



Speed Control of DC Motor Using Fuzzy Logic

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Abstract— As far as the laws of mathematics refer to reality, they are not certain, and as far as they are certain, they do not refer to reality. When it comes to solving real world problem uncertainty in the system becomes inevitable, this is where fuzzy logic comes into action. A Fuzzy tool is a mathematical tool that deals with uncertainty around us making Fuzzy system to be a system that takes in imprecise data and vague statements which is all the information we need and produces an output as a decision with a compromise of the amount of uncertainty we are willing to accept. In this paper, the speed of a DC shunt motor is controlled using the fuzzy logic technique. Under unavailability of motor and load parameters, an absolute speed trajectory control can be achieved. This control schemes fetches a very acceptable result in short time. The Fuzzy method adopts a human-like intuition to the control strategy and is self-tolerant to inputs which are not so precise 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. Hence, the discussed strategy is used 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 the output of the fuzzy controller changes the duty cycle of a switching device which then controls the supply voltage to the armature. In this way, the speed of the DC motor is controlled by regulating the armature supply voltage.

Index Terms—Fuzzy logic controller, Speed control of DC motor, Pulse width modulation

I. INTRODUCTION

The DC motor is armature controlled by converter whose switching frequency is controlled by fuzzy logic controller. FLC takes two inputs, one is error and other is change in error. The output of FLC is control signal which is then compared with reference signal using comparator in PWM controller. The pulses are used to drive the switch in converter to get the desired output voltage at armature to maintain a specific speed. In this way, the speed control is achieved with this control scheme which involves FLC.

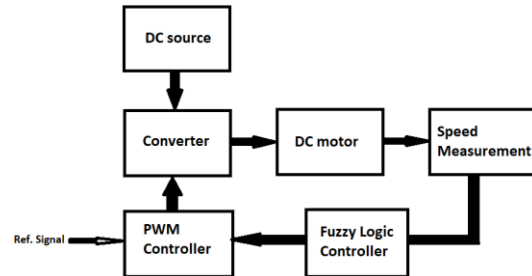


Fig 1: Block diagram of control system

In the above block diagram a typical setup of fuzzy logic controller with DC motor is shown. A regular 220 or 240 DC supply is fed to the DC motor through DC-DC converter. As for the type of converter and its specification, it is designed according to the requirement and specification of motor model (or DC machine); a buck converter is used for armature control method of speed control. A MOSFET is used as a switch as it has low input resistance and higher switching frequency keeping switching losses to minimum as well as higher capacity to withstand inrush current. The PWM controller feeds pulses of varying duty cycle to the MOSFET. Reference signal is generally a saw-tooth wave of amplitude slightly higher than the amplitude of control signal received from fuzzy logic controller. The frequency of reference signal is kept more than 100K to in order to get pulses near to the same frequency so that the ripples in the output voltage and current can be minimized. The duty cycle of the PWM varies according to the comparison between the amplitude of saw-tooth wave and FLC output. In this setup the duty cycle varies between 0.1 to 0.9. The objective of this paper is to control the speed of DC motor using fuzzy logic and to verify the result.

A. Design of Buck Converter

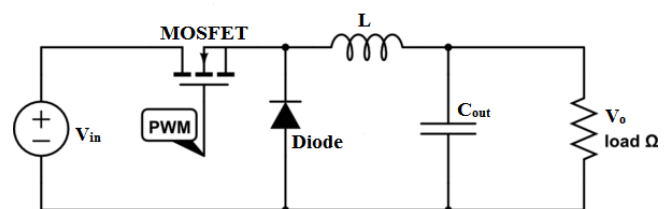


Fig 2: Buck converter

Since the the output voltage has to be varying, an average of 190 V output voltage is considered and the efficiency of converter is assumed to be 90% which is not unrealistic being

a worst case efficiency of the converter [9]. With constant input voltage of 220V the maximum duty cycle is found to be

$$D = \frac{V_o}{V_{in} \times \eta}$$

$$D = \frac{190}{220 \times 0.9}$$

$$D = .96 \text{ i.e } 96\%$$

Now to find the value of inductor and capacitor following assumptions are made. The ripple current to be $\Delta I_L = 22 \text{ mA}$. with minimum switching frequency of converter be $f_s = 20 \text{ KHz}$.

Therefore,

$$L = \frac{V_{in} \cdot D(1 - D)}{\Delta I_L \times f_s}$$

$$L = \frac{220 \times .96 \times (1 - .96)}{0.022 \times 20K}$$

$$L = 19.2 \text{ mH} \approx 20 \text{ mH}$$

Note: To reduce the ripple current the value of inductor can be increased.

To find the value of output capacitor C_{out}

$$C = \frac{\Delta I_L}{8 \times f_s \times \Delta V_o}$$

Where, ΔV_o is desired output voltage ripple. As it is should be very less, ΔV_o is assumed to be 2mV. Therefore, from above formula

$$C = 68 \mu F$$

The designed converter specification is used with little variation in the simulink model where the output of fuzzy logic controller is compared with reference wave and pulses are generated which is then fed to MOSFET that is working as a switch.

B. Fuzzy logic controller

There are specific components characteristic of a fuzzy controller to support a design procedure [5]. Fig.3 shows the controller between the pre-processing block and post processing block [4].

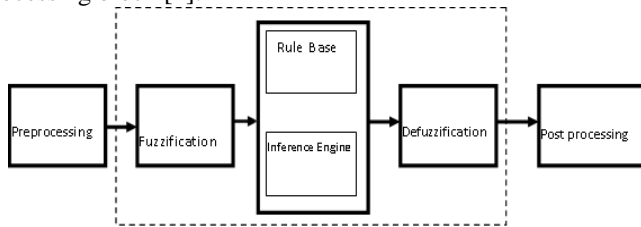


Fig.3: Structure of fuzzy logic controller

The algorithm of fuzzy rule-based inference consists of three basic steps and an additional optional step [2].

1. Fuzzy matching: Calculate the degree to which the input data match the condition of the fuzzy rules.
2. Inference: Calculate the rule's conclusion based on its matching degree.

3. Combination: Combine the conclusion inferred by all fuzzy rules into a final conclusion
4. Defuzzification (optional): It is optional because Sugeno method doesn't undergo defuzzification process only Mamdani does.

The above steps are clarified in a descriptive image as shown in fig.4.

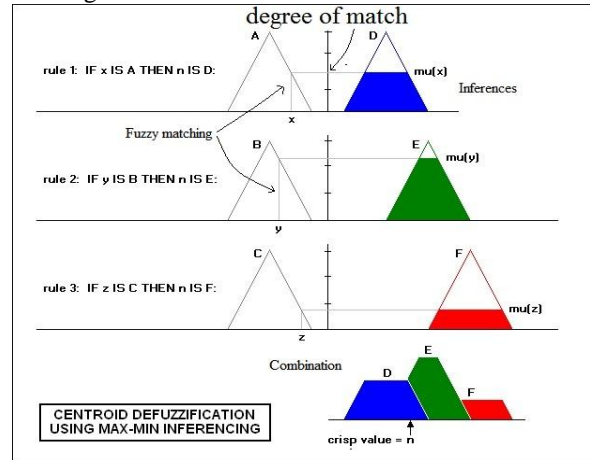


Fig. 4: Overview of fuzzy matching, inferences and defuzzification

As an example in the above figure consider the membership function of input (speed) be represented by A as small, B as normal and C as big, similarly the membership function of output (voltage) be represented by x as small, y as regular and z as big. The universe of discourse for input membership function is speed (S) and that for output membership function is output voltage (V). Now to learn the degree of match for speed and inferences consider a following mathematical observation

$$\text{MatchingDegree}(S, r) = \mu_{small}(S) = 0.5$$

$$\text{MatchingDegree}(S, r) = \mu_{normal}(S) = 0.8$$

$$\text{MatchingDegree}(S, r) = \mu_{big}(S) = 0.2$$

If we suppose the speed is 1200 then degree of match for each truth values can be noted down from above equations. Hence the fuzzy set for the input speed becomes

$$\mu(S) = \{(0.5, small), (0.8, normal), (0.2, big)\}$$

The respective inferences are made and combined using max-min method and resultant of inferences is obtained as shown in fig.5.

Defuzzification is when all the actions that have been activated are combined and converted into a single non-fuzzy output signal which is the control signal of the system. There are dozens of theoretical rules that can be applied to defuzzify the inference of FLC like Mean of Maximum (MOM) or Centre of Area (COA) or simply centroid. The centroid method is widely chosen over other methods because it provides crisp value based on centre of Area of the resulted inference.

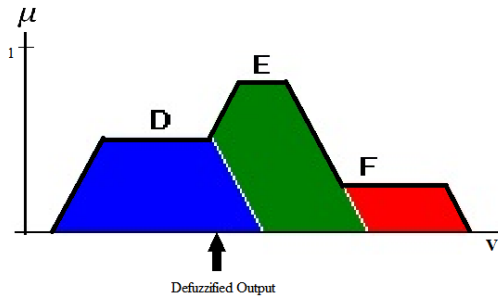


Fig.5: Defuzzification using COA

The centroid (or COA) defuzzification method calculates the weighted average of a fuzzy set. The result of applying COA defuzzification to a fuzzy conclusion V can be expressed by the formula.

$$v = \frac{\sum_i \mu_s(V_i) \times V_i}{\sum_i \mu_s(V_i)} \quad (1)$$

Where, $\mu(V)$ could be,

$$\mu(V) = \{(0.2,120), (0.5,130), (0.5,170), (0.8,200), (0.3,220), (0.1,240)\}$$

Using the values from above fuzzy set in equation (1)

$$V = \frac{(0.2 \times 120) + (0.5 \times 170) + (0.5 \times 130) + (0.8 \times 200) + (0.3 \times 220) + (0.1 \times 240)}{(0.2 + 0.5 + 0.5 + 0.8 + 0.3 + 0.1)}$$

$$V = \frac{424}{2.4} = 176.67$$

Hence, the new control signal (voltage in this case) becomes 176.6

II. ALGORITHM-I

In this algorithm the speed control of the DC motor is carried out by changing the voltage that is being supplied across the armature winding [4]. For simplicity, the flux is kept constant so that the speed is dependent only on one variable i.e. voltage and the aim is to vary this particular variable only which will produce the desired result. The simulation comprises of four different stages which are as follows:

1. Obtaining the input for the fuzzy logic controller by comparing the reference speed to the output speed.
2. Designing the fuzzy logic controller.
3. Generation of pulses of varying duty cycle of a pulse generator which is fed to the DC-DC converter.
4. Designing of suitable DC-DC Buck converter to supply the desired voltage to the armature circuit.

The simulation is carried out using Simulink in MATLAB. The main objective is to keep the speed of the motor constant irrespective of the changes in load variation on the motor shaft. The simulation is done on a separately excited DC shunt motor whose model is available on the Simulink platform. The motor parameters are decided based on the readily available motor models under specification category and changes to such specifications can be made based on the requirements. Separately excited DC shunt motor is chosen so as to keep the flux generated by the field winding constant. When the flux generated by the field winding is kept constant then the speed

of the motor can be controlled by the variation of voltage across the armature of the motor. The output that is available from the fuzzy logic is in the range of -1 to +1. It is then compared with a saw tooth waveform coming from a signal generator at a frequency of 100 kHz. Thus, a pulse of varying duty cycle is generated based on the control signal from the fuzzy logic controller and it is used to control the switching operation of the n-channel MOSFET used in the DC-DC buck converter.

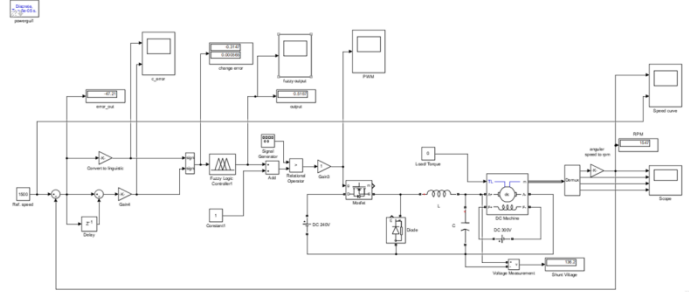


Fig. 6: Simulink model for algorithm-I

A. FLC design in algorithm-II

As discussed in section above in the two inputs for FLC i.e. error and change in error as shown in fig.7 and fig.8 where the linguistic variables are stated in table 1 below:

Table 1: Linguistic variables

NB	Negative Big
NM	Negative Medium
NS	Negative Small
Z	Zero
PS	Positive Small
PM	Positive Medium
PB	Positive Big

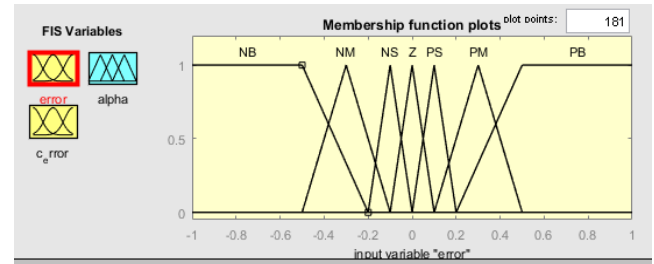


Fig.7: Input (error) membership function plots

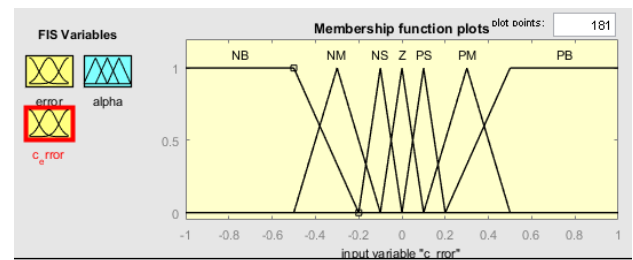


Fig.8: Input (change in error) membership function plots

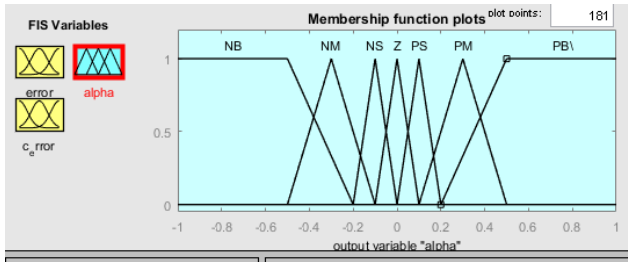


Fig.9: output (control signal: alpha) membership function plots

Similarly the output of FLC is shown in fig.9. The membership functions are identical in all inputs and output. First and last member function have trapezoidal membership and remaining five have triangular. The range (on universe of discourse) for each variable is taken from [4]. However as per the simulation result, based on the inference from the result these ranges can be altered to get the optimal performance or speed time curve.

The output and input are related by following rule base

Table 2: Rule Base for algorithm-I

e ce	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

Two inputs are combined using AND method and the inference is made using max min inference method. Based on these rule the output is defuzzified using centroid method. The surface view of complete control strategy is given in fig.10.

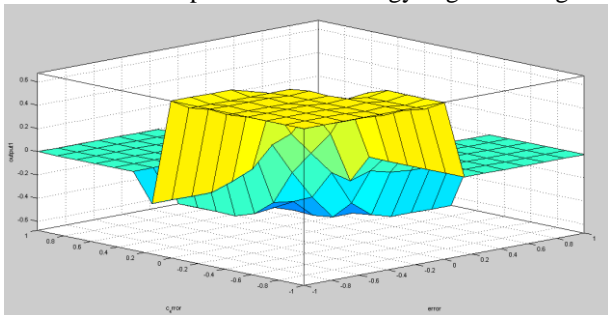


Fig.10: Surface view of FLC used in algorithm-I

III. ALGORITHM-II

In this algorithm the speed control of the DC motor is carried out by changing the voltage that is being supplied across the field winding [6]. For simplicity, the voltage across

armature is kept constant so that the speed is dependent only on one variable i.e. field current and the aim is to vary this particular variable only which will produce the desired result. The speed of the motor at each and every instant is then compared with a reference desired speed. After the comparison with the reference signal an error signal is generated which serves as one of the inputs to the fuzzy logic controller. This error signal is the change in speed. The other input is obtained by measuring the amount of current flowing through the field winding. Now when the two inputs to the fuzzy logic controller are obtained then the scaling of each of these inputs is done to bring the values of each inputs in the range of the input for which the fuzzy logic controller is designed. This process is called Fuzzification. The range of the input for which the controller is designed is from -1 to +1. So, the inputs are fuzzified to bring them in the desired range of -1 to +1.

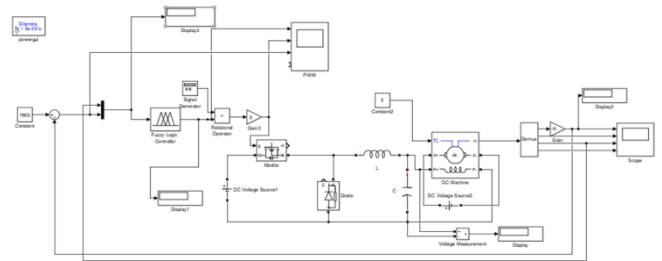


Fig. 11: Simulink model for algorithm-II

A. FLC design in algorithm-II

As discussed in section above in algorithm-II the two inputs for FLC i.e. difference in reference speed and output speed (error) and field current as shown in fig.12 and fig.13 where the linguistic variables are stated in tables below:

Table 3: linguistic variables for field current

S	Small
BNO	Below Normal
NO	Normal
ANO	Above Normal
L	Large

Table 4: linguistic variables for speed error

LS	Low Speed
US	Under Speed
NS	Normal Speed
OS	Over Speed
RA	Run Away

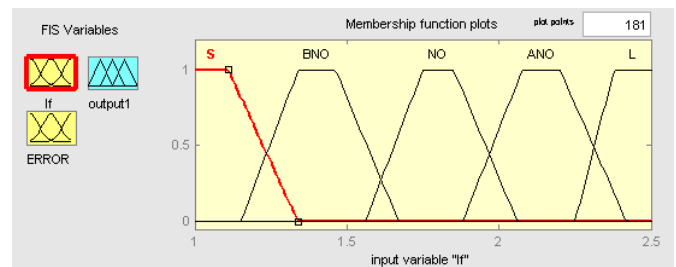


Fig.12: Input (field current) membership function plots

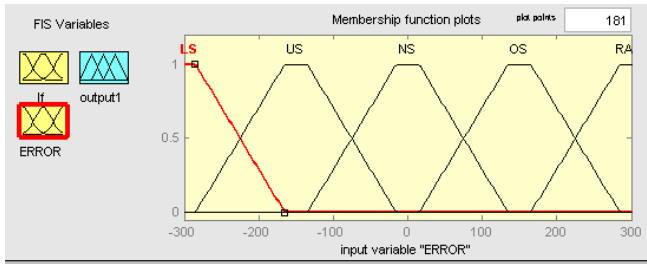


Fig.13: Input (speed error) membership function plots

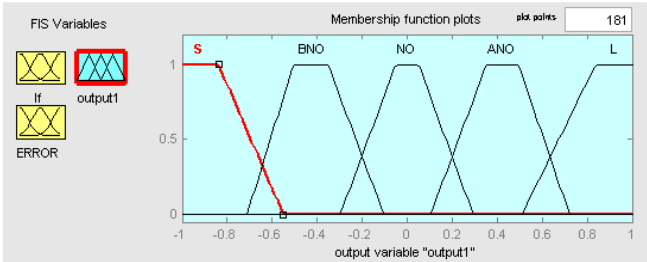


Fig.14: Output (control signal: alpha) membership function plots

Similarly the output of FLC is shown in fig.14. The membership functions are identical in all inputs and output. All the linguistic variables have trapezoidal membership function. The range (on universe of discourse) for each variable is taken from [6]. However as per the simulation result, based on the inference from the result these ranges can be altered to get the optimal performance or speed time curve. The output and input are related by following rule base

Table 5: Rule base for algorithm-II

		Speed				
		LS	US	NS	OS	RA
Field Current	S	NO	ANO	S	ANO	L
	BNO	NO	BNO	BNO	ANO	ANO
	NO	ANO	ANO	NO	ANO	ANO
	ANO	NO	NO	ANO	NO	NO
	L	BNO	BNO	L	BNO	BNO

Two inputs are combined using AND method and the inferences are combined using min max inference method.

IV. RESULT

Both the algorithms are simulated in MatLab Simulink with 2 fuzzy sets and a rule base of 7x7 linguistic variables and 5x5 linguistic variables in the first and second algorithm respectively. With higher number of linguistic variables the fuzzy logic converter becomes more vibrant towards performing the control action.

Table 6: Output obtained from both algorithms

SL. No.	Ref. Speed in rpm	I/P Torque in N-m	Algorithm-I		Algorithm-II	
			O/P Speed in rpm	Settling time in sec.	O/P Speed in rpm	Settling time in sec.
1	1700	2	1705	0.25	1638	0.76
2		5	1691	0.19	1620	0.32

3	1600	10	1691	0.12	1597	0.18
4		2	1603	0.37	1637	0.94
5		5	1592	0.16	1540	0.37
6	1500	10	1591	0.12	1578	0.19
7		2	1505	0.85	1580	1.25
8		5	1491	0.18	1554	0.38
9		10	1490	0.13	1460	0.21

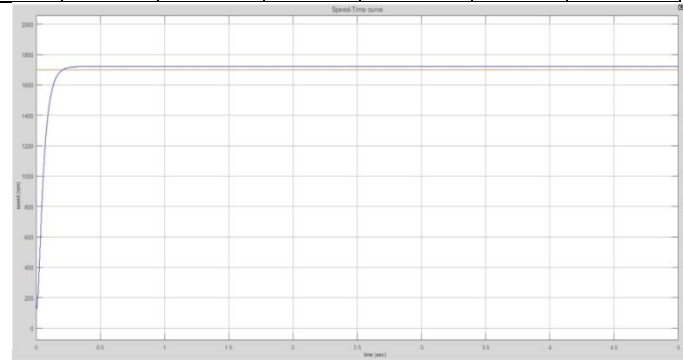


Fig.15: Speed-time graph of DC motor in algorithm-I

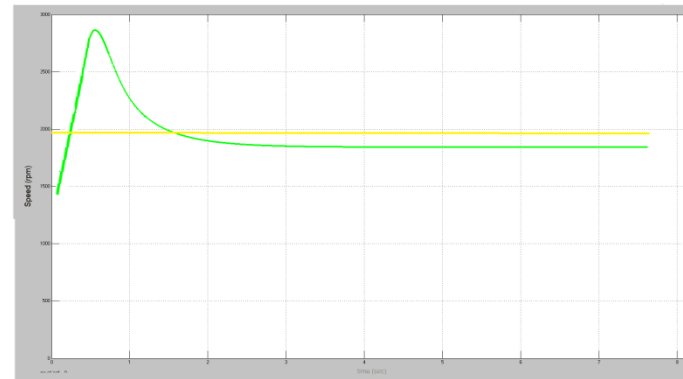


Fig.16: Speed-time graph of DC motor in algorithm-II

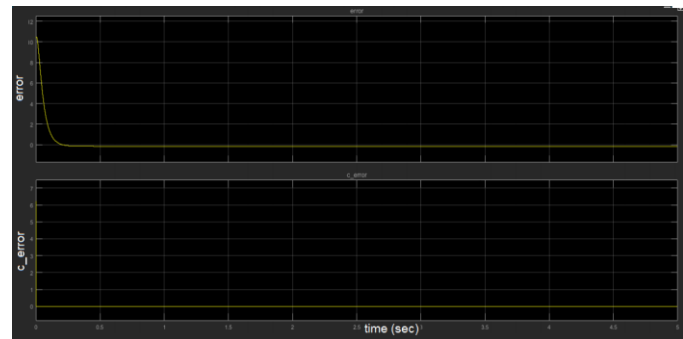


Fig.17: Error and change in error

In the first algorithm it can be seen that when the reference speed is kept constant and the input torque is varied then there is no observable change in the motor output i.e. the speed remains constant and magnitude is what it is desired. The table 6 shows constant speed operation of DC motor irrespective of loads in both algorithms. Therefore, it can be concluded that the output speed remains constant irrespective of the change in load of the motor however there is a change in settling time which decreases with increase in load.

In the second algorithm it can be seen the output speed of the motor remains constant although the load is varied but there is quite an error in the output speed. In fig.16 it can be observed that the overshoot is very large because the two input functions field current and speed difference are not closely related. Therefore, the control system becomes more easy and accurate if inputs are of same kind like that of in algorithm-I. Hence, it can be said that the first algorithm is more suitable for speed control of the DC motor. It is to be noted that both the simulations are performed using the same motor specifications and same converter specifications.

V. CONCLUSION

Speed control of a separately excited DC motor is performed successfully by using FLC in two different algorithms. The simulation is carried out in Matlab Simulink environment. FLC is used on two method of speed control i.e. armature controlled and field control. The DC motor is made to run on constant speed with different loads (on 2, 5 and 10 Nm). The results clearly shows the performance of FLC which has proven itself an efficient controller when settling time, speed and steady state error or %Mp is taken into consideration.

Two algorithms have different control mechanism (armature and field), therefore, two different fuzzy logic controller was designed for each. To observe the difference in performance FLC in algorithm-II is designed with only 25 rules where as in FLC in algorithm-I is designed with 49 rules as a result it can be observed that the steady state error is greater in algorithm-II and maximum overshoot is greater at low load. The precision of the controller becomes low if the number of rules in FLC is less. But as the rule increases the mapping of linguistic variables on membership function plot becomes more sophisticated.

REFERENCES

- [1] Yasser Ali Almatheel, Ahmed Abdel Rahman. "Speed control of DC motor using Fuzzy Logic Controller." *International Conference on Communication, Control, Computing and Electronics Engineering (ICCCCEE)*. IEEE, 2017.
- [2] John Yen, Reza Langari. *Fuzzy Logic (Intelligence, Control, and Informatioun)*. Pearson Education (Singapore) Pte. Ltd., 2005.
- [3] Marcela Litcanu, Petru Andea, Frigura-Iliasa Flaviu Mihai. "Fuzzy logic controller for permanent magnet synchronous machines." *2015 IEEE 13th International Symposium on Applied Machine Intelligence and Informatics (SAMII)*. Herl'any, Slovakia: IEEE, 2015.
- [4] S. Aydemir, S. Sezen, H.M. Ertunc. "Fuzzy logic speed control of a DC motor." *The 4th International Power Electronics and Motion Control Conference, 2004. IPEMC 2004*. Xi'an, China: IEEE, 2004. 766-768.
- [5] Sandeep Jain, Vaibhav Bajpai, Shikhar Goel. *Geeks for Geeks*. 20 october 2018 <<https://www.geeksforgeeks.org/fuzzy-logic-introduction/>>.
- [6] Saneifard, S., et al. "Fuzzy-logic-based speed control of a shunt DC moto." *IEEE Transactions on Education* (1998): 159-164.
- [7] Debasish, Pal and Bhattacharya. "Effect of Road Traffic Noise Pollution on Human Work Efficiency in Government Offices, Private Organizations, and Commercial Business Centres in Agartala City Using Fuzzy Expert System: A Case Study." *Advances in Fuzzy Systems* (2012).
- [8] Farid, et al. "A Fuzzy Logic Approach for Quality of Service Quantification in Wireless and Mobile Networks." *10th IEEE International Workshop on Performance and Management of Wireless and Mobile Networks* (2014).
- [9] Basic Calculation of Buck converter power's stage, *Texas Instrumentation*, SLVA477B–December 2011–Revised August 2015 <<http://www.ti.com/lit/an/slva477b/slva477b.pdf>>