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# Performance Evaluation of Fuzzy based Water bath System with Variation in Number of Linguistic Variables and Membership Function Range

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***ABSTRACT- The proposed work describes the designing of water bath system based on fuzzy logic and performance evaluation of fuzzy logic controller in Water-Bath temperature control system using SIMULINK and MATLAB Fuzzy Logic Toolbox. The motto of this paper is using fuzzy logic for controller design which outperforms conventional controllers like PID and gives water-bath output with maximum smoothness, uniformity and minimum overshoot. Performance evaluation has been done for this system using Triangular and Gaussian membership function. Number of linguistic variable (fuzzy sets) used are nine and eleven for each membership function. Also each membership function is tested with MF base range width 0.8 and 1. The evaluation is done for the parameters rise time, settling time, overshoot. The fuzzy inference used is of MAMDANI type and centre of gravity (COG) technique used for defuzzification.***

***Keywords: Fuzzy logic, Triangular, Gaussian Membership function, Water-bath system, SIMULINK.***

## I. INTRODUCTION

Water-bath temperature control system is most essential process control application. Many commercial companies need water bath temperature control system for maintaining liquid at particular temperature. Academic laboratories[11], biological research labs need it to preserve biological samples at constant temperature. Thus due to need of time researchers found it one of the areas to focus their research work. The main focus is given to get output temperature as close as set temperature within defined timing range with good tracking capacity. Currently work is being done on Fuzzy Controller, Neural Network, and Hybrid Controller.

Classical control theory like PID usually requires a mathematical model. If the inaccuracy occurs in mathematical model then it degrades the performance of the system**.** Thus fuzzy logic is one of the strong alternatives of conventional controllers due to its unique features.

**Advantages of fuzzy logic**

- Fuzzy logic is flexible to use since rules can be altered and modified easily.
- Fuzzy logic is easy to learn and apply to any system since it does not require mathematical modeling of plant.
- It gives better performance for non-linear and complex systems.

Water bath system is non-linear system. Thus conventional controllers which was used initially in water bath system are tend to have slow response and lag in output. Thus fuzzy logic based controllers can be better performers for non-linear and complex systems since it is robust, knowledge based and easy to implement system. Developing fuzzy logic controller is cheaper and it can be designed by expert operator.

Om Prakash Verma et al. [1] worked on designing of water bath system based on fuzzy logic controller. This work has been done with 7 fuzzy sets, 49 rules and Gaussian type of membership function. Naw Octavia et al. [2] worked on water bath system using fuzzy logic with seven linguistic variables with 50% overlap and Gaussian membership function. Proposed water bath system is designed using fuzzy controller with nine as well as eleven linguistic variables. For 9 fuzzy sets 81 rules are created while 121 rules created for 11 fuzzy sets.

Comparison analysis is done with Gaussian and Triangular membership function with two different base range of MF [-0.4,0.4] & [-0.5,0.5]

## II. SYSTEM OVERVIEW

Water Bath system is mainly used in process control applications. Its main parts are water tank, sensor, heater and stirrer. Input of system is cold water and output is hot water. Water volume is constant thus flow rate of input and output are same.

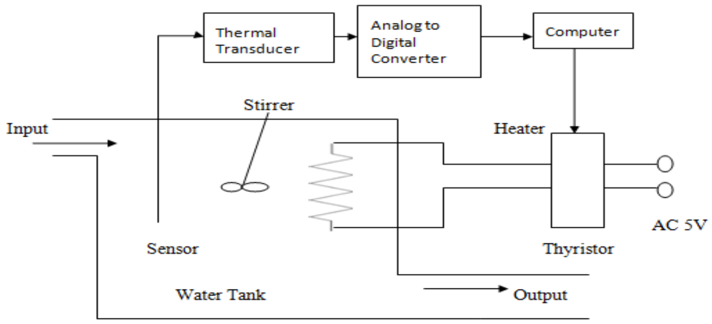


***Figure 2.1 Water bath system***

The dynamics of the water-bath temperature control system

$$\frac{dT}{dt} = \frac{F}{V}(T_i - T) + \frac{Q}{\rho V C_p} \qquad \text{....... (1)}$$

Where: T = Tank Temperature
F = Flow rate
Ti= Inlet temperature
V= Volume of tank
Q= Heat input
$C_p$= Specific gravity
$\rho$ =Density of water

The equation of water bath temperature control system presented in continuous time as

$$\frac{dy(t)}{dt} = \frac{F(t)}{C} + \frac{Y_0}{RC} - \frac{Y(t)}{RC} \qquad \text{....... (2)}$$

Where: t= time
T= sampling time period
Y (t) = output temperature in ℃
F (t) = heat flowing inward the system
$Y_0$ = room temperature
C= system thermal capacity
R= thermal resistance between the system borders and surroundings.
Assume R and C constant.
Laplace transform of equation (2) is

$$sY(s) = \frac{F(s)}{C} + \frac{y_0(s)}{RC} - \frac{Y(s)}{RC}$$

Let,

$$a = \frac{1}{RC}, \quad b = \frac{1}{C}$$

and $U(s) = F(s) + \frac{a y_0(s)}{b}$

$$Y(s)\left(s + \frac{1}{RC}\right) = \frac{F(s)}{C} + \frac{y_0(s)}{RC}$$

$$Y(s)(s + a) = b\left[F(s) + \frac{a y_0(s)}{b}\right]$$

$$G(s) = \frac{Y(s)}{U(s)} = \frac{b}{s+a} \qquad \text{....... (3)}$$

Taking the z transform

$$G(Z) = \frac{Y(z)}{U(z)} = \frac{bz}{(z-a)(z-1)} \qquad \text{...... (4)}$$

a, b are some constant values depending on R and C, the remaining parameters are given below

Where $\alpha = e^{-aT}$

$\beta = \frac{b}{a}(1- e^{-aT})$

Parameters are a =$1.0051\times10^{-4}$ and b =$8.67973\times10^{-4}$ was obtained from the real water bath plant. Thus equation (4) becomes

$$G(Z) = \frac{Y(z)}{U(z)} = \frac{0.26z}{(z-0.9969)(z-1)}$$

$$G(Z) = \frac{Y(z)}{U(z)} = \frac{0.26z}{(z^2-1.9969z+0.9969)} \qquad \text{....... (5)}$$

sampling period is T>= 30sec.

## III. DESIGN PROCEDURE

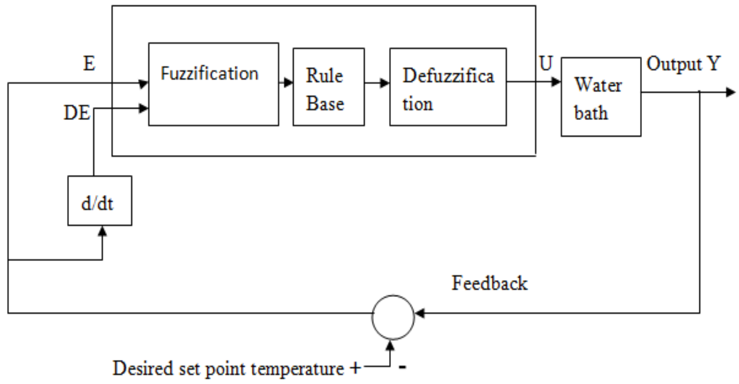


*Figure 3.1 Block diagram of FLC with Water-bath system*

FLC controller has two input and one output. The inputs of FLC are error (E) and derivative of error (DE), U is the output of fuzzy logic controller. Error temperature is difference between desired set temperature and actual output temperature in the form of feedback. Derivative of error is obtained by derivation of error temperature with respect to time. Above block diagram has water-bath system as a plant and fuzzy logic based controller. 3 parts of FLC are fuzzification, defuzzification and rule base.

Fuzzification conversion of crisp to non crisp or fuzzy values. Rule base is set of rules designed by expert to apply the system. fuzzification is conversion of non crisp or fuzzy to crisp values. The output of FLC is control signal U which act as input to plant and drives the water bath system.

### A) GUI tools for implementation

- FIS editor defines input and output of system.
- Rule Base editor creates rules for system.
- Membership function editor defines membership function type, its name and corresponding range.
- Rule viewer gives numeric values output for given numeric input.
- Surface viewer represents input and output graphically.

### B) Membership function

Two inputs error (E) and derivative of error (DE) as well as output control signal(U) represented in membership functions are defined with common range[-1,1] . Proposed system uses 9 and 11 fuzzy sets each with MF base range [-0.4.0.4] and [-0.5,0.5] separately. Range [-0.4,.4] forms MF base width 0.8 unit and [-0.5,0.5] forms base width 1 unit from the range[-1,1]. Analysis is done for Gaussian as well as triangular membership function.

Nine fuzzy sets are (VHP,HP,MP,LP,ZE,LN,MN,HN,VHN)

Eleven fuzzy sets are (EHP,VHP,HP,MP,LP,ZE,LN,MN,HN,VHN,EHN)

Where:

EHN: Extreme high negative VHN: Very High Negative HN: High Negative

MN: Medium Negative LN: Low Negative

ZE : Zero Error

LP: Low Positive MP: Medium Positive HP: High Positive

VLP: Very High Positive EHP: Extreme High Negative

Following graphs will show how Gaussian and Triangular MF with 9 and 11 fuzzy sets with MF range of base range [-0.4,0.4] and [-0.5,0.5]

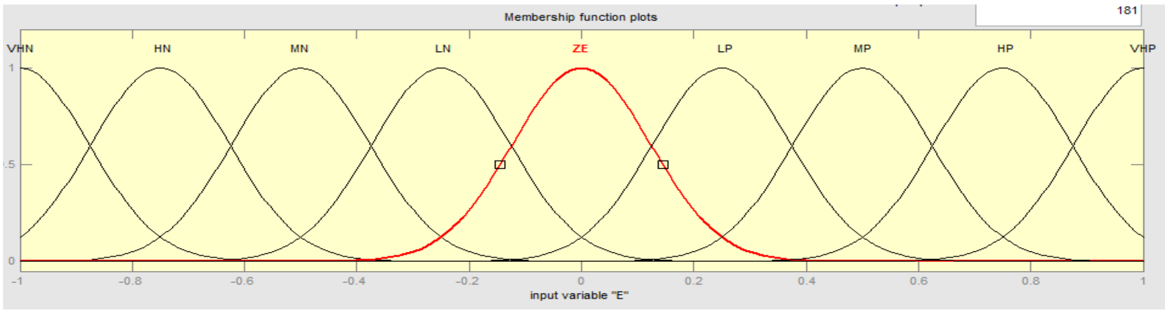


*Figure 3.2 Gaussian MF base range [-0.4,0.4] and 9 fuzzy sets*

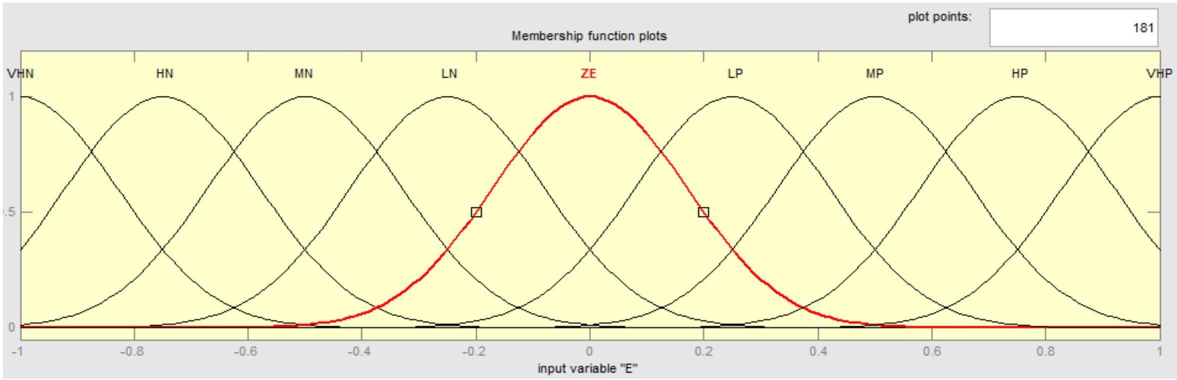


*Figure 3.3 Gaussian MF base range [-0.5,0.5] and 9 fuzzy sets*

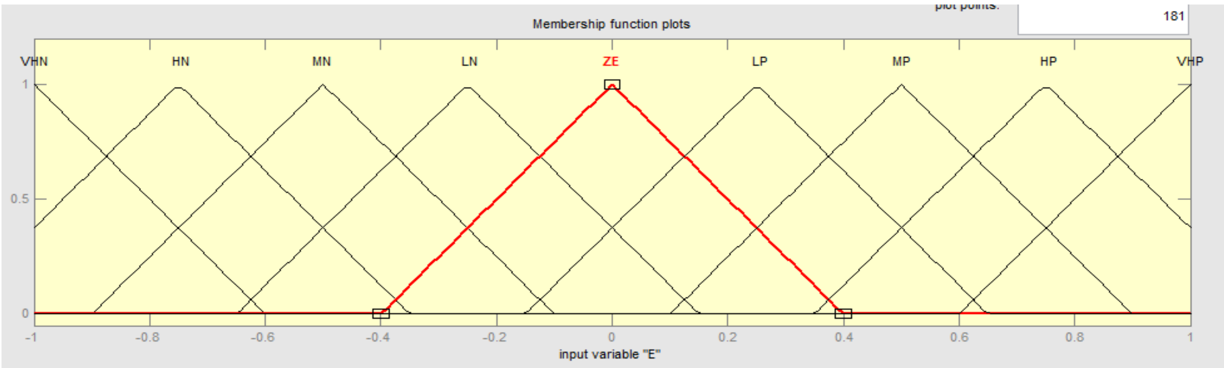


*Figure 3.54 Triangular MF base range [-0.4,0.4] with 9 fuzzy sets*

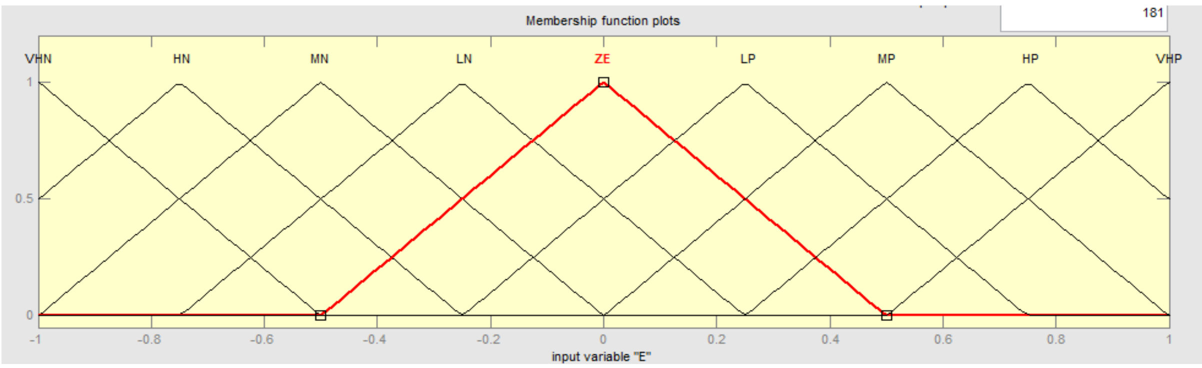


*Figure 3.6 Triangular MF base range [-0.5,0.5] with 9 fuzzy sets*

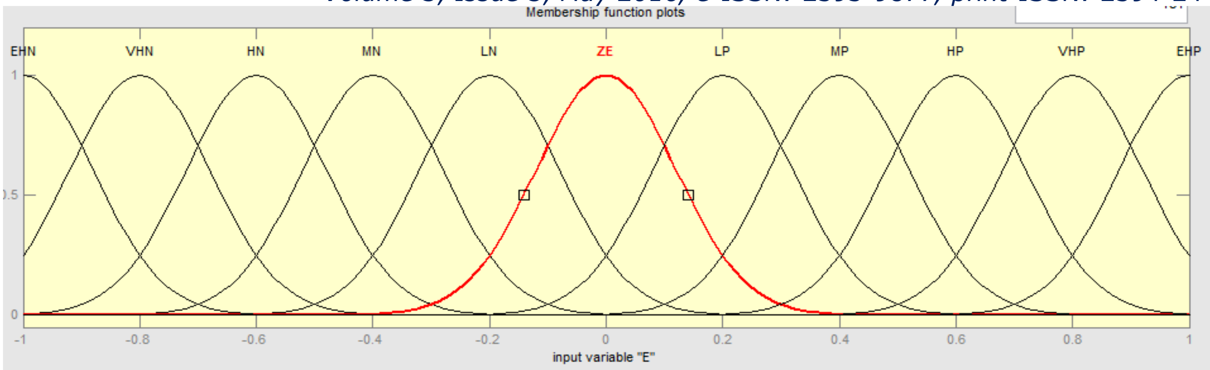


***Figure 3.7 Gaussian MF base range [-0.4,0.4] with 11 fuzzy sets***

**C) Rule Base**

Rules have format IF-THEN. "If" part is input ,"AND" combines two inputs while "Then" is conclusion part.

Rule 1: If E is MN and DE is HN then U is VHN.

Rule 2 :If E is HN and DE is LP then U is MN

.

Rule 49: If E is HP and DE is MN then U is LP

For 9 fuzzy sets 81 rules are created , and 121 rules are created for 11 fuzzy sets which are applied to system.

***Table 3.1 Rule base for 9 fuzzy sets and 81 rules***

| DE↓ E→ | *VHN* | *HN* | *MN* | *LN* | *ZE* | *LP* | *MP* | *HP* | *VHP* |
|---|---|---|---|---|---|---|---|---|---|
| ***VHP*** | ZE | LP | MP | HP | VHP | VHP | VHP | VHP | VHP |
| ***HP*** | LN | ZE | LP | MP | HP | VHP | VHP | VHP | VHP |
| ***MP*** | MN | LN | ZE | LP | MP | HP | VHP | VHP | VHP |
| ***LP*** | HN | MN | LN | ZE | LP | MP | HP | VHP | VHP |
| ***ZE*** | VHN | HN | MN | LN | ZE | LP | MP | HP | VHP |
| ***LN*** | VHN | VHN | HN | MN | LN | ZE | LP | MP | HP |
| ***MN*** | VHN | VHN | VHN | HN | MN | LN | ZE | LP | MP |
| ***HN*** | VHN | VHN | VHN | VHN | HN | MN | LN | ZE | LP |
| ***VHN*** | VHN | VHN | VHN | VHN | VHN | HN | MN | LN | ZE |

***Table 3.2 Rule base for 11 fuzzy sets and 121 rules***

| DE↓ E→ | *EHN* | *VHN* | *HN* | *MN* | *LN* | *ZE* | *LP* | *MP* | *HP* | *VHP* | *EHP* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***EHP*** | ZE | LP | MP | HP | VHP | EHP | EHP | EHP | EHP | EHP | EHP |
| ***VHP*** | LN | ZE | LP | MP | HP | VHP | EHP | EHP | EHP | EHP | EHP |
| ***HP*** | MN | LN | ZE | LP | MP | HP | VHP | EHP | EHP | EHP | EHP |
| ***MP*** | HN | MN | LN | ZE | LP | MP | HP | VLP | EHP | EHP | EHP |
| ***LP*** | VHN | HN | MN | LN | ZE | LP | MP | LP | VHP | EHP | EHP |
| ***ZE*** | EHN | VHN | HN | MN | LN | ZE | LP | MP | HP | VHP | EHP |
| ***LN*** | EHN | EHN | VHN | HN | MN | LN | ZE | LP | MP | HP | VHP |
| ***MN*** | EHN | EHN | EHN | VHN | HN | MN | LN | ZE | LP | MP | HP |
| ***HN*** | EHN | EHN | EHN | EHN | VHN | HN | MN | LN | ZE | LP | MP |
| ***VHN*** | EHN | EHN | EHN | EHN | EHN | VHN | HN | MN | LN | ZE | LP |
| ***EHN*** | EHN | EHN | EHN | EHN | EHN | EHN | VHN | HN | MN | LN | ZE |

## IV. SIMULATION RESULTS

Water bath system model is developed using SIMULINK as shown in figure 4.1. This SIMULINK model consist of FLC designed by using fuzzy logic tool box. Step inputs are used to define input temperature and time range. Thus output temperature is obtained as close a set point. Reference profile is used for simulation shown in table 4.1

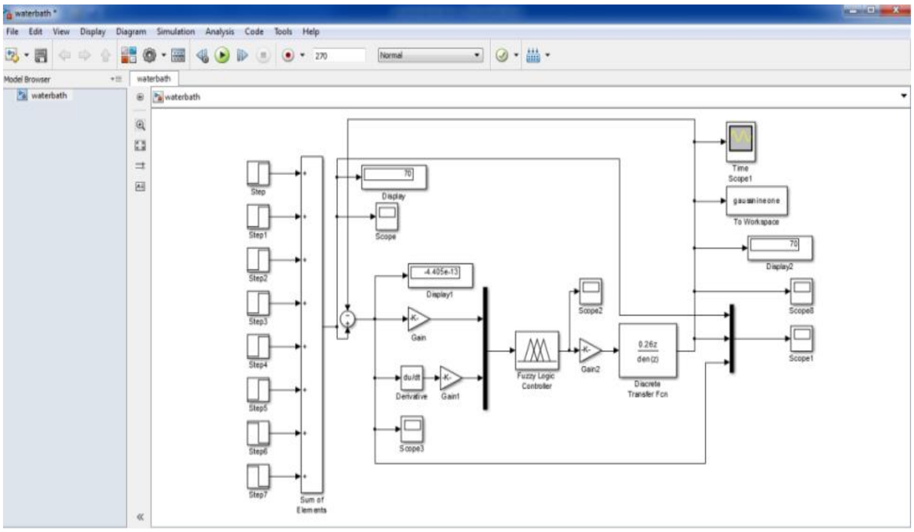

***Figure 4.1 Water bath system SIMULINK model***

***Table 4.1 Desired set point temperature and time period***

| Reference Temperature | Time |
|---|---|
| 40 | 0 <= t <= 30 |
| 50 | 30 <= t <= 60 |
| 60 | 60 <= t <= 90 |
| 70 | 90 <= t <= 120 |
| 80 | 120 <= t <= 150 |
| 90 | 150 <= t <= 180 |
| 80 | 180 <= t <= 210 |
| 70 | 210 <= t <= 240 |

Simulation results are shown below in the form of output waveforms. Desired set point temperature waveform is yellow color waveform, while error waveform shown by magenta and output waveform shown by green color. From simulation results for different models rise time, settling time and overshoot is calculated. Total 8 approaches by variation in number of linguistic variable and MF base range for designing FLC are followed. The comparative analysis is shown in following tables.

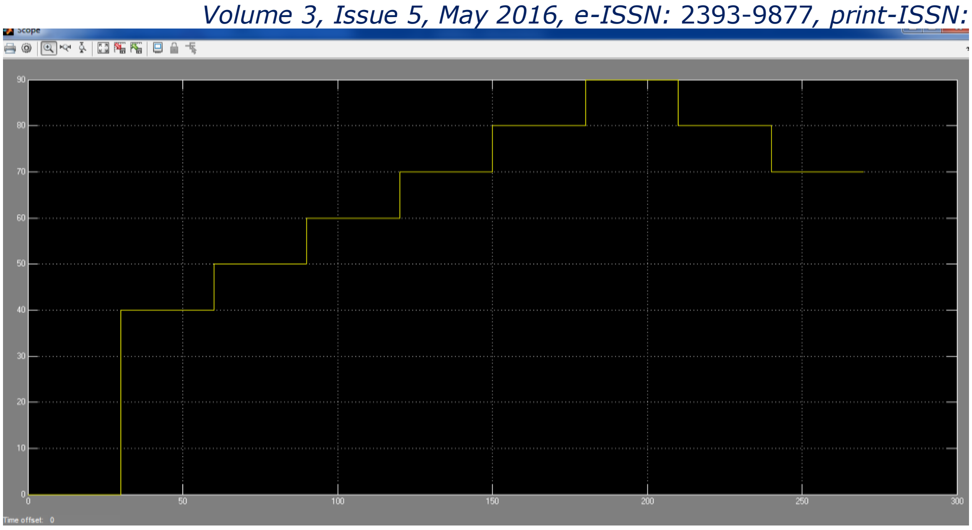


***Figure 4.2 Output waveform for input temperature with time range***

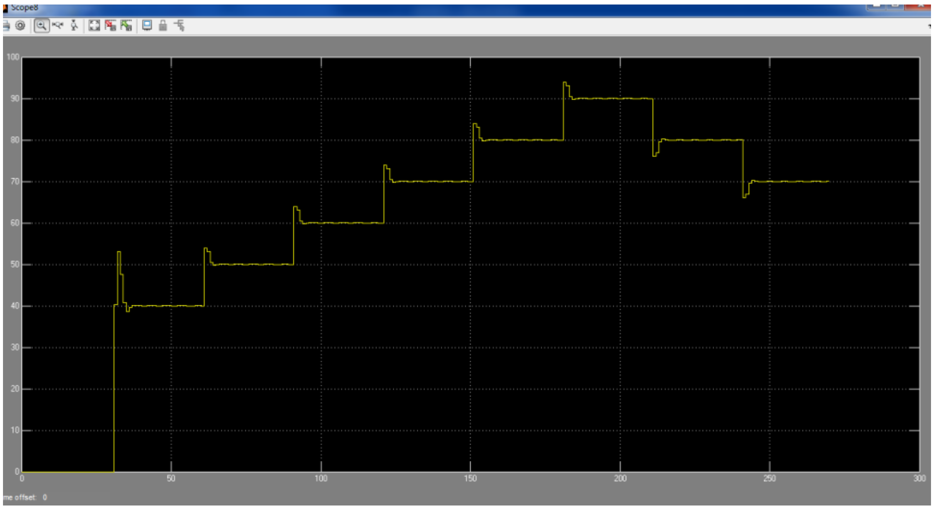


***Figure 4.3 Output waveform for controller output***

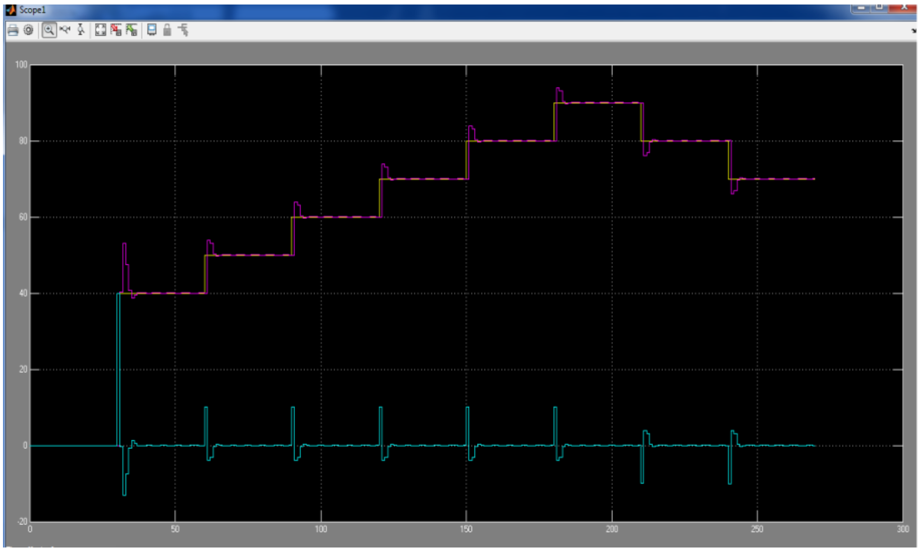


***Figure 4.4 Output waveform of controller, error and input temperature for 9 fuzzy sets gaussian MF with base range[-0.5,0.5]***

***Table 4.2 Results for Triangular MF with base range [-0.4,0.4]***

| Parameter | 9 fuzzy sets | 11 fuzzy sets |
|---|---|---|
| Rise Time | 60.69 | 60.58 |
| Settling Time | 243.68 | 243.85 |
| Overshoot | 35.94 | 38.34 |

***Table 4.3 Results for Triangular MF with base range [-0.5,0.5]***

| Parameter | 9 fuzzy sets | 11 fuzzy sets |
|---|---|---|
| Rise Time | 61.37 | 61.11 |
| Settling Time | 244.74 | 244.74 |
| Overshoot | 34.37 | 36.44 |

***Table 4.4 Results for Gaussian MF with base range [-0.4,0.4]***

| Parameter | 9 fuzzy sets | 11 fuzzy sets |
|---|---|---|
| Rise Time | 60.63 | 60.55 |
| Settling Time | 243.19 | 243.72 |
| Overshoot | 37.93 | 39.74 |

***Table 4.5 Results for Gaussian MF with base range [-0.5,0.5]***

| Parameter | 9 fuzzy sets | 11 fuzzy sets |
|---|---|---|
| Rise Time | 60.76 | 60.67 |
| Settling Time | 243.62 | 243.92 |
| Overshoot | 34.23 | 36.18 |

## V. CONCLUSION

Performance evaluation has been done for water bath system using FLC with Triangular and Gaussian membership function. Number of linguistic variables used are nine and eleven while MF range width is 0.8 and1. FLC performance is checked for all these models separately. Gain parameters are GE=0.02. GDE=0.02, and GU=150 are used. Results obtained by [1],[2] has overshoot 39.98 but proposed system has overshoot 34.23 and other models also have shown significant reduction in overshoot. It is observed by results that as the MF base width gets wider overshoot tend to reduce. Also as number of fuzzy set are increased, overshoot gets reduced. For the wider MF base width, good stability and smoothness observe. FLC designed for water –bath system with higher number of variables and Gaussian type MF with higher base range width performs better with good tracking capability and less overshoot.

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