Semarak Engineering Journal

Journal homepage:
https://semarakilmu.my/index.php/sej/index
ISSN: 3036-0145

Optimizing Expenditure in Automated Electrical Control Systems through Advanced PLC Integration

Abbas Moloody[1,*], Azizan As'arry[1], Mohd Khair Hassan[2], Raja Kamil[2], Irfan Bahiuddin[3]

[1] Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia (UPM), 43400 Serdang, Malaysia
[2] Department of Electrical and Electronics Engineering, Faculty of Engineering, Universiti Putra Malaysia (UPM), 43400 Serdang, Malaysia
[3] Dept. of Vocational College, Universitas Gadjah Mada (UGM), Sekip Unit I Yogyakarta 55281, Bulaksumur Yogyakarta 55281, Indonesia

ARTICLE INFO

Article history:
Received 11 January 2026
Received in revised form 2 March 2026
Accepted 17 April 2026
Available online 12 May 2026

Keywords:
Evidence reliability; Intelligent automatic control; auditing practices; compliance automation; Programmable Logic Controller

ABSTRACT

In contemporary industrial settings, Programmable Logic Controllers (PLCs) serve as crucial systems for customizable monitoring and management. By combining relay-based logic with cloud-enabled computing, PLC architectures successfully address the drawbacks of conventional electrical systems, including intricate wiring, diminished reliability, and elevated power usage. Utilizing PLC solutions based on organized design approaches and optimization principles facilitates the creation of more intelligent and efficient automated systems. Consequently, PLC technologies provide significant advantages to electrical automation by improving durability, dependability, and operational efficiency. From a regulatory and organizational standpoint, businesses frequently encounter significant expenses in order to fulfill contractual and compliance obligations. Conventional manual supervision demands significant labor, while incorporating automated compliance mechanisms within control systems alleviates these challenges by decreasing reporting inaccuracies and enhancing audit trail reliability. This decrease in audit risk also lowers additional auditing costs. These ideas are demonstrated through a scenario featuring automated control integration in the procurement process for public transportation services catering to elderly and disabled users, emphasizing persistent issues within Normative Multi-Agent Systems.

1. Introduction

The swift progress of industrial automation has heightened demands for electrical automation control systems, especially as the application of Programmable Logic Controllers (PLCs) becomes more prevalent and advanced [1]. PLCs signify a successful combination of conventional control techniques with contemporary scientific and technological resources. Leveraging computer-based programming, PLCs can be tailored with great adaptability to fulfill actual production requirements, greatly improving operational productivity and effectiveness [1]. In implementation, PLC development relies on programming logic, ladder diagrams, and structured statement tables, which

---

[*] *Corresponding author.*
E-mail address: a.moloody@gmail.com

https://doi.org/10.37934/sej.14.1.160174

collectively establish the basis of system control. Nevertheless, in electrical engineering and automation settings, several practical obstacles may still arise, hindering the peak performance of PLC-based systems [2]. Tackling these challenges necessitates a comprehensive examination of PLC roles and impacts in electrical automation, facilitating system enhancement, increased efficiency, and simpler functioning in both industrial and everyday scenarios [2]. The swift progress of industrial automation has heightened demands for electrical automation control systems, especially as the application of Programmable Logic Controllers (PLCs) becomes more prevalent and advanced [1]. PLCs signify a successful combination of conventional control techniques with contemporary scientific and technological resources. Leveraging computer-based programming, PLCs can be tailored with great adaptability to fulfill actual production requirements, greatly improving operational productivity and effectiveness [1].

In implementation, PLC development relies on programming logic, ladder diagrams, and structured statement tables, which collectively establish the basis of system control. Nevertheless, in electrical engineering and automation settings, several practical obstacles may still arise, hindering the peak performance of PLC-based systems [2]. Tackling these challenges necessitates a comprehensive examination of PLC roles and impacts in electrical automation, facilitating system enhancement, increased efficiency, and simpler functioning in both industrial and everyday scenarios [2]. From a business viewpoint, organizational operations are influenced by contractual structures that dictate stakeholder relationships and duties [3]. Legal and economic theory frequently perceives organizations as interrelated networks of contractual agreements between individuals [4]. These agreements generally comprise foundational and regulatory standards that create and uphold social and organizational order [3], [5].

Meeting these standards and showing adherence requires considerable effort and resources. Businesses dedicate significant time and financial resources to gather, validate, and report compliance documentation, but these tasks continue to be very resource-heavy. Integrating information systems reduces these expenses by facilitating the organized collection and assessment of compliance data, while also averting violations through built-in compliance measures [6]. In this context, the current study investigates how assurance can be provided in settings where control processes are entirely automated. It examines the roles of management, auditors, and various stakeholders, concentrating on what qualifies as sufficient and trustworthy compliance evidence. Utilizing well-established audit theory, the research posits that automated control systems can significantly lower compliance expenses by enhancing preventive and detection measures. This role is backed by a case study that explores the use of automated control systems in the acquisition process for public transport services, as shown in Figures 1 and 2., [7].

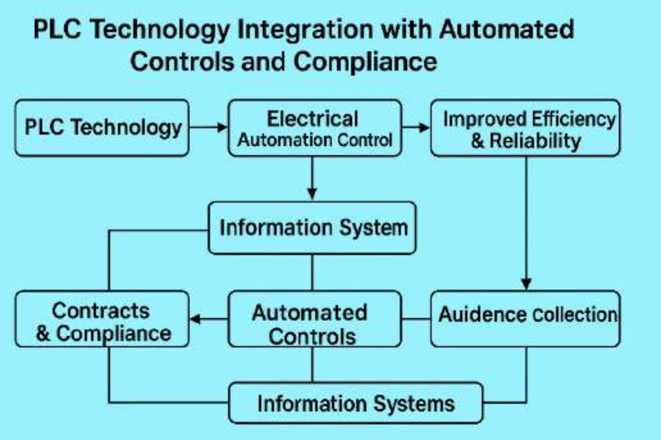

Fig. 1. PLC Automation in Auditing From Implementation to Evidence

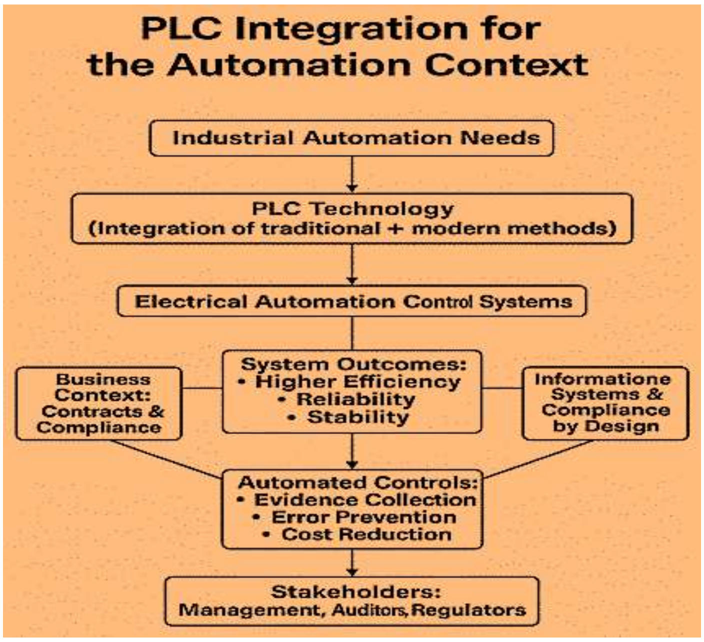

Fig. 2. PLC Technology for Compliance and Process Reliability

2. Core Principles and Applications of PLC Systems

A Programmable Logic Controller (PLC) is an adaptable electronic control system for overseeing industrial operations with great accuracy. Functioning as a programmable memory unit, it retains and performs logic-driven commands, Figure 3. PLCs are commonly employed for automated management and operational data recording. By integrating relay-contact principles with technologies like cloud computing, PLCs address the shortcomings of traditional electrical systems, including complicated wiring, low dependability, and excessive energy consumption [8–9]. PLCs take signals from field devices through input modules, analyze them in the CPU, and generate outputs based on set logic, allowing for adaptable and smart system control. They provide robust resistance to outside interference and permit tailored control systems to address various operational requirements. In contrast to electromechanical systems, PLC programming streamlines setup, automatically assessing inputs and performing tasks without the need for complicated manual instructions [10,11]. When created with thorough design and control logic evaluation, PLC projects attain greater consistency, efficiency, and dependability in industrial uses.

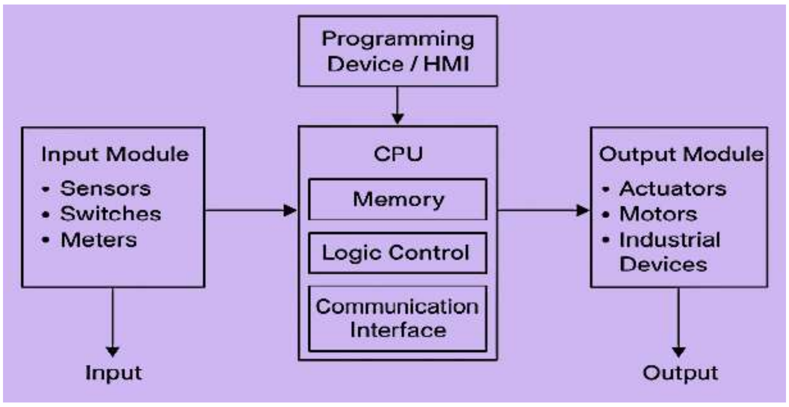

Fig. 3. PLC Configuration and Components

3. Theoretical Model for PLC-Based Automation Management

3.1 Communication Framework Design and Implementation

In electrical automation control systems, the communication infrastructure is essential for system dependability, effectiveness, and scalability. Networks typically have many terminal nodes, resulting in a complex topology, with power units linked through wired or wireless connections. Traditional radio-based communication is economical but restricted in stability and dependability, rendering it inadequate for terminals needing constant operation. Cutting-edge communication technologies tackle these challenges by providing flexible routing, real-time data reporting, and enhanced security, albeit with increased implementation expenses. Ethernet has emerged as the standard for industrial communication, connecting field devices with enterprise management systems to facilitate complete digitalization.

Optical fiber is frequently utilized as the Ethernet backbone, offering excellent resistance to interference and reliable real-time monitoring, even under challenging conditions [12–13]. Network bus cycles are split into reserved and non-reserved time periods, with time-sensitive IO data sent during reserved periods to guarantee predictable communication. UDP-based debugging is utilized for interaction between PC and embedded hardware. On the PC side, UDP applications are developed as DLLs to connect the visualization module to the PLC via specific functions. For example, a DLL such as dllUdp.dll created in Visual C++ can help with UDP functions, enabling custom features in the visualization software to interact directly with the PLC for effective real-time monitoring, see Table 1.

3.2 PLC Circuit Design and Configuration

Fieldbus technology, being a sophisticated data communication network, links distributed field devices to a centralized control system, enhancing openness, interoperability, reliability, flexibility, and operational safety. In this design, the PLC acts as the main control unit, accommodating different cable types to guarantee reliable signal transmission [14]. PLC-driven systems control communication by enhancing data transfer, distributing resources, and ensuring secure processes.

In application, these systems adjust to various environmental and operational circumstances. For example, in processes where temperature is critical, the PLC combines temperature variables with optimization methods to ensure consistent performance. The configuration module specifies essential components, including module IDs, rack positions, and connection techniques, enabling smooth integration of hardware and software. Analog I/O tasks necessitate accurate calibration of signal types, offsets, measurement ranges, and filtering intervals, adhering to industry standards.

At the software level, instruction codes establish the foundation for dependable process execution. Merging instructions into functional modules enables intricate tasks like parameterized I/O, precision adjustments, complete process simulations, and automated module coding, enhancing machining accuracy and product quality. The PLC carries out instructions by retrieving data from the image and element registers and producing control signals for actuators and devices. In the output refresh phase, all outputs are refreshed instantaneously. Adhering to engineering best practices, the design of systems must keep input circuits and total automation at a maximum of 80% of the rated capacity, guaranteeing safety margins and enduring reliability, as shown in Table 2 and Figure 4., [15].

Table 1
Communication Techniques in Electrical Automation

Communication Method	Cost	Reliability	Security	Application Suitability	Advantages	Limitations
Ordinary Radio Communication	Low	Low	Basic	Not suitable for high-reliability distribution terminals	Low cost, simple implementation	Unstable, prone to interference, unsuitable for critical systems
Advanced Wireless (with free routing & active reporting)	High	High	Strong	High-reliability distribution terminals	High security, flexible routing, proactive reporting	High cost of deployment and maintenance
Ethernet (Standard)	Medium	High	Moderate	Field device layer to enterprise management layer	Integration of control and management networks, supports digitalization	Susceptible to noise in industrial environments if not fiber-based
Optical Fiber Ethernet (Backbone)	Medium–High	Very High	High	Real-time monitoring in high-noise industrial environments	Excellent anti-noise performance, reliable, supports long-distance communication	Higher installation and maintenance cost
UDP Communication with DLL Integration	Medium	High (with proper configuration)	Application-dependent	Embedded system to PC communication (visualization)	Real-time data transfer, seamless PLC integration, customizable functions	Requires advanced programming (DLL development), potential packet loss without proper handling

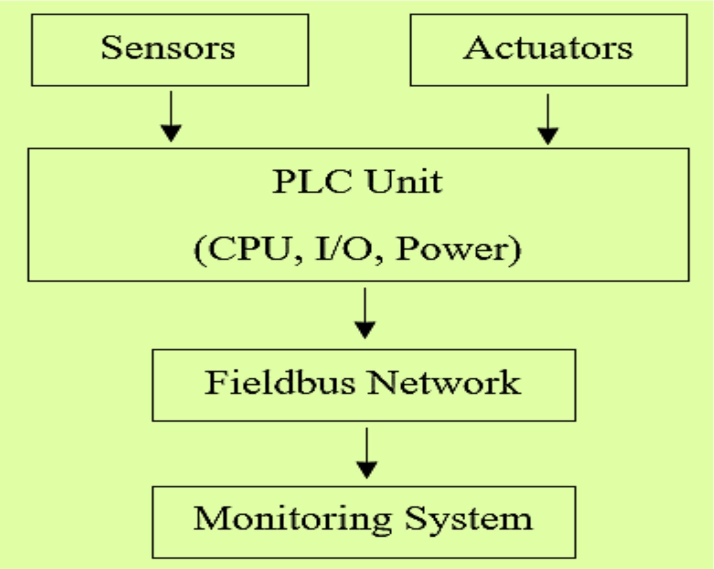

Fig. 4. PLC Circuit Design with Fieldbus Integration

Table 2
Key Factors in PLC Circuit and Analog I/O Setup

Category	Parameters / Features	Purpose / Importance
Fieldbus Communication	Network topology, supported protocols, cable specifications	Ensures reliable connectivity between field devices and central control unit
PLC Power Management	Voltage range, current rating, load capacity	Provides stable operation and prevents overloading
Module Configuration	Module name, rack slot number, wiring method	Enables structured system design and easy maintenance
Analog Input	Signal type (voltage/current), offset, range, filtering time	Guarantees measurement precision and standard compliance
Analog Output	Output range, response time, compensation factors	Improves control accuracy and process reliability
Software Instructions	Functional blocks, precision compensation, simulation routines	Enhances machining accuracy and facilitates automated programming
Capacity Utilization	≤ 80% of rated input/output load	Improves safety and prolongs system lifetime

3.3 Control System Software Development

In automation systems, software consists of an organized collection of code sequences transformed into executable commands, improving hardware performance and facilitating control goals. The most essential element is the control-oriented software, illustrated in Figure 5. The input module includes a touch screen interface, functioning as the operational panel and primary user interface for efficient human-machine interaction. The host system employs touch-screen macro programming to control the PLC.

For particular control functions, the primary PLC program invokes subroutine modules, generating ladder diagrams for different tasks. Data preparation begins with modifying information in office applications and storing it in CF cards in BIN format. These cards are placed into the touch screen, where macro-instruction processes transfer the data into the W1-2000 address. This process guarantees seamless integration of data management, program execution, and overall system oversight, as shown in Table 3.

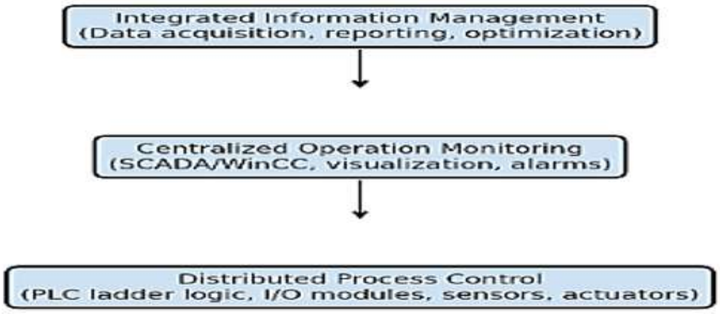

Fig. 5. Layered Architecture of PLC-Driven Electrical Automation System Information, Supervision, and Process Control

Table 3
System Development and Troubleshooting in PLC Automation

Stage	Description	Tools/Methods Used
Control Flowchart Design	Visualizes logical sequence of actions and conditions	Flowchart tools, process diagrams
PLC Program Development	Implementation of ladder diagrams, statement tables, or function blocks	PLC programming software (e.g., TIA Portal)
Debugging & Modification	Iterative correction until system fulfills all functions	Online debugging, simulation tools
Motion Control Integration	Use of stepper/servo motors for trajectory and precision control	Servo drives, trajectory control modules
Remote Monitoring Setup	Establishing communication, visualization, and alarm systems	WinCC/SCADA, network configuration
Simulation & Verification	Hardware-in-the-loop and software simulation of controlled objects	PLC hardware + software simulation platforms
Final Deployment	Program download to actual PLC with technical documentation prepared	PLC racks, expansion modules, field devices

4. PLC-Based Electrical Automation Troubleshooting

The architecture of a PLC-driven electrical automation system is structured in three levels: distributed process control, centralized operational oversight, and integrated information management. At the distributed control level, application programs are created with PLC tools utilizing ladder diagrams, statement lists, or function block diagrams to oversee equipment metrics and facilitate automated actions. Development starts with a control flowchart for the system, illustrating the sequences of operations and logical conditions. Designing ladder diagrams or programming in alternative PLC languages requires a process of iterative debugging and enhancement, along with thorough technical documentation [16].

For motion management, PLCs utilize trajectory regulation through stepper and servo motors for accurate position control, managed acceleration, and exceptional reliability. In chemical production and control systems, PLCs enhance device synchronization, decrease response durations, and improve system reliability. Remote supervision further decreases operational expenses, minimizes cabling, streamlines installation, and enhances flexibility and safety. Standard PLC racks consist of main, expansion, and configuration racks, with system growth accomplished through remote I/O, network setup, and equipment integration. Analog control modules enhance signal conversion, increasing accuracy and flexibility. Development generally comprises three roles: programming the PLC, constructing the WinCC monitoring interface, and developing a simulation model for the controlled object. Once debugging is complete, the validated program is uploaded to the PLC. The regulated object is subsequently simulated through a combined hardware-software approach, guaranteeing that its behavior matches the desired process. Incorporating hardware PLCs, WinCC monitoring, and simulation provides operational efficiency that closely aligns with the real system.

5. Auditing and Automation Principles Iin Control Systems

The principle of compliance by design focuses on integrating regulatory and control measures directly into business processes and the information systems that govern them. Conformance testing enables organizations to assess in advance if processes align with compliance standards [14]. Nonetheless, two critical inquiries emerge: How can legal and regulatory obligations be converted into process-specific limitations? To what degree does adherence to processes provide evident assurance and dependability? To tackle these inquiries, it's essential to revisit fundamental principles of audit theory.

5.1 Real-World Consistency

Utilizing Clark and Wilson's framework [9], auditing differentiates between internal and external consistency. An effectively designed, specification-validated, and tested computer system shows internal consistency by generating correct outputs from precise inputs. Nevertheless, internal reliability by itself does not ensure external consistency, which necessitates that outputs truly represent actual real-world conditions. Obtaining this alignment necessitates technical accuracy backed by protective measures: organizational strategies (division of responsibilities, role-specific duties), procedural strategies (regular maintenance, ongoing monitoring, structured oversight), and physical strategies (restricted access, security fences, identity validation). Collectively, these crucial controls guarantee that the integrity of technical systems is supported by human, procedural, and physical measures, facilitating effective and dependable compliance in execution.

5.2 Audit Risk Assessment Framework

Auditors must offer reasonable assurance that management's assertions are precise, genuinely representing real circumstances, and comprehensive, encompassing all pertinent elements. Audit risk is referred to as "the risk that the auditor might unintentionally neglect to appropriately alter their opinion on financial statements that are significantly misstated" [13]. To evaluate and reduce this risk, auditors utilize the Audit Risk Model (ARM), a systematic framework for planning and conducting audits, formally expressed as equations 1 and 2 as shown below:

$$\text{AuditRisk} / \text{InherentRisk} = \text{ControlRisk} \times \text{DetectionRisk} \tag{1}$$

or in logarithmic form:

$$\ln(\text{AuditRisk}) = \sum \ln(x),\ x \in \{\text{InherentRisk}, \text{ControlRisk}, \text{DetectionRisk}\} \tag{2}$$

This framework assists auditors in defining the suitable extent of procedures by assessing the probability of misstatements, the efficiency of internal controls, and the risk of undiscovered errors. The key benefit lies in offering a systematic method for managing risks, guaranteeing that audit decisions are dependable and grounded in evidence. The model directs auditors regarding the level and thoroughness of substantive testing, with each element targeting a particular dimension of audit risk. Inherent Risk (IR) refers to the probability of a significant misstatement in a management assertion prior to accounting for controls, usually elevated for complicated or fraud-sensitive transactions.

Control Risk (CR) refers to the likelihood that internal controls do not succeed in preventing or identifying misstatements, where deficiencies or vulnerabilities elevate this risk. Detection Risk (DR) refers to the possibility that auditors do not recognize a material misstatement even after conducting tests, owing to constraints in sampling or the adequacy of evidence. Auditors modify testing intensity by evaluating the interplay of IR, CR, and DR: high IR and CR necessitate a reduction in DR through more detailed procedures, whereas lower IR and CR permit less comprehensive testing.

5.3 Control System Automation

During formal compliance validation of a business process and its software system, like conformance testing [14], each transaction is properly structured and complies with defined terms. Abstraction and data encapsulation guarantee that information is reachable only through permitted applications, avoiding unintended mistakes, unauthorized modifications, or abuse. Automated, integrated controls serve two primary purposes: they avert material misstatements, minimizing internal control risk, and bolster the dependability of audit evidence by preserving precise transaction records. Consequently, detection risk, or the likelihood that auditors do not recognize a significant misstatement, is reduced. With a predetermined acceptable audit risk, any decrease in control and detection risks enables auditors to depend less on substantive testing, lightening their workload and reducing audit expenses. Essentially, automating controls reduces expenses by enhancing the prevention of misstatements (compliance by design) and the identification of misstatements (audit evidence reliability). These advantages are demonstrated through real-world auditing situations in the next section, Figure 6 and Table 4.

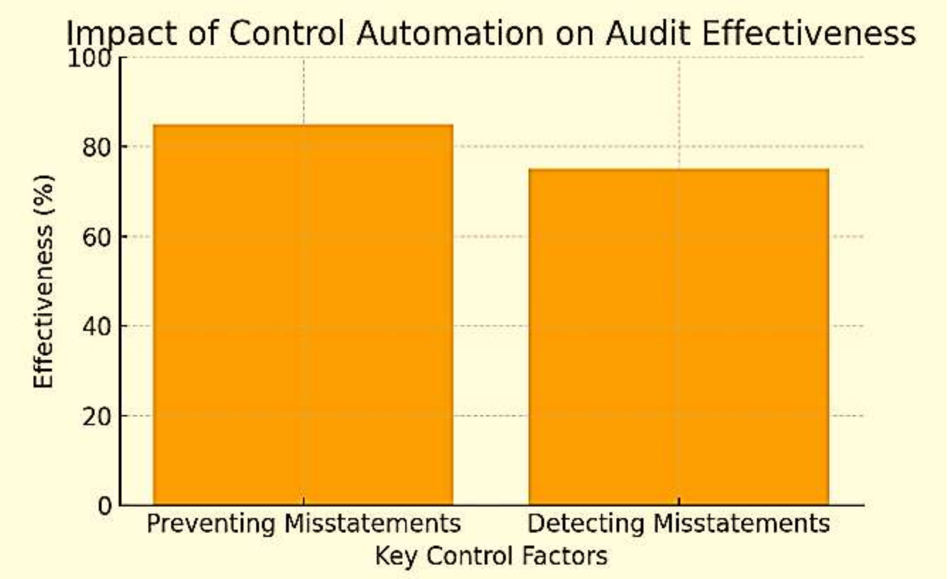

Fig. 6. Control Automation and Audit Effectiveness

Table 4
Benefits of Automated Control in Auditing.

Prevention of Misstatements	Embeds compliance into processes, reducing internal control risk	Lowers the likelihood of material errors or intentional manipulation
Detection of Misstatements	Ensures accurate and reliable transaction data, strengthening audit evidence	Reduces detection risk and minimizes the need for extensive substantive testing

5.4 Automated Control System Deployment

When a business process and its associated software are officially confirmed for compliance, such as through conformance testing [14], every transaction is accurately organized and fulfills contractual requirements. Through the use of abstraction (information hiding), access to data is limited to authorized applications, minimizing unintentional mistakes and deliberate tampering. Automated and integrated controls offer two primary advantages: they reduce material misstatements, minimizing internal control risk, and enhance the reliability of audit evidence, boosting auditor confidence. This approach minimizes detection risk, enabling auditors to depend less on extensive substantive testing. As a result, auditing becomes more effective, and associated costs, which typically comprise a significant portion of overall control expenditures, are reduced. Automated controls therefore enhance compliance and audit quality by improving both the prevention of errors (compliance by design) and their identification (trustworthy audit evidence). The next section demonstrates these advantages in real-world contexts.

6. Public Transport Service Procurement as Case Study

This case study explores the acquisition of public transit services for social care in the Netherlands, mainly aiding senior citizens, people with physical disabilities, and individuals facing mental health challenges. Municipalities are tasked with contracting these services under stringent regulatory supervision, including European Directive 2004/18/EC, which upholds principles of equal treatment, proportionality, and transparency. An illustrative case is the TaxiBus agreement (TED 2010/S 31-044711, 13/02/2010), in which SRE served as the contracting authority for fifteen municipalities in the Eindhoven area, overseeing financial duties and assisted by an independent external auditor. The Transport Service Provider (TSP) offered demand-responsive taxi bus services, obtaining set monthly payments from SRE along with passenger contributions.

The agreement required detailed documentation of every trip that was requested, finished, or canceled, along with passenger information that impacts billing. It outlined safety regulations, driver requirements, service standards, geographic coverage, fare systems, and passenger types, along with performance metrics and consequences for breaches. Monthly bills from TSP were provided with comprehensive Excel spreadsheets that recorded trips, patient identifiers, schedules, and trip specifics, adhering to a specified data protocol for content and order. Regardless of these actions, risks persisted since the Excel file was fully created by the TSP, which posed a possibility for incomplete reporting or tampering, illustrating typical agency issues [10].

To address this, SRE established automated controls in two phases: validation and recalculation, as shown in Figure 7. Validation included four assessments: (1) confirming the presence of all essential data elements; (2) checking syntactic rules, like ID numbers; (3) validating semantic agreement with contractual standards, for example, location details within the contract area; and (4) aligning data elements, such as correlating trip distances with travel zones. Every row in the Excel matrix indicated a trip, and these verifications were implemented methodically. After validation, invoices were independently recalculated. Differences beyond set tolerances necessitated TSP justification, and insufficient explanations permitted SRE to issue credit invoices. This automated method improved transparency, reduced the risk of manipulation, and guaranteed adherence to contractual and regulatory requirements, Figure 8.

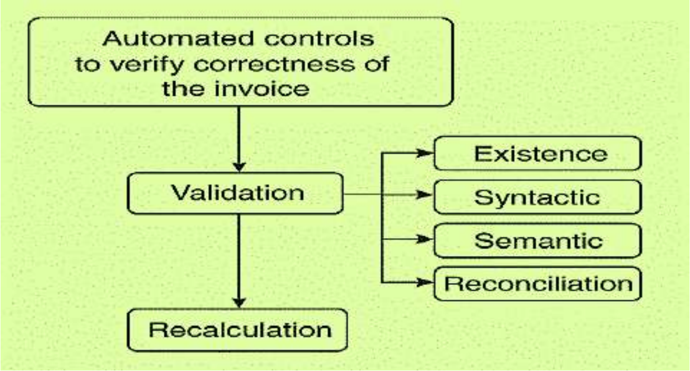

Fig. 7. Invoice Verification and Auditing Procedures

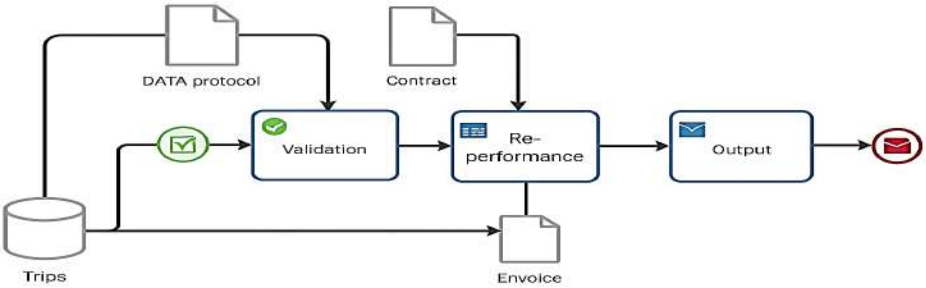

Fig. 8. Automated Invoice Accuracy Systems

The agreement mandates that an independent certified auditor delivers an annual qualified opinion regarding the trustworthiness of billing procedures and associated information systems. Two facets of integrity are examined: internal and external. Internal integrity is maintained via a four-stage validation process, verifying that all data and transactions adhere to set standards. External integrity is partially guaranteed by the auditor's assessment, which provides merely a temporary "snapshot," and is additionally strengthened by the organized data file containing verification components. The fourth validation phase is vital, confirming that all audit trail events match properly structured transactions and that duties are properly segregated. For instance, trip coordination is managed at headquarters, whereas drivers carry out the journeys, establishing inherent oversight through distinct duties. Validation must clearly verify both transaction integrity and duty segregation; otherwise, recalculated outcomes might not hold evidentiary weight for auditors. In this case study, validation is usually conducted on a monthly basis in batch mode, although it can also be executed in real-time at the row level. Recalculation typically occurs on total aggregates but can also be performed daily or weekly for quicker verification [17–23].

An extensive analysis of the latest developments in PLC-based automation systems highlights a significant emphasis on enhancing performance, improving energy efficiency, and increasing system intelligence. Nonetheless, the majority of current research explores these factors separately, with minimal focus on combined cost optimization and adherence to regulations. To place the current work within the existing research context, a comparative analysis of recent studies is performed, as outlined in Table 5.

Table 5
Benchmarking of Recent PLC-Based Automation Studies

Study Focus (2020–2025)	Core Technology	Optimization Target	Method Used	Limitations Identified	Gap Addressed by This Work
Smart Factory Automation	PLC + IoT	Energy efficiency	Data-driven control	Limited cost modeling	Integrates cost + compliance + control
Industrial IoT Systems	PLC + Cloud	Monitoring & analytics	Cloud dashboards	Weak real-time actuation	Adds real-time control + audit logic
Energy Management Systems	PLC + SCADA	Power consumption	Optimization algorithms	Ignores compliance cost	Includes regulatory cost reduction
Cyber-Physical Systems (CPS)	PLC + AI	System intelligence	Machine learning	High implementation cost	Focus on cost-effective deployment
Traditional Relay Systems	Relay logic	Basic control	Manual wiring	High maintenance cost	Replaces with PLC optimization strategy
Normative Multi-Agent Systems	Agent-based control	Compliance automation	Rule-based agents	Lack of industrial integration	Embeds agents into PLC frameworks

A comparative cost analysis is conducted to assess the economic effects of shifting from conventional relay systems to sophisticated PLC-based architectures. This examination takes into account essential operational and lifecycle cost elements, such as installation, upkeep, energy usage, and expenses related to compliance. The findings, displayed in Table 6, emphasize the possible cost reductions realized via optimized PLC integration.

Table 6
Comparative Cost Analysis, Traditional vs PLC-Based Systems

Cost Component	Traditional System	PLC-Based System	% Reduction	Explanation
Wiring & Installation	Very High	Low	40–60%	Reduced physical wiring
Maintenance	High	Moderate	30–50%	Easier diagnostics
Energy Consumption	Moderate	Low	15–35%	Optimized control logic
Labor (Monitoring)	High	Very Low	50–70%	Automation replaces manual supervision
Compliance & Auditing	High	Low	40–65%	Automated reporting
System Downtime	High	Low	20–45%	Fault detection &

In light of the recognized research gaps and the shortcomings of current methods, a multi-layer optimization framework is suggested to improve both the efficiency and cost-effectiveness of automated electrical control systems. The structure combines control, communication, intelligence, and compliance systems into a cohesive architecture. Table 7 provides a detailed account of the structure and functional roles of each layer.

Table 7
Multi-Layer PLC Optimization Framework

Layer	Components	Function	Optimization Impact
Physical Layer	Sensors, actuators, PLC hardware	Data acquisition & execution	Reduces hardware redundancy
Control Layer	PLC logic, ladder diagrams	Real-time control decisions	Improves efficiency
Communication Layer	IoT, cloud integration	Data exchange	Enables remote monitoring
Intelligence Layer	AI / agent-based rules	Predictive & adaptive control	Reduces failures
Compliance Layer	Normative agents	Regulatory enforcement	Minimizes audit cost
Application Layer	Industry use case (transport)	End-user functionality	Improves service delivery

To provide additional evidence of the proposed method's effectiveness, a trend analysis of operational expenses across various generations of control systems is performed. The examination highlights the shift from traditional relay systems to sophisticated PLC-based solutions that include optimization and compliance capabilities. The trend of cost reduction that results is shown in Figure 9.

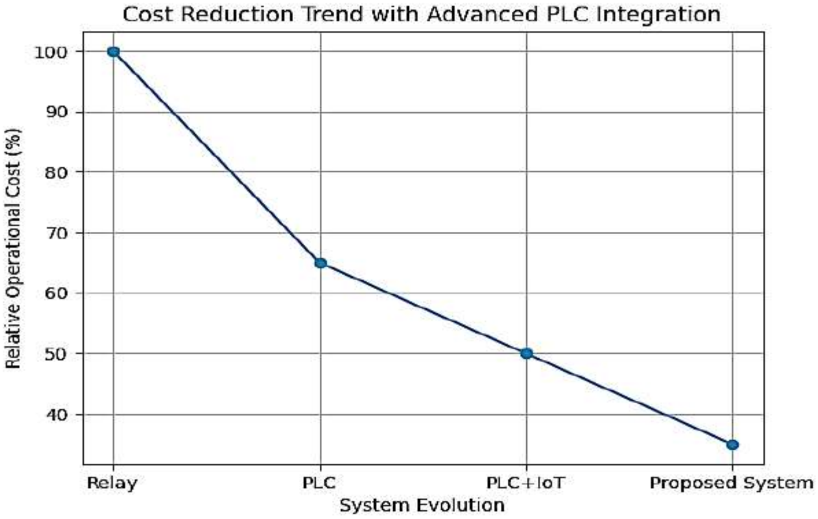

Fig. 9. Use it in the results/discussion section to support your claim of cost reduction through PLC integration

A comparative evaluation of control system performance is provided to assess enhancements in reliability, energy efficiency, and compliance capability among various system architectures, as shown in Figure 10.

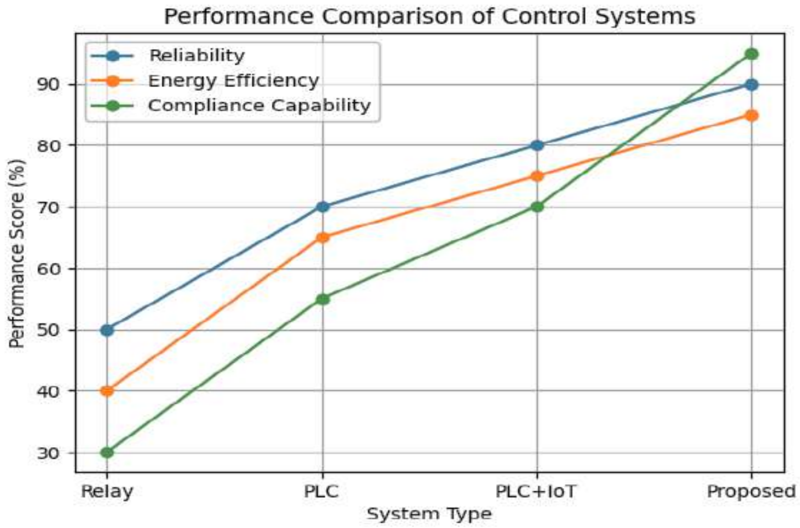

Fig. 9. Comparative Performance Analysis of Control System Architectures

7. Conclusions

Programmable Logic Controllers (PLCs) are crucial for electrical automation control systems, providing significant features and adaptability, although handling intricate control logic may be difficult. Integrating conventional industrial methods with contemporary technologies, particularly computer-based tools, allows PLCs to be programmed according to real production requirements, enhancing productivity, efficiency, dependability, equipment longevity, and facilitating automated power distribution. To maximize these advantages, industry stakeholders must promote research in power distribution systems to attain complete automation and dependable electricity services. This research emphasizes compliance automation and the concept of "compliance by design" from a business and auditing viewpoint. The audit risk model indicates that automated controls cut expenses by reinforcing preventive measures (minimizing internal control risk) and improving the reliability of audit evidence (decreasing detection risk).

This is demonstrated in a public transportation procurement case study, where invoices are subject to automated validation by checking for data presence, syntax, value constraints, and reconciliation. Certified auditors additionally guarantee integrity via expert opinions. The case also relates to wider theory, emphasizing Normative Multi-Agent Systems (NMAS) as a structure for examining constitutive rules, roles of stakeholders, and trust in adherence. Compliance, therefore, goes further than just technical validation to include socio-technical interactions between participants. Future studies may combine NMAS with game-theoretic modeling to explore how normative frameworks, such as IT infrastructure, auditors, and legal institutions, influence the design and operations of automated compliance, enhancing efficiency, accountability, and trust in changing regulatory landscapes.

Reference

[1] Tao, S., W. Wei, S. Yijun, C. Xinyu, and S. Hailong. "Application design of Siemens S7-1200 PLC in elevator operation control system." *Automation Technology and Application*, no. 11 (2016).

[2] Xiaoxia, C., and Q. Xinbiao. "Study on the application efficiency of OPC technology in PLC control system." *Electrical Automation* 38, no. 4 (2016): 110–112.

[3] Boella, G., and L. van der Torre. "Contracts as legal institutions in organizations of autonomous agents." In *Proceedings of the Third International Joint Conference on Autonomous Agents and Multi Agent Systems (AAMAS'04)*, 2004.

[4] Clark, D. D., and D. R. Wilson. "A comparison of commercial and military computer security policies." In *IEEE Symposium on Security and Privacy*, 184–194, 1987. https://doi.org/10.1109/SP.1987.10001.

[5] Searle, J. R. *The Construction of Social Reality*. New York, NY: The Free Press, 1995.

[6] Governatori, G., and S. Sadiq. "The journey to business process compliance." In *Business Process Management*, 426–445. IGI Global, 2009. https://doi.org/10.4018/978-1-60566-288-6.ch022.

[7] Abbas, M., A. Azizan, S. H. Tang, K. Raja, and Z. Ali. "PID controller parameter tuning based on a modified differential evolutionary optimization algorithm for the intelligent active vibration control of a combined single link robotics flexible manipulator." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 52, no. 1 (2024): 234–258. https://doi.org/10.37934/araset.52.1.234258.

[8] Bin, W. "Robot packaging control system of LCD glass substrate based on PLC." *Electrical Automation*, no. 1 (2015): 96–98.

[9] Dong, Y., L. Yong, T. Guoqiang, P. Zhenyu, and Y. Qiaojun. "Design of tunnel fan system based on Siemens PLC." *Automation Instrument* 36, no. 9 (2015).

[10] Peng, W., X. Shixu, and W. Jingwen. "Research and design of automatic weighing monitoring control system based on PLC." *Manufacturing Automation*, no. 10 (2016).

[11] Peihong, M., J. Tinggang, and N. Yugang. "Application of DDE technology in sewage treatment control system." *Electrical Automation* 38, no. 2 (2016).

[12] Yong, Z., W. Aiguo, and Z. Jie. "Lubricating oil production control system based on configuration software and PLC." *Instrument Technology and Sensors*, no. 9 (2015): 74–76.

[13] Xiaogeng, F., and F. Xiao. "Design and research of electrical control system of shearing machine based on PLC." *Mechanical Manufacturing and Automation*, no. 6 (2018).

[14] Kai, W. "Design of automatic control system for machine tools based on PLC technology." *Bonding* 42, no. 6 (2020).

[15] Abbas, M., A. Azizan, S. H. Tang, K. Raja, and Y. Zuhri. "Review of vibration control and optimization in flexible manipulators." *Pertanika Journal of Science and Technology* 33, no. 1 (2025).

[16] Hongming, K., J. Chunfeng, L. Wei, J. Xiaolin, C. Haibo, and K. Hongming. "Design of liquid level and temperature control system based on PLC." *Industrial Instrumentation and Automation Devices*, no. 6 (2015).

[17] Boella, G., and L. van der Torre. "A game theoretic approach to contracts in multiagent systems." *IEEE Transactions on Systems, Man and Cybernetics – Part C* 36, no. 1 (2006): 68–79. https://doi.org/10.1109/TSMCC.2005.854376.

[18] Boella, G., H. Verhagen, and L. van der Torre. "Introduction to the special issue on normative multiagent systems." *Journal of Autonomous Agents and Multi-Agent Systems* 17, no. 1 (2008): 1–10. https://doi.org/10.1007/s10458-008-9042-6.

[19] Clark, D. D., and D. R. Wilson. "A comparison of commercial and military computer security policies." In *IEEE Symposium on Security and Privacy*, 184–194, 1987. https://doi.org/10.1109/SP.1987.10001.

[20] Abbas, M., A. Azizan, S. H. Tang, and K. Raja. "An experimental study on the mechatronics design and implementation of an intelligent active vibration control system for a CSLRFM." *Journal of Advanced Research in Applied Mechanics* 134, no. 1 (2025): 61–89. https://doi.org/10.37934/aram.134.1.6189.

[21] Eisenhardt, K. M. "Agency theory: An assessment and review." *Academy of Management Review* 14, no. 1 (1989): 57–74. https://doi.org/10.5465/amr.1989.4279003.

[22] Knechel, W., S. Salterio, and B. Ballou. *Auditing: Assurance and Risk*. 3rd ed. Cincinnati, OH: Thomson Learning, 2007.

[23] Rozinat, A., and W. M. P. van der Aalst. "Conformance checking of processes based on monitoring real behavior." *Information Systems* 33, no. 1 (2008): 64–95. https://doi.org/10.1016/j.is.2007.07.001.