Optimal structural design and real-time implementation of supervisory controller for a conical interacting tank system

Dhanoj Mohan[1], Dr.Rathika Rani[2] , Dr. G Glan Devadhas[3], Dr.K Gopakumar[4], Shinu M M[5]

1&5,Asst.Professor,3 Professor,Dept of EIE, Vimal Jyothi Engineering College,Chemperi,Kannur,Kerala,India
2.*Professor ,Dept of EIE , ,Annamalai University,Annamalai Nagar ,Tamil Nadu,India*
4 Professor ,Dept of ECE, ,TKM College of Engineering, Kollam, Kerala,India

Abstract:

A lot of research efforts in the process control field have been focused on the control of a nonlinear interacting system. The conical tank is one of the popular nonlinear processes, widely used in various fields, such as the food industry, oil industry, pharmaceutical industry, where the complete drain is required. Engineering institutions having process control lab, the conical tank setup is important to demonstrate the nonlinear dynamics. On the other hand, an interacting system or coupled system is one in which the dynamics of one system affect the dynamics of the other system and vice versa. The construction of two conical tanks, connected in a manner to demonstrate the interacting and non-interacting behavior of a complex nonlinear structure is explained in this paper. The complexity of the structural design of the entire setup is optimized by sharing the components with the nearby flow and level process. The interacting and noninteracting connections are configured by the adjustment of hand valves. The entire setup is a novel structural design that is useful for research institutions.

Key Words: Ratio Controller, Conical Tank, Nonlinear System, PLC, SCADA

Introduction:

Process Control is one of the emerging areas of Instrumentation engineering. It deals with process variables like Flow, Level, Temperature, Pressure, Humidity, Concentration, etc., various unit operations, process dynamics, and control design for various processes. The active changing of the process varies from the desired value is monitored and adjusted by the command signal from the control algorithms for manipulating the final control element. The selection, design, simulation, optimization of the right controllers for the right process is the main area of research in automatic control [1,4,7]. The development of HMI (Human-machine Interface) [8] have brought the process control area in another pace which closely monitors, supervises, and controls the variables. Advanced systems like PLC, SCADA, DCS are dominating in the process control industry for the past two decades because of their ability to monitor, control, supervise the systems with the distributed networked-based structure [5,6]. It increases the demand for Instrumentation engineers in power plants, Oil and gas industry, petroleum industry, water distribution system, smart grid, etc. The development of IIOT (Instruments Internet of Things), Smart and Intelligent systems, novel machine learning algorithms will set a new dimension in intelligent automation and control areas. In academia most of the systems are modeled as first-order linear time-invariant systems which are much more ideal and they deviate from the industrial applications. The practical systems are normally nonlinear, time-varying, unstable in nature [2,3]. It is important to give the industrial exposure to the students to reduce the curriculum gap. This paper explains the development of a double conical tank system developed indigenous in the process control laboratory with optimized structure. The ratio controller is developed to maintain the head of on tank by manipulating the ratio of the flowrate. The control logic is developed in PLC Ladder logic and SCADA unit is used to monitor the parameter variations.

Methodology

Process Flow Diagram (PFD)

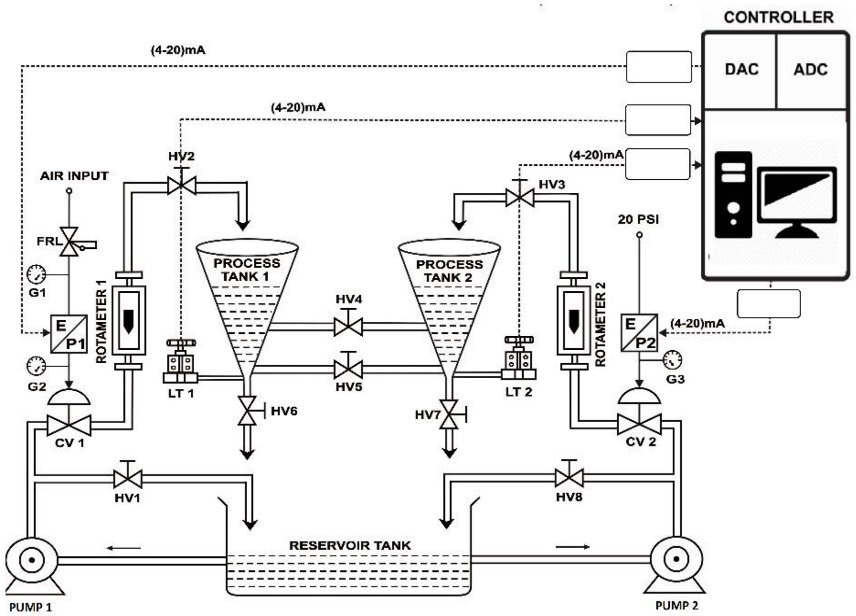

Fig1. Process Flow Diagram of Conical tank Interacting system

The process flow diagram is a diagram that shows the flow of variables from the input side to the product line. The main pieces of equipment, their specifications the mass flow, and the material flow are explained on the PFD. The process consists of two tanks Process tank 1, process tank 2 in which the level should be controlled as shown in Fig 1.LT1 and LT2 are two DPTs (Differential pressure transmitters) used to find the level of the tanks based on the differential pressure principle. The output of DPT is a standard signal ranging from 4mA to 20 mA which is given as the measured variable to the computer. The output from the computer is the command signal that passes through the current to pressure converter. The final control element is a control valve which manipulates the inflow rate of the conical tank. To drain the water from the conical tank hand valves are employed, which are directed to the reservoir. Two electric pumps help to pump water into the conical tanks. Each of the pumps is connected to the pneumatic control valve and return valve. There are two I to P converters that help in the conversion of the 4-20mA to 3-15 psi. This setup has two rotameter which aids in the measurement of the flow rate in LPH. For the system integration a LAN cable has been provided which supports interfacing with a computer.

Structure Optimization

Mechanical setup mainly consists of two conical tanks which induces nonlinearity in to the system. The two conical tanks can be used as interacting with the help of two valves as described earlier. The two-process stations, level process station and the flow process station present on the right and left side of the conical tank setup are used to optimize by sharing the equipment requirements like rotameters, pumps, I to P converters, control valves, and reservoirs. The optimized setup is shown in Figure 2. The level of the tank can be viewed by the mechanical level gauges. The electronic output of measured variable is readout with the help of DPTs. A three-way valve is used to direct the flow of water from the other station to this setup . All the pipe connections are completely made of stainless steel.

Fig:2 Optimised structure of conical tank level process

Mathematical Model of Conical tank Interacting system

Mass balance around TANK1 is given by Equation (1.1)

$$F_{IN1} - F_{OUT1} - \text{sign}(h_1 - h_2)\beta_{12}\sqrt{|h_1 - h_2|} = \frac{1}{3}\left[A(h_1)\frac{dh_1}{dt} + h_1\frac{dA(h_1)}{dt}\right] \quad (1.1)$$

Mass balance around TANK2 is given by Equation (1.2)

$$F_{IN2} - F_{OUT2} + \text{sign}(h_1 - h_2)\beta_{12}\sqrt{|h_1 - h_2|} = \frac{1}{3}\left[A(h_2)\frac{dh_2}{dt} + h_2\frac{dA(h_2)}{dt}\right] \quad (1.2)$$

Where,

'A' Cross sectional area of tank cm^2

h_1 – Head of tank 1 cm

h_2 - Head of tank2 cm

β1 valve coefficient of HV6

β 2valve coefficient of HV7

β12 2valve coefficient of HV4

The first principal model of interacting system is given by following nonlinear Equations (1.3) and

$$\frac{dh_1}{dt} = \left[\frac{F_{IN1} - \beta_1\sqrt{h_1} - \text{sign}(h_1 - h_2)\,\beta_{12}\sqrt{|h_1 - h_2|} - \frac{1}{3}\,h_1\,\frac{d}{dt}\big(A(h_1)\big)}{\frac{\pi R^2 h_1^2}{3H^2}}\right] \quad (1.3)$$

$$\frac{dh_2}{dt} = \left[\frac{F_{IN2} - \beta_2\sqrt{h_2} + \text{sign}(h_1 - h_2)\beta_{12}\sqrt{|h_1 - h_2|} - \frac{1}{3}\,h_2\,\frac{d}{dt}A(h_2))}{\frac{\pi R^2 h_2^2}{3H^2}}\right] \quad (1.4)$$

From equation (1.3),(1.4) it is clear that the system is nonlinear interacting process These equations are simulated in MATLAB Simulink in order to get the open loop characteristics of the tank, as shown in figure 3. This open loop response is used to design and analysis of the performance of the controller.

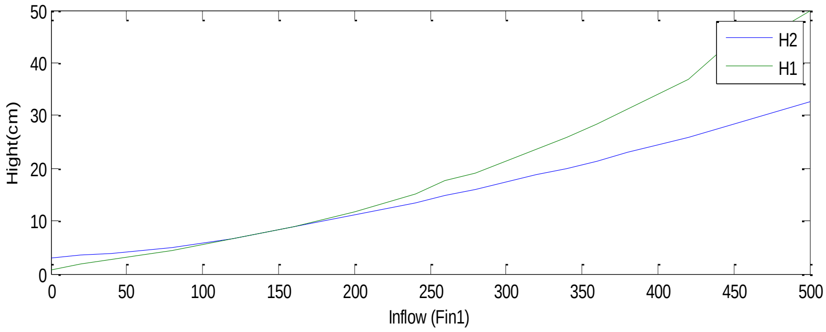

Fig: 3 Open loop response of the conical tank interacting system

Development of HMI:

The whole system is controlled and monitored by the SCADA (Supervisory Control and Data Acquisition). The HMI (Human Machine Interface) provides the visualization of the entire system in a monitor and the control buttons as shown in Figure 4.

Here the HMI provides the switches for selecting the manual/automatic mode, ratio controller mode. In the manual mode of control, the controller output can be set to any value according to the operator's wish. In the automatic mode of control, the level setpoint is set to 95% of the tank, if the tank level reaches the set point level then the control valve is turned off. In the ratio controller mode, the ratio between the levels of two tanks is adjusted with a ratio of two. The second tank is the controllable tank, the first tank level is taken as the uncontrollable parameter for the ratio controller. The level in the controllable tank is maintained as twice the level of the first one to maintain the given ratio two. The HMI provides the facility of monitoring the process parameters. It shows the level readings, controller outputs, and the graphical representation of both the level and the controller parameters.

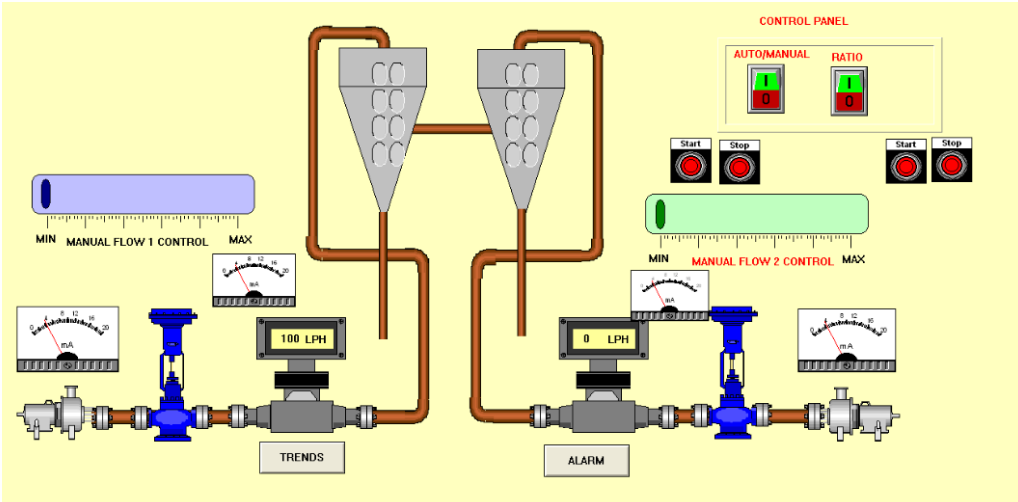

Figure 4 SCADA Visualization

Controller Design

The system is implemented and interfaced with the PLC. The SCADA interface gives a visual indication of the process parameters. The switching of different conditions like manual and automatic control actions can be achieved through the HMI.The controlling action is done for maintaining the levels of the two tanks in a fixed ratio. The level of one tank is controlled by controlling the input flow rate of the output of a PLC. The uncontrollable tank's level is taken as the reference for the second tanks set point. Both the levels and the controller outputs are displayed in HMI for graphical visualization of the process.

The controller gives an accurate controlling action on the process successfully and the graph of level (in Y axis) of two tanks are show with respect to time (in X axis) in figure. The figure 5 shows the changes of level of the controllable tank for a constant level of the uncontrollable tank. The figure 6 shows the variation in level of controllable tank, for the small change in the level in the uncontrollable tank, i.e. the response to a change in process condition. In both the causes the system settles at a point to maintain the ratio of level of the level in the two tanks.

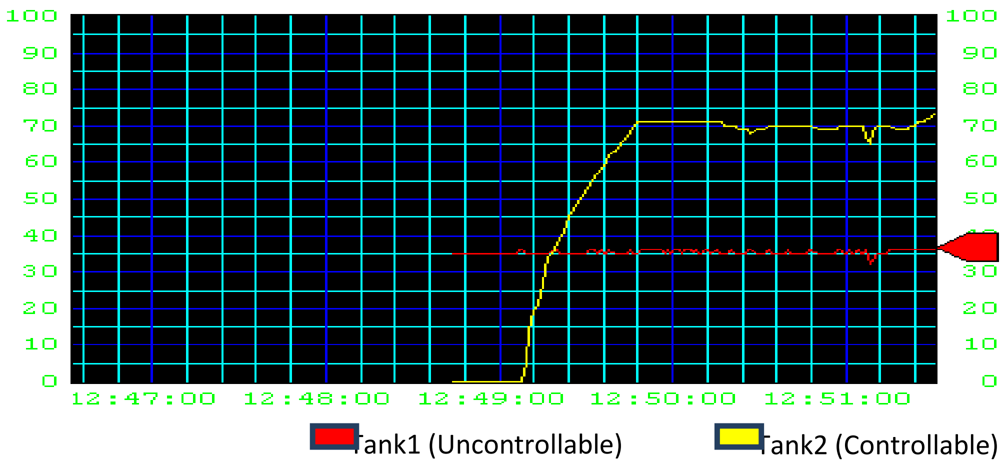

Figure 5 Out put for fixed process condition

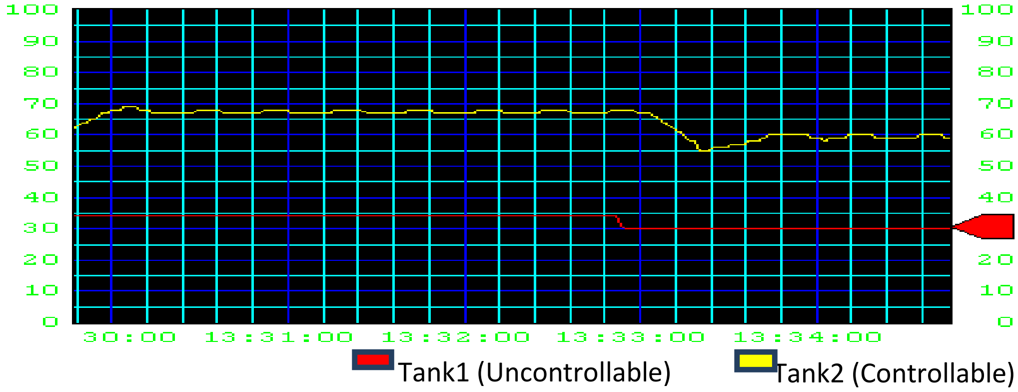

Figure 6 Out put for change in process condition

CONCLUSION

This paper gives a solution to design and build a ratio controller in a conical tank system that has been a significant learning experience. The system is modeled using first principle modeling simulated in Matlab. The hardware system is developed in the laboratory using the available resources and the structure is optimised by sharing the equipments of near by stations. The HMI is developed using intouch SCADA software. Using PLC the ratio controller is designed and the performance is studied in real time. This work has clearly demonstrated the goals of controlling a process within the user set ratios which is useful for manufacturing industries across a broad range of applications**.** This work achieved its aim of developing and automating the nonlinear level control process, with provision for expansion for implementing different nonlinear control strategies.

References

1. Sudharsana Vijayan, G. Glan Devadhas**,** Elizabeth George, IMC and Adaptive Associated With PID Controllers for Nonlinear Level Process, International Review of Automatic Control (IREACO), Vol 10, No 5 (2017) pp 410-416
2. Sangeetha.K,Glan Devadhas.G,Mary Synthia Regis Prabha D.M., A Fractional Order Controller for a Nonlinear System, Journal of Advanced Research in Dynamical and Control Systems,Volume 10, Issue 2, 2018 pp 110-118
3. Thara.N K,Glan Devadhas G,Shinu M M ,Modelling and Controller Design for a Nonlinear Conical System, Journal of Advanced Research in Dynamical and Control Systems,Volume 10, Issue 2, 2018, pp 119-126

A. Ganesh Ram & S. Abraham Lincoln, A Model Reference Based Fuzzy Adaptive PI Controller for Non Linear Level Process System, International Journal of Recent Research and Applied Studies, 14 (2), Feb 2013.

4. Dhanalakshmi, R., Vinodha, R., An Auto-Tuning Fuzzy PI Controller Using Subtractive Clustering For Spherical Tank Process – A Real-Time Performance Evaluation, (2014) International Review on Modelling and Simulations (IREMOS), 7 (4), pp. 694-702.
5. Ali, A., Wahid, N., Said, B., Fuzzy Logic Controller Optimization Based on PSO and BBO for Quadruple Tank System, (2015) International Review on Modelling and Simulations (IREMOS), 8 (5), pp. 540-549.
6. Gaya, M., Bisu, A., Salim, S., Madugu, I., Yusuf, L., Kaurangini, M., Khairi, M., Optimal PID Design Approaches for an Inverted Pendulum System, (2016) International Review of Automatic Control (IREACO), 9 (3), pp. 167-174.
7. Immanuel.J, Parvathi.C.S, L. Shrimanth Sudheer, and P. Bhaskar, Implimentation of MATLAB-GUI based Fuzzy Logic Controllers for Liquid level Control System, International Journal of Electrical Engineering, 6(1),June 2014.