PSO Design an Optimal Fuzzy Controllerfor Heat Exchanger Temperature

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Abstract

The temperature in numerous chemical, industrial, heating ventilation and air conditioning HVAC applications is a very crucial variable. The temperature in these applications should be under control. This worked signs Fuzzy logic controller FLC for heat exchang system using a new technique. Heat exchang systems are used for transferring heat from a hot field to a cooler field; sotemperature control of outlet fluid is prime importance. The system of heat exchanger is always used for controlling the different temperature between outlet fluid and inlet fluid. Due to difficulty finding the parameters of the smart controller FLC, (Particle swarm optimization technique) have been projected to form the parameters of FLC. PSO is a heuristic method in computational algorithm. The contribution of our work is present PSO as a designer of FLC. The consequences demonstrate the designed controller reach to set point with the shortest time.

Keywords: PSO, FLC, Simulation, Heat exchanger, Temperature.

الخلاصة

إن درجة الحرارة في الكثير من التطبيقات الكيميائية والصناعية فضلا عن تطبيقات تدفئة وتهوية وتبريد الهواء تعد من العوامل البالغة الأهمية وعليه فلابد من أن تكون درجة الحرارة في هذه التطبيقات مسيطر عليها. تم في هذا لبحث تصميم مسيطر ضبابي للمبادلات الحرارية. يتم إستخدام المبادلات الحرارية لنقل الحرارة من المائع الساخن إلى آخر أقل سخونة. إن السيطرة على درجة حرارة المائع الخارج من المبادل الحراري ذات أهمية قصوى. نظراً لصعوبة التعرف على المتغيرات في نظام المسيطر الضبابي، فقد تم اللجوء إلى تقنية جديدة وهي تقنية تحسين سرب الطيور. إن الإسهام الفعلي في هذا البحث هو إستخدام تقنية سرب الطيور كأسلوب تصميمي لنظام المسيطر الضبابي. يعمل المسيطر الذي تم تصميمه على تنظيم درجة حرارة المائع الخارج من المبادل الحراري ضمن القيم المحددة مسبقاً وخلال أقصر وقت ممكن وبغض النظر عن الحمل أو الإضرابات أو الإجهاد وغيرها...

الكلمات المفتاحية: تحسين سرب الطيور، المسيطر الضبابي، محاكاة، مبادل حراري، درجة الحرارة.

1.Introduction

In achieveing of most chemical processes CP involves the production or incorporation of energy to heat. Heat exchang system HES usually can use in CP to reject heat to a cooler fluid from the hot fluid via solid wall. There are many types of HES are used in the industry purpose. Sometime this purpose use shell further more, it uses tubes.HES is shown in figure 1. Tube and shell may be the best devices are used in HES. A wide collection of temperatures or pressures can applied in heat exchangers applicable. In shell as well as tube of HES there are two fluids, first one flows through the tubes and a other flows within the space between the tubes shell (Anton Sodja *et. al.*, 2009; Katsuhiko Ogata 2010). The temperature of HES should be settled at a desired point with respect of the process requirement figure 1 shows the schematic diagram of HES. The control of heat-exchanger system consists of sensors, actuators limitation represents and serious problem from the point of optimal energy. The nonlinearity of HES is a big problem has been influence dperformance. Inour objective there are:

1) A real temperature plant
2) Tank of heated water
3) Plate heat-exchanger (the process taken from hot water to cold)
4) Two thermocouples (are located in the inlet and outlet)
5) Motor driven valve(to circulate water electrically and continuously)

The heated reservoir in a plate of HES is the counter-current flow fluid, sensors calculate the temperature (thermocouples) then both flow rates can be monitored. The controller of heater power can be achieved by time control using other external loop. The motor driven valve is to control flow of the heating fluid (Kiam Heong Ang *et al.*, 2005). The complicated systems have been developed by sophisticated control. One of them exist the tuning of PID Fuzzy logic controller to be a successful technology(Mridul Pandey *et.al.,* 2012, Zadeh,1989). Fuzzy logic (FLC) applications simulate human decision maker to create the precise solutions from certain or approximate information. But the drawback of this controller is how we cantune the parameters of FLC(Larsen , 1979). The conventional method recognizes by(trial and error), whilet his controller may exhibit undesirable results similar to a high overshoot. To minimize the overshoot so increased the performance of HES, we propose an optimal fuzzy logic controller is implemented using particle swarm optimization PSO algorithm. This paper is organized as follows: section 2 gives a brief introduction of heat exchang system. Assumptions made and sources of disturbances are also described along with mathematical modeling of system. Section 3 describes particle swarm optimization PSO. Section 4 describes fuzzy logic controller and its tuning, its membership function and rule base. Sections 5 and 6 show the implementation and simulation of the model with its resultant graphs. Sections7 and 8 show the results, discussions and conclusions.

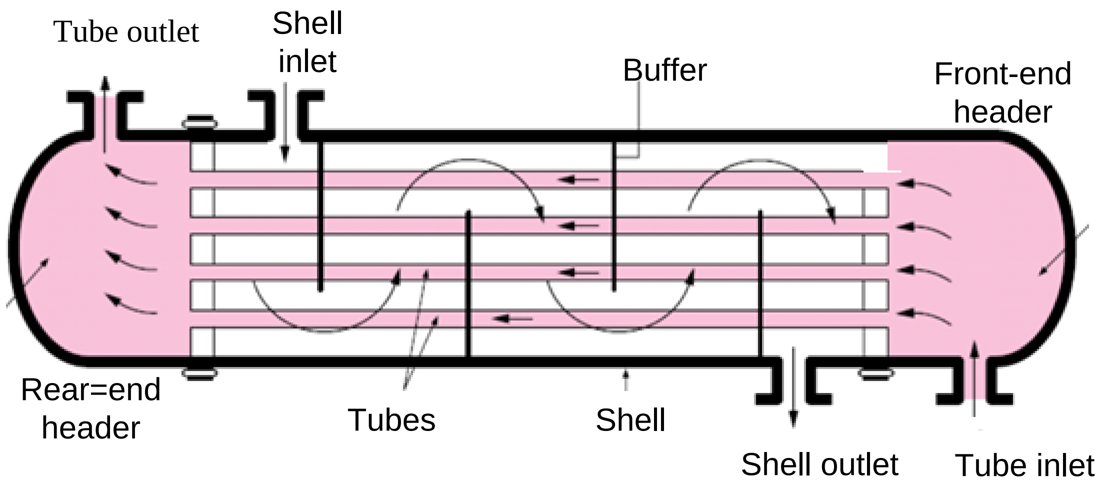

Fig. 1 Shell and tube of heat exchanger system.

2. Heat Exchang System (HES)

The most chemical procedures based on heating coordination, they consist of a chemical reactor (CR) and a shell and tube heat exchanger system. The steam comes from the boiler and flows from beginning to end of the tubes. The process runny flows via the shells and tube heat exchanger system (HES).The process fluid which is the output of the CR is stored in a tank. The tank supplies the liquid to the HES. The boiler supplies the super-steam to increase the heat of flow fluid in HES to reach the desired set point (Castellano *et.al.*, 1997). The storage tank consist of equipment have the process of fluid to HES using a pump and a non-returning valve. There are paths of non-condenseds team to go out of the shell and tube HES with the purpose of avoiding the blocking of HES.

2.1. Some Assumptions

Many assumptions are considered in this work they are:

(i) Neglect the heat storage capacity of the insulating wall.
(ii) The out flow rate equal to the inflow.
(iii) The sensing element was a thermocouple which is implemented in feedback path of the control.
(iv) Thet hermocouple converts the output temperature to a standardized signal in the range of 4-20 mA. Then the desired temperature of the fluid is calculated by the thermocouple and sent to the transmitter unit.
(v)The controller tacks a signal from the transmitter unit.

2.2. Mathematical Modeling of (HES) Heat Exchanger System

The heat exchanger system (HES)consists of:

An actuator, sensor (thermocouple), valve, are mathematically modeled and simulated by MATLAB/SIMULINK. Figure 2 shows the Modeling heat exchanger system. The process data’s are given from(Dinuzzo F. and Ferrara A. 2009):

1. Exchanger response to the steam flow gain $= 50℃/kg/sec$
2. Exchanger response to variation of process temperature gain $= 3℃/℃$
3. The range of temperature sensor $= 0℃\ to\ 70℃$
4. Exchanger response to variation of process fluid flow gain $= 1℃/kg/sec$
5. Control valve capacity for steam $= 1.6\ kg/sec$
6. Time constants$=30\ sec$
7. Time constant of temperature sensor $= 10\ sec$
8. Time constant of control valve $= 3\ sec$
9. Gain of current to pressure converter $= 0.75$
10. Gain of valve $= 0.13$
11. Transfer function of process $= \frac{50e^{-s}}{30s+1}$
12. Transfer function of valve $= \frac{0.13}{3s+1}$
13. Transfer function of disturbance variables are:

    (i) Flow of inlet$= \frac{1}{30s+1}$ (dominant pole).

    (ii) Transfer function of thermocouple $= \frac{0.16}{10s+1}$.

    (iii) Temperature $= \frac{3}{30s+1}$

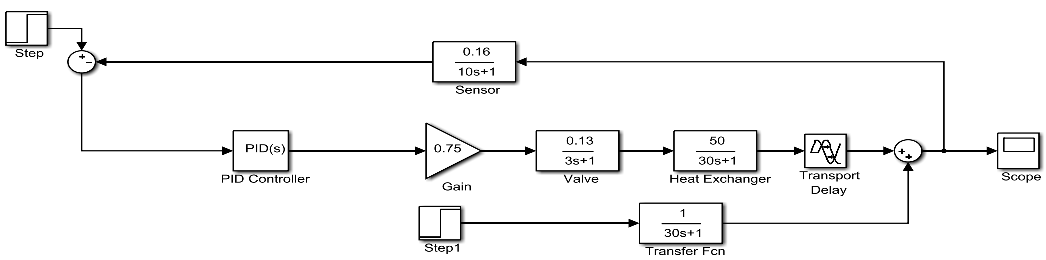

Fig.2 Modeling heat exchanger system.

3. Particle Swarm Optimization (PSO)

The behavior of (bird flocks or fish swarm) and its dynamic searching for food have been simulated by (Kennedy and Eberhart in 1995),(Krohling and Rey, 2001), (Hackl *et.al.*, in 2016; Chraibi *et.al.*, 2016).The mathematical model of routine life of these animals becomes one of the most accepted methods in optimization and Artificial Intelligent (AI) namedParticle swarm optimization (PSO). This method has many benefits to heuristic way for researchers:

1) A robust method in solving non-linearity or non-differentiability problems.
2) The PSO algorithm didn't use evolutionary operators (mutation or crossover).

PSO can summarize by taking a set of random companions as a (swarm) while each component represents a (particle), it is assumed the particles fly in many directions to meet the demand fitness function (Ishaque *et al.*, 2012). These directions (n-dimensional) characterize the space of search. For the i^{th} particle and n-dimensional space can be formed in Eq. (9), and the best position in the Eq. (10):

$$x_i = (x_{i,1}, x_{i,2}, \ldots\ldots x_{i,n}) \qquad (1)$$

$$P_{best_i} = (P_{best_{i,1}}, P_{best_{i,2}}, \ldots\ldots P_{best_{i,n}}) \qquad (2)$$

The velocity is an essential part of how PSO work can be calculated using Eq. (3), this equation shows the modified velocity depend on the distance between ($P_{best_{i,d}}$) and (g_{best_d}). The current velocity can modify the position of each particle by Eq. (4).

$$V_{i,m}^{(It.+1)} = W * V_{i,m}^{(It.)} + c_1 * r * \left(P_{best_{i,m}} - x_{i,m}^{(It.)}\right) + c_2 * r * \left(g_{best_m} - x_{i,m}^{(It.)}\right) \qquad (3)$$

$$x_{i,m}^{(It.+1)} = x_{i,m}^{(It.)} + v_{i,m}^{(It.)} \qquad (4)$$

Where: i = 1, 2, 3 … number of particles

m = 1, 2, 3 … number of dimensions

It. is Iterations pointer

W: Inertia weight factor.

C_1, C_2: Acceleration constant.

r: random variable between (0 – 1).

$V_{i,m}^{It}$: the velocity of particle number (*i*) at iteration number (*It*).

$X_{i,m}^{It}$: Current position of particle (*i*) at iteration (*It*).

P_{best} : Previous best position of the particle number (*i*).

G_{best} : Global best particle among all the swarm.

4. Fuzzy Logic Controller (FLC)

The scaling of Fuzzy Logic Controller is very important in order to process the input to get the output reasoning there are four steps involved in the creation of a rule based fuzzy system in Mamdani type:

(1) Categorize the ranges and name of inputs and outputs.
(2) Input and output membership functions should be created.
(3) Build the rules (if …then…) statement.
(4) Combine the rules and defuzzify the output

The adjusting scales of the inputs and outputs in FLC are very important (Jang ,1993). The performance of fuzzy logic operations determines by decision-making-logic together with the knowledge about the outputs of each IF-THEN rules. Those calculate the crisp values of output by calculating the center of gravity or the weighted average this process called defuzzification.

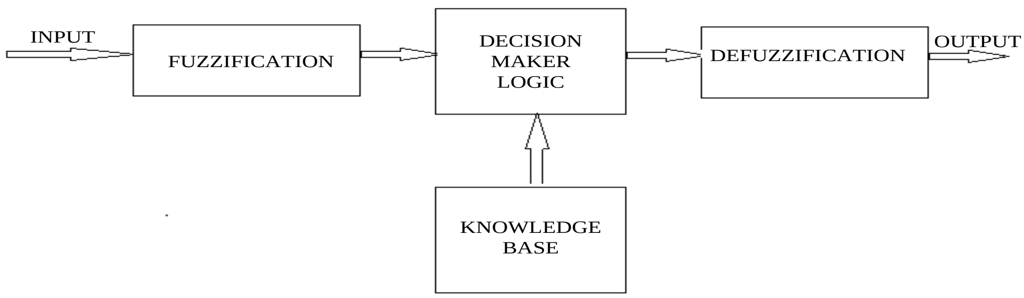

Fig. 3 Fuzzy Controller Block Diagram.

The FLC are designed with two input variables, error and rate of error and one output variable (i.e.) the hot water flow rate to the shell side (Rahman *et.al.,* 2013). Figure 3 shows Mamdani based fuzzy inference system uses linear membership function for both inputs and outputs. For the FLC the input variables are error (e)and rate of error (Δe), and the output variable is the change in controller. Figure 5 shows the output Surface diagram of FLC. The rule base framed for shell and tube heat exchangers are tabulated in Table1.

For the evaluation of the rules, the fuzzy reasoning unit of the FLC has been developed using the Max-Min fuzzy inference method (Cortes-Rios *et.al.*, 2014). In the particular FLC, the centroid defuzzification method is used. Linguistic variables for error, rate of error and controller output are as follows.

Table 1: Linguistic variables and Rules control of fuzzy logic controller.

		Δe			
	LN	SN	Z	SP	LP
LN	LP	LP	MP	SP	Z
SN	LP	MP	SP	Z	SN
d/dt(Δe) Z	MP	SP	Z	SN	MN
SP	SP	Z	SN	MN	LN
LP	Z	SN	MN	LN	LN

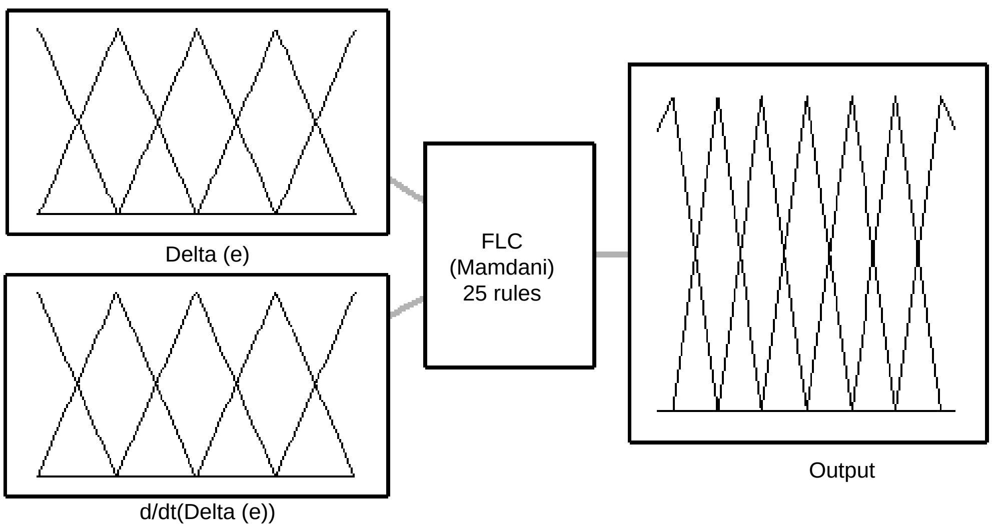

Fig. 4Membership function of error,membership function of rate of error andmembership function of control output.

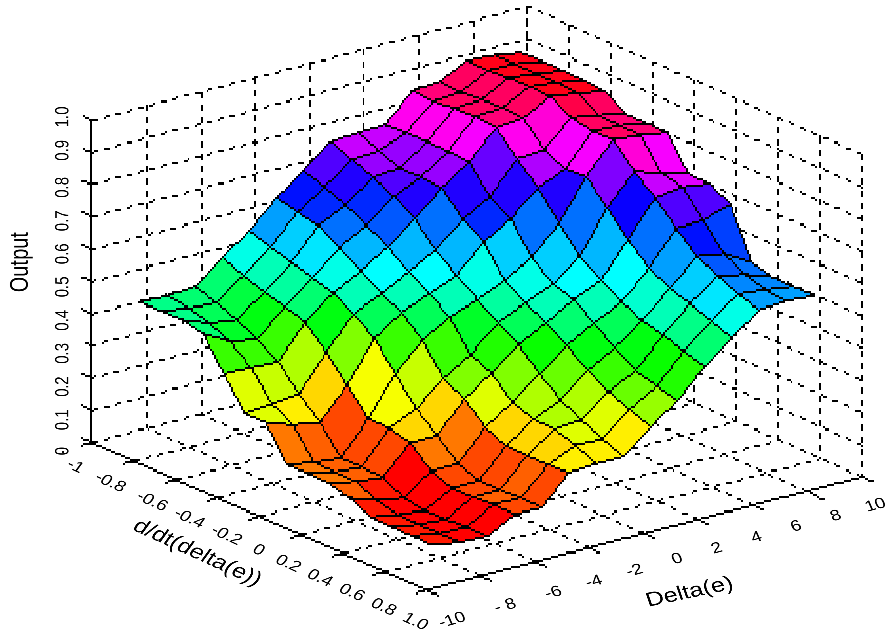

Fig. 5 Surface diagram of FLC.

5. PSO-FLC Implementation

The fuzzy rules and the shape of (input / output) Membership Functions (MFs) are not available. In general, there is no formal framework to choose these parameters, hence tuning them and learning models have become an important subject in fuzzy control. In such situations an ordinary FLC used (trial-and-error) to determine its parameter. Fuzzy controller designed to observe the pattern of the power loop error signal to update the pitch control correspondingly, the reference power, track the maximum power according the wind speed, this controller has two inputs (error-power e and rate of error-power (*de/dt*), each input has five triangle membership, and twenty five (*if*) statement rules are used. In our work PSO was utilized to design seven triangles MFs as an optimal shape for (output MFs), the particles of PSO have information about the shape of MFsFigure 6 shows the flow chart of the proposed method. They have 3-dimension represents three points (the top of the triangle), they have the same remoteness points for other mid side, and these triangles were presented in figure 6. Thebehaviorof (Bird 4) flock search for food. The circles means the best points have been visited by a bird, and the star is the best point visited by the flock. The final velocity and its individual components are also depicted in Bird 4.The PSO algorithm is implemented using MATLAB/m-file program, this program linked with the system simulation MATLAB/SIMULINK to calculate the fitness functions. The Integrated of Square Error ISE is the optimization criteria of our work as bellow:

$$FF = ISE = \int_0^t e^2(t)dt \tag{5}$$

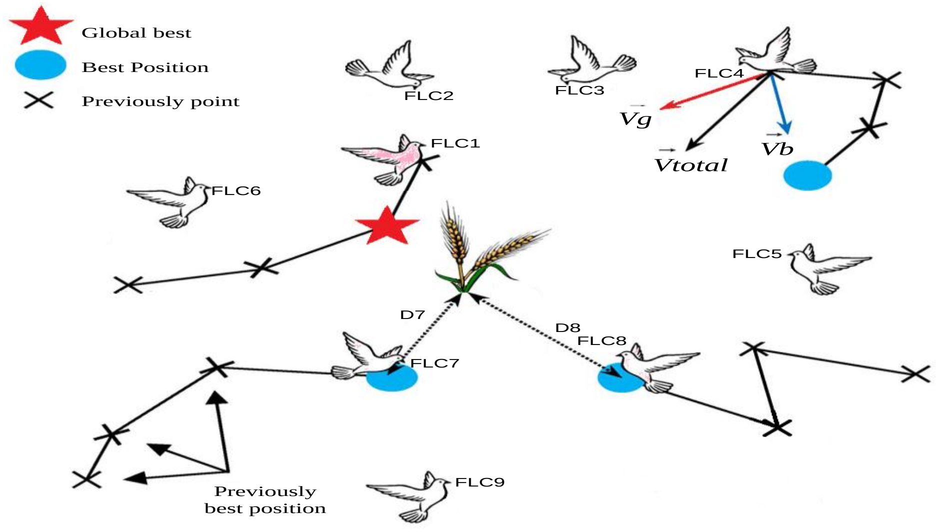

Fig. 6 Simulation of purposed technique (Particle Swarm optimization) .

6.Simulation

The simulation for different control mechanism discussed above was carried out in Simulink in MATLAB and simulation results have been obtained.

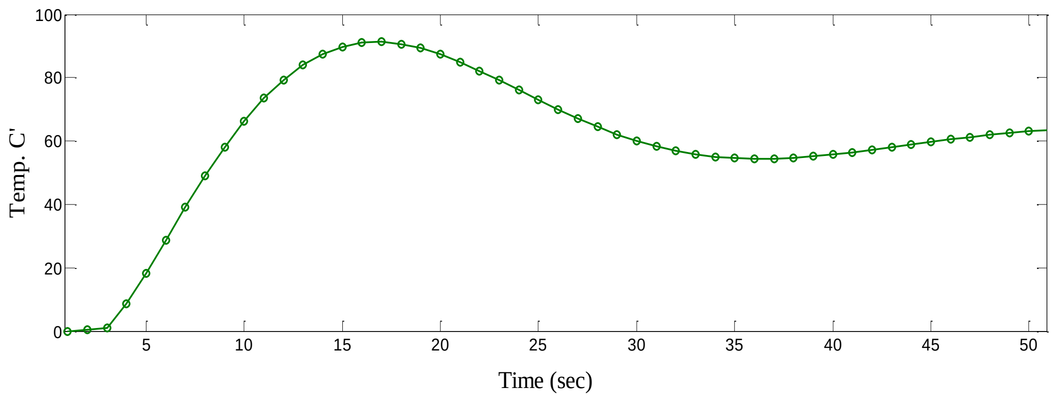

Fig. 7 PID step response.

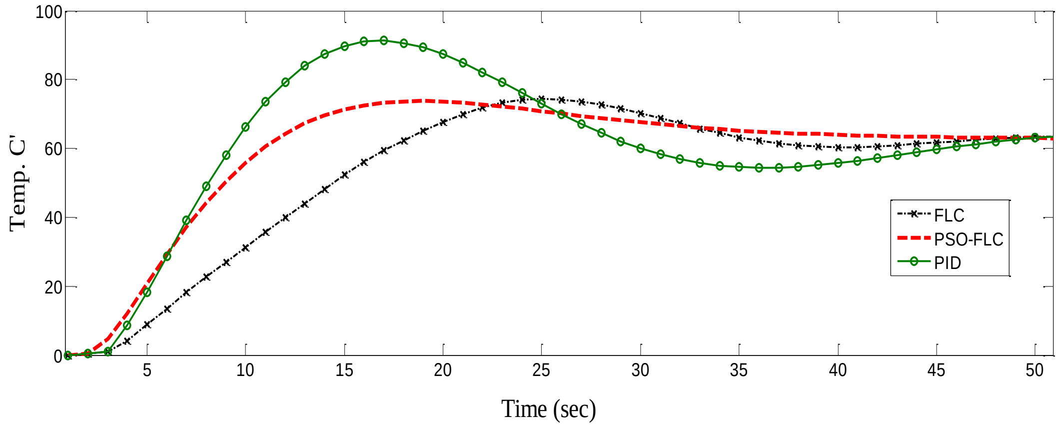

Fig. 8 Step response of PID controller, FLC and PSO-FLC.

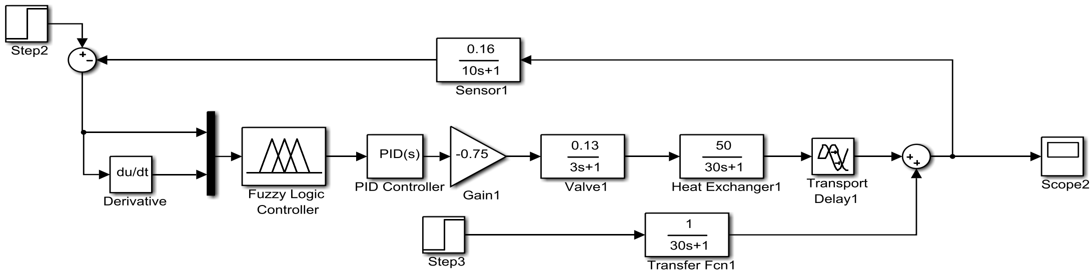

Fig. 9 System in FLC controller.

7. Simulation Result sand Discussions

Fuzzy logic controller FLC is developed with 5 membership functions for each input variable was simulated in MATLAB as shown in figure 9. The assessment performance of different controllers, this work has considered two vital parameters of the step response of the system. The (i) parameter is the maximum overshoot, (ii) the settling time. In this paper control of heat exchanger temperature is done by three different controllers. In PID controller the parameters have been tuned automatically by MATLAB In step response, it was found that the large overshoot and satisfactory settling time both of which are undesirable. Fuzzy logic controller FLC is developed with 5 membership functions for each input variable before tuning was a large settling time and overshoot satisfactory. But, with optimal Fuzzy Logic Controller PSO-FLC both settling time and overshoot were satisfactory as shown in figure 8. Figure 10 shows output memberships after tuning.

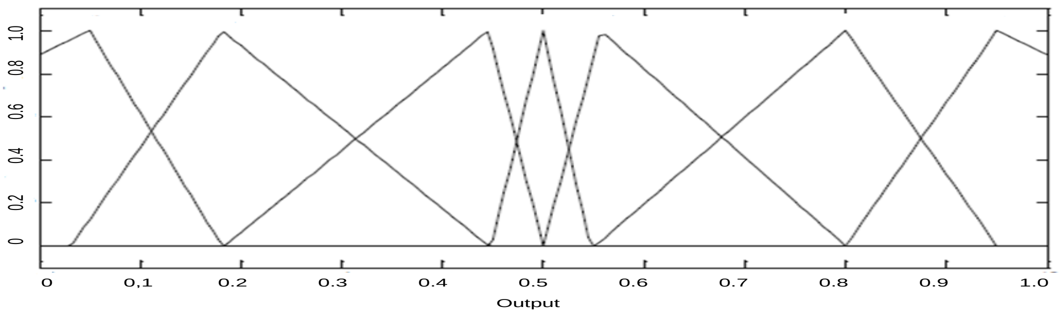

Fig. 10 The output memberships after optimization.

8. Conclusions

1) The unsatisfactory results obtained using fuzzy control while proposed approach FLC was a super scheme due to its ability of prediction.
2) Robust controllers have been designed to give a superior performance for different devices.
3) Fuzzy Logic Control FLC was proposed as a powerful tool. FLC applications can solve the highly nonlinear problems. Generally, the fuzzy system is designed by converse with an expert and framing this system implicit information about the fundamental process into fuzzy parameters (set of linguistic variables and fuzzy rules).
4) Actually, in the complex control tasks, obtaining the fuzzy knowledge base from an

expert is regularly created using trial and error; this method gives parameter on a tedious and unreliable approach, and the parameters are farther than its optimal values.

5) Characteristically, the scaling of the FLC parameters needs an effective and preferable method. In this work a powerful algorithm has proposed as an automaticmethod in fuzzy system design.
6) The Particle Swarm Optimization (PSO) is considered one of modern heuristic algorithms and stochastic algorithm.

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