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A Review on Speed Control Techniques of Separately Excited DC Motor

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Abstract

Nowadays, many moving devices receive their energy from a battery. DC motor is the most suitable option for these systems. In addition, the speed of these motors can be controlled easily and in the extensive range. Intelligent control methods are widely used in control of the industrial processes due to simplicity and high capabilities. In this paper, the fuzzy resistance speed controller has been designed and presented for DC motor. This controller stabilizes speed of motor in the desirable path despite changes of load torque or change of motor elements. One of the other features of this controller is the multivariate objective function which is able to supply dynamical behavior of the motor. Rapid response, permanent fault and low overshoot are about the other advantages of this method.

Keywords: *resistance speed control, fuzzy logic, multivariate objective function, DC machine, PID controller*

1. Introduction

DC drives are widely applied in the fields such as controllable variable, suitable adjustment of speed and different working states [1-2]. DC motors are of the first electrical motors in the industry, which are applied in high powers and broad voltage ranges and in different nominal speeds due to simplicity of controlling their speed [3]. The method which has been considered for controlling the speed in this paper is speed control with voltage control. To control voltage, classical control methods (PID) and modern control methods (fuzzy logic) are used [4-5]. Armature voltage control method always has a maximum accessible speed. This maximum speed is obtained for maximum permissible voltage. In fact, a type of remote control applied in DC motor plays main role in optimal performance of the motor. Fuzzy control method is one of the suitable methods for control of nonlinear systems [6]. Fuzzy systems provide systems based on a set of lingual rules with a nonlinear mapping. Since implementation of mappings is not easy, fuzzy systems can be found in a broad spectrum of engineering applications [7]. Evident characteristic of the fuzzy controllers is independence of the controller parameters in state space and controlled process variables. Of the other advantages of this controller are high response speed, low complexity and volume and controllability of the motor speed in broad range of the desired reference speeds [1, 3].

2. Modeling of Separately excited DC motor

Schematic diagram of separately excited DC motor is shown in Figure 1 and relations of this motor include [8-9]:

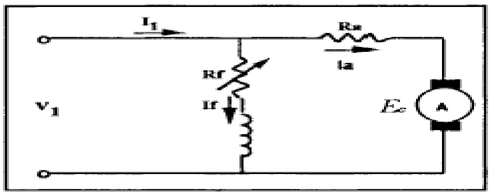

Figure 1. Schematic diagram of separately excited DC motor

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$$V_1=Vf=Va=Ec+IaRa \tag{1}$$

$$I_1=Ia+If \tag{2}$$

$$Ec=K\Phi n \tag{3}$$

So that V1 is terminal voltage, Vf is excitation voltage, Va is armature voltage, Ec is back electro-motive *force in volt, K* is fixed coefficient*, Φ is* magnetic flux of each pole in Webber, n is rotational speed in r/min, Ra is armature resistance, I1 is line current in ampere, If is excitation current , Ia is armature current. It can be shown that change of load causes change of line current (I1) and change of armature current (Ia). Speed of motor is calculated according to Relation (4) in case line voltage, armature current, field flux and fixed coefficient are specified.

$$n = \frac{Ec}{K\Phi} = \frac{V1 - IaRa}{K\Phi} \tag{4}$$

Now, speed of motor can be obtained in excitation current by susbtitting Relation (2) in (4).

$$n = \frac{V1 - I1Ra + IfRa}{K\Phi} \tag{5}$$

With Formula (4), ratio of speeds can be obtained in two different functional states as follows:

$$\frac{n_{new}}{n_{old}} = \frac{E_{cnew}}{E_{cold}} * \frac{\Phi_{old}}{\Phi_{new}} \tag{6}$$

In case load is applied on axis of the unadjusted motor, line current and armature current will increase. On the other hand, back electro-motive force is reduced considering that speed of motor has direct relation with *back electro-motive* force and reverse relationship with discharge [1]. Goal of speed control is to return speed of motor to a desired reference speed automatically due to changes of load. The speed control system has been applied with Matlab Simulink) software elaborated on a separately excited DC motor with nominal voltage of 300 volts and nominal round of 1400 rpm and also for parameters of the motor which are given in Table 1.

3. Principles of Fuzzy Logic

The word"fuzzy" in dictionary means vague, indistinct or inaccurate and chaotic [10]. Fuzzy systems are the systems with accurate definition and fuzzy control is a special type of nonlinear control which is accurately defined as well. Although fuzzy systems describe uncertain and unspecified phenomena, fuzzy theory is an accurate theory [10]. In summary, starting point of construction of a fuzzy system is to obtain a set of if-then rules from knowledge the experts or knowledge of the studied field. The next stage is combination of these rules in a single system [11]. Different fuzzy systems use different principles and methods for combination of these rules. We then mention some of the concepts and definitions relating to fuzzy logic. Definition (1) of fuzzy set: here, we assume that X is reference set and includes all possible elements and members in discussion with the desired user. A classic set A is specified in reference space X with a function $\mu_A(x)$ which can have only two values (0,1) but a fuzzy set A is specified in reference space X with a function $\mu_A(x)$ which takes values in interval [0,1]. Therefore, a fuzzy generalization set is a classic set which permits membership function to take any value in interval [0,1]. In fact, we see that there is nothing ambiguous for fuzzy sets but fuzzy set is a set with a continuous membership function [11-12]. A fuzzy set A can be shown in X with a set of ordered pairs x and its membership value can be shown as follows: $A = \{(x, \mu_A(X)) | x \in X \}$. Definition (2): Union of two fuzzy sets: union A,B is a fuzzy set in X which is shown with A∪ B and is defined with membership function. $\mu_{A \cup B}(x) = \max[\mu_A(x), \mu_B(x)]$. Definition (3): intersection of two fuzzy sets: intersection A,B of a fuzzy set is X which has been shown with A ∩B and is defined with membership function. $\mu_{A\cap B}(x)=\min[\mu_A(x),\mu_B(x)]$. Definition (4): complement of fuzzy set: complement of fuzzy set A is fuzzy set A in X of which membership function is defined as $\mu_{\bar{A}}(x)=1-\mu_A(x)$. To control fuzzy logic, other cases such as fuzzy rules and fuzzy combination (fuzzy inference) are also important. A fuzzy rule has an IF-THEN format as follows:

If (x is A and y is B) THEN (z is C)

Where x,y,z are fuzzy variables and A,B,C are fuzzy subsets in reference sets X,Y,Z.

Definition (5): fuzzification: fuzzy controller has been designed only for processing of fuzzy quantities. Therefore, all input values should be converted into fuzzy sets before use. In other words, stage of definition of the fuzzy sets relates to input and output variables. For definition of these fuzzy sets, we should have primary knowledge of definition for each one of these variables. In most cases, output error i.e. difference between output of the process and reference signal and changes or its derivative constitute inputs of fuzzy system. Definition (6): defuzzification: it converts the fuzzy set into a number based on one of the common defuzzification methods such as center of gravity method or height method which is output of controller. Among them, center of gravity defuzzification method is regarded as one of the most common and applicable methods. In this method, center of gravity of output numerical values is selected according to center of gravity of membership function and is expressed as follows [1, 4], [9-10], [18-19]:

$$CG = \frac{\sum_i \mu i(yi)\, yi}{\sum_i \mu i(yi)} \tag{7}$$

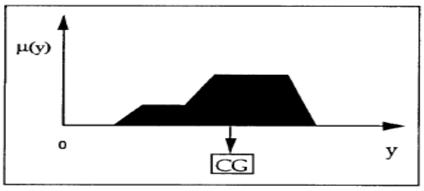
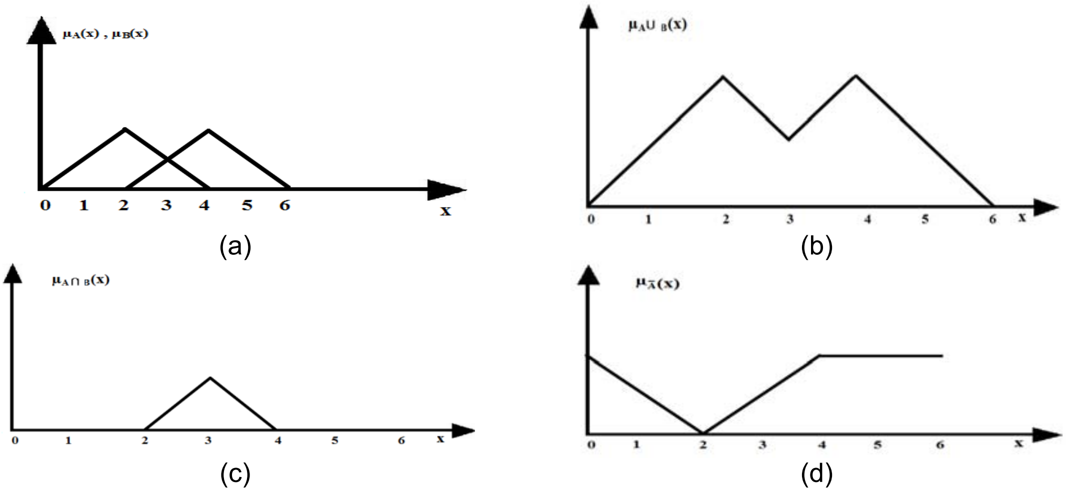


Figure 2. Graphic design of defuzzifier of center of gravity

Figure 3 The operations which are performed on fuzzy sets.



(a) (b)

(c) (d)

Figure 3. The basic operations on fuzzy sets a) Conventional fuzzy sets b) union c) Intersection d) complement

4. PID Controller

PID controller has been used to compare its response with results in this proposed method [13-14]. It is necessary to note that more than half of the industrial controllers which are applied today use PID control designs [14], [22-23]. Since most PID controllers are adjusted in situ, different adjustment rules have been suggested. The controllers can be adjusted in situ carefully and delicately with these rules. Values of this controller can be obtained from trial and error method and with response of system. In this case, the system is applied as a closed loop and with a PID controller [15]. We first delete controllers I, D from the circuit obtain gain limit or K_P *crit* by increasing K_p. we consider K_p of the system as ½ of K_P *crit* and then put the integral in the circuit. We change coefficient of the integral from large values to small values until the system is located in threshold of fluctuation. The above coefficient is the integral coefficient of the controller [11, 12]. At the same time, we put the derivative control in the circuit and increase its coefficient from small values to large values until the system becomes stable and error of the system becomes zero. In this regard, coefficients of the controller are specified and coefficients of the PID controller which have been designed are as follows:

$$k_p = 0.1,\ k_i = 0.0001\ ,\ k_d = 0.012$$

So that , K_p, K_i,K_d are Proportional Gain, integral gain and derivative gain [16-17].

4.1. Studying Results of Simulating PID Controller

For simulation, Matlab Simulink software has been used. Type of the motor used in this simulation is separately excited DC motor and parameters of the motor are given in the appendix. The load applied on the motor is T_L=200+5sint.DC and we studied speed of motor in different stages.

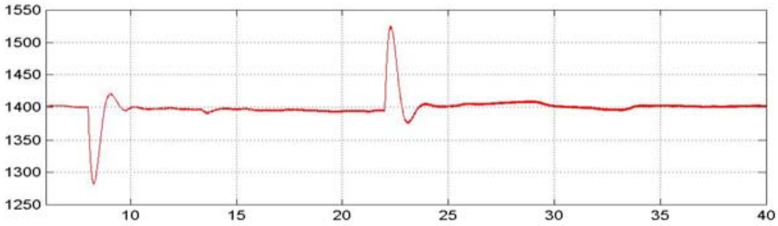


Figure 4. Curve of speed variation in time for parameters of dc motor

In Figure 4, speed in load loss is 1400 and when we applied 200+5sint on it in 8 s, speed is reduced to 120 rounds and reaches its reference speed again after some seconds and removes moment in 23 s and the speed goes beyond the reference speed at this time and reaches its reference speed after some seconds.

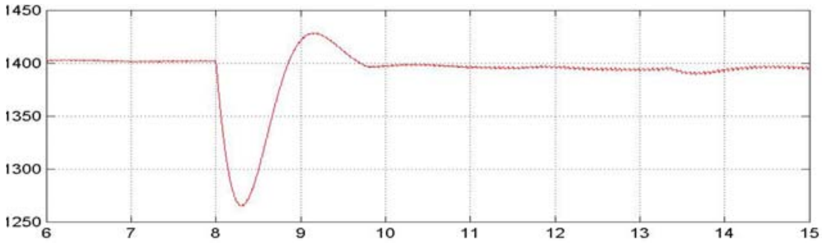


Figure 5. Curve of speed variation in time for 10% increase of parameters of dc motor(R_a, L_a, *TL, J*)

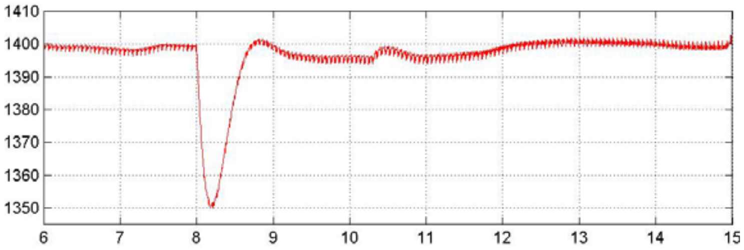


Figure 6.Curve of speed variation in time for 40% decrease of parameters of dc motor(R_a, L_a, TL)

5. Fuzzy Logic Controller

Main structure of a fuzzy control system has composed of fuzzifier, fuzzy rules base, decision and defuzzifier [18-19]. Fuzzy control has been used in a closed loop system. Any change in speed of motor which can be due to changes of moment, reference speed or changes in elements of the motor such as change in resistance of armature etc [20]. which cause change of output voltage [19, 21]. To control voltage, two parameters of speed error and changes of speed error are used. Speed error is obtained according to Relation 8 by difference of speed at any moment n(k) and reference speed n_{REF} and its positivity or negativity indicates less or more speed of motor than the reference speed and its values indicates this difference of speed.

$$e(k) = n(k) - n_{REF} \tag{8}$$

The second parameter is change of speed error which is obtained from difference of speed at any moment n(k) and speed at the previous moment n(k-1):

$$\Delta e(k) = n(k) - n(k-1) \tag{9}$$

Positivity or negativity of this parameter indicates ascending or descending trend of motor speed changes and its value indicate intensity of these changes. The fuzzy controller covers the entire space of the input variables considering these two parameters and all possible states are considered for change in speed of motor. For each one of the input variables, the fuzzy system and its output are regarded as membership function with five ranges of VL, L, ZE, S and VS. Considering that we consider five ranges for each input variable and the control system has two inputs b, we will have totally 25 rules in center of fuzzy rules. These rules are shown in Table 2 for simplicity [13-14], [28-29].

Table 2. Fuzzy rules

S **DS**	**VS**	**S**	**ZE**	**L**	**VL**
VL	ZE	S	VS	VS	VS
L	L	ZE	S	VS	VS
ZE	VL	L	ZE	S	S
S	VL	VL	L	ZE	S
VS	VL	VL	L	L	ZE

Membership functions used in this simulation for speed error and changes of speed error and also output (ΔV) are shown in Figure 7 to 9.

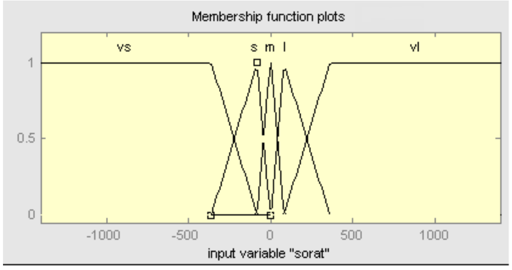


Figure 7. Membership function of speed error

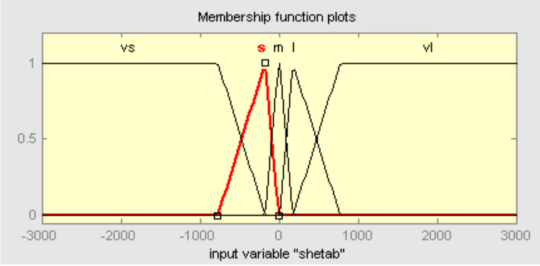


Figure 8. Membership function of speed error changes

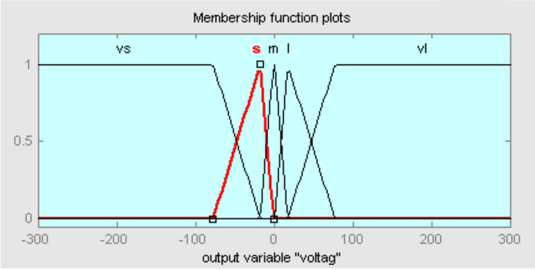


Figure 9. Membership function of output (ΔV)

5.1. Studying Results of Simulating Fuzzy Controller

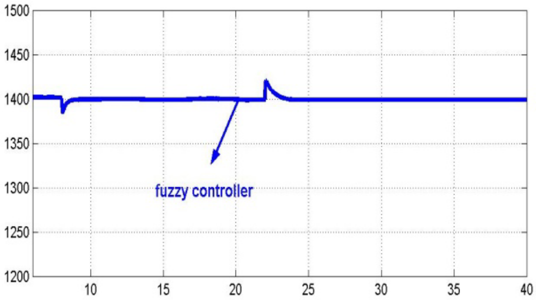


Figure 10. Curve of speed variation in terms of time for parameters of dc motor (speed in No load of 1400 rpm)

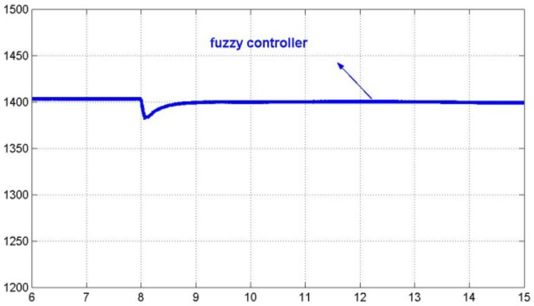


Figure 11 . Curve of speed variation in terms of time for 10% increase of parameters of dc motor(R_a, L_a, TL, J)

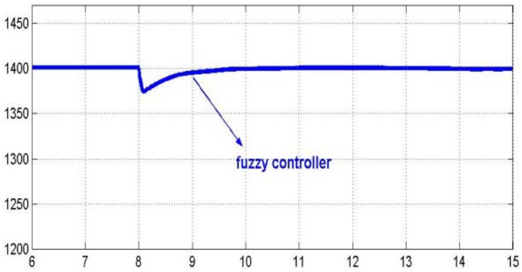


Figure 12. Curve of speed variation for 40% decrease of parameters of dc motor R_a, L_a, TL, J)

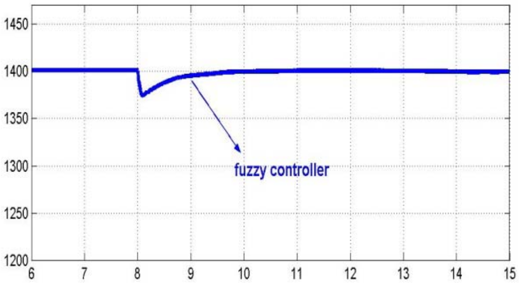


Figure 13. Curve of speed variation for 10% decrease of parameters of dc motor (R_a, L_a, TL)

6. Studying Results of Simulation in Fuzzy and PID Controllers

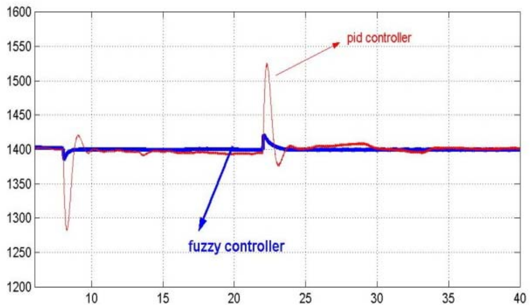


Figure 14. Curve of speed variation in terms of time for parameters of dc motor (*Ra, La, TL, J*)

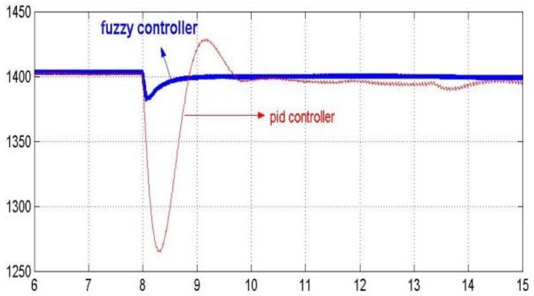


Figure 15. Curve of speed variation in terms of time for 10% increase of parameters of dc motor (*Ra, La, TL, J)*

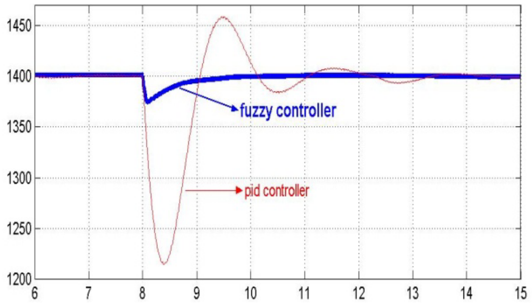


Figure 16. Curve of speed variation in terms of time for 40% increase of parameters of dc motor (*Ra, La, TL, J)*

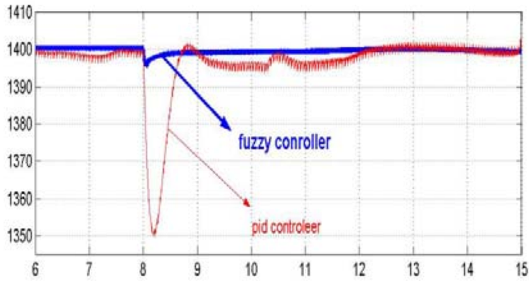


Figure 17 . Curve of speed variation in terms of time for 40% decrease of parameters of dc motor (*Ra, La, TL)*

As Figure 17 shows, our reference speed is 1400 rpm and we applied load with specifications of is T_L=200+5sint on the motor in 8s. As shown above, decrease of speed in a 5-volt phase in PID is 50 rounds and decrease of speed in the classic system is more than that in the fuzzy systems which is one of the disadvantages of classic systems (PID). Of the other disadvantages of the classic systems are fluctuation of speed, long stability time (reaching reference speed) and overshoot.

7. Conclusion

In this paper, fuzzy and classic design of the DC motor speed controller (PID) has been mentioned irrespective of delay resulting from mechanical time constant of the motor which is available in all speed control methods. Fuzzy control method has desirable quality compare with other methods due to speed, accuracy and independence of the controller from variables of the controlled process, simplicity of design and controllability of speed in broad ranges of reference speeds. This priority in small changes of reference speed is very considerable.

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