

# Design and Analysis of a PID Controller for Water Level Regulation in a Tank System

Veena Vanamane, S Zuha Afsheen, Thrisha M, Preksha Malipatil, Chirasvi S N

Dept. Of electrical and electronics Engineering.  
MVJ college of Engineering Bengaluru, India..

**Abstract-** In many industrial applications, maintaining a steady water level in tank systems is crucial. The design and analysis of proportional (P), proportional-integral (PI), and proportional-integral-derivative (PID) controllers for a single-tank water level control system are presented in this study. MATLAB/Simulink is used to create and construct a mathematical simulation model. Rise time, settling time, overshoot, and steady-state error are used to assess the controllers. The P controller has steady-state error; the PI controller decreases error but increases overshoot, and the PID controller offers ideal performance with better stability and quicker reaction, making it appropriate for efficient water level control, according to the results.

**Keywords-** Water level control, Single-tank system, Proportional (P) controller, Proportional-Integral (PI) controller.

## I. INTRODUCTION

A fundamental issue in control engineering, water level control in tank systems is essential to many industrial applications, including boilers, chemical processing, water treatment facilities, and storage systems. System stability, safety, and effective operation are guaranteed by maintaining the appropriate liquid level. However, nonlinear dynamics, input and outflow disruptions, and time-varying system characteristics make controlling the water level difficult. Therefore, to obtain precise and reliable performance, an efficient control method is needed.

Because of their dependability, simplicity, and ease of implementation, proportional (P), proportional-integral (PI), and proportional-integral-derivative (PID) controllers are among the most used control strategies. By modifying the control input appropriately, these controllers aid in reducing the discrepancy between the intended and actual water levels. The P controller provides a straightforward method with quick reaction, however it frequently leads to steady-state inaccuracy. Although the PI controller removes steady-state error, it may cause overshoot and a slower reaction time. By using derivative action, the PID controller enhances transient performance and system stability.

A single-tank water level system's mathematical model is created and examined. MATLAB/Simulink simulation is

used to assess the performance of P, PI, and PID controllers. The best control approach for water level regulation is found by comparing important performance metrics such rise time, settling time, overshoot, and steady-state error.

### Objectives

- To create a system dynamics-based mathematical model of a single-tank water level control system.
- To create controllers for controlling the water level that are proportional (P), proportional-integral (PI), and proportional-integral-derivative (PID).
- To use MATLAB/Simulink for simulation and analysis in order to implement the planned controllers.
- To increase performance by adjusting the controller's parameters using techniques like Ziegler-Nichols.
- To assess and contrast P, PI, and PID controller performance using metrics such as rising time, settling time, overshoot, and steady-state error.
- To choose the best controller for obtaining precise and steady water level control.
- To examine how the system reacts under various operational circumstances and disruptions.

## II. METHODOLOGY

The methodology used in this work is centered on the methodical design, modeling, simulation, and performance assessment of a P, PI, and PID controller-based water level

control system. To guarantee precision and clarity in analysis, the entire process is broken down into multiple phases.

### 1. System Overview and Presumptions into multiple phases.

#### 1. System Overview and Presumptions

A single-tank water level system is examined, in which the outflow happens via an outlet at the tank's bottom and the intake rate is regulated. To make the analysis simpler, the following presumptions are made:

The cross-sectional area of the tank is consistent. The fluid is homogenous and incompressible. The flow is laminar and continuous. According to a linear approximation, the outflow rate is proportionate to the water level.

#### 2. Mathematical Modeling

The system is modeled using the principle of mass balance, where the rate of change of water volume in the tank is equal to the difference between inflow and outflow.

A single-tank water level system is examined, in which the

$$A \frac{dh(t)}{dt} = Q_{in}(t) - Q_{out}(t)$$

Assuming a linear relationship for outflow:

$$Q_{out}(t) = kh(t)$$

Substituting and simplifying, the system equation is obtained. By applying the Laplace Transform, the transfer function of the system becomes:

$$\frac{H(s)}{Q_{in}(s)} = \frac{1}{As + k}$$

This represents a first-order dynamic system.

#### 3. Controller Design

Three types of controllers are designed to regulate the water level:

- **Proportional (P) Controller:** Produces control action proportional to the error signal. It improves response speed but cannot eliminate steady-state error.
- **Proportional-Integral (PI) Controller:** Adds integral action to eliminate steady-state error but may introduce overshoot.

- **Proportional-Integral-Derivative (PID) Controller:** Combines proportional, integral, and derivative actions to achieve better transient and steady-state performance.

The general control law is given by:

$$u(t) = K_p e(t) + K_i \int e(t) dt + K_d \frac{de(t)}{dt}$$

#### 4. Adjusting the Controller

The Ziegler–Nichols tuning method, which offers a methodical approach to obtaining approximate controller gains, is first used to establish the parameters. To increase performance indicators like overshoot and settling time, more manual fine-tuning is done in the simulation environment.

#### 5. MATLAB/Simulink Simulation

MATLAB/Simulink is used to implement the entire system. The model consists of:

The tank system's transfer function Blocks of controllers (P, PI, PID) loop of feedback using a level sensor Step input for the intended water level

To guarantee a fair comparison, simulations are run for every controller under the same circumstances.

#### 6. Performance Assessment Standards

- **Rise Time:** The amount of time needed to initially achieve the desired level
- **Settling Time:** The amount of time needed to stabilize within reasonable bounds
- **Overshoot:** The highest point above the intended level
- **Steady-State Error:** Ultimate departure from the target

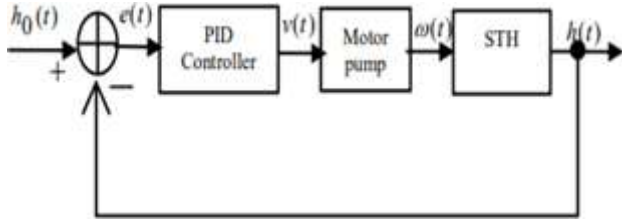
#### 7. Analysis of Disturbances

Disturbances such abrupt variations in inflow or outflow are introduced to test robustness. To assess the controller's capacity to sustain stability under various circumstances, the system reaction is examined.

#### 8. Comparative Evaluation

Simulation results are plotted and contrasted. The most effective controller is found using numerical values and graphical analysis (step response curves). It is anticipated that the PID controller will offer the optimal balance of precision, speed, and stability.

**BLOCK DIAGRAM**



The overall system is a feedback control system as shown in the block diagram. Firstly, a reference input height level,  $h_0(t)$ , is set that shows the desired level the tank has to be filled. In the forward path, we have the PID controller that controls the speed of the DC motor. The speed of the motor is directly related to the water flow rate  $q_{in}$  supplying the tank. At the output of the overall system, we have the water level,  $h(t)$  and this information is feedback at the input and compared with the reference desired level.

The error signal between the actual output and the reference,  $e(t)$  will be an input signal to the PID controller and the speed of the motor  $[\omega(t)$  in rad/s] will be adjusted (either increased or decreased) to control the flow rate  $q_{in}$  until the required target water level is achieved. The speed information of the motor is assumed to be obtained from speed measurement device such as tachometer. The speed will be transformed by the speed to height transformation (STH) block that relates the speed to the flow rate and then to the water level  $h(t)$ .

**MATLAB SIMULATIONS:**

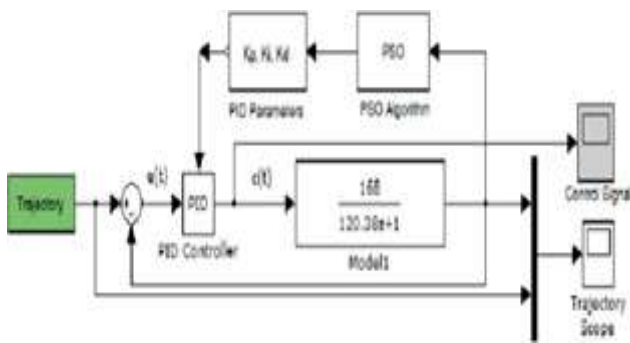


Fig. PID Controlled Water Level Control Process

A closed-loop control system in which the system output is controlled by a PID controller. An error signal is produced by comparing the intended input (trajectory) with the actual output. The PID controller processes this error to generate a control signal that powers the system.

The Particle Swarm Optimization (PSO) technique is used in this model to tune the PID settings rather than by hand. The PSO algorithm looks for ideal values that enhance system efficiency.

A transfer function is used to simulate the plant, and the feedback loop guarantees precise tracking with lower error, better stability, and quicker reaction.

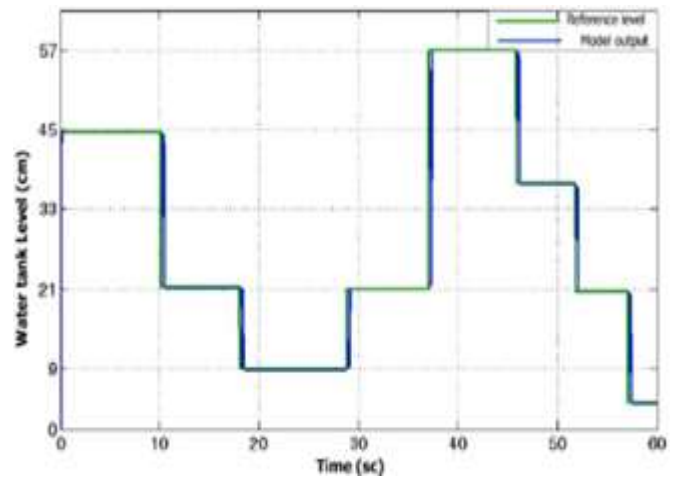


Fig. Response to step input reference

The control system's tracking performance for a changing reference (trajectory) input. The blue line shows the actual system output, and the green line shows the intended water level.

The graph demonstrates how well the controller monitors various step changes in the reference signal over time. The system reacts fast and follows the target level with little delay whenever the setpoint changes. Transient response, including a modest lag or minor overshoot, is shown by the small variations seen during transitions.

Overall, the PID controller (tuned using PSO) offers precise tracking, strong stability, and effective disturbance handling, as seen by the near overlap between the reference and output signals. This attests to the control strategy's efficacy in preserving the intended water level under various circumstances.

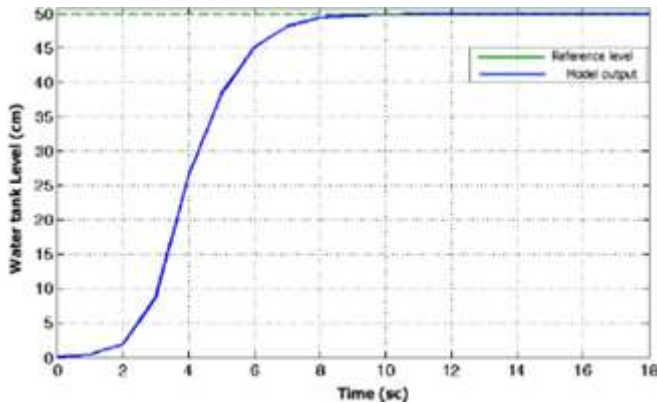


Fig. Response to step transition input reference

The system's step reaction, with a constant target water level serving as the reference input. The setpoint is represented by the green dashed line, and the system output is displayed by the blue curve.

The response shows that the system steadily rises from zero to the required level. Good stability is indicated by little to no overshoot and rapid system settling. The controller appears to be well-tuned, offering the best possible balance between speed and accuracy, based on the smooth and monotonic rise. The controller's ability to maintain the correct level is confirmed by the modest steady-state error (almost nil).

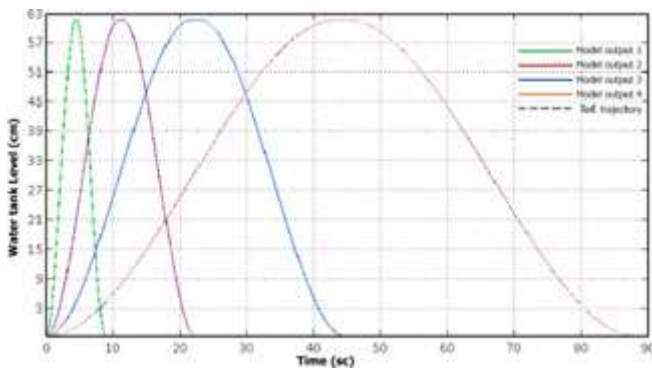


Fig. Response to reference trajectory

A comparison of several system responses under various tuning or controller settings. The reference trajectory is shown by the dotted line, and each curve depicts the system's output for various parameter values.

The difference in curves illustrates how system performance is impacted by controller tuning:

Certain answers show greater overshoot but a quicker rising time.

Others respond more slowly while maintaining greater stability.

Oscillations on some curves may indicate less-than-ideal tuning.

In order to get a balanced response with low overshoot, quick settling time, and high accuracy, this comparison emphasizes the significance of appropriate tuning (such as PSO optimization). It shows that, when compared to non-optimized settings, optimized PID parameters greatly enhance overall system performance.

### III. RESULTS AND DISCUSSION:

MATLAB/Simulink was used to assess the suggested water level control system's performance under various operational scenarios. The simulations' outcomes unequivocally show how successful the PID controller optimized with the Particle Swarm Optimization (PSO) technique is.

The tracking response shows that the system precisely and little deviates from the different reference values. Excellent tracking ability and quick dynamic response are demonstrated by the output, which closely resembles the intended trajectory. When the setpoint is abruptly changed, small transient variations are seen, but the system immediately stabilizes and exhibits good disturbance rejection.

The system effortlessly reaches the required water level with little overshoot and a shorter settling time, according to the step response analysis. The controller's ability to operate steadily is confirmed by the lack of oscillations. Furthermore, the steady-state error is almost negligible, indicating a high degree of accuracy in maintaining the necessary level.

Various controller responses were assessed in the comparative analysis. It is clear that poor tuning causes oscillations, delayed response, and increased overshoot. The PSO-optimized PID controller, on the other hand, achieves a balanced performance with reduced overshoot, increased stability, and a quicker rise time.

Overall, the findings show that system performance is greatly improved when PSO and PID control are integrated. Because

the suggested approach guarantees effective water level control, it is appropriate for real-time industrial applications where stability and accuracy are crucial.

#### IV. CONCLUSION

This study investigated the performance of P, PI, and PID controllers for a single-tank water level control system using a MATLAB/Simulink-based simulation model. The controllers were evaluated based on key time-domain specifications, including rise time, settling time, overshoot, and steady-state error. The results showed that the P controller is simple but unable to eliminate steady-state error. The PI controller improves accuracy by reducing steady-state error; however, it introduces higher overshoot and slower response. In contrast, the PID controller demonstrates the best overall performance, providing faster response, improved stability, minimal overshoot, and negligible steady-state error. Therefore, the PID controller is the most effective and reliable option for maintaining precise water level control in industrial tank systems.

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