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PLC and SCADA Design of Dairy Industry

Mayur Patil[1]; Sayyad Ayaj Riyaj[2]; Sayyad Sameer Shahabuddin[3]; Wadgaonkar Hrushikesh Kanifnath[4]

[1]Assistant Professor, Savitribai Phule Pune University S. B. Patil College of Engineering

[2]Department of Electrical Engineering Savitribai Phule Pune University S. B. Patil College of Engineering

[3]Department of Electrical Engineering Savitribai Phule Pune University S. B. Patil College of Engineering

[4]Department of Electrical Engineering Savitribai Phule Pune University S. B. Patil College of Engineering

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Abstract: Dairy processing, including pasteurization, storage, and packaging, demands precise control to ensure product safety, quality, and efficiency. This report presents the design of an automated dairy processing system using PLC (Programmable Logic Controllers) and SCADA (Supervisory Control and Data Acquisition) technology. The proposed system integrates sensors (temperature, level, flow, and pH) and actuators (valves, pumps, motors) with PLCs to execute control logic, and a SCADA HMI for real-time monitoring, data logging, and operator interaction. Automation is essential in large- scale dairy plants to reduce manpower, prevent contamination, and optimize processes. The system aims to automate milk pasteurization, Clean-In-Place (CIP) cleaning cycles, and packaging lines, resulting in consistent product quality, improved throughput, and traceability. Technical specifications, software details, and implementation methodology are discussed, and advantages and limitations of the PLC/ SCADA solution are highlighted.

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I. INTRODUCTION

Milk is one of the most valuable and widely consumed foods globally. Dairy plants must rapidly convert raw milk into safe, high-quality products (pasteurized milk, cheese, yogurt, etc.) while maintaining strict hygiene and regulatory standards. Pasteurization (e.g. heating milk to ~66–72 °C) is critical to eliminate pathogens and extend shelf life. However, large-scale pasteurization and processing are labor- intensive and sensitive to human error.

Traditional control methods (manual valves, on- off controllers) struggle to maintain the precise temperature, timing, and flow required at high volumes. Industrial automation resolves these challenges by using PLCs and SCADA systems.

PLCs are rugged industrial controllers that execute logic based on real-time sensor inputs, controlling pumps, valves, motors, and safety interlocks. SCADA systems provide a graphical operator interface (HMI), alarms, trending, and data acquisition. Together, they form the backbone of an industrial control system (ICS) for dairy processing. By automating control loops (temperature, level, flow) and sequencing tasks, PLC/SCADA ensures precise operation and rapid response to deviations. Modern dairy plants increasingly adopt such systems to meet growing demand while assuring food safety and reducing costs.

II. OBJECTIVE

- Automate Pasteurization: Use PLC control to maintain precise heating (e.g. in plate heat exchangers) and holding times, and coordinate cooling stages.

- Automate Packaging: Control filler machines and conveyors to ensure consistent fill volumes and packaging speed.

- Automate CIP Cleaning: Sequence valves and pumps to clean process tanks and piping with detergents and sanitizers, minimizing water/chemical use.

- Real-time Monitoring (SCADA): Implement HMI screens for operators to monitor process variables (temperature, level, flow) and alarms, and to record historical data.

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- Data Logging and Traceability: Store process data (temperatures, timings, batch IDs) for quality control and regulatory records.

- Improve Efficiency and Safety: Increase throughput while maintaining product quality, and incorporate safety interlocks (emergency stops, overload protection) into the control logic.

III. PROBLEM STATEMENT

Manual or semi-automated control of dairy processes has significant limitations. Inconsistencies in pasteurization temperature or holding time can lead to microbial spoilage. Manual cleaning (CIP) and filling processes are slow and error-prone. Labor-intensive operations increase production costs (labor can be ~50% of cost) and elevate safety risks. High manual involvement also hampers data collection and traceability. In large-capacity plants, relying on human operators for timing and adjustment is impractical – e.g. maintaining 66–72°C for 20–40 minutes across large volumes requires complex coordination and manpower. Therefore, an integrated PLC/SCADA solution is needed to automate the dairy production line, ensuring precise control of temperature, flow, and timing, as well as automated cleaning and packaging, to improve efficiency, consistency, and safety.

IV. NEED OF THE PROJECT

Automation is crucial for competitive dairy production. A PLC/SCADA system can ensure consistent quality and food safety by tightly regulating process variables. Automation reduces contamination risk and labor (automated valves and pumps replace manual tasks). It provides flexibility and scalability, allowing product recipes or batch sizes to change in software rather than hardware.

Automated CIP greatly improves hygiene by precisely controlling cleaning cycles. Real-time monitoring and logging enable traceability and compliance, meeting stringent food industry regulations. Finally, data analysis from SCADA can optimize energy and resource use (e.g. minimizing water and chemical usage during CIP). These benefits justify the project’s goal to apply PLC/ SCADA automation to milk pasteurization, storage, and packaging lines.

V. LITERATURE REVIEW

Automation in the dairy industry has been studied extensively. Heema et al. (2022) note that modern dairy plants have rapidly integrated automation to boost productivity and ensure product safety. They emphasize that automation can greatly improve safety, quality, and profitability by optimizing control of processing parameters. For example, automated milking robots and PLC-controlled processing lines replace manual labor for consistent operation. Another survey by Rashmi et al. (2019) observes that the integration of PLC and SCADA has transformed dairy operations from farm to packaging, yielding more sustainable and efficient production. The Clean-In-Place (CIP) process is a critical example. Dhage & Dhage (2016) highlight that CIP is essential for hygienic dairy production, involving sequential rinses with alkali, acid, and water. They and others propose PLC/SCADA- controlled CIP systems that automate these rinse sequences, monitor chemical levels and pH, and recycle solutions for efficiency. Such systems reduce downtime and ensure thorough cleaning without manual intervention. Similarly, Yaseen et al. (2022) describe a PLC/ SCADA system for large-scale milk pasteurization; they observe that pasteurizing extends milk shelf life from ~2 days to up to 10 days, but requires elaborate equipment and manpower at scale.

Their work underscores the need for automation to handle high volumes. The Dairy Processing Handbook (Tetra Pak) outlines industry practices, stating that each processing unit (pasteurizer, filler, etc.) is typically controlled by a PLC and monitored by SCADA. At the plant level, multiple PLCs are coordinated under a unified SCADA system to sequence production and manage interlocks. This layered ICS architecture (sensors/actuators at Level 1, PLCs at Level 2, SCADA/MES at Level 3) is standard in dairy factories. In the literature, these technologies have proven effective at enhancing product consistency, enabling data- driven decision making, and improving operational safety.

VI. PROPOSED SYSTEM

The proposed automated dairy plant will integrate PLCs, sensors, actuators, and a SCADA system to control all key processes. Hardware components include: PLC controllers (for example, Siemens S7 or Allen-Bradley CompactLogix) with digital/analog I/O modules; temperature sensors (RTDs or thermocouples) on heaters and tanks; level sensors in pasteurizer vessels; flow meters on inlet and outlet lines; pH sensors in CIP drain tanks; motors and electric valves on pumps and pipelines. Software components include a PLC program (written in ladder logic or structured text) implementing control sequences and interlocks, and a SCADA package (such as Siemens WinCC or Wonderware) providing an HMI, alarms, trending, and OPC-based data connectivity. In the control architecture, each process unit (e.g. pasteurizer, fill line) has a local PLC that executes the required logic. These PLCs communicate with a central SCADA server via Ethernet for supervisory monitoring. The SCADA HMI displays real- time status of sensors and actuators, alarm notifications, and allows operators to change set points within safety limits. The SCADA also logs process data to a historian database for traceability. Overall, the system forms a typical multi-layer ICS: sensors/actuators (layer 1) → PLCs (layer 2) → SCADA/MES (layer 3). A block diagram of the control system would show raw milk input feeding the pasteurization unit, sensors measuring its temperature/flow/level, and a PLC controlling heating elements and pumps.

After pasteurization and cooling, the processed milk flows to storage tanks or filling machines, whose operations (filling valves, conveyors) are similarly PLC- controlled. After each batch, the CIP subsystem (with its own set of sensors and valves) is activated under PLC logic to clean the lines. Throughout, the SCADA HMI connects to all PLCs to provide supervisory control and data acquisition. (This conceptual block diagram follows standard dairy automation architecture.

VII. METHODOLOGY

The system development follows a structured approach:

- Requirements Analysis: Define process specifications (pasteurization temperature and time, CIP steps, production rates) in consultation with dairy engineers.

- Hardware Design: Select PLC model and names for all key variables. Configure data logging and user access levels.

- Implementation: Program the PLC logic using tools like Siemens TIA Portal or Allen-Bradley RSLogix. Configure SCADA graphics and communications to PLC (e.g. via Modbus TCP or OPCUA).

- Control Scheme Design: Develop control algorithms for each process (PID loops for temperature, ON/OFF sequences for tanks and valves). Draft a ladder logic flowchart or use function blocks (IEC 61131-3).

- SCADA Design: Design HMI screens reflecting the plant layout (tanks, pipelines, valves). Create alarm/tag names for all key variables. Configure data logging and user access levels.

- Implementation: Program the PLC logic using tools like Siemens TIA Portal or Allen-Bradley RSLogix. Configure SCADA graphics and communications to PLC (e.g. via Modbus TCP or OPCUA).

- Integration and Testing: Install sensors and actuators on the actual equipment. Connect all I/O to the PLC and establish SCADA links. Perform subsystem tests (heater control, CIP cycles) in a simulated environment first. Then conduct on-site commissioning: verify temperature profiles during pasteurization, ensure correct CIP valve sequencing, calibrate flow/level sensors.

- Validation: Collect data for a pilot run to confirm that the automated system meets quality standards (e.g. microbiological tests on pasteurized milk) and complies with regulatory requirements

VIII. BLOCK DIAGRAM

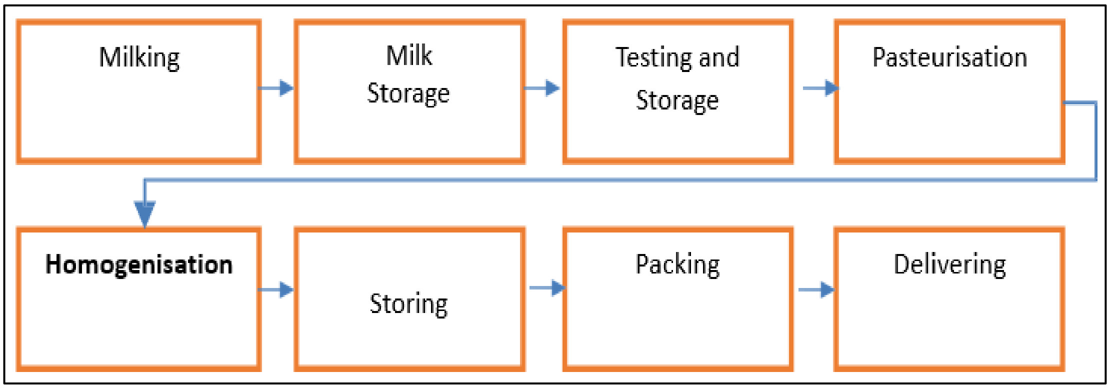

Fig 1 Block Diagram

IX. WORKING

The automated process operates as follows:

- Milk Reception: Raw milk arrives and passes through a flow meter into the pasteurization unit. The PLC opens the hot water and closes the cold water valves on a plate heat exchanger to gradually raise milk temperature. Using a PID loop, the PLC maintains the milk at the set point (e.g. 66 °C) for the required hold time. After heating, the PLC reverses valves to introduce chilled water, cooling the milk to ~4 °C before transfer to storage. Throughout, level sensors ensure tanks do not overflow, and alarms notify the operator of any deviations.

- Homogenization and Separation (optional): If included, the PLC also controls homogenizer pumps and cream separators by managing drive motors and pressure valves.

- Packaging: When filling bottles or cartons, sensors (e.g. proximity, photo detectors) on the conveyor confirm correct positioning. The PLC opens a fill valve for a timed duration to dispense the right volume of milk, then signals the conveyor to advance. This sequence repeats under SCADA oversight.

- CIP Cleaning: After production, the PLC initiates the CIP cycle. Valves are opened to flush the system: e.g. hot water rinse (controlled by temperature and flow sensors), followed by alkali cycle (monitored by pH sensors) and an acid rinse. The system then flushes with clean water to neutralize the pipes. Wastewater is piped to a holding tank and can be measured (level sensor) and pH-checked before disposal. The entire cleaning sequence is automated – the operator simply starts the CIP routine on the SCADA HMI, and the PLC executes each step, interlocking motors and valves to prevent conflicts.

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At every stage, the SCADA system logs temperatures, flow rates, and cycle times. It also displays alarms (e.g. "High Temperature", "Low Flow") for prompt response. Historical trends can be reviewed to verify that each batch met specifications, thus ensuring quality control.

X. SYSTEM DEVELOPMENT

Development began with PLC programming in ladder logic. Each function (pasteurizer control, filler operation, CIP sequence) was coded as a separate rung logic or function block. Safety interlocks (emergency stops, high-temperature cutoffs) were implemented to shut down equipment if conditions 7. 21 13 4 exceed limits. SCADA screens were designed to mimic the plant layout: for instance, a graphic showing the pasteurizer with color-coded temperature indicators and valve statuses. SCADA alarms were defined for out-of-range conditions. The team used a modular approach: after coding one process (e.g. pasteurizer), it was tested in simulation; then hardware inputs/outputs were wired, and real-time testing was performed. All programming changes were documented in accordance with IEC 61131-3 best practices for PLC code management.

Commissioning involved iterative refinement. For example, thermocouples were calibrated to match actual temperature readings. The PLC PID tuning was adjusted so that the pasteurization hold tank temperature ramped without overshoot. The SCADA data logging (e.g. to SQL database) was verified by extracting logs for validation. The final system was load-tested with continuous runs to ensure stability over time.

XI. SOFTWARE DETAILS

The PLC software was developed using IEC 61131-3 languages. Ladder Logic (LD) was used for sequential operations (fill cycles, valve sequences), while Function Block Diagram (FBD) or Structured Text (ST) was applied for PID loops in temperature control. The SCADA package (e.g. Wonder ware In Touch, Ignition, or Siemens WinCC) was configured with a real- time tag database and graphical HMI screens. Communication was implemented via industrial Ethernet (e.g. Modbus TCP/IP or OPC UA) between PLCs and SCADA. SCADA databases stored recipes (set points, timings) and historical logs. Security was set up with user roles: operators can change set points but engineers can modify control logic. All software follows best practices: modular code blocks in the PLC, commenting, and SCADA alarm descriptions, facilitating maintenance and future upgrades.

XII. SOFTWARE SPECIFICATION

- PLC: Siemens S7-1200 CPU

- SCADA: PC running Windows 10 (64-bit) with Intel Core i5, 8 GB RAM. Software: SCADA suite (e.g. FactoryTalk View or WinCC) with OPC server.

- HMI: Touch screen monitors for operator consoles, designed with intuitive process graphics.

XIII. ADVANTAGES

The PLC/SCADA automation offers numerous benefits:

- Improved Product Quality: Automation maintains precise control of pasteurization temperature and timing, reducing batch-to- batch variability.

- Increased Efficiency: Continuous automated operation allows higher throughput; PLC interlocks and sequencing eliminate delays between batches.

- Enhanced Food Safety: Automated CIP ensures thorough cleaning of tanks and pipes, reducing contamination risk.

- Data and Traceability: SCADA logging provides complete records of each process parameter, facilitating quality audits. - Reduced Labor: Manual tasks (e.g. monitoring temperatures, opening/closing valves) are minimized, saving labor costs (labor can be ~50% of production cost).

- Safety and Sustainability: The system can swiftly shut down upon unsafe conditions. According to industry reports, PLC/SCADA modernization has made dairy operations more sustainable and safe.

Overall, automation makes dairy production more consistent and profitable. As one review concludes, "automation using PLC and SCADA in the milk industry is a game-changer, making dairy production more sustainable, efficient, and profitable".

XIV. LIMITATIONS

Despite its advantages, PLC/SCADA systems have some drawbacks. The **initial capital cost** is high: PLCs, SCADA licenses, and sensors represent a significant investment. **Complexity** can be a challenge; troubleshooting requires skilled engineers familiar with control systems. Automated systems may be less flexible than manual ones if recipes change frequently, requiring reprogramming. There is also a risk of downtime: if the control system fails, the entire plant may halt, whereas manual operations might limp along. Cyber security is another concern – networked control systems must be protected against unauthorized access. Finally, small-scale dairies may find full automation overkill given their limited production needs. These limitations must be weighed against the long-term gains in efficiency and quality.

XV. CONCLUSION

The integration of PLC and SCADA in dairy processing plants enables precise, reliable automation of pasteurization, cleaning, storage, and packaging. The proposed design leverages industry-standard PLCs to execute control logic and a SCADA system for supervisory monitoring, aligning with best practices outlined in the Tetra Pak Dairy Processing Handbook. By automating critical operations, the system ensures food safety and consistent product quality while reducing manual labor and errors. Literature and case studies indicate that such automation is rapidly becoming the norm in modern dairies. In conclusion, the PLC/SCADA solution provides a robust foundation for efficient dairy production. Future enhancements may include integration with IoT sensors and MES systems for even deeper data analytics and Industry 4.0 capabilities, further advancing the dairy industry's productivity and sustainability.

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