An Investigation in to the Performances of Fuzzy PD Like and PID-PSO Controllers for Internal Combustion Engine

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ABSTRACT

The Controller design is considered as an the important part in the IC engines, to get a stable operation which is the main objective for engine generator set, through controlling the throttle angle to get constant engine rotation speed at different load conditions. The Model has been taken from previous research, considering the throttle angle as an input while the output is the rotation speed then the controllers have been designed to adjust the rotational speed with the help at Matlab and Simulink techniques. Two main types of controllers have been used in this work which are; PID and Fuzzy PD like controllers. The Proportional-Integral-Derivative parameters have been tuned by particle swarm optimization technique and for the first controller and validated by Integral Square Error (ISE), Integral Time Absolute Error (ITAE) and Integral Absolute Error (AE). While, Fuzzy PD like consisted of seven membership function and forty nine rules. Finally, the results showed the superiority of PID based on Particle Swarm Optimization (PSO) compared with Fuzzy PD like controller.

Key word: Engine generator set, PID-PSO, Fuzzy PD like

التحقق من اداء المسيطر المشابه للتناسبي التفاضلي ذو المنطق المضبب و المسيطر التناسبي التكاملي التفاضلي – تقنيه الحشد الجزيئي لمحرك احتراق داخلي

الخلاصة :

يعتبرتصميم المسيطر جزءأ مهما في محركات الاحتراق الداخلي للحصول على عمليه مستقره وهو الهدف الرئيسي لمجوعه (المولد الذي يعمل بالمحرك) من خلال التحكم في زاويه الخنق للحصول على سرعه دورانيه ثابته للمحرك في حالة الاحمال المختلفة . اخذ النموذج من الابحاث السابقه باعتبار زاويه الخنق كمدخل بينما الاخراج هو سرعة الدوران .ثم استخدمت مسيطرات لضبط سرعة الدوران بمساعده برنامج معالج

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المصفوفات. استخدم نوعان رئيسيان من المسيطرات في هذا العمل المسيطر التناسبي التكاملي التفاضلي والمسيطر المشابه للتناسبي التفاضلي ذو المنطق المضبب . معاملات المسيطر التناسبي التكاملي التفاضلي قد ضبطت بواسطة تقنية الحشد الجزيئي وهذه التقنيه قيمت بواسطة معايير الاداء (تكامل مربع الخطأ, تكامل زمن مطلق الخطأ وتكامل مطلق الخطأ) , بينما المنطق المضبب يتالف من سبع دوال عضويه وتسعه واربعون قاعده . اظهرت النتائج النهائيه تفوق المسيطر التناسبي التكاملي التنفاضلي بالاعتماد على تقنيه الحشد الجزيئي مقارنه مع المسيطر المشابه للتناسبي التفاضلي ذو المنطق المضبب.

INTRODUCTION

The most common application for single speed engines is the generator sets, also called GenSets. A GenSet consist of an internal combustion engine coupled to a three phase generator and sometimes an external control system for electrical power produce, where there is a need for backup power in case of mains grid failure, with ranging from several kW to MW. There are two main objectives for the controller in a single speed engine. The controller must provide accurate set point tracking as well as rapid compensation of load disturbances without steady state error [1]. When the GenSet is running in normal operation producing electric power, the engine speed and thus the generator frequency, must be held at a constant level that is drop regulation is used. Drop regulation means that the nominal speed is changed depending on the engine load. When the load on the generator changes, the engine will experience changed resistance in turning the generator. This will cause a change in engine speed. If the load is increased, the engine speed will drop. The task of the controller is now to compensate for the load disturbance in a way such that the engine speed returns to the desired value as smoothly and fast as possible. High scale power is created by three phase synchronous generator, called as Alternator. The driven shaft in the turbines or engine as a mechanical part, while for the electrical parts, are the placed on the immobile part known stator. Also, the windings of the armature are designed for generation of equalized three phase voltages coordinated to improve the same number of magnetic poles as the field winding that is on the rotor. The rotor is supplied with one or more short-circuited windings known as Damper winding. At constant speed, the rotor is driven by prime mover and excited by direct current flow. The excitation may be supplied through brushes and slip rings by means of AC generators mounted on the same shaft as the rotor of the synchronous machine [2]. While the internal combustion engines component are seen every day in Automobiles, power plant, home generators and other application. The term Internal combustion refers also to gas turbines except that the term is usually applied to reciprocating internal combustion (I.C.) engines like the ones found in everyday automobiles. An Internal Combustion Engine (ICE) is an artifact that generates mechanical power from the chemical energy [3].The engine consists of the two types: Spark Ignited (SI) and Compression Ignited (CI) [4]. The input parameters of the engine can be divided into four parts which are: throttle angle, spark advance angle (SA), exhaust gas recirculation (EGR), and air-fuel ratio (A/F) which involved in the output parameters. The output parameters can be divided into: engine speed, torque, fuel consumption, exhaust emissions, and drivability [5].

The aim of this paper is applying the control system to nonlinear model of the engine which includes:

Design of PID controller that improves the engine performance after tuning the controller parameters by using particle swarm optimization (PSO) technique which didn't used before this time to find the optimum PID parameters that lead to control the engine speed for running speed application also design fuzzy-PD like controller that improves the engine performance aiming to maintain the constant rotational speed and obtaining lowest overshoot, the error of steady state and quickly arriving to the target at constant speed with good stability.

Engine Generator Set Model

The simulation of engine has been modeled depending on four cylinder spark ignition internal combustion engine with throttle angle and engine speed as input and output for the system respectively [6]. The system modelling consists of five main elements which are: throttle valve, intake manifold, mass flow rate, compression stroke and recently the generated torque and the angular acceleration [7].

J : Engine Rotational Moment of Inertia (kgm2)
$\dot{m}_{ai}$: Mass Flow Rate into Manifold (g/s)
$\dot{m_{ao}}$: Mass Flow Rate of Air out of the Manifold (g/s)
N : Rotation Engine Speed (RPM)
$\dot{N}$: Engine Angular Acceleration (rad/s2)
p_{amb} : Ambient (Atmospheric) Pressure (bar).
p_m : Manifold Pressure (bar)
$\dot{p_m}$: Rate of Change of Manifold Pressure (bar/s),
T : Temperature (K)
Teng : Torque Produced by the Engine (Nm)
Tload : Load Torque (Nm)
Vm : Manifold Volume (m3)
σ : Spark Advance (deg)
θ : Throttle Angle (deg)

Throttle Valve

Throttle valve is one of the major components of electrical (engine-generator) set. Changing the aperture angle of the valve to set the amount of air- fuel ratio mixture through the combustion [8] .The throttle element is considered the first part of the simulation. Here, the control of the input is the angle of the throttle plate. The mass flow rate of air into the intake manifold can be expressed by equation (1) [9- 12]. Right hand side of the equation consists of two functions$f(\theta)$ and $g(p_m)$. The first function $f(\theta)$ can be calculated from the empirical study as a function to the throttle angle can be expressed by equation (2) while $g(p_m)$ can be expressed as a function of two parameters; atmospheric and manifold pressures. When the higher vacuum or lower manifold pressure, the flow rate through the throttle part is sonic and it is a function of the throttle angle depend on the low pressure behavior, the compressibility equations with a switching condition can be expressed by equation (3) [13]

$$\dot{m}_{ai} = \mathrm{f}(\theta) g(p_m) \quad \dots (1)$$

Where:

$$\mathrm{f}(\theta) = \mathrm{a}_0 - \mathrm{a}_1\theta + \mathrm{a}_2\theta^2 - \mathrm{a}_3\theta^3 \quad \dots (2)$$

Where; $\mathrm{a}_0, \mathrm{a}_1, \mathrm{a}_2, \mathrm{a}_3$ are constant, $\mathrm{a}_0 = 2.821$,$\mathrm{a}_1 = 0.05231$, $\mathrm{a}_2 = 0.10299$,$\mathrm{a}_3 = 0.00063$

$$g(p_m) = \begin{cases} 1 & , \ p_m \le \frac{p_{amb}}{2} \\ \frac{2}{p_{amb}}\sqrt{p_m p_{amb} - p_m^2} \ , & \frac{p_{amb}}{2} \le p_m \le p_{amb} \\ -\frac{2}{p_m}\sqrt{p_m p_{amb} - p_{amb}^2}, & p_{amb} \le p_m \le 2p_{amb} \\ -1 \ , & p_m \ge 2p_{amb} \end{cases} \quad \ldots (3)$$

Intake Manifold

The intake manifold designed to bring the air to each cylinder's engine through a pipe called runner. The throttle plate or sometimes called butterfly valve where it is existed at the upstream end of the intake system to control the air flow rate through the intake manifold for SI engines [14].

The intake manifold model has been simulated as a differential equation as a function for the manifold pressure. The net rate of changing of mass flow with respect time can be estimated through the calculation of variation between the incoming and outgoing of mass flow rates [9]. Depend on the gas low, this quantity is proportional to the derivative of time for the manifold pressure can be expressed by equation (4) [15].

$$\dot{p_m} = \frac{RT}{V_m}(\dot{m}_{ai} - \dot{m}_{ao} \quad \ldots (4)$$

Where:

R is Specific Gas Constant

Intake Mass Flow Rate

Based on the empirically derived equation, equation (5) describes the air mass flow rate out of the cylinders from the manifold. Whereas, ($\dot{m}_{ao}$) as a function of the speed of engine and manifold pressure [16].

$$\dot{m}_{ao} = -b_0 + b_1 N P_m - b_2 N {P_m}^2 + b_3 N^2 P_m \quad \ldots(5)$$

Where

; $b_0 = 0.366$, $b_1 = 0.08979$, $b_2 = 0.033$, $b_3 = 0.0001$.

Compression Stroke

Four-cylinder four-stroke engine located inline path, the four strokes (intake, compression, combustion, and exhaust) simultaneously convenes in this model. The second stroke is the compression stroke started from the instant at which the intake stroke ended after delaying the crank revolution 180° during the combustion phase.

Generated Torque and The Angular Acceleration

The torque is considered as the final parameter of the engine simulation model. An empirical formula to calculate the torque of the engine depends on the charge of the air mass, the mixture ratio of air/fuel, the advance of spark, and finally the engine speed as given by equation (6) [10] while the angular acceleration of the engine can be expressed by Equation (7) [9, 17].

$$T_{eng} = -c_0 + c_1 m_a + c_2(A/F) - c_3(A/F)^2 + c_4\sigma - c_5\sigma^2 + c_6 N - c_7 N^2 + c_8 N\sigma + c_9 \sigma m_a - c_{10}\sigma^2 m_a \quad \ldots(6)$$

Where:

$c_0 = 181.3$, $c_1 = 379.36$, $c_2 = 21.91$, $c_3 = 0.85$, $c_4 = 0.26$, $c_5 = 0.0028$, $c_6 = 0.027$, $c_7 = 0.000107$, $c_8 = 0.00048$, $c_9 = 2.55$, $c_{10} = 0.05$.

$$J\dot{N} = T_{eng} - T_{load} \quad \ldots(7)$$

Model Simulation

Figure (1) represents the IC engine system Simulink model (without controller). It is clear that the input variable is the throttle angle, while the output variable is the speed of the engine equations (1-7) that has been obtained from previous research by Crossly and Cook [11] and the corresponding Simulink model has been chosen from [9].

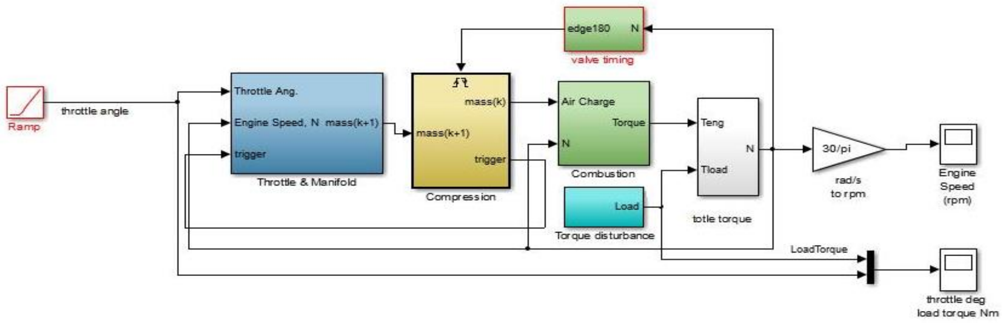


Figure (1) open loop system simulation model

Throttle /Manifold, Intake, Compression and Combustion Subsystem

Figure (2) represents the Simulink model of throttle / manifold subsystem. The subsystem has been consisted of three equations (1), (2) and (3), the natures of these equations are nonlinear for different variables, and also a multi input system. Since the throttle subsystem has three inputs (throttle angle, manifold pressure and atmospheric pressure) as shown in Figure (3).

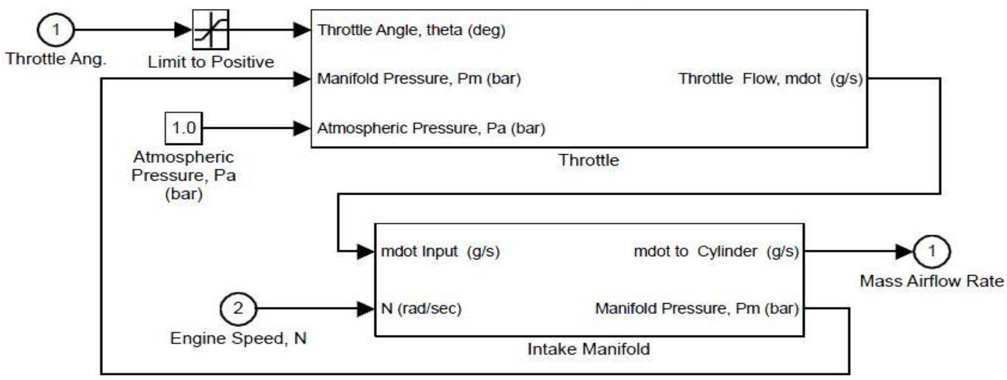


Figure (2) Throttle and Intake manifold subsystems

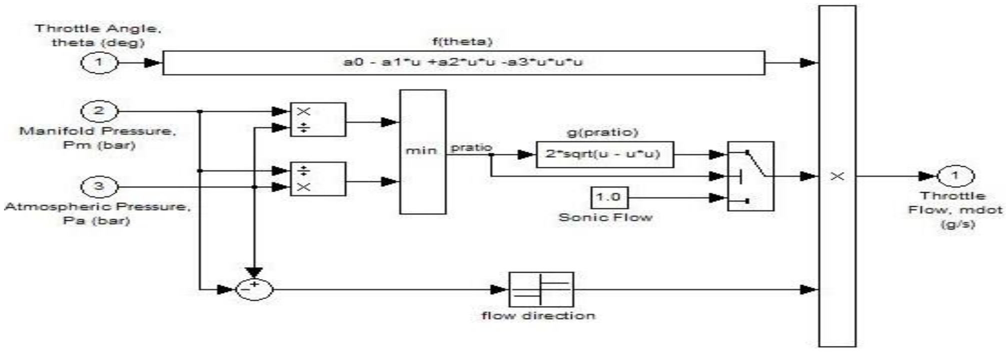


Figure (3) mass rate, throttle Angle and Pressure subsystem

Equation (4) can be simulated as shown in Figure (4) to determine the mass flow rate out of the cylinder, then to be treated with the mass flow rate into the cylinder to obtain the manifold pressure, while equation (5) is a function of engine speed and manifold pressure.

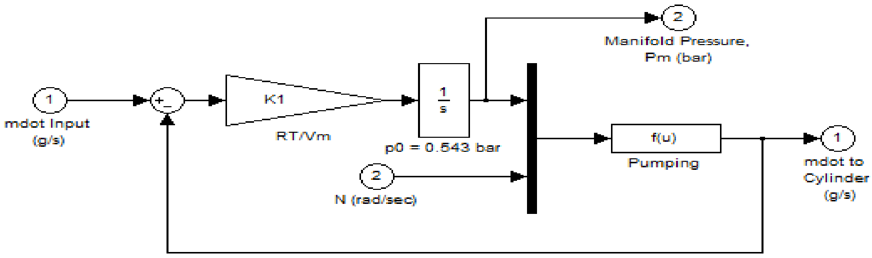


Figure (4) shows the Simulink model to calculate the mass flow rate

Figure (5) shows the model which uses a Mux block to combine these variables into a vector that provides input to generate the torque of the engine. Then the generated torque may be simulated through the functional block as described by the empirical formula.

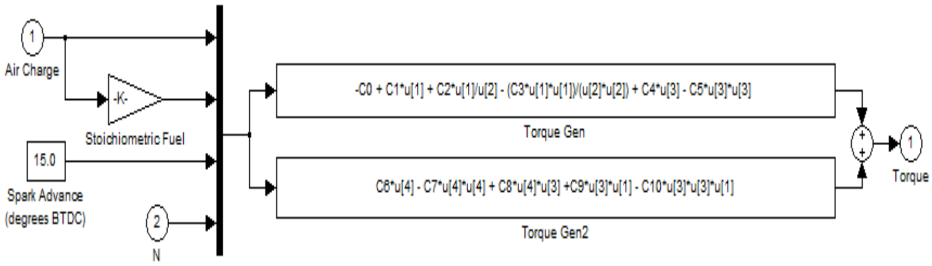


Figure (5): Torque of the engine subsystem

PID Controller

The most widely used control structure in the industrial control is the Proportional-Integral-Derivative PID controller. Over 90% of used operation controllers are PID controllers, this is because PID controllers are easy to tune, implement, and available at low cost [18]. A conventional PID controller is designed to regulate the throttle angle keeping constant speed in the presence of the drag torque. The equation of the PID controller in continuous time domain is:

$$u(t)=ke(t)+k\dot{e}(t)+k\int_0^t e(t)\,dt \qquad \ldots(8)$$

Where:
u (t): throttle angle (deg).
e(t): error in speed which is the difference between the desired engine speed r(t) and the actual speed y(t) as defined below:
e (t) = r(t)-y(t) and $\dot{e}(t)$ is the rate of change in the speed error (rad/sec).
However, Figure (6) shows a block diagram PID controller with closed loop system.

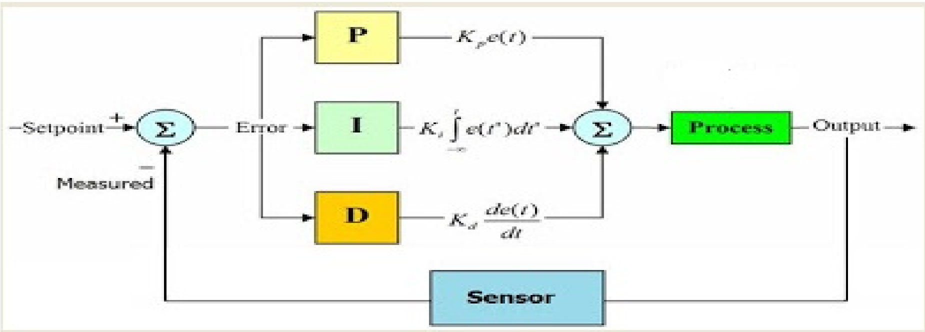


Figure (6) Closed loop system with PID controller [18]

Fuzzy Logic (FL)

FL was first proposed by Zadeh (1965) and is based on the concept of fuzzy sets [19]. On the other hand, FL is often defined as multi-valued logic (0 to 1) [20]. While Linguistic variables which allows computation with words instead of numbers [21] also membership functions are the essence of fuzzy sets. The function is used to associate a degree of membership of MFs can have different shapes. The simplest and most commonly used MF is the triangular-type because they give good results and computation is simple [22]. Finally the biggest advantage of fuzzy control is to provide an effective and efficient methodology for developing nonlinear controllers in practice without using highly advanced mathematics. The starting point in the construction of a fuzzy system is the forming of a knowledge-based consisting of IF-THEN rules [23]. Fuzzy algorithm consist of four major units, which are; Fuzzification, Rule Base, Inference Engine and Defuzzification as shown in figure 7 [24]

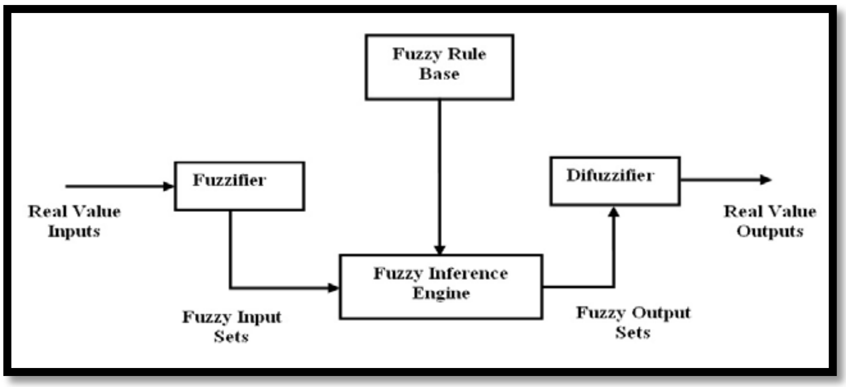


Figure (7): Configuration of a fuzzy control system [24]

PARTICLE SWARM OPTIMIZATION (PSO)

In PSO, each single solution is a “bird” in the search space; this is referred to as a “particle”. The swarm is modeled as particles in a multidimensional space, which have positions and velocities. These particles have two essential capabilities: their memory of their own best position and knowledge of the global best. Members of a swarm communicate good positions to each other and adjust their own position and velocity based on good positions [25]

$$v(k+1)i, j = w. v(k)i. j + c1r1(g\ best – x(k)I ,j) + c2r2(p\ bestj – x(k)I ,j) \quad \ldots (9)$$

$$x(k+1)I ,j = x(k)I ,j + v(k+1)i,j \quad \ldots.(10)$$

Where:

vi,j : velocity of particle i and dimension j, xi,j : position of particle i and dimension j, c1, c2: known as acceleration constants, W : inertia weight factor, r1, r2 : random numbers between 0 and 1, p best: best position of a specific particle, g best : best particle of the group.

In the gbest model, the trajectory for each particle’s search is influenced by the best point found by any member of the entire population. The best particle acts as an attractor, pulling all the particles towards it. Eventually all particles will converge to this position. The Pbest model allows each individual to be influenced by some smaller number of adjacent members of the population array [26]. Compared with GA and ANN optimization algorithm, standard PSO has the advantages of simple structure, fast convergence velocity and extensive adaptability.

Performance indices are defined as a quantitative measure to depict the system performance of the designed PID controller. Using this technique an ‘optimum system’ can often be designed and a set of PID parameters in the system can be adjusted to meet the required specification. For a PID- controlled system, there are often three indices to depict the system performance [27]:

Integral Square Error (ISE) = $\int_0^\infty e^2(t).\,dt$ …(11)

Integral Absolute Error (IAE) = $\int_0^\infty |e(t)|.\,dt$ …(12)

Integral Time Absolute Error (ITAE) = $\int_0^\infty t.\,|e(t)|.\,dt$ …(13)

Results and Discussion

Engie Generator Set Model Without Controller

The previous research [6] tested a model with unit step input as throttle angle variation between 8.973^o – 11.93^o at variation of uniform load 50% from maximum power, to obtain the suitable rotational speed as shown in figure (8 and 9). Then, the open loop test of engine model with ramp input which represent the throttle angle (0-90^o) with step of 5^o at no load condition, starting at 0 time instant with interval (0-17sec). The purpose of changing the unit step to ramp input function is; to study the system performance, maximum power and maximum speed for system at specified the throttle angle from (5^o to 90^o) as shown in figure (10).

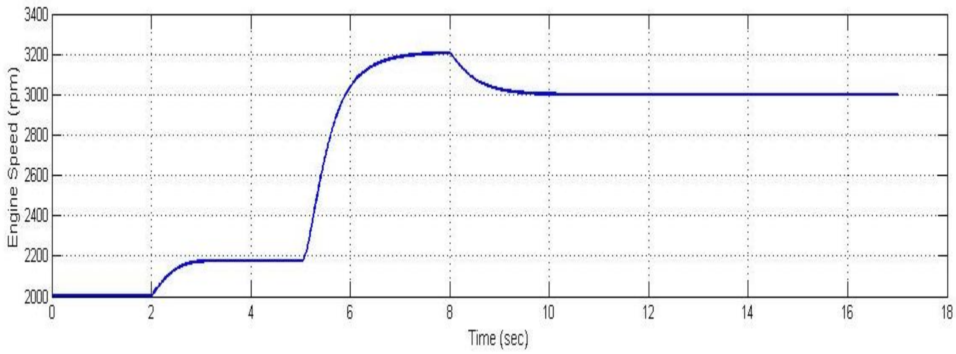


Figure (8) rotation Engine speed response

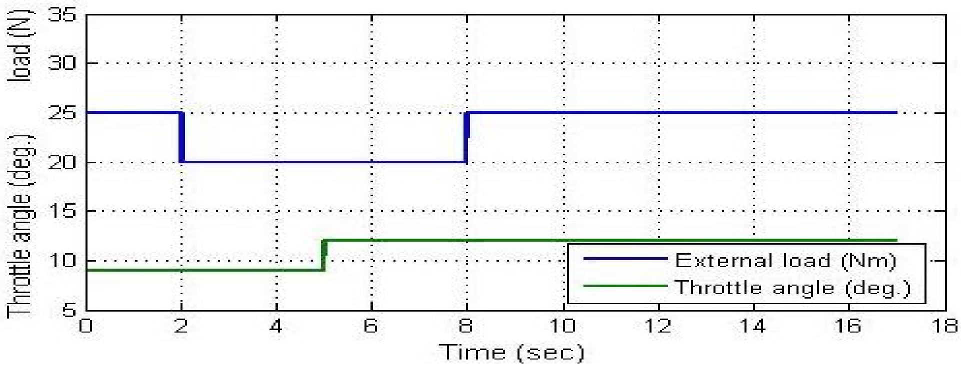


Figure (9) External load and Throttle Angle versus time

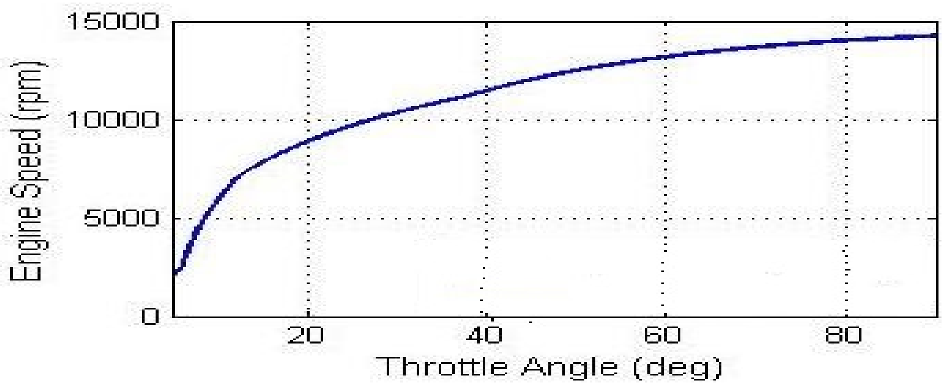


Figure (10) Variation of Rotation engine speed with Throttle angle

Figure (11) shows the relationship between the engine power – engine rotation speed whereas the increasing of engine rotation speed leads to increase in engine power until the speed reaches to 7000 rpm, then the power begin to decrease because of the inadequate time to ignition and burning the fuel completely to release the stored energy and the four strokes not achieved completely whereas the intake and exhaust valve still open.

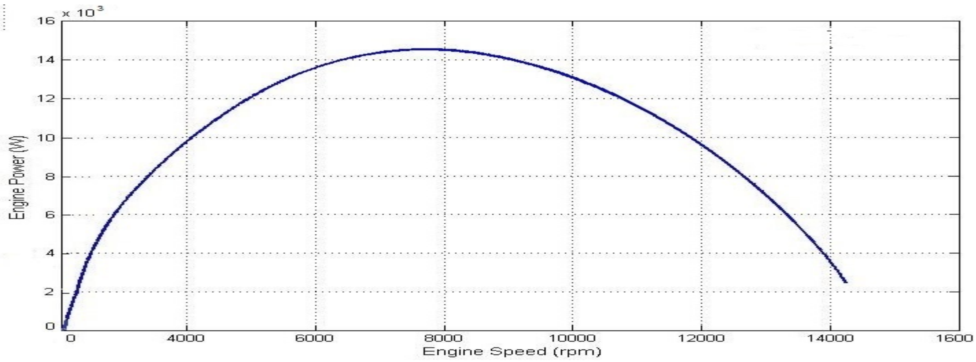
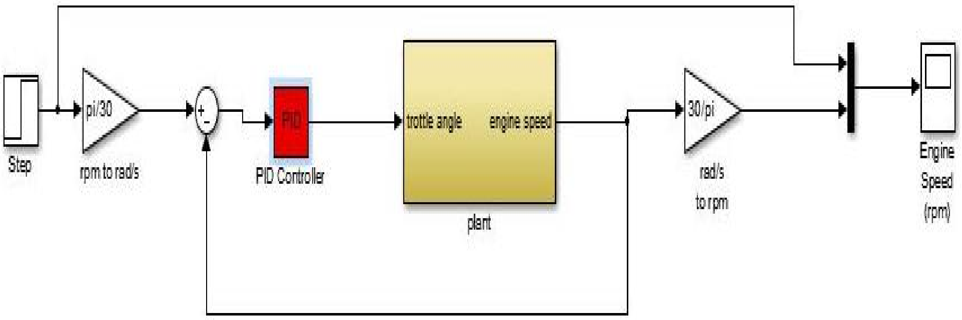


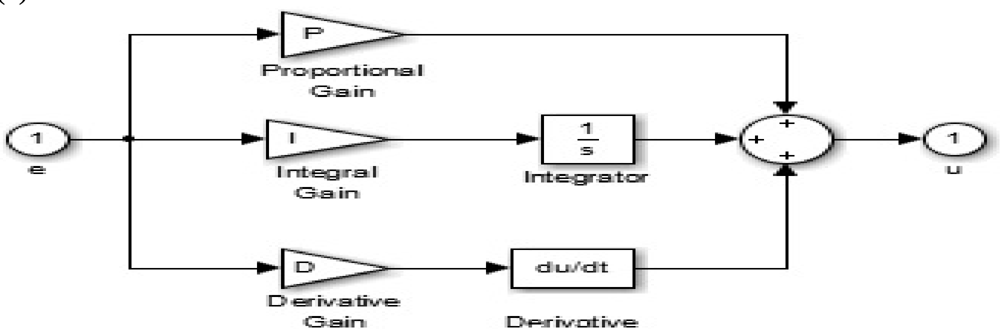
Figure (11) Variation of engine rotation speed with engine power

PID-PSO controller

Figure (12) shows the complete block diagram engine speed control system using conventional PID controller.



(a)



(b)

Figure (12) (a) System block diagram and (b) PID block diagram

The PSO tuning algorithm to adjust the corresponding values of gain is explained by using flow chart as shown in Figure (13).

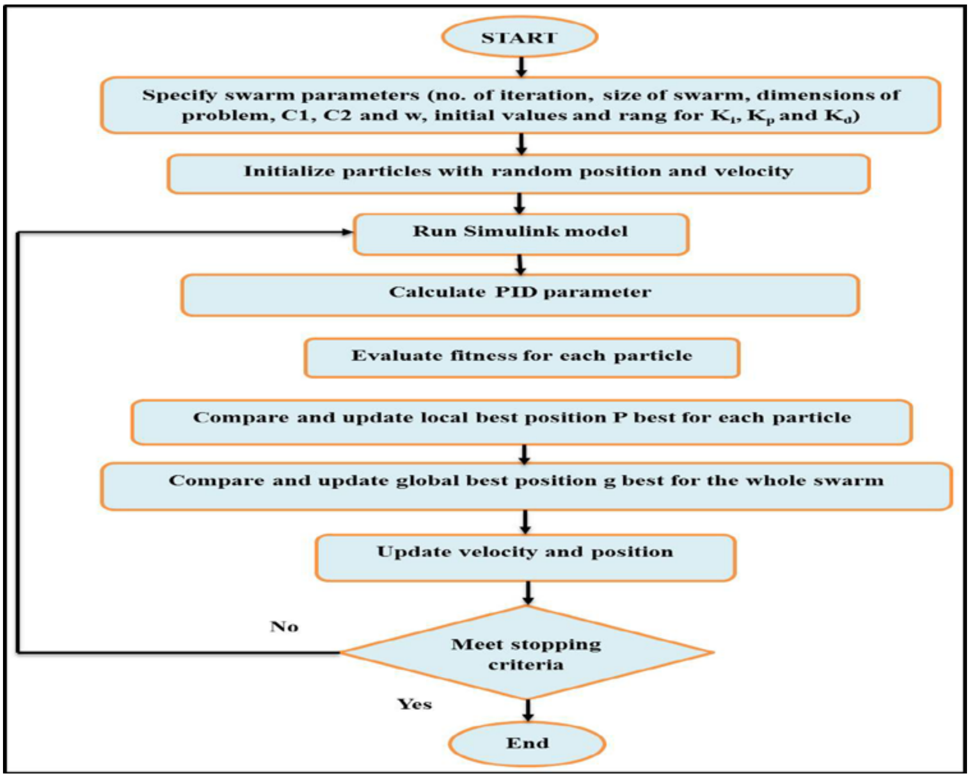


Figure (13) PSO Algorithm Flow Chart

The PSO algorithm parameters that achieved better solution depends on integrator square error (ISE) evaluation method are listed in Table (1).

Table (1): Parameters of PSO algorithm for tuning gains of PID controller

Swarm size (Number of birds)	60
Number of iterations	200
Cognitive coefficient (C1)	2
Social coefficient (C2)	2
Inertia weight (w)	2

Figures (14, 15 and 16) show the response performance of rotation engine speed after tuning the PID parameters by using PSO based on ISE, ITAE and IAE methods respectively and tables (2, 3 and 4) show response characteristic for ISE, ITAE and IAE methods respectively method. Whereas, The optimal PID-controller gains tuned by PSO method are using ISE method are Kp = 1.7948, Ki = 0.6768and Kd= 0.1000 while the optimum gains values using ITAE are; Kp=1.5521, Ki=0.6051 and Kd=0.1000 and finally the optimum gains values using IAE are; Kp=1.0281 , Ki= 0.5849and Kd=0.07 .

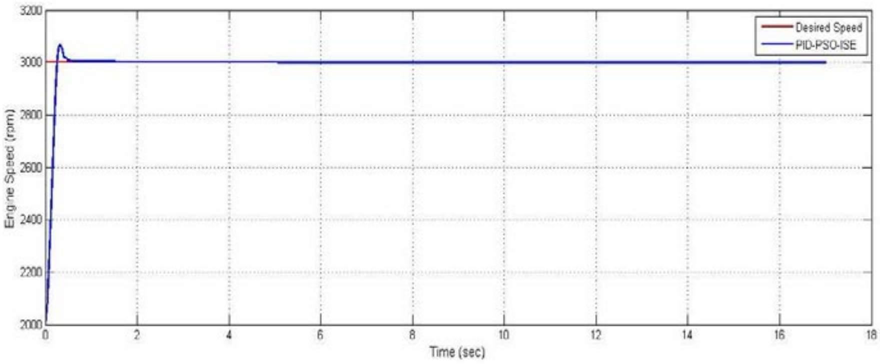


Figure (14) Engine rotation speed response with PID controller tuned by PSO – ISE (at no load)

Table (2) Response characteristic for PSO tuned method based on ISE method

Parameters	Value
Rise Time	0.1773 sec
Settling Time	0.4037 sec
Ess	0
% Overshoot	2.2686 %
Peak Time	0.3250 sec

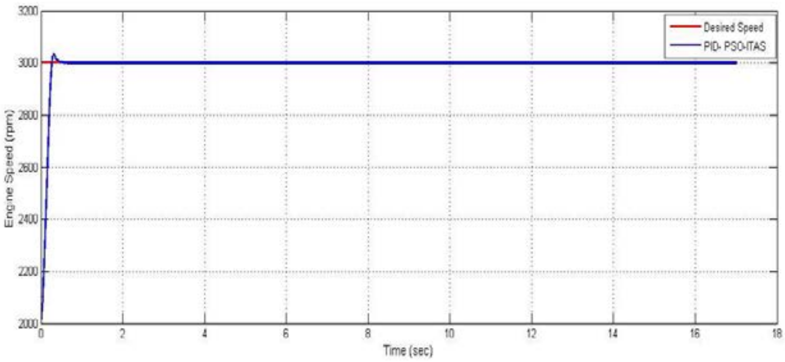


Figure (15) Engine rotation speed response with PID controller tuned by PSO-ITAE

Table (3) Response characteristic PSO tuned method based on ITAE method

Parameters	Value
Rise Time	0.1808 sec
Settling Time	0.3565 sec
Ess	0
% Overshoot	1.1833 %
Peak Time	0.3160 sec

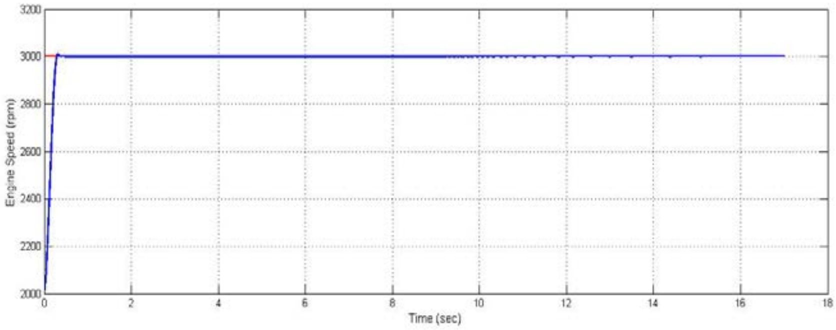


Figure (16) engine rotation speed response with PID controller tuned by PSO-IAE

Table (4) Response characteristic PSO tuned method based on IAE method

Parameters	Value
Rise Time	0.1862 sec
Settling Time	0.2743 sec
Ess	0
% Overshoot	0.3648 %
Peak Time	0.3080 sec

From the results above the designed PID controller using PSO based optimization for all performance indices have less settling time and overshoot compared with previous research [28] as shown in table (5).

Table (5) Comparison in Output Response with PID Controller Tuned by Different Methods

Parameters	**Ziegler Nichols**	**Heuristic**	**Linearization**	**ISE**	**ITAE**	**IAE**
Rise Time	0.265 s	0.301 s	0.417 s	0.1773s	0.1808s	0.1862s
Settling Time	1.295 s	1.643 s	1.583 s	0.4037s	0.3565s	0.2743s
Ess	0	0	0	0	0	0
% Overshoot	47.7%	2.7%	11.2%	2.2686%	1.1833%	0.3648%

Fuzzy Pd Like Controller

In this section, a PD like Fuzzy Controller is developed. This controller uses the continuous form of the conventional PD controller equation as follows:

$u(t)$=k_p x $e(t)$+ k_d x $ce(t)$ … (14)

Where

k_p and k_d are proportional and differential gain factors, $e(t)$ is the error and $ce(t)$ is the change in error. There are two inputs for PD like fuzzy controller which are: error and change in error while there is one output (throttle angle) as show in figure (17)

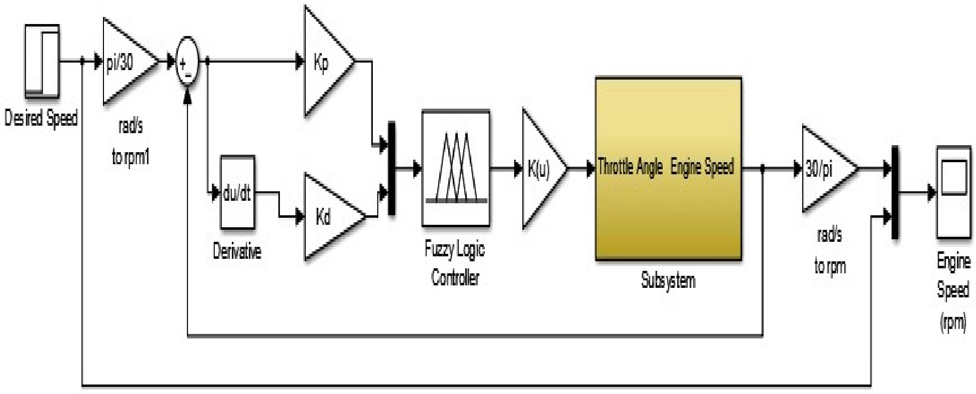


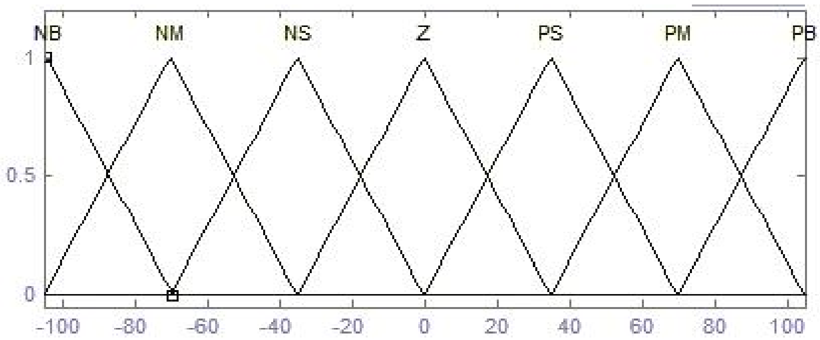
Figure (17) Closed loop system with PD like fuzzy controller

Assuming that there are seven membership functions on each input of the universe of discourse; NB stands for Negative Big, NM stands for Negative Medium, NS for Negative Small, Z for Zero, PS for Positive Small, PM for Positive Medium and PB stands for Positive Big. A widely used function is called triangular membership functions are chosen for all the inputs and output fuzzy sets as shown in Figure (18). From the number of the membership functions on the universe of discourse, there are forty- nine possible rules that can be used as the rule-base as shown in table (6).

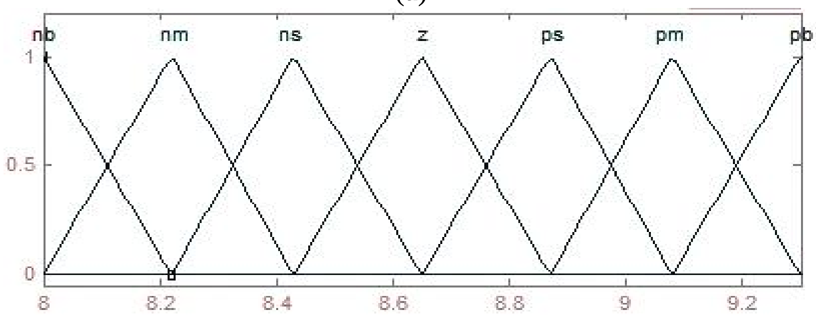
Table (6): Rule base of the PDFC [29]

Base rules		**Error (E)**						
		NB	NM	NS	Z	PS	PM	PB
Chang of Error (C E)	NB	NB	NB	NM	NM	NS	NS	Z
	NM	NB	NB	NM	NS	NS	Z	PS
	NS	NB	NM	NS	NS	Z	PS	PM
	Z	NB	NM	NS	Z	PS	PM	PB
	PS	NM	NS	Z	PS	PS	PM	PB
	PM	NS	Z	PS	PM	PM	PM	PB
	PB	Z	PS	PS	PM	PB	PB	PB

The range of input variables between (-105 to 105) depends on the range of error which had obtained from PID controller trial and error method. While the range of output variable between (8 to15) depends on the suitable angle which had obtained from PID controller trial and error method.



(a)



(b)

Figure (18) Membership Function for (a) Input variable and (b) Output Variable

Figure (19) shows engine rotation speed response without load and table (7) shows response characteristic for system.

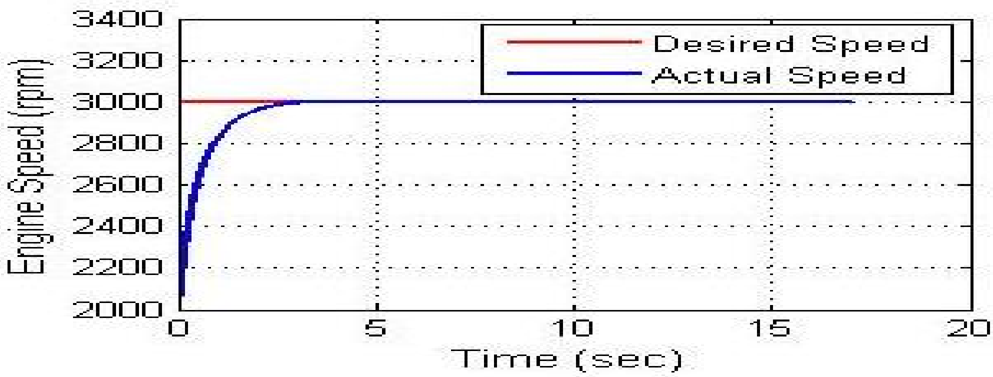


Figure (19) Engine rotation speed response at no load

Table (7) Response Characteristic

Parameters	**Value**
Rise Time	1.3309 sec
Settling Time	2.3547 sec
Ess	0
% Overshoot	0 %

Conclusins

From the results, the designed PID controllers using PSO based optimization have less settling time compared with the Fuzzy PD to regulate engine speed for all performance indices (ISE, IAE, and ITAE). Furthermore, the PSO-based PID controllers which are optimized with different performance index have similar performances, except that is optimized by IAE where less settling time and overshoot is seen. Therefore the benefit of using a modern optimization approach is observed as a complement solution to improve the performance of the PID controller designed by conventional method. On the other hand there are many techniques can be used as the optimization tools and PSO is one of the recent and efficient optimization tools.

References

[1] K. L Cheong, P. Y. Li, and J. Xia, "Control oriented modeling and system identification of a diesel generator set (genset)" In IEEE American Control Conference (ACC), pp. 950-955, 2010.

[2] T. W. Mon and M. M. Aung, "Simulation of synchronous machine in stability study for power system", World Academy of Science, Engineering and Technology, pp.128-133,2008.

[3] M. Y. Hassan and S. T. Al-Wais," Comparison Between Adaptive Fuzzy and PID Fuzzy Automotive Engine Controllers in Idle Speed Mode", Eng. And Tech Journal, Vol.28, No.23, pp.6786-6800, 2010.

[4] J. M. Molinar-Monterrubio and R. Castro-Linares," Sliding Mode Observer for Internal Combustion Engine Misfire Detection: Experimental Results" IEEE International Conference on Mechatronics, pp. 1-6, 2009.

[5] S. Mohammad reza," A Mean Value Internal Combustion Engine Model in MapleSim" , unpublished Master thesis, University of Waterloo, Canada, 2010.

[6] S. Namitha, R. Shantharama, " Fuzzy Logic Controller for the Speed Control of an IC Engine using Matlab \ Simulink", International Journal of Recent Technology and Engineering (IJRTE), Vol.2, No.2,pp. 124-127, 2013.

[7] A. A . Stotsky," Automotive Engines Control, Estimation, Statistical Detection", Springer-Verlag Berlin Heidelberg,2009.

[8] Y . Pan, U. Ozguner, and O. H. Dagci," Variable-structure control of electronic throttle valve", IEEE Transactions on Industrial Electronics, Vol. 55, No.11, pp.3899-3907,2008.

[9] Y. Kitsuka, T. Nomura, H. Suemitsu, and T. Matsuo," Adaptive Estimation of Mass Flow Rate of a Four-Cylinder Spark Ignition Engine". ICROS-SICE International Joint Conference, pp. 5224-5229, 2009.

[10] T. Kamaruddin, N. A. Tengku and , I. Z. Mat Darus ,"Neuro-Fuzzy Identification of an Internal Combustion Engine", International Journal of Simulation--Systems, Science & Technology, Vol. 13, No.3B, pp.30-37,2012.

[11] P. R . Crossley and J. A . Cook," A nonlinear engine model for drivetrain system development", International Conference on Control, pp. 921-925. IET,1991.

[12] A. Triwiyatno, M. Nuh, A. Santoso and N. Sutantra," Engine torque control of spark ignition engine using fuzzy gain scheduling". TELKOMNIKA (Telecommunication Computing Electronics and Control), Vol. 10, No. 1, pp. 83-90, 2012.

[13] B. K. Powell," A dynamic model for automotive engine control analysis", 18th IEEE Conference on Decision and Control including the Symposium on Adaptive Processes, Vol. 18, pp. 120-126, IEEE,1979.

[14] S. T. Al-Waysee," Fuzzy Logic Controller Design for an Automotive Engine ", unpublished Master thesis, University of Technology, Baghdad, Iraqi, 2007.
[15] E. Hendricks, "Engine Modeling for Control Applications: A Critical Survey", Meccanica International Journal, Vol. 32, No. 5, PP. 387-396,1997.
[16] P. Yoon, S. Park, and M. Sunwoo, "A Nonlinear Dynamic Model of SI Engine for Designing Controller", FISITA World Automotive Congress, 2000.
[17] B. K.Powell, and J. A. Cook," Nonlinear low frequency phenomenological engine modeling and analysis, American Control Conference, pp. 332-340, IEEE,1987.
[18] D. Yu, and J. Zang, "Research of PID Controller and Fuzzy PID Controller", International Journal of Information and Systems Sciences, Vol. 2, No. 3, PP. 384-397, 2006.
[19] L. A. Zadeh, "Fuzzy Sets", Information and Control, Vol.8, No.3, pp. 388-353 ,(1965).
[20] B. K. Bose, "Modern Power Electronics and AC Drives", USA Prentice Hall , 2002
[21] A. P. Engelbrecht, "Computational Intelligence", 2nd Edition, John Wiley and Sons Ltd, 2007.
[22] R. S. Burns, "Advanced Control System", India by integra software eservice Pvt Ltd, 2001.
[23] H. Ying, "Fuzzy Control and Modelling Analytical Foundations and Applications", IEEE Press, 2000.
[24] H. A. Hamad, "Fuzzy Logic-Based AVR Simulation for Steady-State Stability [Enhancement", unpublished master thesis, University of Technology,Baghdad, Iraq, 2006.
[25] A. T. Humod and W.N. Al-Din Abed, " Fuzzy-Swarm Controller for Speed-Governor of
Synchronous Generator", Eng. And Tech Journal, Vol. 31, Part (A) No.7,pp.1239-1259, 2013
[26] H. He, J. Z. Zhou, H. Lei, C. S. Li and L. Yang, "Research on Fuzzy-PID Excitation Controller of Synchronous Generator Based on Improved PSO Algorithm",Proceedings of the Eighth International Conference on Machine Learning and Cybernetics, Baoding, IEEE Publisher, Vol.2, 2009.
[27] M. I. Solihin, L. F .Tack, and M. L.Kean," Tuning of PID Controller Using Particle Swarm Optimization (PSO)", International Journal on Advanced Science, Engineering and Information Technology, Vol.1,No.4,pp. 458-461,2011.
[28] K. H. Mohd, K. Aishwarya, A. R. Ribhan Zafira and A. Siti Anom, "Design a PID Controller for a Constant Speed of Combustion Engine", Australian Journal of Basic & Applied Sciences, Vol.5, No.12 pp. 1586-1593, 2011.
[29] M. H. Saleh, M. Z. Othman and A. A. Al-Qassar," Design and Simulation of Fuzzy Like Pd Controller for Autonomous Mobile Robot", Iraqi Journal of Computers, Communications, Control and Systems Engineering, , Vol.11,No. 2, pp.38-45,2011