



Performance Enhancement of Liquid Filling Process Using Feedforward-Feedback PID Control under DCS Environment

Anindya Dwi Risdhayanti, Dinda Ayu Permatasari, Muhamad Rifa'i, Irfin Sandra Asti

Electro Engineering, State Polytechnic of Malang, Jl. Soekarno Hatta no.9 Malang, 65141, Indonesia

ARTICLE INFORMATION

Received: October 21, 2025

Revised: December 05, 2025

Accepted: December 06, 2025

Available online: December 08, 2025

KEYWORDS

Feedforward-Feedback Control, DCS Siemens PCS7, PID Tuning, MIMO System, Industrial Automation.

CORRESPONDENCE

Phone: +6289515949478

E-mail: risdhayanti@polinema.ac.id

ABSTRACT

This study presents the implementation of a Feedforward-Feedback Control method on a Siemens SIMATIC PCS7-based Distributed Control System (DCS) liquid filling process to enhance system stability, response speed, and control accuracy. One of the primary challenges in industrial process control is the presence of disturbances that cause deviations from the desired set point. To address this, a control strategy combining feedforward and feedback actions was developed to anticipate and correct process variations in real time. The system employs a Multi-Input Multi-Output (MIMO) architecture, featuring two primary control variables: liquid level and reactor temperature. Flow rate and liquid level measurements were obtained using the Waterflow YF-S401 and Ultrasonic HC-SR04 sensors, both of which demonstrated a linear relationship between output voltage and the measured physical quantities, with stable real-time responses displayed on the HMI. The PID controller parameters were tuned using the built-in PID Tuner, yielding $K_p = 50$, $K_i = 150.329$, and $K_d = 0$. Experimental results show that the feedforward-feedback approach reduced the settling time from 78 seconds to 50 seconds and decreased the steady-state error from $\pm 3.8\%$ to $\pm 1.2\%$. In temperature control, the system successfully reached the operating point of 50°C with a steady-state error of less than 1% and a settling time of approximately 60 seconds. The system was configured with AI, AO, DI, DO modules and PROFINET communication, programmed using Sequential Function Chart (SFC) and Continuous Function Chart (CFC). The results demonstrate that the feedforward-feedback control significantly improves process performance and offers strong potential for application in larger-scale industrial automation systems.

INTRODUCTION

The development of the liquid material processing industry requires efficient and accurate control systems to ensure the quality of the final product. One of the most critical aspects of this process is temperature regulation, which directly affects the physical and chemical properties of the materials being processed. This process often involves various types of liquids with different physical characteristics that can influence flow rate and heat transfer performance.

The liquid processing industry demands a precise and efficient control system, especially for temperature and level regulation, as these variables have a direct impact on product quality and process efficiency [1], [2], [3], [4]. Temperature and level control in a MIMO (Multi-Input Multi-Output) reactor mini-plant is highly relevant in several industrial sectors, including chemical, energy, and water treatment. The feedforward control method offers significant advantages because it can predict and compensate for disturbances before they affect the system output, unlike feedback control, which only reacts after deviations occur [5], [6].

Previous studies have shown that integrating a PT100 temperature sensor and heater actuator within a feedforward control scheme improves efficiency and reduces temperature deviations from the setpoint [7]. In this mini-plant system, the integration of the YF-S401 flow sensor and HC-SR04 ultrasonic sensor, both connected to the DCS SIMATIC PCS 7, enables precise and automated control of the pump motor, solenoid valve, and proportional valve. The DCS S7-400 and SIMATIC PCS 7 platforms offer a reliable and flexible distributed control environment, enabling seamless HMI (Human-Machine Interface)[8] integration through Continuous Function Chart (CFC) and Sequential Function Chart (SFC) features. This enables operators to monitor and control processes in real time with optimal usability and reliability [9], [10], [11], [12], [13].

Therefore, this research aims to design and implement a temperature and level control system for a multi-input multi-output (MIMO) water tank reactor mini-plant using DCS S7-400 and SIMATIC PCS 7, along with developing a user-friendly HMI that facilitates operation and enhances overall system performance.

METHOD

Table 1 shows the material and equipment description. The experimental setup for this study utilized a Distributed Control System (DCS) platform based on Siemens SIMATIC PCS 7 (S7-400) to implement integrated process control for small-scale liquid processing. The I/O Module ET200M served as the main interface for acquiring sensor data and controlling actuators [14]. Measurement of process variables was achieved using a PT100 temperature sensor for monitoring liquid temperature [15] and a flow meter to measure the flow rate during the filling operation.

Table 1. Material and Equipment Description

No	Name of Equipment	Description
1	SIMATIC PCS 7 (S7-400)	A Distributed Control System (DCS) is used for integrated process control management.
2	I/O Module ET200M	Input/output module for reading signals from sensors and controlling actuators.
3	PT100 Sensor	A temperature sensor is used to measure the liquid temperature in the control process.
4	Heater	Heating actuator to maintain liquid temperature according to the setpoint.
5	Electronic Control Valve	Electronic valve to control liquid flow during the filling process.
6	Water Tank	Tank used to store liquid during filling and temperature control processes.
7	SIMATIC Manager, WinCC Application Software	Software for programming and configuring DCS using CFC/SFC and HMI.
8	Power Supply	Power source for electronic devices within the system.
9	PROFIBUS and PROFINET Cables and Connectors	Communication media connecting DCS hardware components.
10	Water Pump	Actuator used to pump liquid into the tank during the filling process.
11	Pipes and Fittings	Connecting channel between the tank, pump, and control valve.
12	Control Relay	Used for on/off control of actuators and other devices.
13	Flow Meter	Device used to measure liquid flow rate in the system.
14	Computer/Laptop	Used for system programming and monitoring in DCS-based control.
15	Digital Multimeter	Device used to measure voltage, current, and resistance during testing.

To regulate process conditions, several actuators were employed. A heater maintained the liquid temperature at the desired set point, while an electronic control valve and water pump regulated the liquid flow within the system. The water tank, pipes, and fittings formed the hydraulic circuit, ensuring continuous flow and process stability. A control relay was used to perform on/off switching functions for actuators and auxiliary components.

The system configuration and monitoring were performed using SIMATIC Manager and WinCC software, which enabled the implementation of control logic through Continuous Function

Chart (CFC) and Sequential Function Chart (SFC) programming environments. Communication between hardware components was established through PROFIBUS and PROFINET cables, supported by a dedicated power supply. A computer was used for programming and supervision, while a digital multimeter facilitated electrical measurements during testing and calibration. Overall, this integrated setup ensured reliable operation and provided a realistic simulation environment for both industrial and educational applications.

Filling Control

Figure 1 illustrates the implementation of the Feedforward control strategy in the liquid filling process, where the liquid level setpoint is compared with the actual output to generate an error signal, which is then corrected by the PID controller [16]. Meanwhile, the feedforward component anticipates and compensates for the effects of disturbances directly. The combined control signal regulates the Proportional Control Valve to maintain the stability of the liquid level within the tank, ensuring system accuracy even in the presence of external disturbances.

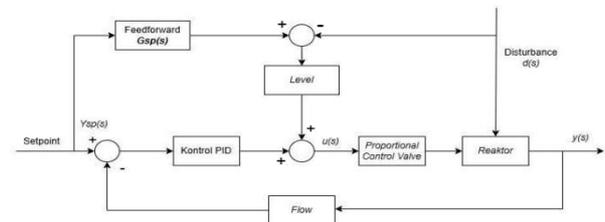


Figure 1. Feedforward-Feedback Control For Filling Process

Additionally, this hybrid control configuration enhances system responsiveness by integrating predictive and corrective mechanisms. The feedforward path acts proactively to minimize the impact of measurable disturbances before they affect the process, while the feedback PID ensures fine-tuned correction of any remaining errors. As a result, the overall control performance achieves a faster settling time, reduced steady-state error, and improved robustness against fluctuations in inflow rate or external environmental changes, leading to more stable and precise process regulation.

Temperature Control

Figure 2 illustrates the implementation of Feedforward-Feedback control in a temperature control system, where the temperature setpoint is compared with the PT100 sensor output to generate an error signal, which is then processed by the PID feedback controller. Meanwhile, the Feedforward control anticipates disturbances by providing direct corrective signals to the heater. The combination of these two control methods enables the system to maintain the temperature at the desired setpoint efficiently and responsively, even when subjected to significant changes or disturbances.



Figure 2. Feedforward Method Control for Temperature Process

Furthermore, the hybrid control structure enhances both the stability and adaptability of the system. The feedback loop ensures continuous correction of residual errors and drift, while the feedforward path acts predictively to counteract load variations, such as sudden changes in ambient temperature or heat loss in the medium. As a result, the system achieves a faster response time, minimal overshoot, and superior steady-state accuracy, making it highly effective for real-time industrial temperature regulation where precision and consistency are critical.

Mechanical Design

Figure 3 presents the physical design of the Feedforward-Feedback control implementation system for the liquid filling process in a small-scale processing unit. The control configuration was developed based on an extensive literature review of prior research on process control and automation systems. This setup integrates predictive feedforward and corrective feedback mechanisms to enhance system stability and accuracy during the filling process.

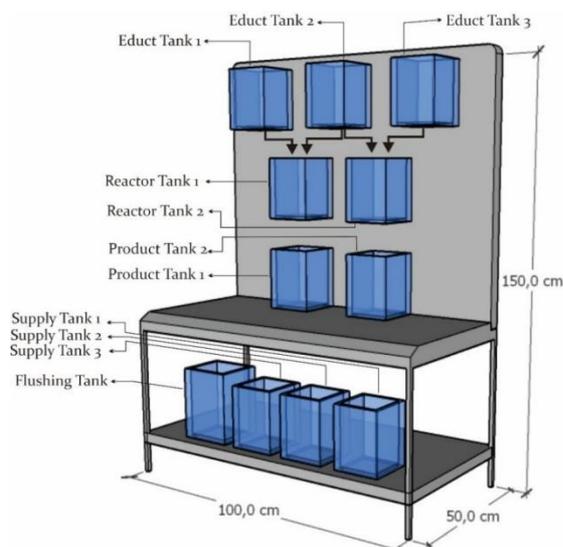


Figure 3. Mechanical Design

The prototype is constructed with compact dimensions of $50 \times 100 \times 150$ cm, making it suitable for laboratory-scale industrial simulations. The system features a 4-liter liquid capacity and is constructed from durable aluminum and plywood materials, ensuring both rigidity and ease of assembly. The main power supply operates at 220 V AC, while liquid transfer is driven by a 12 V DC pump. Flow direction is managed using solenoid valves, and precise flow regulation is achieved through a servo-controlled proportional valve.

The system utilizes a Distributed Control System (DCS) platform as its central controller, enabling integrated monitoring and control through the Feedforward-Feedback method. The liquid level range is designed between 1–15 cm, with flow rates adjustable from 0.3 to 1 liter per minute. This configuration enables real-time compensation for process disturbances, ensuring the filling process remains accurate, efficient, and responsive. Overall, the prototype effectively represents a miniature industrial control process, suitable for both educational and research applications in process automation.

DCS Configuration

The hardware and network configuration were carried out on the computer used as the Operator Station (OS). The network setup on the OS was established to enable communication between the DCS-PCS7 controller and the Engineering Station (ES), allowing data to be downloaded from the ES to the DCS-PCS7 controller. In this case, both the OS and ES are implemented on the same computer, utilizing a shared connection to the controller. The hardware configuration was designed in accordance with the specifications presented in the Table 2.

Table 2. Hardware Configuration

No	Hardware	Serial Number
1	Power Supply Module PS 407 10A	6ES7 407-0KA02-0AA0
2	CPU 416-2 DP	6ES7 416-2XN05-0AB0
3	CP 443-1	6ES7 443-1 EX20-0XE0
4	2x Digital Input Module: DI 32 x DC 24V	6ES7 321-1BL00-0AA0
5	4x Digital Output Module: DO 16 x REL. AC 120V/230V	6ES7 322-1 HH01 -0AA0
6	2x Analog Input Module: AI 8 x 16 BIT	6ES7 331-7NF00-0AB0
7	2x Analog Output Module: AO 8 x 12 BIT	6ES7 332-5HF00-0AB0
8	PN IO	00-1B-1B-12-A6-F1
9	IE General	18-03-73-D2-65-CI
10	Bus Address IM 153-2	153-2BA02-0XB0

Figure 4 shows the interface during the configuration of the Automation System (AS), while Figure 5 presents the configuration view for Hardware, Digital Input (DI), Digital Output (DO), Analog Input (AI), and Analog Output (AO) modules. To establish proper communication between all components, the AS, OS, and ES were configured using the PROFINET communication protocol with compatible IP addresses, as shown in Figure 6.

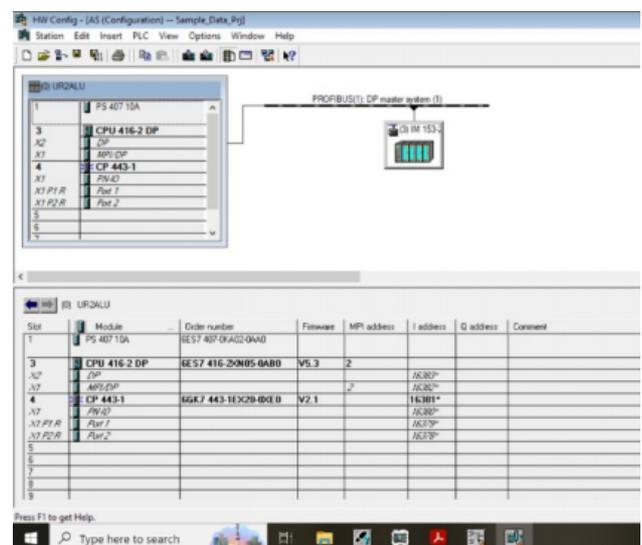


Figure 4. AS Configuration

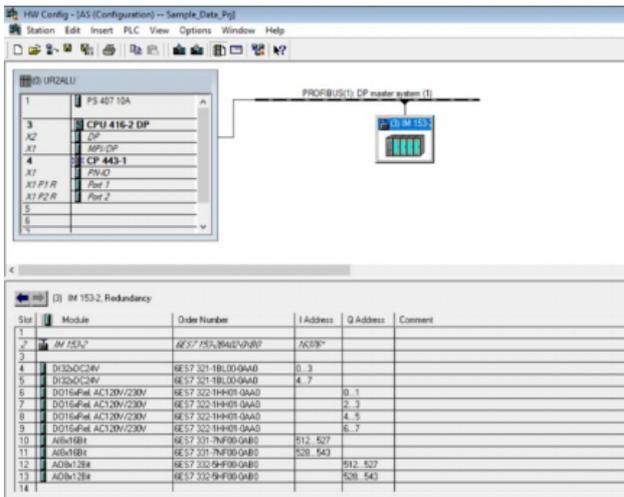


Figure 5. Hardware, DI, DO, AI, AO Configuration

The configuration process ensures that each hardware module communicates seamlessly with the central controller. Digital modules were assigned for discrete on/off control of actuators such as solenoid valves and pumps, while analog modules handled continuous signal processing from sensors, including flow and level measurements [17]. This modular arrangement enhances system flexibility, allowing for precise monitoring and control of process parameters in real-time.

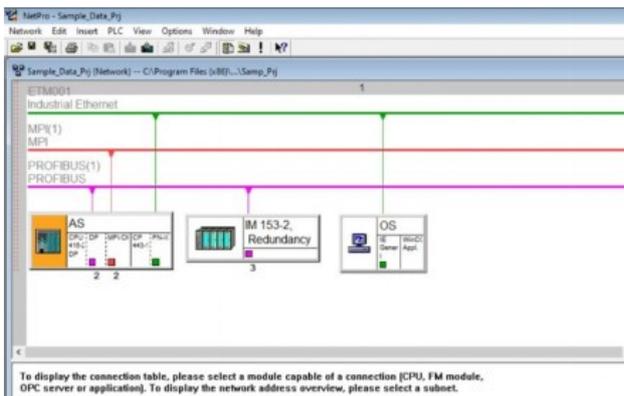


Figure 6. Network Configuration in Net-Pro

Additionally, the integration through PROFINET enables high-speed and deterministic data exchange between the DCS controller (PCS 7 S7-400) and the operator interface shown in Table 3. This network configuration supports real-time diagnostics, automatic synchronization, and data consistency across all control layers. As a result, the system achieves efficient coordination between hardware and software components, ensuring robust communication performance essential for industrial-scale automation and laboratory-based training applications.

Table 3. Network Configuration for Hardware

No	Component	Address
1	Automation Station (AS)	Profibus (Address 2)
2	Operator Station (OS)	Profinet (IP Address 192.168.0.1)
3	Engineering Station (ES)	Profinet (IP Address 192.168.0.2)

SIMATIC PCS 7 Program Design

Figure 7 illustrates the overall process and instrumentation diagram (P&ID) of the small-scale liquid processing unit, designed to implement the feedforward-feedback control method. The system comprises three eductor tanks, two product tanks, and a series of pumps, solenoid valves, and sensors that form an interconnected fluid transfer network. Each educt tank is equipped with a flow transmitter (FT) to measure the liquid flow rate, while level transmitters (LT) and limit switches (MS) on the product tanks monitor and control the filling levels. The integration of these sensors and actuators enables precise regulation of the liquid mixing and filling processes under distributed control.

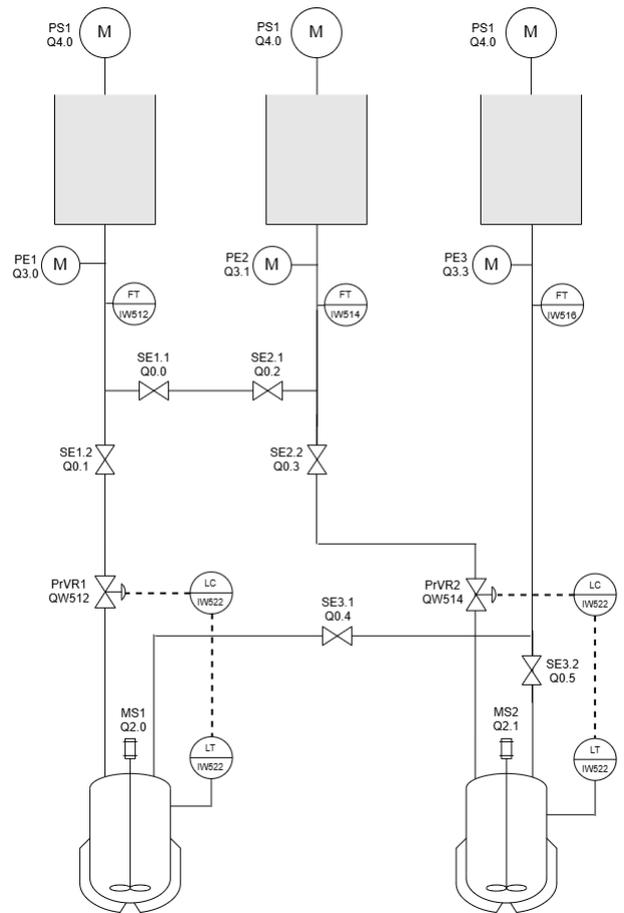


Figure 7. P&ID System Design

The control sequence begins with the activation of pumps (PE1, PE2, PE3), which transfer liquid from the educt tanks through solenoid valves (SE) toward the product tanks. The system utilizes feedback from flow and level sensors to dynamically adjust valve openings, ensuring that the process variables align with the desired setpoints. The control logic is managed by the Distributed Control System (DCS) PCS 7, which coordinates the interaction between field devices and the automation modules.

Although Continuous Function Chart (CFC) and Sequential Function Chart (SFC) configurations are not explicitly shown in this figure due to their complexity, they form the core of the control implementation. The CFC structure is used to design continuous control loops such as flow and level regulation, while the SFC logic manages sequential operations like valve switching

and tank filling order. These combined configurations ensure that the process operates automatically, safely, and efficiently, providing a realistic industrial simulation environment for process control studies.

RESULTS AND DISCUSSION

PID testing was conducted to observe the control performance in maintaining the stability of the liquid level in the Reactor Tank. The implementation of the PID controller was carried out within the Continuous Function Chart (CFC) block and integrated into the Sequential Function Chart (SFC) to execute the process logic systematically and in a distributed manner.

In Figures 8 and 9, the input and output of the CFC PID block are illustrated, where the input consists of the error signal generated from the difference between the setpoint and the actual liquid level measured by the HC-SR04 ultrasonic sensor. This error value is then processed by the PID controller to produce an output signal that serves as the control command for the actuator, specifically the servo motor that regulates the control valve.

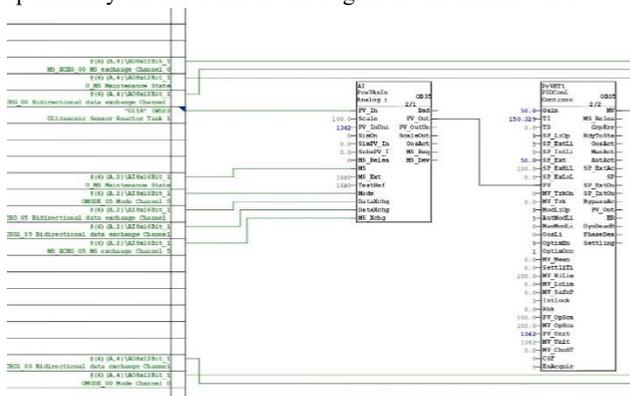


Figure 8. CFC Input in PID Block

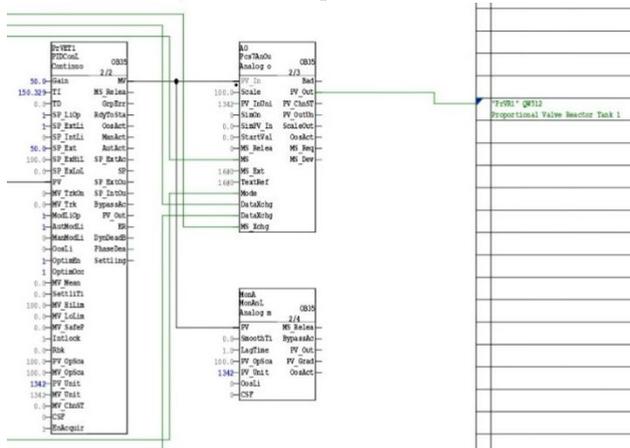


Figure 9. CFC Output in PID Block

In its implementation, the PID output proportionally adjusts the valve opening based on the magnitude of the error. When the liquid level is far from the setpoint, the control valve opens wider to accelerate the filling process. Conversely, as the level approaches the setpoint, the valve opening is gradually reduced to prevent overshoot, thereby ensuring smooth and stable level control within the reactor tank.

The integration of the CFC PID block within the SFC ensures that the control logic operates consistently according to each stage of the process. Once the system reaches the initial filling condition (level < 50%), the PID controller gradually adjusts the output response until the setpoint is achieved. Each transition between steps in the SFC is triggered based on specific logical conditions, such as time or liquid level thresholds. This combination enables precise, structured, and optimizable control performance.

Figure 10 illustrates the visual representation of the PID block in the CFC, along with the control logic structure in the SFC. It also shows the WinCC interface in RUN mode, where the system is actively executing the SFC logic for the reactor filling process. The steps labeled “START,” “Start Filling,” and “Stop Filling” have been successfully completed, as indicated by green check marks. This demonstrates that the system is capable of automatically and stably executing the control sequence in accordance with the designed feedforward-feedback control strategy.

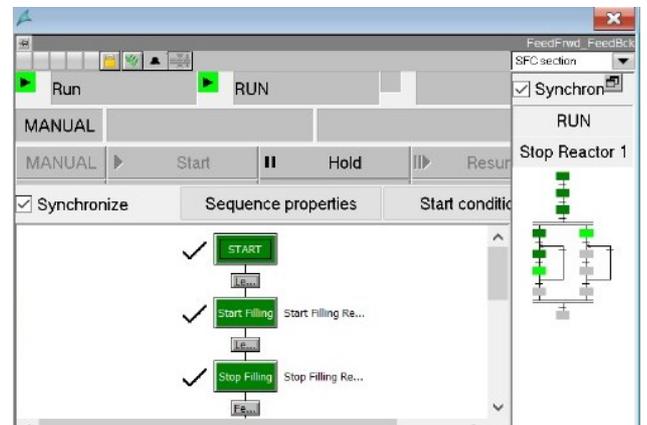


Figure 10. SFC testing interconnected with CFC

Figure 11 illustrates the continuation of the SFC logic when the system detects a disturbance, such as the liquid level in Reactor Tank 1 or Reactor Tank 2 dropping below the setpoint. In this condition, the SFC automatically reactivates the Feedforward and Fill Reactor steps for the respective tank that experiences the deficit. Once the filling process is completed, the system proceeds to the Heating 50°C stage, which represents the initial heating phase of Reactor 1 until the temperature reaches 50°C. This process is executed automatically through the CFC temperature control block, which regulates the operation of both the heater and agitator. When the minimum temperature is achieved, the SFC marks this step with a check symbol (✓), indicating that the process has been successfully completed.

This demonstrates that the Feedforward-Feedback control system operates continuously and adaptively. When a deviation from the ideal condition occurs, the system responds autonomously by repeating the filling step without any manual intervention. The seamless integration between feedforward prediction and feedback correction ensures that both reactor tanks remain within their optimal volume limits throughout the operation, even when disturbances occur, such as the concurrent flow being directed to the product tank.



Figure 11. Control Testing CFC in PID block and SFC

Furthermore, the system maintains process synchronization between the two reactors, enhancing overall efficiency and process continuity within the small-scale processing unit. This autonomous coordination between filling, heating, and mixing stages exemplifies the robustness and responsiveness of the integrated DCS-based feedforward-feedback control architecture.

Time Response Analysis

Subsequently, the test results are presented in graphical form through WinCC, illustrating the system's dynamic response to setpoint changes for both Feedback Control and Feedforward-Feedback Control schemes under disturbances in the outlet flow directed toward the Product Tank. The graph displays a comparison between the Setpoint (SP), Process Variable (PV), and Manipulated Variable (MV) over real-time operation.

During the filling process, the graph shows the variation of tank level over time when the system experiences disturbances caused by fluctuations in the outlet flow rate. With the implementation of the feedforward scheme, the system effectively compensates for these disturbances, maintaining the liquid level close to the setpoint without significant overshoot. The response indicates that the control loop quickly adjusts the valve opening and pump speed to sustain the desired filling rate even when the outflow changes dynamically.

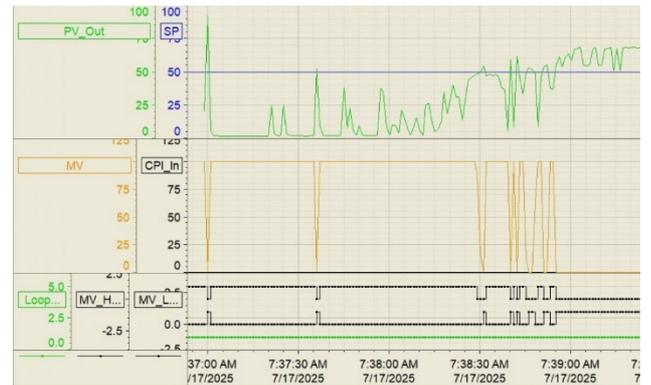


Figure 12. WinCC Time Response for Feedback Filling Process

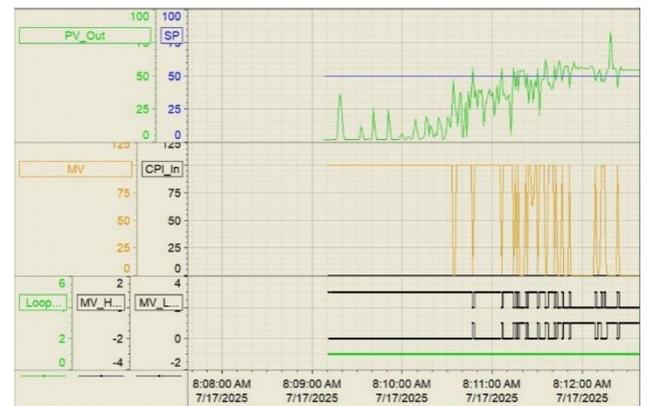


Figure 13. Feedforward-Feedback Control for Filling Process

In the temperature control process, the WinCC graph demonstrates the heating response of the liquid in the Reactor Tank when the setpoint is adjusted to 50°C. Under the Feedforward-Feedback Control configuration, the system successfully reaches the target temperature with a steady-state error of less than 1% and a faster settling time compared to the pure feedback control scheme. The MV (Heater Output) signal exhibits a proportional adjustment pattern corresponding to the heating energy demand, while the PV (Temperature) follows the SP smoothly and stably without excessive oscillation.

This performance confirms that the combination of Feedforward-Feedback control not only accelerates the system's response to changes and disturbances during the filling process but also ensures high temperature stability during the heating phase in the Reactor Tank. Therefore, the developed DCS-based system successfully achieves efficient and adaptive multi-variable (MIMO) control, aligning with the principles of modern control systems applied in small- to medium-scale chemical process industries. Table 4 shows the performance comparison of feedback control, feedforward-feedback control, and temperature control.

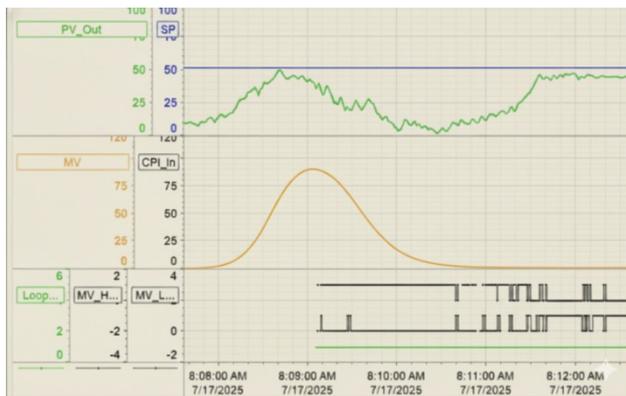


Figure 14. Temperature Control

Table 4. Level and Temperature's Performance Comparison

Control Scheme	Time Settling (ts)	Error Steady State (e_{ss})	Control $u(t)$	Response
Feedback Control	78s	$\pm 3.8\%$	Highly fluctuating and unstable response with significant overshoot; slow in correcting errors (reactive correction).	
Feedforward-Feedback Control	50s	$\pm 1.2\%$	Smoother, more stable, and faster response; almost no overshoot with rapid error correction (anticipatory and corrective behavior)	
Temperature Control	60s	$\pm 0.8\%$	Fast and stable response; negligible overshoot, smooth convergence to the setpoint, and adaptive performance under varying load conditions.	

Discussion

Integration of Flow and Level Sensors

The integration of the YF-S401 flow sensor and the HC-SR04 ultrasonic level sensor demonstrated accurate, stable, and linear measurement characteristics across the operational range. The voltage output of both sensors showed a consistent proportional relationship with flow rate and liquid level, ensuring reliable data acquisition for the DCS-based control structure. These findings align with previous studies emphasizing that high-fidelity sensing is essential for achieving precise control performance and minimizing measurement-induced disturbances in automated industrial processes [5], [6]. The real-time data visualization on the HMI further confirms that communication via PROFINET operates with low latency, enabling seamless interaction between sensors, actuators, and controllers.

Performance of Feedforward–Feedback Control in the Liquid Filling Process

The feedforward–feedback control scheme substantially improved the dynamic behavior of the filling process compared with conventional feedback-only control. The reduction of the settling time from 78 seconds to 50 seconds and the decrease in steady-state error from $\pm 3.8\%$ to $\pm 1.2\%$ demonstrate the ability of the feedforward path to proactively compensate for measurable disturbances before affecting the system output. This result is consistent with literature reporting that hybrid control architectures enhance transient response and robustness against flow-rate variations in fluid-handling systems [5], [6].

The controller tuning performed in the PCS7 CFC environment yielded parameters ($K_p = 50.0$, $K_i = 150.329$, $K_d = 0$) that matched the system's dynamic characteristics, resulting in smooth convergence to the setpoint with negligible overshoot. Similar observations were reported by Amelia [7], who highlighted that combining predictive feedforward actions with structured PID tuning significantly improves stability in liquid-level control. Therefore, the implemented strategy not only accelerates system response but also supports more efficient and disturbance-tolerant process operation.

Feedforward–Feedback Temperature Control Analysis

In the temperature control experiment, the feedforward–feedback PID structure successfully maintained the reactor temperature at the 50°C setpoint, achieving a steady-state error of only 0.8% with no overshoot. The smooth and monotonic temperature response indicates that the feedforward component effectively anticipates thermal disturbances, such as heat loss while the PID feedback loop compensates for residual tracking errors.

These results reinforce findings in the literature that hybrid thermal control strategies enhance both stability and precision, particularly in small-scale chemical processing systems requiring fast regulation and tight temperature tolerances [7]. The system's ability to sustain the setpoint despite fluctuations in heating load confirms that the integrated DCS-PID architecture is well-suited for real-time thermal management applications.

Implications for DCS-Based Industrial Automation

The study demonstrates that the Siemens SIMATIC PCS7 platform, when combined with CFC and SFC programming, provides a robust and flexible environment for implementing multi-variable, sequential, and continuous control. The seamless communication across DI/DO/AI/AO modules through PROFINET supports deterministic and high-speed data exchange, which is essential for coordinating sensors, actuators, and visual interfaces in industrial automation.

These outcomes align with recent work highlighting that modern DCS architectures enhance process reliability, scalability, and operator monitoring capabilities in complex industrial systems [18], [19], [20]. The successful integration of feedforward–feedback control into a DCS environment confirms the feasibility of applying this method to larger-scale liquid processing industries, where precision, real-time adaptation, and disturbance rejection are critical.

Comparative Interpretation and Research Contribution

This research offers a more comprehensive experimental demonstration of hybrid feedforward–feedback control within an industrial-grade DCS compared to existing studies that employ conventional PID control in liquid-processing systems. Its main contributions include a fully implemented feedforward–feedback control architecture on a real DCS platform, as opposed to simulation-only studies; a quantitative evaluation of dynamic performance—such as settling time and steady-state error—under real disturbances; and a tightly integrated sensor–actuator–controller–HMI system, demonstrating practical readiness for industrial deployment. Collectively, these advancements expand current knowledge on hybrid control strategies in DCS applications and provide empirical validation for implementing such methods in small to medium-scale automation systems.

CONCLUSIONS

The integration of the feedforward–feedback control method within the DCS-based process system effectively improves both level and temperature control performance. The system achieves faster response, reduced steady-state error, and superior stability compared to conventional feedback control, confirming its reliability and adaptability for small-scale industrial automation applications.

ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support provided by the DIPA Politeknik Negeri Malang under the Department of Electrical Engineering Research Grant Scheme. The authors also extend sincere appreciation to the Industrial Automation Laboratory for providing the necessary equipment, technical assistance, and research facilities throughout the study. Special thanks are given to the students and academic staff who contributed to the implementation and testing of the control system prototype. This research was successfully completed with the continuous support and collaboration of Politeknik Negeri Malang.

REFERENCES

- [1] D. Derlukiewicz, “Application of a design and construction method based on a study of user needs in the prevention of accidents involving operators of demolition robots,” *Appl. Sci.*, vol. 9, no. 7, p. 1500, 2019, doi: 10.3390/app9071500.
- [2] N. Mardiyah, A. Sudrajat, and A. Faruq, “PLC human machine-interfaces based system for Vietnam drip coffee maker application,” *Kinet. Game Technol. Inf. Syst. Comput. Netw. Comput. Electron. Control*, pp. 35–44, 2017, doi: 10.22219/kinetik.v3i1.272.
- [3] C. Leung, “Effects of control transition strategies and human-machine interface designs on driver performance in automated driving systems,” *Int. J. Automot. Eng.*, vol. 15, no. 1, pp. 36–46, 2024, doi: 10.20485/jsaeijae.15.1_36.
- [4] P. Tyubaeva, “Life cycle of functional all-green biocompatible fibrous materials based on biodegradable polyhydroxybutyrate and hemin: synthesis, service life, and the end-of-life via biodegradation,” *ACS Appl. Bio Mater.*, vol. 7, no. 4, pp. 2325–2337, 2024, doi: 10.1021/acsabm.4c00010.

- [5] E. Prihantoro, M. F. Iqbal, and N. Fitriyana, “Implementation of feedforward control to improve liquid level stability in process automation,” *J. Control Autom. Syst.*, vol. 8, no. 2, pp. 101–109, 2020.
- [6] D. Prafista, A. Setiawan, and R. Budiyo, “Performance comparison of feedforward and feedback control in dynamic fluid level systems,” *Indones. J. Instrum. Control Eng.*, vol. 6, no. 1, pp. 45–53, 2024.
- [7] R. Amelia, “Design of feedforward temperature control system using PT100 sensor and heater actuator,” *J. Appl. Mechatronics Eng.*, vol. 3, no. 2, pp. 87–94, 2021.
- [8] Salisa 'Asyarina Ramadhani, Muhammad Ilhamdi Rusydi, Andriwo Rusydi, Minoru Sasaki, and Luxfy Roya Azmi, “Electroencephalography on Controlling Assistive Device: A Systematic Literature Review,” *Andalas J. Electr. Electron. Eng. Technol.*, vol. 4, no. 2, pp. 58–72, Nov. 2024, doi: 10.25077/ajeet.v4i2.42.
- [9] R. Lew, R. Boring, and T. Ulrich, “A prototyping environment for research on human-machine interfaces in process control use of Microsoft WPF for microworld and distributed control system development,” *Proc. ISCRS*, pp. 1–6, 2014, doi: 10.1109/isrcs.2014.6900111.
- [10] K. Garbera, K. Ciura, and W. Sawicki, “A novel approach to optimize hot melt impregnation in terms of amorphization efficiency,” *Int. J. Mol. Sci.*, vol. 21, no. 11, p. 4032, 2020, doi: 10.3390/ijms21114032.
- [11] Y. He, “OHMI: the ontology of host-microbiome interactions,” *J. Biomed. Semantics*, vol. 10, no. 1, 2019, doi: 10.1186/s13326-019-0217-1.
- [12] T. Louw, “Don't worry, I'm in control! Is users' trust in automated driving different when using a continuous ambient light HMI compared to an auditory HMI?,” *Proc. ACM Int. Conf.*, 2021, doi: 10.1145/3473682.3481875.
- [13] J. Liu, “Prediction of human–machine interface (HMI) operational errors for maritime autonomous surface ships (MASS),” *J. Mar. Sci. Technol.*, vol. 27, no. 1, pp. 293–306, 2021, doi: 10.1007/s00773-021-00834-w.
- [14] M. A. H. Prastyana and B. Purwahyudi, “Prototype of Automatic Transfer Switch (ATS) for Solar Power Plant Based on Arduino Uno,” *JEECS (Journal Electr. Eng. Comput. Sci.)*, vol. 8, no. 1, pp. 1–8, Jun. 2023, doi: 10.54732/jeeecs.v8i1.1.
- [15] Abdul Manab, M. Bahrul Muttaqin, Andre Rabiula, S. 'Asyarina Ramadhani, Yosi Riduas Hais, and Desrinal Tessel, “ADDIE-Based Development of a Solar-Powered Sprayer for Efficient Weed Control in Remote Oil Palm Plantations,” *J. Nas. Tek. Elektro*, pp. 91–99, Jul. 2025, doi: 10.25077/jnte.v14n2.1221.2025.
- [16] H. D. Laksono, Avif Tiftazani, Mumuh Muharam, Rizki Wahyu Pratama, Riko Nofendra, and S. 'Asyarina Ramadhani, “Performance Evaluation of Load Frequency Control in Reheat Power Systems with Filtered PID Controllers,” *Andalas J. Electr. Electron. Eng. Technol.*, vol. 5, no. 1, pp. 23–30, May 2025, doi: 10.25077/ajeet.v5i1.95.
- [17] Andicho Haryus Wirasapta, Salisa 'Asyarina Ramadhani, S. S. Mishi, and Z. H. Malik, “Design and Simulation of a QPSK Demodulator Using Discrete Components,” *J. Nas. Tek. Elektro*, pp. 126–134, Nov. 2025, doi: 10.25077/jnte.v14n3.1386.2025.
- [18] R. Geniet and N. Singh, “Refinement-based formal development of human-machine interface,” *Proc. Form. Methods Softw. Eng.*, pp. 240–256, 2018, doi: 10.1007/978-3-030-04771-9_19.
- [19] F. Wang, X. Li, and J. Pan, “A human-machine interface based on an EOG and a gyroscope for humanoid robot control and its application to home services,” *J. Health. Eng.*, pp. 1–14, 2022, doi: 10.1155/2022/1650387.

- [20] D. Ammar, H. Guo, A. Misra, B. Jia, and S. Bao, "Identifying user needs and current challenges of external interface design for AV-VRU communications: insights from an expert survey data analysis," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2678, no. 4, pp. 228–242, 2023, doi: 10.1177/03611981231184239.

industrial control, process automation, and educational laboratory development.

AUTHOR(S) BIOGRAPHY



Anindya Dwi Risdhayanti

Anindya Dwi Risdhayanti is a lecturer and researcher at the Department of Electrical Engineering, Politeknik Negeri Malang. She earned her Master's degree in Control System Engineering from Institut Teknologi Sepuluh Nopember (ITS), Surabaya. Her research interests include distributed control systems (DCS), automation, embedded systems, and intelligent control applications. She has authored several journal articles, books, and intellectual property works related to industrial automation and control.



Dinda Ayu Permatasari

Dinda Ayu Permatasari a master's degree in Electrical Engineering from the Institut Teknologi Bandung in 2019 and received a bachelor's degree in Electrical Engineering from State Polytechnic of Malang in 2016. She is a lecturer at the Department of Electronics Engineering, Politeknik Negeri Malang, Indonesia. Her research focuses on control systems, embedded electronics, and artificial intelligence applications in automation. She has published several papers in national and international journals and actively contributes to community service projects involving technology-based solutions for education and industry.



Muhamad Rifa'i

Muhamad Rifa'i earned his S.T. and M.T. degrees in Electrical Engineering from Universitas Brawijaya, Indonesia, in 2001 and 2009, respectively. He later completed his Doctoral degree in Electrical and Informatics Engineering at Universitas Negeri Malang, Indonesia. From 2001 to 2005, he worked as an Electrical Engineer in various industrial sectors. Since 2005, he has been affiliated with the vocational institution Politeknik Negeri Malang. His research interests include renewable energy, power electronics, automation, and algorithms.



Irfin Sandra Asti

Irfin Sandra Asti is a lecturer and researcher at the Department of Electrical Engineering, Politeknik Negeri Malang, Indonesia. She has been actively involved in teaching and applied research in the fields of industrial automation, control systems, and electrical engineering. Her academic and professional work focuses on the development and implementation of automation technologies, instrumentation systems, and applied engineering solutions for vocational education and industry. She has contributed to various research and community service projects, particularly those related to