Compartive Study of Optimal Self Tuning Fuzzy Pid, Fuzzy and Pid Controller for Speed Control of BLDC Motor

Hameed Ali Mohammed
Control and Computer Eng. Dept., College of Petroleum & Minerals Engineering, Tikrit University, Iraq.

الخلاصة

في هذا البحث تمت دراسة ومقارنة أنواع مختلفة من تقنيات السيطرة للسيطرة على سرعة محرك التيار المستمر. المسيطرات التي تم تصميمها هي عبارة عن مسيطر تقليدي ونوعين من المسيطرات الذكية. المسيطر الأول الذي تم تصميمه هو المسيطر التناسبي التكاملي. المسيطر الثاني هو المسيطر الضبابي حيث يعطي نظام سيطرة مستقر إذ يتكون من ادخالين وإخراج واحد وان دوال العضوية لكل من الإدخال والإخراج هي سبع دوال من نوع المثلث. أخيرا، تم تصميم الضبابي الأمثل ذاتي الضبط لبارامترات المسيطر التناسبي التكاملي التفاضلي للسيطرة على سرعة محرك التيار المستمر حيث يقوم بتضبيط قيم الكسب (KP،KI& KD). الإخراج لنظام السيطرة الضبابي يمثل بارامترات المسيطر التناسبي التكاملي التفاضلي. تمت مقارنة استجابات السرعة لمحرك التيار المستمر وللمسيطرات الثلاثة. نتائج المحاكاة تبين ان المسيطر الذي تم اقتراحه يعطي استجابة أفضل مقارنة بالمسيطرات الأخرى. كذلك فان للمسيطر المقترح القدرة للوصول إلى السرعة الهدف والمتانة في التغلب اضطرابات العزم الخارجي.

Abstract

In this research we presents a compared to different study of speed control system technique for a BLDC motor. The Control modules that have been designed is one of several types of traditional control and adaptive. First, the controller is designed according to conventional PID controller. Secondly, Fuzzy control systems that are basically robust have been designed with seven membership functions, two inputs and one output. Finally, the optimal fuzzy self-tuning PID controller (STFPID) is then designed with automatically tuning PID controller parameters (KP,KI& KD), were the fuzzy logic technique is used to adjust all gain value of PID controller. The gain value of PID are the output signal of the fuzzy controller. The performances of the speed response with three controllers are compared. The results of simulation shown that the designed STFPID controller Achieve best performance of the BLDC motor, a perfect tracking of speed give low rise time , less maximum overshoot ,settling time , less steady state error and give best response versus PID and Fuzzy Logic technique. The ability technique to achieving the target speed and robustness to eliminate the load disturbances are one of the important aspects of this study.

Keywords

BLDC Motor Fuzzy logic controller, STF PID controller, speed control of BLDC.

1. Introduction

DC motors are widely used in many applications, the BLDC motor speed can be controlled by various control system technique [1]. We can control speed of DC motor by using many techniques such as modeling, simulation and parameters tuning etc. The conventional (PID_ controller) is the most commonly used in process industries. About 90% of industrial system use PID controllers. Intelligent control is an interdisciplinary idea combining computer science, control theory, operations research and artificial intelligent techniques, aiming to achieve optimal control [2]. It is well known that the adaptive systems, which can provide such human experience such as the field of knowledge, uncertain argument, an adaptive to a different environment noisy and time, it is important in solving the problems of intelligent control process. The BLDC motor speed can be adjusted to a large values as to provide high performance [3] .The technique that are aim to adjust the speed response of BLDC motor is one combination between conventional & intelligent technique types, the techniques can be: Fuzzy Logic, the combination between them (ANFIS controller) or self-tuning fuzzy PID controller. The (STFPID) controller is combination of pure PID controller and fuzzy inference system. BLDC motors are suitable for large- scale control of speed and there's a lot of drives, adjustable speed .We can controlled the speed of DC motors manually or automatically by using many controllers type [4].

2. Problem Formulation

The target of this research is to tune of the PID parameters by using various intelligent methods for concentration control of dc motor speed and comparative the different for three controllers [5]. The BLDC motors are the best for wide scales speed and therefore used in many drives adjustable [6]. To make BLDC motor model similar to PID transfer function must converted it to a single transfer function as shown in equation.1[7]. Fig.(1). shows the BLDC motor mathematical model[8].
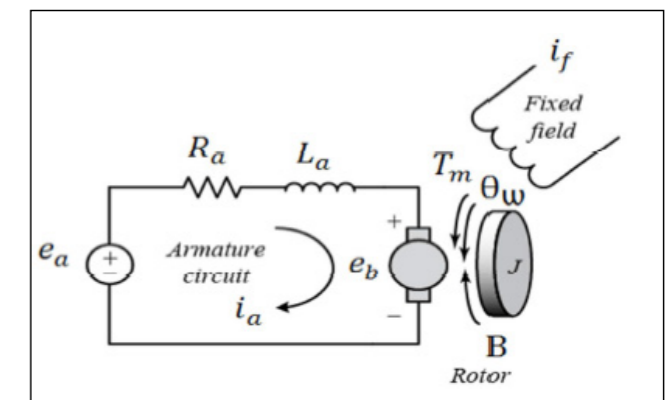

Fig. (1): Model of BLDC Motor

$$\frac{\omega(s)}{v(s)} = \frac{Kt}{LJS^2 + (LD + RJ)S + KtKb} \quad ---- (1)$$

Table I shows the BLDC motor parameters and their values:

Table (I):Parameters of BLDC Motor

Parameter	Values and units	Parameters	Values and units
J: Rotor inertia	10^{-5} Kgm s^2/rad	D :viscous friction constant	10^{-4} Kg-m s/rad
) k_b: EMF constant	0.1434 Vs rad- m/a	L: electric resistance	0.054 H
R: electric resistance	12 Ω	Kt: Torque constant	0.1433 Kg-Nm/A

Fig. (2) shows the response of the DC motor speed in the open loop circuit system state and applied an external torque amount of 20Nm at time equal 0.5 sec. Where we note that the speed broke down when the external torque applied, there for we need to design of the control system to increase the stability of speed when applied external torque, as well as access the required reference speed.
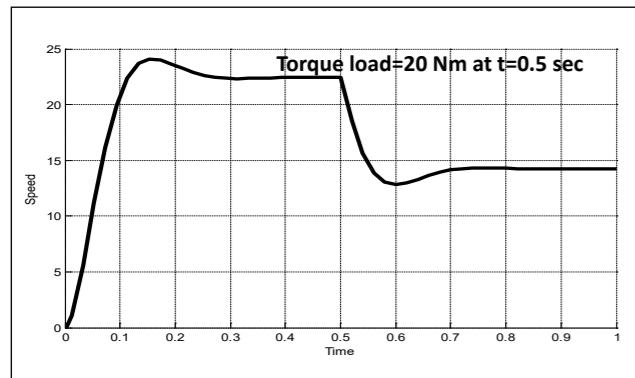

Fig. (3): Simulink Model PID Controller

Fig. (2):Open loop speed response of the DC motor

4. Conventional Pid Design

The PID controller is a feedback type conventional controller which stands for Proportional-Integral-Derivative [9]. The error (e) between the target set point and the current speed is used to generate proportional, integral and derivative action[10]. We pplied Ziegler-Nichols method to design the PID controller. Fig. (3) shows the Simulink model of the PID controller. The transfer function used for PID controller is [11]:

U = (Proportional gain + Integral gain + Derivative gain)

$= (Kp)+(Ki /s)+(Kds)$ - - - - - - - (2)
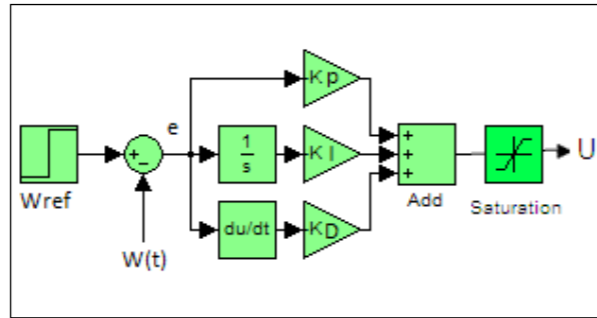
5. Conventional Fuzzy Logic

The main structure parts of the FLC are a fuzzification part, a fuzzy logic reasoning part, a knowledge base, and a defuzzification part. In this paper we have two inputs fuzzy logic control, 7-membership function of each inputs (e and ch_e) & outputs. To design the fuzzy controller first should be created rule base in FIS Editor. It was subsequently tuning gain values for each input (G(e), G(ch-e)) and output, G(u) ,as well as adjust the membership functions and the amount of overlap between them. Fig. (4) shows the simulation model of fuzzy logic design.
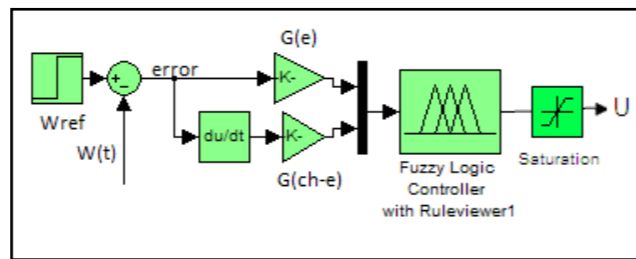

Fig. (4): Fuzzy Logic Controller

The triangular membership functions of these fuzzy sets for error & change of error are cleared with seven triangular membership functions. The membership functions is shown in Fig. (5). We notice that the , (L,H ,Z ,s, m,b) as low, high, near zero, small, medium and b big respectively. , Lm stands for low-medium, Hb for high big, and so on [7].
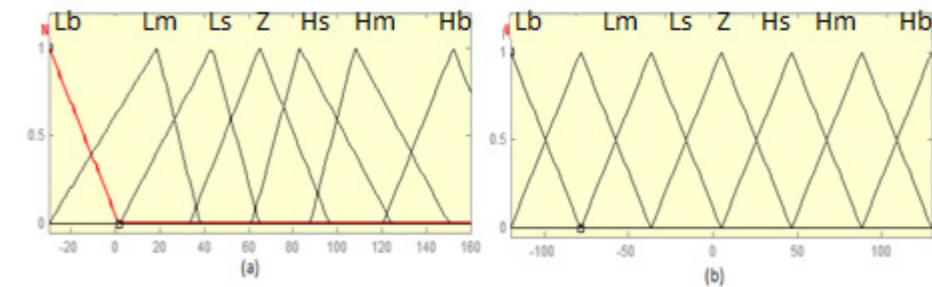

Fig. (5): FLC membership functions of input (a- error & b- ch-error)

Table (2): Fuzzy control

error/ch-error	Lb	Lm	Ls	Z	Hs	Hm	Hb
Lb	Lb	Lb	Lb	Lb	Lm	Ls	z
Lm	Lb	Lb	Lb	Lm	Ls	Z	Hs
Ls	Lb	Lb	Lm	Ls	Z	Hs	Hm
Z	Lb	Lm	Ls	Z	Hs	Hm	Hb
Hs	Lm	Ls	Z	Hs	Hm	Hb	Hb
Hm	Ls	Z	Hs	Hm	Hb	Hb	Hb
Hb	Z	Hs	Hm	Hb	Hb	Hb	Hb

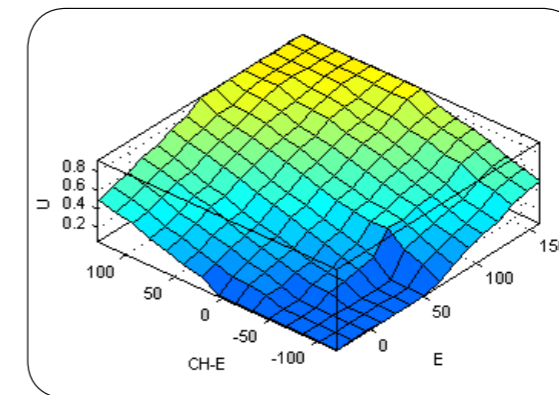Then system is run and the 3-dimensional behavior of the FLC is shown in fig.(6).

Fig. (6): 3D view of the FLC response

6. Self Tuning Pid Controller

Its need to automatically adjust PID gain parameters for obtaining the best response for short time because the Conventional PID controller not given desired performance for systems with uncertain dynamics and non-linearity [9]. Fig. (6) shows general block simulation of Self-tuning fuzzy PID_controller .The automatic tuning for PID gain has been done using fuzzy logic techniques. Figure.7 shows the complete Simulink/MATLAB block for STF PID controller [12].
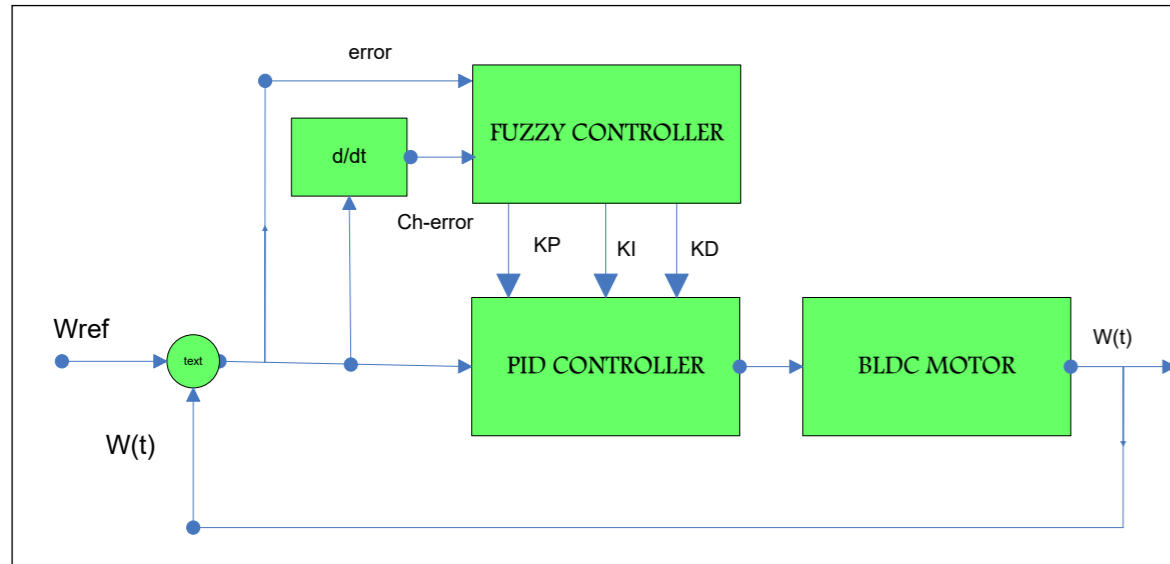

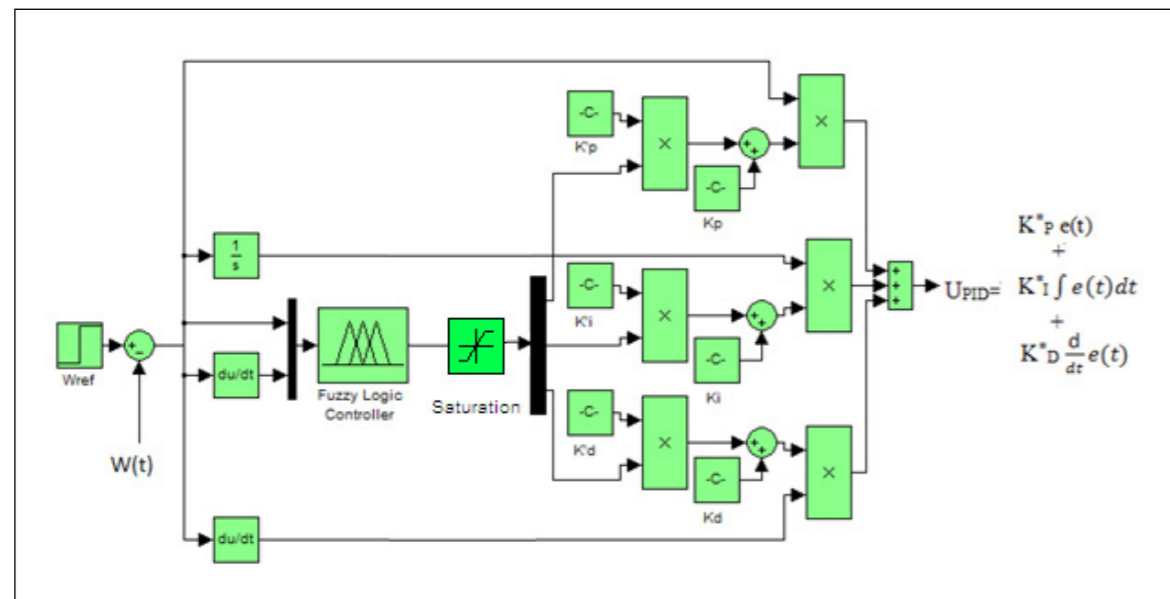**Fig. (7): Block Simulation of STF PID controller**

Fig. (8): Simulink/Model of STF PID controller

The STFPID transfer function that used in this work is :

$$U^{PID} = K_P^* \, error \, (t) + K_I^* \int error(t)dt + K_D^* \frac{d}{dt} error(t) \; - - - - - - \; (3)$$

where :

(K_P^*, K_I^*, K_D^*) are the PID gain parameters that can be tuned. The adaptation equation for PID parameters can be given as [13]:

$K_P^* = K'_P + K_P$
$K_I^* = K'_I + K_I$
$K_D^* = K'_D + K_D$

Where $(K'_P \; K'_I \; K'_D)$ are the outputs of the fuzzy controller that are varying with time and we can be calculated it as:

$(K'P) = (K_p - K_{p\,min})/(K_{p\,max} - K_{p\,min}) \; - - - - - \; (4)$
$(K'I) = (K_i - K_{i\,min})/(K_{i\,max} - K_{i\,min}) \; - - - - - \; (5)$
$(K'D) = (K_d - K_{d\,min})/(K_{d\,max} - K_{d\,min}) \; - - - - - \; (6)$

Where: $(K_P \; K_I \; K_D)$ are the initial values of the PID gain [13,14].

The variable parameters of the PID gains is $((K_{p\,min}, K_{p\,max})) , ((K_{i\,min}, K_{i\,max})) \& ((K_{d\,min}, K_{d\,max}))$ respectively. We determined the parameter width of each PID gain by using the simulation result as shown in fig.(9). fig.(10) shows the response of (P,I and D) of error to determine the PID range gains [15].
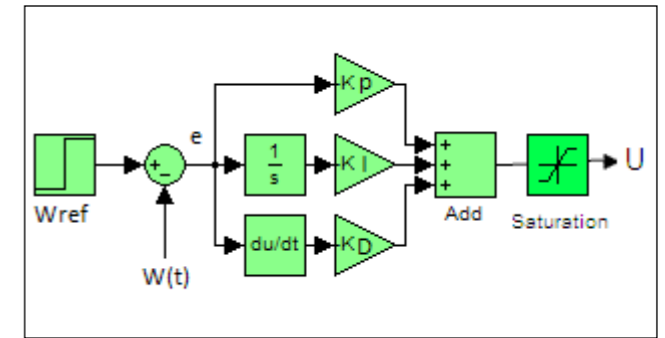

Fig. (9): Simulation part of PID controller parameters

It was taken the maximum and minimum variable ranges of the PID controller gains as shown below:

$Kp \in [-10,65]$, $Ki \in [0. 1, 3]$ and $Kd \in [-820, 130]$.

Therefor can be calculated equations 4, 5 and 6 as follows[16]:

$(K'P) = (Kp +10)/75$
$(K'I) = (Ki - 0. 1) / 2.9$
$(K'D) = (Kd +820)/950$

Toning membership functions and toning their own elements, and the amount of overlap between them to obtain the suitable value for the PID gain [17].The inputs to controller are (e) and (ch-e) while the output is self-tuning fuzzy PID gain(Kp, Ki , Kd) . Structure of fuzzy-PID controller with two input-three output structure implemented in Matlab as shown in Fig.(10) [18].
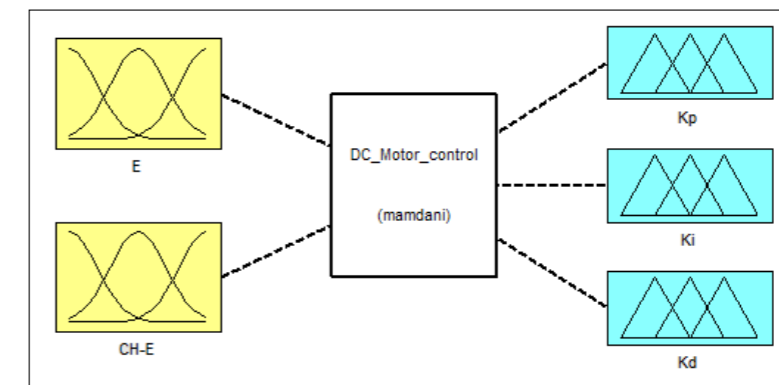

Fig.(10): Fuzzy inference block

The most important parts in design of fuzzy logic system are the inputs and outputs membership functions, and the if-then rules knowledge. The three input- output tables corresponded to PID gains parameters, which are shown as table (3), table (4) and table (5).

Table (3): K'P Fuzzy rule table

	CH-ERROR						
K'$_P$	Lb	Lm	Ls	Z	Hs	Hm	Hb
Lb	Hb	Hb	Hm	Hm	Hs	Z	Z
Lm	Hb	Hb	Hm	Hs	Hs	Z	Z
Ls	Hm	Hm	Hm	Hm	Z	Z	Ls
Z	Hm	Hm	Hs	Z	Ls	Ls	Lm
Hs	Hs	Hs	Z	Ls	Ls	Lm	Lm
Hm	Hs	Z	Ls	Lm	Lm	Lm	Lb
Hb	Z	Z	Lm	Lm	Lm	Lb	Lb

(ERROR — row axis label)

Table (4): K'I Fuzzy rule table

	CH-ERROR						
K'$_I$	Lb	Lm	Ls	Z	Hs	Hm	Hb
Lb	Lb	Lb	Lm	Lm	Ls	Z	Z
Lm	Lb	Lb	Lm	Ls	Ls	Z	Z
Ls	Lb	Lm	Ls	Ls	Z	Hs	Hs
Z	Lm	Lm	Ls	Z	Hs	Hm	Hm
Hs	Lm	Ls	Z	Hs	Hs	Hm	Hb
Hm	Z	Z	Hs	Hs	Hm	Hb	Hb
Hb	Z	Z	Hs	Hm	Hm	Hb	Hb

(ERROR — row axis label)

Table (5): K'D Fuzzy rule table

	CH-ERROR						
K'$_D$	Lb	Lm	Ls	Z	Hs	Hm	Hb
Lb	Hs	Ls	Lb	Lb	Lb	Lm	Hs
Lm	Hs	Ls	Lb	Lb	Lb	Lm	Hs
Ls	Z	Ls	Lm	Lm	Ls	Ls	Z
Z	Z	Ls	Ls	Ls	Ls	Ls	Z
Hs	Z	Z	Z	Z	Z	Z	Z
Hm	Hb	Ls	Hs	Hs	Hs	Hs	Hb
Hb	Hb	Hm	Hm	Hm	Hs	Hs	Hb

(ERROR — row axis label)

The STF-controller has two input (error & change of error) and three output variables (K'P, K'I& K'd) [19]. The Rule viewer got the parameters from Fuzzy PID controller is shown in figure(11), there are 49 rules are defined [20,21].
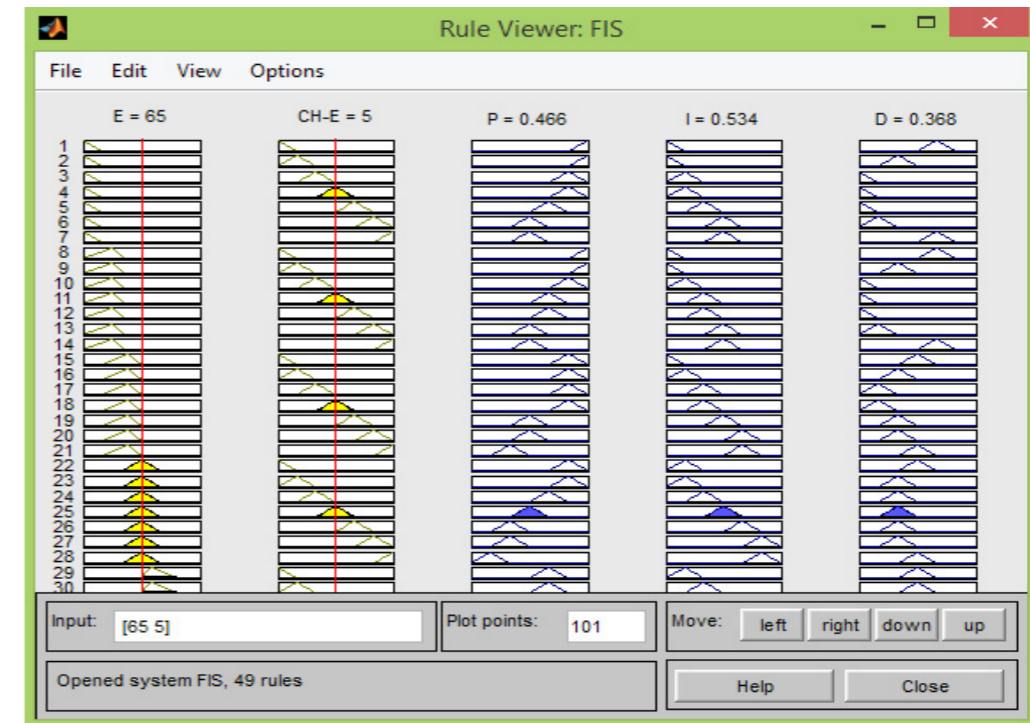

Fig. (11): The Rule viewer of the Self-tuning Fuzzy Controller

6. RESULT & DISCUSSION

In this work we presents a compared to different study of speed control system technique for the BLDC motor. To declaration the performance of three controllers, It is compared with design conventional PID controller , FLC and (STFPID) controller. Fig.

(12) shows the BLDC motor step speed responses with three different controllers technique in no load, where we was chosen the reference speed at 60(rpm) without applied external torque load. Fig. (12) show the speed response of the BLDC motor with three controllers with no load conditions,.
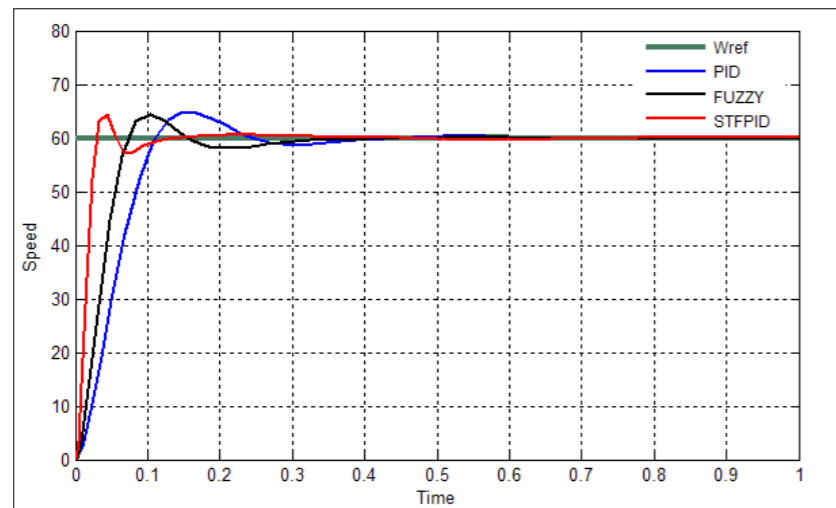

Fig. (12): The three different controllers responses

The parameters gain of the conventional PID controller that are used in this controller are (P= 1.764, I=19.74 and D=0.0274) . From responses shown in Fig. (15), note that self- tuning fuzzy PID

control gives the better performance compared to other controllers. Table VII lists the performance of BLDC Motor with three controllers.

Table (6): Performance Comparison of PID , FL and STFPID Controller

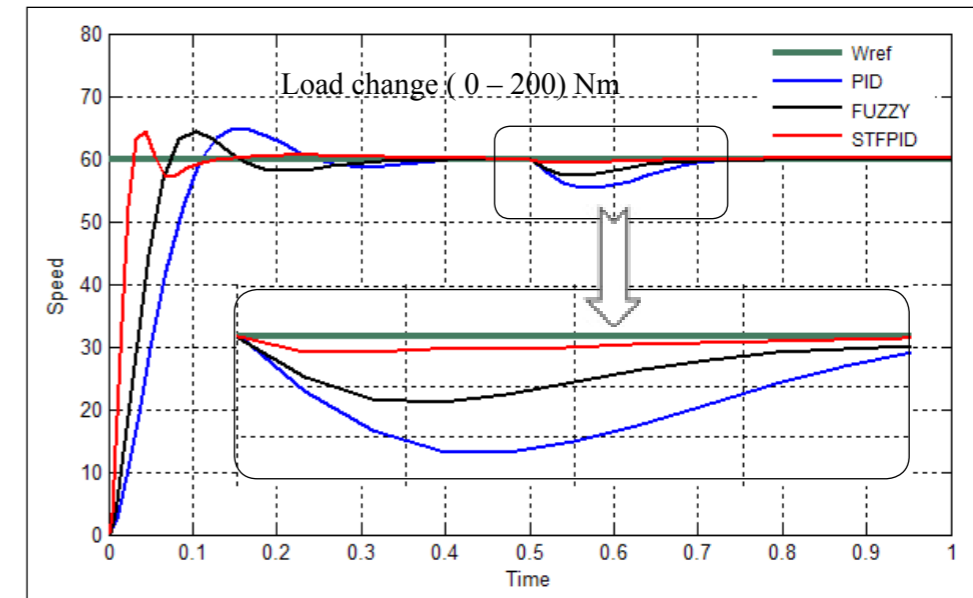| Controller Type	Rise Time (ms)	Settling Time ((ms	Mo.sh (%)	Pick Time ((ms
PID	0.0745	0.325	8.12	1.08
Fuzzy	0.0487	0.263	7.32	1.07
STFPID	0.0191	0.156	7.41	0.54

Fig. (13): The Speed Response for BLDC Motor with external load step change from 0 to 20 Nm at time = 0.5 sec.

From simulation results, It is found that the self-tuning fuzzy PID gain controller is the best in that it cancelation external torque disturbances comparative with other controller. The ability controllers to achieving the target speed of BLDC Motor speed is one of the important aspects of this study. Fig. (14) shows the speed responses of the DC motor with three different controllers technique, when we changed the desired speed from (60 - 120) r.p.m . Fig. (19) shows the speed responses characteristics of the BLDC motor speed with pulses change in desired speed from - 60 to 60 rpm.
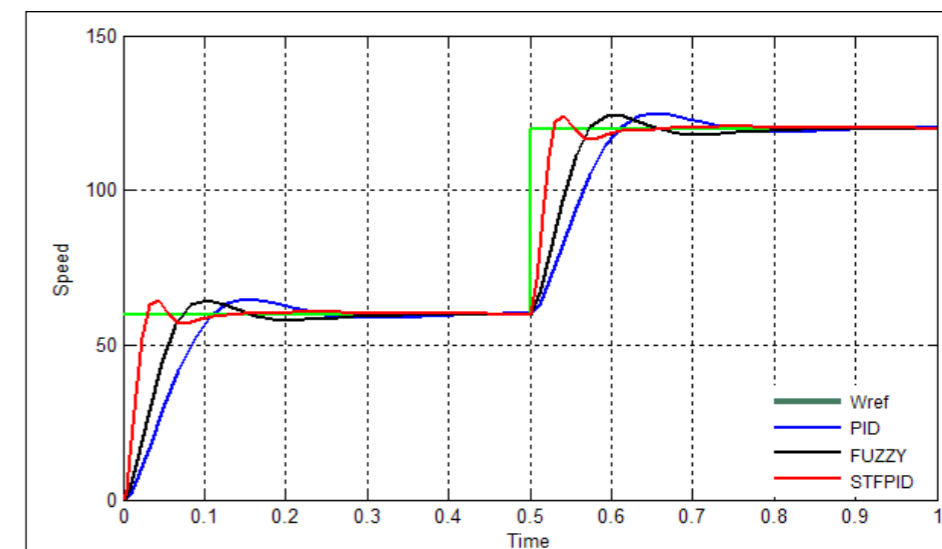

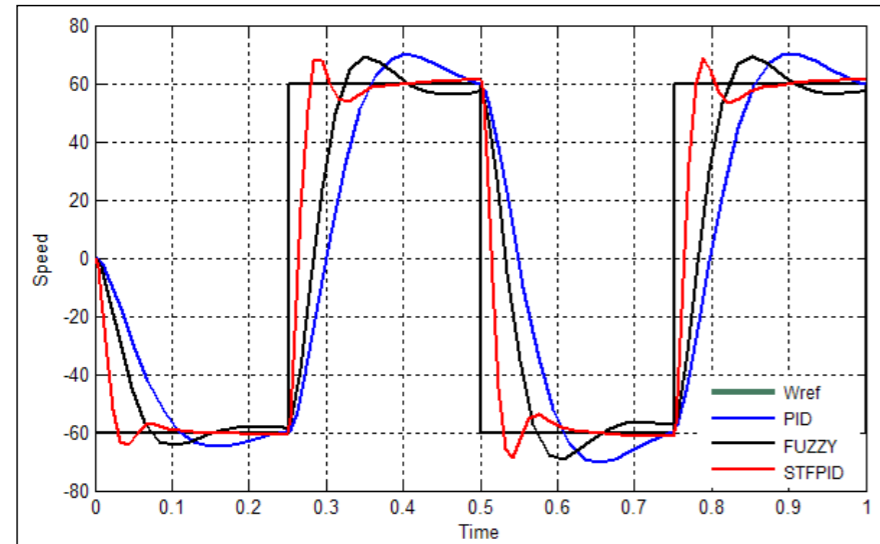**Fig. (14): Step change desired speed at t=0.5 sec from 60 - 120 rpm.**

Fig. (15): DC motor speed with pulses change in reference speed from -60 to 60 rpm

From figs. (14 and 15), it is noted that the speed response with the STFPID controller is the faster to achieve the reference speed compared with other controllers.

8. Conclusion

In this work, the optimal self-tuning PID system is designed and simulated with automatically tuning PID controller parameters(KP,KI& KD).

According to the MATLAB/Simulink result shown in table VII, it is obvious at the same condition of operate the speed response of BLDC motor using (STFPID) technique given best performance than the pure PID-controller and Fuzzy logic system. In addition, the speed of the motor is constant during change the load and robust for cancelation the external load disturbances. Finally, it is found that the (STFPID) Controller gives a better results.

References

[1] Upalanchiwar, T. and Sakhare, A.V. Design and implementation of the fuzzy PID controller using Matlab/simulink model. International Journal of Research in Computer and Communication Technology, 3(3): 369-372. (2014).

[2] Liu, G., Min, J. and Sheng, Q. Brushless DC motor fuzzy PID control system and simulation. Sensors & Transducers, 181(10): 111-116. (2014).

[3] Chopra, V., Singla, S.K. and Dewan, L. Comparative analysis of tuning a PID controller using intelligent methods. Acta Polytechnica Hungarica, 11(8): 235-249. (2014).

[4] Waleed I. Hameed and Mohamad, K.A. Speed control of separately excited DC motor using fuzzy neural model reference controller. International Journal of Instrumentation and Control Systems (IJICS), 2(4): 27-39. (2014).

[5] Bansal, U.K. and Narvey, R. Speed Control of DC Motor Using Fuzzy PID Controller. Advance in Electronic and Electric Engineering, 3(9): 1209-1220. (2013).

[6] Chengaiah, C.H. and Venkateswarlu, K. Comparative study on Dc motor speed control using various controllers. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 3(1). (2014).

[7] Adewuyi, P.A. DC motor speed control: A case between PID controller and fuzzy logic controller. International Journal of Multidisciplinary Sciences and Engineering, 4(4): 36-40. (2013).

[8] Nasri, M., Nezamabadi-pour, H. and Maghfoori, M. A PSO-based optimum design of PID controller for a linear BLDC motor. World Academy of Science, Engineering and Technology, 26: 211-215. (2007).

[9] Panjwani, B. and Mohan, V. Comparative performance analysis of PID based NARMA-L2 and ANFIS control for continuous stirred tank reactor. International Journal of Soft Computing and Engineering (IJSCE), 3(5): 20-23. (2013).

[10] Vaishnav, S.R. and Khan Z.J. Design and performance of PID and fuzzy logic controller with smaller rule set for higher order system. Proceedings of the World Congress on Engineering and Computer Science, 24-26 October, San Francisco, USA: pp. 1-4. (2007).

[11] Kumar, N., Gupta, H. and Choudhary, R. "Analysis Fuzzy Self Tuning of PID Controller for DC Motor Drive. IJITKM Special Issue: 148-152. (2014).

[12] Zulfatman and Rahmat, M.F. "Application of SLTF Controller on Industrial Hydraulic Actuator using System Identification Approach". IJSEIS. (2009).

[13] Aldair, A.A. Design of Neuro_fuzzy Self Tuning PID Controller forAntilock Braking Systems. Journal of Babylon University/Engineering Sciences, 22(4): 775-787. (2014).

[14] Jang, J.S.R. and Gulley, N. Fuzzy logic toolbox user guide. The Mathworks Inc. (1995).

[15] Muhammed, K.K. and Abdulhameed, M.A. Design and implementation of a fuzzy logic based a photovoltaic peak power tracking controller, Al-Rafadain Engineering Journal, 20(5): 48-57. (2012).

[16] Abdulhameed, M.A. Design and Implementation of a fuzzy logic based photovoltaic peak power tracking controller. Master Thesis in College of Engineering -University of Mosul, Iraq. (2010).

[17] Kandiban, R. and Arulmozhiyal, R. Design of adaptive fuzzy PID controller for speed control of BLDC motor. International Journal of Soft Computing and Engineering (IJSCE), 2(1): 386-391. (2012).

[18] Mohiuddin, M.S. Comparative study of PID and fuzzy tuned PID controller for speed control of DC motor. International Journal of Research in Engineering and Technology (IJIET), 2(4): 291-301.(2013).

[19] Ghanim, Z.M. Design and simulation of DC motor drive controller by using PID and fuzzy logic. Master

Thesis in Electrical and Electronic Engineering-Atılım University. (2015).

[20] Yu, B., Zhu, H. and Xue, C. Research on adaptive fuzzy PID synchronous control strategy of double-motor. I.J. Intelligent Systems and Applications, 5: 28-33. (2011).

[21] Chetaswi, K., Sudheer, Y. and Kumar, M.P. Speed Control of Separately Excited DC Motor Using Computational Method. International Journal of Advanced Trends in Computer Science and Engineering, 3(1): 523– 525. (2014).

[22] Batayneh, W. and Nawafleh, N. Comparative study of DC motor speed control using neural networks and fuzzy logic controller. International Mechanical Engineering Congress and Exposition, Houston, Texas, USA, November 13–19: 10p. (2015).

Lower Bound Estimates for Approximation by Neural Networks for Functions in L_p. Spaces for p<1.

Eman S. Bhaya and Sarah A. Alameedee
Mathematics Department, College of Education for pure sciences, University Babylon, Iraq.

الخلاصة

قدمنا في هذا لبحث نظرية مباشرة للتقريب باستخدام الشبكات العصبية للدوال في الفضاءات L_p، عندما p<1.

الكلمات المفتاحية

الشبكات العصبية، مقياس النعومة، مبرهنة مباشرة.