Neuro-Fuzzy Controller Design for a Dc Motor Drive

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Abstract: This paper presents a neuro-fuzzy controller design for speed control of DC motor. The most commonly used controller for the speed control of dc motor is the conventional Proportional-Integral-Derivative (PID) controller. The PID controller has some disadvantages like: high overshoot, sensitivity to controller gains and slow response. Fuzzy control and neuro-fuzzy control are proposed in this study. The performances of the two controllers are compared with PID controller performance. In this paper, neural networks are used in a novel way to solve the problem of tuning a fuzzy logic controller. The neuro fuzzy controller uses neural network learning techniques to tune membership functions. For the speed control of dc motor drives, it is observed that neuro-fuzzy controller gives a better response compared to other controllers.

Keywords: DC motor; PID controller; Fuzzy logic controller; Neuro-fuzzy control

1. INTRODUCTION

Direct Current motor drives have been widely used where accurate speed control is required. The development of high performance motor drives is very important in industrial as well as other applications [1]. The DC motors are used in various applications such as defence, industries, robotics etc. Due to their simplicity, ease of application; reliability and favorable cost DC motors have long been a backbone of industrial applications. DC drives are less complex with a single power conversion from AC to DC. DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved for this purpose. The PID controller is one of the conventional controllers and it has been widely used for the speed control of DC motor drive [2]-[4]. The values of proportional (P), integral (I) and derivative (D), can be interpreted in terms of time, P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, or the power supplied to a heating element.

Fuzzy logic is one of the popular new technologies in intelligent control, which is defined as a combination of control theory, operations research, and artificial intelligence (AI). Since the announcement of the first fuzzy chips in 1987, fuzzy logic is still perhaps the most popular area in AI [5].

2. CONTROLLERS STRUCTURE

A. PID Controller

Block diagram of the drive with PID controller is shown in Fig. 1. The speed error e(t) between the reference speed u(t) and the actual speed N of the motor is fed to the P-I-D controller. The Kp, Ki and Kd are the proportional, integral and derivative gains of the P-I-D controller The transfer function of a PID controller is given by

$$C(s) = Kp + \frac{K_i}{s} + Kds = Kd\,\frac{S^2 + 2\zeta w_n S + w_n^2}{S} \qquad (1)$$

$$2\zeta w_n = Kp / Kd, \quad w_n^2 = Ki / Kd \qquad (2)$$

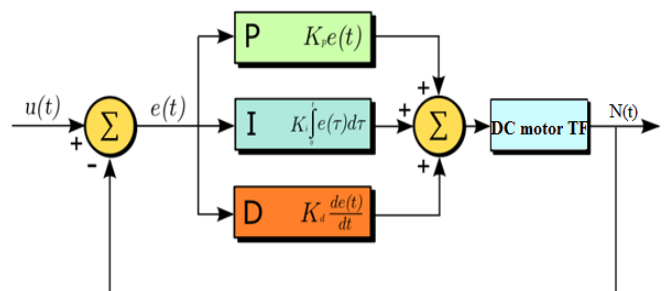where ζ and w_n, are damping ratio and undamped natural frequency [6].

Fig. 1. PID controller structure

B. Fuzzy Controller

Fuzzy control provides a formal methodology for representing, manipulating and implementing a human's heuristic knowledge of how to control a system. Fuzzy controller block diagram is given in Fig. 2, where we show a fuzzy controller embedded in a closed-loop control system. The plant outputs are denoted by y(t), its inputs are denoted by u(t), and the reference input to the fuzzy controller is denoted by r(t).

The fuzzy controller has four main components:
(1) The "rule-base" holds the knowledge, in the form of a set of rules, of how best to control the system.
(2) The inference mechanism evaluates which control rules are relevant at the current time and then decides what the input to the plant should be.
(3) The fuzzification interface simply modifies the inputs so that they can be interpreted and compared to the rules in the rule-base.
(4) Defuzzification converts the conclusions reached by the inference mechanism into plant inputs [9].

Neuro-fuzzy system shown in Fig. 3 combines neural networks and fuzzy logic. It has recently gained a lot of interest in research and application [7], [8].
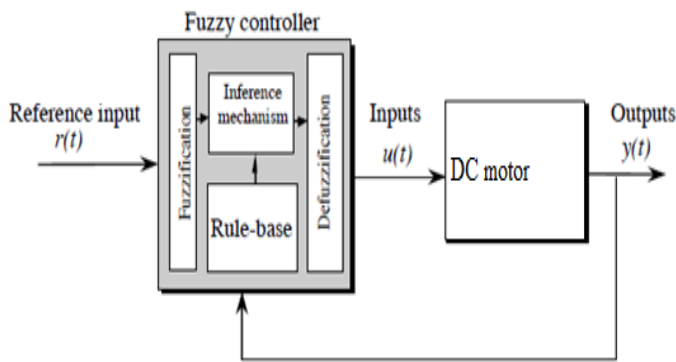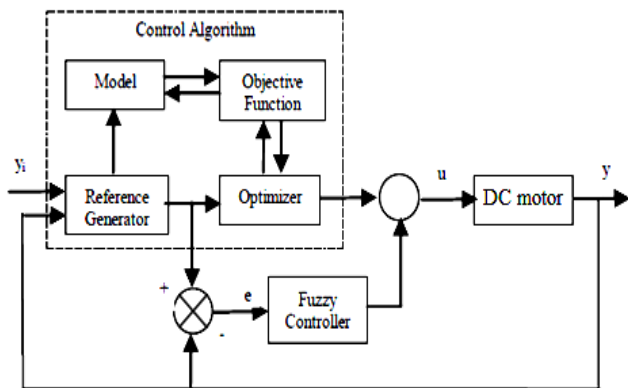

Fig. 2. Fuzzy controller architecture

Fig. 3. Neuro – Fuzzy control scheme

Table 1: Rule base for 5 membership functions

E_N $\frac{dE_N}{dt}$	NL	NS	ZE	PS	PL
NL	NL	NL	NL	NS	ZE
NS	NL	NS	NS	ZE	PS
ZE	NL	NS	ZE	PS	PL
PS	NS	ZE	PS	PS	PL
PL	ZE	PS	PL	PL	PL

C. Neuro-Fuzzy Controller

The adaptive neuro-fuzzy inference system (ANFIS) uses a feed forward network to search for fuzzy decision rules that perform well in a given task. Using a given input/output data set ANFIS creates a fuzzy inference system for which membership function parameters are adjusted using a combination of a back propagation and least square method [9].

ANFIS estimator design consists of two parts: constructing and training. In the constructing part, structure parameters are determined. These are type and number of input Membership Functions (MFs), and type of output MF. Effective partition of the input space is important and it can decrease the rule number and thus increase the speed in both learning and application phase. Output MFs can be either a constant or in linear form.

Both of the two forms are used for the output MF in this study. Having described the number and type of input MFs, the estimator rule base is constituted. Since, there is no standard method to utilize the expert knowledge; automatic rule generation method is usually preferred. According to this method, for instance, an ANFIS model with two inputs and five MFs on each input would result in $5^2 = 25$ Takagi-Sugeno fuzzy if-then rules automatically. Although this method may requires much computational knowledge, especially in systems that have to be defined with many inputs. It is used in this study due to the advantage of MATLAB software. Therefore, rule bases of estimators are formed automatically with the number of inputs and number of MFs. After the ANFIS structure is constructed, learning algorithm and training parameters are chosed. As mentioned earlier in this paper, back propagation or hybrid learning can be used as a learning algorithm. Therefore, hybrid learning algorithm is adopted in this study.

Parameters in the algorithm are epoch size (presentation of the entire data set), error tolerance, initial step size, step size decrease rate, and step size increase rate. Since there is no exact method in the literature to find the optimum of these parameters a trial and error procedure is used. MATLAB fuzzy logic toolbox is used to design ANFIS estimators' structures. Using the given training data set, the toolbox constructs an ANFIS structure using either a back propagation algorithm alone, or in combination with least squares type of method (hybrid algorithm). ANFIS model can be generated either from the command line, or through the ANFIS editor GUI. In this study, ANFIS Editor graphical user interface (GUI) is used to generate ANFIS models with the chosen

design parameters in the construction phase. MATLAB code is used to train the ANFIS structure in the training step.

The three steps of ANFIS estimator design are as follows:
1. Generated training data is loaded to the Editor GUI.
2. Design parameters, number and type of input and output MFs, are chosen. Thus, initial ANFIS structure is formed.
3. The code for training is run with an initial structure.
4. ANFIS structure constituted after training is saved.

3. SIMULATION RESULTS AND DISCUSSION

In order to validate the control strategies as described above, digital simulation are carried out on a converter dc motor drive system (see Appendix). The MATLAB/SIMULINK model of the system under study with all three controllers is shown in Figs. 4-6.

The response of motor speed with PID controller is shown in Fig. 7. Figure 8 shows response of motor speed to a unit step input with a fuzzy controller. Figure 9 shows the response of the motor speed to a unit step input with a neuro-fuzzy controller. Figure 10 shows the response of motor speed to a unit step input with three different controllers A comparison has been made between maximums overshoot (MP), rise times (rt) and settling times (ts) of system with three different controllers as illustrated in Table (2).

Table 2. A comparison of maximum overshoot, rise time, settles time for three different controllers

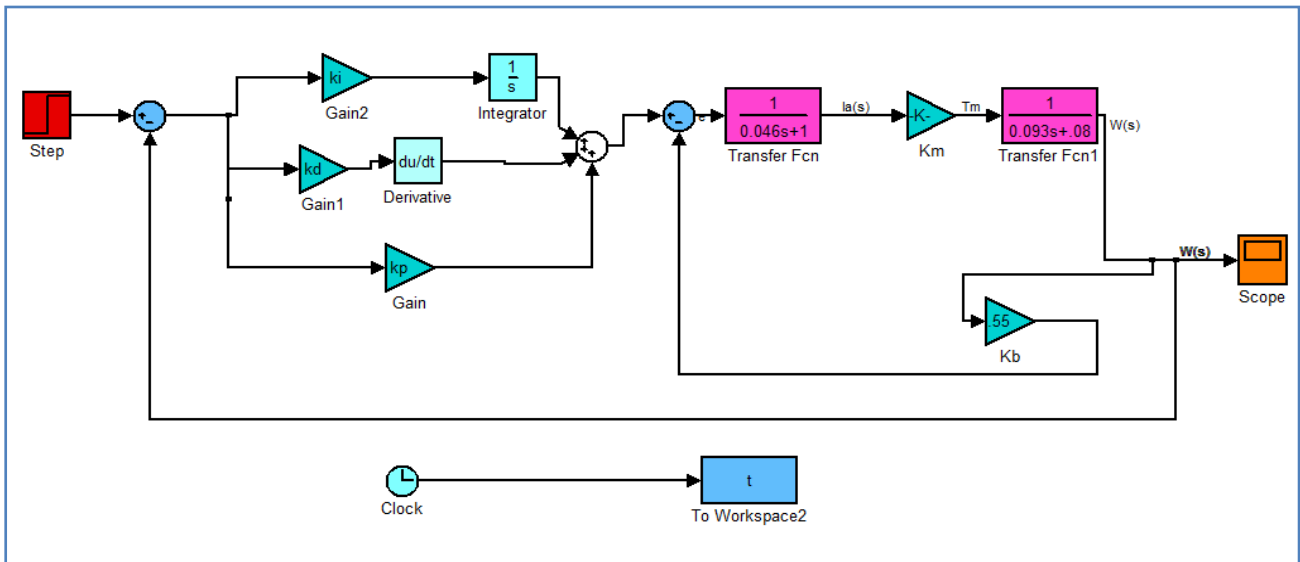| Controller	MP (%)	Tr(Sec.)	Ts (Sec.)
PID	7.93	0.2577	0.9465
Fuzzy	1.5	0.3909	1.3
Neuro-Fuzzy	4.78	0.2748	0.8531

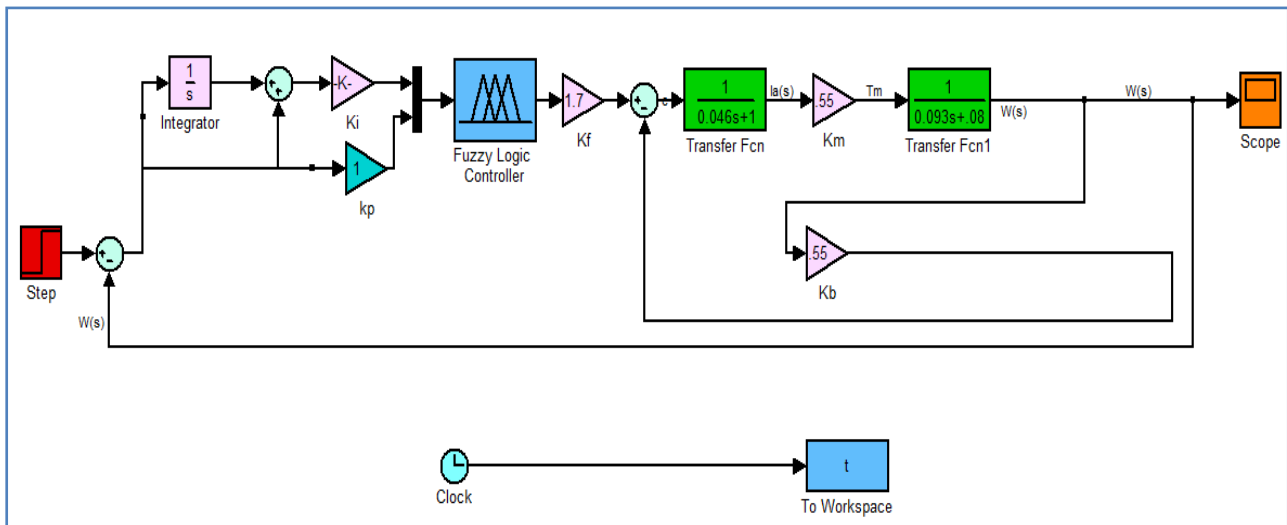**Fig. 4.** PID controller for speed control of DC motor

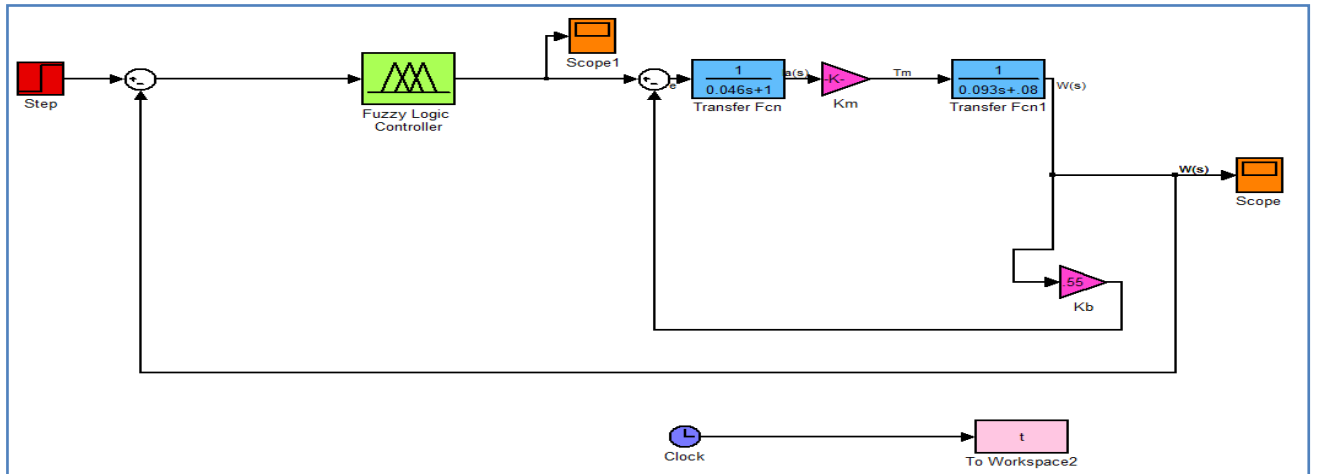**Fig. 5.** Fuzzy controller for speed control of DC motor

Fig. 6. Neuro-Fuzzy controller for speed control of DC motor
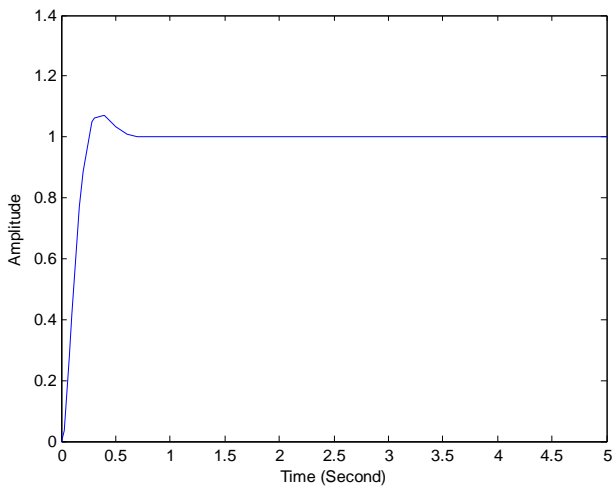

Fig. 7. Motor speed response with PID controller
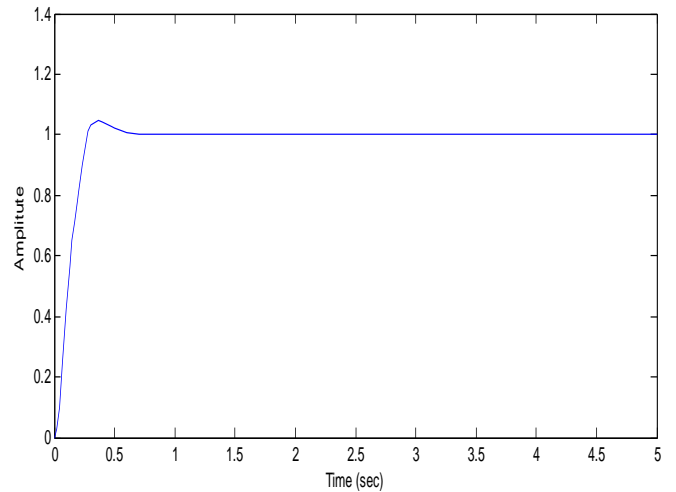

Fig. 9. Motor speed response with neuro fuzzy controller
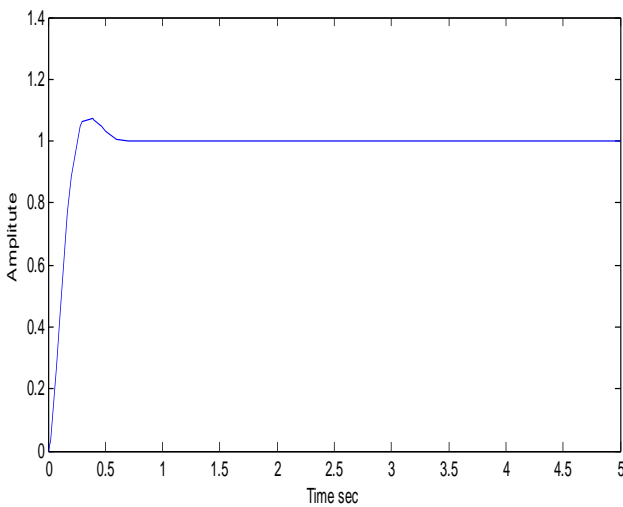

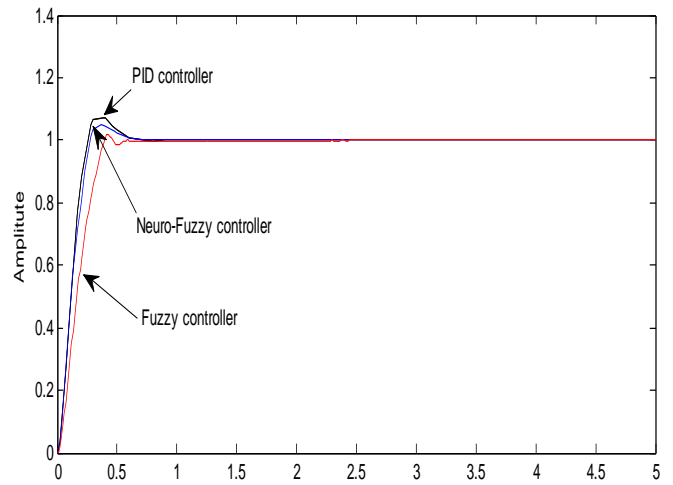**Fig. 8.** Motor speed response with fuzzy controller

Fig. 10. Motor speed response with three different controllers

4. CONCLUSIONS

In this paper, the DC motor has been reviewed from control theory perspective. PID controller and intelligent techniques such as Fuzzy logic controllers and their hybrid (ANFIS) are used for DC motor speed control.

In the Design with PID controller, lots of attempts are needed to choose the right term, which gives a good response.

Design with fuzzy controller gives perfect results, but also a trial-and-error method is needed to find the required parameters.

Design with neuro-fuzzy controller reached a very good response and was very fast. The advantages of the Neuro-Fuzzy controller are that it determines the number of rules automatically, reduces computational time, learns faster and produces lower errors than other methods. With proper design a Neuro-Fuzzy controllers can replace PID and Fuzzy controllers for the speed control of dc motor drives.

From simulations, it is concluded that the use of ANFIS reduces design efforts and gives better results.

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APPENDIX

Motor's Parameters

The motor used in this experiment is dc separately excited, rating 2.5hp at rated voltage 110 V, and the motor's parameters are as follows [1]:

Armature resistance (Ra) = 0.6 Ω

Armature inductance (La) = 8 mH

Back e.m.f constant (K) = 0.55 V/rad/s

Mechanical inertia (J) = 0.0465 kg.m^2

Friction coefficient (B) = 0.004 N.m/rad/s

Rated armature current (Ia) = 20 A