Kahramanmaras Sutcu Imam University
Journal of Engineering Sciences

Investigation of The Success of Particle Swarm Optimization Based PID, Classic PID and Fuzzy Type Inspection Methods in Speed Control of DC Motor

Doğru Akım Motorunun Hız Denetiminde Parçacık Sürü Optimizasyonu Tabanlı PID, Klasik PID ve Bulanık Tipi Denetim Yöntemlerinin Başarımlarının İncelenmesi

Mahmut Altun[1], *Yunus Çelik*[1] *and Mahit Güneş*[1*]

[1] Kahramanmaraş Sütçü İmam University, Department of Electrical-Electronics Engineering, Kahramanmaraş-Turkey

*Sorumlu Yazar / Corresponding Author: Mahit Güneş, mgunes@ksu.edu.tr

ABSTRACT

This paper presents a comparison of the success of Fuzzy Logic Control (FLC), Particle Swarm Optimization (PSO) based PID and classic PID over speed control of DC motors. Motors known as a component that convert electrical energy to mechanical energy are quite common in our devices. DC motors are one of the most used components of industry. DC motors have two important advantages as speed variation and torque. Generally, speed variation is performed by changing armature voltage. In this paper, speed control of a DC motor and mathematical model of DC motor were presented. The performances of the control methods used in this study in DC motor speed control have been examined and supported with graphs by testing under different inputs, noise and load at certain times. The performance measures of the controllers were evaluated taking into consideration the rise time, the settling time and the overshoot.

Keywords: Fuzzy Inspector, Particle Swarm Optimization, DC Motors

ÖZET

Bu çalışma Bulanık kontrol, Parçacık Sürü Optimizasyon tabanlı PID ve klasik PID kontrol yöntemlerinin DA motorların hız kontrolü üzerindeki başarımlarının karşılaştırılması çalışmalarını sunmaktadır. Motorlar elektrik enerjisini mekanik enerjiye çeviren elemanlar olarak bilinirler ve kullanıdığımız bir çok cihazda yaygın bir şekilde bulunurlar. DA motorları endüstride yaygın olarak kullanılan elemanlardır. DA motorların, hız değişimi ve tork olarak iki önemli parametresi mevcuttur. Genellikle hız değişimi armatür voltajına bağlıdır. Bu çalışmada DA motorun hız kontorlü üzerinde çalışmalar yapılmış, matematiksel modeli gösterilmiş. Bu çalışmada kullanılan denetim yöntemlerinin DA motor hız kontrolündeki başarımları belirli zamanlarda farklı girişler, gürültü ve yük altında test edilerek incelenmiş ve grafiklerle desteklenmiştir. Denetleyicilerin performans ölçümleri yükselme zamanı, yerleşme zamanı ve aşım dikkate alınarak değerlendirilmiştir.

Anahtar Kelimeler: Fuzzy Denetim, Parçacık Sürü Optimizasyonu, DC Motorlar

1. INTRODUCTION

DC motors are commonly used in every part of our lives so their control is quite important. DC motors are used in robots, home tools because of their trustable structure and low costs. These motors can be controlled by different traditional and modern control methods. PID control is one the methods for speed control of DC motors. Proportional (P) Integration (I) and Derivative (D) are control parameters for PID and their combination can be used in the control of DC motors as PI, PD, etc. But most of the cases determining these parameters takes long times (Yaras and friends., 2013). Different control methods are existing in the industry and correct implementation of these control methods can improve the performance and save energy. The aim of this work is to design a fuzzy controller and PID controller and compare the performances. PID parameters are determined by Particle Swarm Optimization method. Mostly DC motors are controlled for speed and positions and in this paper, speed control is worked. Control systems face some difficulties like instability, vibration, long settling time and overflow of reference point. Solving these problems can be possible with high accuracy modeling and high-performance control. Most of the systems in the industry are not linear that's why it is necessary to model these systems as possible as correct (Kushwah and friends., 2013; Yuksel, 2009).

Mostly modeling systems with a hundred accuracy is not possible. Moreover, PID control of non-linear systems is a difficult task. This is the reason why we need modern control systems that minimize noises. Top modern control methods are expert systems, Fuzzy control, and Artificial Neural Networks. These three modern control systems are promising and popular nowadays. Fuzzy can model non-linear systems contrary to traditional control systems. Fuzzy presents easier, faster and more trustable solutions and has more advantage compared to traditional control systems. Fuzzy can be applied most of the control systems. Most commonly it is taking the place of PID day by day. PID requires a mathematical model of the system. Fuzzy is an alternative method that doesn't need mathematical model of the systems and can be used with easy if-then rules. Fuzzy control methods have wider operations and can work with different types of noise signals. Today's control systems are getting complicated day by day and these systems need modern control methods instead of traditional control methods. In this paper, PSO based PID tuning, FLC and classic PID control methods are examined with step function and variable inputs. Performance comparison of control methods are supported with graphics.

2. DIRECT CURRENT MOTOR MODEL

In this paper, DC motor parameters are predetermined from Kushwah paper. Speed control of DC motors can be done by using different control methods. Speed control can be adjusted with wide range according to needs. In industry, speed control and sensitive position controls are quite common. PID control is one of the methods applied in this paper and it requires mathematical model of the system. That is why physical and mathematical model of DC motors are presented (Kuo, 1999, Fallahi and friends., 2009, Yuksel, 2009).

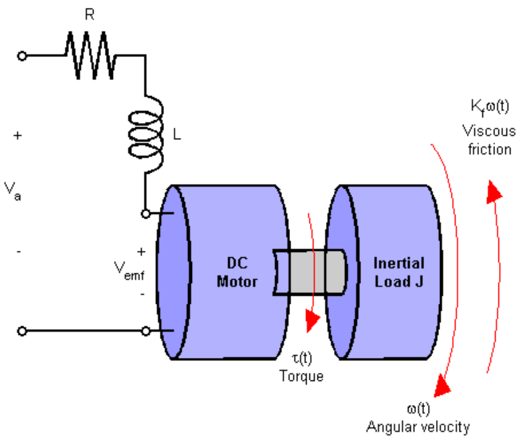

Figure 1. Physical Model of DC Motor

Mathematical equations are derived from physical model with electrical principles. Armature voltage is calculated from Kirchoff rules in equation 1 below;

$$V_a(t) = R_a I_a(t) + L_a \frac{dI_a(t)}{dt} + E_b(t) \tag{1}$$

$$E_b(t) = K_b\,\omega(t) \tag{2}$$

Torque moments are calculated in equation 3 and 4;

$$T_m(t) = K_t I_a(t) \tag{3}$$

$$T_m(t) = J_m \frac{d\omega(t)}{dt} + B_m\omega(t) + T_{yük} \tag{4}$$

Derivative of Θ position gives angular velocity ω in equation 5;

$$\omega(t) = \frac{d\theta(t)}{dt} \tag{5}$$

$$V_a(t) = R_a I_a(t) + L_a \frac{dI_a(t)}{dt} + K_b\,\omega(t) \tag{6}$$

$$K_t I_a(s) = sJ_m\omega(s) + B_m\omega(s) + T_{yük} \tag{7}$$

$$I_a(s) = \frac{sJ_m\omega(s)+B_m\omega(s)+T_{yük}}{K_t} \tag{8}$$

$$V_a(s) = \omega(s)\frac{\left[s^2 L_a J_m(s) + s\left(R_a J_m(s) + L_\alpha B_m\right) + \left(R_a B_m + K_b K_t\right)\right]}{K_t} \quad (9)$$

In literature, some works accept B_m as a zero and equations below shows a transfer function;

$$\frac{\omega(s)}{V_a(s)} = \frac{K_T}{\left[s^2 L_a J_m(s) + s\left(R_a J_m(s) + L_\alpha B_m\right) + \left(R_a B_m + K_b K_t\right)\right]} \quad (10)$$

When we move the equation from time domain to s domain;

$$\omega(s) = s\theta(s) \quad (12)$$

$$\frac{\theta(s)}{V_a(s)} = \frac{K_T}{\left[s^3 L_a J_m(s) + s^2\left(R_a J_m(s) + L_\alpha B_m\right) + s\left(R_a B_m + K_b K_t\right)\right]} \quad (13)$$

Required motor parameters can be written and create the transfer function of the system (Fallahi and friends., 2009).

Table 1. DC Motor Parameters

Parameter	Symbol	Unit	Value
Armature Voltage	V	Volt	200V
Armature Resistor	Ra	Ohm	0.5 ohm
Armature Inductance	La	Henry	0.02
Tork constant	Kt	N.m/A	0.5
Rotor inertia	Jm	$Kg.m^2$	0.1
Electromotive Force	Kb	V.s/rad	1.25
Viscous Friction	Bm	N.m.s/rad	0.008

Where Ia represents armature current, ω represents angular velocity, θ represents angular Position and Tm represents motor torque. DC motor parameters are taken from Kushwah paper;

A DC motor is modeled in the Simulink environment with parameters and mathematical equations.

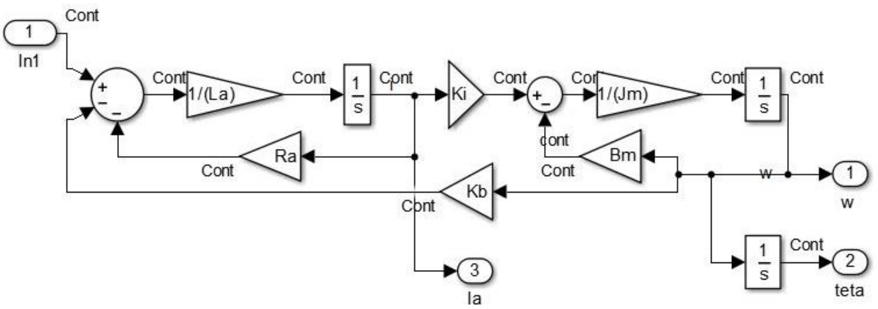

Figure 2. DC Motor Model

3. METHODS

3.1 FUZZY CONTROL

Fuzzy systems are rule-based systems and most important part is if-then rules. A fuzzy if-then expression was characterized by a continuous membership function. After defining the fuzzy system and membership functions, the rules must be defined so that each component of the control variables is taken. These rules associate the input variables with the output variables using if-then expressions to decide. For example, if the speed of the car is high, then limit gas amount. If the pressure is high, give more volume. In order to define Fuzzy membership functions, programmers have come up with a number of different ways with the help of their inferences and experiences. The stages of FLC can be handled in four basic chapters as fuzzification, inference, rule base and de-fuzzification (Sit and friends.,2016, Ekren,2009, Gani and friends.,2016).

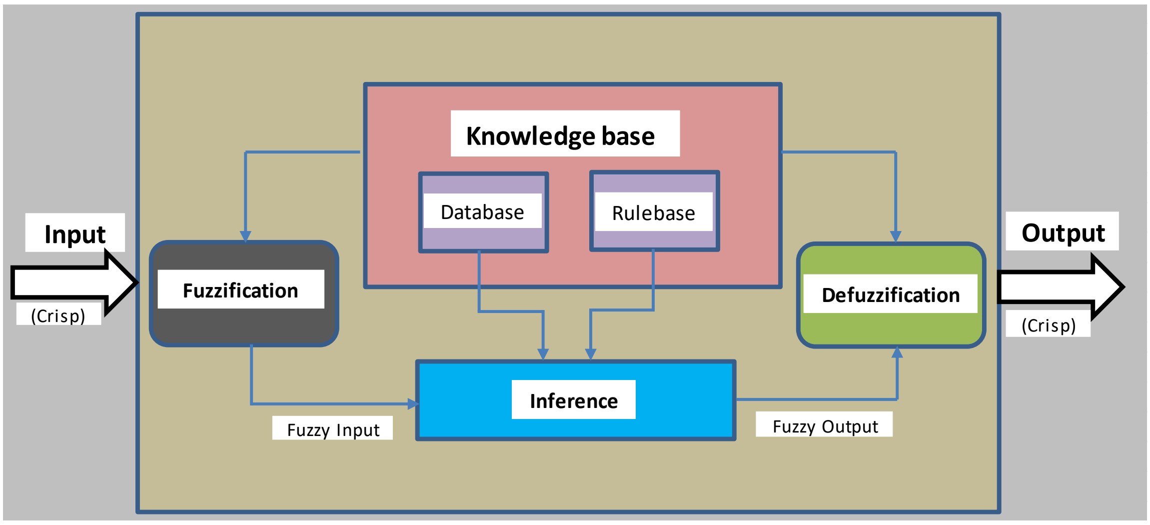

Figure 3. Fuzzy Control Block Diagram

The fuzzification transforms the input information from the system into linguistic terms. The fuzzy inference unit generates fuzzy results by applying the fuzzy values coming from the fuzzification phase to the rules base. In order to obtain a sharp value at the outset, the de-fuzzification phase works and the sharp output is generated. The most widely used method in fuzzy inference methods and the method used in this study is the Mamdani method (Sit and friends., 2016, Ekren,2009, Gani and friends.,2017, Ozcalik and friends.,2014).

Figure 4 and Figure 5 show member functions for e and de. As it can be seen clearly from figure 4, the triangle is crisper around 0 points then -0.4 and 0.4. In fuzzy systems, expert opinion is quite important. An expert person can determine the range of membership functions or type of member function by trial and error methods to get the best output. This logic is the same for de in figure 5.

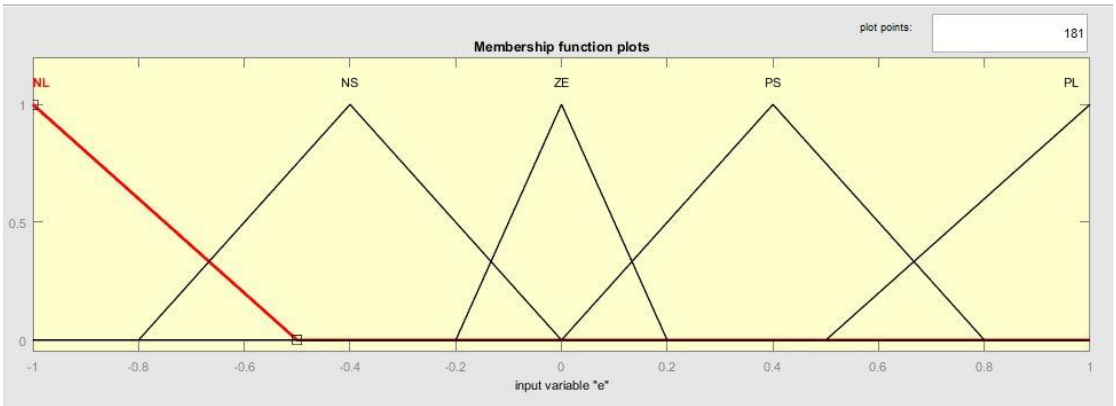

Figure 4. Defined Membership Function for e

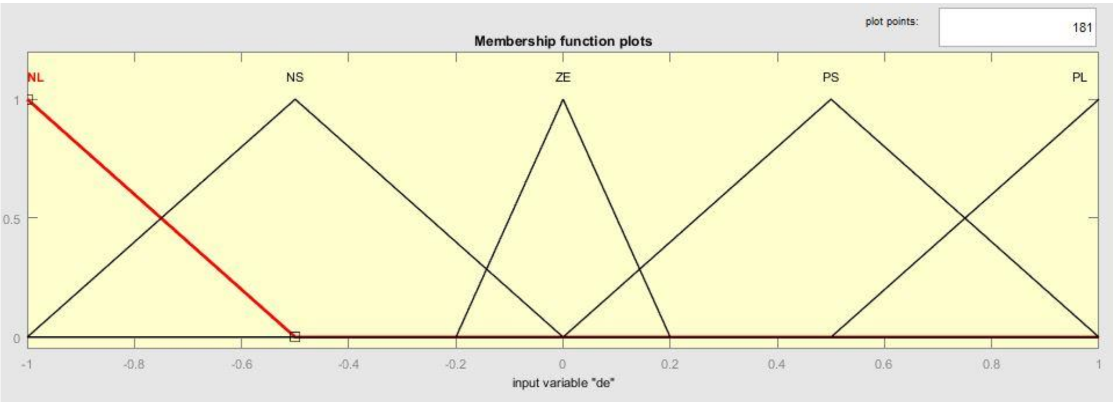

Figure 5. Defined Membership Function for de

The modeling of the system has been done with modern control method FLC and PSO. The fuzzy model consists of a combination of a FLC and a DC motor model. Inside the FLC the rule tables and membership functions are embedded. Membership functions embedded in the FLC. Membership functions used in this study are triangular and trapezoid membership functions. Control can be made more successful by developing the rule table and membership functions. Trapezoid Membership Function is used for negative big and positive big values. For other values, Triangle Membership Function is used. Figure 6 represents output variable u as a membership function.

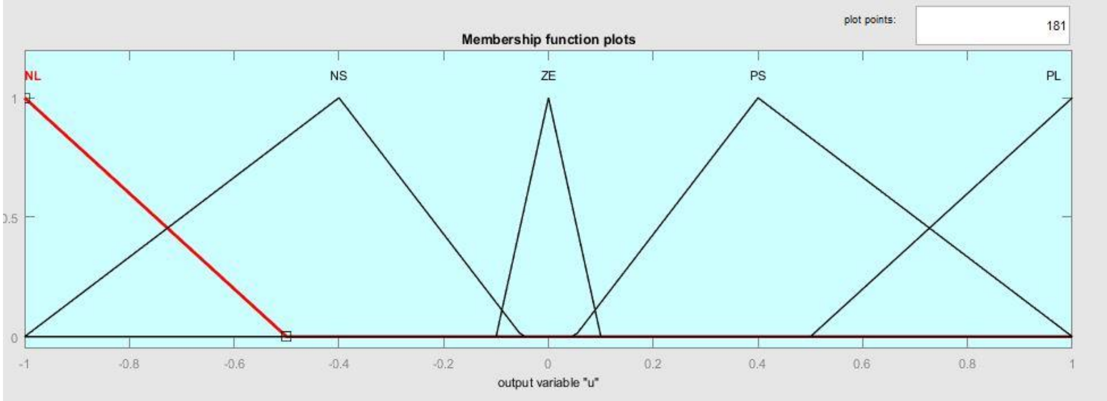

Figure 6. Defined Membership Function for u

Table 2. Fuzzy Rule Table

Δe \ e	NL	NS	ZE	PS	PL
NL	NL	NL	NL	NS	ZE
NS	NL	NL	NS	ZE	PS
ZE	NL	NS	ZE	PS	PL
PS	NS	ZE	PS	PL	PL
PL	ZE	PS	PL	PL	PL

Where e represents error and Δe represent changes in error. There are two types of gain block in the model. Blue ones are ordinary gains. Green ones are used to scaling the value. Gain1 and Gain5 are used to convert the signal from radian/second to revolution per minute. This conversion is made by multiplying radian/second with 0.104 at Gain5. To get radian/second back, Gain1 is multiplied by revolution per minute. There are three scale blocks in the output of e, de and FLC. The usage purpose of the scale is to hold control signal in a certain range.

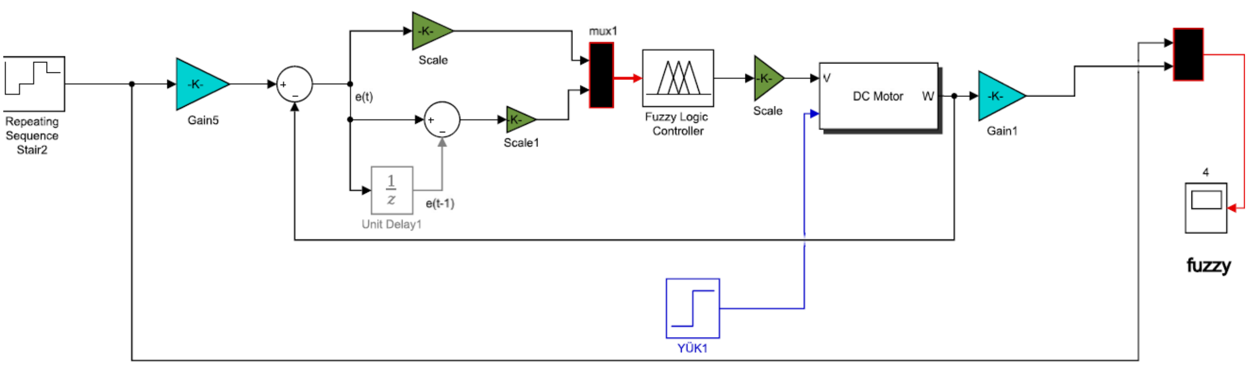

Figure 7. Fuzzy Control System Model

3.2 PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) is a population-based stochastic optimization technique developed by inspiration of the behavior of birds. Mostly, this method used in the control of nonlinear systems. It gives successful results for multi-variable systems. PSO is started with a group of random solutions (particle swarms) and with the help of update, it aims to find the most appropriate solution. In each iteration, the particle positions are updated to the two best particles. First one is the particle that has the best fitness value among the same numbered particles used so far. This particle is called local best 'pbest' and must be stored in memory. The other is the particle that provides the best fitness value that is obtained among all the particles so far in the population. This particle is global best and is indicated by 'gbest' (Kaushal and friends., 2014, Berber and friends.,2016, Ali,2015).

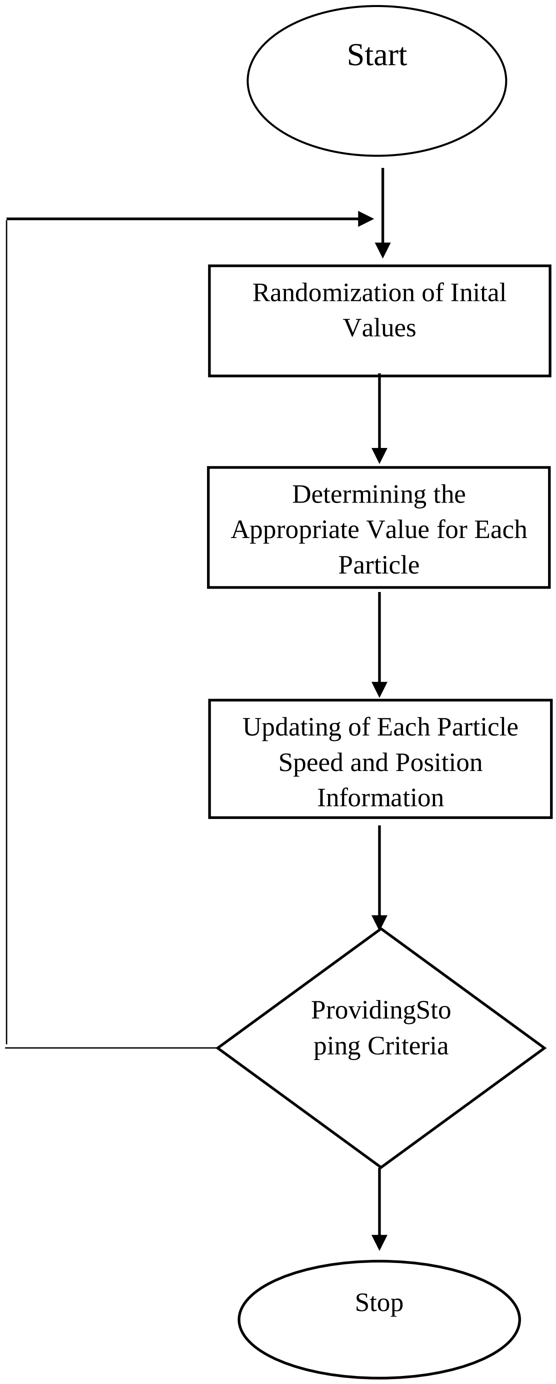

Figure 8. Particle Swarm Optimization Block Diagram

Table 3 presents Kp, Kd, and N values for self-tuning and PSO based tuning. Values are not similar and results too.

According to below algorithm in figure 9, PSO based PID parameters are calculated. Below table shows PID parameters for automatic tuning and PSO. Equation shows the calculation of velocity in iteration.

$$V_i^{(k+1)} = V_i^{(k)} + c_1 * r_1 * (P_{i,best}^{(k)} - s_i^{(k)}) + c_2 * r_2 * (g_{best}^{(k)} - s_i^{(k)}) \quad (14)$$

Where c1 and c2 are learning factors, r1 and r2 are random variables between 0 and 1 (Kaushal and friends., 2014). Pbest i is individual local best and gbest is global best solution. Vi is velocity of particle, Si is position of particle, i is particle number and k is iteration number (Ali, 2015, Rahmani and friends., 2012).

Table 3. PID&PSO-PID Parameter Values

Parameters	PID Tuning Tool	PSO Tuning
Kp	0.0268813131153353	0.09
Ki	0.331284104512576	1.3
Kd	0.00054049478322019	0.004
N	2792.87195182912	100

Where N is iteration number and chosen 100 for PSO algorithm. Figure 9 shows PSO based PID control system. The difference between PID and PSO-PID is the Kp,Ki,Kd values which are indicated in Table 3. These values are embedded to PID control block so the system model is the same but PID parameters are different. These new parameters give better results than classic PID tuning methods. In case of changing in the model, the result may not be as good as old model. So this PSO parameters are not adaptive but give better result for current model. It is neccesary to calculate new PSO PID parameters for different models.

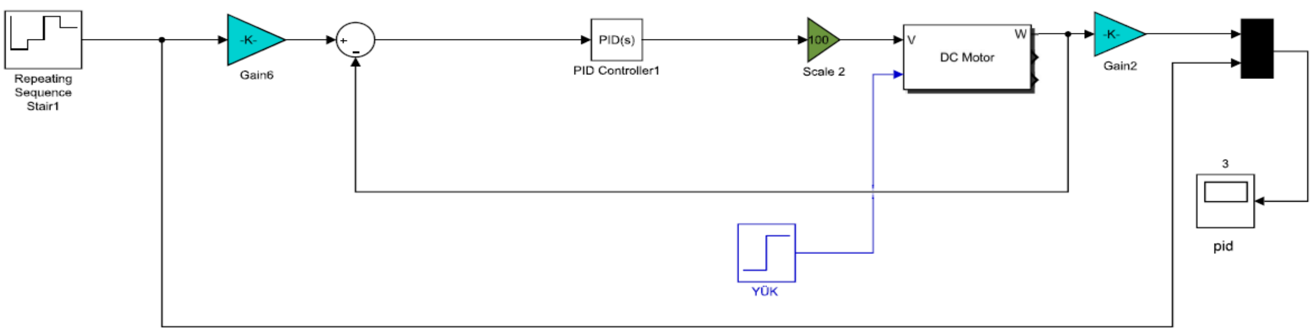

Figure 9. PSO-PID and PID Control System Model

4. RESULTS

Fuzzy, PID and PSO based PID tuning results are exhibited respectively in Figure 10, 11,12.

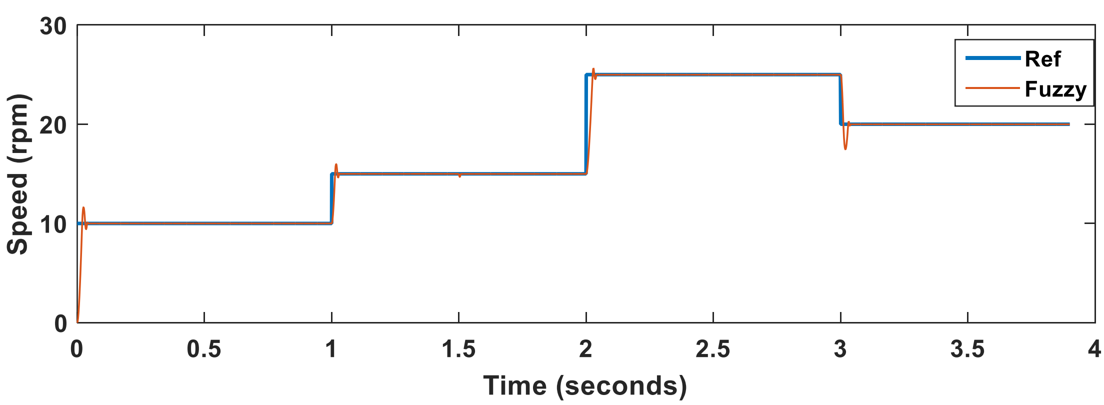

Figure 10. Fuzzy Control Success under Repeating Sequence Stair Input and Load

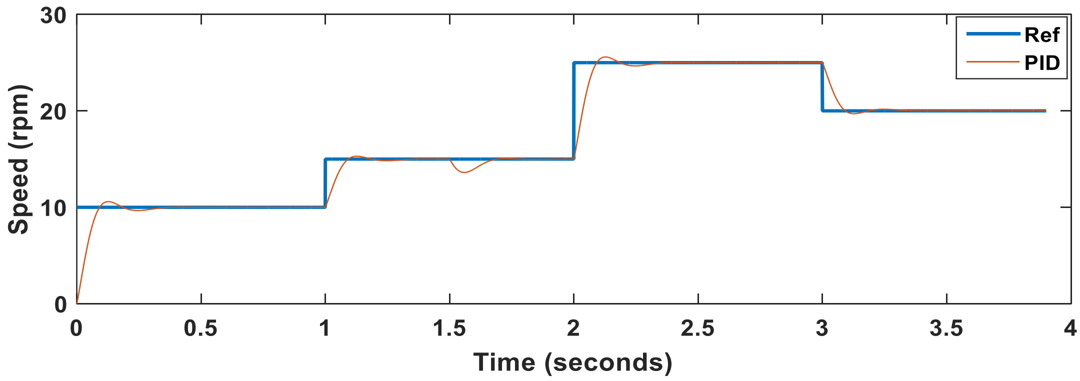

Figure 11. PID Control Success under Repeating Sequence Stair Input and Load

PID self-tuning follow the reference after a long settling time which is quite small in fuzzy control. In each sequence, with the help of control, system follows the reference input. According to control method, settling time, overshoot etc. parameters differ from each other. Figure 13 and 14 shows every control techniques in one graphic, fuzzy has the best settling time over PID and PSO-PID.

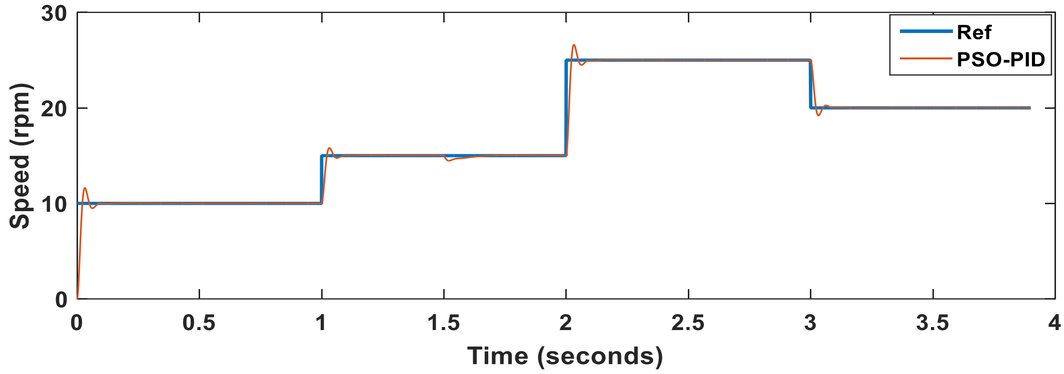

Figure 12. PSO-PID Control Success under Repeating Sequence Stair Input and Load

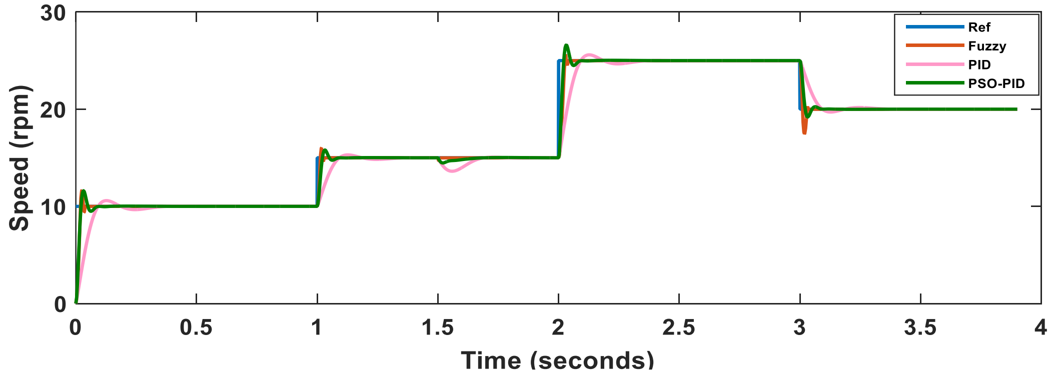

Figure 13. Fuzzy & PID & PSO-PID Control Success

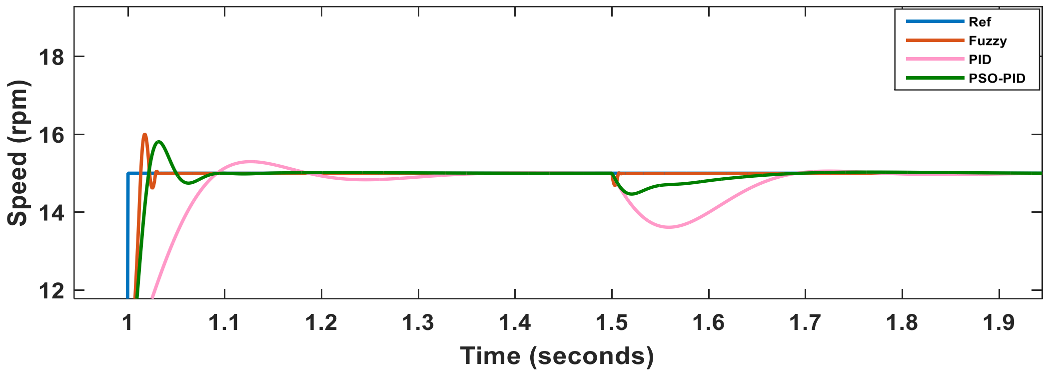

Figure 14. Fuzzy & PID & PSO-PID Control Success

5. CONCLUSION

This section presents the simulation results for three of the control techniques which are Fuzzy, proportional–integral–derivative (PID) and PSO based PID (PSO-PID). Also, comparison of these control mechanisms exists in terms of applied variable reference speed and under load condition. When a repeating sequence stair input is applied to the system, the speed levels are assigned 10 rpm initially, 15 rpm, 25 rpm and 20 rpm with 1-second intervals. At the same time, a load of 0.5 N.m is included as a disturbance at 1.5th second. Under these effects, the DC motor is controlled separately by PID, Fuzzy, PSO-PID techniques and the actual output is reached by each control mechanism. The performance of these controls applied to the DC motor was compared and their superiority and weaknesses were analyzed. Also, the time response performances of the system are presented in Table 4.

Table 4. The Time Response Performance of Control Techniques over DC Motor System

Performance Term	Fuzzy	PID	PSO-PID
Rise Time (sec)	0.019	0.092	0.021
Overshoot (%)	16.4	6	16.2
Settling Time (sec)	0.043	0.3	0.12
Peak Time (sec)	0.025	0.13	0.032

PSO-PID control technique has provided remarkable results according to PID in terms of rising time and settling time as seen in table 4. However, PID comes out with less overshoot than PID-PSO such as a %10 difference. Therefore, it can be determined PID is more suitable technique than PSO-PID and Fuzzy for any system that requires less overshoot. In contrast, PID fails by rising time and settling time when compared to PSO-PID. If a system requires quick response to reach the reference speed, PSO-PID proves to be more successful and stable. Additionally, PSO-PID managed the load condition at 1.5. second as well and tolerated the effects of a load more effective than PID. Also, a Fuzzy technique has been considerably successful under the load condition.

6. REFERENCES

Kaushal, A., Thakur, N., Nagaria, D. (2014). Comparison of Speed Control of DC Motor Using Fuzzy- PID and PSO-PID Technique. *International Journal of Information & Computation Technology*. ISSN 0974-2239 Volume 4, Number 6 (2014), pp. 553-558.

Ghareaghaji, A. (2015). A Comparison between Fuzzy-PSO Controller and PID-PSO Controller for Controlling a DC Motor. *Bulletin of Electrical Engineering and Informatics* Vol. 4, No. 2, June 2015, pp. 130~135 ISSN: 2089-319.

Kuo, Benjamin C. (1999). Otomatik kontrol Sistemleri, 7. Baskı, *Literatür Yayıncılık*, İstanbul.

Gani, A., Keçecioğlu, OF., Açıkgöz, H., Yıldız, C., Şekkeli, M. (2016). Simulation Study on Power Factor Correction Controlling Excitation Current of Synchronous Motor with Fuzzy Logic Controller, *International Journal of Intelligent Systems and Applications in Engineering*, 4(1) pp. 229–233.

Gani, A., Kilic, E., Kececioglu, OF., Acikgoz, H., Tekin, M., Sekkeli, M. (2017). A Simulation Study on Controlling Excitation Current of Synchronous Motor and Reactive Power Compensation via PSO Based PID and PID Controllers. *Symposium on Innovations in Intelligent Systems and Applications.*

İ. Yüksel. (2009). Otomatik Kontrol Sistem Dinamiği ve Denetim Sistemleri, Matlab ile Genişletilmiş 6. Baskı, *Nobel Yayın Dağıtım,* Ankara.

Kushwah, R., Wadhwani, S. (2013). Speed Control of Separately Excited DC Motor Using Fuzzy Logic Controller, *International Journal of Engineering Trends and Technology (IJETT)* - Volume4 Issue6.

M, Fallahi., S, Azadi. (2009). Fuzzy PID Sliding Mode Controller Design for the Position Control of a DC Motor, *International Conference on Education Technology and Computer*, 2009, s. 73-77.

O, Ekren. (2009). Fuzzy logic control of the compressor speed and electronic expansion valve in a chiller. *Dokuz Eylül University, Institute of Science, Doctoral Thesis*, İzmir, Turkey.

Ozcalik, HR., Gani, A., Kilic, E., Kececioglu, OF. (2014). DC Servo Motor Speed Control in Nonlinear Load by Using Different Fuzzy Membership Functions. *Academic Platform Journal of Engineering and Science*, 2(3), 1-8

Berber, O., Ateş, M., Alhasan H., Gunes, M. (2016). Parçacık Sürü Optimizasyonu ve PID ile Mobil Robotun Optimum Yörünge Kontrolü. *Kahramanmaras Sutcu Imam University Journal of Engineering Sciences*.

Rahmani, R., Mahmodian, M., Mekhilef, S., Shojaei, AA. (2012). Fuzzy Logic Controller Optimized by Particle Swarm Optimization for DC Motor Speed Control. *2012 IEEE Student Conference on Research and Development.*

Sit, S., Ozcalik, H., Kilic, E., Altun, M. (2016). Comparative Study of the Success of PI and PI-Fuzzy Controller for Induction Motor Drive using SVPWM Method. *International Journal of Engineering Science Invention* ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726.

Sit, S., Ozcalik, H., Kilic, E., Doğmuş, O., Altun, M. (2016). Asenkron Motorların Online Adaptif Sinirsel-Bulanık Denetim (ANFIS) Sistemine Dayalı Hız Denetim Performansının İncelenmesi. *Çukurova Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi*, 31(ÖS 2), ss. ÖS 33-ÖS 42, Ekim 2016.

Yaraş, İ., Hüseyinov, R., Namazov, M., Çelikkale, İ., Şeker, M. (2013). Fuzzy Control and Sliding Mode Fuzzy Control of DC Motor, *Journal of Engineering and Natural Sciences Mühendislik ve Fen Bilimleri Dergisi.*