Journal of Artificial Intelligence and Computing (JAIC)
ISSN (e): 3005-3358
Volume: 3, Number: 1, Pages: 20 - 25, Year: 2025

Future of Programmable Logic Controller, Recent Trends, and Challenges

Muhammad Husnain Shahid, Muhammad Hammad Tahir, Asma Arshad, and Arooj Abbas *

Electrical Engineering Department, Government College University, Lahore, 54000, Pakistan
Corresponding author: Muhammad Husnain Shahid

Received: 10/04/2025, Revised: 04/06/2025, Accepted: 20/06/2025

***Abstract*—Programmable Logic Controller (PLC)- based systems play a fundamental role in industrial automation, modern automated systems, and industrial control systems, monitoring, controlling, and optimising complex processes across modern industries. PLCs are digital computers specifically designed to operate in harsh industrial environments such as manufacturing plants, power stations, oil refineries, and transportation systems. Unlike conventional control systems, which rely on electromechanical relays and wiring, PLCs use programmable software and modular hardware, providing flexible, efficient, and reliable automation solutions. The use of PLC technology has significantly improved productivity, reliability, and safety in industrial operations.**

***Index Terms*—PLC, CPU, SCADA, HMI.**

I. Introduction

A programmable logic controller (PLC)-based system typically comprises a central processing unit (CPU), input/output (I/O) modules, a power supply, a communication interface, and programming software [1-2]. The CPU executes programs written in ladder logic, structured text, or function block diagrams. Input modules are used to receive signals from different sensors, switches, and field devices, and output modules are used to control actuators, motors, relays, and valves. Together, these elements enable real-time monitoring and control of industrial processes. PLCs provide greater flexibility, allowing the system to be modified, trouble-shooted, and expanded without major hardware changes [3]. The major task of the PLC-based systems is the automation of electromechanical processes. In traditional relay-based systems, circuit modifications require extensive rewiring, making them cumbersome and prone to errors. PLCs have been used to replace these systems with software-controlled logic, enabling engineers to apply and adjust control strategies efficiently [2]. Therefore, PLCs have become indispensable in automated production lines, robotic systems, conveyor systems, and other industrial applications [4].

PLCs have cyclic-scan modes of operation in which I/O signals are read, control logic is executed, and output updates occur repeatedly. This deterministic cycle is used to ensure a real-time response to system changes. The ability of PLCs to perform accurate and reliable control makes them appropriate for applications as diverse as assembly lines, water treatment plants and energy distribution systems [1], [3]. Another important advantage of PLC-based systems is their integration with other automation technologies, such as Supervisory Control and Data Acquisition (SCADA) systems, Human Machine Interfaces (HMI), and Industrial Internet of Things (IIoT) platforms. Communication protocols such as Modbus, Profibus, and Ethernet/IP enable PLCs to communicate with supervisory systems to remotely monitor, visualise, and control industrial processes [2], [5].

Recent changes in the field of Industry 4.0 has increased the capabilities of PLC further. Modern PLCs support cloud connectivity, edge computing, predictive maintenance, and data analytics, transforming conventional automation systems into smart industrial ecosystems. Integration with IoT technologies enables machines to communicate and exchange operational data, leading to more efficient processes, reduced downtime, and data-driven decision-making [5], [6]. PLCs are used in many industries. In the manufacturing industry, they have automated assembly lines, packaging, and material handling. In the energy field, PLCs areresponsiblge for the generation and distribution processes. Water treatment, transportation, and renewable energy systems are other areas that benefit from PLC-based automation [4]. These broad applications of PLC technology demonstrate its versatility and importance in the modern industrial world. However, PLC-based systems have issues, particularly in cybersecurity. Increased connectivity to digital networks exposes PLCs to potential cyber threats that can compromise critical industrial operations. Researchers are actively developing secure protocols and protection mechanisms to ensure system reliability and safety [6].

In summary, PLC-based systems are an integral part of modern industrial automation systems and offer several advantages, including flexibility, reliability, and real-time control. With their ability to integrate to advanced system such as SCADA IIoT and smart manufacturing platform they become basic to Industry 4.0. As industries have been embracing digital transformation, PLCs will continue to play a crucial role in improving productivity, safety, and operational efficiency.

A. PLC System History

PLCs were developed in the late 1960s after industries realised the need for a more flexible and reliable alternative to conventional relay-based control systems. PLCs replaced timers, hardwired logic and electromechanical relays used before PLCs as essential components of industrial automation. These systems were cumbersome, hard to service, and required extensive rewiring whenever their control logic needed to be changed. In 1968, a General Motors project team led by Richard Morley designed the first PLC to meet the requirements of a programmable, easily customizable control system for auto assembly. This early PLC was referred to as Modicon 084 and it featured complex relay panels that were replaced by it and its downtime and maintenance costs became minimal.

In the 1970s and 1980s, the development of microprocessors then integrated into PLCs made them faster in processing power and larger in their memory size. They were also equipped with communication capabilities enabling the PLCs to interface with other systems. In the 1990s PLCs added support to sophisticated programming languages and connections to Supervisory Control and Data Acquisition systems. PLCs are considered fundamental units of Industry 4.0 and smart manufacturing systems because in recent years, the technology has continued to develop with additions of the Industrial Internet of Things, cloud computing, and artificial intelligence.

B. PLC System Definition

A Programmable Logic Controller is an industrialized digital computer used to control functions like logic, sequencing, timing, counting and arithmetic functions in order to automate industrial processes.

PLCs are specifically designed to work within harsh conditions such as extreme temperatures, humidity, vibration, as well as electrical noise. They are developed with easy-to-use languages like ladder logic that resembles electrical relay diagrams hence, engineers and technicians can be able to easily design and debug control systems.

II. Fundamentals of Spread Spectrum

PLC systems are run on a repeat cycle called scan cycle. This cycle is made up of three steps:

Input Scan: The PLC senses the condition of all the input devices.

Execution of a Program: According to the input data, the CPU executes the control program.

Output Scan: PLC also regards the output devices status based on the results of the program.

This cycle is used repeatedly, and it allows monitoring and controlling processes in industries in real time.

A. Components of PLC Based System

A PLC based system contains multiple components which are required to integrate to effectively carry out automation tasks.

CPU (Central Processing unit): The CPU is the brain of the PLC. It executes the control program held in memory, processes the input signals and determines the correct response of output actions. It also controls communication with other telecommunications and carries out diagnostic functions.

Input Modules: The external devices interconnecting with input modules are sensors, switches, push buttons, limit switches. These signals may be computerized (on/off) or analog. These signals are translated into a form that can be processed by the CPU by the input module.

Output Modules: Output modules convert the signals in the PLC to external devices including motors, relays, solenoids as well as alarms. Depending on the control logic, the output module brings or brings out these devices to do certain things.

Power Supply: The electric power supply will be used to supply the required electrical energy required by PLC system to run. It changes the voltage in coming into it into appropriate levels needed by the PLC components.

Programming Device: Control programs are written, edited and uploaded to the PLC by a programming device. Monitoring and debugging of the system is also made possible.

Communication Interfaces: The PLCs are also modernized in the sense that they support communication ports and protocols, thus, allowing them to communicate with other systems, such as the SCADA, the Human Machine Interfaces and the other PLCs. Common communication protocols are modbus, Ethernet/IP and Profibus.

Memory Unit: The control program, system configuration and data needed to operate are stored in the memory unit. It makes sure that the PLC is capable of executing instructions in a consistent manner and also storing valuable information even when the power is not present.

B. PLC Applications Across Industries

Programmable logic controllers show their essential value to multiple industries because each industry needs different automation solutions that meet its specific requirements.

Aerospace and Defense Manufacturing: In aerospace facilities, PLCs coordinate complex assembly processes that require both precision tooling and environmental controls and safety interlocks. The systems operate all processes starting from composite curing ovens until they reach the automated material handling systems which transport components through their multi stage production lines. The capability to combine different PLC systems from various manufacturers including Allen Bradley and Siemens into a single facility enables aerospace manufacturers to achieve equipment standardization for their global business activities.

Food and Beverage Production: Food processing plants use PLCs to achieve product quality control which meets all FDA requirements. The industrial control systems of this facility operate three functions which include pasteurization temperature control, packaging line conveyor speed management, and automated clean in place sanitary equipment cleaning between production cycles.

Energy and Utilities: Power generation facilities and utility companies use PLCs to control critical infrastructure including turbine operations, electrical grid switching, and environmental monitoring systems. The controllers feature a strong design which guarantees dependable performance under difficult conditions while they deliver essential real time information for both grid stability and regulatory compliance.

Data centers: Data centers require advanced PLC based systems to control HVAC systems and backup power operations and environmental monitoring activities. The systems need to connect more than 100 input and output components together with various motorized equipment which includes cooling fans and compressors and automated fire suppression systems.

C. PLC Control Processing

The PLC based system control processing executes through a user created program which interacts with the physical world through input and output interface devices.

The Programmable Logic Controller system functions as an industrial process monitoring and control system which operates through computer technology.

The PLC processing cycle, which the PLC processing cycle calls its scan cycle, consists of multiple sequential steps.

The PLC begins its operation by reading input signals that come from sensors, switches, and any other devices that connect to the system. The PLC executes user programs that developers write in either ladder logic or function block diagram languages.

The PLC sends output signals to control devices which include valves and motors and actuators.

The PLC sends and receives information to and from other devices which include human machine interfaces and supervisory control and data acquisition systems and additional PLCs.

The PLC performs self diagnostic tests to check whether it operates correctly while it detects any system failures.

The PLC system handles two different processing modes which include cyclic processing and event driven processing.

The PLC system processes its program when events occur or when specific interrupts happen. The PLC system executes its program according to predetermined time schedules.

D. PLC Execution

The PLC program executes its operations by processing each rung and block of code in sequential order.The program divides itself into smaller components which developers can use as reusable subroutines. The PLC program functions through a sequential process which executes all rungs and blocks according to their defined order. The program can be broken down into smaller, reusable sections that exist as subroutines.

E. Advantages of PLC based System

The system allows users to modify its operational settings through various programming methods.

PLCs are engineered for industrial settings, ensuring high reliability.

The system enables users to implement PLCs across various applications which range from small to large scale operations.

F. Common PLC Programming Languages

Ladder Logic is a graphical programming language that describes a program as a sequence of Interconnected rungs.

A Function Block Diagram is a graphical programming language that depicts a program as a Sequence of interconnected blocks.

Structured Text is a programming language that uses text based code to create structured programs.

III. Case Studies of PLC Based System

A. Case Study 1

Improving Production Efficiency with a PLC System: A large food and beverage company was experiencing production line downtime due to manual processes and outdated equipment. The company required a solution which would boost operational efficiency while decreasing work interruptions. The company used a PLC system to automate its production line while monitoring all equipment and operational activities in real time. The system generated a 20 percent boost in operational capacity which resulted in a 50 percent decrease of operational interruptions.

B. Case Study 2

Reducing Waste with a PLC System: A dairy products manufacturer was experiencing high levels of waste due to overfilling of product containers. The company needed a solution which would decrease waste while enhancing precise operations. The company used a PLC system to manage its filling operations while receiving immediate updates about current product filling status. The system achieved a 30 percent decrease in waste through its capacity to enhance precise product filling operations.

C. Case Study 3

Ensuring Food Safety with a PLC System: A meat processing facility needed to protect product safety through temperature monitoring and refrigeration Unit control. The facility implemented a PLC system for temperature monitoring-, which provided real time temperature data and activated alarms when temperature levels surpassed safe operating limits. The system Improved food safety standards while the facility achieved compliance with all necessary regulatory standards.The food and beverage industry benefits from PLC implementation according to these case studies. Companies that automate their operations while minimiasing waste and maintaining food safety standards Achieve higher efficiency and profitability from their operations while providing customers with top-quality products.

IV. PLC Engineering and Integration Challenges

A. Debugging

Identifying Issues in Complex Logic: PLCs are also inherently hard to debug since they are a system that interacts with unpredictable physical hardware and involves finding logical errors in the system. The issue is also exacerbated by the fact that conventional tools cannot record the high frequency data that can be analyzed in detail.

The Core Problem: PLC logic runs in a continuous, infinite loop called a scan cycle. A fault can last just a few milliseconds, and it is not visible to regular monitoring equipment.

Advanced Complications:

Data Scarcity to Analytics: Advanced analytics systems demand high quality and high frequency data to drive predictive maintenance or quality control algorithms. Most older PLCs do not have enough internal memory and processing power to record data at the resolution needed and engineers cannot see the small trends that usually lead to a failure.

Intermittent Environmental Faults: These are often external hardware issues such as electrical noise in heavy machinery, or component wear due to heat, dust, or humidity, and are not caused by the code. One of the most frequent troubleshooting problems is to differentiate between logical error and sensor fault due to environmental conditions.

B. Integration: Connecting with MES, ERP, and Advanced Systems

Integration now is not limited to connecting an HMI anymore. It requires paralleling the deterministic, real time environment of the PLC with the event driven, transactional architecture of enterprise IT systems. This remains the biggest hurdle when it comes to fully realizing Industry 4.0 benefits.

The Core Problem: PLCs operate on fixed, rapid scan cycles measured in milliseconds as compared to enterprise systems which are designed for event driven updates or batch processing. This fundamental architectural difference creates data silos and introduces latency.

C. Specific Integration Barriers

MES (Manufacturing Execution Systems): MES systems anticipate event based information. As an instance, a signal is generated to show that a part has been finished whereas PLCs generate continuous cyclic information. Any mismatch in this leads to delays and inconsistency in production planning and quality management unless sophisticated data buffering logic is applied.

ERP (Enterprise Resource Planning): ERP systems are not designed to support real time processing of business, but in batch mode. The only way to bridge this gap is by significantly increasing middleware between real time tag data and business transactions to make the system even more complex and offer more points of failure.

Data Silos and Proprietary Protocols: The proprietary communication protocols of many PLCs are based on legacy and are not compatible with the existing Ethernet based networks or cloud platforms. This will not allow useful operational data to be exposed to sophisticated analytics tools.

D. Security: Protecting Against Cyber Threats and Critical Infrastructure Risks

PLCs are not designed to be in the networks that we have today as they were developed to work in isolated settings only. Their legacy architecture makes them a high value target to the state sponsored forces and criminal groups, and its impacts can be as disruptive as production to the physical destruction of vital infrastructure.

The Main problem: Lack of fundamental security measures in IT such as authentication or encryption is so pervasive in the majority of PLCs. Once the attacker gets access to the network, he/she has complete access to the physical process.

Critical Threat Vectors:

Denial of Service (DoS) through Network Flooding: It was shown in a 2006 power station incident that when a large volume of network traffic is flooded into a PLC, it can crash its communication processor and will no longer respond. In that instance, recirculation pumps failed which proves the point that even the simplest congestion of the network can lead to physical protection failures.

Targeted Sabotage The Stuxnet Precedent: In 2010, the Stuxnet worm was discovered that demonstrated that an executed malicious code running in a PLC can lead to the physical destruction of equipment in this case centrifuges by changing the operational values and simultaneously reporting normal functioning to the operators. This attack has served as the blueprint of attack on the nuclear, water and power system.

• Unauthorized Logic Modification: Attackers or non expert personnel can upload altered logic that will circumvent safety interlocks, potentially causing catastrophic damage to the equipment.

E. Programming: Writing Efficient, Readable, and Scalable Code

The life of PLC programs is usually 15-20 years. It is difficult to write code that is fast enough to support high speed modern process, and clear enough to be understood and maintained years later, when there is a shrinking pool of qualified personnel.

The Core Problem: Ample language deficiencies and disordered logic. Traditional Ladder Logic can be used by electricians, but this type of logic cannot easily be applied to the high mathematical functions, data processing, and sophisticated control programs needed in the modern factory.

Development Limitations:

Language Barriers: Although Structured Text and Function Block Diagrams offer more flexibility in more complicated operations, they demand more and more difficult to find skill sets. When the engineering team enters into the Ladder Logic, they often write code that is needlessly complicated and hard to maintain when used to handle complex tasks.

Lack of Collaborative Development Tools: In contrast to the current state of software development in the IT industry, PLC development environments do not usually have a strong version control software like Git, collaborative code editing, and automated testing pipelines. This causes slows in development and risk of mistakes in large scale systems.

Hardcoding and Code Duplication: One such issue is the replication and pasting of logic between the same machines instead of developing reusable Function Blocks. Due to this, one bug fix will have to be made on perhaps dozens of locations, which is much more risky in terms of maintenance.

F. Maintenance: Troubleshooting Hardware, Software, and Skills Gaps

Theoretical concept realization to real life conditions is where maintenance takes place. The key problem is to correctly identify a code fault or a wiring fault or an environmental failure and have to face the fact that technicians with experience working with old fashioned proprietary systems are highly scarce.

The Core Problem: Symptoms of faults are often misleading, and professional knowledge is vanishing. With the retirement of experienced staff, the institutional knowledge needed to trouble shoot and maintaining the legacy systems is lost along with the retirement of the staff.

Key Maintenance Hurdles:

Hardware and Environmental Degradation: Aging parts failure, instability of supplies of power and environment (heat, dust, and humidity) are typical and frequent cases. Signals can be disrupted by electrical interference of nearby machinery in a way that is similar to logical faults.

Component Obsolescence: Replacement I/O modules or even cabling associated with a PLC system older than 20 can be out of stock, and engineers have to resort to risking field repairs of the system, or incur expensive, and unplanned systems migrations.

The Skills Gap: The old generation of engineers who are used to traditional Ladder logic are retiring and newer generations of engineers tend to come to the field with experience in high-level programming languages like Python or C++. This leaves an empty field where not many professionals can work efficiently in the border between OT and IT settings.

V. PLC Based Systems Future Trends and Developments

This section describes major future trends and developments in the PLC technology.

A. Integration with Industrial Internet of Things(IIoT)

The Industrial Internet of Things is one of the new paradigms that are disrupting systems of isolated islands of automation to fully interconnected systems. IIoT allows the communication of field devices, sensors, actuators and controllers including PLCs over standard networks and sharing of data in a continuous stream.

Traditionally, PLCs were implemented that executed locally running control logic and communicated the limited set of data with the supervisory systems. In contrast, next generation PLCs are being built to have a strong IIoT integration capability with real time data acquisition, edge analytics, and easy connection to sketches of higher-level enterprise systems. This integration enables:

Generally speaking, some of the advantages of an information ecosystem are; Continuity of data flow from PLCs to cloud or local analytics platforms, enabling manufacturers to monitor the health of equipment, production rates and anomalies in real time.

Maintenance teams can view the data from the PLC remotely which reduces downtime and enables greater responsiveness of operations.

It is also possible to communicate between PLCs and other automation elements with Internet of Things(IoT) protocols, such as MQTT, OPC UA, and Restful API.

B. Adoption in the Industries of 4th Generation and Smart Manufacturing

Industry 4.0 focuses on digital transformation, automation intelligence and cyber physical systems connected. PLC based systems are making their way towards support for these principles by integrating with smart factory architectures.

Future PLC toward Vision for the PLC's function is increasingly that of a node in a system of cyber physical things Physical machines and digital networks And alone work hand in hand. These systems:

Enable coordinated efforts the various machine using prediction scheduling and adaptive control strategies.

Facilitate the vertical and horizontal integration, from devices on the shop floor to enterprise resource planning systems.

PLC systems are changing from static single purpose systems to modular systems that can be reconfigured with little software changes. For example, museum flexible manufacturing systems are able to respond to actual time demands with automated production sequences that may not have been programmed in great detail.

The PLCs with integrated Advanced Human Machine Interfaces provide graphical representation, touch pads and augmented reality view to the operators. These systems make humans better comprehend the complex conditions of machines and should better the flaws in maintenance and functioning of machines.

C. Artificial Intelligence is used and integrated with Machine Learning

Artificial Intelligence and Machine Learning are changing how industrial systems anticipate failures and optimize processes as well as react to changing conditions. Although PLCs have historically implemented deterministic and rule based logic, information on PLC's future is pushing them towards intelligent decision support.

Be Towards AIO Communication is remotely collaborating with all PLC data streams and artificial network models to forecast ways of hindering equipment breakdowns prior when they happen. Techniques include:

Pattern recognition for vibration, temperature and current data. Regression models to estimate trends of degradation.

Incorporating AI into PLCs allows equipment form bolnaise pleased unintended cross sections, adopts the rasing of up keep and improves activity midst option and purposes the life.

Machine Learning Models To Collaborate On IO Control To

Utilize PLC System. This approach is particularly useful in applications where the dynamics of a process are non linear, or where there is uncertainty about the process, such as chemical processing or synthetic control of robotics.

D. Advances in the Communication and Networking

Future PLC systems will be based on advanced communication technologies like high speed and resilient data exchange.

Time Sensitive Networking introduces deterministic Ethernet communications, where data is delivered with minimal data-packet pairing and with guaranteed timing. PLCs on TSN may strongly cooperate with robotics, motion control and safety systems and sprinkle synchronization throughout the hybrid distributed devices.

With the adoption of the 5G networks, wireless communication is a practical option for industrial control in large facilities, outdoors or in mobile automation units like autonomous guided vehicles. 5G has; higher data throughput, low latency communications, support to massive networks of sensors.

Wireless PLC connectivity is one of the most important advantages that offer more freedom of automation, lower the cost of cabling and allow mobile automation innovations.

E. Enhanced Cybersecurity

The Terms of Connectivity not only is connectivity increasing, but security is of prime importance. Future PLCs are adding security by design, including encryption, secure boot, and compliance with IEC 62443 standards.

PLCs are kicking to built-in intrusion detection system (IDS) and monitoring to protect from cyberattacks that could cause considerable disruption to operations.

VI. Conclusion

PLCs play a critical role in the automation of industries, providing consistent and dependable control in various industries. Industry 4.0 is increasing the PLCs because of technological advancement and the necessity to have smarter systems.

This report discusses basic characteristics of PLCs, hardware and software components, problems and future trends, and the use of PLCs in the aerospace and defence manufacturing, food production, power generation and data centres.

Despite remaining an important component of the operational safety, the shift to Industry 4.0 has proven to have severe limitations in the older systems, with the integration issues, cybersecurity issues, financial factors, and the shortage of personnel skills becoming the critical obstacle to the modernization.

The trends in the future are outlined in terms of evolution and upgrading rather than replacement that can be not cost effective. The adoption of regular communication standards, including OPC UA, improved cybersecurity measures, connection to the industrial IOT, and adoption of technologies like AI and machine learning, manufacturers can bridge the gap between traditional Operational Technology (OT) and modern IT frameworks and provide smarter, safer, and more efficient manufacturing facilities in the future.

FUNDING STATEMENT

The author(s) received no specific funding for this study.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest to report regarding the present study.

AUTHOR CONTRIBUTIONS

Conceptualization, M.H.S.,M.H.T., A.A. and A.A.; methodology, A.A., M.H.S., M.H.T; software, A.A., M.H.T, and M.H.S.; validation, A.A., A.A., M.H.S., M.H.T.; writing—original draft preparation, A.A.; writing—review and editing, M.H.S. and M.H.T.

FUNDING STATEMENT

This research received no external funding.

INSTITUTIONAL REVIEW BOARD STATEMENT

Not applicable.

INFORMED CONSENT STATEMENT

Not applicable.

DATA AVAILABILITY STATEMENT

Data is available on reasonable request.

References

[1] M. Li, "On the application of PLC technology of electrical automation engineering," Applied Mathematics and Nonlinear Sciences, vol. 7, no. 2, pp. 275-285, 2023.

[2] S. Ahmad and V. Shukla "Industrial Automation through PLC and SCADA," International Journal for Research in Applied Science and Engineering Technology (IJRASET), vol 13, no 2, pp. 123-132, 2025.

[3] D. A. Shahakar et al., "A Comprehensive Review of PLC Automation for Industrial Process Control and Monitoring System," IJRASET, vol. 12 no. 7, pp. 98-110, 2025.

[4] A. Al Naib and M. Mohammed, "Design and Implementation of a PLC-Based SCADA System for Real-Time Monitoring of Photovoltaic Energy Conversion," Journal of Engineering Sciences, vol. 14, no. 3, pp. 45-55, 2020.

[5] J. Wei, and "Convergence of IoT and PLC in Industrial Automation: Emerging Trends and Technical Challenges," Applied and Computational Engineering, vol. 9, no. 1, pp. 12-24, 2025.

[6] H. Cui, R. Louden and J. Hong, "An Overview of the Security of Programmable Logic Controllers in Industrial Control Systems," MDPI Encyclopedia Advances in Industrial Control Systems, vol. 2, pp. 1-15, 2024.