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Gain Scheduling PID Controller for Conical Tank Level Control

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Abstract: Level control of nonlinear systems is an important problem in process industries. The conical tank system is a nonlinear process because the cross-sectional area varies with the height of the liquid. Conventional PID controllers often fail to provide satisfactory performance over the entire operating range of such nonlinear systems. This paper presents the design and implementation of a Gain Scheduling PID controller for controlling the liquid level in a conical tank. The nonlinear model of the conical tank is derived using mass balance principles. The operating region of the tank is divided into different sections and separate PID parameters are designed for each region. A gain scheduling mechanism is used to switch the controller parameters based on the current tank level. The proposed control system is implemented and simulated using MATLAB/Simulink. Simulation results show improved dynamic response, reduced overshoot, faster settling time and better set-point tracking compared to a conventional PID controller.
Keywords: Gain Scheduling, PID Controller, Conical Tank System, Level Control, Nonlinear System, Process Control.

I. INTRODUCTION

Control of liquid level in tanks is an essential requirement in many industrial applications such as chemical processing plants, water treatment systems, petroleum refineries, and food industries. Maintaining the desired level ensures safe and efficient operation of the system. The conical tank is a commonly used nonlinear process in control engineering studies. Unlike cylindrical tanks, the cross-sectional area of a conical tank varies with height. Because of this varying geometry, the dynamic behavior of the system becomes nonlinear. Traditional linear controllers such as PID controllers may perform well only around a specific operating point but fail to provide good performance across the entire operating range. Gain Scheduling is a widely used control technique for nonlinear systems. In this approach, the controller parameters are adjusted automatically according to the operating conditions of the system. The operating range is divided into multiple regions, and different controller gains are assigned for each region. This paper focuses on designing a Gain Scheduling PID controller for a conical tank level control system. The mathematical model of the system is derived, the controller gains are obtained for different operating regions, and the entire control system is simulated.

II. LITERATURE REVIEW

Kadu, C. B., & Patil, C. Y. (2016)[1].Design and implementation of stable PID controller for interacting level control system. Procedia Computer Science, 79, 737-746 in this present study a Stability Region Analysis method for designing PID controller for time delay system is validated with real time experimentation with Interacting process. The higher order system is reduced into first order plus time delay (FOPDT) model. A polyhedral sets in the 3D (three dimensional) search band parameter space Kp Ki Kd is resulted from set of stable PID controllers for a fixed value of Kd, and it is faster and simple to identify these regions. The stability region verification is done with dual locus diagram.

Eapen, I. M., & Rose, L. (2017, February)[2] Nonlinear intelligent controller for a level process. In 2017 International Conference on Innovations in Electrical, Electronics, Instrumentation and Media Technology (ICEEIMT) (pp. 128-131). IEEE. The control of a non-linear process is a difficult task in process industries. Real processes often exhibit nonlinear behavior. Many process industries use conical tanks because its shape contributes to better drainage. Its non-linearity due to the constantly changing cross section makes the control of a conical tank a challenging problem. In order to improve the control effectiveness of some nonlinear processes, a novel Nonlinear Guided Intelligent Controller (NGIC) inspired by the bio cooperative regulation mechanism and the regulation.

Villani, M., Sani, L., Pecori, R., et.al (2018)[3]. An Iterative Information-Theoretic Approach to the Detection of Structures in Complex Systems. Complexity, 2018(1), 3687839.Systems that exhibit complex behaviors often contain inherent dynamical structures which evolve over time in a coordinated way. In this paper, we present a methodology based on the Relevance Index method aimed at revealing the dynamical structures hidden in complex systems.

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The method iterates two basic steps: detection of relevant variable sets based on the computation of the Relevance Index, and application of a sieving algorithm, which refines the results..

Binette, J. C., & Srinivasan, B. (2016)[4] On the use of nonlinear model predictive control without parameter adaptation for batch processes. Processes, 4(3), 27.Optimization techniques are typically used to improve economic performance of batch processes, while meeting product and environmental specifications and safety constraints. Offline methods suffer from the parameters of the model being inaccurate, while re-identification of the parameters may not be possible due to the absence of persistency of excitation. Thus, a practical solution is the Nonlinear Model Predictive Control (NMPC) without parameter adaptation, where the measured states serve as new initial conditions for the re-optimization problem with a diminishing horizon. In such schemes, it is clear that the optimum cannot be reached due to plant-model mismatch. However, this paper goes one step further in showing that such re-optimization could in certain cases, especially with an economic cost, lead to results worse than the offline optimal input.

Londhe, P. P., Kadu, C. B., & Parvat, B. J. (2016) [5] IMC-PID controller designing for FOPDT & SOPDT systems. IJIREEICE, 4(5), 185-189.FOPDT and SOPDT systems are common in industries like reactors and boilers, where conventional PID controllers often perform poorly due to dead time. IMC-based PID design offers better robustness, stability, and disturbance rejection than classical tuning methods. Londhe, Kadu, and Parvat (2016) showed that IMC-PID provides systematic tuning formulas and improved control for FOPDT and SOPDT models, making it a reliable approach for real-time industrial applications.

III. METHODOLOGY

A. Mathematical Model

The conical tank is a nonlinear system because its cross-sectional area changes with the liquid height. To design a gain scheduling PID controller, we first need to develop a mathematical model that relates the inlet flow rate and the liquid level inside the tank. The dynamic behavior of the tank can be described by the principle of mass balance, which states that the rate of change of liquid volume in the tank equals the difference between the inflow and outflow rates.

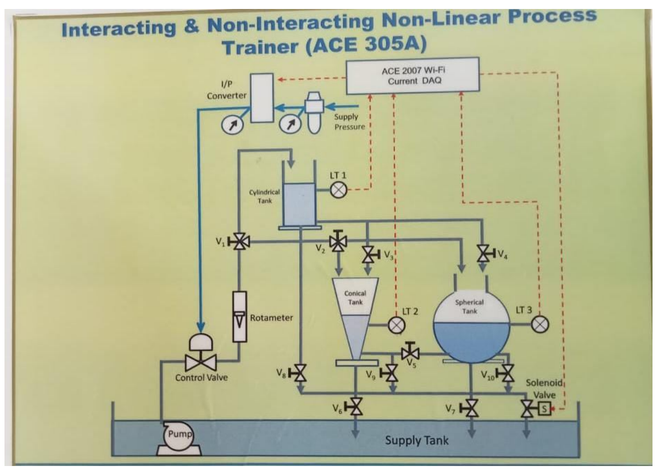

Fig. 1. *Schematic Representation of Nonlinear control system*

1) Mass balance equation,

$$\frac{dv}{dt}=qin(t)-qout(t)$$

Where,

V=liquid volume of the tank (m^3)

qin=inflow rate (m^3/s)

qout=outflow rate (m^3/s)

- Volume of conical tank,

$V=\frac{1}{3}\pi r(h)^2 h$

Since the radius varies linearly with height:

$$r(h)=rt\frac{h}{H}$$

Hence, the cross-sectional area:

$$A(h) = \Pi\left(\frac{r_t}{H}\right)^2 h^2$$

2) Nonlinear Dynamic Model

Substituting A(h) and applying Torricelli's law for outflow:

$$qout(h)=Cd a_0\sqrt{2gh}$$

The dynamic equation becomes:

$$\frac{dh}{dt} = \frac{1}{A(h)}[qin(t)- Cd a_0\sqrt{2gh}$$

This is the **nonlinear differential equation** representing the tank level system.

3) Transfer Function (FOPDT Model)

$$G_i(s) = \frac{k_p e^{-\theta s}}{T_i s + 1}$$

Where,

Kp=process gain

$Ti =$ time constat

θ=time delay

IV. EXPERIMENTAL RESULTS

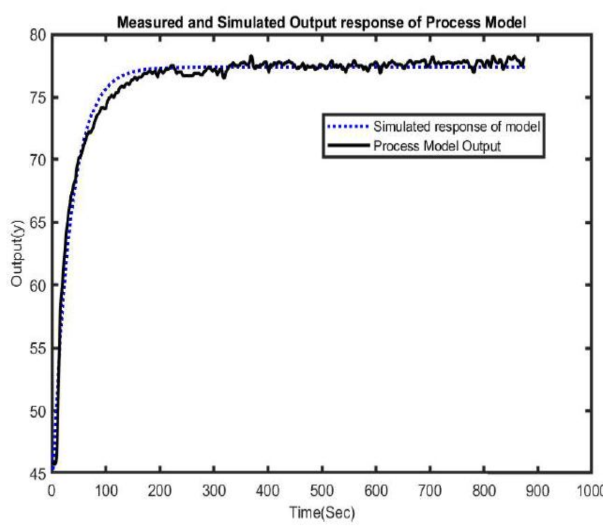

Fig.2. *Model Validation*

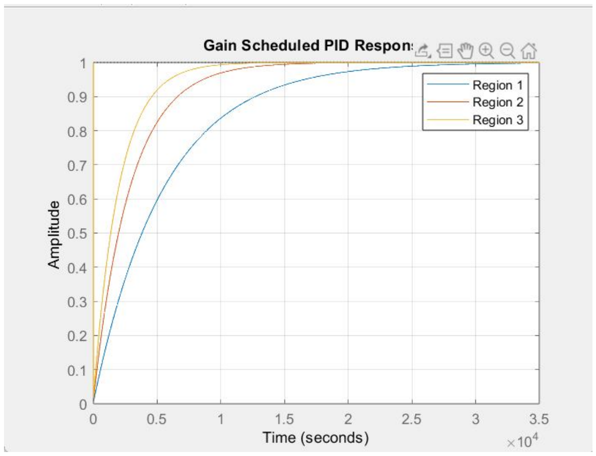

Fig 3. Gain Scheduling PID Response

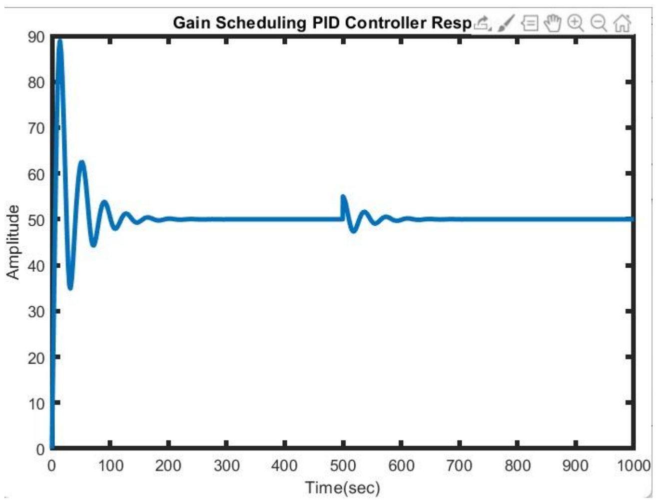

Fig. 4. Gain Scheduling PID Response with Disturbances

V. CONCLUSION

The design and simulation of a Gain Scheduling PID controller for controlling the level of a conical tank system. The nonlinear behavior of the tank was handled by dividing the operating range into multiple regions and assigning different PID gains for each region. Simulation results demonstrated that the Gain Scheduling PID controller significantly improves the dynamic performance compared to a conventional PID controller. The proposed method provides faster response, reduced overshoot, and better set-point tracking.

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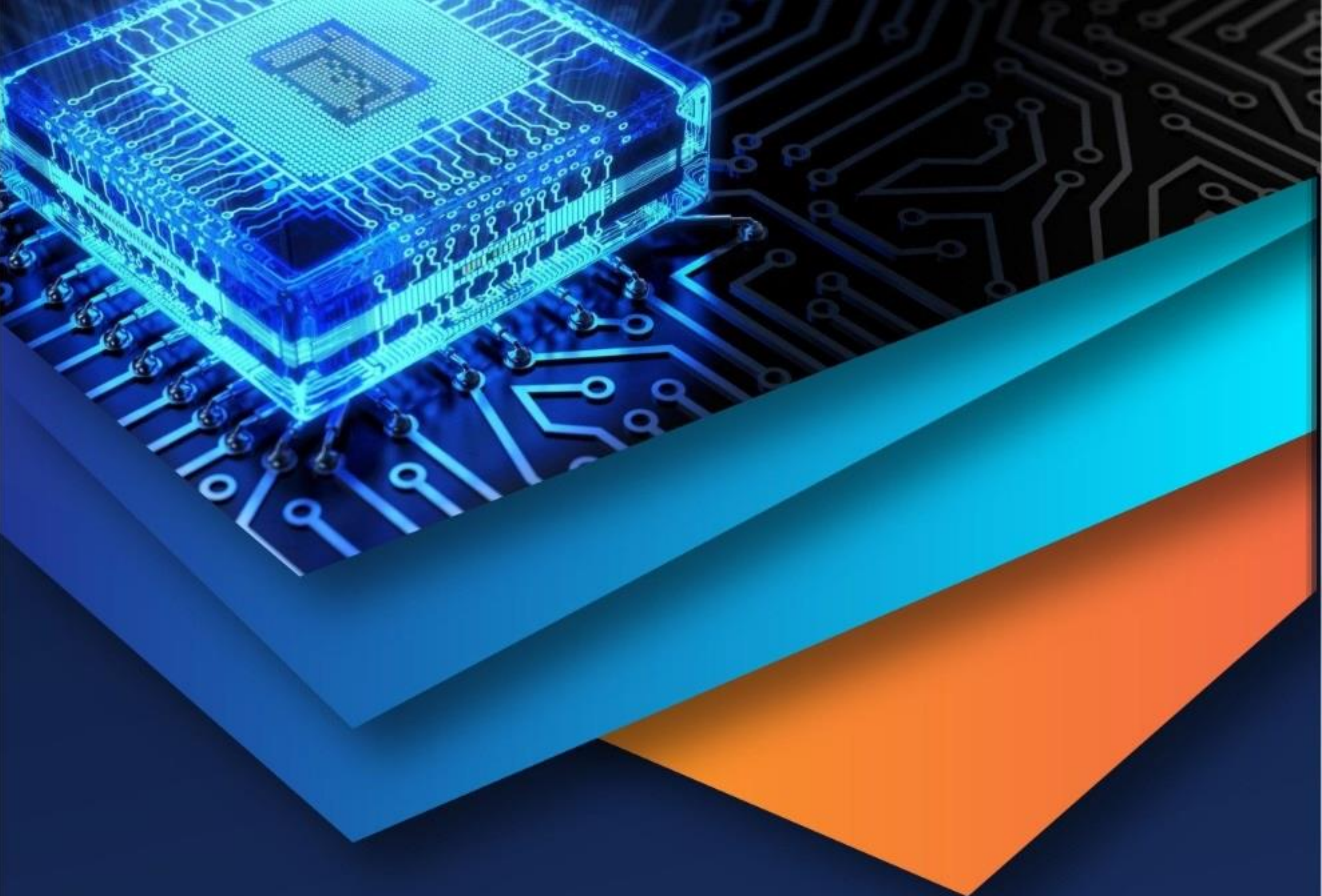

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