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RTD-A CONTROLLER FOR SPHERICAL TANK SYSTEM

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Abstract

The RTD-A controller is a rapidly developing alternative to the traditional PID controller. RTD-A can manage systems with unpredictable behavior since it contains a separate robustness tuning parameter. With a straightforward interface unit, the RTD-A control method has been applied to regulate the liquid level in the spherical tank system. The main goal of this research paper is to develop a system for regulating the liquid level in a spherical tank using RTD-A controller. RTD-A algorithm is used to regulate the liquid level in a spherical tank. To regulate the nonlinear process, gain scheduling for the RTD-A controller was also performed. PID and RTD-A controllers are compared with simulation outputs. Based on the outcome observation, it can be concluded that the performance of the closed loop process using RTD-A algorithm is superior to than that of PID controller.

Keywords: Spherical Tank System, RTD-A Controller, PID Controller.

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1.INTRODUCTION

Many industrial industries employ spherical tanks as surge tanks and for the storage of gaseous fuels, cryogenic liquids, and other liquids. The different vessel geometries result in nonlinear dynamical behavior in the liquid levels in these containers that is more challenging to manage than those in conventional containers. A transient model is needed to predict dynamics and develop a model-based controller for controlling the level in tanks. The modelling of liquid in a spherical tank is a challenging task because it incorporates nonlinearity along the liquid height. A wide range of controllers has been in specifically made to regulate the level in process sectors. The architecture of the controllers in the control system places a priority on modelling issues. The process plant that has been selected for research is a spherical tank with a variable liquid level. In obtaining the model of the process plant the designer must follow any one of the two ways mentioned here. The first approach is using the knowledge of science for deriving the physical parameters to yield models. This theoretical analysis of the model provides inaccurate information about the processing facility because the precise data is not replicated. This modeling is known as mechanistic modeling whose procedures rely upon mathematical and science knowledge of the process.

A model is a physical representation of a process available in nature. Mathematical models of chemical processes are especially useful for the optimization and design of new processes. A spherical tank displays nonlinear behavior throughout the tank's height. Process tanks are of different geometry to store fluids in the process industry such as cylindrical, conical, and spherical. The first two are common and control of level is also obvious as the technology is available. The spherical tanks are chosen for its safety. The surface area of the liquid in the vessel determines how high it will rise. The surface area of liquid in spherical tank changes non-linearly with its height. It raises a complexity in control. The existence of Process models' non-linearity implies designing of nonlinear / heuristic / intelligent controllers for the spherical tank system. Hence there is a need to study modeling and control aspects of the level control using spherical tanks.

A nonlinear spherical tank level process is investigated, with parameters that fluctuate with respect to the process variable. The mathematical modelling of the tank provides the foundation for assessing the controller's performance. It is a theoretical approach to dynamics based on mass conservation rules. Despite the system's complexity, it turns out that its overall behavior is well described by a series of linear models at specified operational points. The linear models represent a nonlinear system in the form of transfer function models of FOPDT type at each operating points. The experimental data are acquired to obtain the transfer function model. The real time experimental set up is used for system identification [28]. The transfer function models are leading to the pathway for obtaining the closed loop responses of the system. To stabilize chemical process loops and provide sufficient disturbance rejection, controller tuning is essential in process industries. The best controller is needed to regulate the liquid level in many processes to get stable outcomes with fast action. Figure 1 depicts a schematic drawing of a spherical tank level device.

Figure 1 Schematic sketch of spherical tank system

2. LITERATURE REVIEW

In literature review overview of RTD-A controller evolution, tuning of controllers using heuristic optimization algorithms is presented.

Ogunnaike and Mukati (2003) developed a novel control strategy known as next generation regulatory controller in the year 2003. It has four controller tuning parameters in the design which directly relates the setpoint tracking, disturbance rejection, robustness, and aggressiveness characteristics of the controller [θR, θT, θD, θA]. Therefore, it is also referred to a four-mode control technique or RTD-A controller. Another, main characteristics of this controller are that the tuning parameters are standardized to be in the range 0 and 1. Each tuning parameter can be adjusted independently to achieve any desired performance attributes. The RTD-A controller is implemented in discrete time. The discrete model of the process in FOPDT form is considered to design a controller. In the control strategy, a single control moves to be held over a prediction horizon beyond the process dead time is calculated and applied at each time instant. The model error is decomposed into estimates of the effect of plant model mismatch and unmeasured disturbances separately. The model output prediction update is carried out based on the effects of unmeasured disturbances in the error model. Finally, control action is computed at every time instant for a single control move by minimizing the difference between the predicted model output and desired plant output.

Mukati and Ogunnaike (2004) presented a robustness stability analysis for the processes with model mismatch. A typical FOPDT model is considered to demonstrate the possible effect of independent tuning parameters on the performance attributes. In this illustration, at a time one tuning parameter is changed whereas other tuning parameters kept at a constant value. A 10% model parameter uncertainty is introduced, and four values are chosen for θR to exemplify the robustness characteristics. The θT value is changed to show the setpoint tracking ability of the controller on the process output. The four different θD value is chosen to demonstrate the controller's disturbance rejection characteristics. A theoretical stability analysis is carried out using the system's characteristics equation. The roots of the characteristics equation should lie within aunity circle for the stable closed loop system. Also, the isothermal polymerization reactor process is considered to implement the RTD-A controller. Similar to the first case, 10% uncertainty is added to the process static gain, dead time and process time constant. The performance of the RTD-A controller is compared with IMC – PID in terms of different integral performance measures. There was no great improvement in the performance with the chosen 1controller tuning parameters.

Ogunnaike and Mukati (2006) discussed the simple theory of RTD-A controller design, development and implementation for a SISO process . It is demonstrated on nonlinear polymerization reactor process in simulation with and without sensor noise. It is shown the performance in setpoint tracking and disturbance rejection with RTD-A controller is better than the IMC- PID controller. The closed loop stability analysis and method to choose the tuning parameters are not addressed in detail.

Mukati et al. (2009) presented a robust stability analysis for an RTD-A controller. The tuning rules are developed for the processes without and with too much noise. The controller tuning, development and implementation are demonstrated on a liquid level control process and a non-linear pilot-scale physical vapor deposition process. It showed better performance with minimum tuning work than the PID controller. The proposed controller can be implemented on any process which is represented by its equivalent FOPDT model.

Yelneedi et al. (2008) implemented RTD-A controller for automatic control of anesthesia. The main focus is on controlling the hypnosis by regulating the propofol. The dynamics of patients described by a fourth order non-linear pharmacokinetic - pharmacodynamic representation. The RTD-A performance is compared with the MPC and PID controller. The servo, regulatory response and robustness of the regulatory control is tested. It is found performance with RTD-A controller is better than PID and MPC. Sreenivas et al. (2009) investigated the performance of RTD-A controller in the regulation of Hypnosis (Sendjaja et al. 2011). Its efficacy is compared with PID, MPC in single loop control. It is found that the closed loop response is better with the MPC and RTD-A control scheme.

Sendjaja et al. (2011) developed a simplified block diagram illustration for the RTD-A control scheme in a SISO process. It showed, a novel control scheme is seen as a generalized predictor added with a filter to remove noise in the feedback path and a filter is added in series with a setpoint. The modified semi analytical tuning rules are proposed by comparing the Ogunnaike's tuning rule. The proposed tuning rules tested on different process models. The Integral

Absolute Error (IAE) performance is investigated with IMC-PI control and total variation in the process input. It showed equitable performance than the other one.

Srinivasan and Anbarasan (2013) proposed a fuzzy logic tuned RTD-A control scheme for a non-linear system. The fuzzy scheduling is one of the adaptive control strategies. The RTD-A tuning values are obtained using fuzzy rules. The proposed scheme tested on pH process, liquid level control in the conical tank process and Type 1 diabetic process. The linearized transfer function is derived at different operating points of the non-linear process. The servo and regulatory performance of RTD-A is compared with Dynamic Matrix Control (DMC) type MPC and IMC-PID controller. In a robust analysis, the performance of the RTD-A controller and MPC would be similar for the increased prediction horizon value. Overall, the proposed control scheme is as simple as IMC-PID and will be able to give better controller performance.

Anbarasan and Srinivasan (2015) developed a simple control law for a second order process with dead time (SOPDT) model. Its block diagram compared with IMC and Smith Predictor Controller (SPC) representation. The control law can be used for both minimum phase process and non-minimum phase process. It is demonstrated on under damped minimum phase SOPDT model and critically damped non-minimum phase SOPDT model. The effect of each tuning parameter on the process output is analyzed thoroughly. It showed superior performance with the SOPDT based control law. Also, it is tested on a CSTR non-linear process in simulation. The CSTR process possesses under damped characteristics. The Equivalent non-minimum phase SOPDT model is derived for the CSTR first principle non-linear model. The RTD-A controller performance is compared with MPC, SPC, IMC and PID. It is found better performance with RTD-A in terms of integral performance indices. The characteristics equation to check the closed loop stability is also discussed.

Mani and Pinagapani (2016) developed the RTD-A controller to control an air feed system in Polymer Electrolyte Membrane fuel cell. The setpoint tracking and disturbance rejection ability of the proposed scheme is analyzed in terms of Integral Square Error (ISE) and computation time. It is compared with the established controllers like PID and MPC. The RTD-A servo performance is better under no load condition Sun et al. (2018) derived a control law for general multivariable systems. The servo response, regulatory performance, robust performance of the derived control law demonstrated using three simulation examples. Recently, a next generation regulatory RTD-A controller developed to control the multivariable industrial processes with a mixer of hard and soft constraints by Haseena and Srinivasan (2018). The simplicity and efficacy of the control scheme demonstrated through simulation on test bench process.

3. SYSTEM METHODOLOGY

Spherical liquid tank systems are commonly employed in the chemical industry, and liquid level management is critical [28]. Computerized systems provide a user-friendly interface for practitioners to solve challenges involving real-time processes. Their interactive usage with process control elements readily solves challenges in modelling and control issues with the aid of software.

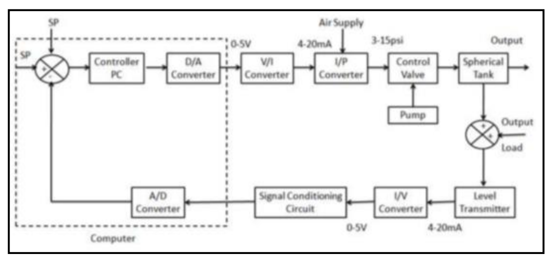

Figure 2 Block diagram representation of spherical tank system

Figure 3 Experimental Setup

The process tank has 25 cm diameter, 25 cm height and volume capacity of 8.1 liters whose body is framed of ss-316 stainless steel. The process tank input is connected to ball valve, which controls the inlet flow of liquid. The level of the tank is controlled by controlling the inlet flow rate. The load disturbance is fed to the process tank by manipulating the hand valve present at the outlet of the tank. The level of water in the tank is sensed using a differential pressure transmitter and transferred to the computer system as (4-20) mA to the interface module through a (I/V) current to voltage converter.

3.1 Mathematical Modelling

The modeling of the spherical tank is divided into two cases based on the change in water level and height.

CASE1:

When the liquid column's height (H) is equal to the radius (R) of the spherical tank (R=H). In this case, the level of the water has been raised to half of the system's capacity. As a result, the radius will be equal to the height of the water in the system. (R=H). The nonlinear spherical tank system's first-order differential equation is given by the equation,

$$\frac{dv}{dt} = F_{in} - F_{out} \tag{1}$$

Considering the volume of the tank V as

$$V = \frac{4}{3}\pi R^3 \tag{2}$$

F_{in} = entrance flow velocity.

F_{out}= discharge flow velocity.

R = The tank's radius.

A mass balance equation is used to determine the amount of water in the system at any particular time,

$$F_{in} - F_{out} = Ah \tag{3}$$

A = region cross-sectional.

H = Tank's overall height.

$$\frac{dV}{DT} = A\frac{dh}{dt} = F_{in} - F_{out} \tag{4}$$

Substituting the equation (3) and A = $4\pi R^2$ in equation

$$F_{in} - F_{out} = \frac{1}{3}AR = \frac{1}{3}AH \tag{5}$$

considering R = h

$$\frac{H}{h} = \frac{r}{R} \tag{6}$$

$$R = \frac{rh}{H} \tag{7}$$

Assuming the $F_{out} = \frac{h}{R_v}$ (8)

Where Fout is linearly related to 'h' through 'R,'.

$$F_{out} = \frac{h}{R_v} \tag{9}$$

$$F_{in} = A\frac{dh}{dt} + \frac{h}{R_v} \tag{10}$$

$$F_{in}(s) = AS(s) + \frac{H(s)}{R_v} \tag{11}$$

$$\frac{H(s)}{F_{in}(s)} = \frac{R_v}{1+AR_vS} \tag{12}$$

$$\frac{H(s)}{F_{in}(S)} = \frac{K}{1+\tau S} \tag{13}$$

Considering, R_v= K, $\tau = AR_v$, Where k=0.523 and τ = 1027

$$\frac{H(s)}{F(s)} = \frac{K}{1+Ts} \tag{14}$$

$$R_v = \frac{(h)^{\frac{1}{2}}}{C} \tag{15}$$

The developed mathematical model for case 1 is given as,

$$\frac{H(s)}{Fin(s)} = \frac{K}{1+Cs} \tag{16}$$

CASE 2:

When the liquid column's height (H) is greater or smaller than the radius (R) of the spherical tank (R/H). The system is experiencing a change in the area with respect to the radius in the case. This condition occurs when the system level is below or above to the radius in this the water-filled to 50%.

The tank with angle θ,

$$\tan\theta = \frac{r}{h} = \frac{R}{H} \tag{17}$$

$$r = R\left(\frac{h}{H}\right) \tag{18}$$

Area of the tank, A =$4\pi r^2$ (19)

Substituting the equation (2) in area,

$$A = 4\pi\left(\frac{R}{H}^2\right)h \tag{20}$$

Differentiating the equation (3),

$$dA/dt = 8\pi\left(\frac{R}{H}^2\right)h\left(\frac{dh}{dt}\right) \tag{21}$$

Volume of the tank,

$$V = \frac{4}{3}\pi r^3 \tag{22}$$

$$V = Ah \tag{23}$$

Differentiating the equation (6),

$$\frac{dv}{dt} = \left[A\left(\frac{dh}{dt}\right) + h\left(\frac{dA}{dt}\right)\right] \tag{24}$$

Substituting the equation (16) and (19),

$$\frac{dV}{dt} = \left[A\frac{dh}{dt} + h8\pi\left(\frac{R}{H}\right)h\left(\frac{dh}{dt}\right)\right] \tag{25}$$

$$\frac{V}{dt} = \frac{dh}{dt}\left[A + h^2\left(\frac{R^2}{H}\right)\right] \tag{26}$$

The first order differential equation for the nonlinear spherical tank system is. given by the equation,

$$F_{in} - F_{out} = \frac{dV}{dt} \tag{27}$$

Substituting the equation (26) in equation (27),

$$F_{in} - F_{out} = \frac{dh}{dt}\left[A + h^2\left(\frac{R^2}{H}\right)\right] \tag{28}$$

Considering the F_{out} value,

$$F_{out} = K(H)^{\frac{1}{2}} \tag{29}$$

Substituting the equation (18) in equation (20),

$$F_{in} - K(H)^{\frac{1}{2}} = \frac{dh}{dt}\left[A + h^2 8\pi\left(\frac{R^2}{H}\right)\right] \quad (30)$$

$$\frac{dh}{dt} = \frac{\left(-k(H)^2\right)}{\left(A + h^2 8\pi\left(\frac{R^2}{H}\right)\right)} \quad (31)$$

$$\frac{dh}{dt} = \frac{F_{in} - K(H)^{\frac{1}{2}}}{4\pi\left(\frac{R^{\frac{1}{2}}}{H}\right)h^2 + h^2 8\pi\left(\frac{R^2}{H}\right)} \quad (32)$$

$$\frac{dh}{dt} = \frac{\left[Fin - K(H)^{\frac{1}{2}}\right]}{12\pi\left(\frac{R^2}{H}\right)h^2} \quad (33)$$

$$\frac{dh}{dt} = F_{in} - \left[12\pi\left(\frac{R^2}{H}\right)H^2\right] - K(H)^2 - 12\pi\left(\frac{R^2}{H}\right)H^2 \quad (34)$$

Assuming,

$$\alpha = \frac{1}{12\pi}\left(\frac{R^2}{H}\right) \quad (35)$$

$$\beta = K\alpha \quad (36)$$

Substituting the α and β value in equation (34),

$$\frac{dh}{dt} = \alpha F_{in} h^{-2} - \beta h^{-\frac{3}{2}} \quad (37)$$

For linearizing $Fin\ h^{-2}\ and\ h^{-\frac{3}{2}}$ in equation (37),

$$F(h, F_{in}) = F(h_s, F_{in\ s}) - 2F_{in}h^{-3}(h - h_s) + hs^{-2}(F - F_{in\ s}) \quad (38)$$

Initially, take $\frac{dh}{dt} = h^{-\frac{3}{2}}$

$$h^{-\frac{3}{2}} = h^{-\frac{3}{2}} - \frac{3}{2}h^{-\frac{5}{2}}(h - h_s) \quad (39)$$

Substituting the equation (38) and equation (39) in equation (37),

$$\frac{dh}{dt} = \alpha[F(h_s, F_{in\ s}) - 2F_{in}h_s^{-3}(h - h_s) + h_s^{-2}(F - F_{in\ s})] - \beta\left[h^{-\frac{3}{2}} - \frac{3}{2}h^{-\frac{5}{2}}(h - h_s)\right] \quad (40)$$

At initial steady state condition,

$$\frac{d(h - h_s)}{dt} = \left[\alpha[-2F_{in}h_s^{-3}(h - h_s) + h_s^{-2}(F - F_{in\ s})] + \frac{3}{2}\ h^{-\frac{5}{2}}(h - h_s)\right] \quad (41)$$

Considering

$$y = h - h_s \quad (42)$$

$$U = F - F_{in\ s} \quad (43)$$

Substituting the y value and U value in equation (41),

$$\frac{dy}{dt} = \left[\alpha[-2F_{in}h_s^{-3}y + h_s^{-2}U] + \frac{3}{2}h^{-\frac{5}{2}}y\right] \quad (44)$$

Considering $\alpha F_{in\ s} = \beta h_s^{\frac{1}{2}}$

$$\frac{dy}{dt} = -2\beta h_s^{-\frac{5}{2}}y + \alpha h_s^{-2}U + \frac{3}{2}h^{-\frac{5}{2}}y \quad (45)$$

$$\frac{dy}{dt} = -\frac{1}{2}\beta h^{-\frac{5}{2}}y + \alpha h_s^{-2}U \quad (46)$$

Multiplying by $\beta hs^{-\frac{5}{2}}$ on both side equation (45),

$$\left[\frac{2}{\beta}h_s^{\frac{5}{2}}\right]\frac{dy}{dt} + y = \frac{2\alpha}{\beta}h_s^{\frac{1}{2}}U \quad (47)$$

Assuming $\tau = \frac{2}{\beta}h_s^{\frac{5}{2}}$, $C = \frac{2\alpha}{\beta}h_s^{\frac{1}{2}}$ in equation (46),

$$\tau\left(\frac{dy}{dt}\right) + y = CU \quad (48)$$

Applying the Laplace transform in equation (46),

$$\tau SY(S) + Y(S) = CU(S) \quad (49)$$

$$(\tau S + 1)Y(S) = CU(S) \quad (50)$$

The transfer function of the system for case 2 condition is given as,

$$\frac{Y(S)}{U(S)} = \frac{C}{\tau S + 1} \quad (51)$$

3.3 Design of RTD-A Controller

RTD-A is a novel control method that replaces the PID controller. When it comes to adjusting parameters, the RTD-A is more transparent than the PID controller.it is essential to build a tool that allows users to work with the RTD-A system [30].

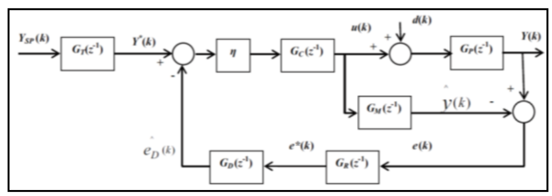

Figure 4 Block diagram of RTD-A controller

The reaction of the level-controlled spherical tank employing RTD-A at various operating points, as well as the controller output, which is the inflow rate. The performance of the optimal tuned RTD-A controller is analyzed from the servo response, regulatory response and robust response of the processes considered. The successive step changes applied on the process setpoint in each case to study the setpoint tracking ability of the controller with the proposed optimization scheme.

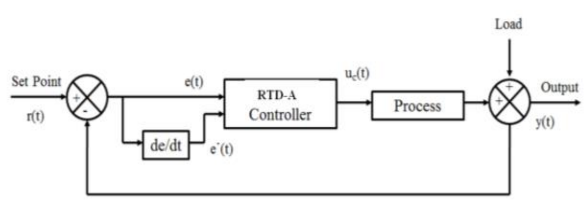

Figure 5 Closed loop RTD-A controller scheme of Liquid Level Spherical tank system

3.4 RTDA Algorithm for Spherical Tank System

RTDA algorithm provides a real-time control solution for level control in spherical tank systems, allowing for efficient and accurate control of the liquid level. The Actual Dynamics of the spherical tank process is approximated as a first order model to describe the process behavior. The generalized transfer function model is given by equation (52),

$$y(s) = \frac{k}{\tau(s)+1}u(s) \quad (52)$$

where K is the steady state gain and t is the time constant. The predicted output,$\hat{y}(k+i)$ is given in the equation (53),

$$\hat{y}(k+i) = b^i\hat{y}(k) + c\eta_i u(k)$$

for 1≤ i≤ Q (53)

Where,$\eta_i = \frac{1-b^i}{1-b}$;b = $exp\left(\frac{\Delta t}{\tau}\right)$;c=K(1-b) The control action u(k) remains the same for the whole prediction horizon (Q), i.e.,

$$u(k+i) = u(k)$$

for 1 ≤ i ≤ Q (54)

To account for the effect of unmeasured disturbances and other modelling mistakes, this prediction must be modified. Due to a mismatch between the plant and the model, the model output y(k) differs from the real process output y(k). Every moment's prediction needs to be revised. Equation (55), where e(k) is the current error, gives the model mismatch.

e(k)=y(k)-$\hat{y}(k)$ (55)

The non-biasing prediction error is denoted by $\widehat{e_d}(k)$ which is determined by the parameter θ_R as given in the equation (56),$\widehat{e_d}(k-1)$ the weighted sum of prior error information, and e(k) is the current error information.

$$\widehat{e_d}(k) = \theta_R\widehat{e_d}(k-1) + (1-\theta_R)e(k) \quad (56)$$

The future estimate of the error is determined by the disturbance rejecting parameter θ_D as given in the equation (57),

$$\widehat{e_d}(k+i) = \widehat{e_d}(k) + \frac{1-\theta_D}{\theta_D}\left[1-(1-\theta_D)^i\right]\Delta\widehat{e_d}(k)$$

for 1≤ $i \leq Q$ (57)

where, $\Delta\widehat{e_d}(k) = \widehat{e_d}(k) - \widehat{e_d}(k-1)$ i.e., the difference between errors at two consecutive instants. The updated predicted output for Q-step prediction is given in the equation (58),

$$\tilde{y}(k+i) = \hat{y}(k+i) + \widehat{e_d}(k+i)$$

for1 $\leq i \leq Q$ (58)

The desired setpoint trajectory $y_t(k)$ can be determined as given in the equation (59), where s_q is the desired setpoint.

$$y_t(k) = \theta_T y_t(k-1) + (1-\theta_T)s_q(k) \quad (59)$$

Assuming, setpoint remains the same for the whole prediction horizon i.e. S_q(k+i) = S_q(k), i = 1,2, Q. The future reference trajectory is given in the equation (60).

$$y_t(k+i) = \theta_T^i y_t(k) + \left(1-\theta_T^i\right)s_q(k)$$

For 1 $\leq i \leq Q$ (60)

The objective function of the RTDA controller is given in theequation (61).

$$\min_{u(k)} \sum_{i=1}^{q}[y_t(k+i) - \tilde{y}(k+i)]^2 \quad (61)$$

The control action u(k) is updated to minimize the difference between model predicted output $\tilde{y}(k)$ and reference trajectory y_t(k) for Q-step. On solving the optimization problem, the expression for u(k) is given in the equation (62),

$$u(k)=\frac{1}{c}\frac{\sum_{i=1}^{q}\eta_i\omega_i(k)}{\sum_{i=1}^{q}\eta_i^2} \quad (62)$$

$$\omega_i = y_t(k+i) - b^i\hat{y}(k) - \widehat{e_d}(k+i)$$

For1 $\leq i \leq Q$ (63)

where ω_i is the stipulated error. The overall aggressiveness tuning parameter θ_A depends on prediction horizon (Q) as given in the equation (65),

$$Q = 1 - \frac{\tau}{t_s}\ln(1-\theta_A) \quad (64)$$

$$\theta_A = 1 - e^{-(p-1)\frac{\Delta t}{\tau}} \quad (65)$$

Where t_s is the sampling time and θ_A is the aggressiveness tuning parameter.

From the equation (56),

$$\widehat{e_d}(k) = \theta_R\widehat{e_d}(k-1) + (1-\theta_R)e(k)$$

Where θ_R is a parameter for Robustness tuning that ranges from 0 to 1. It has an impact on the closed loop system's stability.by raising the value of R, the controller's resilience is improved. The future error is then determined using the current error estimate to update the model forecast. [34]

$$\theta_R = 0.5^g or > 0.9^h \quad (66)$$

From the equation (57),

$\widehat{e_d}(k+i) = \widehat{e_d}(k) + \frac{1-\theta_D}{\theta_D}\left[1-(1-\ \theta_D)^i\right]\Delta\widehat{e_d}(k)$
for $1 \leq i \leq Q$

θ_D is the tuning parameter for disturbance rejection, and it ranges from 0 to 1. The controller's ability to reject disturbances is reduced as θ_D is raised from 0 to 1. [34]

$$\theta_D = \geq (1-\theta_R) \quad (67)$$

From the equation (59),

$$y_t(k) = \theta_T y_t(k-1) + (1-\theta_T)s_q(k)$$

Where $\theta_T (0 < \theta_T < 1)$,is used as the set point tracking tuning parameter.[34]

$$\theta_T = 10^{\frac{-2T}{\psi}} \quad (68)$$

4. RESULT AND DISCUSSION

The level control of nonlinear stochastic processes is one of the primary issues in the process business. Conventional controllers, which are frequently used, have a straight forward framework but fall short in their ability to handle control problems. Due to tuning-related issues, they are not very appropriate for controlling nonlinear processes. In this research, a nonlinear spherical tank system's RTDA (Robustness, Setpoint tracking, Disturbance Rejection, Aggressiveness) controller is created. In contrast to conventional controllers, the designed RTDA controller encourages the autonomous tuning of controller parameters to obtain the best control performance. Every tuning parameter improves the closed loop system's overall efficiency. When RTDA and PID controllers are contrasted, it is found that RTDA is superior in every way for reliable closed loop operation.

For real-time implementation and testing of the different controllers, a spherical tank level process with a liquid level system is utilized. This system enables to test the performance of the controllers in regulating the liquid level within the tank. The mathematical model is developed using first principle modeling and is given for the two cases in equation 69 and 70.

$$G_{c1}(S) = \frac{0.523}{1027S+1} \quad (69)$$

$$G_{c2}(S) = \frac{11.49}{8772S+1} \quad (70)$$

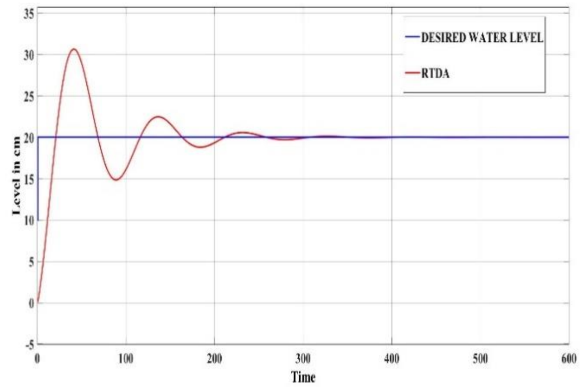

Figure 8 Response of RTDA controller for case 1

The response of the spherical tank system to an initial load disturbance clearly indicates the effectiveness of the RTD-A controller. The controller successfully rejects the disturbance, as evidenced by the figure 8 and 9. This response aligns with the transfer function of the system and RTD-A controller reacts very quick.

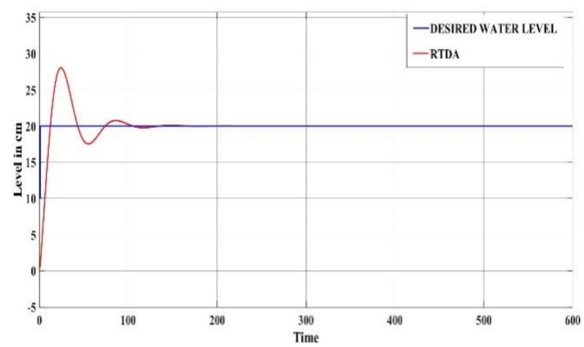

Figure 9 Response of RTDA controller for case 2

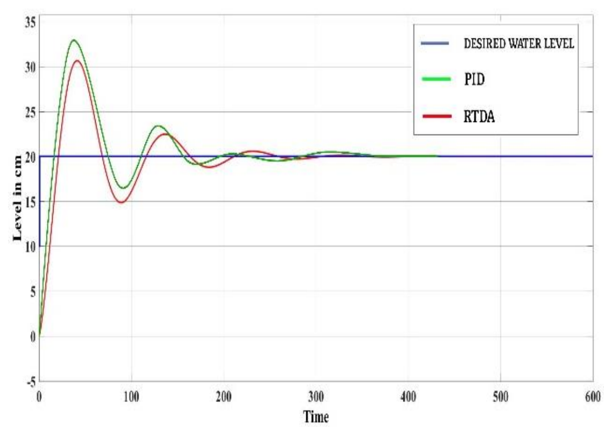

Figure 10 Comparison of RTDA and PID controller of spherical tank system for case 1

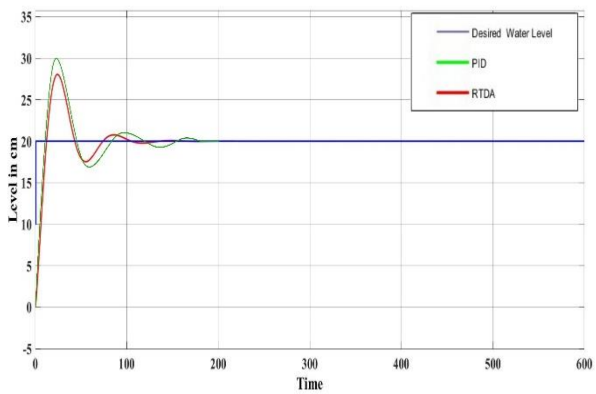

Figure 11 Comparison of RTDA and PID controller of spherical tank system for case 2

Step changes are applied when faced with the difficult scenario to check whether the controllers can endure the characteristics of setpoint tracking. The outcomes of the simulation made sure that all the management strategies could monitor setpoint changes. When PID was used, the changes in servo response changed the regulatory response, but not with RTDA controllers, where tuning parameters are directly linked to performance characteristics. The RTDA controller's tuning settings, which operate independently, are the real cause of this.

From the figure 10 and 11 the comparison of RTDA controller with the PID controller is clear. The various time domains of RTDA and PID is compared, and the RTDA parameters are tabulated in table 1. From the table 2 and 3 the settling time, rise time of RTDA controller is quite faster th

an the PID controller.

RTDA parameters	Case 1	Case 2
θ_R	0.2	0.4
θ_T	0.1	0.3
θ_D	0.2	0.4
θ_A	0.0016	0.0019

Table 1 Tuning parameters Case 1and Case 2.

Specification	RTDA	PID
Settling time (s)	20.00	20.5
Overshoot (%)	30.5	33.5
Rise time (s)	3.9073	4.9084
Peak time	20.00	21.00

Table 2 Comparison of RTDA and PID controller of spherical tank system Case 1.

Specification	RTDA	PID
Settling time (s)	20.00	20.5
Overshoot (%)	27.00	30.00
Rise time (s)	4.00	5.00
Peak time	19.00	19.05

Table 3 Comparison of RTDA and PID controller of spherical tank system Case 2.

The output shown in Figure. 10 and 11, where the RTDA controller responded to applied load disruptions more quickly than the PID controller. For both controllers, a simulation study has been performed. The efficacy and accuracy of the output were evaluated based on the performance of the RTD-A controller which clearly shown in table 2 and 3. The output shows the result, that the RTDA controller outperformed than the PID.

CASE 1:

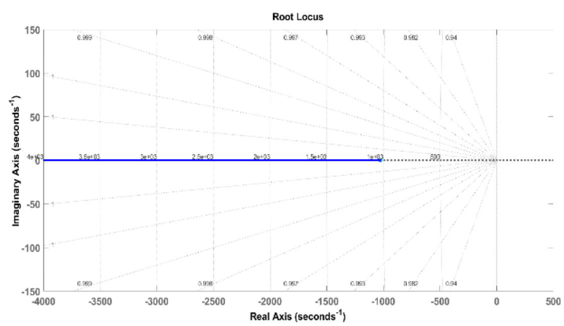

Figure 12 Root locus of spherical tank system for case 1

For Case 1: Figure 12, shows the root locus plot of the transfer function that describes the dynamic behavior of a spherical tank system. The plot illustrates how the system's poles, which are the values of system that make the denominator of the transfer function zero, change as the gain of the system varies. The system is stable if all the poles lie in the left half of the complex plane, meaning their real parts are negative. In this case, the plot shows that the system is stable for the process gain value.

CASE 2:

For Case 2: Figure 13, shows the stability analysis graph for a spherical tank system illustrates the relationship between the liquid volume in the tank and the tank's stability margin, which is the amount of additional force required to cause the tank to tip over. As the liquid volume increases, the stability margin decreases, and the tank becomes more prone to tipping over. Understanding this graph is important for designing a safe and stable spherical tank system.

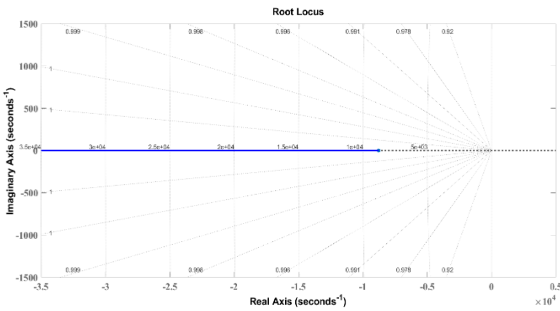

Figure 13 Root locus of spherical tank system for case 2

5. CONCLUSION

The RTD-A controller is a rapidly developing alternative to the traditional PID controller. It can manage systems with unpredictable behavior since it contains a separate robustness tuning parameter with a straightforward interface unit. RTD-A control method was applied to regulate the level of spherical tank process. The primary objective of this research is to develop closed loop based RTD-A controller for the proposed spherical tank. This work is implemented through MATLAB. Its performance was tested for different characteristics such as servo performance, disturbance rejection ability and robustness in real time. Based on the results of the performance, it can be stated that the RTD-A controller performs better performance than the PID Controller. Finally, the closed loop performance with the RTD-A controller along with stability analysis shows better performance than PID controller.

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