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A Comprehensive Review of PLC Automation for Industrial Process Control and Monitoring System

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Abstract: *Programmable Logic Controllers (PLCs) are key to modern industrial automation, offering reliable and flexible control for complex processes. This review outlines PLC architecture, operation, and their role in real-time monitoring, fault detection, and integration with sensors, actuators, and human-machine interfaces. Recent advances—faster processors, modular design, and open communication protocols—enhance scalability and interoperability. Emerging trends such as Industrial Internet of Things (IIoT) connectivity, cloud supervision, and AI-driven predictive maintenance are also discussed. The paper highlights how PLC automation improves safety, energy efficiency, and overall productivity in industrial process control and monitoring.*

Keywords: *PLC, industrial automation, human machine interface, programming language, process control*

I. INTRODUCTION

Industrial automation is the application of control systems—such as computers, programmable controllers, and information technologies—to operate industrial equipment and processes with minimal human intervention. Industrial automation has gained much attention because it provides a means to automatize the multipart industrial processes by employing modern techniques and computer assisted technology to achieve a number of sustainable and competitive advantages in the manufacturing industry. [3] Its primary objectives are improved productivity, consistent product quality, higher safety standards, and reduced operational costs. Automation evolved from simple mechanization and relay-logic control in the early 20th century to electronic and digital systems in the 1960s. The emergence of the Programmable Logic Controller (PLC) was a turning point: it replaced hard-wired relay panels with flexible, software-based logic, enabling rapid reconfiguration of manufacturing lines and significantly lowering maintenance downtime.

Modern industrial automation is a multilayered ecosystem that integrates sensors, actuators, and distributed control networks. Communication protocols such as Modbus, Profibus, and Industrial Ethernet support real-time data exchange between field devices and supervisory platforms like Supervisory Control and Data Acquisition (SCADA) or Distributed Control Systems (DCS). The advent of Industry 4.0 and the Industrial Internet of Things (IIoT) has further expanded automation capabilities. Cloud connectivity, edge computing, artificial intelligence, and predictive analytics are now enabling adaptive control strategies, remote diagnostics, and energy-efficient operation. Despite these advances, PLCs remain the backbone of industrial process control due to their reliability, deterministic operation, and seamless integration with modern networking standards.

II. FUNDAMENTALS OF PLC

A. Architecture of PLC

A Programmable Logic Controller (PLC) is a ruggedized industrial digital computer designed for real-time monitoring and control of machinery and processes. Their programming is done using dedicated software, developed by each PLC producer, but having as common point the use of Ladder Diagram (the electrical command schemes).

The structure of a PLC is made of:

- the central unit: represents the most important part of the programmable controller and it has 3 important parts: processor, memory and power source. It practically leads the entire process.
- the programming unit: currently, it is represented, in most cases, by a computer through which programs can be written, which then are uploaded on the central unit for running. In the case when an easier to manoeuvre unit is desired, most companies will supply the programmers with consoles (laptop type systems), through which programs for controllers can be written
- input/output modules: they allow the interconnection with the process, receiving or giving out signals to it. These can be directly linked with the central unit or through distance control (if a certain process requires it);

- base: the device on which the central unit, the input/output modules and other additional functioning modules (where needed) are set. The internal structure of a PLC is presented in Fig. 1. [1]

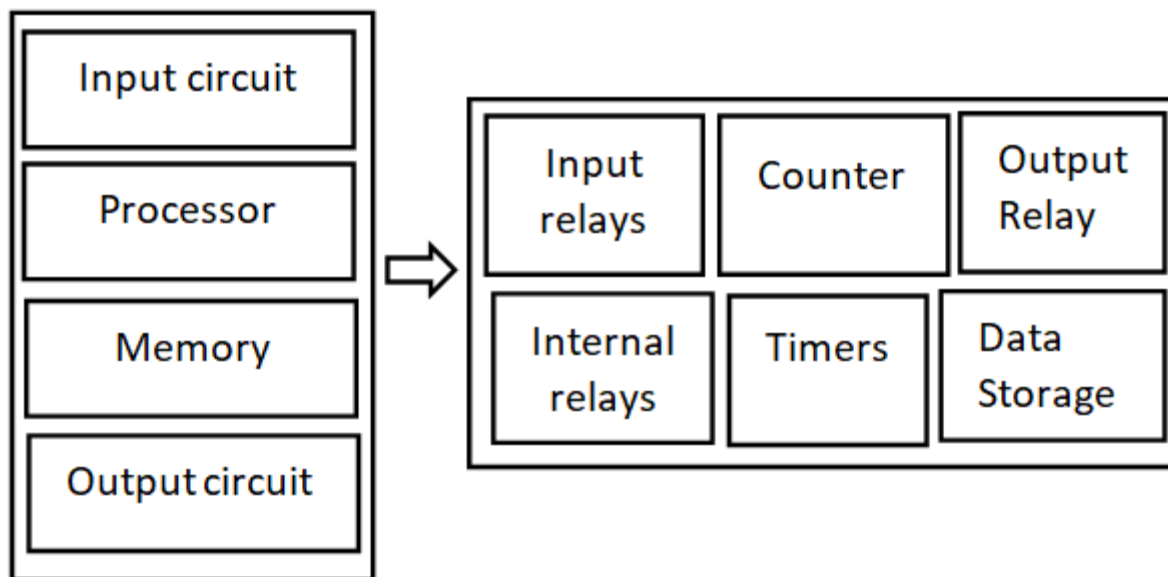


Fig 1. The Internal Structure of PLC

B. Programming Standards

Programming follows the IEC 61131-3 standard, which defines five languages:

- Ladder Diagram (LD) – graphical, resembles relay logic.
- Function Block Diagram (FBD) – block-oriented for complex control.
- Structured Text (ST) – high-level, Pascal-like.
- Instruction List (IL) – low-level, assembly-like (deprecated).
- Sequential Function Chart (SFC) – step/transition based for sequential processes.

The programming using Ladder Diagrams appeared in the case of programmable controllers due to the necessity to have an easy programming way which allows the realization of applications without having complex programming knowledge. The Ladder Diagrams are taken from electrical field and they inherit certain names and representations from this field. The base elements of the ladder diagrams are the contacts and coils. [2]

III. LITERATURE REVIEW

A. PLC in Industrial Process Control

Operating as ruggedized digital computers, PLCs continuously acquire signals from a diverse array of field devices—ranging from temperature and pressure transmitters to proximity sensors and flow meters—execute user-defined control algorithms, and actuate outputs such as motors, valves, heaters, and relays. This closed-loop functionality enables the precise orchestration of complex operations, from sequential machine tasks to sophisticated feedback and proportional–integral–derivative (PID) regulation that maintains critical process variables within stringent setpoints.

Their robust architecture and modular design have rendered PLCs indispensable across a wide spectrum of industrial domains. In discrete manufacturing, they coordinate automated production lines, robotic assembly cells, and high-speed packaging systems. In continuous and batch process industries—including chemical and petrochemical production, pharmaceuticals, and food and beverage processing—PLCs ensure accurate dosing, blending, and environmental management. Utilities and infrastructure sectors, such as power generation, water and wastewater treatment, and advanced building automation, similarly depend on PLCs to uphold safety, efficiency, and operational continuity under demanding conditions.

Contemporary PLC platforms integrate seamlessly with higher-level supervisory environments such as Supervisory Control and Data Acquisition (SCADA) and Distributed Control Systems (DCS).

Employing industrial communication protocols like Modbus, Profibus, and Ethernet/IP, they facilitate high-fidelity data exchange, remote diagnostics, and predictive maintenance, thereby enabling proactive optimization of plant performance. With deterministic scan cycles, standardized programming environments, and exceptional tolerance to electrical noise and environmental stressors, PLCs remain the preferred solution for mission-critical industrial process control, surpassing both legacy relay logic and general-purpose computing alternatives in reliability, scalability, and ease of maintenance.

Industrial processes are commonly classified into three types:

- Discrete Process – Produces distinct items in separate steps; uses event-driven control.
- Continuous Process – Material flows without interruption; requires precise, steady control of variables such as temperature or pressure.
- Batch Process – A fixed quantity is processed in defined stages, combining discrete sequencing with continuous regulation.

B. Communication and Networking

Effective communication and networking are essential for integrating PLCs into modern industrial automation. A PLC must exchange data rapidly and reliably with field devices, supervisory systems, and enterprise networks to enable real-time control and monitoring.

Industrial communication typically uses fieldbus and Ethernet-based protocols designed for deterministic performance and noise immunity. Widely adopted standards include Modbus, Profibus/PROFINET, DeviceNet, and EtherNet/IP, which support high-speed data transfer and interoperability among multi-vendor equipment. For higher-level integration with SCADA, DCS, and manufacturing execution systems, protocols such as OPC UA provide secure, platform-independent communication.

Networking topologies range from simple point-to-point links to complex hierarchical architectures with switches and routers that segment control, supervisory, and enterprise layers. Redundant ring or mesh configurations are often employed to ensure fault tolerance and continuous operation in critical plants.

Modern PLC networks increasingly incorporate Industrial Internet of Things (IIoT) concepts—cloud connectivity, wireless sensors, and edge computing—allowing remote diagnostics, predictive maintenance, and data analytics while maintaining stringent cybersecurity measures.

C. Comparative Analysis

Programmable Logic Controllers (PLCs) continue to evolve in response to the demands of Industry 4.0, the Industrial Internet of Things (IIoT), and smart manufacturing. Modern PLCs are increasingly integrated with cloud platforms and edge computing, enabling real-time data acquisition, remote monitoring, and predictive maintenance. This connectivity facilitates advanced analytics and optimization of industrial processes, improving efficiency, reducing downtime, and lowering operational costs.

Artificial intelligence (AI) and machine learning algorithms are being incorporated into PLC systems to support adaptive control, fault detection, and process optimization. These capabilities allow PLCs to respond dynamically to changing conditions and make data-driven decisions, enhancing both safety and productivity.

Communication protocols have also advanced, with high-speed, deterministic Ethernet-based standards such as PROFINET, EtherNet/IP, and OPC UA enabling seamless integration between PLCs, SCADA, and enterprise systems. Cybersecurity has become a major focus, with PLCs now designed to resist unauthorized access, network attacks, and malware, ensuring reliable operation in increasingly connected industrial environments.

Moreover, soft PLCs—software-based controllers running on general-purpose computers—offer flexibility, scalability, and cost benefits, especially for retrofitting older plants. Modular and compact hardware designs continue to improve, supporting smaller footprints and energy-efficient operation.

IV. FUTURE TRENDS

Programmable Logic Controllers (PLCs) continue to evolve in response to the demands of Industry 4.0, the Industrial Internet of Things (IIoT), and smart manufacturing. Modern PLCs are increasingly integrated with cloud platforms and edge computing, enabling real-time data acquisition, remote monitoring, and predictive maintenance. This connectivity facilitates advanced analytics and optimization of industrial processes, improving efficiency, reducing downtime, and lowering operational costs.

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V. APPLICATIONS

Programmable Logic Controllers (PLCs) are extensively utilized across a wide range of industrial sectors due to their reliability, real-time performance, and flexibility. In discrete manufacturing, PLCs coordinate complex production lines, robotic assembly cells, and high-speed packaging systems, ensuring precise sequencing, timing, and synchronization of operations. In process industries, such as chemical, petrochemical, pharmaceutical, and food and beverage manufacturing, PLCs regulate both continuous and batch processes by monitoring and controlling critical parameters such as temperature, pressure, flow, and chemical composition, thereby maintaining consistent product quality and operational safety. Furthermore, PLCs play a vital role in utilities and infrastructure, including power generation, water and wastewater treatment, and building automation, where they manage electrical loads, control pumps and valves, and oversee environmental systems to ensure uninterrupted operation and adherence to safety standards. With the advent of Industry 4.0, PLCs are increasingly integrated with advanced technologies, including predictive maintenance, cloud-based monitoring, and data-driven process optimization, enabling smarter, more efficient industrial operations. Their modular hardware, compatibility with modern communication protocols, and seamless interfacing with supervisory systems such as SCADA and DCS make PLCs highly versatile, serving as the backbone of both traditional and next-generation automation systems.

VI. CONCLUSION

Programmable Logic Controllers (PLCs) continue to serve as the foundational element of industrial automation, offering deterministic, real-time control across discrete, continuous, and batch processes. Their adaptability, modular architecture, and robust design make them highly effective for integration with modern supervisory systems, communication networks, and Industry 4.0 frameworks, including IIoT, cloud-based analytics, and predictive maintenance. While Distributed Control Systems (DCS) and Programmable Automation Controllers (PACs) provide complementary solutions for large-scale or hybrid processes, PLCs remain indispensable due to their versatility, ease of programming, and reliability under harsh industrial conditions. Future developments in AI-driven control, edge computing, enhanced cybersecurity, and advanced data analytics are poised to further extend PLC capabilities, enabling more intelligent, resilient, and optimized industrial operations.

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