# Modeling And Performance Analysis of FOPID Controller for Interacting Coupled Tank System

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*Process control is fundamental in modern interaction since it ensures security and improvement in a cycle. Furthermore, process control is a valuable apparatus to fulfill the ecological strategy and item quality necessities. In ventures, one of the controlling system factors is fluid level, the fluid level regulators are a critical concern and well-known interaction, and the aggregate illustrative additionally genuine world in designing techniques. Fluid-level coupled tank framework can be set up into two popular types of interfacing and non-associating structure. This work centers around associating coupled tank control frameworks, numerous issues impacting the fluid level like nonlinearity of the framework, displaying vulnerabilities, and complex investigation, so to conquer those issues, to acquire steady stable results and quick reactions different regulators are required.*

*The liquid must be transferred and kept in a holder for control design in the modern day. The study of a partial request proportional-integral-derivative (PID) regulator for controlling a fluid level of the tank framework is presented in this work. FOPID and TID controller techniques are tested and demonstrated for coupling connected tank systems using several partial request regulators, including Commande Robuste d'Ordre Non-Entire (CRONE), Tilt-Integral Derivative (TID), and Fractional order PID (FOPID).*

*The result reaction is directed with the MATLAB®/Simulink® circumstance to check the exhibition of the framework. The reproduction results showed that by controlling connecting coupled tank system (CTS) without aggravation, the reaction is great, however remembering outside unsettling influence for the subsequent tank, the regulator shows a feeble reaction aside from the FOPID regulator. The explanation is FOPID regulator has at least two changed boundaries that expand the vigor of the framework. From the regulators tried in this work, the partial request relative basic subordinate regulator (FOPID) has great execution contrasted with PID, TID, and digital- PID regulators. The accomplished presentation particularly of the FOPID regulator is a better performance for CTS compared to the other listed controllers.*

***Keywords**: Process control, Level process, coupled tank, PID, FOPID, Digital-PID*

## 1. INTRODUCTION

Numerous modern and logical cycles need a comprehension of how much substance is in the tank and its different compartments. The more reasonable modern application incorporates tank level measuring of milk, brew, wine in the business, and level measuring of corrosive, oil, water treatment, and dissolvable vessels in synthetic plants; level checking of fluid in supplies. This multitude of enterprises utilizes coupled tank frameworks.

In many cycles, like petrochemical, paper, and water treatment designing is utilizing the compartment to oversee the level of the liquid. An impartial regulator in the level control is to keep up with a given level of the set-point and to get a new set-point. The procedure business requires inflated, maintained compartments that expand to a different supply after which the liquids are handled through fraternization conduct elegant a holder, consistently coordinating the level of liquid in the repository while still maintaining control over the development of the liquid responsibility. The area around Center Enterprises includes a tall and overflowing lead representative chamber. For continuous sources that are remarkable to non-linearity, collaborating paired tank guidelines of framework production is a challenging issue. The primary concern in the framework is how to regulate the liquid level in the connected compartment. For various frustrated reaction intensities, the liquid level is too high, which results in

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annihilation. When the fluid stature is low, the framework might need to have inconsistent meanings. Due to their non-straight element conduct, current interactions present several shifting control challenges [1]. Nonlinear models are utilized where precision over a more extensive scope of tasks is required and where they can be straightforwardly fused into the regulator calculation. Due to the trademark nonlinearity, a large portion of the substance interaction ventures requires control methods, those to control such frameworks utilized partial request controls. The nonlinear framework taken up for the review is the coupled tanks. The design use of fluid level control is gigantic, explicitly in compound interaction businesses.

### 1.1 Types of industrial tank systems:

The level process comes in a variety of forms, including those depicted in Figure 1: spherical tank, cylindrical tank, canonical tank, and rectangle tank. Usually controlled based on the error signal and have a least upstream or downstream control valve when the inlet flow $q_i$ and the outflow $q_o$ of the system has controlled the level of the tank. From those tanks, in this work, we focused on a rectangular coupled tank system.

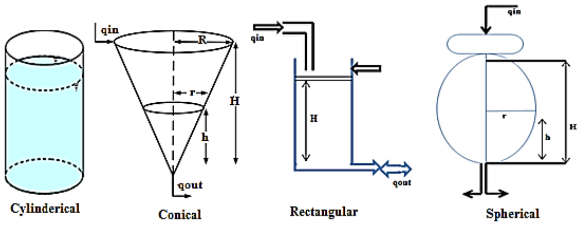


Figure 1. Sorts of tank frameworks [2,3]

In prior enterprises, people used an appropriate fluid height switch to manage the fluid level. At the point when the fluid is up to a persuaded level, the switch is precisely shut or open to control the level. With the consistent advancement of automation, constant control of the fluid level, that is, seeing the liquid level at every one of the periods is needed in the business.

Figure 2. Control of CTS fixed fluid stature switch [4]

Figure 2 shows how individuals utilize a settled liquid stature switch to accurately shut off or adjust the liquid level in a connected tank system. It is a straightforward and persuasive control methodology that has been effectively used for machine control applications in straight systems control. Although it can be difficult to use for nonlinear frameworks and does not always produce the desired results, the simplicity of those regulators may be able to make up for this drawback since some controlled items (objects with basic nonlinearity) call for the use of complex control laws in order to be executed tastefully [5].

The IOPID controls are regularly reused in controlling the pinnacle of the compartment in enterprises since overseeing the fluid in many tanks and undertaking between the tanks might be a clear inconvenience inside the ventures. Relative regulators are proper to direct modern regulators and hence are issues with consistent effort for the advancement of their exhibition and vigor. Practice $PI^{\lambda}D^{\mu}$ among fragmented request full number bits is one option for extending related fundamental subsidiary controls. The partial powers in basic and subsidiary terms are added to the number sought to obtain the FO regulators. It grants us to manage the subordinate Miu ($\mu$ ) and fundamental lambda ($\lambda$) request moreover to the kp, ki, and kd constants where the upsides of $\mu$ and $\lambda$ develop somewhere in the range of nothing and one.

The FO controllers are derived from the integer order by adding the fractional powers in integral and derivative terms, It permits us to regulate the derivative Miu ($\mu$ ) and integral lambda ($\lambda$) order in additionally to the kp, ki, and kd constants where the values of $\mu$ and $\lambda$ invention between (0,1) [6].

The primary issue during a process variable, together with a mutual demonstrative and concrete in engineering practices, is the control of the level process regulator. From various kinds of literature, it is evident that there is a need for effective controllers that improve the time domain performance measures. The success of a fractional-order PID controller to control the method level with regard to the interacting coupled tank is examined in this work. In previous manufacturing, a human-contained fluid level adjustment resulted in a permanent fluid level adjustment while a liquefied one corresponded with a convinced level. Numerous industrial processes, including those in the petrochemical, water treatment, and beer industries, have a container to control their peak. The right controllers are required to control the fluid's volume. A controller's primary function in a system is to maintain a height at the selected point and make it adaptable to the new set point [7].

### 1.2 IOPID controller:

An immediate regulator for the control to get ready with a better-than-average reaction is a PID regulator. A PID regulator is typically used in the procedure and applies the social affair of three different medical exercise combinations to the mix-up banner to explain how far or close the necessary point is from the specific yield. As comprehensively known, these three control exercises are comparing, essentially, and subordinate The key feature when tuning PID regulators is in deci–ding the method for outmaneuvering partners in those three terms to accomplish the transcendent efficient guidance of the system variable for the thoroughly exa–mined issue. also known, the principal reasonable way is to use a straightforward weighted aggregate where each term is copied by a tuning consistent or gain [8] PID's functioning manages everything is that it ascer–tains slip regard from the pre-arranged estimated regard thus the necessary reference. The PID regulator desig–ned a mechanism to reduce the error by altering the system's inputs. Corresponding necessary subor–dinate control is the fundamental control plot of the traditional system [8]. The appraisal of interaction may be gained ground using the right regard of getting kp, ki, and kd.

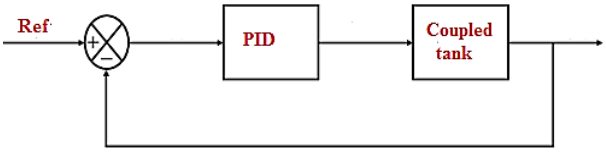


**Figure 3. Block chart of PID regulator [9]**

Figure 3 depicts the connected tank framework being controlled using the -IOPID controller's controller technique. As it were, this controller is suitable for CTS in straight cases because it is possible that in nonlinear scenarios, the requisite yield may not be tracked in all circumstances involving the framework property.

## 1.3 Digital-PID Controller:

Various approaches are used to create the discrete-time PID regulator from the simple accomplice [10]. A PC is a crucial component of the regulator in electronic control systems. The PC typically obtains an evaluation of the controlled variable, as well as reference data, and then generates its yield using an estimation. In case of uncertainty, this output is converted to a simple banner using a D/A converter, which is then amplified by a control amplifier to run the plant. Figure 4 displays a flowchart of a typical progressive control structure in pieces.

Past work on persistent time PID regulator plan in boundary space, comparing results are absent for com–puterized PID regulators. While it is dependably con–ceivable to plan a constant time PID regulator and afterward discretize it for computerized execution, it is desirable to straightforwardly plan the advanced PID in the z-space, particularly within the sight of a testing time that isn't excessively little which is ordinary for auto control frameworks that depend on estimations from the CAN transport [10]. The cutting-edge compu–terized control frameworks require increasingly solid and quickest estimation parts. Field, advanced PID regulator can not just utilize the product to understand the PID control calculation, yet in addition, can utilize the rationale capacity of the PC to make the PID control more adaptable. As of now, computerized PID regulator has been generally utilized in mechanical, electro–mechanical, metallurgy, synthetic industry, etc. [11].

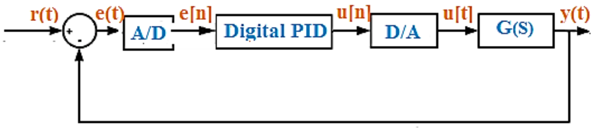


**Figure 4. Block diagram of Digital-PID controller [9]**

1.3.1. Method of conversion:

To transform a continuous transfer function into a discrete function, there are several alternative appro–aches. zero-order hold on the inputs, linear interpolation inputs, impulse invariant discretization, backward and forward euler approximations to the derivative, the tustin approximation or trapezoidal method, and the matched pole-zero method are among them. (for siso system only).

From those noticed sorts of transformation, we select the Trapezoidal rule. The trapezoid-rule repla–cement is also known, especially in computerized and inspected information control circles, as Tustin's strategy. The change is additionally called the bilinear change from the thought to its numerical structure. The plan procedure can be summed up by communicating the standard as displayed: Given a ceaseless exchange work (channel), H(s), a discrete comparable can be found by the replacement.

$$H_T(z)=H(s)|_s=\frac{2}{T}\left[\frac{(z-1)}{z+1}\right]$$

Regulators are needed to guarantee good transient and consistent state conduct for the designing frameworks. To ensure good execution within the sight of unsettling influence and model vulnerability, most regulators being used today utilize some type of negative criticism. Today simple regulators have been supplanted by advanced regulators to accomplish better control [12].

The computerized PID regulator configuration is dependent on simple PID being changed over using bilinear change. This change is given by:

$$s=\frac{2}{T}\left[\frac{(z-1)}{z+1}\right]$$

where T is the example time stretch, in this specific power framework T is little to the point of bringing about a higher example rate, the advanced PID regulator gives a similar outcome as the simple partner true to form. Also, the computerized PC insider savvy yields many benefits, for example, a decrease in cost, the adaptability of the plan change, and critically it immunes to clamor. Any future change in the framework is supplanted by a straightforward programming update over a sweeping equipment substitution. Involving a computerized PID regulator accomplishes an equili–brium in both rising time and overshoot.

## 1.4 TID Controller:

Tilted-Proportional and Integral (TID) Controller are to give an improved input circle regulator gains of the traditional Proportional necessary regulator. In the TID structure, the relative remunerating unit is traded with a compensator having an exchange work portrayed by $\frac{1}{s^{1/n}}$ or $\frac{1}{s^{1/n}}$ . This compensator is thus alluded to via a "Slant" compensator, as it conveys an input gain as a component of recurrence which is shifted or framed for the addition/recurrence of a moderate or positional reward unit. The ideal regulator is thus alluded to as a Tilt-Integral Derivative (TID) regulator. It contains three parts tunable input circle control framework which contains a relatively fundamental subsidiary regulator.

The singular change from the regular regulator is that the related rewarding piece of the system is supplanted with a more sensible compensator which is having an exchange work. The expression "Slant" recommends that it can give a criticism improvement as a recurrence reason that is formed or shifted to progress recurrence of unsurprising repayment substance [13]. An exchange capacity of TID can be composed:-

$$G(s)=k_t(1/s)^{1/n}+\frac{k_i}{s}+sk_d$$

where n is a non-zero real number, the above transfer function is shown in Figure 5 as:

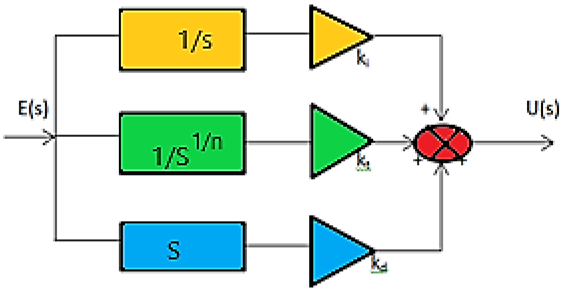


Figure 5. Tilt-integral derivative controller [13]

Figure 5 depicts the TID regulator's schematic diagram. Although the IOPID regulator functions as the management mechanism, the tilt compensator is the key component.

The emphasis in the current industrial process controlling system is on performance. Owing to the issue of various factories disrupting the system, it is necessary to decrease the disturbance, improve the quality of the output, and lower operating costs. Is advantageous to examine a system's performance using a digital and fractional order controller for level process control in a connected, interacting tank system. Digital PID and fractional order PID controllers are suggested in this work. A method using a FOPID controller and a digital PID controller is examined, along with the evaluation of each controller's performance.

The paper is divided into five sections. In section 2, system modeling procedures and methods are described. In section 3, the method of controllers is presented. Section 4 Simulink design of the proposed system, results,s and discussion of the overall paper is presented. Section 5, the concluding remarks are given to summarize the contribution of the work.

## 2. SYSTEM MODELING PROCEDURES AND METHODS

Two tanks are joined together in the shape of an interacting form, and in this case, the size of the first tank is dependent upon the size of the second tank. The height of the tank is kept constant once the fluid is allowed to flow into it and along with it as it exits, according to the honest principle of control interaction boxes. The primary parameter used to control the associated tank device in system industries is the tank's fluid level [14]. To maintain and control the liquid level at a specified cost, the glide entrance charge is regulated. Figure 6's interacting connected tank serves as a schematic representation of a coupled tank device. Through the use of a tiny conduit, Tanks 1 and 2 have been connected. The liquid used within the plant is building up to be non-viscous, incompressible, and constant [15].

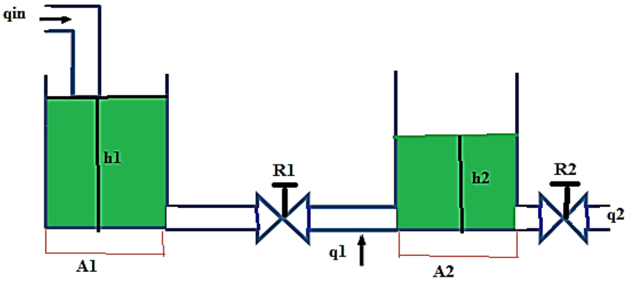


Figure 6. Schematic diagram of interacting coupled tank system [proposed diagram]

where, $q_{in}$ = Volumetric flow rate input (cm$^3$/sec), $q_1$ = Volumetric flow rate from tank 1 to tank 2 (cm$^3$/sec), $q_2$= Volumetric flow rate from tank output (cm$^3$/sec), $h_1$ = Height of the liquid level input (cm), $h_2$ = Height of the liquid level in tank 2 (cm), $A_1$ = Cross-sectional area of tank 1 (cm$^2$), $A_2$ = Cross-sectional area of tank 2 (cm$^2$), $R_1$ = Linear resistance of flow from tank 1 through valve 1 (cm$^{-2}$sec), $R_2$ = Linear resistance of flow from tank 2 through valve 2 (cm$^{-2}$sec). The differential equations of tank 1 and tank 2 are obtained using the flow balance equation and given in (1) and (7).

The main parameters of the above system are, Inlet flow, Out late flow ($q_0$), Cross-sectional areas (A), Heights of liquid in the tank (h), and Valve/ pipe/ resistance (R), Consider the float of the liquid through a pipe from the pump to the system tank and another pipe from the process tank to every other manner tank. The resistance R for liquid-waft in such a box is described as the exchange within the degree difference to unit alternate in glide charge, that is

$$R=\frac{\text{change in level difference}}{\text{change in flow rate, cm}^3\text{/sec}} \tag{1}$$

Changes in the second system will affect the first system. The liquid level in the second tank will affect the level in the first system (interacting system). The differential equations of tank 1 and tank 2 are obtained using the flow balance equation and given in (2) and (8).

For tank 1:-

The mass balance equation can be written as

$$\left.\begin{aligned} A_1\frac{dh_2}{dt}&=q_1-q_2\\ A_2=\frac{dh_2}{dt}&=\frac{h_1-h_2}{R_1}-\frac{h_2}{R_2}\end{aligned}\right\}$$

From the definition of resistance, the relationship between h$_1$, h$_2$, and q$_1$ is given by

$$q_1=\frac{h_1-h_2}{R_1} \tag{3}$$

Substitute (3) into (2) we get,

$$A_1 \frac{dh_1}{dt} = q_{in} - \frac{h_1 - h_2}{R_1} \tag{4}$$

$$R_1 A_1 \frac{dh_1}{dt} = R_1 q_{in} - h_1 + h_2 \tag{5}$$

By taking Laplace's transform

Note that $R_1A_1$ is the time constant of the system, Taking the LT of both sides of (5), we get;

$$R_1 A_1 s h_1(s) = R_1 q_{in}(s) - h_1(s) + h_2(s) \tag{6}$$

$$h_1(s) = \frac{R_1 q_{in}(s) + h_2(s)}{1 + R_1 A_1 s} \tag{7}$$

when $\tau_1 = R_1 A_1$

$$h_1(s) = \frac{R_1 q_{in}(s) + h_2(s)}{1 + \tau_1 s} \tag{8}$$

For tank 2:-

The mass balance equation is

$$A_1 \frac{dh_2}{dt} = q_1 - q_2 \tag{9}$$

$$q_2 = \frac{h_2}{R_2} \tag{10}$$

$$\begin{gathered} A_1 \frac{dh_2}{dt} = q_1 - q_2 \\ A_2 = \frac{dh_2}{dt} = \frac{h_1 - h_2}{R_1} - \frac{h_2}{R_2} \end{gathered} \tag{11}$$

From (11) we get;

$$R_2 R_1 A_2 \frac{dh_2}{dt} = R_2 h_1 - R_2 h_2 - h_2 R_1 \tag{12}$$

On dividing by $R_1$ and taking Laplace transform:

$$A_2 R_2 s h_2(s) + \frac{R_2}{R_1} h_2(s) + h_2(s) = \frac{R_2}{R_1} h_1(s) \tag{13}$$

$$h_2(s)\left(\tau_2 s + \frac{R_2}{R_1} + 1\right) = \frac{R_2}{R_1} h_1(s) \tag{14}$$

where $\tau_2 = R_2 A_2$

Substitute (8) in to (14) and we get,

$$h_2(s)\left(\tau_2 s + \frac{R_2}{R_1} + 1\right) = \frac{R_2}{R_1} \frac{R_1 q_{in}(s) + h_2(s)}{1 + \tau_1 s} \tag{15}$$

$$\begin{gathered} h_2(s)\left(\tau_2 s + \frac{R_2}{R_1} + 1\right)(R_1 + R_1 \tau_1 s) = R_2 R_1 q_{in}(s) + R_2 h_2(s) \\ h_2(s)\left(\tau_2 s + \frac{R_2}{R_1} + 1\right)(R_1 + R_1 \tau_1 s) - R_2 h_2(s) = R_2 R_1 q_{in}(s) \end{gathered} \tag{16}$$

Therefore the transfer function of the two tank interacting system is expressed as;

$$\frac{h_2(s)}{q_{in}} = \frac{R_1 R_2}{R_1 \tau_1 \tau_2 s^2 + (R_1 \tau_1 + R_1 \tau_2 + R_2 \tau_1) s + R_1} \tag{17}$$

$$\frac{h_2(s)}{q_{in}} = \frac{R_2}{\tau_1 \tau_2 s^2 + (\tau_1 + \tau_2 + \tau_1) s + 1} \tag{18}$$

## 2.1 Modeling of coupled tank system with disturbance

Disturbance analysis for an interacting container of fluid-level control systems can be as follows:-
where, $D_{in}$ – disturbance of the system.

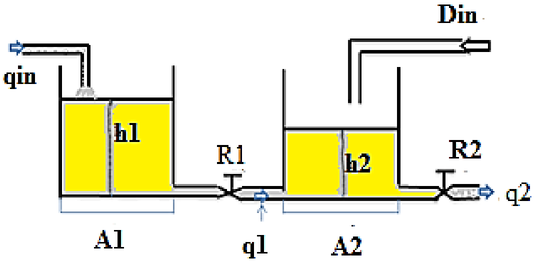


**Figure 7. Schematic diagram of the interacting coupled tank with a disturbance [proposed diagram]**

The disturbance transfer function analysis as below

$$A_2 \frac{dh_2}{dt} = D_{in} - q_2 \tag{19}$$

Since from $q_2 = \frac{h_2}{R_2}$ substitute into (19) and we get;

$$A_2 \frac{dh_2}{dt} = D_{in} - \frac{h_2}{R_2} \tag{20}$$

The LT of (20) we get;

$$\frac{h_2(s)}{D_{in}(s)} = \frac{R_2}{A_2 R_2 s + 1} \tag{21}$$

## 3. METHODS OF CONTROLLERS

There are two categories of control framework in control building such as open loop control framework and closed loop control framework. If the actuating signal (input of the plant/system) depends only on the reference signal and is independent of the plant output it is called an open loop control system while if the actuating signal depends on both the reference signal and output of plant a control system is called feedback control (closed loop) system. The open loop control system is not used in practice since a plant/system is easily affected by parameter variations, noise, and disturbance, but the feedback control system is most widely used in practice because, it can reduce the effect of parameter variations, disturbance and suppress noise. Open loop control methods are where a control accomplishment is self-regulating the response processes but a CLS in which the response affects the input insure that the input will regulate itself based on the response generated.

### 3.1 PI$^{\Lambda}$D$^{\mu}$ CONTROLLER

The FOPID controller has two extra adaptable parameters than the PID controller, and the order of the controller may be selected randomly, the FOPID controller owns more flexibility. In addition to that, the FOPID controller has first-rate adaptability to the parameter variation of the control system. When the constraint of the manipulated device trade is contained with the aid of a certain variety, the system characteristics continue to be unchanged. So the FOPID controller has the characteristic of sturdy robustness.

PID controllers are linear and symmetric and they have headaches with the incidence of non-linearity. This trouble can be solved with the aid of the usage of a FOPID controller. A regulator via integrator of real order λ and differentiator real order μ is a more common purpose of the classical PID-controller which can provide extra flexibility and robustness in tuning and control by way of an additional diploma of freedom within the system.

Podlubny advised an ordinary form of the IOPID manipulation, which is referred to as PIλDμ manage, where the values of λ and μ lie between zero and 1. Related to the PID controller, the FOPID controller has more adjustable parameters, which makes the parameter tuning greater bendy, it is very important significative for successful control accuracy, consequently, the FOPID controller applied for handling a degree method in interacting two-tank [16].

$$G_{fc}(s)=\frac{U(s)}{E(s)}=\mathrm{k_p}+\mathrm{k_i}\,\mathrm{s}^{-\lambda}+\mathrm{k_d}\mathrm{s}^{\mu},\ (\lambda>0,\ \mu>0)$$

Figure 8 demonstrates that λ= 1 and μ = 1 are the conventional PID controller if λ = 1 and μ = 0 it is the conventional PI controller if λ= 0 and μ = 1 it is the unadventurous PD controller, and if both μ and λ = 0 it is P controller, it $\mathrm{PI}^{\lambda}\mathrm{D}^{\mu}$ can be seen that the adjustable range of the fractional $\mathrm{PI}^{\lambda}\mathrm{D}^{\mu}$ the controller is wider than the conventional-PID controller, therefore, the guideline performance of the FOC is greater than the IOPID controls.

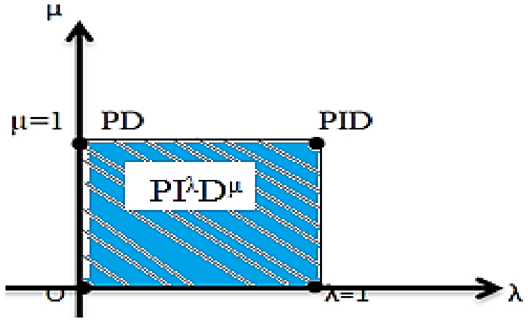


**Figure 8. PID controller graph [ 15]**

### 3.2 Tuning of the controller parameters

Designing the tuning parameter is necessary before moving on to create the controller. The tuning approach is the layout of the poles. The pole placement layout method makes an effort to identify a controller that provides the needed closed-loop poles [17], [18].

First to find the fee of the controller parameter so start from IOPID or traditional PID controller, and think that the procedure is characterized by the second-order version.

$$G_p(s)=\frac{k}{s^2+2\xi\omega_n s+\omega_n^2}$$

Then, the closed-loop system transfer function becomes,

$$G_{cl}(s)=\frac{k\left(k_d s^2 k_p s+k_i\right)}{s^3+\left(2\xi\omega_n+kk_d\right)s^2+\left(\omega_n^2+kk_p\right)s+kk_i}$$

Consequently, selecting an appropriate comparative governance (α), the third order CL system (3rd) {Formatting Citation} determination accomplish like second-order classification consuming the user-specified CL damping ratio $\xi^{cl}$ (percentage of maximum overshoot) and closed-loop natural frequency $\omega_n^{cl}$ (rise time). In this situation, the distinguishing polynomial is inscribed as:

$$\left(s+\alpha\xi^{ci}\omega_n^{cl}\right)\left(s^2+2\xi^{cl}\omega_n^{cl}+\left(\omega_n^{cl}\right)^2\right)=0$$

Relating the coefficients of (25) with the denominator of $G_{cl}(s)$ mathematical modeling of PID controller gain can be calculated as follow.

The overall parameters of the PID controller from the above get in this way,

$$\left.\begin{aligned}k_p&=\frac{\left(1+2\alpha\left(\xi^{cl^2}\right)\left(\omega_n^{cl^2}\right)\right)-\omega_n^2}{k}\\ k_i&=\frac{\alpha\xi^{cl}\left(\omega_n^{cl}\right)^3)}{k}\\ k_d&=\frac{(2+\alpha)\xi^{cl}\omega_n^{cl}-2\xi\omega_n}{k}\end{aligned}\right\}$$

### 3.3 Parameters of level control system

The success of a technique-level manipulation machine in interacting coupled tank for and examining the response of the system with IOPID, digital-PID, TID, and fractional-order PID controller, the selected parameter of the extent tank is specified in Table 1.

However, with the purpose to acquire a very good control of overall performance the bodily parameter values of the plant ought to be predicted. The problem with the parameter estimation for this device is because of the nonlinear dependence on the parameters, we do not forget the physical parameter's value from the subsequent Table 1 the outcomes of the environmental changes on the plant, and the dimension noise.

**Table 1. Physical parameters of coupled tank system [19]**

| NO | Description | Parameter | Value | Units |
|---|---|---|---|---|
| 1 | Area of Tank 1 | A1 | 250 | cm$^2$ |
| 2 | Area of Tank 2 | A2 | 250 | cm$^2$ |
| 3 | Resistance of Tank 1 | R1 | 0.01 | Sec/cm$^2$ |
| 4 | Resistance of Tank 2 | R2 | 0.01 | Sec/cm$^2$ |
| 5 | Height of Tank 1 | h1 | 50 | cm |
| 6 | Height of Tank 2 | h2 | 15 | cm |

Since the open-loop transfer function of the system is given above standard 2nd order and the unknown open-loop system parameters, ξ, and $\omega_n$ are obtained. Using the parameters given in Table 1.

$$\left.\begin{aligned} k &= \frac{R_2}{\tau_1 * \tau_2} \\ \omega_n &= \sqrt{\frac{1}{\tau_1 * \tau_2}} \\ \xi &= \frac{\tau_1 + \tau_2 + R_2 A_1}{2 * \tau_1 * \tau_2 * \omega_n} \end{aligned}\right\}$$

$$k = \frac{R_2}{\tau_1 * \tau_2} = \frac{0.01}{(250 * 0.01) * (250 * 0.01)} = 0.0016$$

$$\omega_n = \sqrt{\frac{1}{\tau_1 * \tau_2}} = \sqrt{\frac{1}{6.25}} = \sqrt{0.16} = 0.4$$

$\xi = \frac{\tau_1 + \tau_2 + R_2 A_1}{2 * \tau_1 * \tau_2 * \omega_n} = 1.5$ (due to the overall transfer function of the closed-loop plant being third order )

$$K_p = \frac{\left(1 + 2\alpha \left(\xi^{cl}\right)^2 \left({\omega_n}^{cl}\right)^2\right) - \omega_n^2}{k} = 5037.5$$

$$k_i = \frac{\alpha \xi^{cl} \left(\omega_n^{cl}\right)^3}{k} = \frac{7.6}{0.0016} = 4750$$

$$k_d = \frac{(2 + \alpha)\xi^{cl} \omega_n^{cl} - 2\xi\omega_n}{k} = \frac{4.5}{0.0016} = 2812.5$$

$K_p$, $K_i$, and $K_d$ are constant terms so we don't need to use units.

The closed loop analysis of proportional-integral-derivative controller with a plant of interacting coupled tank system as follows,

$$G_p(s) = \frac{0.0016}{S^2 + 1.2S + 0.16} \tag{26}$$

The disturbance that consider $\frac{h_2(s)}{D_{in}(s)} = \frac{0.01}{2.5s + 1}$

For modeling of coupled tank machine with dis–turbance, use the plant of CTS cascade with a disturbance that considered then control the nonlinear machine the use of FOPID controller.

The choice of the favored parameters of a closed contraption and the utilization of the connection, the pick up of the classical-PID controller advantage is taken into thought which creates one of a kind shaft situation at exact- damping and recurrence, providing relative dominance (α) is chosen on iteratively by utilizing assessing the accurateness of machine reaction. Here unique issues of the closed-loop scheme favored are $\xi^{cl} = 0.95$ and ${\omega_n}^{cl} = 2$ rad/sec selecting the appropriate value of the relative dominance by trial and error by checking the accuracy of the system response.

## 4. SIMULINK DESIGN OF THE PROPOSED SYSTEM AND RESULTS

### 4.1 Simulink model of CTS with disturbance

The execution of the association coupled tank gadget is examined by the utilization of its MATLAB/Simulink adaptation with considering around outside unsettling influence, the parameters utilized to carry out the reenactment inquired about are given in Table 1.

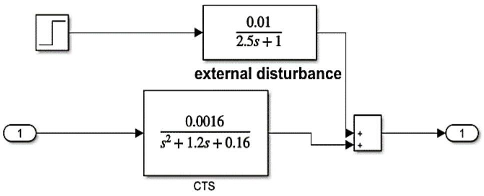


**Figure 9. Simulink model of CTS with disturbance**

A very faint response is shown in Figure 9's result. This suggests that a controller is necessary (22) for controlling the CTS. As an outside disturbing influence on the plant, the unsettling influence does not transfer in a cascade structure. If the disturbance was thought to be internal, the configuration would take the form of a cascade [20]. The disturbing factor could be moisture or other outside noise that makes the device or other words device is tall nonlinear in the event of these distur–bances.[ 21].

### 4.2 Performance of interacting CT-based PID controller without disturbance

Utilizing MATLAB/Simulink, the cooperation coupled tank system without external disturbing impact was completed [22] to demonstrate how the connection coupled tank with a PID controller performs.

Table 1 contains the parameter for the degree cont-rol, and Figure 10 contains the Simulink representation of the associated tank in interaction with the PID controller. And after that assess the in-general execution of collaboration coupled tank framework based comp-letely PID controller with and without disturbance.

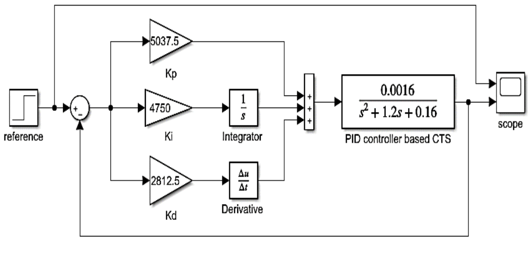


**Figure 10. Simulink model of CTS-based PID controller**

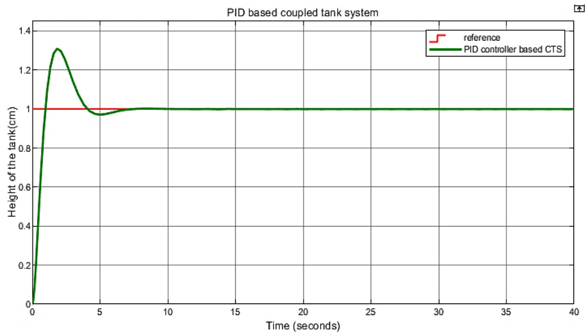


**Figure 11. Simulation result of interacting CTS with PID controller**

The behavior of the simulated interaction between CTS using an IOPID controller yields a modest reaction as compared to the desired output. The output response is shown in Figures 12 and 13 while the device is considering a disturbance (which indicates that the system is nonlinear).

### 4.3 Performance of interacting CT-based pid controller with disturbance

Higher overall performance of the quick reaction criteria is suggested by comparing to discern eleven the output response of the IOPID controls for the connected interactive tank with external disturbance.

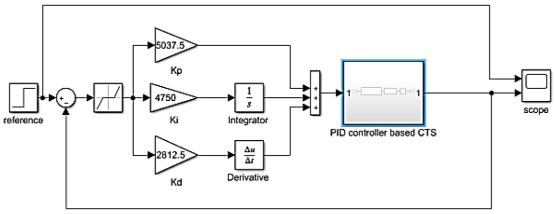


Figure 12. Simulink model of CT-based PID controller with disturbance

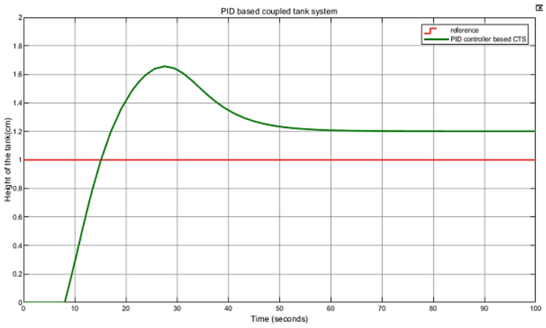


Figure 13. Simulation result of interacting CTS-based PID controller with disturbance

### 4.4 Performance of interacting CT-based DPID controller without disturbance

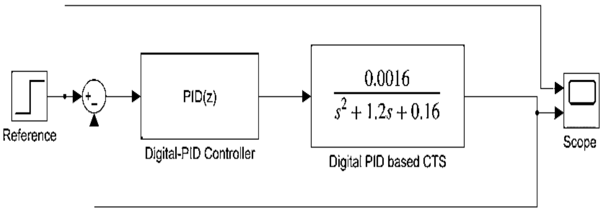
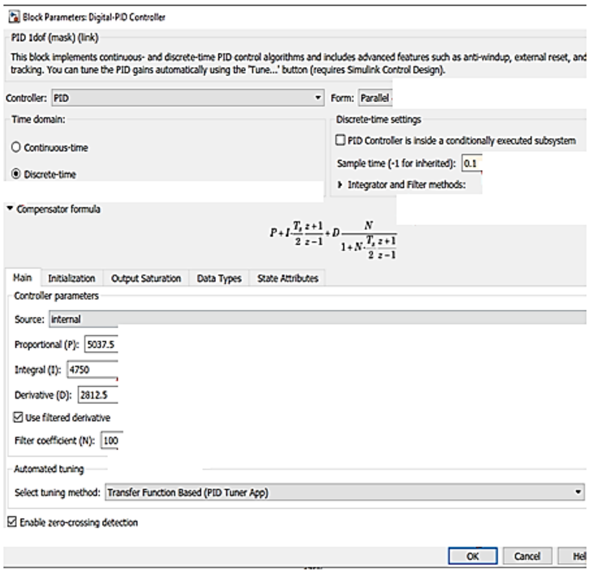


Figure 14. Simulink model of CTS-based Digital-PID controller

The step-by-step digitization of the process using Simulink diagrams is shown in Figure 14 together with a Simulink model of a CTS-based digital PID controller. First, pick discrete time by clicking and double-clicking the block diagram of the PID manipulation block in the MATLAB library. To enhance overall performance, go to the discrete-time settings and change the sample time (Ts). Use 0.1 s, then choose the parallel format, a specific analog to digitized and filtered approach method, and lastly choose the trapezoidal integration method. This method's employment is justified by the fact that trapezoidal or bilinear transformation alone can convert continuous to discrete and, in addition, can change the reaction into a continuous one. then is going to track the parameters, input the parameters, and controller parameters.


Block Parameters: Digital-PID Controller

PID 1dof (mask) (link)

This block implements continuous- and discrete-time PID control algorithms and includes advanced features such as anti-windup, external reset, and tracking. You can tune the PID gains automatically using the 'Tune...' button (requires Simulink Control Design).

Controller: PID

Form: Parallel

Time domain:

○ Continuous-time

● Discrete-time

Discrete-time settings

☐ PID Controller is inside a conditionally executed subsystem

Sample time (-1 for inherited): 0.1

Integrator and Filter methods:

Compensator formula

$$P+I\cdot\frac{T_s}{2}\frac{z+1}{z-1}+D\frac{N}{1+N\cdot\frac{T_s}{2}\frac{z+1}{z-1}}$$

Controller parameters

Source: internal

Proportional (P): 5037.5

Integral (I): 4750

Derivative (D): 2812.5

☑ Use filtered derivative

Filter coefficient (N): 100

Automated tuning

Select tuning method: Transfer Function Based (PID Tuner App)

☑ Enable zero-crossing detection

Figure 15. Step to conversion process using Simulink block diagram

Figure 15 indicates the conversion processes, the parameter that modifies the values, and the technique of the filter. The reenactment result of the cooperation connected tank with the use of a digital-PID controller without disturbing influence receives a wonderful reaction compared to the PID controller however this result isn't the preferred yield reaction. Since testing time is added in addition to I, P, and D parameters, the advanced PID controller performs better than an IOPID controller. But this brutal digital PID controller isn't the best result. The framework does not take into account outside unsettling influences (which force the device to be excessively nonlinear); its yield response is displayed in Figure 16.

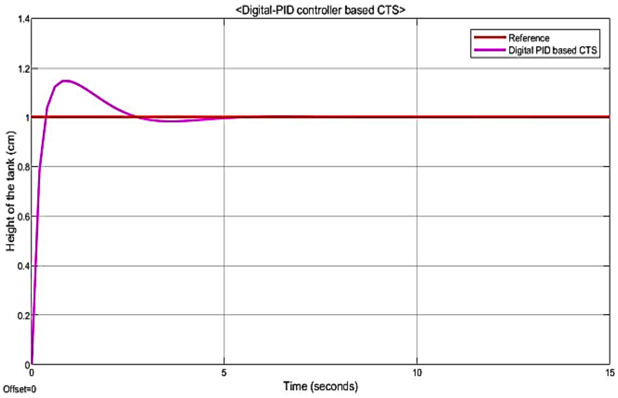


Figure 16.Simulation result of CTS-based Digital-PID controller

### 4.5 Performance of interacting ct-based dpid controller with disturbance

A sophisticated PID controller with unnerving outside interference occurs in the Simulink demonstration of Figure 17. Think about how the uncomfortable influence is there in the simulation, not just one or two. The computerized PID controller in SIMULINK's PID(z) demonstration appears to use the Trapezoidal con–version approach.

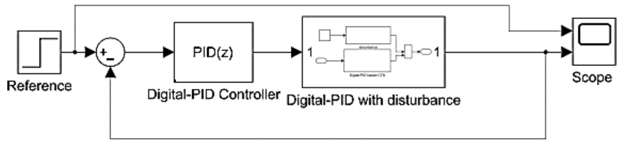


**Figure 17.Simulink model of CTS-based Digital-PID controller with disturbance**

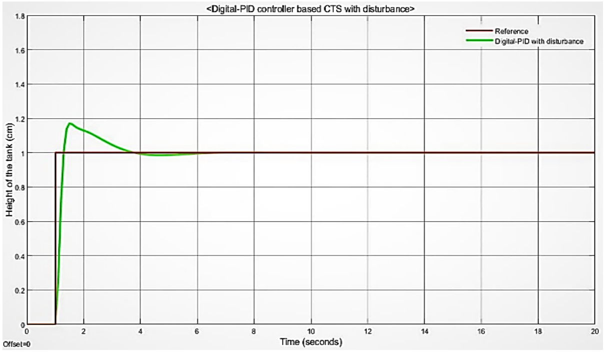


**Figure 18.Simulation result of CTS-based Digital-PID controller with disturbance**

When the testing time alters the reenactment conclusion result of the Digital-PID controller differing yield demonstrates in Figure 18. This suggests choosing the most excellent charge to urge a way better reaction. So the proper esteem of the testing time for digital-PID controller is 0.1sec this gets using checking the precision of the response. And the transformation framework utilizes trapezoidal bilinear transformation.

## 4.6 Performance of interacting coupled tank without TID controller

MATLAB/Simulink model of interacting tanks with TID control is shown in Figure 19.

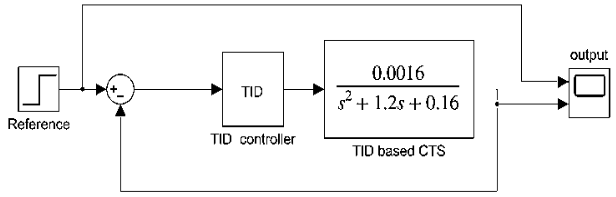


**Figure 19. Simulink model of CTS-based TID controller**

At the time TID controller for CTS directing occasions utilized the parameter values of Ki and Kd similar to IOPID be that as it may Kt is based on the Tilt compensator.

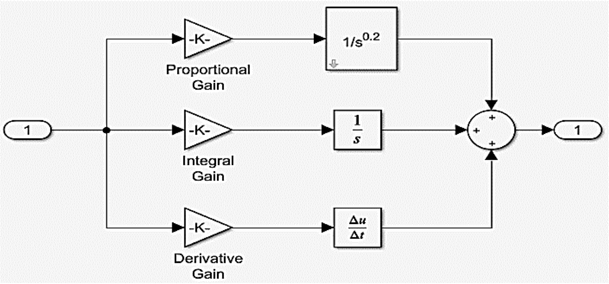


**Figure 20. Internal of tilted integral derivative (TID) controller**

Figure 20 showed a TID piece chart; the inner part of the TID controller contained comparable PID parameters, but the TID had expanded tilt parameters, which suggested the presence of a tilt compensator. The value of Tilt is changeable as you would like; thus, for this plan, use the value of "n" is 5 based on the trial method. Figure 21 shows the reaction of the CTS-based TID controller.

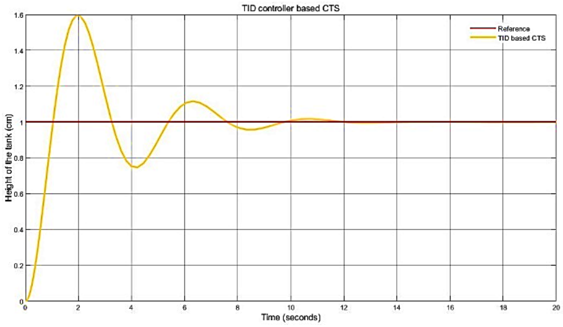


**Figure 21.Simulation result of CTS-based TID controller**

According to the reenactment results, the TID controller isn't an appropriate controller for the CTS. The outcome shows that annoyed wavering is more accurate than the over-reenactment result. Additionally, avoid selecting the preferred response for the direct device. The TID controller, which is primarily based on CTS, suggests in Figure 22 for a nonlinear framework (taking external disturbing influence into account).

## 4.7 Performance of interacting coupled tank-based TID controller with disturbance

The disturbance added to the plant and the TID controller for CTS with disturbance result is shown in Figure 23.

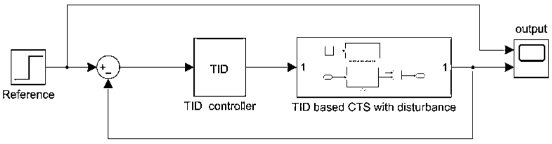


**Figure 22.Simulink model of CTS-based TID controller with disturbance**

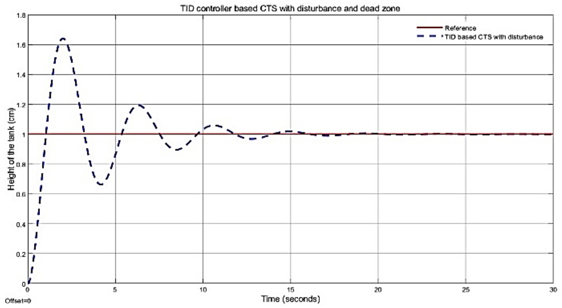


**Figure 23.Simulation result of CTS-based TID controller with disturbance**

According to the outcome shown in Figure 23, a device's output reaction is below the set factor while the price of n is increasing, but if the price of n is equal to 5, the overshoot is 115%. On the upward push period of 488.654msec, 96.5% of the interaction level tank's targeted output is attained. This implies that a nonlinear interacting linked tank machine is not a good candidate for a TID controller.

## 4.8 Performance of interacting Ct-based FOPID controller without disturbance

To display the performance of coupled interacting tank with fractional order PID controller in MATLAB /Simulink, the parameters of the extent manage are the same as given in desk 1. FOPID controller combines PID controllers gain and in addition to 2 parameters, those are lambda (λ) with quintessential gain and Miu (μ) with derivative advantage. A simulated model for the fractional-order PID manage machine is shown in Figure 24.

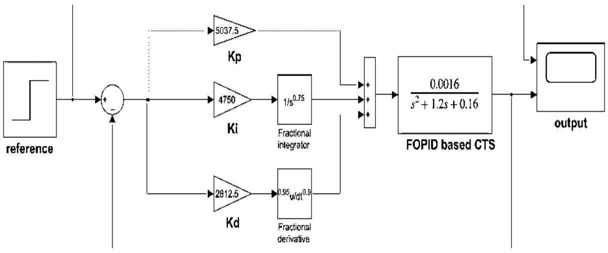


Figure 24. Simulink model of CTS-based FOPID controller

The value of fractional order of λ and μ is attained based on the trial approach the use of between the range of boundary.

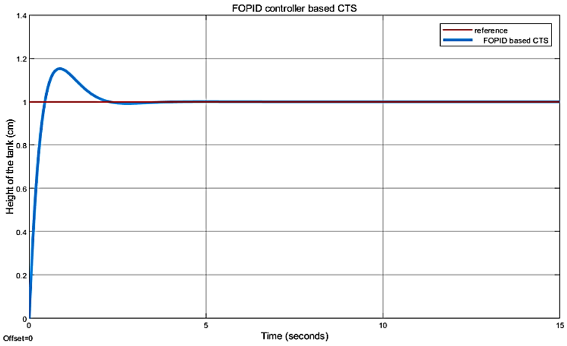


Figure 25. Simulation result of CTS-based FOPID controller

Figure 25 illustrates the higher response for linear devices in the common comparison evaluation of the simulation result of the entire controller-based CTS without any disruption. Comparing this outcome to the ones previously acquired, it displays a strong perfor–mance. In Figure 26, the CTS high nonlinear device is depicted.

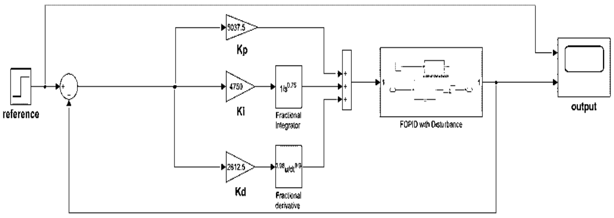


Figure 26. Simulink model of CTS-based FOPID controller with disturbance

## 4.9 Performance of interacting CT-based FOPID controller with disturbance

Figure 27 result shows better results compared to others results especially compared to FOPID without distur–bance. The range of essential and derivative order is [0, 1]. By checking the accuracy of the reaction the para–meter cost selected for λ and μ, are 0.75 and 0.95 respectively.

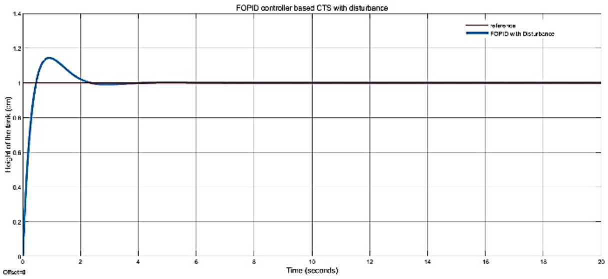


Figure 27.Simulation result of CTS-based FOPID controller with disturbance

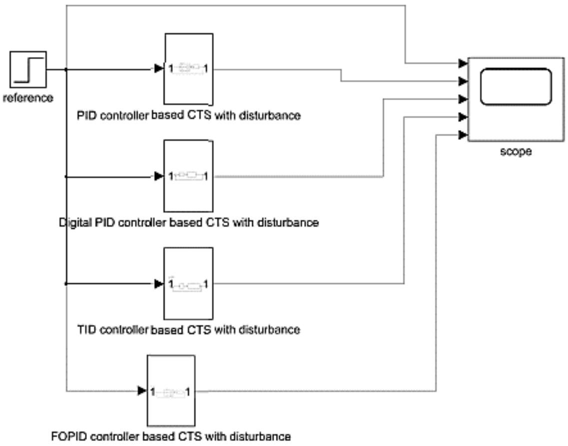


Figure 28.Comparative performance analysis of CTS with PID, digital PID, TID, and FOPID controller

Table 2. Comparative results of all methods of controllers considering disturbance

| Methods of controller | Performance criteria's | | | | | | Integral and derivative order | |
|---|---|---|---|---|---|---|---|---|
| | **Overshoot Os (%)** | **Undershoot (%)** | **Rise time Tr (sec)** | **Delay time Td (sec)** | **Peak time Tp (sec)** | **Settling time** | λ | μ |
| IOPID | 30.925 | 1.789 | 0.790 | 1.013 | 2.302 | 8.195 | 1 | 1 |
| Digital-PID | **17.059** | **-0.824** | **0.223** | **1.359** | **1.540** | **6.612** | - | - |
| TID | **115.965** | **2.562** | **0.488** | **1.034** | **2.162** | **15.508** | - | - |
| FOPID | 14.368 | 1.969 | 0.336 | 0.338 | 1.014 | 3.581 | 0.75 | 0.95 |

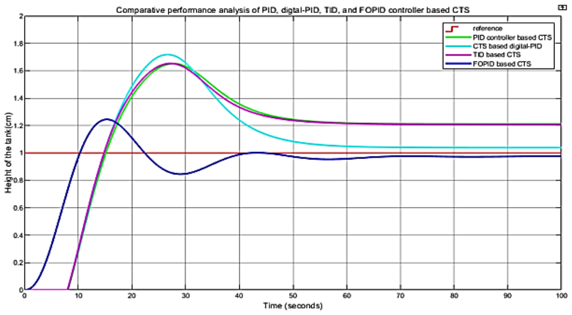


Figure 29.Simulation results of comparative performance analysis of CTS with PID, digital-PID, TID, and FOPID controller with disturbance

Figure 28 shows the Simulink model of Comparative performance analysis of CTS with PID, digital PID, TID, and FOPID controller.

Figure 29 shows the overall simulation results in this paper and the comparision between each other. As seen in the figure blue color is a great performance compared to others.

## 5. CONCLUSION

FOPID regulator with crucial request and subsidiary request has superior strength when contrasted with different styles of a regulator like TID, Digital-PID, and number request relative basic subordinate regulators that tried in this compositions. The reproduction final product shows that regulators utilized in straight instances of CTS in the general exhibition are great, but comprehensive of outside aggravation on the subsequent one tank the regulators tried on this compositions don't show higher response other than FOPID regulator. The reason is FOPID regulator has an additional two control levels of opportunity that blast the heartiness of the framework.

For the most part, the general work shows that the FOPID regulator is the legitimate regulator to screen the nonlinear gadget, form vulnerability, a rebate of unsettling influence, and overseeing of time defer analyses to various inspected regulators. Accordingly, the strength of the FOPID regulator is higher satisfaction in contrast with the tried regulator on this composition.

## ACKNOWLEDGMENT

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## NOMENCLATURE

| | |
|---|---|
| CTS | Coupled tank system |
| CL | Closed loop |
| CRONE | Commande Robuste d’Ordre Non Entire |
| DPID | Digital proportional-integral-derivative |
| D/A | Digital to analog conversion |
| FOPDT | First-order plus dead time |
| FOTF | Fractional-order transfer function |
| FOC | Fractional order controller |
| FOMCON | Fractional-order modeling control |
| FOPID | Fractional order proportional integral derivative |
| IOPID | Integer order proportional integral derivative |
| PID | Proportional plus integral plus derivative |
| TID | Tilt-Integral Derivative |
| ZOH | Zero-order hold |
| $\lambda$ | Fractional order lambda |
| $\mu$ | Fractional order miu |
| $k_p$ | Proportional gain |
| $k_i$ | Integral gain |
| $k_d$ | Derivative gain |
| $\xi$ | The damping ratio of the second-order plant |
| $\omega_n$ | The natural frequency of the second-order plant |
| $\alpha$ | Relative dominance |
| $Q_{in}(t)$ | The flow of liquid into tanks |
| $Q_{out}(t)$ | Out flow of liquid |

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# МОДЕЛИРАЊЕ И АНАЛИЗА ПЕРФОРМАНСИ ФОПИД КОНТРОЛЕРА ЗА ИНТЕРАКЦИЈСКИ СПОЈЕНИ СИСТЕМ РЕЗЕРВОАРА

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Контрола процеса је фундаментална у савременој интеракцији јер обезбеђује сигурност и побољшање у циклусу. Штавише, контрола процеса је вредан апарат за испуњавање еколошке стратегије и потреба за квалитетом предмета. У подухватима, један од фактора контролног система је ниво течности, регулатори нивоа течности су критична брига и добро позната интеракција, а збирни илустративан додатно оригиналан свет у техникама пројектовања.

Оквир спојеног резервоара на нивоу течности може се поставити у два популарна типа повезујућих и неповезаних структура. Овај рад се усредсређује на повезивање спојених оквира за контролу резервоара, бројна питања која утичу на ниво течности као што је нелинеарност оквира, приказивање рањивости и сложена истрага, како би се решили ти проблеми, да би се постигли стабилни стабилни резултати и брзе реакције, потребни су различити регулатори.

Течност се мора пренети и чувати у држачу за контролно дизајнирање у данашње време. У овом раду је приказана студија пропорционално-интег–рално-деривационог (ПИД) регулатора делимичног захтева за контролу нивоа флуида оквира резервоара. Технике ФОПИД и ТИД контролера су тестиране и демонстриране за спајање повезаних система резервоара помоћу неколико регулатора парцијалних захтева, укључујући Commande Robuste d'Ordre Non Entire (ЦРОНЕ), нагибно-интегрални дериват (ТИД) и ПИД фракционог реда (ФОПИД).

Реакција резултата је усмерена са МАТЛАБ®/ Симулинк® околношћу да се провери излагање оквира. Резултати репродукције су показали да је контролисањем система спојног резервоара (ЦТС) без погоршања реакција одлична, али имајући у виду спољашњи узнемирујући утицај на следећи резервоар, регулатор показује слабу реакцију поред ФОПИД регулатора. Објашњење је да ФОПИД регулатор има најмање две промењене границе које проширују снагу оквира. Од регулатора који су испробани у овом раду, делимични захтев рела–тивног основног подређеног регулатора (ФОПИД) има одлично извршење у поређењу са ПИД, ТИД и дигиталним ПИД регулаторима. Остварена презен–тација посебно ФОПИД регулатора је боља пер–форманса за ЦТС у односу на остале наведене контролере.