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Dynamic Responce of DC Motor Via Fuzzy Logic and PID Controllers

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ABSTRACT
Fuzzy set Theory of Lotfi A. Zadeh (1965) [1] has been one of the most important area for researches due to its advanced applications in many fields which has the ability to deal with non-linearity and independence of plant modeling, especially in Electrical machines and its control techniques to reach optimum Dynamic response with load variations. In this paper control of direct current (DC) motor with conventional controls proportional–integral–derivative (PID) and fuzzy logic control (FLC) has been investigated and compared with each others for different operating conditions. The mathematical model of Dc motor was modeled and simulated in Matlab Simulink (Mathworks) with illustrated graphs and plots. The performance of the model is expected to show a great results for the fuzzy logic control (FLC) over the PID control [2].

INDEX TERMS DC Motor, Electrical Machines, Fuzzy Logic Controller (FLC), Fuzzy Inference System (FIS), Linguistic Variables, Membership Functions (MFs), Nonlinear Systems, PID Controllers, Simulation Analysis.

I. INTRODUCTION

THE Machines have become integral part of our life, in fact they are replacing the human being in performing a variety of tasks such as robot manipulators , electrical home appliances,etc. Accordingly, the importance of controlling this machines and the improvement of its performance has grown over the years. In the last decades, many control techniques have been developed providing an efficient performance. However, These controllers relies on an exact mathematical model of the plant and a constant parameters which is not the real case when it comes to the electrical machines .The non-linearity attributes of electrical machines like flux saturation, temperature impact on machine parameters, drive inertia, eddy current, hysteresis losses and load variations affect many conventional controllers performance and the machine response. Here comes the need for new control approach over the classical controllers to deal with the non-linearity attributes of the electric machines which make it very difficult to construct a non-linear model for an actual machine.Instead of ordinary or crisp set that only take 0 (false) or 1 (true) where ordinary controllers based on, fuzzy set theory introduced by Lotfi A. Zadeh [1,3] (1965) which is a class of objects with a continuum of grades of membership, Such a set is characterized by a membership (characteristic) function which assigns to each object a grade of membership ranging between zero (false) and one (true). Fuzzy logic controllers (FLC) based on Fuzzy set model can deal with complex non-linear multi-dimensional systems, systems with parameters variation or where the sensor feedback signals are not totally precise [4,5,6]. Based on linguistic rules, manipulating and implementing a human's heuristic Knowledge the controller model does not need to use any machine parameters to make a controller adjustment, giving robust performance, under load disturbance and parameters variation [7,8,9]. The development and applications of power electronics in industry has directly increased the use of Direct Current (DC) machine, because their unique properties such as, high starting torque, high reliabilities, high response performance and low costs, DC motors are widely used in many industrial applications such as rolling mills, chemical process, electric trains, cranes, etc [10]. Where speed and position control of motor are required. Speed control in DC motors was obtained by means of voltage control first in (1891) by Ward Leonard. This paper presented an application of fuzzy logic to control the speed of a DC motor the mathematical model of Dc motor was modeled and simulated in Matlab Simulink (Mathworks). A comparative study is also presented between a traditional controller such as proportional–integral–derivative (PID) controllers and fuzzy logic controllers (FLC) on terms of the dynamic response, Settling time, rising time, peak time and overshoot.

II. MATHEMATICAL MODEL OF DC MOTOR

DC motors are usually used in applications that need precise position control and wide speed range control. A separately excited DC motor is the most preferable type to be used in such applications, it has armature and field winding which is separately supplied. The most famous method to obtain an efficient speed control of this type is the armature voltage control. The speed of the DC motor depends on the back electromotive force (Eb) which is directly proportional to armature voltage and the is inversely proportional to the flux. Therefore, in order to change the speed of the DC motor, the back emf of the motor is changed and this can be done by changing the armature voltage. The DC motor model equations which consists of electrical and mechanical equations are presented in terms of motor parameters:
The armature voltage equation is given by:

$$Va = Eb + Ia.Ra + La(\frac{dIa}{dt}) \quad (1)$$

The mechanical equation of the DC motor can be derived by using Newton's laws:

$$Tm = J(\frac{d\omega}{dt}) + B.\omega + TL \quad (2)$$

The motor torque (Tm) and the armature current (Ia) are proportional by this relation:

$$Tm = Kt.Ia \quad (3)$$

The back electromotive force (EMF), (Eb), is related to the angular velocity (ω) by:

$$Eb = Kb.\omega \quad (4)$$

. By using Laplace transformation of the equations (1) and (2) we have:

$$Ia(s) = \frac{Va(s) - Eb(s)}{Ra + La.S} \quad (5)$$

$$\omega(s) = \frac{Tm(s) - TL(s)}{J.S + B} \quad (6)$$

After simplifying the previous model equations, the overall transfer function between the input $Va(s)$ and the output ω can be written as:

$$\frac{\omega(s)}{Va(s)} = \frac{Kt}{(J.La.S) + (J.Ra + B.La)S + (B.Ra + Kb.Kt)} \quad (7)$$

Parameters table of the dc motor and block diagram figure from Matlab (Simulink) are represented as follows:

TABLE 1. DC motor parameters

Parameter	Quantity
Armature voltage (Va)	100 (V)
Armature Resistance(Ra)	0.4 (Ω)
Armature Inductance(La)	0.1 (H)
Moment of inertia of the rotor (J)	0.1 $(Kg.m^2)$
Damping ratio of mechanical system (B)	0.03 $(N.m.s)$
Motor torque constant (Kt)	1.4 $(N.m.A)$
Back emf constant (kb)	1.25 (V/rad/sec)

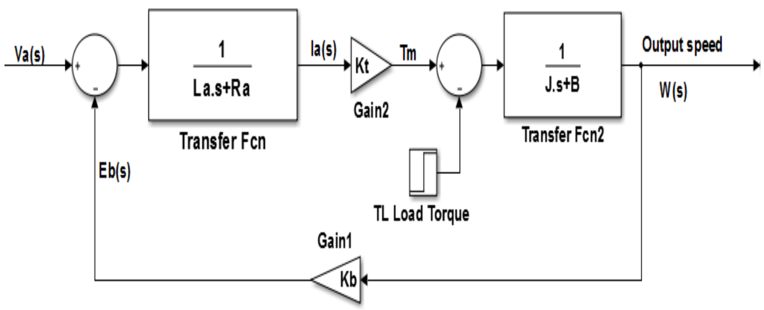

FIGURE 1. DC motor model block diagram.

III. FUZZY LOGIC CONTROLLER (FLC)

Fuzzy logic controller (FLC) was first introduced by professor Lotfi Zadeh (1965) and becomes the most active research area in application of the fuzzy set theory. U nlike traditional controllers, (FLC) based on linguistic control strategy that allows the designer to deal with qualitative, uncertain, imprecise and non-linear plant or model [11,12]. That control strategy which made (FLC) gains its popularity in various control fields with much robustness, adaptability and high performance. Fuzzy logic controller can be decomposed into six fundamental components as the following diagram represents:

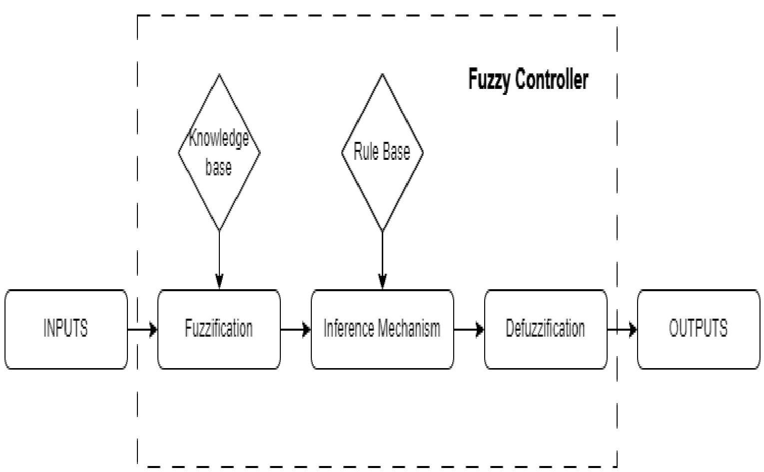

FIGURE 2. Fuzzy logic controller structure.

1) Fuzzy inputs: the inputs are usually crisp or boolean logic values which takes only true or false (zero or one), which calculated from measurement devices such as sensors, transducers or rotary encoders, etc. The state variables representing the system dynamic performance will be taken as input signal to the controller.
2) Fuzzification: the process of transforming numerical variable input values into a linguistic variables or fuzzy values which have the value of the closed interval [0,1]. There are different types of fuzzifications such as Gaussian,trapezoidal and triangular.
3) Fuzzy knowledge base: it memorizes the knowledge about all input and output fuzzy relationship in a nature language, by using human logic (if then) as the rule base where if side is called the condition and then side is called the conclusion. It also contains membership function which connects the inputs to the fuzzy rule base and the outputs to the system.
4) Fuzzy inference mechanism: the most important part of (FLC) to make the controller work effectively by producing the control actions. It evaluates the fuzzy rules in a way similar to human thinking and creates an output for each rule. Mamdani fuzzy inference system which proposed in (1974) [13] and Takagi-Sugeno Fuzzy system can be a part of constructing the fuzzy inference model. Control system with Mamdani fuzzy inference method is created by integrating a set of linguistic control rules that obtained from human expert operators with the output of each rule is a fuzzy set. While in Takagi-Sugeno fuzzy inference the output membership function is a singleton set that constant or a linear function of the input values.
5) Fuzzy rule base: a set of rules that built by the expert using various (if then) statements to create the controller outputs.
6) Defuzzification: the process of transforming the fuzzy values into crisp values. There are many methods of defuzzification such as the centroid and maximum methods.

IV. FUZZY LOGIC CONTROLLER DESIGNING

After introduced the fuzzy logic controller components now In order to control the system using fuzzy logic controller some concepts are required. The linguistic variables are introduced in terms of inputs,outputs and their membership functions (MFs). Fuzzy rule base is determined using the human logic (if then) which creates the controller outputs. The fuzzy logic controller is designed using (FIS) editor created using fuzzy logic toolbox in Matlab (Simulink).

A. Membership functions for input and output linguistic variables

The choice of membership functions (MFs) plays a vital role in building of fuzzy logic controller. Membership functions (MFs) have various shapes and types like triangular, gaussian, trapezoidal, etc [14]. Another important factor that determines the shape of the controller is the fuzzy inference system (FIS),in this model A Mamdani type fuzzy inference engine was used as it's easier to understand rule bases and has more intuitive, it is suitable to an application where the rules is created from human expert knowledge. Triangle membership function are used to represent the linguistic input and output variables. They are easier to implement and faster than many types of membership functions. The inputs of the fuzzy logic controller are the speed error '$e(t)$' and the change in speed error '$ce(t)$'. The input variables can be represented by the following equations.

$$e(t) = \omega_r(t) - \omega_m(t). \tag{8}$$

$$ce(t) = e(t) - e(t-1). \tag{9}$$

Where; $e(t)$is the speed error signal, $e(t-1)$ is the previous error signal, $ce(t)$ is the change in error signal, $\omega_r(t)$ is the reference speed, and $\omega_m(t)$ is the motor speed. A set of seven membership functions are used to represent each input and output of the DC motor model. The linguistic variables are defined as {LN, MN, SN, Z, SP, MP, LP}, where LN means large negative, MN means medium negative, SN means small negative, Z means zero, SP means small positive, MP means medium positive and LP means large positive. The following figures present the used (MFs) and their distribution on the universe of discourse:

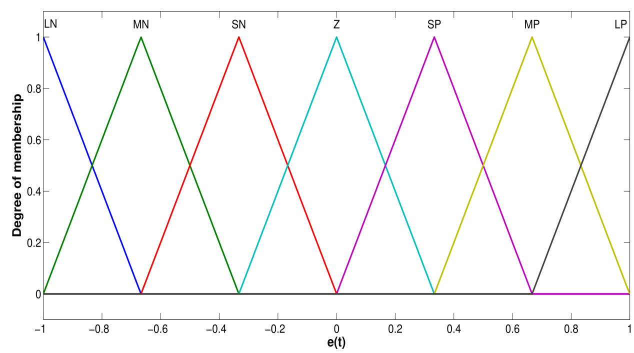

FIGURE 3. Fuzzy input variable e(t).

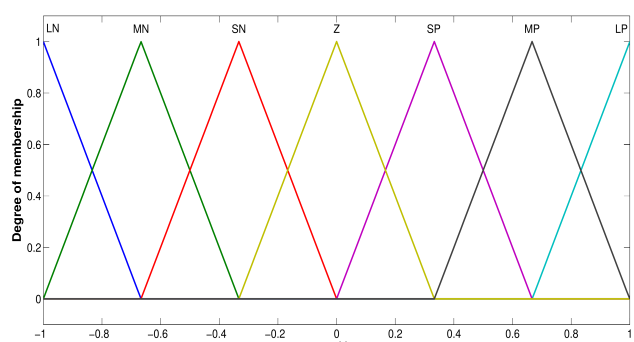

FIGURE 4. Fuzzy input variable ce(t).

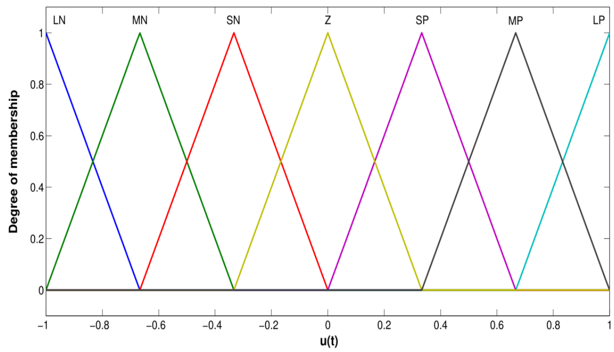

FIGURE 5. Fuzzy output variable u(t).

B. Construction of the rule base fuzzy inference system.

The construction of the fuzzy rule base is done by if-then rule between the two input variables, each input variable has seven linguistic values that generate forty-nine rules, the output variable was obtained by (AND) or min (minimum) implication method and center of gravity or (centroid) as the defuzzification method [15]. The construction of the rule base can be visualized from the following table:

TABLE 2. Rule base of fuzzy controller.

	$e(t)$	error signal						
$ce(t)$		LN	MN	SN	Z	SP	MP	LP
Change in error	LN	LN	LN	LN	LN	MN	SN	Z
	MN	LN	LN	LN	MN	SN	Z	SP
	SN	LN	LN	MN	SN	Z	SP	MP
	Z	LN	MN	SN	Z	SP	MP	LP
	SP	MN	SN	Z	SP	MP	LP	LP
	MP	SN	Z	SP	MP	LP	LP	LP
	LP	Z	SP	MP	LP	LP	LP	LP

The surface plot of the used rules in fuzzy logic controller is shown in figure 6. This figure represents a three-dimensional graph between the controller inputs and outputs, it shows the control response behaviour with the variation of the controller inputs.

V. DC MOTOR CONTROL VIA MATLAB (SIMULINK).

In this model the speed of the separately excited dc shunt motor is controlled by changing the voltage supply to the armature winding with constant flux linkage generated by the field windings. The main intention of this control is to keep the dc motor speed constant regardless of the load variations. The dynamic response of the dc motor has been investigated and inspected with the proportional–integral–derivative (PID) and fuzzy logic control (FLC) controllers.

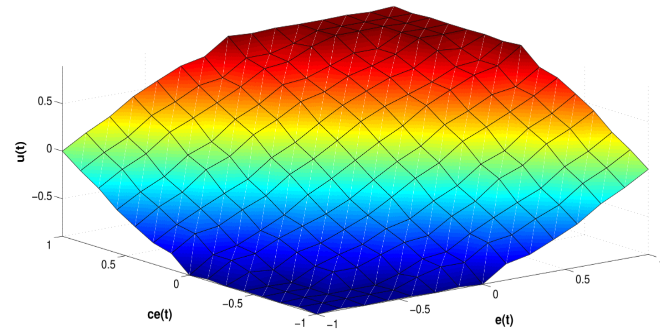

FIGURE 6. Surface view of fuzzy rules.

A. Proportional–integral–derivative (PID) controller.

Proportional integral derivative Controller or PID Controller is a closed loop feedback controller which is a stable and accurate controller that has been applied in various industrial applications and fields. It gains its popularity and reliability from its efficient properties like a robust performance, a fast action controller and a simple construction. Figure (7) represents the basic PID controller structure and equation (10) describes the relation between error signal e(t) and the control signal.

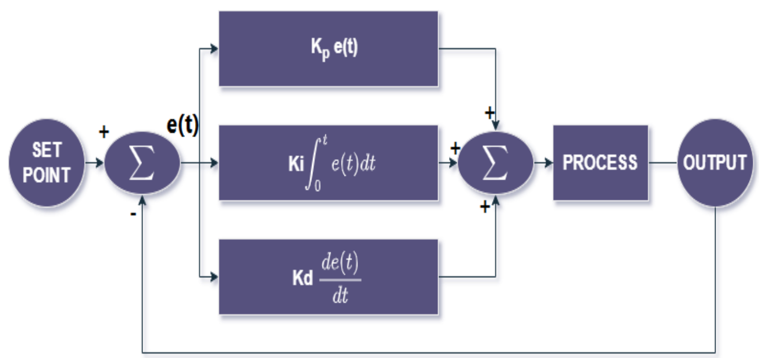

FIGURE 7. PID controller diagram.

$$u(t) = K_P.e(t) + K_I \int e(t)dt + K_D \frac{de(t)}{dt} \qquad (10)$$

PID controller is processed by calculating an error value that is the difference between a desired set-point by the operator and a measured process value that obtained by sensors or actuators or any other measuring instruments. In order to reach optimal control performance and response, the controller is seeking to minimize the error signal by changing the inputs of the system, and this can be achieve by adjusting the proportional gain (Kp), the integral gain (Ki) and the derivative gain (kd). There are a few different ways to approach a PID parameters tuning such as a manual tuning and Ziegler-Nichols tuning [16]. In this paper a soft tuning method is done using a tool in Matlab (Simulink).

B. Result and discussion.

In this model the speed of a DC motor is controlled via fuzzy logic FLC and PID controller [17]. By using DC motor parameters in table (1) the result are obtained from Matlab (Simulink) [18], the simulation result is shown in figure (8) for starting unload condition then with motor loaded after five seconds in form of a step input with a value of (TL=5 N.m), the input voltage also represented as a step input (Vs=100 V), the reference speed is defined as 100 rpm. From table (3) it is obvious that FLC has better performance than PID controller in terms of rising time, peak time, overshoot and settling time.

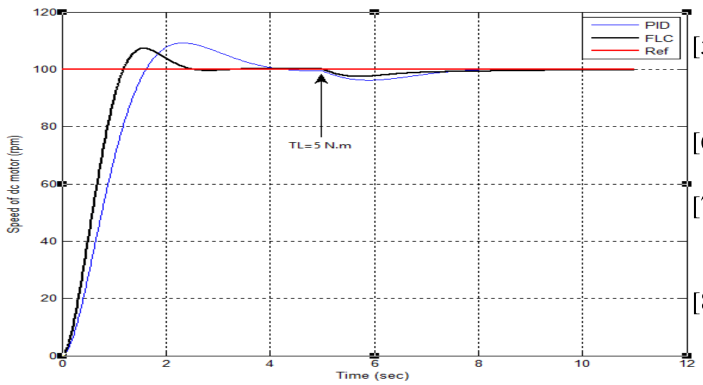

FIGURE 8. DC motor step response with FLC and PID controllers.

TABLE 3. Comparison between PID and FLC controllers.

Parameters	PID	FLC
Rise time (sec)	1.1004	0.8013
Peak time (sec)	2.4000	1.6000
Overshoot %	9.1542	7.6019
Settling time (sec)	6.8997	6.0289

VI. CONCLUSION

In this paper the speed of a DC motor is controlled via fuzzy logic and PID controller. The simulation results from Matlab (Simulink) show that the rising time, peak time, overshoot and settling time and overall control performance has been enhanced effectively by the applied FLC controller. The proposed fuzzy logic controller shows also more advantages such as high flexibility, better dynamic and static performance, capability of dealing with non-liner systems or models and simple construction based on human logic (if then) rules. This superiority over conventional control methods permitted the designers to apply this control method to fields like the metro system in the city Sendai of Japan, automatic focus cameras, household materials such as dishwashers and also automobile industry.

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