REAL TIME PERFORMANCE ANALYSIS, FAULT DETECTION AND CONTROL IN CONICAL TANK SYSTEM

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Abstract—*Conical tank system is a non-linear system. Due to its non-linear behaviour, it is a challenging problem to control the liquid level in the tank. Real time processes are always exhibits non-linear property. In many process industries like Chemical industries, Petroleum industries, Paper industries, Water treatment plants, Fermentation industries etc.., it is preferred to have conical tank system because, it leads to better drainage of solid mixtures, slurries and viscous liquid at the bottom of the tank. In this project work, Internal Model Controller(IMC) is designed and response of the process is obtained in both simulation and real time. Due to changes in process parameters the behaviour of the system can be varied. To measure an exact performance of the system, the faults introduced into the conical tank system and to be detected. If not, the faults which degrade the performance of the system. Various fault diagnosis methods are to be considered. PID controllers are used to detect the faults in conical tank system. Consequently, they can provide better output performance which can be measured in terms of overshoot, set point tracking and settling time.*

Keywords—Conical tank system, PID controller, Internal Model Control, Fault diagnosis and estimation

1. INTRODUCTION

Conical tank system is a nonlinear system which consists of broad area at the upper end and becomes narrow at the lower end. In the ap plication of process industries, controlling the physical variables such as flow, level, temperature and pressure is a challenging one even at different disturbances are occurred into the process. Proportional Integral Derivative(PID) controller are mostly used in process industries due to its acceptable performance[1].

Mostly in level based control process, the shape of the tank has major role in process. The availability of the tank in the process industries in the shape of linear and non-linear like cylindrical type, spherical type and conical type etc... In cylindrical type tanks, there will not be better drainage. To achieve complete drainage of the liquid, conical shaped tank is preferred in process industries. In process industries, the liquids will be processed in conical tanks for chemical storage, concrete mixing, food processing and waste product draining etc... So that, to control the level of the conical tank is a challenging problem due to its continuous variation in the area of cross section of the conical tank.

Thereafter, a non-linear controller is designed by Anandanatarajan et al. [2] on the basis of a variable transformation for the first order non-linear process with dead time, which is tested on a conical tank level process with dead time. The Ziegler Nichols PI controller gives an oscillatory response even at the nominal operating point.

In [1], P. Aravind et al. proposed a nonlinear model of conical tank level control system and real time system designs are analysed and their implementation of the PI controller is done by direct synthesis method and skogestad method. In [2], D. Hariharan et al. designed the mathematical modeling of single conical tank, two conical tanks of non-interacting type system and two conical tanks of interacting type system is designed and also obtained the responses of the process.

In [4], J. Arputha Vijay Selvi et al. proposed conventional PID and IMC, are considered and are comparatively analysed using standard robustness measures for stability and performance. In [5], Jeffrey E. Arbogast et al. implemented the novel IMC correlations calculate a filter time constant based upon the modal of the process and the user's choice for the closed loop time constant. The set point tracking and disturbance rejection performance of the IMC tunings are also demonstrated.

In [6], D. Angeline Vijula et al. implemented the mathematical modeling of a conical tank system has obtained and then model based controller(IMC) has designed for controlling the level of the conical tank system. In [7], E. Kesavan et al. proposed IMC based PI and scheduled PI for nonlinear systems are designed. The servo mechanisms are analysed by adding the disturbance to the process and output is retained to the setpoint of the process.

In [8], S. Vadivalagi et al. presented the parameters are optimally and robustly adjusted with respect to the system dynamics. In [9], P. Suganthini et al. proposed the IMC controller which proven that the IMC control method is to enhance the stability of the conical tank system.

In [10], T. Pushpaveni et al. designed the Model Predictive Controller(MPC) to track the setpoint changes and load disturbances which control the level and also to enhance the stability in the conical tank system.

In [11], L. Ren et al. analyzed the process noise which includes sensor fault information. The sensor incipient fault can be detected by the distribution of the feature extracted from process noise in KPCA(Kernal Principle Component Analysis) space.

The intention of this paper is to design and compare the performance of PID controller and IMC controller. The proposed schemes are imposed on the non-interacting conical tank system which is stationary in time, but non-linear property in operating level. Futhermore, the objective is to analyse the performance of the non-interacting conical tank system and then to detect the occurrence of abnormalities in the conical tank system.

The paper is organized as follows: Section II provides a brief description about conical tank system. Section III moves to focus on mathematical modeling of non-interacting conical tank system. Design and selection of PID controller parameters are discussed in Section IV. In Section V, IMC controller is designed and comparative simulation results are also presented. Section VI, methods of fault diagnosis is provided. Finally, conclusions are drawn in Section VII.

2. PROCESS DESCRIPTION

A. Description of the Conical Tank System

The experimental setup of conical tank system is shown in Fig. 1 which is designed by interacting and non-interacting type. The system consists of conical tank, reservoir tank, centrifugal pump, differential pressure transmitter (DPT), air regulator, (I/V) converter, electro pneumatic converter (I/P), LabVIEW card.

Fig. 1. Experimental Setup of Conical Tank System

The level in the tank which is measured by using DPT and the signals can be transmitted in the form of (4-20mA) to the (I/V) converter. The LabVIEW card was interfaced to the Personal Computer (PC). After, designed the controllers in the PC, the control signals are transmitted in the form of current signal (4-20mA) to the (I/P) converter then it passes the air signal to the pneumatic control valve. The control valve which is actuated by this signal to produce the required flow of water into the conical tank and outflow is considered as constant. There is a continuous flow of water in and out of the conical tank.

B. Process Model of conical Tank System

The structure of non- interacting conical tank system is shown in Fig. 2 in which tank-1 inlet F_{in1} being the inflow rate(m^3/s) and outlet is F_{in2} which is the fluid level(m). H_1 represents the total height of the tank 1and h_1 represents the level of the tank-1. Similarly, the inlet flow of tank-2 represents the F_{in2} and outlet flow of the tank-2 represents the $F_{in3.}$ H_2 represents the total height of the tank-2 and h_2 represents the level of the tank-2. MV1, MV3, MV21 represents rotameter.

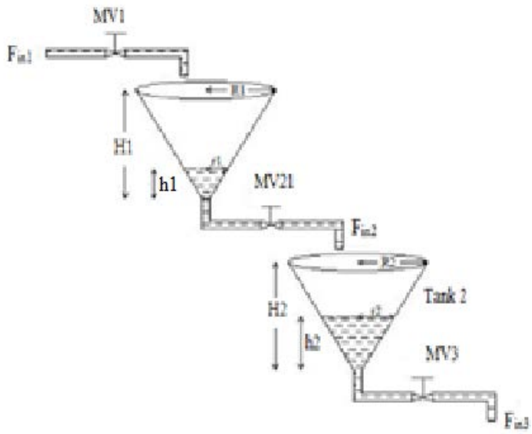

Fig. 2. Process Model of Non-interacting Conical Tank System

3. MATHEMATICAL MODELING

Using mass balance equation, the mathematical modeling for two tank non-interacting conical tank system is derived below,

Rate of accumulation of mass in the tank	=	Mass of inlet flow rate	-	Mass of outlet flow rate

The transfer function of the two tank non-interacting conical tank is given by,

$$\frac{Y_2(s)}{U_1(s)} = \frac{kk_1}{(\tau_1 s+1)(\tau_2 s+1)} \tag{1}$$

To obtain the transfer function of the proposed system, by considering the following specifications as follows,

i) R = Top radius of the conical tank = 17cm

ii) H = Maximum height of tank 1 and tank 2 = 70 cm

iii) F_{in1} & F_{in2} = Maximum inflow to tank 1 and tank 2 = 500 LPH

iv) C_{v1} & C_{v2} = Valve coefficient of MV_1 & MV_2 = 14 (1 inch)

v) C_{v12}=Valve coefficient of MV_{12}= 11(3/4 inch)

Hence, the transfer function of two conical tank non-interacting system is given by,

$$\frac{Y_2(s)}{U_1(s)} = \frac{0.0207}{626.5352s^2 + 50.2932s + 1} \quad (2)$$

A. Real Time Data Logging

The two conical tank non- interacting system input-output data are required which are collected in real time setup of conical tank system is shown in Fig. 2. From this, the level of the tank1 represented as h_1 and the level of the tank 2 represented as h_2.The various input-output data are collected from two conical tank non- interacting system and among some are presented in Table I.

TABLE I. INPUT-OUTPUT DATA COLLECTION

Fin 1 = 100 LPH			Fin 2 = 62 LPH		
Fin2 (LPH)	***h1 (cm)***	***h2 (cm)***	***Fin1 (LPH)***	***h1 (cm)***	***h2 (cm)***
32	21	15	150	11	5
100	25	25	275	28	18
150	20	33	325	33	21
..	..	..	..	..	..
..	..	..	..	..	..
113	0	46	440	43	26

4. CONVENTIONAL PID CONTROLLER

Conventional PID controllers have been widely used in many process control industries. It has a simple structure and acceptable performance. The transfer function of two conical tank non-interacting system has derived, the controller has to be designed for maintaining the system to the desired set point. This can be obtained by properly selecting the tuning parameters which are K_P, T_I and T_D for a conventional PID controller. The required gain values of PID controller are obtained by using cohen and coon tuning recommentations. Fig 3 shows the response of Conventional PID controller and the tuning parameters are $K_P = 376.693$, $K_I = 0.0445$ and $K_D = 5.2932$.

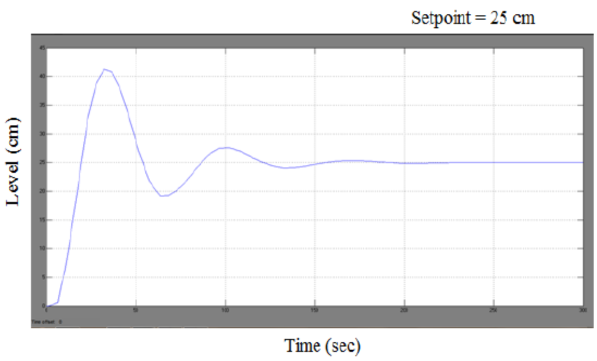

Fig.3. Response of Conventional PID Controller

Fig. 4 shows the real time response using PID controller it reaches the level in a tank at 25 cm and also Fig. 5 shows the response of PID controller using data logger values.

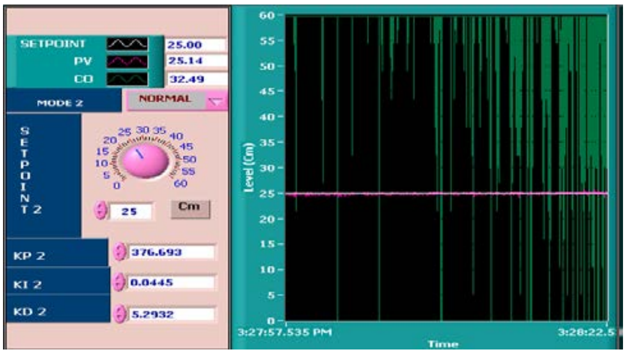

Fig. 4. Real Time Response using PID Controller- Set point=25 cm

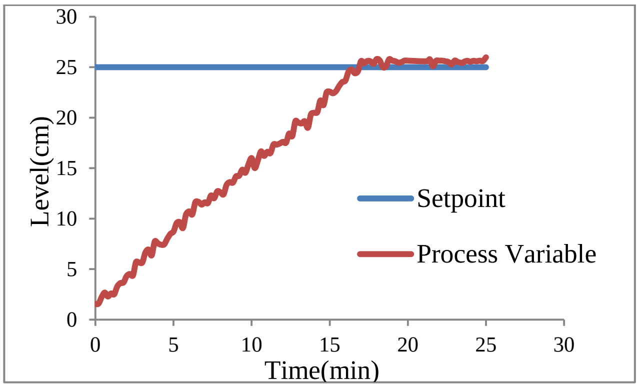

Fig. 5. Real Time Response of PID Controller using Data Logging-Setpoint=25 cm

5. INTERNAL MODEL CONTROLLER

Internal model control is model based controller. The Fig. 6 shows the IMC structure which makes use of a process model to identify the effect of immeasurable disturbance on the process output and then counteracts that effect. Internal model controller is based on the control system, which holds some model of the process to be controlled then a faultless control can be attained in the conical tank system.

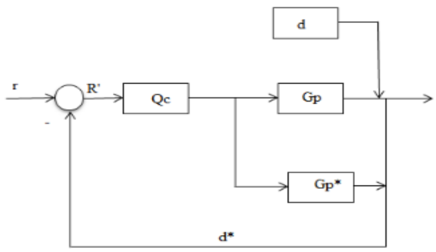

Fig. 6. Block Diagram of IMC

In this diagram, G_p is the process plant, G_p^* is the model of the process, *Qc*, is an controller, to control the process, d^* is an unknown disturbance affecting the system. The manipulated input *u* is introduced to both the process and its model. The process output, *Y* is compared with the output of the model, resulting in a signal d^*.

IMC is designed for the conical tank system by the transfer function given in equation (3)

$$G_p(s) = \frac{0.0207}{626.5352s^2 + 50.2932s + 1} \quad (3)$$

From this, IMC is designed by the given equation (4)

$$G_{IMC}(s) = Q_c(s)G_f(s) \quad (4)$$

where,

$Q_c(s)$ = inverse of the model of the process

$G_f(s)$ = low pass filter

The transfer function of the low pass filter is given below

$$G_f(s) = \frac{1}{\tau_1 s + \tau_2 s + 1} \quad (5)$$

The model is an exact representation of the process, $G_p(s) = G_p^*(s)$. The closed loop output signal for the IMC is, therefore $Y(s) = G_p(s)u + d$. The closed loop response is obtained using IMC. This improves the robustness of the system, the response using IMC is shown in Fig. 7.

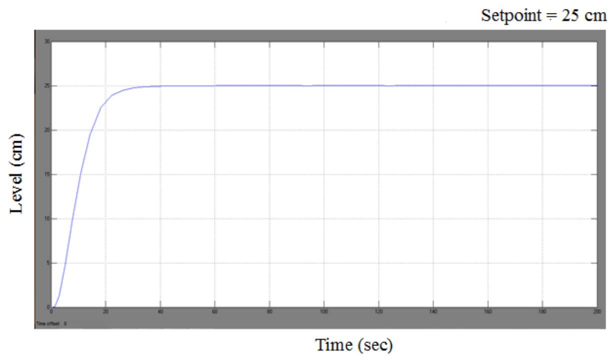

Fig. 7. Response of Internal Model Controller

Fig. 8 shows the real time response of IMC controller using LabVIEW and it reaches the setpoint in 20 cm at 35 secs.

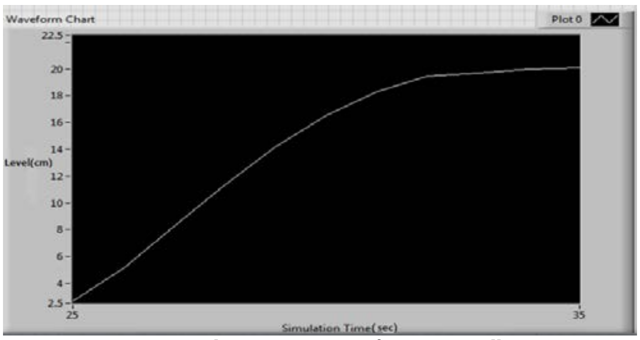

Fig. 8. Real Time Response of IMC Controller

The servo response was also obtained for changing set point profile from 25 cm to 50 cm without an influence of any external disturbance. Fig. 9 shows the set point tracking for different changing set points of level in tank 2.

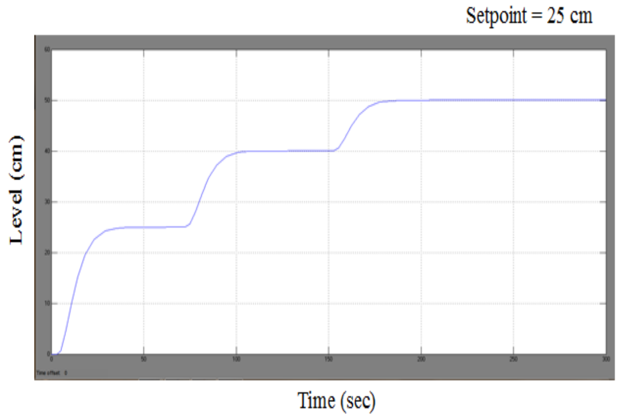

Fig. 9. Response of Servo Operation for IMC

A sudden disturbance is given by pouring water into tank 2 while the system becomes stable. The leakage of some amount of water from tank 2 is considered as the error introduced to the system. Fig. 10 shows the regulatory response obtained at different set points from 25 cm to 42 cm by introducing disturbance and the error in the tank2.

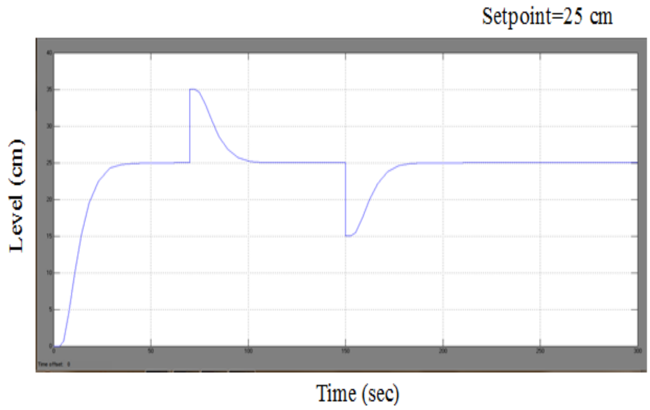

Fig. 10. Response of Regulatory Operation for IMC

After the tuning procedures are done through the controllers of conventional PID and IMC control techniques, the responses are analysed to a step input. The responses of conventional PID and IMC controllers are compared, which is shown in Fig. 11.

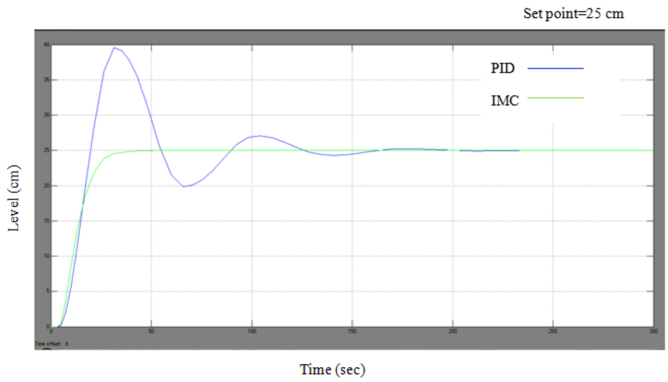

Fig. 11. Comparative Responses for PID and IMC

In the time domain, specifications for a control system design involve certain requirements associated with the time response of the system. A comparative study of their performance has been in the Table II.

Table II. Comparison of Time Domain Parameters

S.NO	TIME DOMAIN PARAMETERS	PID	IMC
1.	Settling Time(sec)	150	52
2.	Overshoot	41	0

The requirements are often expressed in terms of the standard quantities on the rise time, settling time, overshoot, peak time, and steady state error of a step response. From the above observation, IMC controller shows the better settling time and there is no overshoot in the two conical tank non- interacting system.

6. METHODS OF FAULT DETECTION

Associated with an increasing demand for high performance and additionally for more safety and dependability of dynamic systems, and a characteristic pattern toward system automation, fault detection and diagnosis is becoming a strategic necessity as a result of increasing economic and natural requests. Early detection and diagnosis of process faults while the plant is as yet working in a controllable district can help keep away from abnormal event progression and reduce productivity loss.

A fault can be defined as an unforeseen change of the system functionality which may be related to a failure in a physical component or in a system sensor or actuator. Fig. 12 shows the general components of fault diagnosis framework.

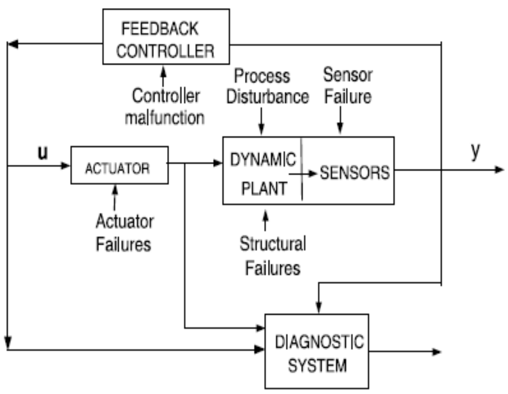

Fig.12. Components of Fault Diagnosis

By varying an supply pressure in the air regulator, atmost 70% of openings in the control valve. Fig. 13 shows the real time response by varying the supply pressure in air regulator using PID controller and also it takes 10 mins time to reaches the set point at 20 cm.

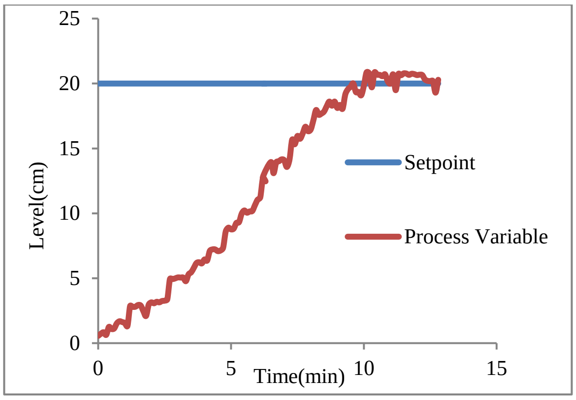

Fig. 13. Real Time Response by Varying the Supply Pressure in Air Regulator at 1kg/cm^2

Fig. 14 shows the real time response by varying the supply pressure in air regulator using PID controller. It reaches the desired setpoint in 7.8 mins. Because, the control valve of a tank gets fully opened condition.

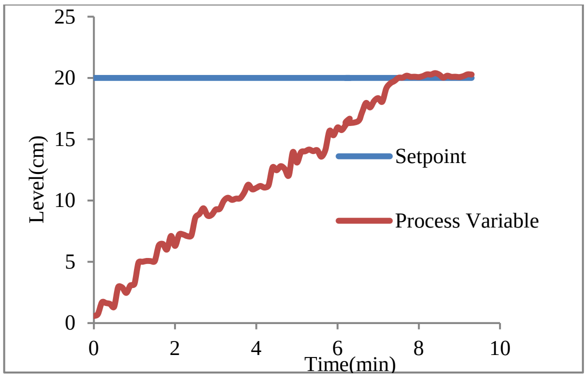

Fig.14. Real Time Response by Varying the Supply Pressure in Air Regulator at 2kg/cm^2

In non-interacting conical tank sytem, reaches the setpoint in the inlet flow rate is setted at 250 LPH and outlet flow rate is 138 LPH and then observed the response that is shown in the Fig. 15.

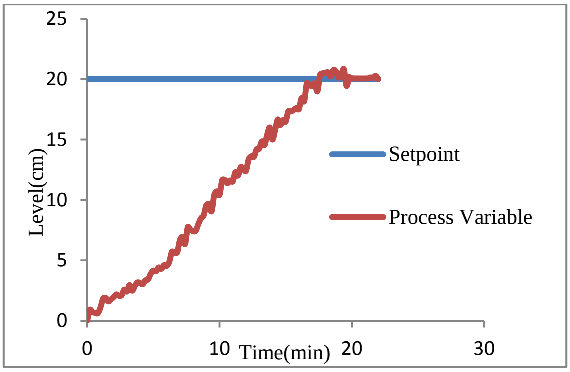

Fig. 15. Real Time Response under Normal Condition

After, the tank reaches the setpoint by adding 30 LPH in the inlet flow rate and then observed the reponse using PID controller that is shown in Fig.16.

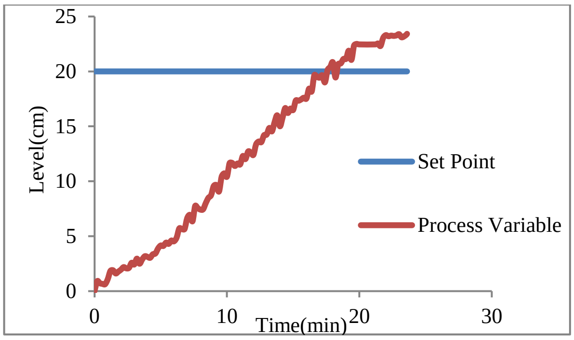

Fig. 16. Real Time Response by Indroducing Disturbance in Rotameter

7. CONCLUSION

In this proposed work, two conical tank of non-interacting type is taken as a non-linear system. For which, a conventional PID controller is designed to achieve the level control in conical tank system. But due to the unsatisfactory performance of the conventional PID controller, a model based controller of IMC is designed and placed in the forward path of the system. From the comparative results, it is found that the settling time and the overshoot of conventional PID controller such as 150 secs and 41 % are higher than the IMC controller. Various faults are introduced into the conical tank system and observed the responses using PID controller in real time. Simulated studies have also proved that IMC control technique has good servo tracking and disturbance rejection capability.

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