Speed Control of DC Motor Using Fuzzy Logic Controller

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***Abstract*—Direct current (DC) motors are controlled easily and have very high performance. The speed of the motors could be adjusted within a wide range. Today, classical control techniques (such as Proportional Integral Differential - PID) are very commonly used for speed control purposes. PID controller requires a mathematical model of the system. However, it is observed that the classical control techniques do not have an adequate performance in the case of nonlinear systems. Thus, instead, a modern technique is preferred: fuzzy logic. fuzzy logic controller base on experience via rule-based knowledge. Design of fuzzy logic controller requires many design decisions , for example rule base and fuzzification. The FLC has two input ,one of these inputs is the speed error and the second is the change in the speed error. There are 49 fuzzy rules which are designed for the fuzzy logic controller. The center of gravity method is used for the defuzzificztion. Fuzzy logic controller uses mamdani system which employs fuzzy sets in consequent part. PID controller chooses its parameters base on trial and error method. PID and FLC are investigated with the help of MATLAB / SIMULINK package program simulation. It is found that FLC is more difficult to design compared with PID controller, but it satisfies non-linear characteristics of DC motor more suitably. The results show that the fuzzy logic has minimum transient and steady state parameters , which shows that FLC is more efficient and effective than PID controller.**

Keywords: DC Motor, PID, FLC, Simulink

I. INTRODUCTION

Almost every mechanical movement that we notice around us is accomplished by an electric motor. Electric machines are a means of converting energy. Motors take electrical energy and produce mechanical energy. Electric motors are used to power hundreds of devices we use in everyday life. Electric motors are broadly classified into two different categories : DC (Direct Current) and AC (Alternating Current). Within these categories are numerous types, each offering unique abilities that suit them well for specific applications. In most cases, regardless of type, electric motors consist of a stator (stationary field) and a rotor (the rotating field or armature) and operate through the interaction of magnetic flux and electric current to produce rotational speed and torque. DC motors are used for fast transportation, electric trains, electric vehicles, electric winches, printers, floppy drives, paper industry, etc. where adjustable speed and precise positioning is important. In the last few years, with the improvements in technology, they are also used in home applicants and other applications demanding low power, low cost and adjustable speed, which have a broad usage. Another reason they have many usages is that the control of DC motors are easier than Alternative Current (AC) motors. Compared to AC motor drivers, the circuits of DC motor drivers are much simpler and cheaper, so DC motors are more preferred for adjustable speed applications. For the applications, the speed control system used is as important as the motor driver. Open loop systems are not used for constant speed applications. In these systems, the change in the armature voltage and the rotor speed because of the load is ignored, the rotor speed increases or decreases with the load. That is the reason why the open loop systems are not preferred instead the closed loop systems are used. Proportional-Integral (PI) controller is widely used in closed loop controllers for speed control of DC motors. PID control technique is widely used for the control of dynamic systems. Due to the simplicity of its application, PID control technique is used for various industrial applications. The earlier usages include pneumatic systems, vacuum systems and solid state analog electronics. Later, the digital applications of microprocessors have started being used. Controllers are used to modify the behavior of this system so that it behaves in a specific desirable way over a time. One of these controllers is fuzzy logic controller. In this study, the construction of a MATLAB/Simulink model has been performed to better understand the system reactions which is necessary for speed control of a DC motor using fuzzy logic.

II. SPEED CONTROL USING PID CONTROLLER

In the case of speed control with closed loop systems, the output value is rendered independent of the system variables. Using the loop shown in Figure 1, we want to keep the motor speed constant. For the closed loop system in question, the motor speed is adjusted according to the reference value. The true speed of the motor is measured using a tachometer. For different load values, primary voltage or armature voltage are changed to keep the motor speed at the reference value. As the motor voltage is regulated with the use of semi-conductors, the system is efficient and stable. PID controller is miniature part of embedded system, but it operates the majority of the control systems in the world, and it's used for wide range of problems like (motor drive, automotive, flight control, instrumentation). In Figure 1, the PID controller controls the speed of the DC motor and relays it to the output. The error signal $e(t)$ is multiplied by the proportional gain (P) and the integral of the error signal is multiplied by the integral gain (I) and the differential of the error signal is multiplied by the differential gain (*D*) at the controller. PID systems are the summation of the proportional control, the integral control and the differential control effects. PID controller output can be defined as in Equation below.

$u(t)/e(t) = P + I(1/s) + Ds$
where: $P = 2.287$
$I = 909.4$
$D = -0.000417$

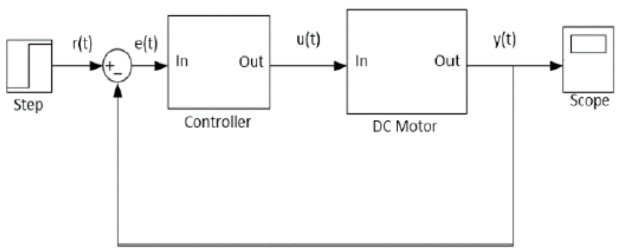


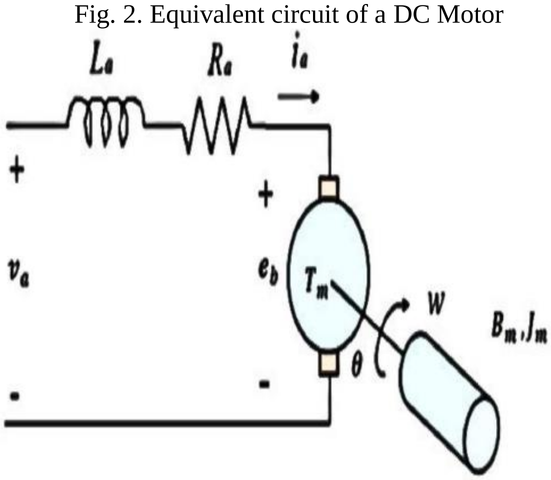
Fig. 1. Block Diagram of the System

When the PID controller is merged with a closed loop system, it will change the effect of the control until the error becomes zero. The greatest advantages of the PID control are the absence of steady state error, the easy implementation and the fast response when the parameters are selected.

III. THE DC MOTOR

In modeling, the aim is to find the governing differential equations that relate the applied voltage to the produced torque or speed of the rotor. Fig.2 shows the equivalent circuit with armature voltage control and the model of a general mechanical system that incorporates the mechanical parameters of the motor and the mechanism coupled to it. Armature reactions effects are ignored in the description of the motor. The fixed voltage V_f is applied to the field and the field current settles down to a constant value. A linear model of a simple DC motor consists of a mechanical equation and electrical equation.

Fig. 2. Equivalent circuit of a DC Motor



From Figure (2), Kirchhoff's Voltage Law (KVL) is applied to the electrical circuit. These can be written:

$$E_a(t) = Ra.Ia + L_a(di_a/dt) + e_b \quad (1)$$

Where: E_a is armature voltage (V), I_a is armature current (A), R_a is armature resistance (Ω), L_a is armature inductance (H), e_b is back EMF (V). Setting $e_b(t)$ in (1) equals to $K_b.w(t)$ the electrical equation in (1) becomes

$$E_a(t) = Ra.Ia + L_a(di_a/dt) + K_b.w(t) \quad (2)$$

For normal operation, the developed torque must be equal to the load torque plus the friction and inertia.

$$T_m(t) = J_m.(dw(t)/dt) + B_m.w(t) + T_L \quad (3)$$

Where: T_m is motor torque (Nm), J_m is rotor inertia (kg . m^2), W is angular speed (rad/s), B_m is viscous friction coefficient (Nms/rad), T_L is load torque (Nm).Setting $T_m(t)$ equal to $K_t.I_a$ and $T_L= 0$ yields

$$K_T.I_a(t) = J_m.(dw(t)/dt) + B_m.w(t) \quad (4)$$

Taking the Laplace transforms for (2) and (4) yields

$$E_a(s) = R_a(s).I_a(s) + L_a.I_a(s).s + K_b.w(s) \quad (5)$$
$$K_T.I_a(s) = J_m.w(s).s + B_m.w(s) \quad (6)$$

Current obtained from (3-4) as

$$I_a(s) = [J_m.w(s).s + B_m.w(s)]/K_T \quad (7)$$

And then substituted in (5) get

$$E_a(s) = [w(s)/KT].[R_a.J_m.s + R_a.B_m) + (L_a.J_m s^2 + L_a.B_m.s) + K_b.K_T] \quad (8)$$

So the relationship between rotor shaft speed and applied armature voltage is represented by the transfer function and shown in fig.3.

$$[w(s)/E(s)] = K_T/[L_a.J_m s^2 + (R_a.J_m+L_a.B_m).s + (R_a.B_m+K_b.K_T)] \quad (9)$$

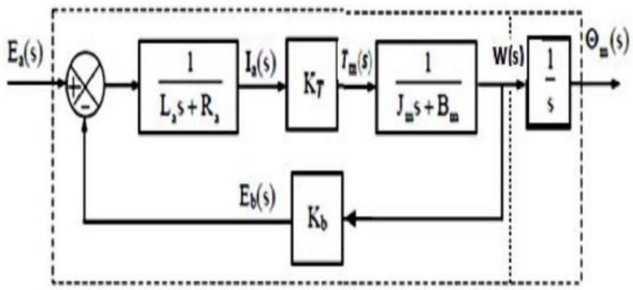


Fig. 3. Block Diagram of DC Motor

The parameters of the DC motor used in the simulation were as follows:

TABLE I.
Parameters of DC Motor

Parameter	Value
Armature Resistance (R_a)	11.2 Ω
Armature Inductance (L_a)	0.1215 H
Rotor Inertia (J_m)	0.02215 kgm
Viscous Friction Coeffcient (B_m)	0.002953 Nms/rad
Torque Constant (K_T)	1.28 Nm/A
Back emf constant (K_b)	1.28 Vs/rad

IV. Speed Control Using Fuzzy Logic Controller

The nonlinear characteristics of a DC motor such as saturation and friction could degrade the performance of conventional controllers. In addition , due to the conventional controllers are fixed structure and fixed parameter, expected difficulties in the tuning and optimization of these controllers would happen. So attempts to overcome these limitations using fuzzy controller. The fuzzy logic, unlike conventional logic systems is able to model inaccurate or imprecise models. the block diagram for the fuzzy logic control system is presented. As it is seen in Figure 2, for the fuzzy logic to control the system there should be two inputs: the error signal and the change in the error. The error value is found by subtracting the instantaneous speed value of the DC motor (that is measured by the encoder connected the output of the motor) from the reference value, and the change in the error signal is found by subtracting the present error value from the previous error. These two data are fuzzed using membership functions of the controller. After the fuzzing, the truth values are extracted using the rules defined earlier and the control signal is defuzzy field. The most important stage of the fuzzy control structures that are widely used in industry nowadays is to determine the set of rules of the systems. The reason for that is the set of rules that will provide satisfactory results can only be defined by an expert who knows the system and has experience with the system. That is only achievable if there is sufficient time to perform numerous trials. Today, because of such problems, investigative methods that will automatically learn and infer from the examples are used to form the necessary set of rules

Fuzzy Inference System (FIS) is the process of formulating the mapping from a given input to an output using fuzzy logic. Fuzzy inference systems have been successfully applied in fields such as automatic control, data classification, decision analysis, expert systems, and computer vision. There are two types of fuzzy inference systems that can be implemented Mamdani-type and Sugeno-type. These two types of inference systems vary somewhat in the way outputs are determined. Mamdani-style inference requires finding the centroid of a two-dimensional shape by integrating across a continuously varying function. Michio Sugeno suggested to use a single spike, a singleton, as the membership function of the rule consequent. A singleton, or more precisely a fuzzy singleton, is a fuzzy set with a membership function that is unity at a single particular point on the universe of discourse and zero everywhere else. The requirement for the application of a FLC arises mainly in situations where:

- The description of the technological process is available only in word form, not in analytical form.
- It is not possible to identify the parameters of the process with precision.
- The description of the process is too complex and it is more reasonable to express its description in plain language words.
- The controlled technological process has a “fuzzy” character.
- It is not possible to precisely define these conditions.

Fuzzy logic control is a control algorithm based on a linguistic control strategy, which is derived from expert knowledge into an automatic control strategy . A block diagram for a fuzzy control system is given in Fig.4. The fuzzy controller consists of the following four components:

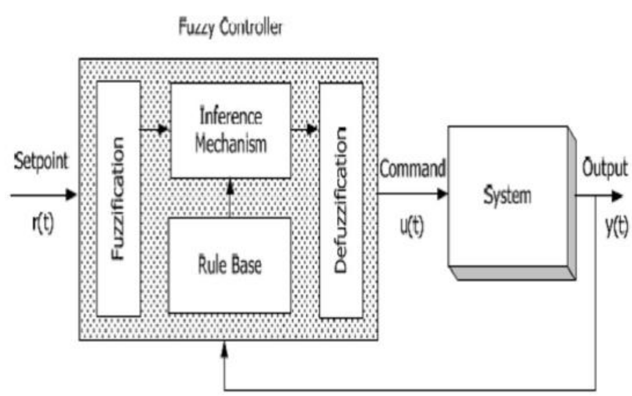


Fig. 4. Structure of Fuzzy Logic Controller

A. Fuzzification

The first step in designing a fuzzy controller is to decide which state variables represent the system dynamic performance must be taken as the input signal to the controller. Fuzzy logic uses linguistic variables instead of numerical variables. The process of converting a numerical variable (real number or crisp variables) into a linguistic variable (fuzzy number) is called fuzzification. This is achieved with the different types of fuzzifiers. There are generally three types of fuzzifiers, which are used for the fuzzification process; they are

1) Singleton fuzzifier.

2) Gaussian fuzzifier.

3) Trapezoidal or triangular fuzzifier.

Here there are two inputs (speed error and change in the speed error) where the speed error has a range from -4.75 to 4.75 and the change in the speed error is from -1.65 to 1.65 which are shown in figures 4,5.The Gaussian fuzzifier has been used for the input and the triangular has been used for the output , the output is the control action which has a range from -7 to 7 which is shown in fig.7.

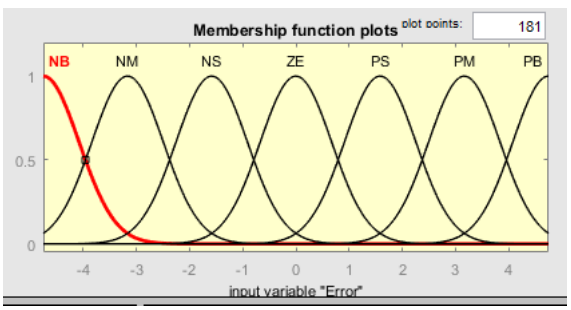


Fig. 5. Error Input

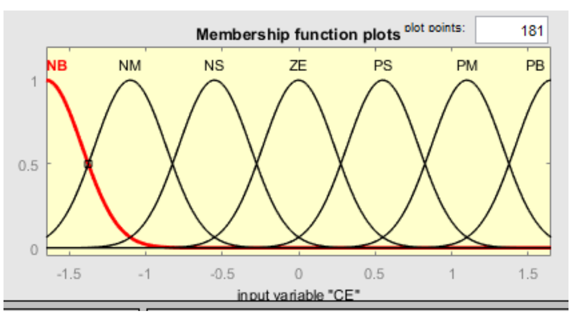


Fig. 6. Change in Error Input

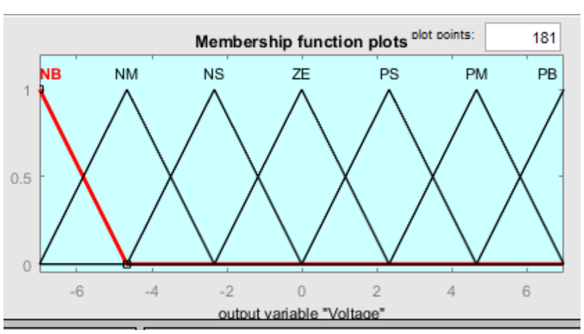


Fig. 7. Output

B.Rule Base

A decision making logic which is, simulating a human decision process, inters fuzzy control action from the knowledge of the control rules and linguistic variable definitions. The rules are in the “If Then” format and formally the If side is called the conditions and the Then side is called the conclusion. The computer is able to execute the rules and compute a control signal depending on the measured inputs error I difference between the output speed and the set point” and error variation as inputs to the fuzzy controller and control function as the output which it will be the armature voltage. In a rule based controller the control strategy is stored in a more or less natural language. A rule base controller is easy to understand and easy to maintain for a non- specialist end user and an equivalent controller could be implemented using conventional techniques. The rules are illustrated in table.2 (7*7=49). The linguistic variables that is used in the rules are:

1) LN Large Negative
2) MN Medium Negative
3) SN Small Negative
4) ZE Zero
5) SP Small Positive
6) MP Medium Positive
7) LP Large Positive

TABLE II.
Rule Base for DC Motor Speed Control

CE / E	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

C. Inference Engine

Inference engine is defined as the Software code which processes the rules, cases, objects or other type of knowledge and expertise based on the facts of a given situation. When there is a problem to be solved that involves logic rather than fencing skills, we take a series of inference steps that may include deduction, association, recognition, and decision making. An inference engine is an information processing system (such as a computer program) that systematically employs inference steps similar to that of a human brain. There are two popular methods (max-min and max-product), In this study the max-min method has been used.

D. Defuzzification

The reverse of Fuzzification is called Defuzzification. The use of Fuzzy Logic Controller (FLC) produces required output in a linguistic variable (fuzzy number). According to real world requirements, the linguistic variables have to be transformed to crisp output. There are many defuzzification methods but the most common method is Center of Gravity (COG). For discrete sets COG is called center of gravity for singletons (COGS) where the crisp control value is the abscissa of the center of gravity of the fuzzy set and is calculated as follows:

$$\mu_{COGS} = \Sigma_i \, \mu_c(x_i)x_i \, / \, \Sigma_i \, \mu_c(x_i)$$

where x_i is a point in the universe of discourse (i=1, 2, 3…) and μ_c (x_i) is the membership value of the resulting conclusion set. For continuous sets summations are replaced by integrals.

V. SIMULATION

Simulation is an inexpensive and safe way to experiment with the system model. However, the simulation results depend entirely on the quality of the system model. It is a powerful technique for solving a wide variety of problems. MATLAB will be used as a simulation tool. The figures (8.9) below show the separately excited DC motor at full load with PID and FLC.

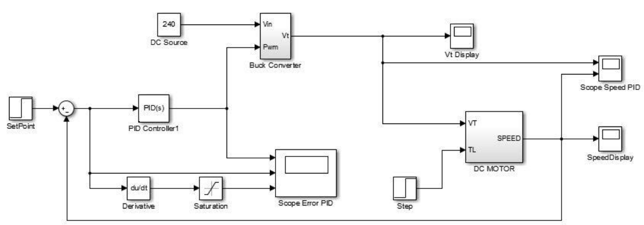


Fig.8. PID Simulation Circuit

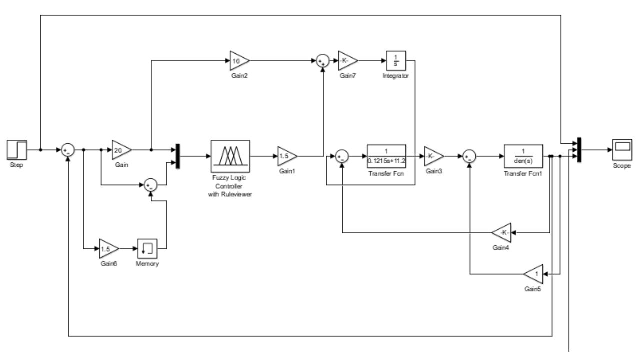


Fig 9. FLC Simulation Circuit

VI. RESULTS AND DISCUSSIONS

To achieve the desired goal of this study which is the speed control of DC motor, DC motor system was converted into its equivalent mathematical model and control system was applied to it through the MATLAB program. Fig.9 shows the comparison of system responses using PID and FLC.

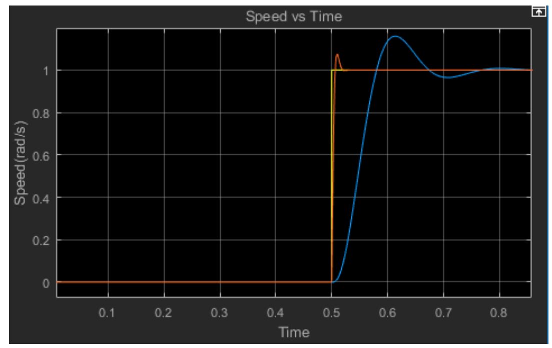


Fig. 10. Graphical Result

VII. CONCLUSION

In this study, the speed control of the DC motor is performed. The PID controller and the fuzzy logic controller are compared From the graphical results obtained through the simulations, we can conclude that the fuzzy logic controller delivers superior performance in contrast to the PID controller.

REFERENCES

[1] Xu, J. Song and Q. Lin, "BRUSHLESS DC MOTOR SPEED CONTROL SYSTEM SIMULINK SIMULATION", IEEE International Conference on Power and Renewable Energy, vol. 4, no. 12, 2017.

[2] Almatheel Y.A. and Abdelrahman A., "SPEED CONTROL OF DC MOTOR USING FUZZY LOGIC CONTROLLER", International Conference on Communication, Control, Computing and Electronics Engineering (ICCCCEE), Khartoum, Sudan, 2017.

[3] Dökmetaş B., Akçam N and Faris, M., "SPEED CONTROL OF DC MOTOR USING FUZZY LOGIC APPLICATION", 4th International Symposium on Innovative Technologies in Engineering and Science, 2016.

[4] C. Navaneethakkannan and M. Sudha, "AN ADAPTIVE SLIDING SURFACE SLOPE ADJUSTMENT IN SLIDING MODE FUZZY CONTROL TECHNIQUES FOR BRUSHLESS DC MOTOR DRIVES", International Journal of Computer Applications, vol. 54, no. 2, pp. 33-40, 2012.