TUNING PROPORTIONAL – INTEGRAL – DERIVATIVE CONTROLLER USING MAMDANI FUZZY LOGIC CONTROLLER FOR PRACTICAL PLANTS [+]

تنغيم المسيطر التناسبي –التكاملي –المشتق– باستخدام المسيطر الضبابي لانظمة عملية

Ahmed Karim Abdullah Albakri [*]

Abstract:

In many instances, the mathematical model of the plant is simply unknown or ill-defined, leading to greater complexities in the design of the control system. It has been proved that intelligent control systems give a better performance in such cases. In this paper two controllers are integrated to obtain the new intelligent controller .The conventional (proportional- Integral- derivate) controller is integrated with intelligent controller ,Fuzzy logic Controller to control two complex plants. Two plants(Automatic Voltage Regulator (AVR),& DC Motor)are taken in this paper and the simulation has been performed using MA TLAB program. Determinately the idea for the proposed method in this paper depends on study the behavior of PID controller on-line then the PID parameters are adjusted by new rule base table for fuzzy controller which govern the output response for the system .During PID studying properties, there are some important relations between time response parameter and PID parameters such as: *IF* steady state error (e_{ss}) high *THEN* increases the Integral constant (K_I.), *IF* rise time (t_r) high *THEN* increase the proportional constant (K_p), *IF* overshot(O.S) high *THEN* increase the derivate constant (K_d), and so on to fill the rule base table, therefore a new rule base table is obtained with a good response for the systems.

المستخلص:

في كثير من الحالات ، النموذج الرياضي للنظام هو ببساطة غير معروف أو غير محددة المعالم ، مما يؤدي إلى تعقيدات أكبر في تصميم نظام التحكم .لقد ثبت أن أنظمة التحكم الذكية تعطي أداء أفضل في مثل هذه الحالات .في هذا البحث تم التعشيق بين مسيطيرين وهما المسيطر الضبابي والمسيطر الثلاثي للحصول على وحده سيطره ذكيـــة تعطي اداء افضل للنظام للسيطرة على نظامين وهما (منظم الفولتية ومحرك تيار مستمر) ، ولقد تم تنفيــذ محاكـــاة باستخدام برنامج الماتلاب واثبتت الفكرة المقترحة في هذا البحث يعتمد على دراسة سلوك معرف المنتج تحكم على الخط ثم المعلمات معرف المنتج يتم تعديلها من قبل قاعدة جديدة للتحكم الجدول حكم غامض التـــي تحكـــم اســـتجابة الانتاج للنظام. معرف المنتج خلال دراسة خصائص ، هناك بعض العلاقات المهمة بـــين زمـــن الاســـتجابة المعلمـــة والمعلمات معرف المنتج مثل : لو استمرار حالة الخطأ (قسم الإحصاء) ، ثم يزيد من ارتفاع مستمر متكاملة (KI.)، وإذا كان الوقت الارتفاع (آر) عالية ثم زيادة متناسبة ثابتة (ك (، إذا تجاوزت)نظام التشغيل) ثم زيادة عالية مستمرة المتفرعة (دينار كويتي) ، وهلم جرا لملء قاعدة الجدول الأساسي ، ولذلك فإن القاعدة الجديدة الجدول الأساسي هو الحصول على استجابة جيدة مع لهذه النظم.

[+]Received on 10/8/2008 ,Accepted on 2/8/2010 .

[*] Asst. Lecturer/ Technical Collage / Almusyeib

Introduction:

More than 90% of industrial controllers are still implemented based upon PID algorithms, particularly at lowest levels [1]. With its three-term functionality covering treatment to both transient and steady-state responses, proportional- integral-derivative (PID) control offers the simplest and yet most efficient solution to many real-world control problems[2].

Fuzzy controllers are used to control consumer products, such as washing machines, video cameras, and rice cookers, as well as industrial processes, such as cement kilns, underground trains, and robots. Fuzzy control is a control method based on fuzzy logic. Just as fuzzy logic can be described simply as "computing with words rather than numbers", fuzzy control can be described simply as "control with sentences rather than equations"[3].

However, it has been known that conventional PID controllers generally do not work well for nonlinear systems, higher order and time-delayed linear systems therefore various types of modified conventional PID controllers such as auto tuning and adaptive PID controllers were developed [4].

This paper is organized, including introduction, the controller types explanation, finally test and simulation of the new controller.

Time Response Parameters and Performance Index:

Depending on the values of time response parameters (Rise Time, Peak Time, Overshoot, Steady State Error ,Settling Time),the responses may be weighted (good or bad).In this paper these parameters are used to control on the rules of Fuzzy logic controller to compare and enhance the output response for the system.In general, the PID controller. design method using the integrated absolute error *(IAE),* or the integral of squared-error *(ISE),* or the integrated of time-weighted-squared-error *(ITSE)* is often employed in control system design because it can be easily evaluated analytically [5].

PID Controllers:

There are several structures for the PID algorithms, but only two types are taken in this paper :

1: Three-Term Functionality and the Parallel Structure [2]

A PID controller may be considered as an extreme form of a phase lead-lag compensator with one pole at the origin and the other at infinity. Similarly, its cousins, the PI and the PD controllers, can also be regarded as extreme forms of phase-lag and phase-lead compensators, respectively. A standard PID controller is also known as the "three-term" controller, whose transfer function is generally written in the "parallel form" given in eq. (1) or its ideal form which is given in eq.(2)

$$G(s) = K_P + K_I \times \frac{1}{s} + sK_D \qquad (1)$$

$$G(S) = K_P(1 + \frac{1}{T_1 s} + T_D s) \qquad (2)$$

where K_p is the proportional gain, K_I the integral gain, K_D the derivative gain, T_1 the integral time constant and, T_D the derivative time constant. The "three-term" functiona1ities are

highlighted by the following:
•The proportional term providing an overall control action proportional to the error signal through the all-pass gain factor.
•The integral term reducing steady-state errors through low-frequency compensation by an integrator
•The derivative term improving transient response through high-frequency compensation by a differentiator

2: Series Structure [2,6]

A PID controller may also be realized in the "series form" if both zeros are real, i.e., if ($T_I>=4T_D$) . In this case, the transfer function can be implemented as a cascade of a PD and a PI controller as shown in equation 6:

$$G(S) = K_P(\alpha + T_D S) \times (1 + \frac{1}{\alpha T_I S}) \quad .(3)$$

$$\alpha = \frac{1 \pm \sqrt{1 - \frac{4T_D}{T_I}}}{2} \quad (4)$$

<u>Fuzzy logic controller :</u>

Figure (1) shows the block diagram of a typical fuzzy logic controller (FLC) , and the system plant as it is shown .

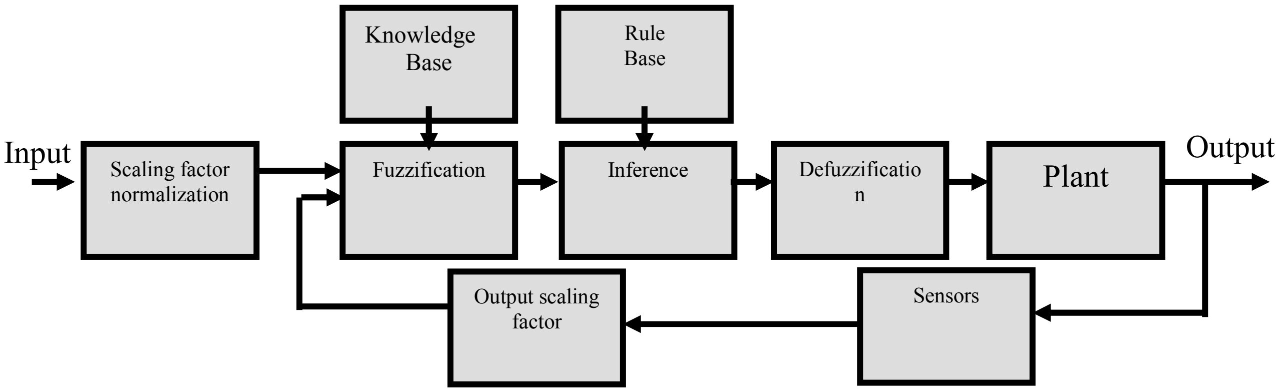

Figure (1) Block diagram of a typical fuzzy logic controller [7]

The fuzzy logic controller consist of:
- Fuzzification (fuzzifier): Change crisp value to linguistic variable .
- Knowledge base: Provides all the necessary definitions for the Fuzzification process .
- Rule base: It is usually obtained from expert knowledge.
- Inference engine
- Defuzzification: Change linguistic variable to crisp value.

<u>Fuzzy PID Controller Structure and Algorithms :</u>

In this section the Fuzzy- PID (FPID)controller will be explained in details .also the proposed algorithm structure for this controller.

Figure (2),shows the general block diagram for FPID controller .The fuzzy controller

is used to adjust the PID controller parameters (K», K" K_D), to obtain the optimal three parameters which gives the best response.

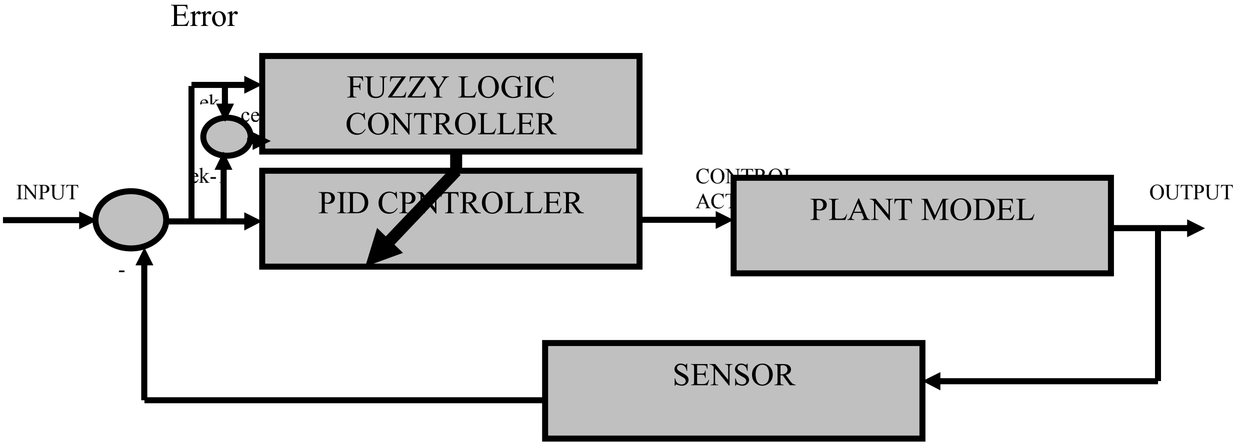

Figure (2): PID- FUZZY controller Structure

In this paper, classic interpretation of Mamdani [3] logic operations are applied, for 'and' minimum is used, for 'or' also with 'maximum'. So with IF-THEN rule, the describe rules of fuzzy algorithm with two dimensional table of rules is shown in table (1).

Table (1): FUZZY Rule Base matrix

de_k \ e_k	NB	NM	NS	ZO	PS	PM	PB
PB	ZO	PS	PM	PB	PB	PB	PB
PM	NS	ZO	PS	PM	PB	PB	PB
PS	NM	NS	ZO	PS	PM	PB	PB
ZO	NB	NM	NS	ZO	PS	PM	PB
NS	NB	NB	NM	NS	ZO	PS	PM
NM	NB	NB	NB	NM	NS	ZO	PS
NB	NB	NB	NB	NB	NM	NS	ZO

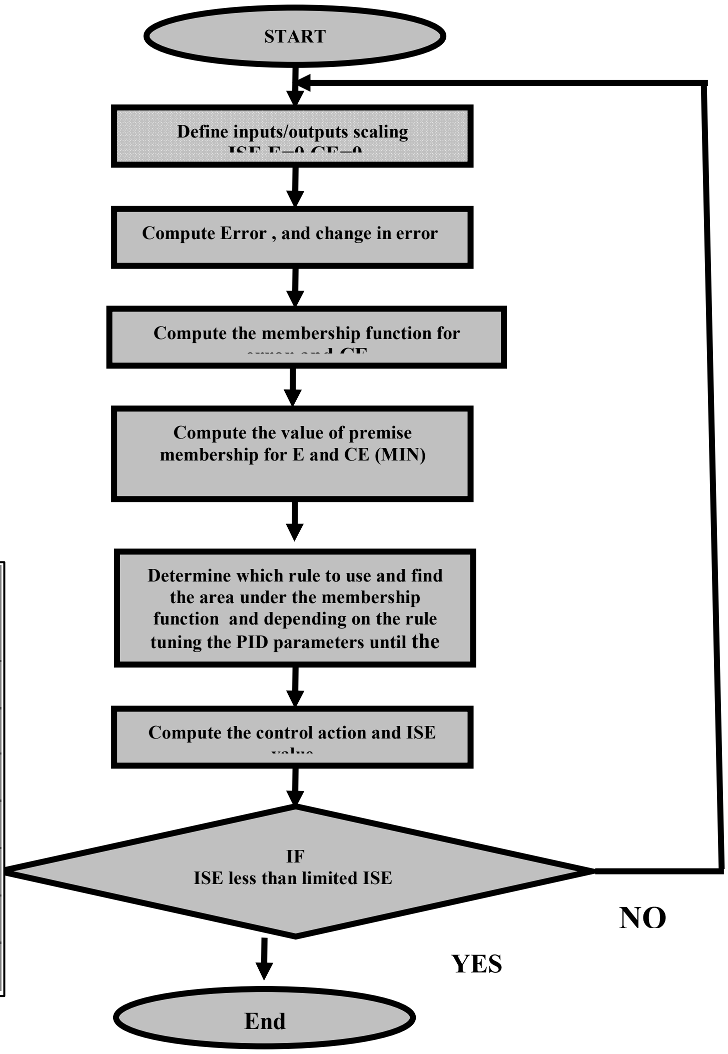

Figure (3): FUZZY-PID controller algorithm

In this paper two controllers (PID and FUZZY) are used to enhance the output response for the systems, the algorithm which merged these controller explained bellow in figure (3).

Simulation Result :

To check the proposed controller , two plants are taken (AVR and DC Motor):

1 Automatic Voltage Regulator (AVR) plant

The basic work of an Automatic Voltage Regulator (AVR) is to hold the output terminal voltage magnitude of a synchronous generator at a limited level. Generally the Automatic Voltage Regulator (AVR) system consist of four main components, namely(Amplifier, Exciter, Generator, and Sensor). For mathematical modeling and transfer function of the four components, these components must be linearized, which takes into account the major time constant and ignores the saturation or other nonlinearities [8,9]. The following model in Figure (4) provide an AVR compensated system

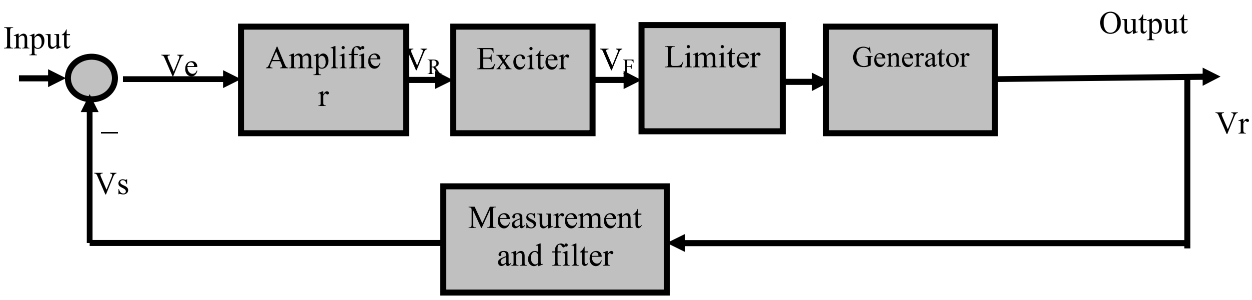

Figure (4):Block diagram of AVR without controller

The transfer function of these components may be represented, respectively, as follows.

-Amplifier Model.

The amplifier model is represented by a gain K_A and a time constant τ_A ; the transfer function is:

$G_A(s)=K_A/(1+S\tau_A)$ (5)

Typical values of (Ka) are in the range of vary with range (10 to 400). The amplifier time constant (τ_A) is very small ranging from(0.02 to 0.1)sec [9].

-Exciter Model.

The transfer function of a modrn exciter may be represented by a gain K_E and a single time constant T_E

$G_E(s)=K_E/(1+S\tau_E)$ (6)

Typical values of K_E in the range of (10 to 400). The time constant τ_E is in the range of(0.5 to 1.0) sec [9].

-Generator Model.

In the linearized model, the transfer function relating the generator terminal voltage to its field voltage can be represented by a gain K_G and a time constant τ_G. SO the transfer functions for the simplest first order model of S.G. is

$$G_G(s)=K_G/(1+S\tau_G) \quad .(7)$$

These constants are load dependent, may vary between (0.7 to 1.0) for K_G and between (1.0 and 2.0) sec for τ_G, from full load to no load [9].

-Sensor model.

The sensor is modeled by a simple first-order transfer function, given by:

$$G_R(s)=K_R/(1+S\tau_R) \quad (8)$$

K_R is very small, ranging from of (0.001 to 0.06)
For practical AVR system the parameters are shown in this table (2) [9] :

Table(2): AVR system parameters

K_A	K_E	K_G	K_R	τ_A	τ_E	τ_G	τ_R
10	1	1	1	0.1	0.5	1	0.06

The output response without controller is shown in figure (5)

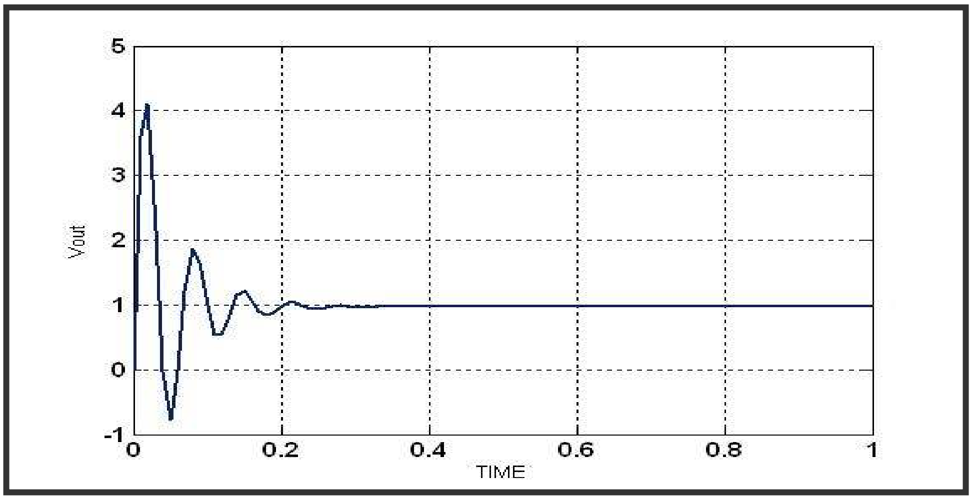

Figure (5):AVR Step output response without controller

1.1: AVR plant with classical PID controller

Figure (9),show the block diagram of AVR Classical -PID Controller

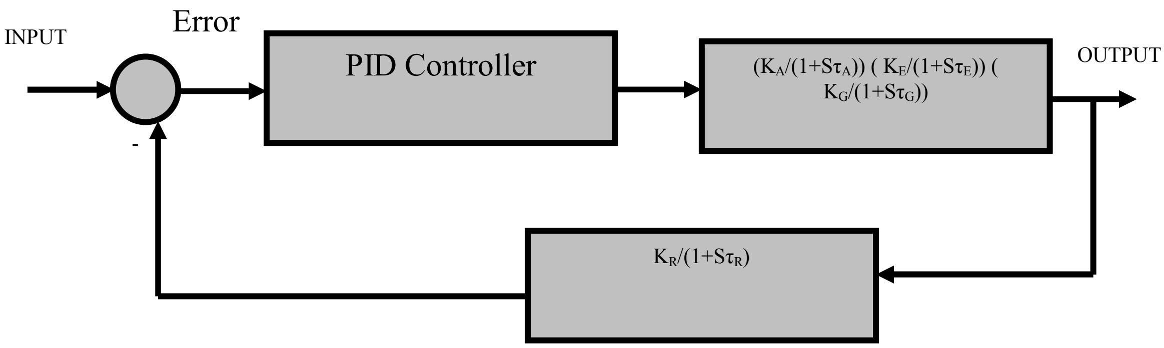

Figure (6): AVR with PID- FUZZY controller

the control action transfer function for the PID is :
where *Kp*, *Ti* and *Td* are the proportional gain, integral time and derivative time, respectively,

$$U(S) = Kp(1 + \frac{1}{TiS} + TdS)E(S) \qquad (9)$$

E(s) and *U(s)*are Laplace transforms of the control signal and the error between the reference signal and the plant output. The PID-controller proposed by Clarke [10 ,11] is used because of its better derivative part.
The controller is of the form

$$U(S) = Kp(1 + \frac{1}{TiS} + TdS)E(S) - \frac{KpTds}{1 + aTds}Y(s) \qquad (10)$$

where *a* is the filtering constant at the interval (0,1), and *U(s)* is Laplace transform of the plant output. The implementation of the derivative part is more realistic than in (9). The low pass filter reduces the effect of the measurement noise, and only the plant output, which is continuous, is differentiated. This controller can be discredited with an approximation *s* = 1 - *d* / *h* , where *h* is the sampling interval, and *d* is the delay operator. Thus, the discrete controller is of the form:

$$u_{pi}(k) = u_{pi}(k-1) + Kp(de(k) + \frac{H}{Ti}e(k))$$
$$u_{\min} \langle = u_{pi}(k) \langle = u_{\max}$$
$$u_d(k) = \frac{T_d}{h + T_d}(au_d(k-1) - K_p dy(k)); \qquad (11)$$
$$u(k) = u_{pi}(k) + u_d(k), u_{\min} \langle = u(k) \langle = u_{\max}$$

where *k* is a sampling time, *e(k)=r(k)-y(k)* is the error signal, *de(k)=e(k)-e(k-1)* and *dy(k)=y(k)-y(k-1)* are the differences. The control signal is restricted to the interval ||*umin,umax*|. To optimized PID controller we used Ziegler- Nichols formula [10]:

K_p=0.5K_C , T_i=0.5Tc, T_d=0.125T_c (12)
where *Tc* is ultimate period and the process gain *Kc* approximately given by:

$$K_C = \frac{4p}{\pi a_m} \qquad (13)$$

where a_m is amplitude of limit cycle and *p* is the relay amplitude
The output response with classical PID controller is obtained by :

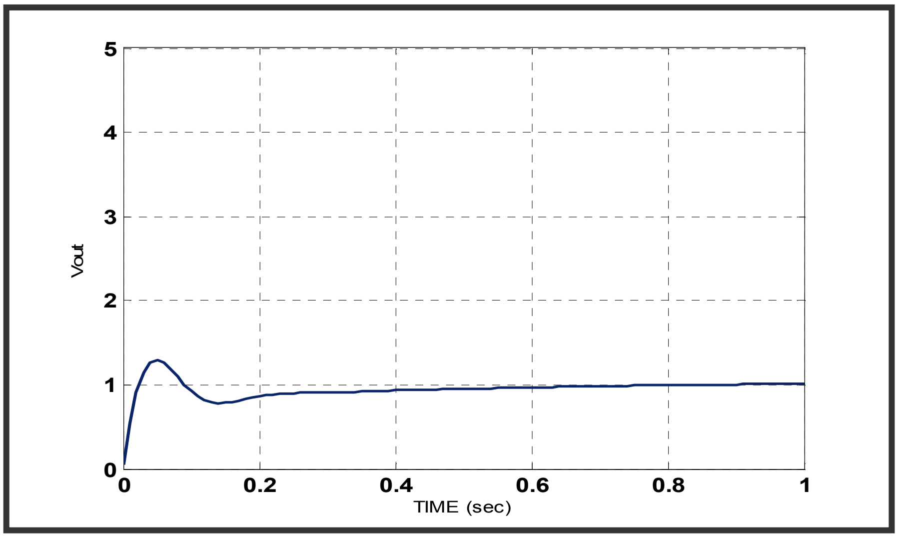

Figure (7):AVR Step output response with PID controller

1.2: AVR plant with FUZZY-PID controller

Figure (11), show the block diagram of AVR with FUZZY-PID Controller

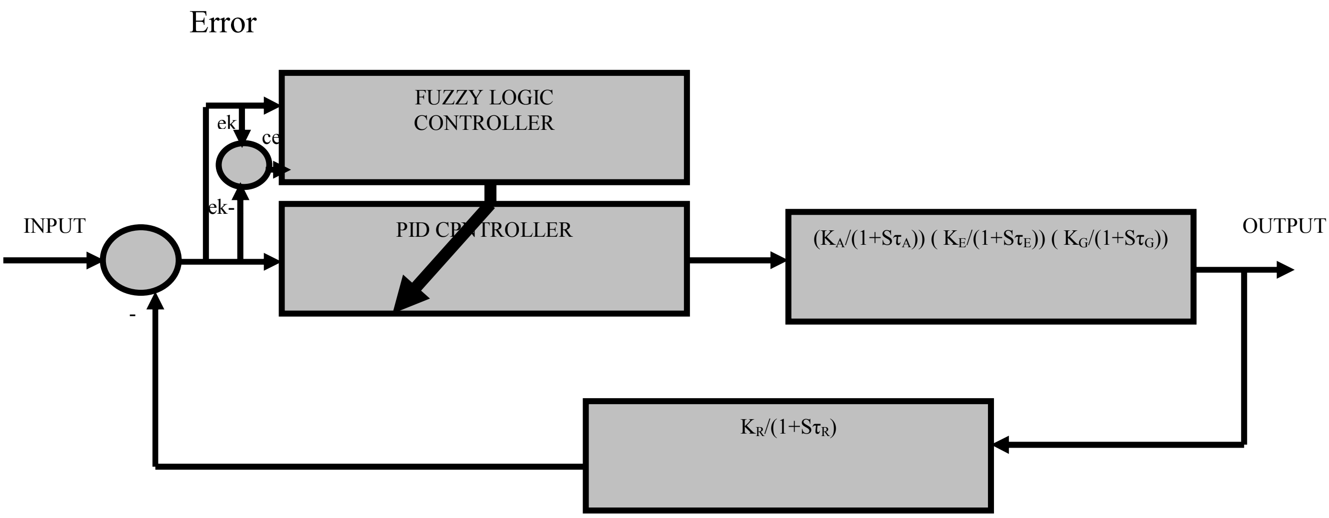

Figure (8): AVR with PID- FUZZY controller

The output responses with this controller is shown in figure (9).

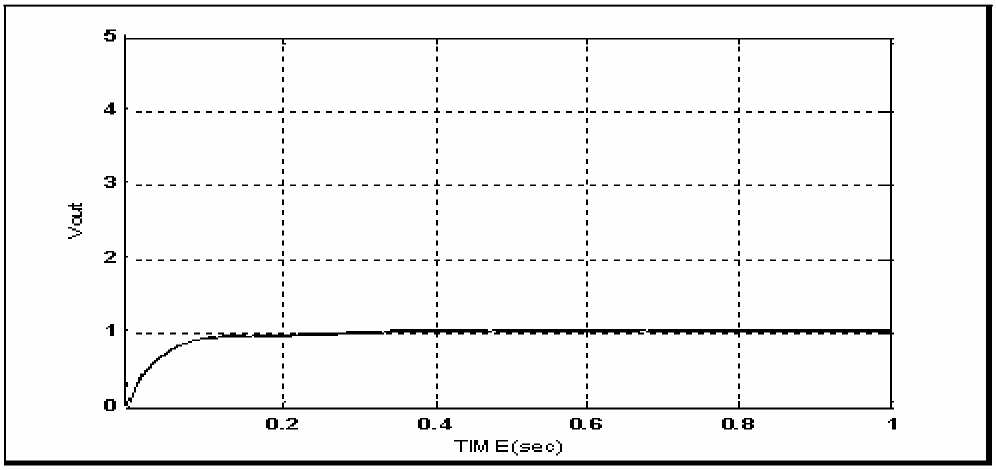

Figure (9): AVR Step output response with Fuzzy –PID controller

Table (3): Step input Time response parameters with ISE for AVR plant

Controller type	ISE %	Time response parameters (sec) 100%			
		Rise time	Peak time	Overshoot	steady state error (ess)(2%)
Without controller	24.2574	0.06	0.075	3.05%	0.2
Classical PID	2.4689	0.06	0.07	0.3%	0.25
FUZZY-PID	1.11521	0.07	0.08	---	0.18

2: DC Motor plant

A permanent magnet direct current (DC) motor is a very common component within many dynamic systems. This case study describes the physics of a standard DC motor. From this general understanding, differential equations are developed to describe the motor's dynamic behavior [9,10]. The block diagram for this plant is shown in figure (8)

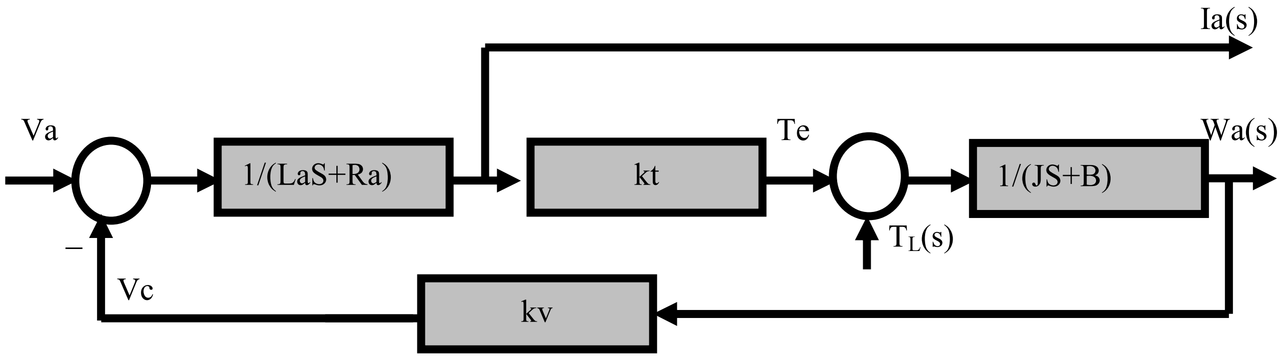

Figure (10): Feedback control system with DC MOTOR plant

the overall transfer function between the output(angular velocity) and input applied voltage given as :

$$\frac{W_a}{V_a} = \frac{k_t / L_a J}{S^2 + [(R_a J + L_A B)/L_a J]s + (R_a B + k_t k_v)/L_a J} \qquad eq(9)$$

Where :
Va: Voltage source across the coil of armature
Ia : Armature current
La: Inductance, which represent the electrical equivalent of the armature coil
Ra: Resistance of armature
Vc: Induced voltage which opposes the voltage source, which generated by rotation of the electrical coil through the fixed flux lines of the permanent magnets
kt: Torque constant
kv: constant ,Vc= kt x Wa
J: Inertia of rotor and the equivalent mechanical load
B: Damping coefficient associated with mechanical rotational system of machine
Wa: Angular velocity

The output responses with different controllers are shown in (figure(11),figure (12),figure(13))

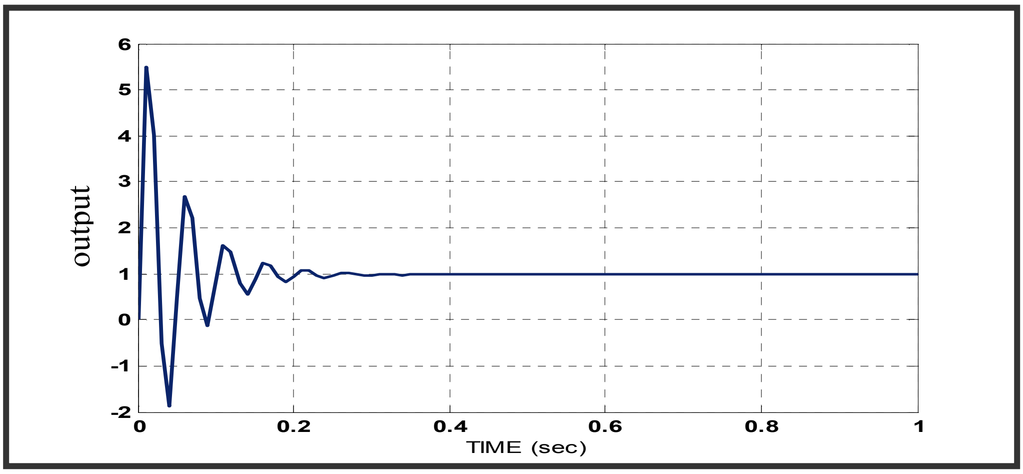

Figure (11):DC Motor Step output response without controller

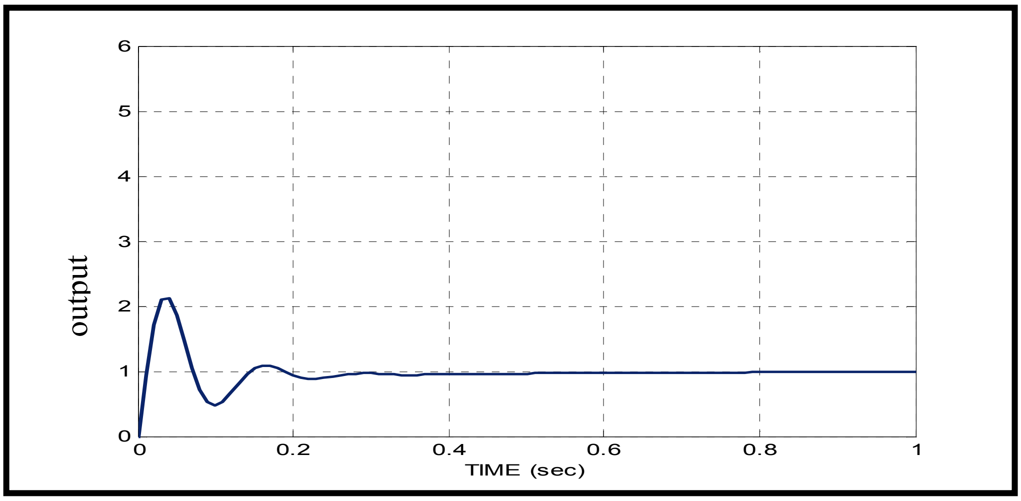

Figure (12): DC Motor Step output response with PID controller

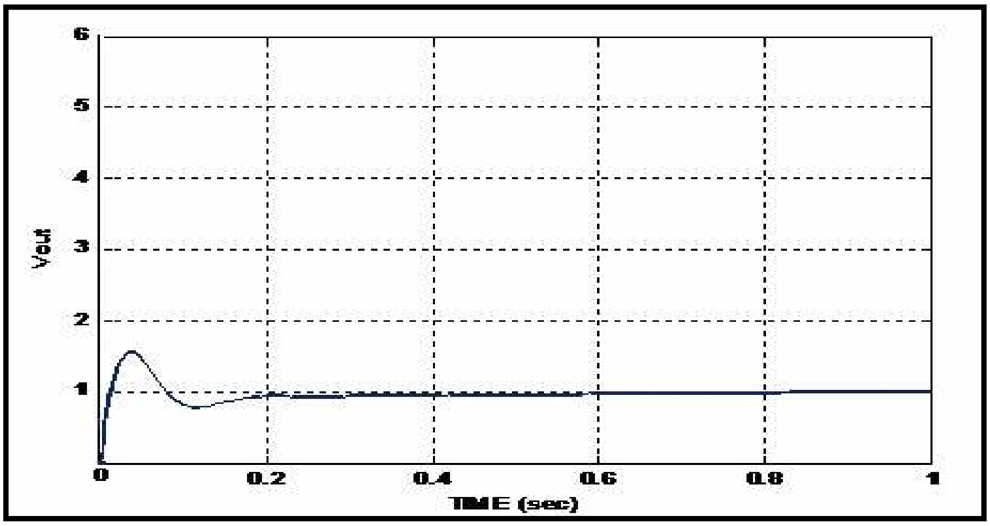

Figure (13):DC Motor Step output response with FUZZY-PID controller

Table (4): Time response parameters with ISE for DC Motor plant

Controller type	ISE%	Time response parameters			
		Rise time	Peak time	Overshoot	steady state error (ess)%
Without controller	35.63%	0.03	0.05	4.4%	0.22
Classical PID	2.9641%	0.04	0.055	1.23%	0.21
FUZZY-PID	1.42%	0.02	0.04	0.50%	0.18

Conclusion:

This paper has presented an intelligent controller (Fuzzy–PID) ,and compared with another controller (classical PID) , also the output responses without any controller are plotted .

From the simulation results :

- Integrated two controller to produce an intelligent controller is really very good method , since the ISE decreased from high (35.63%)value in DC Motor plant to very small value (1.42%) .

-The proposed approach can perform an efficient three term controller , when two parameters of the controller are tuned, a little better performance at settling time is achieved comparing with one parameter adjustment case. Also The proposed controller is really very good controller, since the good responses for two plants with step input are obtained

-More robust stability and good performance characteristic than another controllers such as classical PID or when not use any controller(without controller).

References

1- Pirabakaran K. and Becerra V.M. "Automatic Tuning of PID controllers using Model reference adaptive control technique", *27th Annual Conference of IEEE industrial Electronics Society ,*IECON01,2001
2- Ang, K. H. G. Chong, and Li Y." PID Control system analysis , Design and technology " *IEEE transaction on control sytems technology* , Vol.13 No. 4 July, 2005.
3- Jantzen J. "*Design of Fuzzy controllers* ", Technical univ. of Denemark , department of Automation, tech. report no 98-e 864, 19 aug 1998
4- Viljamaa P. and Koivo H.N., "Fuzzy Logic in PID Gain Scheduling", *Third European Congress on Fuzzy and Intelligent Technologies EUFIT'95*, Aachen, Germany, August 2831, 1995.
5- Jones A.H. and Oliveira P.B.D "Genetic autotuning of PID controllers " *proc. inst. electrical engineering conf. genetic algorithms eng. System* pp.141-145, Sept. 1995
6- Li Y., Feng W., Zhu K., Guan X., and Ang K.H., "PID easy and automated generation of optimal PID controllers" *in proc, 3rd Asia- pacific Conf. control and measurement ,Dunhuage P.R.china*, 1998, pp.29-33
7- Cirstea M.N. , Dinu A., Khor J.G.,and Mccormik M." Neural and fuzzy logic control of drives and power systems" *IEEE transaction on control systems technology* , 2002.
8- Kundur P., '*Power System Stability and Control'*, McGraw-Hill, 1994
9- Saadat H. ' *power system analysis*' New York , McGraw-hill 1999
10- Clarke D., "*Automatic tuning of PID regulators*" Expert Systems and Optimization in Process Control, Technical Press, Aldershot, England, 1986
11- Awang N.I. Wardana "PID-Fuzzy Controller for Grate Cooler in Cement Plan" Control Department ,Indonesia Cement and Concrete Institute Jalan Raya Ciangsana, Bogor, 16969, Indonesia,2002