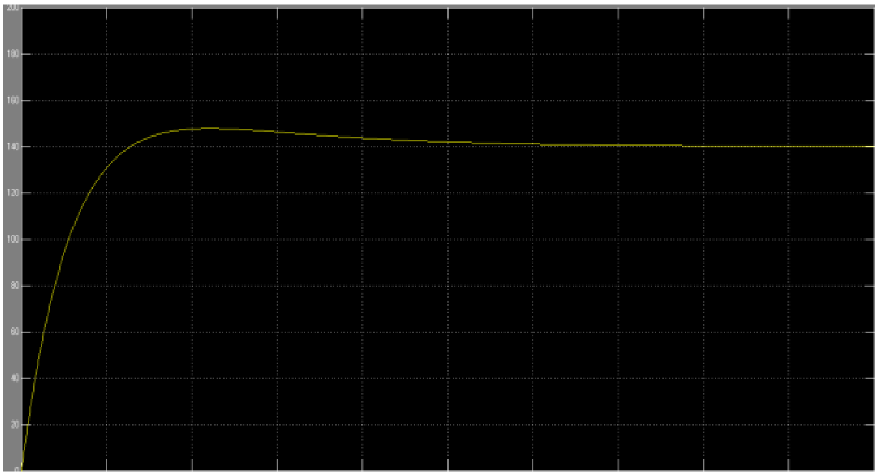

Figure 3: Speed Response of PID controlled motor

The above response shows that it has some overshoot and having more settling time. So to improve the speed response and to lower the settling time FLC is used. Non linear characteristics of DC motor such as saturation and friction could degrade the performance of used conventional PID controller. Therefore there is need of controller who overcome this disadvantages of PID controller. FLC is one of that controller which can overcome it.

IV. FUZZY LOGIC CONTROLLER

A fuzzy control system is a control system based on fuzzy logics. Fuzzy logic is a way of mapping from input space to output space [2]. It has many advantages over other conventional controllers like simplicity of control and possibility to design without knowing the exact model of the process.. FLC having mainly three parts

- Fuzzification
- Knowledge base and inference engine
- Defuzzification

Fuzzification: It is a process of transforming crisp values into membership functions corresponding to fuzzy sets expressing linguistic variables.

Knowledge base and inference engine: The knowledge is stored in form of IF THEN rules. Inference emgine represents the control policy in a structured way of an experienced process operator by combining fuzzy rules to govern system operation.

Defuzzification**:** It converts the modified fuzzy set of system output into a single crisp value.

V. MAMDANI FUZZY INFERENCE SYSTEM

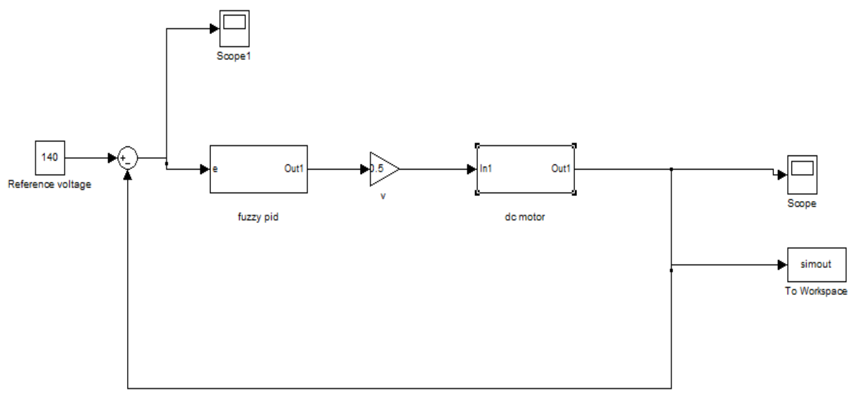

Figure 4: Simulink Block Digram of PID Controlled DC Motor using Mamdani Inference System

Fuzzy pid block is a subsystem contains fuzzy pid mamdani inference system shown below in figure 5.

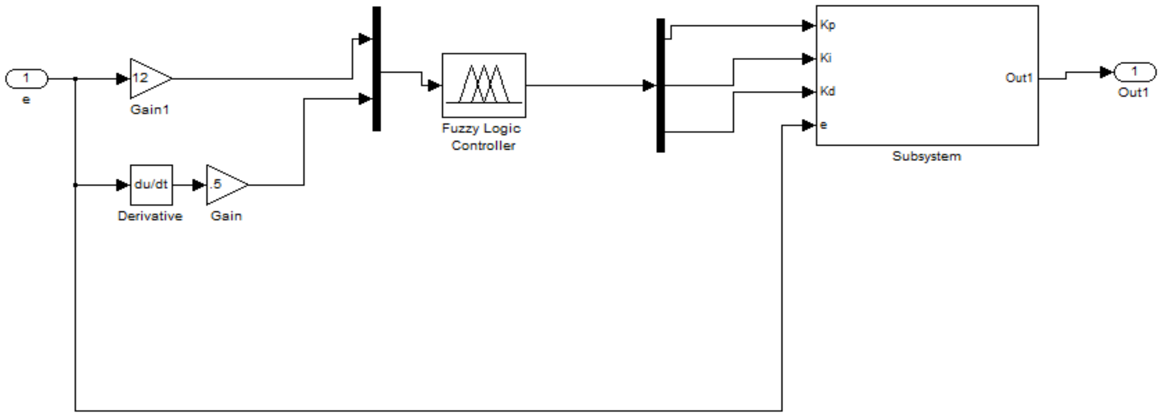

Figure 5: Simulink model of Mamdani FIS PID controlled motor

FLC having two inputs one is error and the other is change in error. For both input different variables are defined below

Table 1: Fuzzy linguistic variable used for input variables

NM	NEGATIVE MORE
LN	LESSNEGATIVE
Z	ZERO
LP	LESS POSITIVE
PM	POSITIVE MORE

Table 2: Fuzzy linguistic variables for outputs

NB	NEGATIVE BIG
NM	NEGATIVE MEDIUM
N	NEGATIVE

Z	ZERO
P	POSITIVE
PM	POSITIVE MEDIUM
PB	POSITIVE BIG

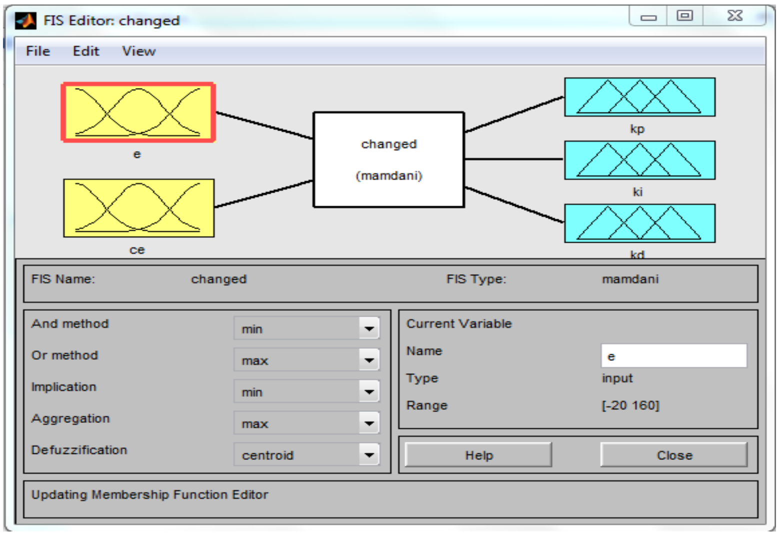

Fig 6: Mamdani FIS editor window for error in speed

Table 3: Membership function for Error

Fuzzy Set	Numerical Range	Membership Function Shape
NEGATIVE MORE	-20 to 39.9	Triangular
LESS NEGATIVE	10 to 100	Triangular
ZERO	39.9 to 100	Triangular
LESS POSITIVE	39.9 to 130	Triangular
POSITIVE MORE	99.9 to 159.9	Triangular

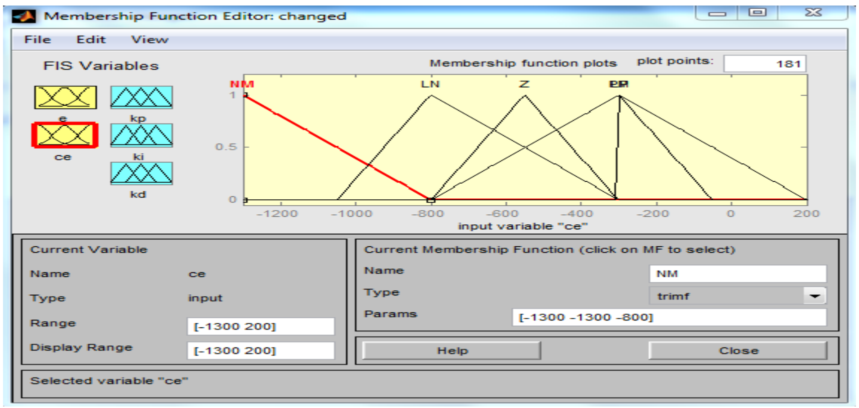

Figure 7: FIS Editor window for change in error

Table 4: Membership function for CE

Fuzzy Set	Numerical Range	Membership Function Shape

NEGATIVE MORE	-1300 to -800	Triangular
LESSNEGATIVE	-1050 to -299.95	Triangular
ZERO	-800 to -300	Triangular
LESS POSITIVE	-799.9 to -50	Triangular
POSITIVE MORE	-300 to 199.92	Triangular

VI. SUGENO INFERENCE SYSTEM

In this inference system there has beed used three FLC's in place of one as that in MAMDANI inference system. And each FLC is given two inputs and one output so that we can have one single output at the end of the system.

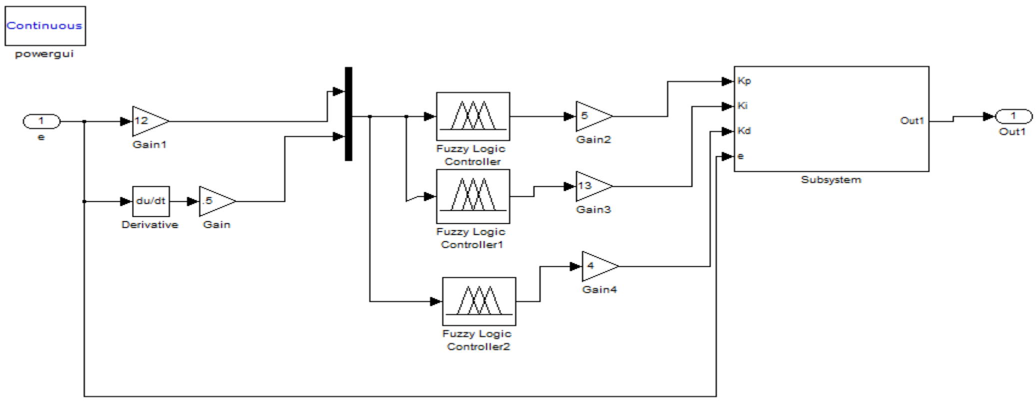

Figure 8: Block diagram of Sugeno FIS system

In this inference system we used three FLC's separately for k_p, k_i and k_d . each FLC is given different set of rules. And they further by combining applied to the subsystem contains PID .

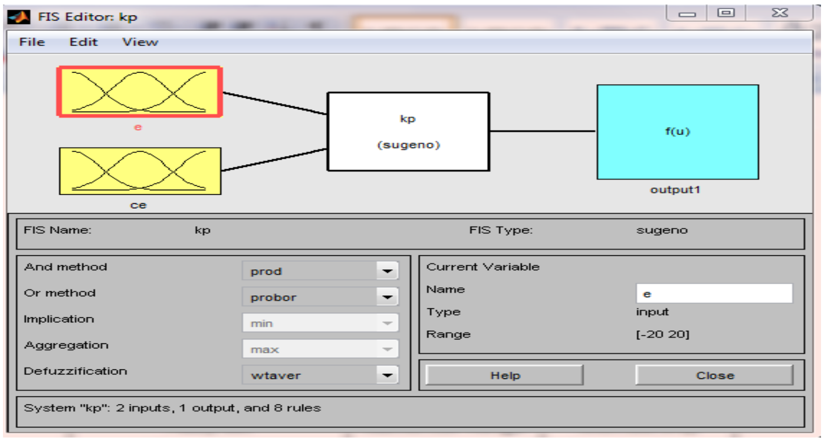

Figure 9: Sugeno FIS editor window for error

Table 5: Membership function for error

Fuzzy Set	Numerical Range	Membership Function Shape
Low	-20.1 to -0.106	Triangular
Medium	-10 to 10	Triangular

High	0 to 20	Triangular

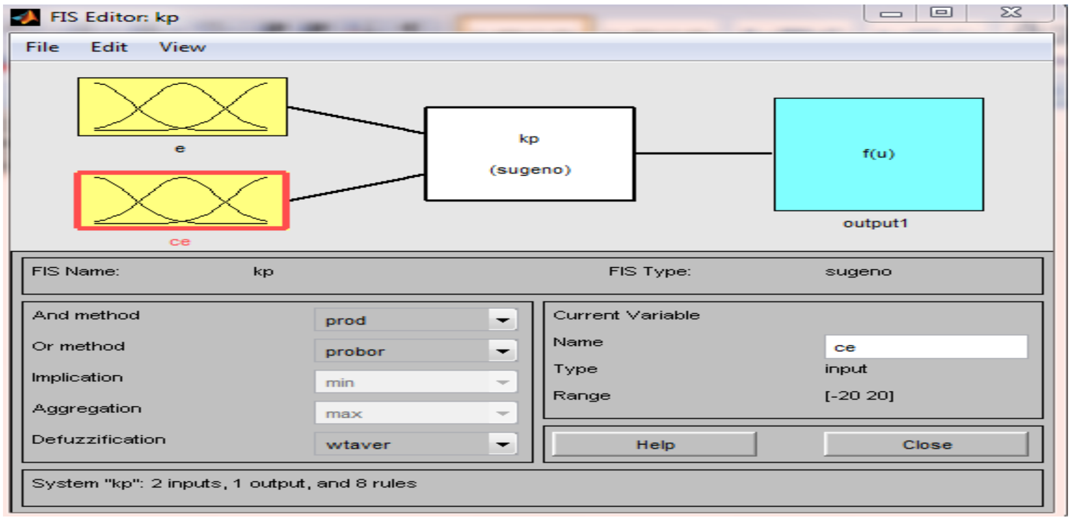

Fig 10: FIS editor window for change in error

Table 6: Membership function for change in error

Fuzzy Set	Numerical Range	Membership Function Shape
Low	-20.1 to 0	Triangular
Medium	-10 to 10	Triangular
High	0 to 20	Triangular

VI. SIMULATION RESULTS

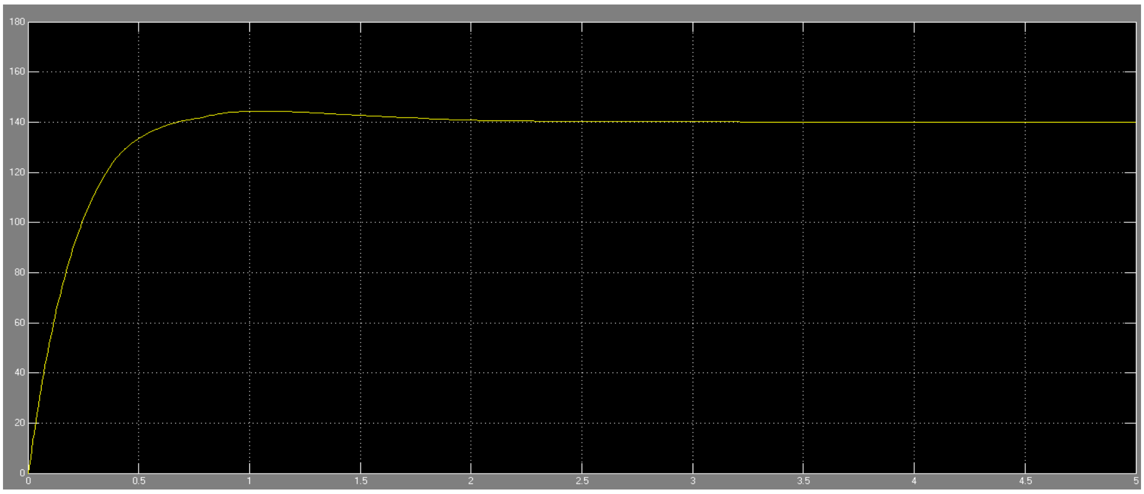

Figure 11: Simulation response of Mamdani PID Controlled Motor

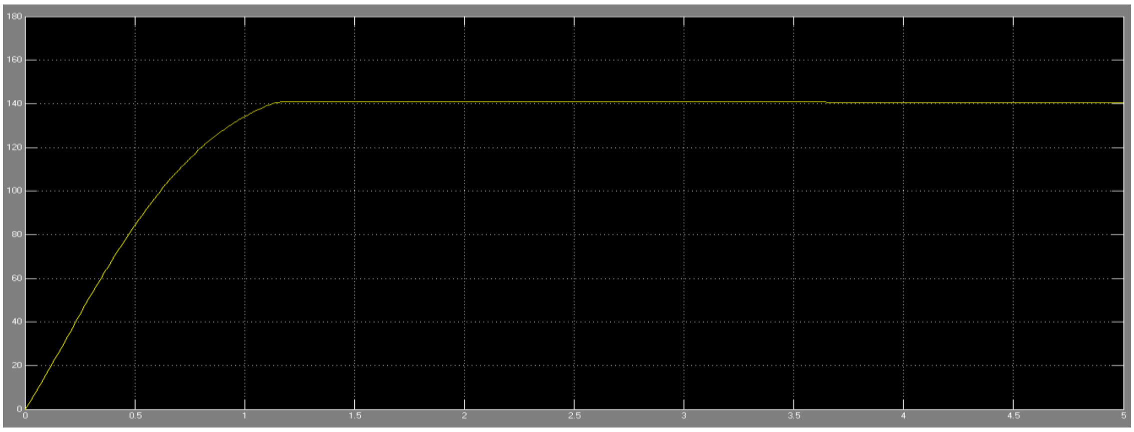

Figure 12: Simulation response of Sugeno PID Controlled Motor

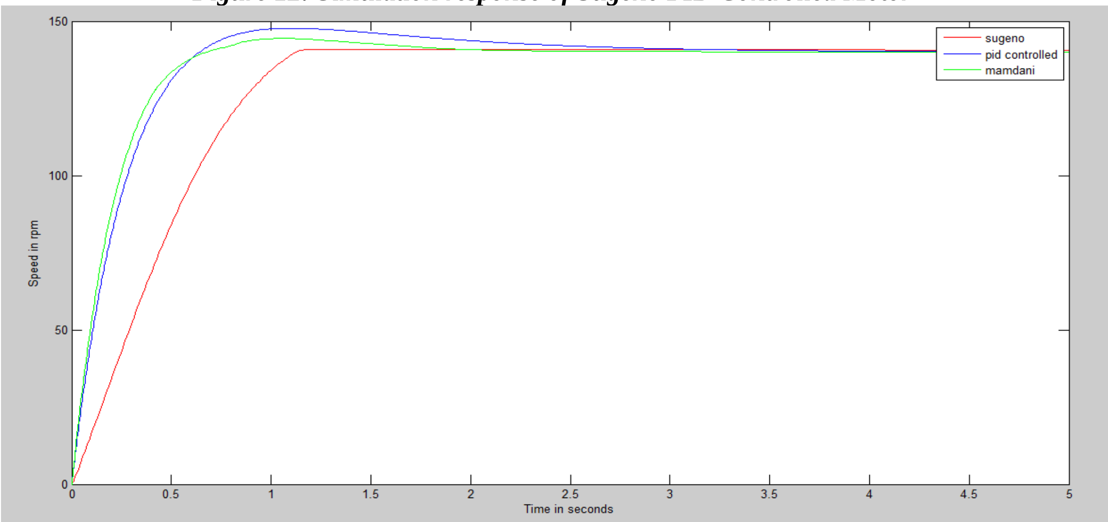

Figure 13: Combined response of PID Controlled Motor, Sugeno PID Controlled and Mamdani PID Controlled Motor

Table 7: Comparative Analysis

Specifications	PID Controlled Motor	Mamdani PID Controlled Motor	Sugeno PID controlled motor
Maximum overshoot	147.3	144.4	140.7
Settling time (sec)	3.065	2.317	1.175

The performance specification from above table shows that the Sugeno fuzzy inference system has better result as compared to that of the Mamdani fuzzy inference system. Mamdani FIS system having better response as compared to conventional PID controller .but overall overshoot and settling time is less in case of Sugeno inference system.

VII. CONCLUSION

In present work, speed comparison of PID controlled motor is presented using Mamdani and Sugeno fuzzy inference system. Speed response are simulated and studied. Mamdani Fuzzy Inference System having better response as compared to PID Controlled motor. Further Sugeno system have better than that of Mamdani system. Simulation result shows that Sugeno having less settling time and minimum overshoot as compared to Mamdani Inference System.

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