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# ANALYSIS OF COUPLED TANK SYSTEM BY USING ADVANCED ARTIFICIAL INTELLIGENCE

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*Abstract:* Wherever liquid level and flow control are crucial, sectors like petrochemical, paper, waste management, and others are the most important ones. Instrumentation engineers frequently deal with process operation under erratic conditions, such as operating below or above set point, which leads to inappropriate performance of plant devices and equipment and also has an impact on product quality. The application of intelligent fuzzy logic is being studied in the coupled-tank plant system to address the aforementioned undesirable scenarios. Even in the presence of simultaneous plant nonlinearity and measurement noise, FLC is able to provide the proper control signal for the coupled-tank system in response to the specified target water level. The primary property of FLC that does not need the explicit identification of the model description or the solution to linear (or nonlinear) equations of the relevant plant dynamics is its capacity to employ merely input-output measurements of the plant in adaptation mechanisms. The FLC results are contrasted with those of the traditional PID controller.

## I. INTRODUCTION

Nowadays, fluids must be pumped, kept in tanks, and then moved to another tank in practically all process industries, including the petrochemical, paper, and water treatment sectors. One of the most pressing issues facing the process industries is the regulation of fluid flow within and between tanks. The industries above are the most important ones where fluid level and flow management are key. The level of the fluid in the tanks must always be under control, and the fluid flow between the tanks must always be managed while the fluids/liquids are processed by chemical or mixing treatment in the tanks. Every chemical engineering system relies on flow and level control within tanks. The connected tank system's nonlinearity makes it difficult for current controllers to constantly offer reliable control. Consequently, a smart controller is suggested [23]. A system that can make decisions like a person is said to be intelligent. They adjust to the circumstances and automatically make the right choices in similar circumstances in the future. Artificial intelligence systems include neural networks (NNs), fuzzy systems, and neuro-fuzzy systems.

Fuzzy systems provide a coherent framework for accounting for variables' progressive or flexible nature and serving as an example of incomplete knowledge. This is an alternative to the traditional approach and is based on the idea that rather than thinking in terms of numbers, people think in terms of language, such as "small" or "large," among other phrases. Zadeh uses fuzzy sets, which he first developed in 1965, to illustrate the idea in plain English. Conditional if-then rules, which use fuzzy sets as linguistic words in the antecedent and conclusion sections, are the true definition of fuzzy systems. These ambiguous if-then rules can be created either by human specialists or, alternatively, by the observed data (examples).

Fuzzy systems are widely utilised in industrial process controllers, decision-making, estimation, and mechanical control systems for things like car controls, air conditioning, and even "smart" homes. They are also employed in a variety of other applications. Fuzzy logic has been used most realistically in Japan's many applications as process controllers. However, Europe saw the most fundamental breakthroughs in fuzzy control.

## II. LITERATURE REVIEW

1. **Fuzzy Control for a Liquid Level System** by **B. M. Al-Hadithi, F. Matia and A. Jimenez[20]**
   In this paper the design of a T-S fuzzy controller was presented for the control of liquid level system represented by the affine Takagi-Sugeno (T-S) fuzzy model. Fuzzy controller (FC) was designed based on pole assignment method. The approach is well suited for the systems where shown a fast response with small overshoot in the transient response and a well damped oscillations with zero steady state error is required.

**2. L. Qi, F. Yanjun, S. Jizhong, and W. Ji's "The Application of Fuzzy Control in Liquid Level System"[4]**

In this study, FLC is used to manage the liquid level. When the findings were compared to PID, it was discovered that the fuzzy control system had improved dynamic performances, no vibration, and reduced maximum overshoot. But the PID controller has longer rise, peak, and correction times.

**3. S. N. Engin, J. Kuvulmaz, and V. E. Omurlu's "Modelling of a Coupled Industrial Tank System with ANFIS"[9]**

In this study, the ANFIS (Adaptive-Network-Based Fuzzy Inference System) is used to represent a connected, interacting, nonlinear liquid levelling tank system. The system is first mathematically modelled, and data obtained from this model is then used to build an ANFIS model of the system. ANFIS and the mathematical model are contrasted, and the versatility of ANFIS modelling is demonstrated.

**4. N. Rajanbabu, S. Sreenadhan, K. A. Fahid, and K. P. Mohandas' Design and Implementation of a Neuro-Fuzzy Controller for a Flow System[14]**

This study compares the performance of a neuro-fuzzy controller to a PID controller. It is created and applied to a flow control system. And they discovered that the suggested controller performed better with less oscillations and a quicker settling period.

**5. G. Shahgholian and A. Movahedi, "Modelling and Controller Design for Non-Linear Liquid Level System Using ANFIS Method"[2]**

In this study, the ANFIS network was used to describe the nonlinear liquid level system. A fuzzy controller was created after the modelling step in order to reach the appropriate liquid level. Since a PI controller was introduced to the system in order to eliminate the steady-state error because a fuzzy input-output controller behaves like a PD controller, a fuzzy PID controller was created.

**6. R. S. M. Malar and T. Thyagarajan's "Modelling of Quadruple Tank System Using Soft Computing Techniques"[6]**

In this study, a quadruple tank system is modelled utilising neural, fuzzy, and neuro-fuzzy soft computing methods. The simulation results are shown in order to evaluate the effectiveness of soft computing methods. Based on Root Mean Square Error data, the ANFIS model is distributed to obtain greater accuracy compared to other soft computing models.

## III. METHODOLOGY

### 3.1 SYSTEM MODELLING

It is crucial to comprehend the system before moving on with the design and development of the controller. Fig. 3.1 depicts the connected tank apparatus (PP 100).

Fig. 3.1: Coupled tank apparatus (PP 100) (courtesy: http://www.kri.com.sg)

It comprises of two tanks set over a reservoir. Each tank's top is filled with water by two independent pumps. For both tanks, an exit is installed close to the base and a scale is affixed to the front. The volume of water that returns to the reservoir is roughly proportionate to the water head in the tank since the return tube is constructed of flexible tubing that helps with variable hydraulic resistance. A signal conditioning circuit transforms the capacitive probe's readings of the water head in each tank into electrical signals (0 to +5Vdc). Electrical signals are calibrated so that a full scale deflection (300 mm) indicates +5 V and 20 mm represents zero due to the device's range of 20 mm to 300 mm [42].

### 3.2 MATHEMATICAL MODELLING OF COUPLED TANK SYSTEM

The connected tank system's basic schematic diagram is displayed in Fig. 3.2. A nonlinear dynamic model is shown in this system. Each and every related linearized disruption model is derived from the nonlinear model in four phases [43]. In this topic, these stages will normally be covered.

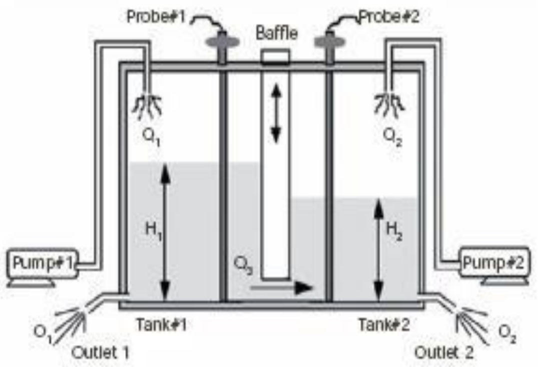


Fig 3.2: Schematic diagram of coupled tank
(courtesy: http://www.eng.nus.edu.sg)

### *3.2.1 A SIMPLE NONLINEAR MODEL OF COUPLED TANK SYSTEM*

Based on Fig. 3.2, a straightforward nonlinear model is created. Let H1 and H2 represent the liquid levels in each tank as determined in relation to the respective outflow. According to a straightforward mass balance, the rate of change of the liquid volume in each tank equals the net flow of liquid into the tank. The dynamic equation is developed as follows for tanks 1 and 2:

$$A_1 \frac{dH_1}{dt} = Q_1 - O_1 - O_3 \tag{3.2.1.1}$$

$$A_2 \frac{dH_2}{dt} = Q_2 - O_2 + O_3 \tag{3.2.1.2}$$

Where,
$H_1$, $H_2$ = height of liquid in tank 1 and tank 2 respectively,
$A_1$, $A_2$ =cross sectional area of tank 1 and tank 2 respectively,
$O_3$ =flow rate of liquid between tanks,
$Q_1$, $Q_2$ = pump flow rate into tank 1 and tank 2 respectively and
$O_1$, $O_2$ = flow rate of liquid out of tank 1 and tank 2 respectively

The Bernoulli equation for a stable, non-viscous, incompressible liquid is suitable since each outlet drain may be treated as a straightforward orifice. Additionally, it states that the outlet flows in each tank are inversely proportional to the square root of the tank's water head. The flow between the two tanks is proportional to the differential head's square root, too.

$$O_1 = \alpha_1 \sqrt{H_1} \tag{3.2.1.3}$$

$$O_2 = \alpha_2 \sqrt{H_2} \tag{3.2.1.4}$$

$$O_3 = \alpha_3 \sqrt{H_1 - H_2} \tag{3.2.1.5}$$

Where 1, 2, and 3 are proportional constants that rely on the gravitational constant, each orifice's cross sectional area, and the discharge coefficient. Equations (3.2.1.3), (3.2.1.4), and (3.2.1.5) are combined in equations (3.2.1.1) and (3.2.1.2) to create a set of nonlinear state equations that explain the connected tank's system dynamics.

$$A_1 \frac{dH_1}{dt} = Q_1 - \alpha_1 \sqrt{H_1} - \alpha_3 \sqrt{H_1 - H_2} \tag{3.2.1.6}$$

$$A_2 \frac{dH_2}{dt} = Q_2 - \alpha_2 \sqrt{H_2} - \alpha_3 \sqrt{H_1 - H_2} \tag{3.2.1.7}$$

### 3.2.2 A LINEARISED PERTURBATION MODEL

Let's assume that the liquid level in the tanks is at a steady state level H1 and H2 for a set of inflows Q1 and Q2. Take into account a little change in each inflow, q1 in Q1 and q2 in Q2. Let h1 and h2 represent the resultant level perturbations, respectively. Equations (3.2.1.6) and (3.2.1.7) follow:

For Tank 1

$$A_1 \frac{d(H_1 + h_1)}{dt} = (Q_1 + q_1) - \alpha_1 \sqrt{(H_1 + h_1)} - \alpha_3 \sqrt{H_1 - H_2 + h_1 - h_2} \tag{3.2.2.1}$$

For Tank 2

$$A_2 \frac{d(H_2 + h_2)}{dt} = (Q_2 + q_2) - \alpha_2 \sqrt{(H_2 + h_2)} + \alpha_3 \sqrt{H_1 - H_2 + h_1 - h_2} \tag{3.2.2.2}$$

On subtracting equations (3.2.1.6) and (3.2.1.7) to the equation (3.2.2.1) and (3.2.2.2), following equations were obtained:

$$A_1 \frac{dh_1}{dt} = q_1 - \alpha_1 (\sqrt{H_1 + h_1} - \sqrt{H_1}) - \alpha_3 (\sqrt{H_1 - H_2 + h_1 - h_2} - \sqrt{H_1 - H_2}) \tag{3.2.2.3}$$

$$A_2 \frac{dh_2}{dt} = q_2 - \alpha_2 (\sqrt{H_2 + h_2} - \sqrt{H_2}) + \alpha_3 (\sqrt{H_1 - H_2 + h_1 - h_2} - \sqrt{H_1 - H_2}) \tag{3.2.2.4}$$

For small perturbations,

$$\sqrt{H_1 + h_1} = \sqrt{H_1} (1 + \frac{h_1}{2H_1}) \tag{3.2.2.5}$$

Hence,

$$\sqrt{H_1 + h_1} - \sqrt{H_1} \approx \frac{h_1}{2\sqrt{H_1}} \tag{3.2.2.6}$$

Similarly,

$$\sqrt{H_2 + h_2} - \sqrt{H_2} \approx \frac{h_2}{2\sqrt{H_2}} \tag{3.2.2.7}$$

And

$$\sqrt{H_1 - H_2 + h_1 - h_2} - \sqrt{H_1 - H_2} \approx \frac{h_1 - h_2}{2\sqrt{H_1 - H_2}} \qquad (3.2.2.8)$$

Applying the approximations from equations (3.2.2.5) to (3.2.2.8), equation (3.2.2.3) and (3.2.2.4) will be:

$$A_1 \frac{dh_1}{dt} = q_1 - \frac{\alpha_1}{2\sqrt{H_1}} h_1 - \frac{\alpha_3}{2\sqrt{H_1 - H_2}} (h_1 - h_2) \qquad (3.2.2.9)$$

$$A_2 \frac{dh_2}{dt} = q_2 - \frac{\alpha_2}{2\sqrt{H_2}} h_2 + \frac{\alpha_3}{2\sqrt{H_1 - H_2}} (h_1 - h_2) \qquad (3.2.2.10)$$

Note that the coefficients of the level perturbations are functions of the steady state operating points H1 and H2 according to equations (3.2.2.9) and (3.2.2.10). Another way to express the equations (3.2.2.9) and (3.2.2.10) is as follows:

$$A_1 \frac{dh_1}{dt} = q_1 - q_{o1} - \frac{\alpha_3}{2\sqrt{H_1 - H_2}} (h_1 - h_2) \qquad (3.2.2.11)$$

$$A_2 \frac{dh_2}{dt} = q_2 - q_{o2} + \frac{\alpha_3}{2\sqrt{H_1 - H_2}} (h_1 - h_2) \qquad (3.2.2.12)$$

where the values of qo1 and qo2 signify changes in the outflow at the drain pipes. This would be appropriate, for example, if the outflow was regulated by an external clamp.

### 3.2.2 FIRST ORDER SINGLE INPUT SINGLE OUTPUT (SISO) PLANT

The baffle is totally lowered so that there is no flow between the two tanks when this composition is being evaluated. The first order differential equation is reduced to the following when equations (3.2.2.9) and (3.2.2.10) are combined:

$$A_1 \frac{dh_1}{dt} = q_1 - \frac{\alpha_1}{2\sqrt{H_1}} h_1 \qquad (3.2.3.1)$$

$$A_2 \frac{dh_2}{dt} = q_2 - \frac{\alpha_2}{2\sqrt{H_2}} h_2 \qquad (3.2.3.2)$$

The output variable for tank 1 (h1) indicates a slight change in the steady state level (H1), and the steady state input flow rate (q1) represents a minor change in both. The definitions of h2 and q2 are similar. Rearranging equations (3.2.3.1) and (3.2.3.2) yields the state space model shown below:

$$\begin{bmatrix} \dot{h}_1 \\ \dot{h}_2 \end{bmatrix} = \begin{pmatrix} -\frac{k_1}{A_1} & 0 \\ 0 & -\frac{k_2}{A_2} \end{pmatrix} \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} + \begin{bmatrix} \frac{1}{A_1} \\ \frac{1}{A_2} \end{bmatrix} \begin{bmatrix} q_1 \; q_2 \end{bmatrix} \qquad (3.2.3.3)$$

### 3.2.2 SECOND ORDER SINGLE INPUT SINGLE OUTPUT (SISO) PLANT

The two tanks form an interaction type configuration if we slightly elevate the baffle, and the state space model of equations (3.2.2.9) and (3.2.2.10) is as follows:

$$\begin{bmatrix} \dot{h}_1 \\ \dot{h}_2 \end{bmatrix} = \begin{pmatrix} -\frac{k_{11}}{A_1} & \frac{k_{12}}{A_1} \\ \frac{k_{21}}{A_2} & -\frac{k_{22}}{A_2} \end{pmatrix} \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} + \begin{bmatrix} \frac{1}{A_1} \\ \frac{1}{A_2} \end{bmatrix} \begin{bmatrix} q_1 \; q_2 \end{bmatrix} \qquad (3.2.4.1)$$

TABLE 3.1
Physical Parameters of Tank

| S. No. | Description | Value |
|---|---|---|
| 1 | Height of tank 1 ($H_1$) | 18 cm |
| 2 | Height of tank 2 ($H_2$) | 14 cm |
| 3 | Proportional Constant ($\alpha_1$ ) | 9.52 |
| 6 | Area of tank ($A_1$) | 34 $cm^2$ |
| 7 | Area of tank ($A_2$) | 30 $cm^2$ |

## IV. BACKGROUND OF CONTROLLERS

We should be knowledgeable about our control objectives before learning about controllers. A control system's primary goal is to keep the process variables (PV) constant despite disruptions. Our system's PV, h2, changes when a disturbance is applied (inflow rate > outflow rate or inflow rate outflow rate), therefore manipulated variable (MV), q1, must be changed in order to counteract the impacts of disturbances. We use controllers to do this, and the entire system is referred to as a control system. In general, we may group them into:

1. Conventional Controllers
2. Intelligent Controllers

### 4.1 CONVENTIONAL CONTROLLERS

Since James Watt utilised a mechanical governor to regulate the speed of his improved steam engine in 1788, control engineering has played a significant role in many sectors. PID controllers are the most often used conventional controllers. The most popular type of feedback controller is a proportional-integral-derivative (PID) controller, which is a fundamental control loop feedback mechanism used in industrial control systems. When a process variable is measured and a desired set point is wanted, a PID controller calculates a "error" in the form of a value as the difference. The controller modifies the process control inputs to lower the error. PID controllers are the best controllers when the underlying process is not known. Although the design is the most important factor, the PID parameters used in the calculation must be tweaked according to the characteristics of the system for optimal performance.

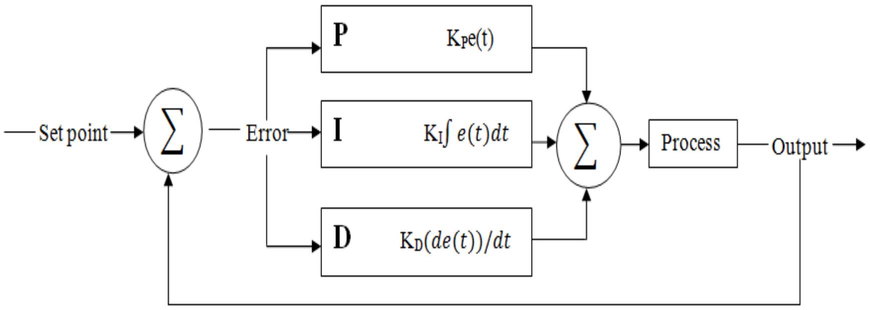


Fig. 4.1: Block Diagram of PID Controller

### 4.4.1 PID CONTROL THEORY

The most common feedback controller is undoubtedly the PID controller. Proportional, Integral, and Derivative, or PID for short, are the three terms that operate on the error signal to generate a control signal. A PID controller has the basic form if u(t) is the control signal, y(t) is the measured output, r(t) is the intended output, and tracking error e(t) = r(t) y(t).

$$u(t) = K_p e(t) + K_I \int e(t)dt + K_D \frac{d}{dt} e(t) \qquad (4.1.1.1)$$

By modifying the three parameters KP, KI, and KD, the appropriate closed loop dynamics is achieved. A step disruption may be refused under the integral phrase. The derivative word is employed to offer response shaping or dampening. Results from applying the Laplace transform to equation (4.1.1.1) are as follows:

$$u(s) = K_P e(s) + K_I \frac{1}{s} e(s) + K_D s e(s) \qquad (4.1.1.2)$$

And the corresponding transfer function is:

$$C(s) = K_P + K_I \frac{1}{s} + K_D s \qquad (4.1.1.3)$$

### 4.1.2 PROPORTIONAL TERM

The output is modified in a proportionate manner to the current error value by the proportional (also known as gain) phrase. By dividing the error by a constant KP, referred to as the proportional gain, the proportional response may be changed. The output is provided by:

$$P_{out} = K_P e(t) \qquad (4.1.2.1)$$

Where
$P_{out}$: Proportional term of output,
$K_P$: Proportional gain,
e: Error = SP – PV &
t: Time or instantaneous time.

## 4.2 INTELLIGENT CONTROLLER

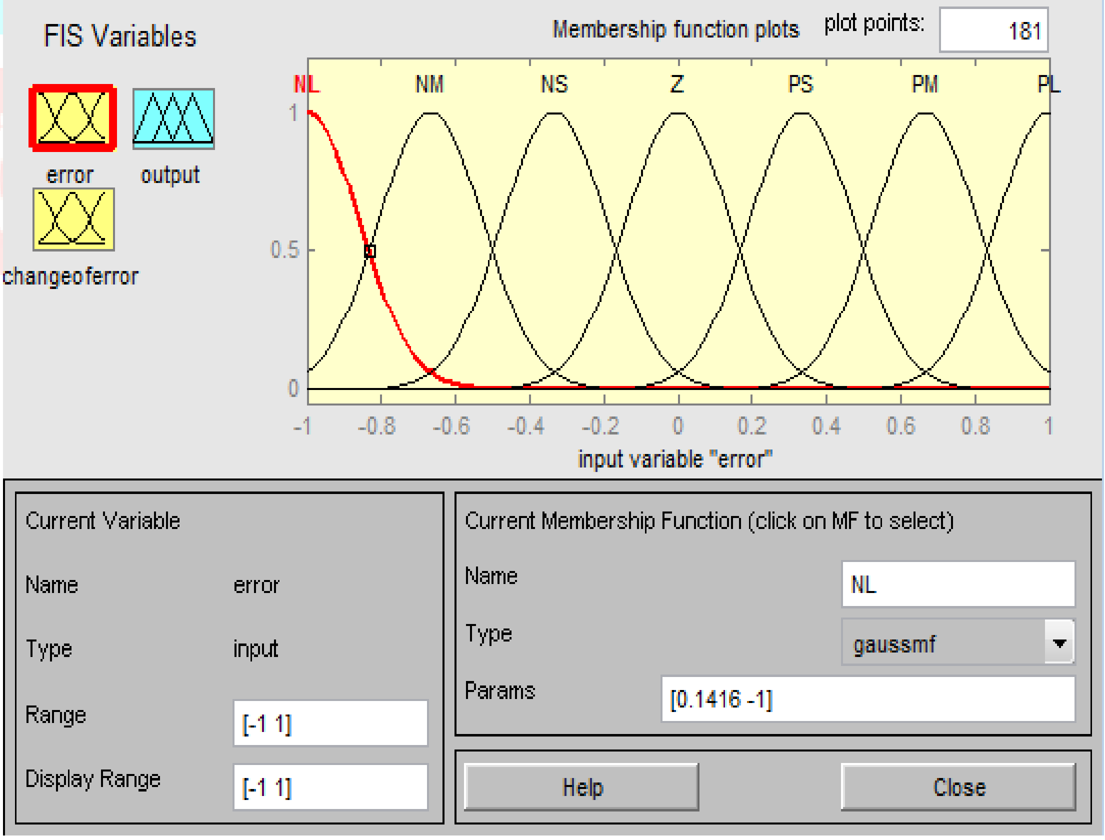
A controller that can make decisions like humans is said to be intelligent. They adjust to the circumstances and are able to make the right judgements on their own in similar situations in the future. Intelligent controllers include those that use fuzzy logic.

### 4.2.1 FUZZY LOGIC SYSTEM

The complexity of the real world is typically caused by uncertainty. Unconsciously, humans have been able to solve complicated, ambiguous, and unclear issues. Humans can reason roughly without needing a detailed description of the issue, which makes this line of reasoning viable. Engineers and scientists are becoming more and more interested in developing methods and approaches that will enable computers to reason under uncertainty as a result of the development of computers and the growth in their computational capability. As a result, fuzzy logic is born. The Oxford Dictionary defines the term fuzzy as being hazy, blurry, loosely defined, perplexing, or confusing. Rule-based or knowledge-based systems are fuzzy systems.

### 4.2.2 DESIGNING OF CONTROLLER

The application itself is the most crucial component of the fuzzy controller's design. The FLC created for a discrete process control application, for instance, will differ from the FLC created for a continuous process control application. Similar to this, one fuzzy system may differ from another fuzzy system even within the continuous process control. The beauty of fuzzy control is that it can be readily changed to meet the requirements of the individual application. One fuzzy system may only require one input variable while another may require two or three input variables to work successfully.

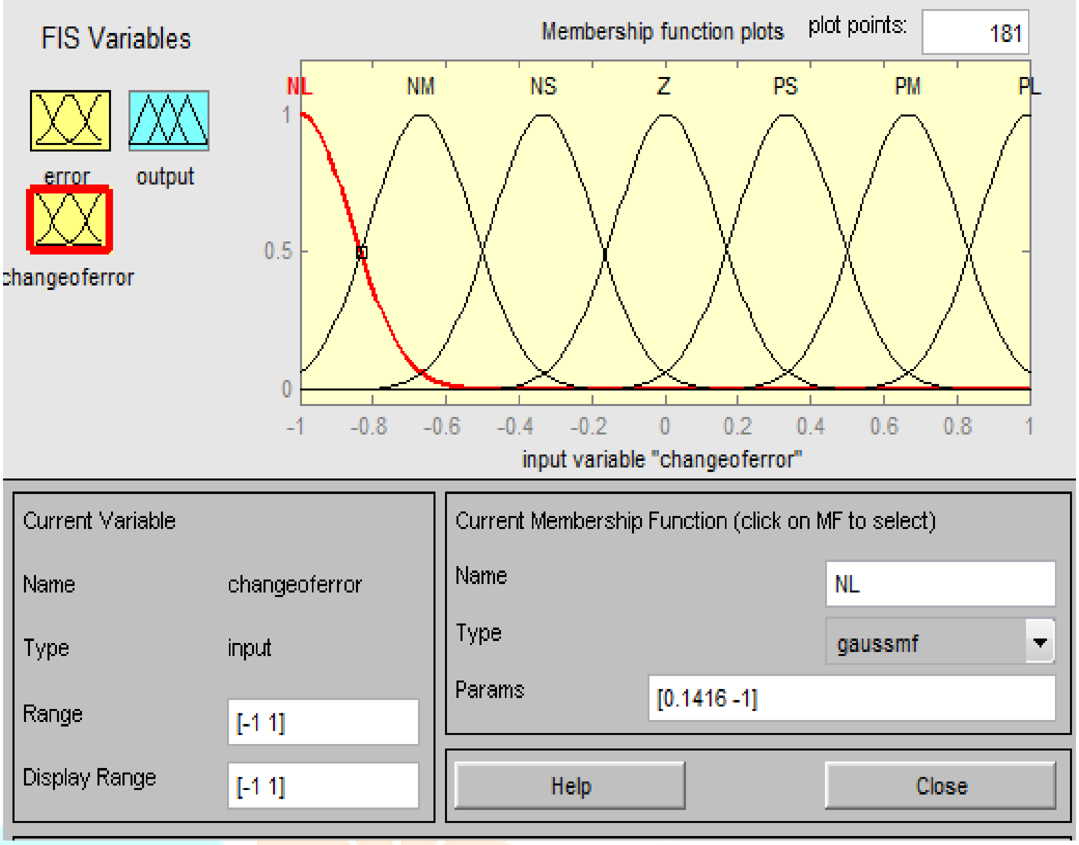


plot points: 181

Current Variable
Name error
Type input
Range [-1 1]
Display Range [-1 1]

Current Membership Function (click on MF to select)
Name NL
Type gaussmf
Params [0.1416 -1]

Fig. 4.2.2.1(a): Membership function for error (e)



plot points: 181

Current Variable

Name changeoferror

Type input

Range [-1 1]

Display Range [-1 1]

Current Membership Function (click on MF to select)

Name NL

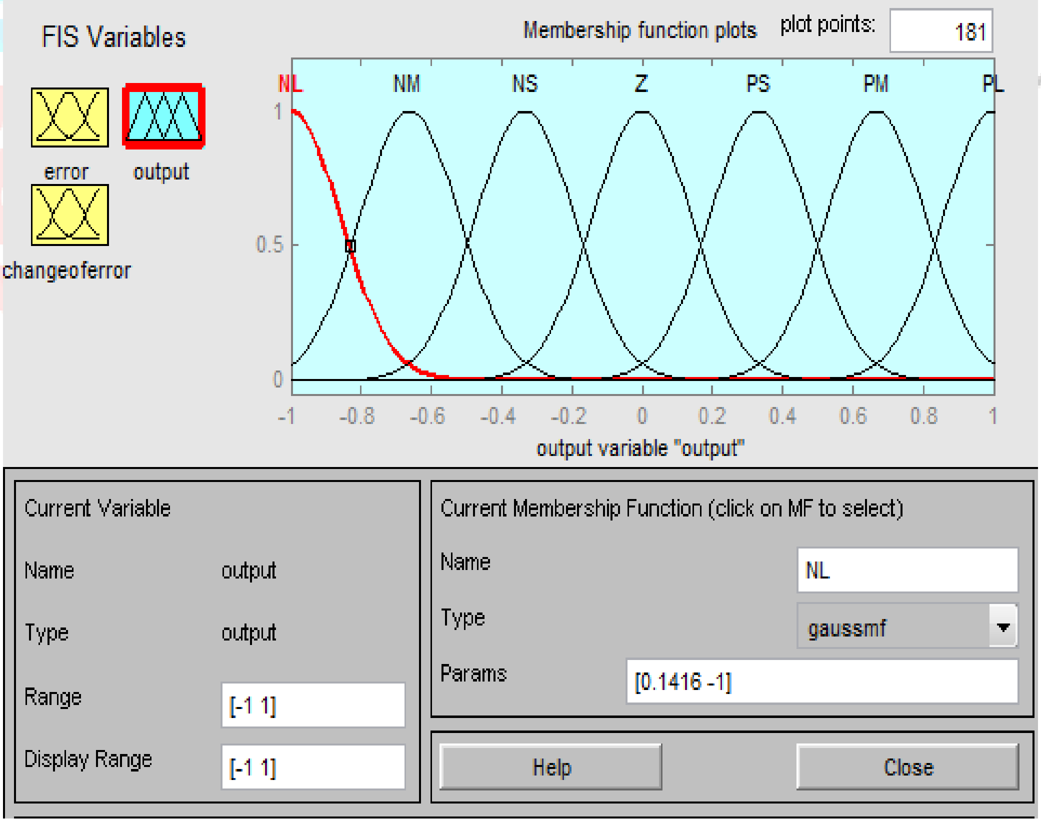
Type gaussmf

Params [0.1416 -1]

Fig. **4.2.2.1(a):** Membership function used for change in error (de)

## 4.3 OUTPUT VARIABLES

One output variable denoted as O is used. Gaussian membership function with seven linguistic values are used and shown in Fig. 4.3.1.



plot points: 181

Current Variable

Name output

Type output

Range [-1 1]

Display Range [-1 1]

Current Membership Function (click on MF to select)

Name NL

Type gaussmf

Params [0.1416 -1]

Fig. 4.3.1: Membership function designed for output (o)

## V. RESULT & DISCUSSION

Through changeable manipulation of the water pump in the first tank, the level in the second tank of the interacting linked tank plant system is managed by PID, FL, and ANFIS controllers. This project's whole programming was carried out in MATLAB [35]. A step input is supplied, then a mixture of sinusoidal input and a constant is added for comparison. 300 seconds are spent using both inputs.

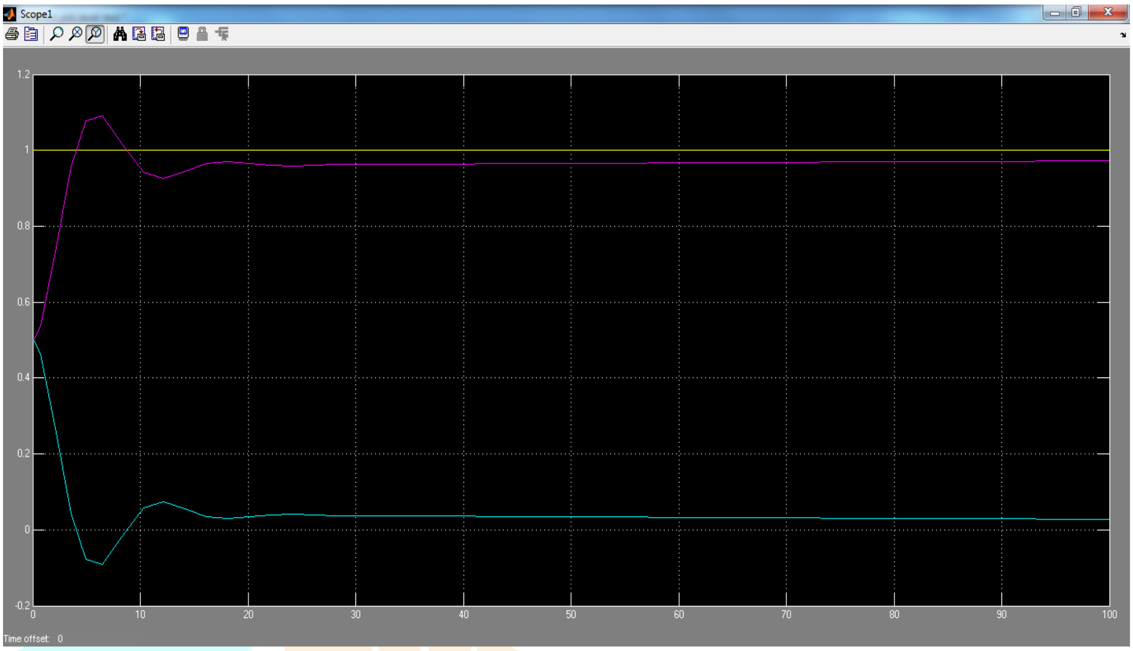


Fig. 5.1: PID step response

As we can see, there is some overshoot in the PID controller mode, which is completely undesirable. A FLC is put in place in order to lessen that. Two inputs are utilised in FLC: error (e) and change in error (de). For the aforementioned investigation, the different gain parameters used were GE = 6, GDE = 1, and GU = 40, where GE stands for gain of error, GDE for gain of change of error, and GU for gain of output, respectively.

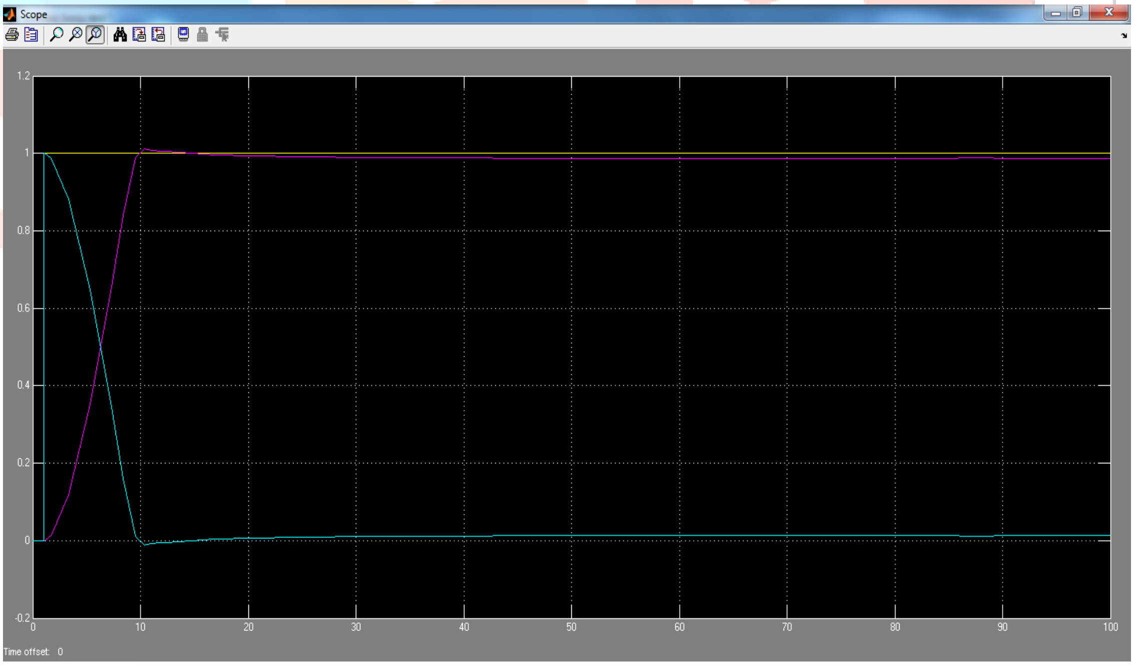


Fig. 5.2: FLC step response

The different parameters for comparison are shown in table 5.1

TABLE 5.1

Comparison of different parameters

| S. No. | Property | PID | FLC |
|---|---|---|---|
| 1 | Rise Time $t_r$(sec) | 4.75 | 9.3 |
| 2 | Peak Time $t_p$(sec) | 7.1 | 10.8 |
| 3 | % Peak Overshoot $M_p$ | 9.1 | 0.8 |
| 4 | Absolute Error | 13.08 | 5.26 |
| 5 | Settling Time $t_s$(sec) | 28 | 13.7 |

Results from this investigation demonstrate that the FLC controller approach offers better control when overshoot is taken into account since it reduces the issue of overrun when compared to PID. When compared to PID, step input results in a 60% reduction in absolute error and a 51% reduction in settling time. Thus, it can be inferred that the suggested FL controller, which reflects fine control quality, is better for managing the liquid level in the process than the typical PID controller. In addition, the idea is straightforward, simple to grasp, and convenient to implement.

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