# Novel ANFIS based SMC with Fractional Order PID Controller for Non Linear Interacting Coupled Spherical Tank System for Level Process

[1*]Jegatheesh A, [2]Agees Kumar C
*1**

[1*,2]Department of Electrical and Electronics Engineering,
[1*] DMI Engineering College, Kumarapuram
[2] Arunachala College of Engineering for Women, Vellichanthai, Kanniyakumari

**Abstract:**
Interacting Spherical tank has maximum storage capacity is broadly utilized in industries because of its high storage capacity. This two tank level system has the nonlinear characteristics due to its varying surface area of cross section of tank. The challenging tasks in industries is to manage the flow rate of liquid. This proposed work plays a major role in controlling the liquid level in avoidance of time delay and error. Several researchers studied and investigated about reducing the nonlinearity problem and their approaches do not provide better result. Different types of controllers with various techniques are implemented by the proposed system. Intelligent Adaptive Neuro Fuzzy Inference System (ANFIS) based Sliding Mode Controller (SMC) with Fractional order PID controller is a novel technique which is developed for a liquid level control in a interacting spherical tank system to avoid the external disturbances perform better result in terms of rise time, settling time and overshoot reduction. The performance of the proposed system is obtained by analyzing the simulation result obtained from the controller. The simulation results are obtained with the help of FOMCON toolbox with MATLAB 2018. Finally, the performance of the conventional controller (FOPID, PID-SMC) and proposed ANFIS based SMC-FOPID controllers are compared and analyzed the performance indices.
***Keywords**:*
*Nonlinear system, Performance indices, ANFIS based Sliding Mode Controller with Fractional order PID, PID controller, Spherical Tank System, FOPID Controller.*

## 1. Introduction

The industrial use of liquid level control is incredible particularly in petroleum refineries and chemical industry. The chemical used in industry need to be pumped as liquid and then collected and pumped into next tank. The liquid processed undergoes treatment using chemicals so that the liquid level in tank will be controlled. Generally, loop control exists in few control loops of a process control system. The frequent challenges in industry is to control the level of liquid in tanks, mixing of chemicals with liquid [8]. Nonlinearity is very difficult problem than the linear problems to be solved. The nonlinear system performance are cannot be predicted based on the equations of first degree and also the mathematical modelling not capable to give common solutions. Chemical industries, waste water treatment industries, power industries, fertilizer industries etc the flow rate of liquid is controlled. The liquid level in a spherical tank system should be controlled, since variation in structure gives nonlinearity of the tank. Compared with various conventional tank system, Spherical tank system has more merits such as product loss reduction, high strength, increased production and inexpensive. To implement ANFIS based Sliding Mode Controller with FOPID controller for liquid level control in nonlinear system [6].

Several controlling methods have been proposed and are implemented by the researchers to control the flow of liquid level are studied. *Elanaz et al.,* (2011) display techniques to the nonlinear problem and achieve fast transient response using Sliding Mode Control. This paper explains the combined feedback fuzzy based SMC [1]. *Govind and Arun* (2017) focused on exploring the method of liquid level control using Sliding Mode Controller with FOPID applied for two tank hybrid system achieves maximum settling time reduction. This method conveys better closed loop performance than the existing method [2]. *Mercy and Giriraj* (2017) proposed the method for nonlinear unstable process which uses the Particle Swarm Optimization method for the purpose of sewage water treatment. This method performs well in time domain specifications, error minimization and external disturbance rejection [3]. *Bharathi et al.,* (2014) presented the method to maintain the liquid level in a desired value by using Model Based Controller and outperform overshoot reduction, better rise time, settling time and error performance indices [4]. *Sakthivel et al.,* (2013) proposed an approach to control the liquid level. This can be done by Fuzzy logic controller which gives better set point tracking, overshoot and rise time [5]. Ansari et al., (2016) identified the control of nonlinear system using Iterative learning control [6]. From the literature, the Fuzzy logic controller cannot adapt for larger range of working environments. Control of liquid level flow is a complicated task because of its nonlinearity exhibited in spherical tank because of the change in area of cross section. Moreover, an ideal model

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with conventional controller or estimated model with a controller having robustness to model parameter uncertainties can efficiently control the liquid level. Although most industrial processes are highly complex and nonlinear, linear methods are frequently sufficient to estimate a process in the region of a single operating point. Some of the techniques implemented to control the level of liquid are proposed is better when compared to other controlling technique. So ANFIS based SMC-FOPID is used.

The main contributions of the paper includes

1. First principle mathematical model is developed for Spherical interacting tank system.
2. Partitioning the whole operating region of Spherical interacting tank system into local linear regions.
3. To design and implement the ANFIS based SMC with FOPID for a Spherical interacting system.
4. Advantage of ANFIS based SMC with FOPID method for a control the liquid level is less sensitive, real time implementation, best time domain specifications and good performance indices [7].
5. Set point tracking performances under the set point for the desired liquid level in two spherical interacting tank system and external disturbances are analyzed through algorithm to demonstrate its effectiveness.

The structure of the research paper is as follows: Section I describes the overall introduction of the proposed framework and the various literature reviews, section II clarifies the proposed system, section III presents the controller design dealing with ANFIS based SMC with FOPID controller. Section IV displays the performances by simulation results and their discussion and section V paper is concluded.

## 2. Process Description

In last three generations, the control of spherical two tank interacting liquid level system has concerned consideration of several researchers around the planet. This is the most significant trouble for the liquid level controlling system because of its non-linearity. The main objective of two spherical interacting systems is to sustain a desired level of the liquid in an interacting tank system when there is an inlet and outlet of water out of the tank correspondingly [11]. The block representation of two spherical interacting tank systems arrangement is displayed in Figure 1. Tank 1 and Tank 2 are equal spherical interacting tanks of Height (H) 40 cm and Radius(R) 20 cm. Tanks are interconnected through a valve whose valve coefficient is P01. Fin l and Fin 2 and Fout l and Fout 2 are the two input and output flows for Tank 1 and Tank 2 respectively. Flow valve Fin 1 is controlled by using a control valve. Let h0 and h1 be the heights of tanks 1 and 2. The liquids flows from Tank 1 to Tank 2 through $MV_{01}$.

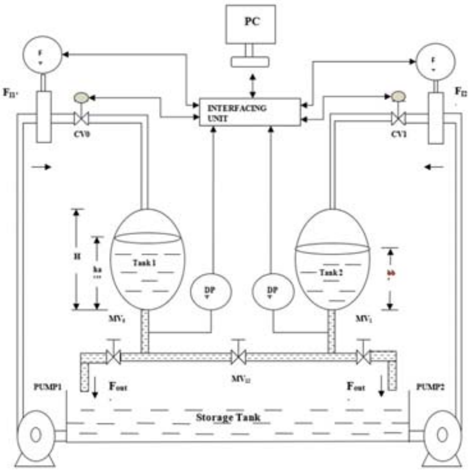


Figure 1: Schematic diagram for two spherical interacting tank systems

The liquid height of the tank is measured by Differential Pressure Transmitters (DPT) output is fed as feedback to the tank to control the level of liquid and input flow is estimated by Magnetic Flow Transmitters (MFT) . CV0 and CV1 represents control valves for this system. [12]. DPT and MFT outputs are the current signals (4-20 mA) which are fed to PC through an interfacing unit having 8 and 2 analog input and output channel. The process variable is $h_b$ and $F_{I2'}$ is kept stable. The valve-l used in this process is to control and maintain the final controlling component of liquid level in Tank 2.

### 2.1. Mathematical Modeling of Two Spherical Tank Interacting System

Figure. 1 displays the modeling of two spherical tank interacting system.

The mass balance equation for Tank 1 can be given as,

$$A_{a'}(h_{a'})\frac{dh_{a'}}{dt} = F_{I1'} - \beta_{a1}\sqrt{h_{a'} - h_{b'}} \quad (1)$$

(1) Is linearized as below

$$A_{a'}(h_{a'})\frac{d(\partial h_{a'})}{dt} = f_a(F_{I1'}) - f_a(h_{a'} - h_{b'}) \quad (2)$$

Apply partial differentiation in Equation (2),

$$A_{a'}(h_{a'})\frac{d(\partial h_{a'})}{dt} = \left(\frac{\partial f_a}{\partial F_{I1'}}\right).\partial F_{I1'} - \left(\frac{\partial f_b}{\partial h_{b'}}\right).\partial h_{a'} - \left(\frac{\partial f_b}{\partial h_{b'}}\right)\partial h_{b'} \quad (3)$$

Equation (3) can be rewritten as,

$$A_{a'}(h_{a'})\frac{d(\partial h_{a'})}{dt} = \partial F_{I1'} - \frac{\beta_{a1}}{2\sqrt{h_{a'} - h_{b'}}}\partial h_{a'} + \frac{\beta_{a1}}{2\sqrt{h_{a'} - h_{b'}}}\partial h_{b'} \quad (4)$$

Apply Laplace transformation in Equation (4),

$$\partial h_{a'} = \frac{\partial F_{I1'} + \frac{\beta_{a1}}{2\sqrt{h_a - h_{b'}}}\partial h_b}{A_{a'}(h_{a'})s + \frac{\beta_{a1}}{2\sqrt{h_{a'} - h_{b'}}}} \quad (5)$$

For Tank 2 the equation of mass balance be expressed as,

$$A_{a'}(h_{a'})\frac{dh_{b'}}{dt} = \beta_{a1}\sqrt{h_{a'} - h_{b'}} - \beta_b\sqrt{h_{b'}} \quad (6)$$

Linearization of above Equation (6) as,

$$A_{b'}(h_{b'})\frac{d(\partial h_{b'})}{dt} = f_a(h_{a'}, h_{b'}) - f_b(h_{c'}) \quad (7)$$

Apply partial differentiation in Equation (7),

$$A_{b'}(h_{b'})\frac{d(\partial h_{b'})}{dt} = \left(\frac{\partial f_a}{\partial h_a}\right).\partial h_{a'} - \left(\frac{\partial f_a}{\partial h_{b'}}\right).\partial h_{b'} - \left(\frac{\partial f_b}{\partial h_{b'}}\right)\partial h_{b'} \quad (8)$$

Rearranging above equation,

$$A_{b'}(h_{b'})\frac{d(\partial h_{b'})}{dt} = \frac{\beta_{a1}}{2\sqrt{h_{a'} - h_{b'}}}\partial h_{a'} - \frac{\beta_{a1}}{2\sqrt{h_{a'} - h_{b'}}}\partial h_{b'} - \frac{\beta_b}{2\sqrt{h_{b'}}}\partial h_{b'} \quad (9)$$

Taking Laplace transformation,

$$\left[A_{b'}(h_{b'})s + \frac{\beta_{a1}}{2\sqrt{h_{a'} - h_{b'}}} + \frac{\beta_b}{2\sqrt{h_{b'}}}\right]\partial h_{b'} - \frac{\beta_{a1}}{2\sqrt{h_{a'} - h_{b'}}}\partial h_{a'} \quad (10)$$

Substituting (5) in (10) we get,

$$\left[A_{b'}(h_{b'})s + \frac{\beta_{a1}}{2\sqrt{h_{a'} - h_{b'}}} + \frac{\beta_b}{2\sqrt{h_{b'}}}\right]\partial h_{b'} = \frac{\beta_{a1}}{2\sqrt{h_{a'} - h_{b'}}}\left[\frac{\partial F_{I1'} + \frac{\beta_{a1}}{2\sqrt{h_{a'} - h_{b'}}}\partial h_{b'}}{A_{a'}(h_{a'})s + \frac{\beta_{a1}}{2\sqrt{h_{a'} - h_{b'}}}}\right] \quad (11)$$

Let us assume,

$$C_a = \frac{1}{2\sqrt{h_{a'} - h_{b'}}}, C_b = \frac{1}{2\sqrt{h_{b'}}},$$

$$R_b = \frac{1}{\beta_{a1} C_a}, R_c = \frac{1}{\beta_b C_b}$$

$$\tau_a = A(h_{a'})R_a, \qquad \tau_b = A(h_{b'})R_b$$

Substituting the values calculated above in (11) we get,

$$\frac{\partial h_{b'}}{\partial F_{I1'}} = \frac{R_b}{\tau_a\tau_b s^2 + [\tau_a + \tau_b + A(h_{a'})R_b]s + 1} \quad (12)$$

**Table 1:** Modeling parameter in four region

| Region | Flow (cm$^3$/sec) | Height $h_{a'}$(cm) | Height $h_{b'}$(cm) | $C_a$ | $C_b$ | $R_a$ | $R_b$ | $\tau_a$ | $\tau_b$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0-24 | 1.714 | 1.612 | 1.5656 | 0.3938 | 0.0082 | 0.1289 7 | 2.1441 | 31.7151 |
| 2 | 25-48 | 6.856 | 6.448 | 0.7828 | 0.1969 | 0.0163 | 0.2579 | 15.232 | 226.659 |
| 3 | 49-72 | 14.97 | 14.06 | 1.066 | 0.1332 | 0.0119 8 | 0.3813 | 28.493 6 | 851.768 |
| 4 | 73-107.85 | 31.9 | 30 | 0.3627 | 0.0912 8 | 0.0352 2 | 0.5564 | 63.85 | 1048.25 8 |

**Table 2:** Transfer function for four region

| Region | Transfer function |
|---|---|
| 1 | $\frac{\partial h_a}{\partial F_{I1'}} = \frac{0.12897}{68s^2 + 67.58s + 1}$ |
| 2 | $\frac{\partial h_a}{\partial F_{I1'}} = \frac{0.2579}{3452.46s^2 + 482.892s + 1}$ |
| 3 | $\frac{\partial h_a}{\partial F_{I1'}} = \frac{0.3813}{24269.94s^2 + 1276.09s + 1}$ |
| 4 | $\frac{\partial h_a}{\partial F_{I1'}} = \frac{0.5564}{66931.25s^2 + 2120.87s + 1}$ |

Substituting the modeling parameters in equation (12) and it is displayed in Table 4 and 1. The transfer functions for the four regions are shown in Table. 2.

## 3. Controller Design

### 3.1. PID Controller

PID controllers are commonly applicable to control strategy in most of the industrial process to effectively solve non-linear and partly unidentified process it became an average tool, that is frequently observed as the worldwide for obtaining practical purposes of feedback control as shown in Figure.2. A large amount of loops are fed as feedback to PID controller [13]. PID estimates an error value e(t). Let m(t) is the control signal denotes the sum of three terms

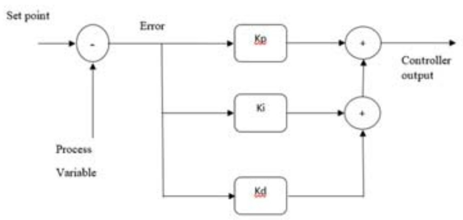


Figure 2: PID Controller Structure

## 3.2. FOPID Controller

Advanced version of PID controller is Fractional Order PID controller. The FOPID controller transfer function is given by,

$$G_c(s) = \frac{u(s)}{e(s)} = k_p + k_I s^{-\lambda} + k_D s^{\mu} \quad (16)$$

Where $G_c(s)$ the transfer function of the controller, (□) is error signal value and $(s)$ is the output obtained. $k_p, k_I$ And $k_D$ are the proportional, integral, and derivative gains achieved. $\lambda$ is the integral part fractional component and $\mu$ is the derivative part of fractional component of as shown in Figure.3. The time domain representation of FOPID controller is given as,

$$u(t) = K_p e(t) + K_i D^{-\lambda} e(t) + K_d D^{\mu} e(t) \quad (17)$$

The FOPID controller design procedure solves five nonlinear equations with five unknowns' $K_P$, $K_I$, , $\lambda$, and $\mu$ values. FOPID controller is used because of its less complexity when compared to other controllers [14].

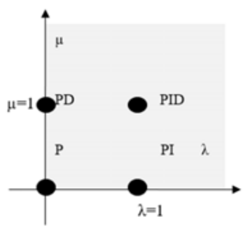


Figure 3: Normal form of FOPID controller

## 3.3 ANFIS based FOPID Controller for Spherical Tank System

ANFIS is abbreviated as Adaptive Neural Fuzzy Inference System. ANFIS is constructed using Fuzzy Inference System (FIS) in simulation toolbox whose membership function parameters are tuned with the help of various techniques. Thus fuzzy system data is modeled. The structure of ANFIS architecture is shown in Figure. 4. The circular nodes denote nodes which are fixed and square node is to be learnt [15]. Interpretably is reduced. The fuzzy rule is given described below

Rule 1:

Input: If x $=A_1$,y $=B_1$,

Output: $Z_1 = p_1$x + $q_1$y + $r_1$,

Rule 2:

Input: If x $=A_2$and y $=B_2$,

Output:$Z_2 = p_2$x + $q_2$y + $r_2$,

Here $A_i, B_i$ (i=1,2) be the fuzzy sets, and $p_i q_i$, $r_i$ (i=1, 2) be the design parameters that are obtained during training process. It is a feed forward fuzzy neural network with five-layer. Each layer specifies the separate information.

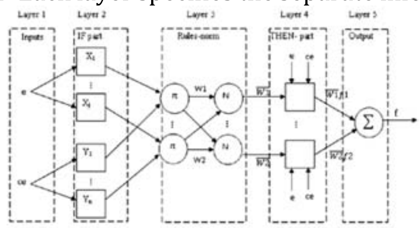


Figure 4: ANFIS Architecture

**First layer** : The first layer is the input layer which describes about the input parameters of the specified controller and they are speed error and its variance ratio mentioned as $x_0$, $x_1$ correspondingly [16]. This input layer immediately presents the inputs to other layer as input.

**Second layer** : The second layer is the fuzzy layer that verifies the values of member function. The input parameter is obtained from the first layer and corresponds as a member function variable. Moreover, it calculates the MF variables that determine the order in which the input parameter $x_0$depend on the fuzzy set data, which acts as the input to the next layer.

**Third layer** : Third layer is the layer of rule in which every node in this layer achieves the function before process. This evaluates the activation level of every layer, as both the layer number and fuzzy rule are equal. The weight of the node is normalized.

**Fourth layer:** Defuzzification process occurs in which it consists of resultant values 'y' is obtained. Links provided between the layers 1-3 & 1-4 by fuzzy singletons are weighted.

**Fifth layer** : The last layer which is said to be output layer. This averages all the inputs which are upcoming are converted into fuzzy and results obtained are in crisp values [20].

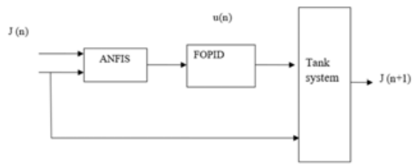


Figure 5: Structure of ANFIS based FOPID Controller

The ANFIS controller depends on shape learning and portioning algorithm with certain regulations. The parameters used are hybrid values. Structure of the system is updated automatically by ANFIS. A simple block that illustrates the ANFIS based FOPID Controller is displayed in Figure.5

### 3.4. SMC Controller

The Sliding Mode Controller is the most dominant technique for controlling the nonlinearity process in presence of external disturbances. The SMC is selected because of its stability and robustness in opposition to several categories of uncertainties such as external disturbances and modeling error [17]. Sliding Mode Controller mainly consists of two stages named as design of a sliding face in order to obtain the desired level of the system behavior such as stability of the basis, when controlled to the surface and the next stage is to prefer appropriate gain of the controller in which the closed loop method is stable on the sliding face.

### 3.5. FOPID-SMC Controller

Sliding Mode Controller is one type of non-linear controller with few merits of robustness and stability against some uncertainties [19]. SMC is very easier to implement when compared to the existing controllers. The FOPID-SMC block diagram is shown in Figure. 6. In SMC controller an error (E) and process output (X) are the input vectors and manipulated variable (U) is the output of the controller. The mathematical modeled equation for the FOPID-SMC controller is represented as,

$$u(t) = K_P E(t) + K_I \int_0^t E(t)dt + K_D \frac{d_E(t)}{dt}$$

$$U = K_{SAT}\left(\frac{u(t)}{\Omega}\right)$$

where, $K_{sat}$ is the gain of the controller, $u(t)$ is the variable to be controlled and Ω is the width of the boundary.

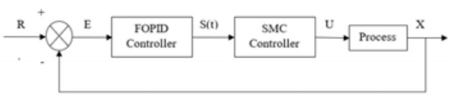


Figure 6: Structure of FOPID with SMC controller

### 3.6. Design of an ANFIS Based SMC with FOPID Controller

The plan of an ANFIS-SMC using the stability criteria named as Lyapunov also applied sliding conditions. The ANFIS based sliding mode controller has several rewards over the conventional sliding mode control which ensures zero steady state error with better set point tracking against parameter and external disturbance also it have stability property. Figure.7. represents the Control Structure of the ANFIS based Sliding Mode Controller block diagram where the controller adapts its parameters (*l*) make use of the adaption law and to end with resultant controller input is send to the interacting tank system as its control input signal [18].

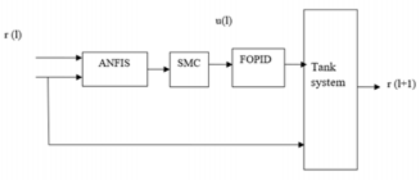


Figure 7: Block diagram for ANFIS based SMC with FOPID Controller

## 4. Simulation Results and Discussions

The proposed ANFIS (Adaptive Neuro Fuzzy Inference System) based SMC-FOPID is simulated in MATLAB/SIMULINK software. Table 3 gives the controller parameter specifications used during simulation in spherical tank. The Trapezoidal type input membership function is used for control design. So far researches have not implemented ANFIS based SMC –FOPID, non-linearity reducing technique in spherical two tank interacting system. The rate of flow in tank at each region is controlled. The ANFIS (Adaptive Neuro Fuzzy Inference System) controller response is compared with conventional FOPID controller and Sliding Mode Controller (SMC). Table 4 shows the parameters specifications used in the ANFIS based SMC-FOPID simulation.

Table 3: Parameters specifications

| **Controller parameters** | |
|---|---|
| **Controller** | **Values** |
| PID | $K_p$ = 5.152, $K_i$ = 0.005, $K_d$ = -29.661 |
| FOPID | $K_p$ = 9.143, $K_i$ = 0.042871, $K_d$ = -4.5476, λ = 0.84797, μ = 1.3358 |
| ANFIS FOPID | $K_p$ = 9.143, $K_i$ = 0.042871, $K_d$ = -4.5476, λ = 0.84797, μ = 1.3358, $K_{ANF}$ = 620.8, $\emptyset_{ANF}$ = 0.038 |
| ANFIS SMC-FOPID | $K_{ANF}$ = 620.8, $\emptyset_{ANF}$ = 0.038, Ku = 4.1278, Tu = 1.72, $K_{pmin}$ = 0.640896, $K_{pmax}$ = 2.00661, $K_{dmin}$ = 0.1158, $K_{dmax}$ = 1.0921424, λ = 0.84797, μ = 1.3358 Ω =50, K= 7.5997 |

Table 4: Parameters of spherical two tank interacting system

| **Notation** | **Description** | **Values** |
|---|---|---|
| D | Diameter | 40 cm |
| R | Radius | 20 cm |

| | | |
|---|---|---|
| H | Height | 40 cm |
| $F_{I1'}$ | Inflow to tank 1 | 107.85 $cm^2/s$ |
| $\beta_{a1}$ | co-efficient valve of $MV_{01}$ | 77.08 $cm^2/s$ |
| $\beta_b$ | Valve co-efficient $MV_1$ | 19.69 $cm^2/s$ |

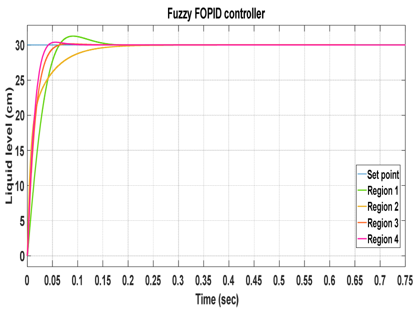


Figure 8: Output of fuzzy FOPID controller for a given step input for all regions

Figure 8 displays the fuzzy FOPID controller output for a given step input for all regions. The time domain specifications and integral performance indices of the above obtained output is given in Table 5. The output values shows the level of liquid is controlled and disturbance is reduced with slight fluctuation.

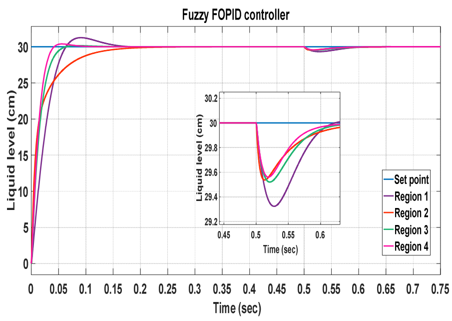


Figure 9: Output of fuzzy FOPID controller for an external disturbance rejection for all regions

Table 5: Time domain and integral performance indices for fuzzy FOPID controller

| Fuzzy FOPID controller | | | | | |
|---|---|---|---|---|---|
| **Regions(R)** | | **R1** | **R2** | **R3** | **R4** |
| Time domain | Rise time (sec) | 1.327 ms | 3.937 ms | 9.5 ms | 15.840 ms |
| | Settling time (sec) | 0.053 ms | 2.056 ms | 4.26 ms | 9.504 ms |
| | Peak time (sec) | 0.080 ms | 0.040 ms | 0.120 ms | 0.020 ms |
| | Under shoot (%) | 0 % | 0 % | 0 % | 0 % |
| | Over shoot (%) | 0 % | 0 % | 0 % | 0 % |
| Performance indices | ISE | 3 | 3.009 | 2.74 | 3 |
| | IAE | 0.1 | 0.09 | 0.09 | 0.1 |
| | ITAE | $3.586e^{-16}$ | $4.619e^{-16}$ | $1.17e^{-16}$ | $3.719e^{-16}$ |

Using Fuzzy FOPID controller in the spherical tank 0% of overshoot and under shoot is achieved in all the four regions as shown in Figure.9.

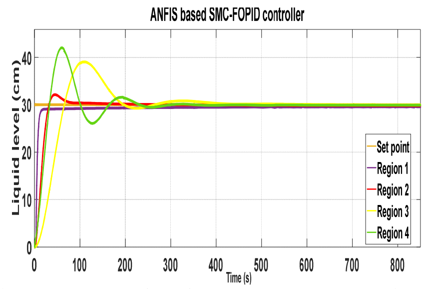


Figure 10: ANFIS based SMC-FOPID output trajectory

Table 6: Time domain and integral performance indices for fuzzy FOPID controller

| ANFIS based SMC with FOPID controller | | | | | |
|---|---|---|---|---|---|
| Regions(R) | | R1 | R2 | R3 | R4 |
| Time domain | Rise time (sec) | 0.322 ms | 2.137 ms | 5.2 ms | 10.8 ms |
| | Settling time (sec) | 0.001 ms | 1.016 ms | 2.02 ms | 4.8 ms |
| | Peak time (sec) | 0.003 ms | 0.005ms | 0.009 ms | 0.008 ms |
| | Under shoot (%) | 0 % | 0 % | 0 % | 0 % |
| | Over shoot (%) | 0 % | 0 % | 0 % | 0 % |
| Performance indices | ISE | 2 | 2.009 | 1.74 | 2 |
| | IAE | 0.1 | 0.09 | 0.09 | 0.1 |
| | ITAE | $2.586e^{-16}$ | $3.619e^{-16}$ | $1.07e^{-16}$ | $2.719e^{-16}$ |

The ANFIS based SMC-FOPID controller in the spherical two tank interacting system provides 0% of overshoot and under shoot in all the four regions and also region 1 shows better results when compared to other 3 regions. Compared to already existing controllers the proposed ANFIS based SMC with FOPID controller achieved better performance in order to control the level of liquid in coupled spherical tank interacting system and also the performance indices such as ITAE, IAE, ISE also reduced is shown in Table.6. The R1 in ANFIS based SMC-FOPID controller gives best performance as shown in Figure.10.

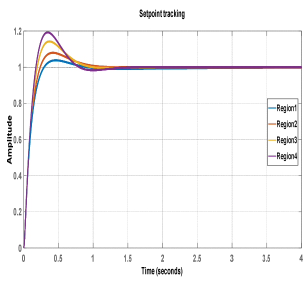

Figure 11: Set point tracking response

Figure.11 demonstrates the tracing performance of the set point of ANFIS based SMC with FOPID controller.

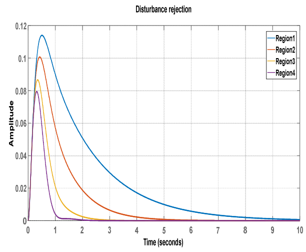

Figure 12: External disturbance rejection capability of ANFIS based SMC-FOPID Controller

ANFIS based SMC with FOPID Controller is also applied for error performance analysis. In this spherical tank system there are four regions in which the liquid level and disturbances occurring in external are controlled.

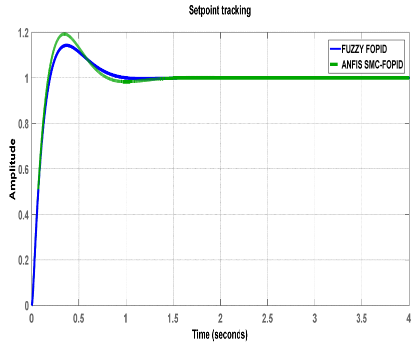

Figure 13: Set point tracking comparison between FUZZY FOPID and ANFIS based SMC-FOPID

Figure 13 shows the FUZZY FOPID and ANFIS based SMC-FOPID set point tracking performance comparison. It is seen that the proposed ANFIS based SMC-FOPID approach conveys the response of the system to the desired level through low settling time as well as steady state error.

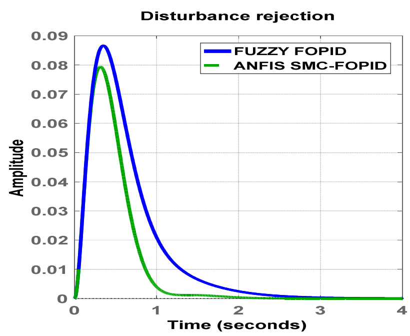

Figure 14: Disturbance rejection comparison

Figure.14 shows the external disturbance rejection capability comparison between FUZZY FOPID and ANFIS based SMC with FOPID Controller. From this, the result shows ANFIS based SMC-FOPID provides better reduction of external disturbance than the conventional technique. Table.7&8 shows the performance comparison of PID, FOPID, ANFIS-FOPID and ANFIS based SMC-FOPID Controller.

Table 7: Performance of various controller output

| Controller | PID | FOPID | ANFIS-FOPID | ANFIS – SMC-FOPID |
|---|---|---|---|---|
| IAF($h_c$) | 3.68 E +03 | 4.17 E +03 | 3.89 E +03 | 4.12 E +03 |
| ISI(F) | 3.63 E +06 | 3.62 E +06 | 3.651 E +06 | 3.628 E +06 |
| MOV | 5 | 8 | 3 | 7 |
| $E_{ss}$ | 1.08 | 1.94 | 0.75 | 1.68 |

Table 8: Performance of various controller output

| Controller | PID | FOPID | ANFIS-FOPID | ANFIS-SMC-FOPID |
|---|---|---|---|---|
| $t_d$ | 250 | 246 | 252 | 242 |
| $t_r$ | 1558 | 1552 | 1560 | 1554 |
| $t_p$ | 1582 | 1613 | 1580 | 2308 |
| $t_s$ | 472 | 468 | 473 | 469 |

The performance evaluation of PID, FOPID, ANFIS-FOPID and ANFIS based SMC-FOPID Controller is analyzed as shown in Table.9.

Table 9: Performance analysis of PID, FOPID, ANFIS-FOPID and ANFIS based SMC-FOPID

| Controller | Chatter Effect | Real time simulation problem | Time taken to reach desired level | Disturbance rejection performance |
|---|---|---|---|---|
| ANFIS-SMC-FOPID | Smooth | Easy | 20 s(T1) 9 s(T2) | Better |
| ANFIS-FOPID | Less smooth as compared to ANFIS-SMC-FOPID | Quite easier than ANFIS-SMC-FOPID | 17 s(T1) 10 s(T2) | Less better compared to ANFIS-SMC-FOPID |
| FOPID | Less smooth | Some difficult | 14 s(T1) 11 s(T2) | Less better |
| PID | Rough | Difficult | 4 sec(Tank 1) 8 sec(Tank 2) | Worst |

From Table.9, ANFIS based SMC-FOPID Controller gives better chattering effect and disturbance rejection capability. Moreover, the time taken to reach the desired level is also less. Compared to other controlling techniques the proposed method provides better output result.

## 5. Conclusion

In this research paper, ANFIS based SMC-FOPID is designed and implemented to control the liquid level in spherical two tank interacting system. The performance of the proposed ANFIS based SMC -FOPID is found to be oscillatory around the set-point value. The proposed ANFIS based SMC-FOPID achieve better time domain specifications such as rise time, settling time; peak time, steady state error and peak overshoot on comparing with other existing controllers explained in the literature reviews. Moreover, the proposed ANFIS based SMC-FOPID performance is best with a set-point which is selected above and below the threshold value. Moreover the disturbance rejection occurring at external of the proposed scheme is analyzed.

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