Performance Analysis of Speed Control of PMDC Motor using Fuzzy Logic Controller

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Abstract

In this study, performance analysis of speed control of PMDC (Permanent Magnet Direct Current) motor using fuzzy logic controller was realized in Matlab/SIMULINK environment. Firstly, the mathematical model was obtained using the mechanical and electrical values of electrical equivalent circuit of the DC motor. Then, the fuzzy logic and PI controller structures was designed. Different references speeds were applied to the systems controlled by the FL and the PI controller. Additionally, in this study, the effect of varying armature resistance of the PMDC motor on the controller structures used in simulations and on the speed of the PMDC motor was also investigated. Comparisons were made for both controllers considering the same conditions. According to the results obtained by using the data in this study, it is observed that the fuzzy logic controller has a better performance than the PI controller.

Key words: DC Motor Control, Fuzzy Logic Controller, Variable Armature Resistance, PI Controller, Matlab/SIMULINK

1. *Introduction*

The PMDC motor is an electric machine that converts direct current electrical energy into the mechanical energy. These machines basically consist of two main parts. The stator is fixed and the rotor rotates.

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Because of their high reliabilities, flexibilities and low costs, DC motors are widely used in industrial applications, robot manipulators and home appliances where speed and position control of motor are required (AHMED et al, 2013). Speed or position control in these machines is easier than other electric machines, so they were preferred in the industry (AÇIKGÖZ, ŞEKKELİ, 2013). DC motors are widely used in industrial control applications due to their simple structures and they have been the subject of many fields of research and development in the industrial control applications. However, they require maintenance because of contact of commutator and brushes with each other. DC motors are most suitable for wide range of speed control and there are many adjustable speed drives (BANSAL, NARVEY, 2013). Control of these motors has become necessary in applications that require a certain amount of power, movement, speed. Classic Control has proven, for a long time, to be good enough to handle control tasks on system control; however, its implementation relies on an exact mathematical model of the plant to be controlled but simple mathematical operations (SALIM et al., 2013).

In this study, firstly, PMDC motor model was designed in Matlab/SIMULINK environment and speed control was performed with fuzzy logic and PI controller. Then, the controllers were compared for different reference speed inputs. Finally, in order to investigate the effect of armature resistance change on the controller structures used in simulations, armature resistances were changed at certain values and the effects were observed. Thus, it will be investigated how an armature resistance, which varies with temperature, affects the speed performance of the PMDC motor.

2. *Dynamic Model of PMDC Motor*

The electrical equivalent model of the PMDC motor is shown in Fig. 1. (SALIM et al., 2013).

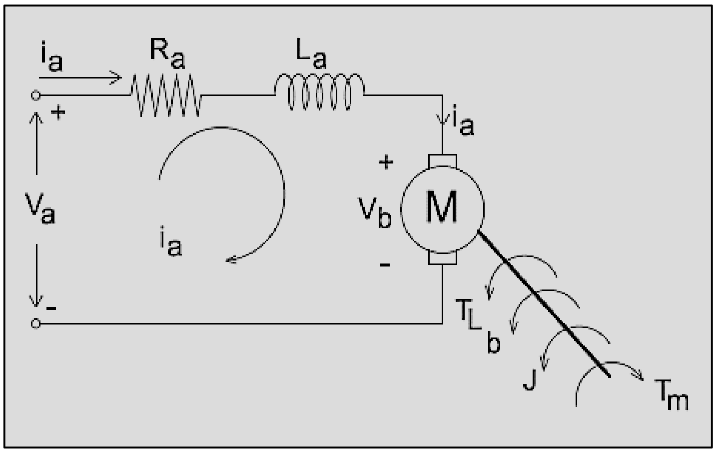

Figure 1. The electrical model of PMDC motor

From the dynamic equations of DC motor following equations are obtained by Kirchhoff Voltage Law,

$$V_a(t) = R_a i_a(t) + L_a \frac{d}{dt} i_a(t) + V_b(t) \quad (1)$$

$$V_b(t) = K_e \omega_r(t) \quad (2)$$

$$\frac{d}{dt} i_a(t) = -\frac{R_a}{L_a} i_a(t) - \frac{K_e}{L_a} \omega_r(t) + \frac{1}{L_a} V_a(t) \quad (3)$$

and from the torque equations are obtained,

$$T(t) = K_m i_a(t) \quad (4)$$

$$T(t) = J \frac{d}{dt} \omega_r(t) + b\omega_r(t) + T_L \quad (5)$$

In this study, the load moment was assumed to be zero ($T_L = 0$) during the all simulations.

$$\frac{d}{dt} \omega_r(t) = \frac{K_m}{J} i_a(t) - \frac{b}{J} \omega_r(t) \quad (6)$$

Parameters of the DC motor are given in Table 1.

Symbol	Explanation	Units	Value
b	Viscous friction	Nms	0.02
J	Inertia moment	$kg.m^2$	0.0243
K_e, K_m	Motor Constant	V.s/rad	0.125
L_a	Armature Inductance	H	0.25
R_a	Armature Resistance	Ω	3.54

Table 1. Parameters of DC motor

The simulation model of the DC motor using Eq. 3 and Eq. 6 is given in Fig. 2.

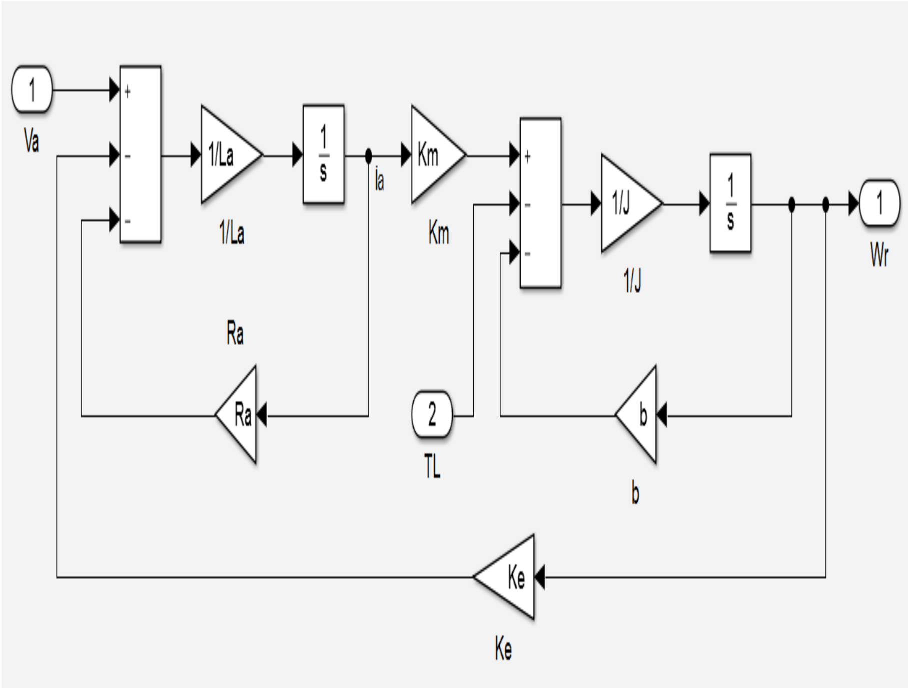

Figure 2. Simulink model of DC motor

As a result, Matlab/SIMULINK model of the DC motor without controller is shown in Fig. 3.

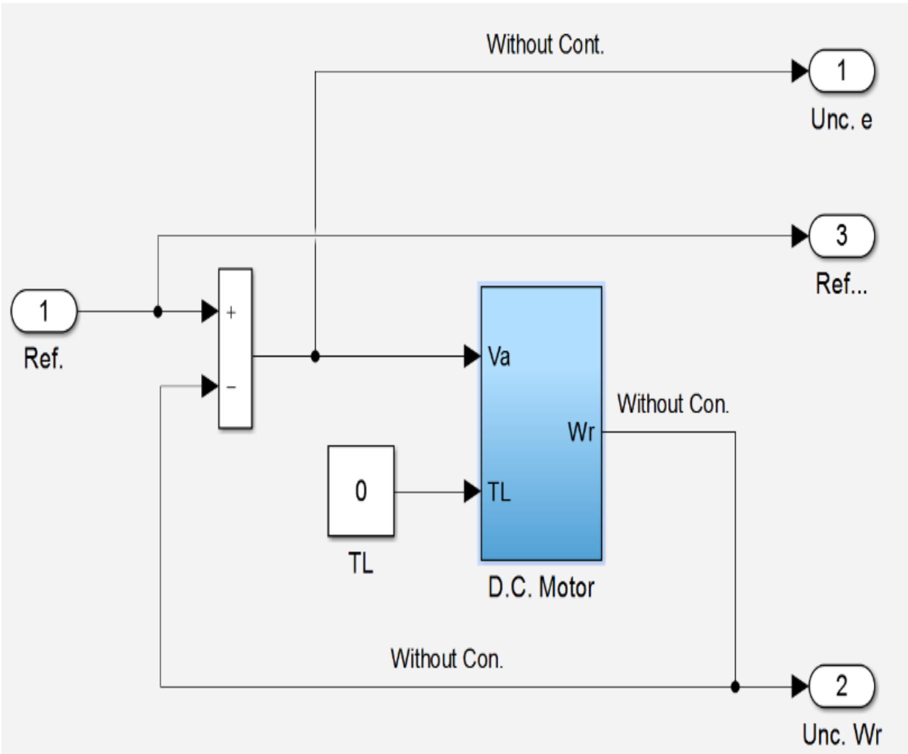

Figure 3. DC motor model without controller

As shown in Fig. 3, the load moment was assumed to be zero. The rotor angular velocity was compared with the given reference input. Firstly, the angular of 100 (rad/s) was applied for reference input. Secondly, this value was increased to 150 (rad/s) in the fifth seconds of the simulation. Finally, it was decreased to 100 (rad/s) again in the tenth seconds of the simulation. The obtained system output is shown in Fig. 4.

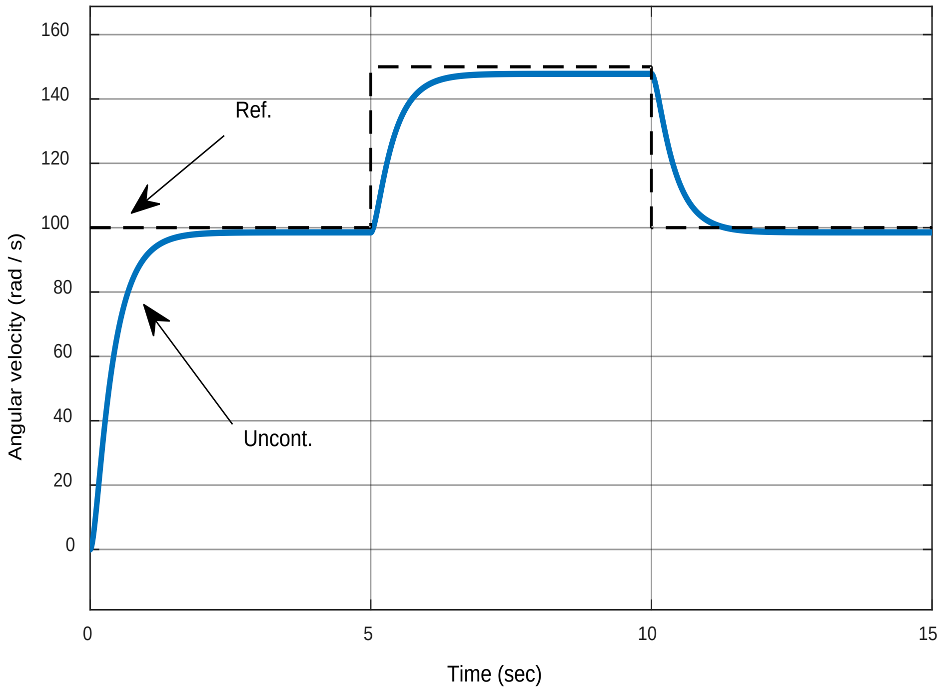

Figure 4. The DC motor speed without controller

According to Fig. 4, when the system is operated without the controller, the rotor angular velocity has not reached the given reference input values and permanent state error has occurred for each different speed references.

3. Controllers

3.1 PI Controller

PI controllers are often used in control applications due to their simple structures. In scientific studies, it is a very common control structure especially in the comparison of different control systems. In this study, was not given detailed information about the PI controller since the FL controller structure was examined. The Matlab/SIMULINK model of a simple PI controller structure is shown in Fig. 5.

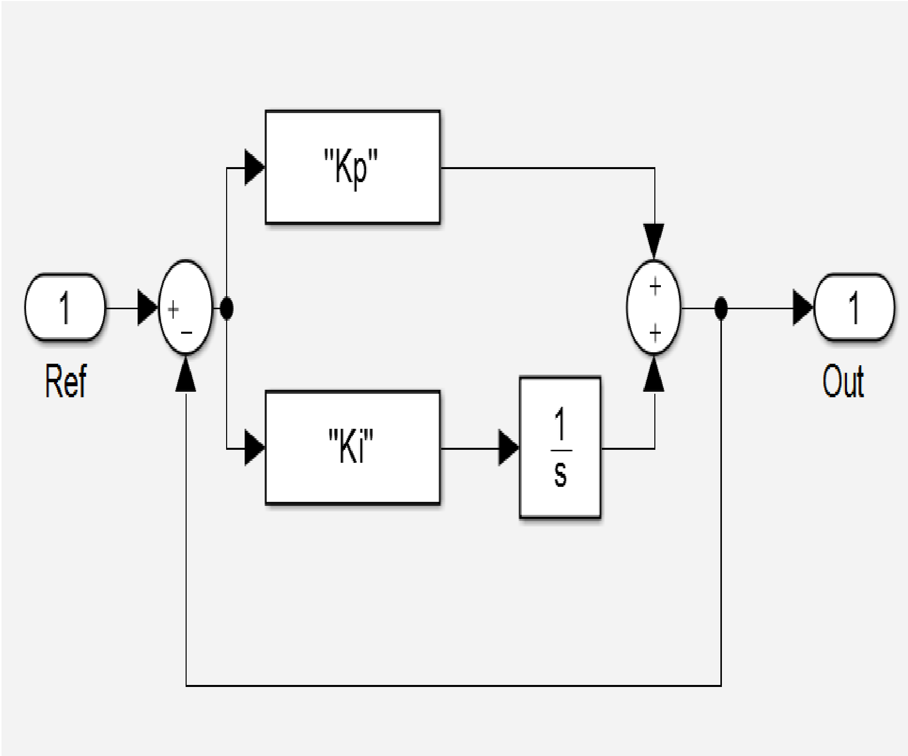

Figure 5. PI controller structure

Where Kp and Ki is proportional gain and integral gain, respectively. In this study, Kp = 1.983 and Ki = 1.969 are selected with Matlab/Tuner. PI controller for the control of DC motor was designed in Matlab/SIMULINK environment is shown in Fig. 6. Angular velocity of the rotor is shown in Fig. 7.

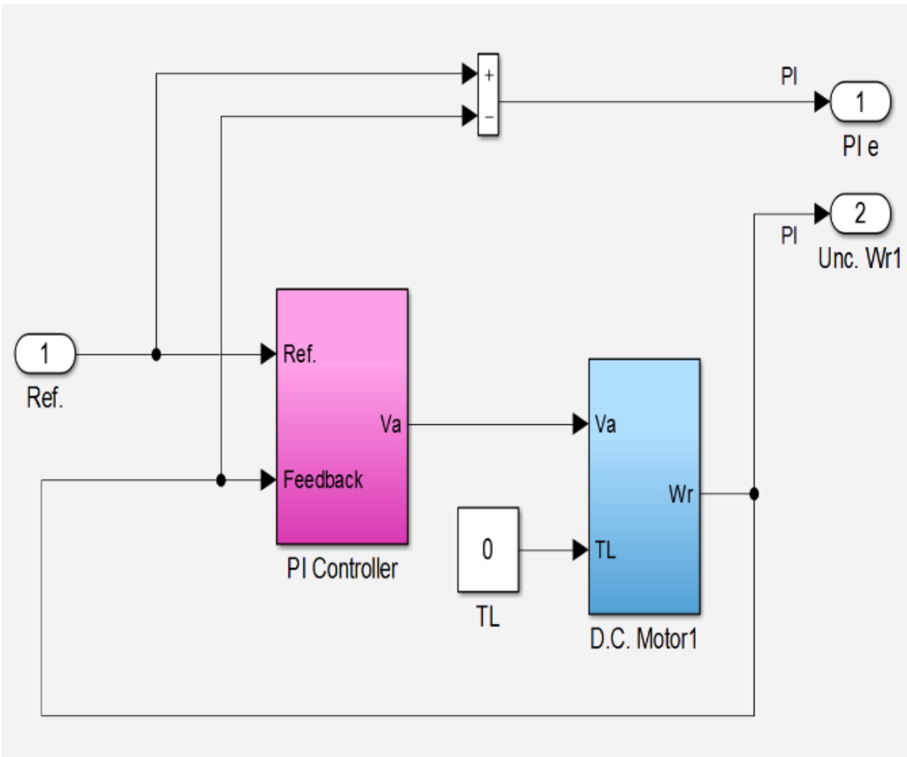

Figure 6. PI controller system

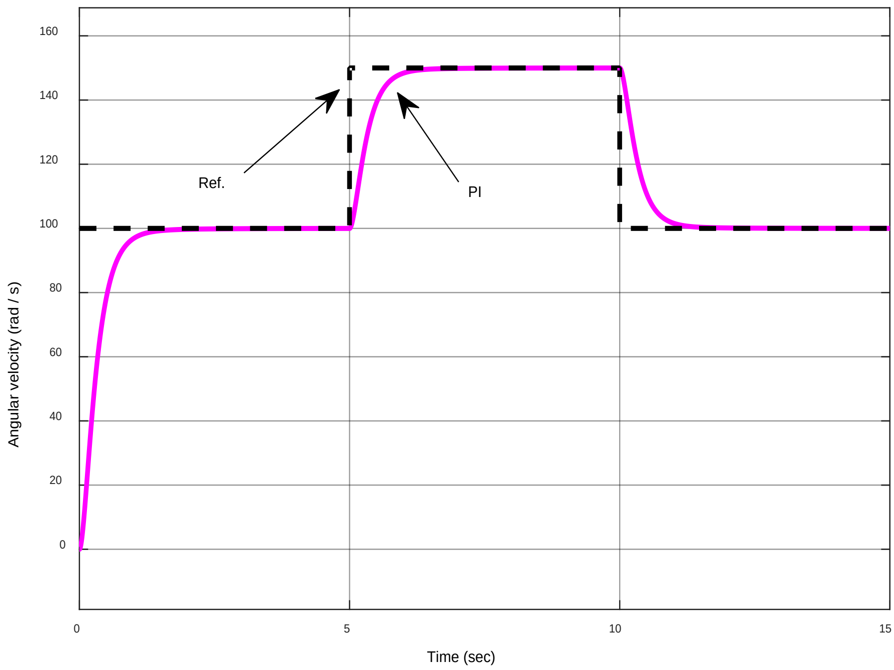

Figure 7. Angular velocity of the rotor with PI controller

3.2 Fuzzy Logic Controller

To design controller of a system, is necessary a mathematical model of that system. It is difficult to obtain mathematical models of nonlinear and uncertain systems. However, fuzzy control defines systems with complex mathematical models and numerical solutions in terms of linguistic variables. Fuzzy logic theory was first introduced by Zadeh (ZADEH, 1965). Later, in his other works about fuzzy logic, he explained that fuzzy logic can be applied to systems with uncertainty and detailed mathematical models (ALTAŞ, 1999). Zadeh (1965) has contributed greatly to the scientific world with a new control method for controlling complex systems.

Mamdani and his colleagues implemented the application for the first time of fuzzy logic theory to control systems (ALTAŞ, 1999). In this work, Matlab/SIMULINK - Fuzzy Logic Toolbox is used for fuzzy logic controller. In addition, Mamdani's fuzzy modeling is chosen for fuzzy modeling.

Additionally, Altaş et al., (2007) designed a direct fuzzy logic controller without using the Fuzzy Logic Toolbox in his published article in 2007 and implemented it to various systems (ALTAŞ, 2007; ALTAŞ, 2008).

The fuzzy logic controller consists of a number of subunits. These are called fuzzification, data base, rule base and defuzzification. The basic block diagram of the fuzzy logic controller is shown in Fig. 8.

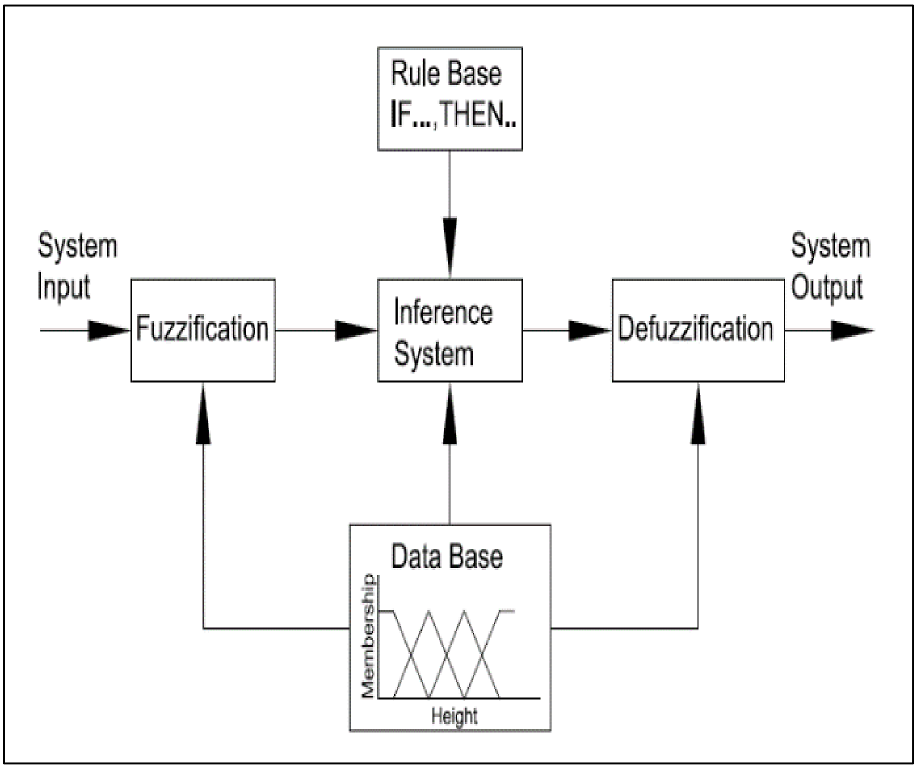

Figure 8. Blocks diagram of FLC structure.

In this study, a fuzzy logic controller with five membership functions was designed for PMDC motor control (MALLA, 2012). Although there are a large number of membership functions for fuzzy controllers, the triangle membership function was used for this study. The membership functions is shown in Fig. 9.

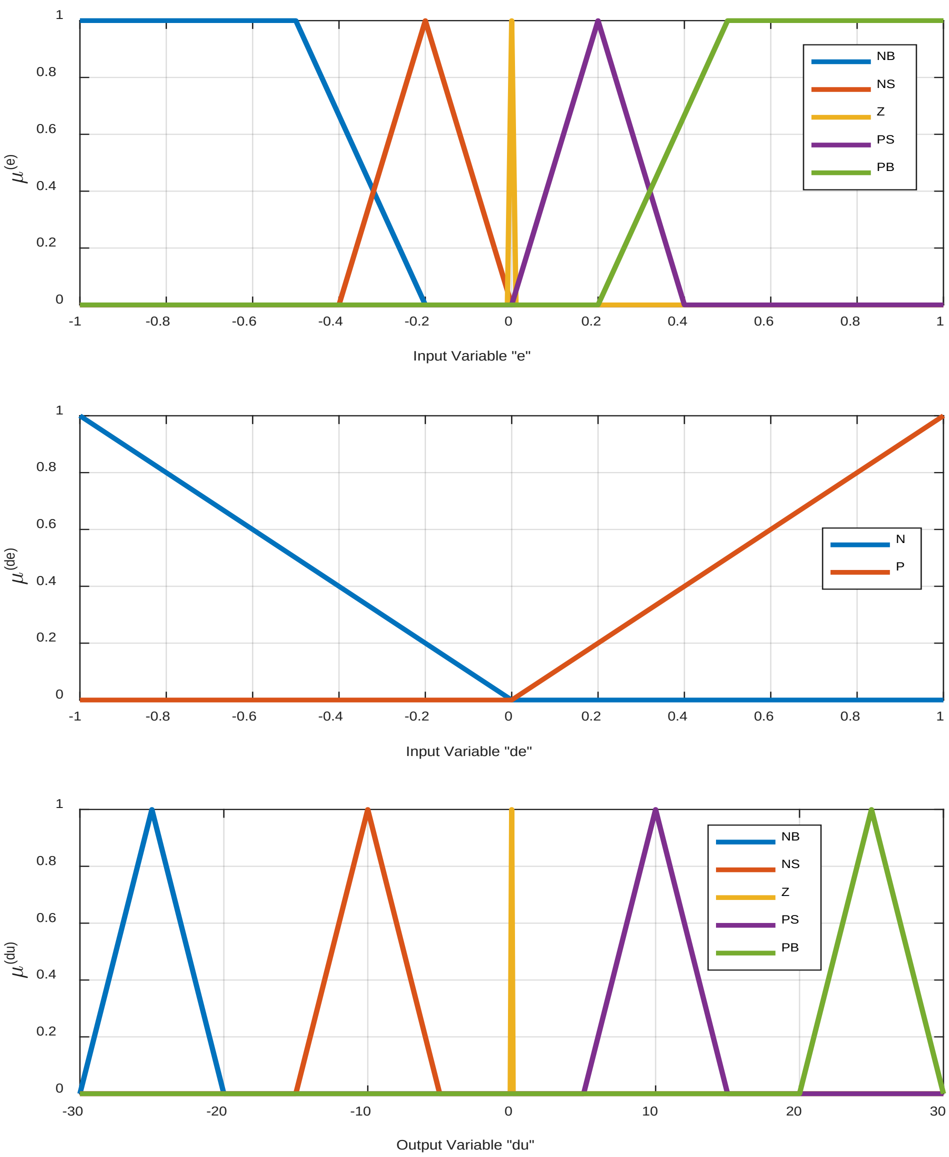

Figure 9. Membership functions of error, change of error and output

After the membership functions were determined, the rule base was created. The rule base for membership functions is given in Table 2. Where, NB: Negative Big, NS: Negative Small, Z: Zero, PS: Positive Small, PB: Positive Big.

du		e				
		NB	NS	Z	PS	PB
de	N			NS		
	P			PS		
	none	NB	NS	Z	PS	PB

Table 2. Rule Base

The system model that provides control of the dc motor with the fuzzy logic controller is shown in Fig. 10.

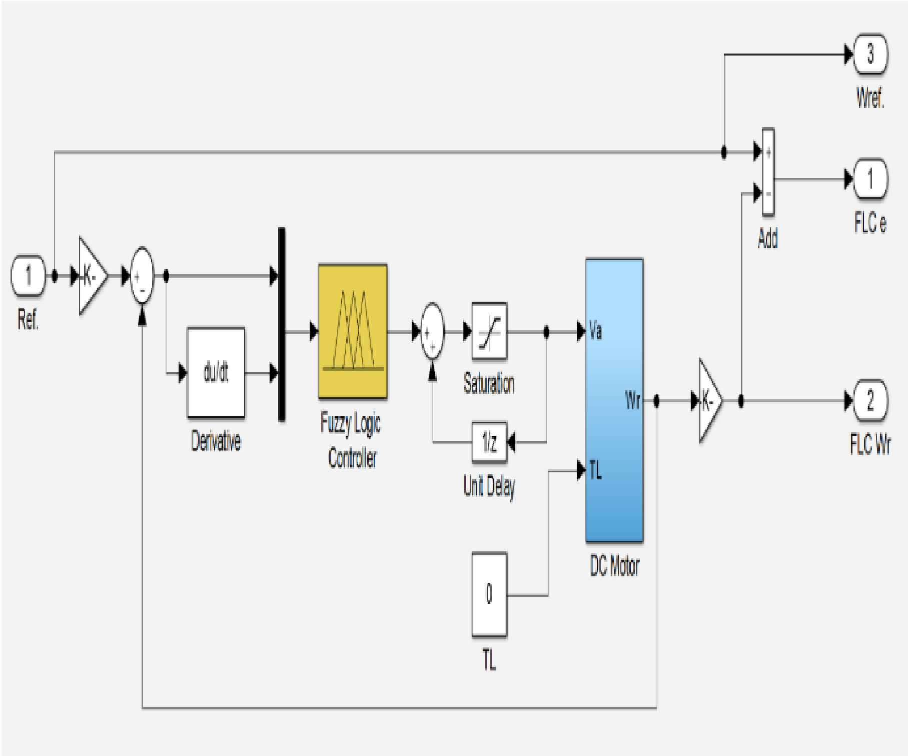

Figure 10. FL controller system

An anti-windup integrator was used at the output of the FL controller to prevent the steady state error (AÇIKGÖZ, ŞEKKELİ, 2013). The rotor angular velocity obtained using the FL controller is shown in Fig. 11.

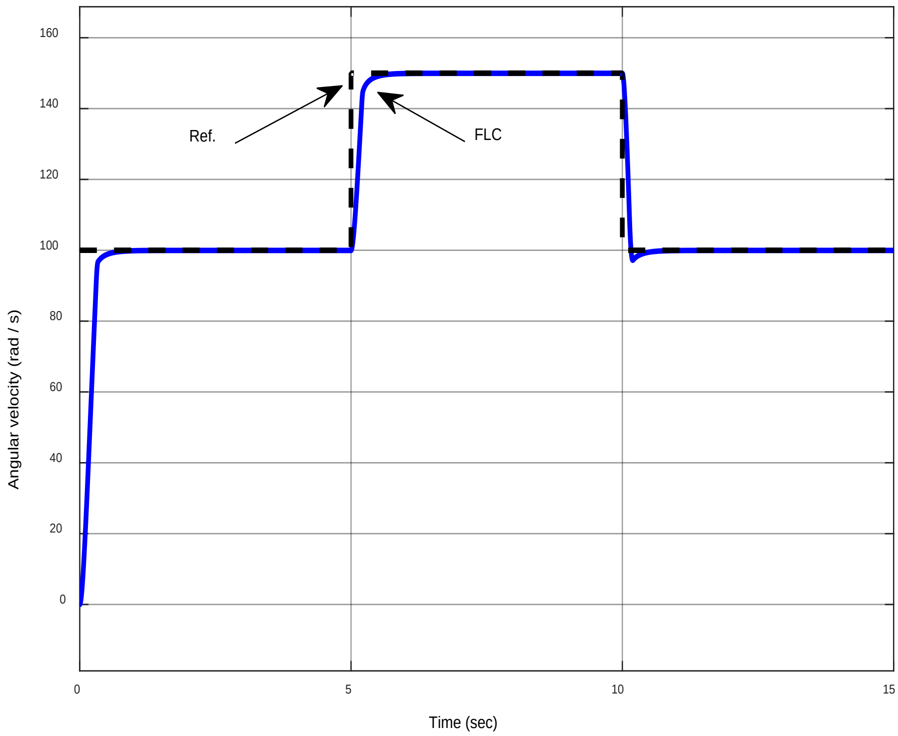

Figure 11. Angular velocity of the rotor with FL controller

4. *Results and discussion*

Firstly, simulation model was designed by using dynamic model of DC motor. Secondly, the speed performance analysis of the DC motor was performed with PI and FL controllers for various speed references. After these operations, the armature resistance of the DC motor was changed and the output was monitored in order to investigate the effect of different armature resistance values on the DC motor speed and controllers. To compare the data obtained, all systems were designed in a single simulation environment. The simulation model and system outputs is shown in Fig. 12, Fig. 13, respectively.

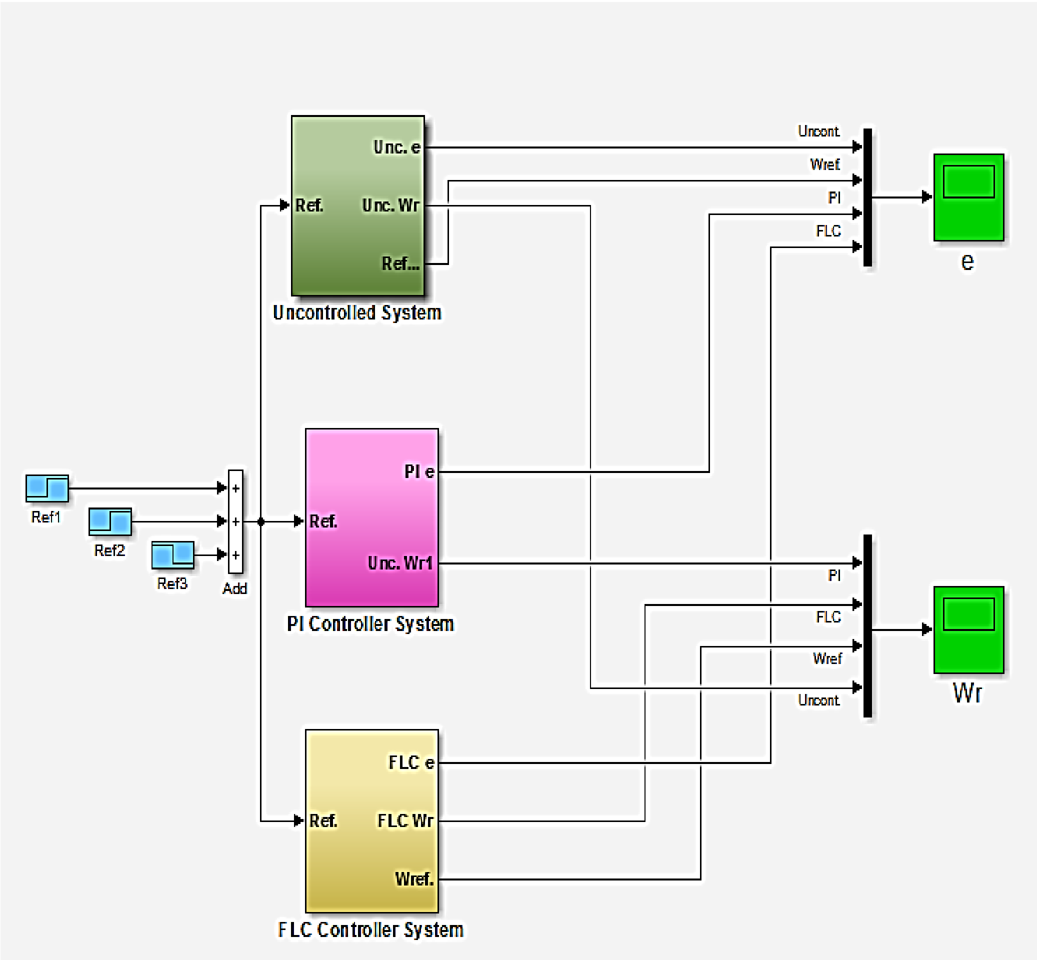

Figure 12. Simulation of all systems

As shown in Fig. 13, the best controller for variable speed references is the fuzzy logic controller. It is observed that the steady state error is zero for both controllers. However, the fuzzy logic controller has performed better than the PI controller in terms of rise time and settling time.

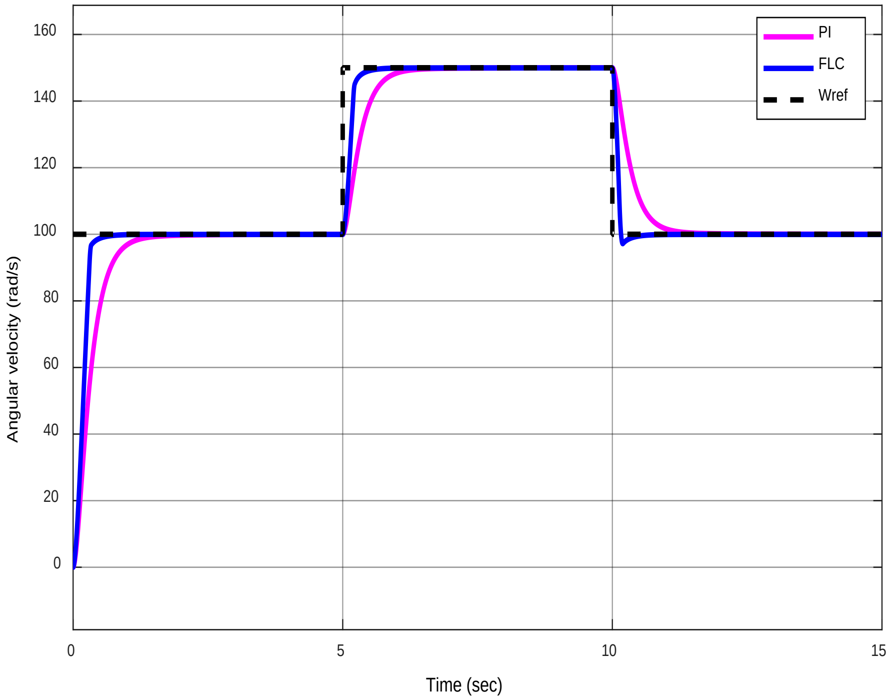

Figure 13. The angular velocity of all systems

The system outputs, when, the armature resistance increased is shown in Fig. 14. It was observed that the angular velocity of the DC motor without the controller is decreased when the armature resistance is increased. When the effect of this process on controller structures is examined, there is no effective change. The steady state error in both controllers is zero. However, increase of armature resistance was delayed rise time and settling time.

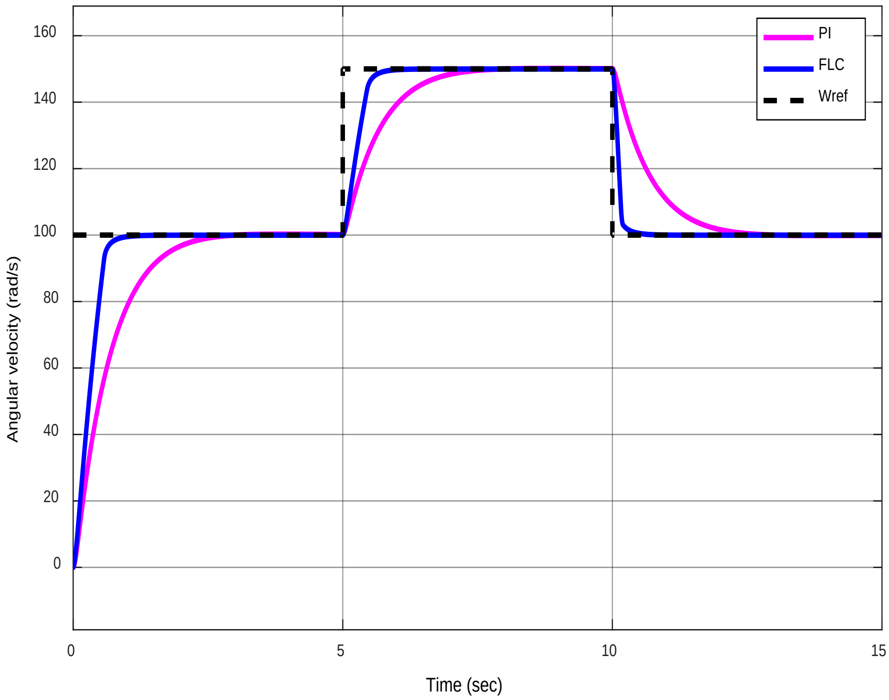

Figure 14. The angular velocity of all systems when $2*R_a$

The system outputs, when, the armature resistance decreased is shown in Fig. 15. It was observed that the angular velocity of the DC motor without the controller increased when the armature resistance was decreased. As shown in Fig. 15, when the effect of this process on controller structures was examined, it has shown that while the armature resistance decreases, both controllers follow the references speeds after a small overshoot.

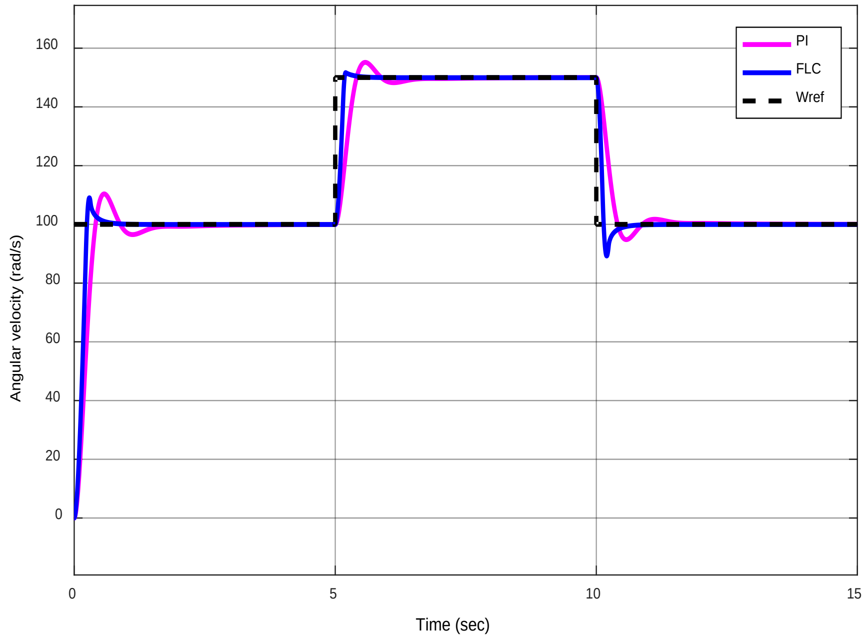

Figure 15. The angular velocity of all systems when $R_a/2$

When the DC motor is running, the resistance of the armature windings that became heated due to brush and commutator contact and friction increases by a certain amount. This heat is also related the environment temperature. Increasing the environment temperature increases the armature resistance by causing the armature windings to get warmer. As shown in Fig.14, the increase in armature resistance causes negative effects for all systems. It was observed that both controllers tracked the reference speeds with a delayed settling time. As shown in Fig.15, the decrease in armature resistance has caused the system an overshoot.

5. Conclusion

In this study, firstly, was designed a dynamic model of DC motor and modeled in Matlab/SIMULINK environment. The obtained model was run directly and the output was observed. Then, PI and FL controller structures were designed and performance analysis of the controllers were compared on the DC motor, respectively. The comparison process was performed with different speed references and different armature resistance values. According to the results on Table 3, the FL controller were provided better performance for both variable speed references and variable armature resistances than the PI controller.

System	***Ra = 3,54 Ω***		***Ra = (3,54*2) Ω***		***Ra=(3,54*0,5) Ω***	
	PI	***FLC***	***PI***	***FLC***	***PI***	***FLC***
Settling Time (s)	1.579	0.567	2.55	0.919	2.132	0.73
Rise Time (s)	0.698	0.302	1.442	0.546	0.353	0.22
Steady State Error (rad/s)	0	0	0	0	0	0
Overshoot (%)	0	0	0	0	7.9	5.2

Table 3. Output value of all systems

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