

Achieving Continuous Process Automation in the PLC World: Architectures, Standards, and Emerging Strategies

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Abstract: *Programmable Logic Controllers (PLCs) were originally designed for discrete, sequential machine control. Yet as industrial automation has evolved, process manufacturers across chemical, oil and gas, water treatment, and power generation sectors increasingly ask whether PLC-based architectures can deliver the reliability, continuity, and analytical depth historically associated with Distributed Control Systems (DCS). This review paper examines the structural gap between PLC capabilities and the requirements of continuous process automation, and presents a comprehensive analysis of the technical strategies, standards, and architectural patterns through which that gap is being closed. Key approaches examined include hardware redundancy architectures including hot standby and triple modular redundancy, advanced PID and cascade control implementation in IEC 61131-3 environments, the adoption of IEC 61499 event-driven function blocks for process applications, the emergence of virtual and soft PLC platforms, and OPC UA-enabled process data integration. An original Continuous Process Automation Achievement Framework (CPAAF) is proposed, providing a structured five-pillar evaluation model for assessing the suitability of PLC-based architectures for continuous process applications. The paper concludes that while no single PLC technology fully replicates the integrated, purpose-built continuous control environment of a mature DCS, the convergence of modern hardware redundancy, advanced software standards, and open connectivity is making PLC-based continuous process automation technically viable and economically compelling across a wider range of process applications than at any prior point in the technology's history.*

Keywords: PLC, continuous process automation, DCS, IEC 61131-3, IEC 61499, hot standby redundancy, virtual PLC, OPC UA, CPAAF, industrial automation, process control, soft PLC

1. Introduction

The Programmable Logic Controller, introduced commercially by Modicon in 1968, was designed to replace relay-based control panels in discrete manufacturing environments. Its architecture- cyclic scan execution, ladder logic programming, and deterministic I/O handling- was purpose-built for the repetitive, sequential logic of assembly lines, packaging machines, and material handling systems. Continuous process control, which governs the sustained, uninterrupted management of flow rates, temperatures, pressures, and chemical compositions in industries such as oil and gas, chemical processing, power generation, and water treatment, belonged to a different architectural tradition: the Distributed Control System, with its integrated PID loop management, plant-wide historian, redundant controller architecture, and process-centric configuration environment [1].

This architectural divide has persisted for decades. DCS vendors including Honeywell, Emerson, ABB, Yokogawa, and Schneider Electric built purpose-built process control platforms with continuous operation, high availability, and integrated alarm management as foundational design requirements. PLC vendors including Siemens, Rockwell Automation, Mitsubishi, and Allen-Bradley built platforms optimised for speed, discrete logic density, and machine-level control [2].

But the divide is narrowing- and the industry has noticed. A 2024 survey conducted by Automation.com found that a significant share of process industry end-users are actively evaluating PLC-based alternatives to DCS for continuous process applications, driven by lower hardware cost, faster

engineering timelines, familiar programming environments, and the broader ecosystem of IIoT and analytics tools available for PLC platforms [3]. The question is no longer whether PLCs can be used in continuous process applications - they clearly can- but what technical provisions, architectural patterns, and software standards are required to make them perform reliably and continuously at the level that process industries demand.

This paper systematically addresses that question. It characterises the structural requirements of continuous process automation, identifies the specific capability gaps in traditional PLC architectures, reviews the technical strategies and standards that address those gaps, and proposes the Continuous Process Automation Achievement Framework (CPAAF) as an original structured tool for evaluating and planning PLC-based continuous process deployments.

2. Requirements of Continuous Process Automation

2.1 Defining continuous process control

Continuous process automation differs from discrete automation in three fundamental characteristics. First, the process never stops: a refinery distillation column, a chemical reactor, or a power generation turbine operates continuously over months or years, with planned shutdowns typically measured in days per year at most. Second, control loops are interdependent: changes in feed rate affect reactor temperature, which affects pressure, which affects product composition — control actions propagate across the process in ways that require coordinated, multi-variable regulation. Third, failure modes have consequence chains: an

uncontrolled deviation in a continuous process does not simply stop a machine; it can trigger cascade failures that affect safety, product quality, environmental compliance, and in worst cases, personnel safety [4].

These characteristics generate specific technical requirements that any control platform must satisfy for continuous process deployment. High availability- the capacity to sustain control function through hardware failures without process interruption- is non-negotiable. Alarm management- the systematic monitoring and prioritisation of process deviations - must be comprehensive and auditable. Process historian integration- the continuous recording of process variable data at sufficient resolution for trend analysis, performance monitoring, and regulatory compliance- is standard expectation. PID control with advanced loop tuning, cascade, ratio, and feedforward configurations is fundamental to process regulation [5].

2.2 Where traditional PLCs fall short

Traditional PLC architectures present four specific limitations for continuous process applications. The first is the scan cycle model: a PLC executes its control program in sequential, cyclic scans. All input states are read at the start of the scan, the program is executed, and all outputs are written at the end. For discrete logic, this is efficient and predictable. For continuous PID control across hundreds of loops, scan cycle limitations- typically 10 to 50 milliseconds for a fully loaded PLC- can introduce control latency that affects loop performance, particularly for fast-responding processes [6].

The second limitation is redundancy architecture. DCS systems are engineered with redundancy as a standard architectural component: redundant controllers, redundant I/O buses, and hot-standby failover are built-in expectations. In traditional PLC systems, redundancy must be deliberately engineered as an add-on, increasing both cost and system complexity [7]. The third limitation is the engineering environment: PLC programming has historically been code-centric, requiring engineers to manually build every process element — valve logic, memory tags, HMI graphics, alarm configurations — from scratch. DCS systems provide pre-engineered process object libraries that dramatically reduce engineering effort for common process elements. The fourth limitation is integrated process historian capability: most PLC platforms do not include a native historian and depend on third-party SCADA systems for data archiving, introducing additional integration complexity and potential points of failure in the data chain.

3. Technical Strategies for Continuous Process Automation

3.1 Hardware redundancy architectures

The most critical technical provision for PLC-based continuous process automation is a validated hardware redundancy architecture. Three configurations are in operational use. In hot standby redundancy, two PLC CPUs run continuously with synchronized program scans. Both processors have continuous access to I/O over redundant buses, and register data is exchanged over a dedicated fibre-

optic synchronization link. When the primary CPU fails, the standby takes over with a switchover time as low as 10 milliseconds- well within the tolerance of most process control loops. The Siemens SIMATIC S7-400H is a widely deployed example, with hot standby failover validated in power plants and gas production facilities [8].

Warm standby redundancy provides a lower-cost alternative in which the standby processor operates in shadow mode, receiving periodic updates from the primary at the end of each scan. Switchover time is longer- typically a few scan cycles- which may cause brief output holds. For processes tolerant of a 100 to 500 millisecond hold, warm standby provides significantly improved availability at lower hardware cost than hot standby. Triple Modular Redundancy (TMR), used in safety instrumented system applications, runs three processors simultaneously with a 2-out-of-3 voting logic for output determination, providing the highest fault tolerance for safety-critical continuous applications [7].

3.2 IEC 61131-3 for process control programming

IEC 61131-3 has evolved significantly since its initial publication to support continuous process control applications alongside its traditional discrete programming heritage. The Structured Text (ST) language provides high-level, Pascal-like syntax capable of expressing complex PID algorithms, cascade control structures, and process state machine logic that would be impractical in Ladder Logic. Function Block Diagram (FBD) provides a graphical representation of continuous control logic- PID controllers, signal conditioners, arithmetic blocks- that directly parallels the DCS configuration environment familiar to process engineers [9].

Modern IEC 61131-3 development environments, including CODESYS, TIA Portal, and Studio 5000, now provide pre-engineered process function block libraries aligned with ISA-88 batch control and ISA-106 procedural automation standards. These libraries provide the process object abstraction- valve control, PID loop management, phase logic - that reduces the engineering effort gap between PLC and DCS for continuous process applications. Control Engineering (2025) reports that the latest IEC 61131-3 environments support object-oriented programming features that enable DCS-style template-based configuration of process objects, further narrowing the engineering productivity gap [9].

3.3. IEC 61499 event-driven control for process applications

IEC 61499, originally published by the IEC in 2005, extends the PLC programming model with an event-driven function block architecture designed specifically for distributed control applications. In IEC 61499, function blocks include both data interfaces (inputs and outputs) and event interfaces (event inputs and event outputs). A function block executes its algorithm only when triggered by an event, rather than on every scan cycle. This event-driven model has two significant advantages for continuous process applications: it enables fine-grained control over execution timing without the fixed overhead of cyclic scan execution, and it provides a distribution model in which control logic can be partitioned

across multiple physical controllers without the programmer managing the distribution explicitly [10].

The Universal Automation Organization has advanced IEC 61499 adoption through a royalty-free runtime execution engine and a growing ecosystem of vendor-independent runtime implementations including the Eclipse Foundation's 4diac project. The O-PAS standard specifies IEC 61499 as the primary programming model for Distributed Control Nodes, making it the emerging standard for software-defined continuous process control [3]. For PLC-based process automation, IEC 61499 provides the bridge between the deterministic, hardware-bound execution model of traditional PLCs and the flexible, distributed execution architecture required for plant-wide continuous process control.

3.4. Virtual and soft PLCs

The separation of PLC runtime software from dedicated hardware- the soft PLC or virtual PLC (vPLC) concept- represents the most transformative recent development in PLC architecture for continuous process applications. A soft PLC runs on a general-purpose computing platform, separating the runtime execution environment from the physical I/O hardware. Remote I/O modules remain in the process field, connected over deterministic industrial Ethernet to the compute platform executing the control runtime [11].

This architecture has several implications for continuous process automation. Hardware refreshes- replacing aging compute hardware with newer, more capable platforms- no longer require re-engineering the control application. Multiple PLC runtime instances can run as virtual machines on a single physical server, enabling consolidation of PLC infrastructure in a manner directly analogous to IT server virtualization. Most significantly, the vPLC architecture enables high-availability deployment using enterprise IT virtualization tools (VMware, Hyper-V, KVM) that provide live migration and failover capabilities beyond what traditional PLC hardware redundancy provides. The most significant operational deployment of vPLC technology in continuous industrial environments is Volkswagen's Audi division installation of SIMATIC S7-1500V virtual PLCs in an axle assembly operation in Neckarsulm, Germany, operational since January 2024 [11].

3.5 OPC UA integration for process data continuity

Continuous process automation requires continuous data: every process variable, at sufficient resolution, archived to a historian and accessible to analytics, optimisation, and enterprise systems. OPC UA (Unified Architecture), standardised as IEC 62541, provides the secure, semantic data connectivity infrastructure that makes this possible for PLC-based process systems without proprietary middleware [12]. OPC UA's publish-subscribe model enables PLCs to push process variable data to historians and analytics platforms at configured intervals, with built-in security (authentication, encryption, access control) appropriate for OT environments. The OPC Foundation's OPC UA FX (Field eXchange) standard, demonstrated with controller-to-controller communications across 20 vendors, further extends OPC

UA's applicability to the peer-to-peer process coordination that continuous process automation requires [3].

4. Continuous Process Automation Achievement Framework (CPAAF)

The Continuous Process Automation Achievement Framework (CPAAF) is proposed as an original five-pillar evaluation and planning model for assessing and implementing PLC-based continuous process automation. The framework provides engineers and plant managers with a structured approach to determining what specific technical provisions are required for a given continuous process application, and to assessing whether a candidate PLC platform and architecture meet those requirements. Table 1 presents the CPAAF structure.

Table 1: CPAAF- Five Pillars of PLC Continuous Process Automation

Pillar	Requirement	Technical Solution	Evaluation Criterion
P1: Availability	Continuous operation through hardware failures	Hot standby / vPLC HA failover	Switchover time $\leq 10\text{ms}$; no loop interruption
P2: Control Fidelity	Accurate multi-loop PID at process timescales	IEC 61131-3 ST/FBD; event-driven IEC 61499	Scan $\leq 10\text{ms}$; cascade/feedforward capable
P3: Data Continuity	Continuous process historian at full resolution	OPC UA pub/sub to historian; redundant paths	Zero data loss; $\leq 1\text{s}$ resolution; audit trail
P4: Alarm Management	ISA-18.2 compliant alarm lifecycle management	Integrated SCADA or edge ML alarm intelligence	EEMUA 191: < 1 alarm/10 min steady state
P5: Scalability	Expand to plant-wide control without re-architecture	Distributed IEC 61499; OPC UA FX; vPLC scaling	New process segments: configuration, not re-code

Pillar 1- Availability- is the foundational requirement that determines whether a PLC-based system can be trusted for continuous process control. The evaluation criterion is stringent: hot standby failover with switchover under 10 milliseconds, and no interruption to active control loops during failover. Systems that cannot meet this criterion are limited to batch or semi-continuous applications where a brief control interruption is tolerable.

Pillar 2- Control Fidelity - addresses the quality of continuous loop control achievable within the PLC programming environment. A scan time under 10 milliseconds for the critical PID loop set, combined with the ability to implement cascade, feedforward, and ratio control configurations without custom code development, is the minimum threshold for process-grade control performance.

Pillar 3- Data Continuity- reflects the operational and regulatory reality that continuous process industries cannot tolerate gaps in their process data record. OPC UA publish-subscribe integration with a process historian, over redundant communication paths, with sub-second data resolution and

tamper-resistant audit trail generation, meets the operational requirements of ISA-18.2 alarm documentation and typical regulatory data retention requirements.

Pillar 4- Alarm Management- is frequently the most overlooked pillar in PLC-to-process deployments. A PLC system with a compliant alarm management architecture-rationalised alarm database, ISA-18.2 lifecycle management, and alarm rate monitoring against EEMUA 191 performance benchmarks- is a fundamental requirement for safe continuous process operation.

Pillar 5- Scalability- determines whether the PLC architecture can grow with the process without requiring re-architecture. Distributed IEC 61499 function block deployment and OPC UA FX peer-to-peer communication enable horizontal scaling that traditional PLC network topologies struggle to support cleanly.

5. Industrial Application Contexts

5.1 Chemical and water treatment plants

Chemical process plants operating batch-continuous hybrid processes- where discrete batch logic (filling, reacting, discharging) is combined with continuous regulatory control of temperature, pressure, and flow within each phase-represent the most natural fit for advanced PLC-based continuous control. IEC 61131-3 Sequential Function Charts (SFC) provide the batch phase sequencing logic aligned with ISA-88 Phase structures, while Structured Text PID function blocks handle the continuous regulatory loops within each phase. For water treatment facilities, where the process operates continuously but at moderate loop counts and with tolerance for brief control interruptions during maintenance, PLC-based hot standby architectures have become an established and cost-effective alternative to DCS [4].

5.2 Power generation and oil and gas

Power generation and oil and gas represent the most demanding environments for PLC-based continuous process control, combining high loop counts, fast-responding processes, stringent safety requirements, and extreme availability expectations. In these contexts, the limiting factor is rarely the PLC hardware itself — modern redundant PLCs with hot standby failover under 10 milliseconds meet the availability requirement — but the engineering environment: the absence of pre-engineered process object libraries and integrated alarm management that DCS platforms provide. Virtual PLC platforms that support multiple simultaneous runtime instances, combined with IEC 61499 distributed function block deployment for plant-wide coordination, are beginning to address this gap in large-scale oil and gas applications [11].

6. Conclusion

The PLC has evolved from a relay replacement for discrete machine control into a platform capable, with appropriate architectural provisions, of sustaining continuous process automation across a wide range of industrial applications. The five pillars of the Continuous Process Automation

Achievement Framework- Availability, Control Fidelity, Data Continuity, Alarm Management, and Scalability- provide a structured evaluation model that maps the requirements of continuous process control to the specific technical provisions that PLC-based systems must address.

No single development has been more significant in this evolution than the convergence of three trends: hardware redundancy achieving sub-10-millisecond failover, IEC 61499 event-driven programming providing the distribution model that IEC 61131-3 cannot, and virtual PLC platforms decoupling runtime from hardware. Together, these enable PLC-based architectures that approach- and in some dimensions exceed- the continuous operation characteristics of traditional DCS platforms, at hardware costs that make the economic case compelling for a growing range of process applications.

The workforce dimension must not be underestimated. Process engineers trained in DCS configuration environments face a genuine competency transition to PLC-based programming, even with the advances in IEC 61131-3 object-oriented programming and IEC 61499 function block libraries. Investment in cross-disciplinary engineering capability- engineers who understand both the process control requirements and the PLC programming environment- is a prerequisite for realising the full potential of PLC-based continuous process automation.

References

- [1] B. Liptak, *Instrument Engineers' Handbook: Process Control and Optimization*, 4th ed., CRC Press, Boca Raton, FL, 2005.
- [2] Twilight Automation, "PLC vs. DCS: Choosing the Right Control System for Your Industrial Application," 2025. [Online]. Available: <https://twilightautomation.com/plc-vs-dcs-choosing-the-right-control-system>
- [3] B. Lydon, "Industrial Controller Software Standards Discussions at ARC Forum 2024," *Automation.com*, Mar. 2024. [Online]. Available: <https://www.automation.com/en-us/articles/march-2024/industrial-controller-software-standards-arc-2024>
- [4] LS Electric, "DCS vs PLC: A Detailed Comparison of Control and Automation Systems," 2025. [Online]. Available: <https://www.lselectricamerica.com/blog/dcs-vs-plc/>
- [5] International Society of Automation, "ANSI/ISA-18.2: Management of Alarm Systems for the Process Industries," ISA, Research Triangle Park, NC, 2016.
- [6] A. J. Thornton, "Scan Time Reduction of PLCs by Dedicated Parallel-Execution Multiple PID Controllers Using an FPGA," *Appl. Sci.*, vol. 12, no. 12, p. 6060, 2022. <https://doi.org/10.3390/app12126060>
- [7] Automation Forum, "Understanding PLC Redundancy: Cold, Warm & Hot Redundancy," 2025. [Online]. Available: <https://automationforum.co/understanding-plc-redundancy-cold-warm-hot-redundancy/>
- [8] Instrumentation Tools, "What is Hot Standby in PLC?" [Online]. Available: <https://instrumentationtools.com/what-is-hot-standby-in-plc/>

- [9] Control Engineering, "Standardizing Control System Programming with IEC 61131-3," Apr. 2025. [Online]. Available: <https://www.controleng.com/articles/standardizing-control-system-programming-with-iec-61131-3/>
- [10] Control Engineering, "What IEC 61499 Means for the PLC," Apr. 2025. [Online]. Available: <https://www.controleng.com/what-iec-61499-means-for-the-plc/>
- [11] Automation.com, "Evolution, State of the Art and Standardization of Virtual PLCs," Oct. 2025. [Online]. Available: <https://www.automation.com/article/evolution-state-art-standardization-virtual-plcs>
- [12] International Electrotechnical Commission, "IEC 62541: OPC Unified Architecture," IEC, Geneva, 2020.
- [13] Open Process Automation Forum (OPAF), "Open Process Automation Standard (O-PAS), Version 3.1," The Open Group, 2023. [Online]. Available: <https://www.opengroup.org/open-process-automation/opas>
- [14] Engineering Equipment and Materials Users Association, "Alarm Systems: A Guide to Design, Management and Procurement," Publication 191, 4th ed., EEMUA, London, 2024.
- [15] B. Lydon, "Process Users Shift from DCS to PLC: PLC vs. DCS Experience Survey," Automation.com, Oct. 2024. [Online]. Available: <https://www.automation.com/en-us/articles/october-2024/process-users-shift-dcs-plc-plc-vs-dsc-survey>
- [16] Universal Automation Organization, "Open Automation Systems: Update on the State of the Art," Automation.com, Sept. 2024.

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