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TEMPERATURE CONTROLLER SYSTEM BASED ON PLCs

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Abstract: Temperature control is a critical parameter across a vast spectrum of industrial applications, including chemical reactors, food processing, metallurgical furnaces, and HVAC systems, where maintaining thermal stability directly influences product quality, safety, and operational efficiency. Traditional temperature control methodologies, often reliant on manual oversight or rigid analog instrumentation, frequently suffer from significant thermal lag, steady-state errors, and poor adaptability to dynamic load changes. This paper presents the design, development, and implementation of an automated, closed-loop industrial temperature control system utilizing a Programmable Logic Controller (PLC).

The core architecture of the proposed system leverages a three-tiered automation framework. At the input stage, a high-precision industrial sensor—specifically a PT100 Resistance Temperature Detector (RTD)—continuously monitors the environmental temperature,

Converting thermal variations into standardized Analog signals. These signals are processed by the PLC's Analog input module. The PLC serves as the central processing unit, executing a robust Proportional-Integral-Derivative (PID) control algorithm programmed via Ladder Diagram (LD) logic. Based on the real-time error computation between the process variable and the user-defined setpoint, the PLC modulates its output signals to drive a Solid*-tate Relay (SSR), which precisely regulates the power delivered to the heating elements and auxiliary cooling fans.

To enhance operational visibility and human-centric control, a Human-Machine Interface (HMI) is integrated into the architecture. The HMI provides real-time data visualization, graphical trend logging, alarm management for thermal overshoots, and an intuitive platform for dynamic setpoint adjustments. Experimental results demonstrate that the PLC-based PID configuration significantly minimizes temperature overshoot, dampens thermal oscillations, and reduces settling time compared to conventional ON/OFF control strategies. Ultimately, the developed system offers a highly modular, scalable, and noise-immune solution capable of achieving precise, continuous thermal regulation in demanding manufacturing environments.

1. INTRODUCTION

The Delta DVP-10SX is an advanced, slimline Programmable Logic Controller (PLC) designed for high-performance industrial automation tasks. It features a compact hardware footprint while offering robust processing capabilities essential for critical manufacturing processes. The DVP-10SX uniquely integrates built-in analog inputs and outputs, eliminating the need for expensive external analog expansion modules. At its core, this PLC acts as the central brain, continuously executing pre-written automation programs. The primary function of this system is to maintain a specified, highly stable temperature within a given industrial environment. It achieves this by reading real-time environmental data and regulating output devices based on programmed operational logic.

The process begins with temperature sensors, such as thermocouples or Pt100s, which continuously measure the heat of the system. These sensors convert physical temperature changes into proportional electrical signals, such as (4 mA) to (20 mA) or voltage. These electrical signals are then routed directly into the built-in analog-to-digital converter (ADC) of the Delta PLC. The DVP-10SX samples these signals with high precision, converting them into readable digital process values. These digital values are continuously compared to the target setpoint temperature defined by the system operator.

Based on any deviation, the PLC executes a Proportional-Integral-Derivative (PID) control algorithm. The built-in PID auto-tuning feature ensures that the system dynamically adapts to changing thermal loads without human intervention. The PLC calculates the exact corrective action needed to bridge the gap between current temperature and the target temperature. This calculated corrective value is then sent through the PLC's built-in digital-to analog converter (DAC). The resulting analog output signal is used to control heating elements (like electric heaters) or cooling mechanisms (like fans or chillers).

For instance, if the temperature drops below the required threshold, the PLC increases the output to drive higher voltage to the heaters, Conversely, if the system overheats, the controller can reduce heating power or activate cooling fans to protect the equipment. This creates a closed-loop feedback system that practically eliminates temperature fluctuations and minimizes human operational error. The system operates autonomously, ensuring strict adherence to thermal standards required in sensitive industries.

2. LITERATURE REVIEW

PLC-based temperature controllers use sensors (like RTDs or thermocouples) to monitor temperature. The PLC processes this data against preset limits or uses a PID algorithm to modulate heating and cooling elements, ensuring precise, automated industrial control. Early Research & Basic Systems: Foundational papers focused on integrating simple LM35 sensors with PLCs (e.g., Siemens S7 series) for basic on/off control.

PID Algorithm Integration: Researchers demonstrated that utilizing Proportional-Integral-Derivative (PID) algorithms in PLC ladder logic minimizes temperature overshoot and steady-state error. Multi-Channel Control: Literature highlights the PLC's capability to process multiple temperature channels simultaneously, ideal for complex, multi-zone industrial ovens.

Data Acquisition: Studies outline how PLCs easily interface with SCADA systems to log temperature data for strict quality control. Advanced Controls: Advanced research highlights incorporating fuzzy logic controllers into PLCs to handle highly non-linear thermal dynamics in environments like cement factories. Simulation & HMI: Studies frequently emphasize pairing PLCs with graphical environments like NI LabVIEW or HMI screens for real-time temperature visualization.

Stability Outcomes: Experimental results from various papers show that PLC-driven PID controllers can maintain temperature stability of up to \(\pm 0.1 \text{ }^\circ\text{C}\) in steady states.

Reliability Focus: Scholars agree that PLCs offer a robust, noise-immune, and highly stable framework over traditional, discrete electronic controllers. Several studies have demonstrated the application of Programmable Logic Controllers in industrial automation and educational training systems. PLC-based control systems are commonly used for process monitoring, machine automation, and supervisory control because of their robustness and real-time performance.

Researchers have developed laboratory-scale process control setups for studying temperature regulation, liquid level control, and flow measurement. These systems provide practical understanding of industrial control strategies while reducing the cost associated with full-scale industrial plants. Human Machine Interface (HMI) technology has also been widely adopted to improve process visualization and operator interaction.

Recent developments in automation training platforms focus on integrating multiple process variables into a single system to provide comprehensive learning opportunities.

Inspired by these developments, the present work combines temperature control, level regulation, and flow monitoring within a single PLC-based experimental setup using Allen-Bradley Micro820 technology.

3. OBJECTIVES

When reviewing existing research and industrial applications, the primary objectives for a PLC-based temperature system generally include:

Precision & Stability: To minimize the error between the measured process value and the setpoint, maintaining steady-state temperature stability (often achieving 0.1 to 1.0) depending on the application.

Process Optimization: To reduce system overshoot and settling time through advanced, automated tuning methods rather than manual control.

eligibility & Noise Immunity: To provide a deterministic, industrial-grade computing environment capable of real-time control that is highly resistant to electromagnetic interference.

utility-Zone Regulation: To scale operations so that multiple heating or cooling zones can be monitored and balanced simultaneously.
Automation & Remote Connectivity: To enable remote monitoring, cloud data logging, and automated alarm systems (e.g., via IoT or SCADA) to reduce human intervention and prevent equipment failure.

Critical Literature Topics to Cover
A thorough review of ScienceDirect and IEEE Xplore should focus on evaluating these major technical elements:
control Algorithms: Studies comparing standard On/Off controls with Proportional-Integral-Derivative (PID) control, as well as modern fuzzy-logic algorithms implemented within Ladder Logic or Structured Text.
Sensor & Actuator Integration: The use of resistance temperature detectors

The objectives of the proposed system are:

1. To design and develop a PLC-based process control trainer.
2. To implement temperature monitoring and control.
3. To implement automatic level control.
4. To measure and display temperature.
5. To provide automatic operating modes.
6. To develop HMI-based process monitoring and operation.
7. To provide a low-cost educational platform for automation training.

4. SYSTEM ARCHITECTURE

The developed system consists of sensing elements, control hardware, actuators, and operator interface devices.
Major Hardware Components

Sr. No.	Component	Function
1	Delta DVP10SX11T	Main Controller
2	HMI	Process Monitoring and Control
3	Temperature Sensor	Temperature Measurement
4	Ceramic Chember	Heating Element
5	Solid State Relay (SSR)	Heater Switching
6	24 V DC SMPS	Power Supply

5. SYSTEM WORKING PRINCIPLE

The Mini Process Control Plant consists of three major process loops:

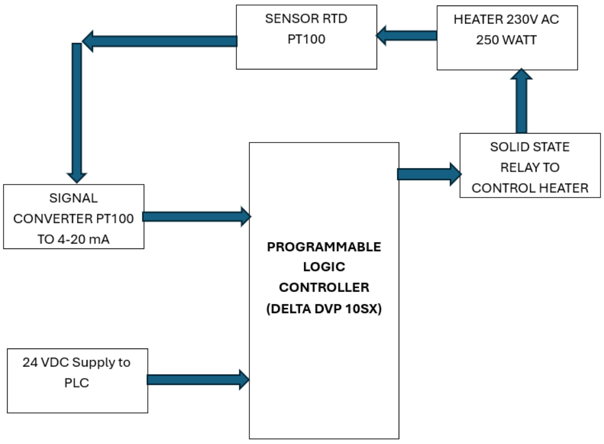


Fig 1: Block Diagram of PLCs based controller

Block-by-Block Workflow

Step 1: Power Supply**:** A 24 VDC power supply continuously energizes the Programmable Logic Controller (PLC).
Step 2: Temperature Sensing: The PT100 RTD sensor measures the live temperature near the 250W heater.
Step 3: Signal Conditioning: The raw resistance change from the PT100 is sent to a signal converter. This transmitter converts the resistance into a standard industrial 4–20 mA current signal.
Step 4: PLC Processing: The 4–20 mA current enters the built-in Analog input channels of the Delta DVP 10SX PLC. The PLC's internal program (typically a PID loop) compares this temperature reading against a user-defined target value (Setpoint).
Step 5: Actuator Triggering: Based on the error between the real temperature and the target, the PLC sends a digital control signal (often using Pulse Width Modulation or PWM) to a Solid State Relay (SSR).
Step 6: Power Regulation: The SSR acts as an electronic switch. It opens and closes to modulate the 230V AC mains power supplied to the 250W heater, maintaining the target temperature.

Key Industrial Concepts Present

Closed-Loop Feedback: Continuous monitoring ensures the system actively corrects any temperature drops or overshoots. Analog-to-Digital Conversion: The PLC digitizes the Analog 4–20 mA signal to evaluate it mathematically. Contactless Switching: The SSR handles rapid switching without mechanical wear, guaranteeing long-term system reliability. A literature survey for a Programmable Logi Controller (PLC)-based temperature control system provides the foundational parameters, control architectures, and benchmarks required to design robust, energy-efficient thermal management processes.

Key System Objectives

When reviewing existing research and industrial applications, the primary objectives for a PLC-based temperature system generally include:

- **Precision & Stability:** To minimize the error between the measured process value and the setpoint, maintaining steady-state temperature stability (often achieving 0.1 to 1.0 depending on the application.
- **Process Optimization:** To reduce system overshoot and settling time through advanced, automated tuning methods rather than manual control.
- **Reliability & Noise Immunity:** To provide a deterministic, industrial-grade computing environment capable of real-time control that is highly resistant to electromagnetic interference.
- **Multi-Zone Regulation:** To scale operations so that multiple heating or cooling zones can be monitored and balanced simultaneously.
- **Automation & Remote Connectivity:** To enable remote monitoring, cloud data logging, and automated alarm systems (e.g., via IoT or SCADA) to reduce human intervention and prevent equipment failure.

Critical Literature Topics to Cover

A thorough review of ScienceDirect and IEEE Xplore should focus on evaluating these major technical elements:

- **Control Algorithms:** Studies comparing standard On/Off controls with Proportional-Integral-Derivative (PID) control, as well as modern fuzzy-logic algorithms implemented within Ladder Logic or Structured Text.
- **Sensor & Actuator Integration:** The use of resistance temperature detectors (RTDs) like PT100 and thermocouples for feedback, alongside solid-state relays (SSRs) for safe, precise modulation of heating/cooling elements.
- **IIoT and Supervisory Control (SCADA):** Research addressing modern Industry 4.0 adaptations, detailing how MQTT, OPC-UA, and cloud platforms transform localized PLC systems into remotely observable networks.

To refine this literature survey, it is helpful to know exactly what you are trying to control.

- What is the **application or industrial sector** (e.g., HVAC, chemical reactor, boiler, manufacturing oven)?
- Are there specific **communication protocols** (e.g., Modbus, OPC-UA) or **hardware brands** (e.g., Siemens, Allen-Bradley, Omron) you are required to use?

Fig 2: PLCs PIN DIAGRAM

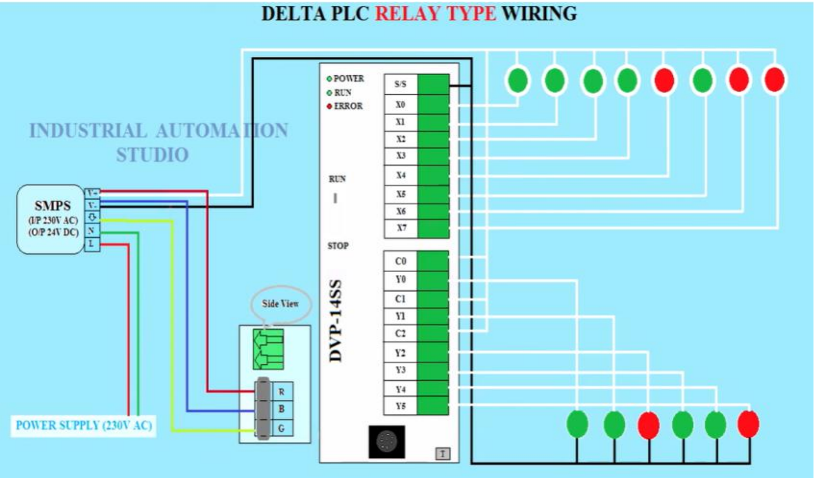


Fig 3: PLCs LADDERD DIAGRAM

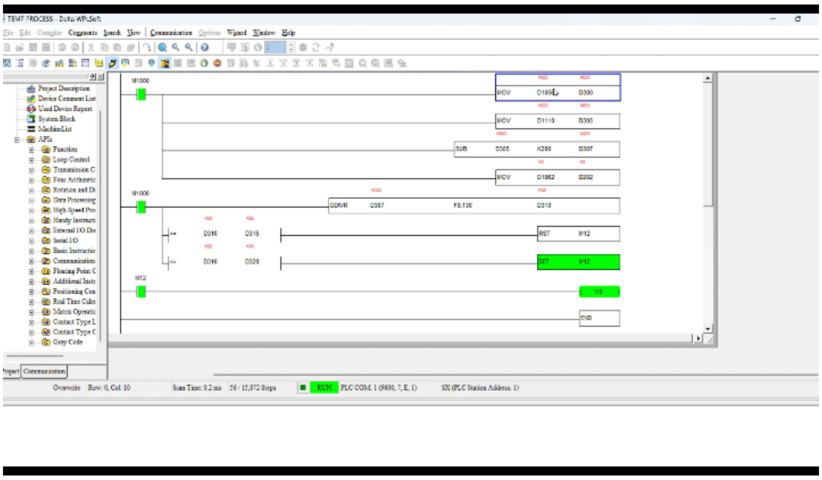


Fig 4: HMI DIAGRAM

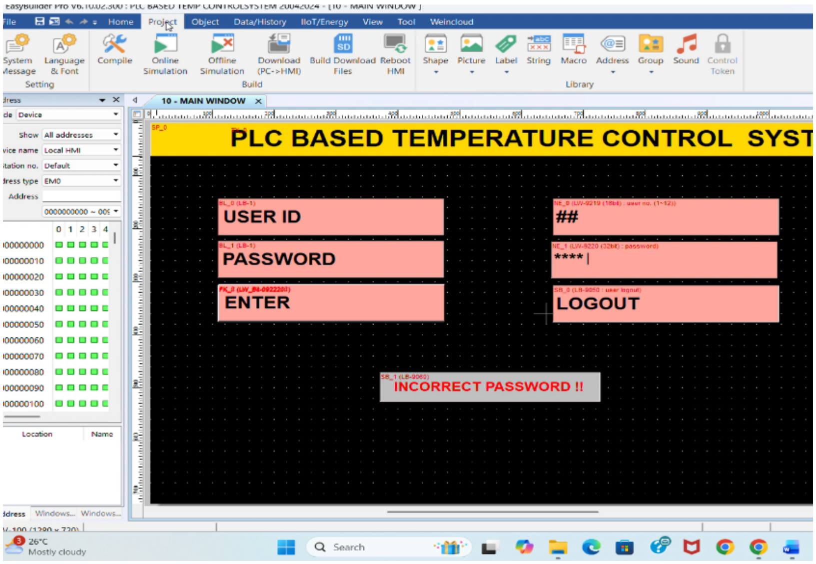
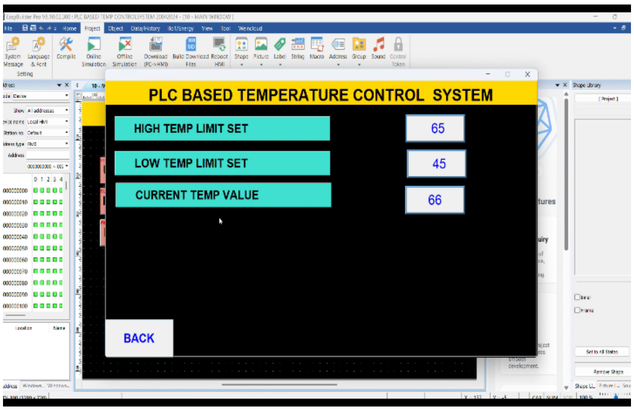


Fig 5: Output Window of HMI



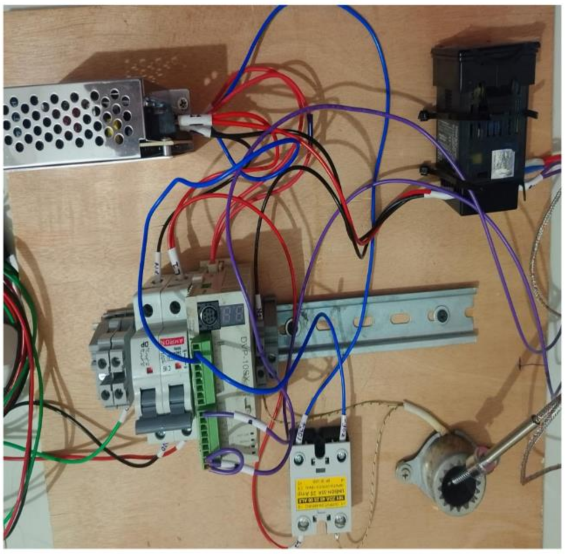
PLC BASED TEMPERATURE CONTROL SYSTEM

HIGH TEMP LIMIT SET 65

LOW TEMP LIMIT SET 45

CURRENT TEMP VALUE 66

Fig 6: Project image



6. ADVANTAGES OF THE PROPOSED SYSTEM

- Hardware Immunity: Built to operate continuously in harsh environments with high dust, moisture, and vibration.
- Electrical Isolation: Integrated optocouplers shield internal processors from high-voltage spikes caused by the 230V AC heater circuits.
- High Noise Immunity: Superior electromagnetic compatibility (EMC) ensures the 4–20 mA Analog signal remains stable near heavy machinery.

High-Precision Control & Tuning

- Built-in PID Frameworks: Dedicated mathematical blocks provide precise, real-time loop execution.
- Deterministic Scanning: Constant, predictable CPU scan times ensure instantaneous response to rapid temperature fluctuations.
- Advanced Scaling Tools: Direct linear instruction blocks (like SCLP) simplify Analog to-digital sensor conversion without complex coding.

Scalability & Flexibility

- Modular Architecture: Allows quick expansion to multi-zone heating/cooling systems by simply adding I/O cards.
- Software Modifiability: Control logic, setpoints, and alarms can be reprogrammed safely without altering

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physical wiring.
- Protocol Interoperability: Native support for Modbus RTU/ASCII facilitates immediate integration with HMIs, VFDs, and smart energy meters.

Fail-Safe Operations & Diagnostics
- Hardware Watchdogs: Internal timers automatically reset the processor or safe-state the system if a software crash occurs.
- Diagnostic Registers: Dedicated internal memory addresses instantly flag sensor wire-breakage (open-circuit) or short-circuit errors.
- Visual Troubleshooting: Integrated LED indicators on the PLC chassis allow field technicians to verify I/O loop integrity instantly.

7. APPLICATIONS

The developed system can be used in:
- Engineering Laboratories
- Industrial Training Institutes
- Automation Training Centers
- Research Laboratories
- PLC Programming Courses
- Instrumentation and Control Education

8. FUTURE SCOPE

1. Integration of Industrial IoT (IoT) and Cloud Logging
   - Objective: To migrate from localized monitoring to global, cloud-based data acquisition.
   - Implementation: Adding an IoT gateway or upgrading the Delta PLC network to support protocols like MQTT or OPC-UA. This allows live temperature trends to stream directly to cloud platforms (like AWS IoT, Azure, or Node-RED), facilitating remote monitoring from any web browser or mobile app.
2. Transition from PID to Intelligent/Fuzzy Logic Control
   - Objective: To improve the system's response time and handle non-linear process disturbances seamlessly.
   - Implementation: Standard PID loops struggle when thermal loads change drastically or unpredictably. Future iterations can implement Fuzzy Logic Controllers (FLC) or Artificial Neural Network (ANN) algorithms. These can be written via Structured Text within the PLC to dynamically adjust heating profiles without manual PID retuning.
3. Implementation of Predictive Maintenance
   - Objective: To transition from reactive maintenance to predicting hardware failures before they occur.
   - Implementation: By continuously monitoring how fast the 250W heater reaches a target setpoint, machine learning models can detect system degradation. For example, if the heating rate slows down over time under identical loads, the system can automatically flag a failing SSR or a degrading heating element.
4. Machine-Vision Thermal Mapping
   - Objective: To achieve comprehensive spatial temperature tracking instead of relying on a single-point feedback sensor.
   - Implementation: Incorporating a thermal imaging camera via an industrial communication interface. While the PT100 checks a specific point, machine-vision integration allows the PLC to read spatial heat maps, preventing localized hotspots across larger heating surfaces.
5. Advanced SCADA and Edge Computing Integration
   - Objective: To build high-fidelity human-machine interfaces (HMI) with edge-processing capabilities.
   - Implementation: Integrating the system with modern SCADA platforms (like Ignition or Delta’s DIA View) . This enables advanced scripting at the edge of the network, local database logging (SQL), automated PDF report generation, and SMS/Email alert dispatches to plant engineers during critical temperature anomalies.

research activities.

9. CONCLUSION

The system effectively controlled the heater using an SSR based on temperature setpoint conditions and maintained the tank level automatically using low-level and high-level float switches. The flow sensor successfully monitored and totalized the water flow using pulse counting logic. The implementation of Automatic and Manual operating modes provided operational flexibility and ease of maintenance.

The integration of HMI enabled real-time monitoring, visualization, and control of the process parameters such as temperature, level status, flow totalizer, pump status, heater status, and alarm indications. The project also improved process reliability, reduced human intervention, minimized operational errors, and enhanced overall system efficiency. The developed system demonstrated the practical application of PLC, sensors, industrial communication, HMI, and automation technologies used in modern industrial process control systems. The project can be further expanded with advanced features such as PID control, integration, cloud monitoring, and industrial HMI systems.

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