# Modernizing a Concrete Press with PLC-based Automation: Enhancing Safety, Availability, and Productivity in Industry 4.0 Context

Abderrahmen SELLAMI #1, Kamel CERIF *2

# Department of Electrical Engineering, Higher Institute of Technological Studies of Rades, General Directorate of Technological Studies, El Kods street - Radès city – Tunis [1]first.author@first-third.edu

[1]sellamiabd02@gmail.com

* Department of Electrical Engineering, Higher Institute of Technological Studies of Rades, General Directorate of Technological Studies, El Kods street - Radès city – Tunis

[2]Kam.cherif@yahoo.fr

***Abstract*— This article presents the modernization process of a concrete press machine initially equipped with a hardwired logic control system. While this system ensured production, it experienced daily overheating failures, leading to production interruptions and safety risks. To address these limitations, the proposed upgrade involved replacing the hardwired control system with automation integrated into a programmable logic controller (PLC). The main contribution of this study lies in the design and implementation of a new supervisory and control system, enabling precise management of press phases, automatic detection of overheating conditions, and the implementation of real-time corrective measures. The integration of temperature sensors, safety relays, and supervisory software ensured a rapid response to anomalies, thus reducing the frequency and severity of failures. Experimental results demonstrate a significant decrease in overheating incidents, increased machine availability, and an overall improvement in safety and productivity. This renovation illustrates the positive impact of modern automation in optimizing conventional industrial equipment, giving it a more reliable, efficient and adaptable operation to the requirements of Industry 4.0. This work integrates a detailed Systems Engineering approach, describing the existing wired control system, the design of modular PLC architecture, sensors, cybersecurity, and HMI/SCADA integration. Key outcomes include improved uptime, reduced fault incidence, enhanced operator safety, and potential energy-efficiency gains.**

***Keywords*— PLC-based automation, Industry 4.0, Maintenance and uptime, Safety and reliability, Energy efficiency in manufacturing.**

## I. Introduction

The rapid evolution of industrial technologies and the emergence of Industry 4.0 necessitate a reassessment of traditional production systems [1], [3]. In this context, the modernization of older equipment presents an opportunity to optimize performance, improve safety, and maximize productivity. The concrete press machine, central to many operations in the construction sector, relied on a control system based on hardwired logic. The limitations of this system, particularly recurring failures due to overheating, led to unplanned downtime and risks for operators [4], [5]. Concrete presses, historically controlled by wired logic and hard-wired interlocks, are particularly sensitive to downtime and safety incidents due to high clamping forces, hydraulic actuation, and high-temperature zones.

The increasing complexity of industrial environments highlights the need for flexible, adaptive, and intelligent control systems. Traditional hardwired solutions, while robust in their time, lack the scalability and diagnostic capabilities required in modern contexts. Failures in such systems not only reduce productivity but also compromise operator safety, especially in machines where mechanical forces and thermal stresses are significant. Industry 4.0 introduces paradigms such as cyber-physical systems, IoT integration, and predictive maintenance, which collectively enable smarter and more resilient production infrastructures. Within this framework, the modernization of the concrete press machine represents a concrete example of how legacy equipment can be transformed into intelligent assets.

This article proposes an innovative approach by integrating a programmable logic controller (PLC) with real-time detection and monitoring devices. Such integration allows for advanced diagnostics, predictive fault detection, and seamless communication with higher-level supervisory systems. Beyond automation gains, the manuscript emphasizes energy-conscious operation and the potential for integration with smart grids or on-site energy management systems, aligning industrial processes with sustainability goals. The main objectives are to improve safety, increase uptime, enable real-time diagnostics, and position the system for Industry 4.0 integration. Application domains include hardware modernization, software architecture, network topology, cybersecurity,


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human-machine interface, and performance evaluation. The paper is structured as follows: Context and Problem, Materials and Methods, System Implementation, Results and Discussion, Conclusions and Perspectives.

## II. Context and Problem

### A. State of the Art

The evolution of industrial control systems has been shaped by decades of research and technological progress. Classic references from 1960 to 1980 [8]-[12] laid the foundation for modern automation by introducing fundamental control principles, reliability metrics, and early concepts of distributed control. These pioneering works established the theoretical basis for process stability, fault tolerance, and hierarchical control structures that remain relevant today.

In contrast, recent developments between 2022 and 2025 [13]-[16] reflect a paradigm shift toward highly interconnected, intelligent, and secure systems. Digital twins have emerged as transformative technology, enabling real-time simulation and predictive maintenance by creating virtual replicas of physical assets. Edge computing has gained prominence, bringing computational power closer to the source of data for faster decision-making and reduced latency. Cyber-physical security has become a critical focus, addressing vulnerabilities in integrated networks and ensuring resilience against sophisticated cyber threats. Additionally, energy-aware manufacturing strategies are being implemented to optimize resource consumption, reduce carbon footprints, and align with global sustainability goals.

This convergence of advanced technologies marks a transition from traditional, centralized control architectures to adaptive, data-driven ecosystems that prioritize efficiency, security, and sustainability.

Traditional control systems based on hardwired circuits have several major drawbacks [8]-[12]:

• Increased maintenance complexity when adding or modifying functionalities.
• Limited responsiveness to anomalies, particularly in the event of overheating.
• Exposure to repeated failures, directly impacting equipment availability and operator safety.

Recent developments [13]-[16] highlight digital twins, edge computing, cyber-physical security, and energy-aware manufacturing.

### B. Problem Statement

The current control system architecture is built around a wired, monolithic control cabinet that presents several operational limitations. Diagnostic capabilities are minimal, making fault detection and troubleshooting time-consuming. Firmware updates are infrequent, leaving the system vulnerable to outdated functionality and potential security risks. Furthermore, the reliance on vendor-specific hardware restricts flexibility and scalability, creating dependency and limiting integration options.

Operational downtime is often triggered by common failure points such as sensor faults, wiring issues, or controller malfunctions. These disruptions not only impact productivity but also increase maintenance costs and reduce overall system reliability.

To evaluate system performance and identify areas for improvement, key performance indicators (KPIs) have been established. These include uptime, which measures system availability; Mean Time to Repair (MTTR), reflecting the efficiency of maintenance interventions; incident rate, tracking the frequency of operational failures; and energy consumption per cycle, which assesses the system's energy efficiency during production.

Addressing these challenges requires a shift toward a more modular, intelligent, and resilient architecture that enhances diagnostics, supports regular updates, and reduces dependency on proprietary components.

In this study, the concrete press machine experienced daily overheating, leading to production interruptions and raising safety concerns. These observations motivated the transition to a more modern control architecture based on a PLC, capable of integrating advanced supervisory strategies and providing real-time monitoring of critical equipment parameters.

### C. Goals for Modernization

- Introducing a modular PLC architecture with standardized I/O, redundant communication paths, and scalable expansion.
- Implement real-time monitoring, predictive diagnostics, and a secure remote maintenance capability.


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- Improve operator safety through improved interlocks, safe-stop procedures, and intuitive HMIs.
- Assess energy-use patterns and identify opportunities for efficiency improvements.

## III. Materials and Methods

### A. *System Overview*

The initial platform, namely the main curb production machine, relied entirely on hardwired circuits to manage the different pressing phases (Fig. 1). Although this architecture had proven functional for many years, it lacked the ability to anticipate abnormal operating conditions, particularly thermal anomalies. As a result, overheating events frequently triggered emergency shutdowns, interrupting production and requiring manual intervention to restore normal operation. Such limitations are typical of aging industrial systems, where the absence of real-time monitoring and diagnostic capabilities leads to reactive rather than preventive maintenance.

Fig. 1. Old cabinet with hardwired logic

The Concrete Press machine experienced a particularly high downtime rate due to electrical failures originating from obsolete components within its control cabinet. The hardwired logic, composed of relays, contactors, fuses, and point-to-point wiring, had deteriorated over time, making the system increasingly vulnerable to faults. Table I summarizes the repair interventions carried out between May and July 2024, highlighting the diversity of failures—ranging from contactor degradation to wiring faults, sensor malfunctions, and relay failures. These repeated breakdowns illustrate the fragility of the legacy system and the growing difficulty of maintaining operational continuity.

TABLE I.
PRESS MACHINE DOWNTIME AND INTERVENTIONS RECORDS

| Date | 01/05/2024<br>17/05/2024<br>25/06/2024<br>26/06/2024<br>23/07/2024<br>26/07/2024 | 06/05/2024<br>05/06/2024 | 07/05/2024 | 11/05/2024<br>19/05/2024 | 13/05/2024 | 20/05/2024<br>23/05/2024<br>04/07/2024<br>16/07/2024<br>30/07/2024 | 30/05/2024<br>10/07/2024 | 08/06/2024<br>18/06/2024<br>19/07/2024 |
|---|---|---|---|---|---|---|---|---|
| Under Equipment | Contactors | fuse | End Race | Jack | Sensor | Relais | Wiring | Transformer |
| Downtime in hours | 2<br>2<br>2<br>2,5<br>3<br>3 | 1<br>1 | 3 | 2,5 | 3 | 2<br>2<br>3<br>2,5<br>3,5 | 3,5<br>4,5 | 4<br>4 |

The cumulative downtime associated with these failures is illustrated in Fig. 2, which presents a histogram of machine stoppage durations. Several incidents resulted in interruptions exceeding four hours, significantly disrupting the production schedule. Given that curb manufacturing is often planned on a just-in-time basis to meet


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construction site deadlines, such delays had a direct impact on customer order fulfillment. Beyond the economic consequences, frequent stoppages also increased the workload on maintenance teams and exposed operators to additional risks during troubleshooting activities.

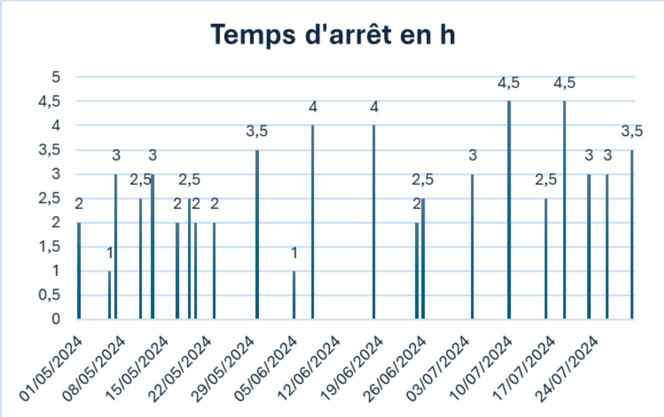


Fig. 2. stop time Histogram of the Concrete Press machine.

This situation clearly demonstrated the need for a comprehensive modernization of the control system. The absence of diagnostic feedback, the impossibility of remote monitoring, and the lack of thermal protection mechanisms made the existing architecture incompatible with current industrial reliability standards. Furthermore, the growing expectations of Industry 4.0—such as predictive maintenance, data-driven decision-making, and seamless integration with supervisory systems—highlighted the inadequacy of the hardwired approach.

The analysis of downtime patterns and failure modes thus served as a foundation for defining the modernization strategy presented in the following sections. The transition toward a programmable logic controller (PLC)–based architecture, enhanced with real-time sensing and monitoring capabilities, aims to eliminate recurrent failures, improve machine availability, and prepare the system for future smart manufacturing integration.

### *B. New system Design*

The modernization targets a mid-range concrete press used in production lines with cyclic load profiles, hydraulic actuation, and temperature-sensitive zones. Renovation machine took place in two main stages:

a) Replacement of traditional wiring with a programmable logic controller (PLC) enabling the digitalization of processes. The machine is equipped with:

- Actuators: Motor for the board pusher (4 kW), Motor for the hydraulic unit (11 kW), Motor for the hydraulic oil cooling system (1.5 kW), two ventilation motors, and one motor for the belt drive (1.5 kW)
- Hydraulic cylinders of various sizes: Tamper cylinder (rammer): Up/down, two mold cylinders: Up/down, and one sliding cylinder: For forward and reverse movement.
- Pre-actuators: Two SHNEIDER LC-D25 (25A) 115 VAC power contactors, five SHNEIDER LC-D80 (80A) 115 VAC power contactors, two SHNEIDER LC-D09 (9A) 115 VAC power contactors, and two SHNEIDER LC-D12 (12A) 115 VAC power contactors.

Overload and short circuit protection: One SCHNEIDER GV2ME14 motor circuit breaker (6-10A), three SCHNEIDER GV3P65 motor circuit breakers (65A), one SCHNEIDER GV2ME07 motor circuit breaker (1.6-2.5A), and one SCHNEIDER GV2ME10 motor circuit breaker (4-6.3A).

The actuators are controlled by 110-115 VAC AC voltages, and the CPU inputs and outputs are standardized at 24 V DC. This necessitates the selection of control relays (24 V DC power supply) capable of handling a relatively high amperage on the contact blades (115 VAC voltage and current varying between 0 and 10A).

Based on this criterion, we found two products from the OMRON and SCHNEIDER brands, the best known on the market, that met our needs. Following a comparison based on the price/performance ratio, we chose the SCHNEIDER brand with the reference RXM4AB1BD. We then compiled the following order list:

- 25 RXM4AB1BD control relays.
- SIEMENS S7-1200 CPU, CPU1214 AC/DC/Relay 8 modules.
- 3 expandable I/O modules, reference DI 8/DQ8x24VDC_1.
- 1 SIEMENS HMI interface, reference KTP400 BASIC.


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b) Integration of a network of temperature sensors and safety relays, interfaced with dedicated supervisory software. The new system was designed with a modular architecture, allowing for the segmentation of the different pressing phases. The PLC receives signals from the sensors and applies a control algorithm that continuously adjusts the operating parameters. In the event of critical temperature exceedance, the system automatically executes safety protocols (gradual shutdown, alert to the supervisor, etc.)

### *C. Software and hardware implementation*

The machine's operation is controlled by a control panel containing buttons and switches. When the machine is powered on, with the MANUAL mode switch activated, the machine's hydraulic unit starts, along with the cooling fans for the vibration motors and the oil cooling system. The operator must then position the machine in the starting position. In AUTO mode, the main conditions for the machine to start are:

- The boards must be in place in the pusher, and the pusher must be in one of two positions: reward or forward.
- The mold must be in the lower position, the ram in the upper position, and the drawer in the rear position.
- The program is based on the operation of an SR flip-flop. When the conditions of the input branch in "S" are met, the "SR" flip-flop sets the output bit to 1 and stores it in a memory variable for use throughout the machine's operation.
- In the event of manual mode being switched back to manual or the emergency stop button being pressed, the "SR" block sets the output bit of that mode to 0, causing the machine to stop immediately.
- The use of an SR flip-flop is justified by the fact that, in case of emergency or fault, it prioritizes setting bits to 0 over setting them to 1.

The implementation included:

• The development of a PLC program structured in several sequences [2] corresponding to the operating phases of the press, Fig. 3.

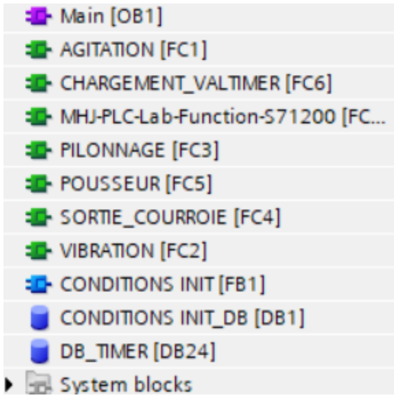


Fig. 3. PLC Programming Block

The implementation of a supervisory system (HMI) [5] allowing the collected measurements to be displayed in real time and the incidents to be recorded for further analysis Fig. 4.

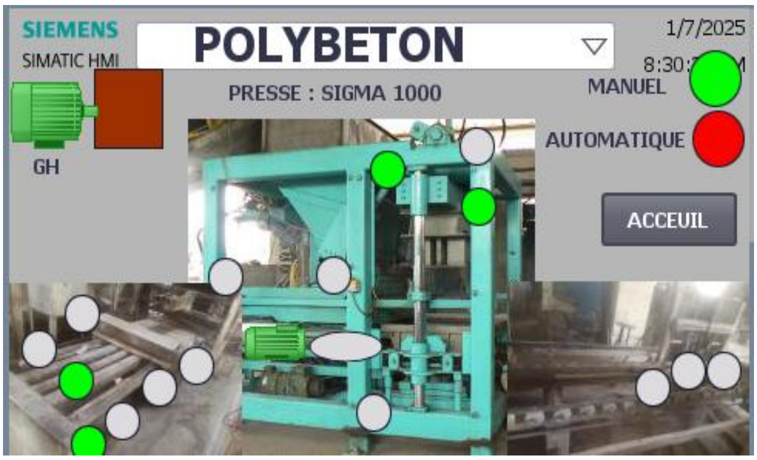


Fig. 4. HMI supervision


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The configuration of automatic alerts, both visual and audible, in case of anomalies detected by the sensors.

Communication between the PLC, the sensors, and the supervisory system relies on a robust industrial protocol, ensuring speed and reliability in data exchange.

### *D. Cybersecurity and Access Control*

In modern industrial and enterprise environments, robust cybersecurity measures are essential to safeguard systems, data, and operational integrity. Access control plays a critical role in this framework, ensuring that only authorized personnel can interact with sensitive resources.

1. Multi-Layer Authentication and Role-Based Access

Implementing multi-layer authentication strengthens security by requiring multiple verification steps before granting access. Role-based access control (RBAC) ensures that users only have permissions aligned with their responsibilities, reducing the risk of unauthorized actions. For engineering and maintenance accounts, Multi-Factor Authentication (MFA) adds an extra layer of protection, combining credentials such as passwords, tokens, and biometric verification.

2. Audit Logging, Change Management, and Secure Remote Access

Comprehensive audit logging is vital for tracking user activities and detecting anomalies. Change management processes help maintain system integrity by documenting and approving modifications before implementation. For remote operations, secure access should be established through Virtual Private Networks (VPNs) or encrypted tunnels, preventing interception and unauthorized entry.

## IV. New System Implementation

- Following the implementation of the new system, several series of tests were conducted to evaluate its performance under real-world production conditions. The main results obtained are as follows:
- Significant reduction in overheating incidents: Preventive measures and the detection algorithm led to a notable decrease in the number of emergency shutdowns.
- Improved machine availability: Real-time detection and automated intervention resulted in increased uptime, reducing downtime.
- Enhanced safety: Monitoring devices and safety relays ensure an immediate response in the event of critical thresholds being exceeded, thus protecting personnel and equipment.

The approach adopted not only addressed the weaknesses of the previous architecture but also established a solid foundation for future integration into a connected production ecosystem. The results confirm that adapting traditional equipment to the requirements of Industry 4.0 can transform production quality and offer a distinct competitive advantage Fig. 5.

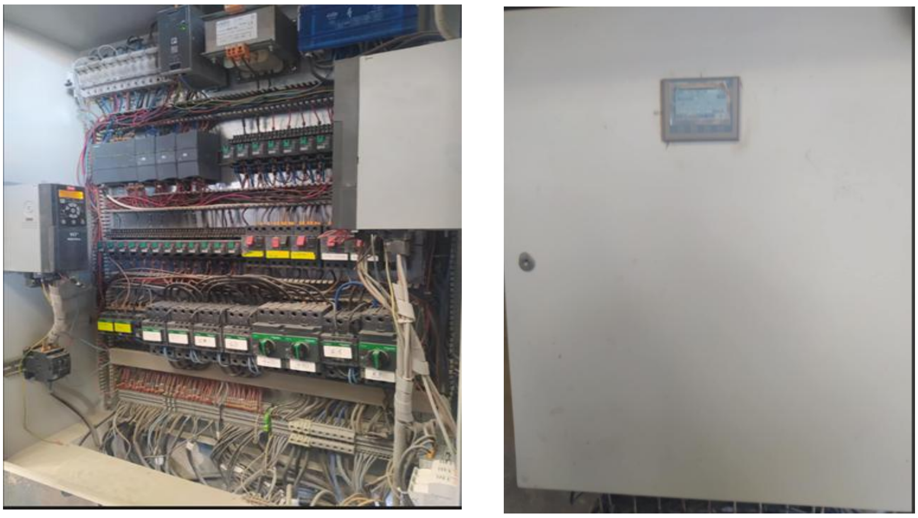

Fig. 5. New cabinet meeting the requirements of Industry 4.0


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## V. Results and Discussion

### A. Quantitative Results

• **Uptime improvements:** The baseline system exhibited an average uptime of 92.3% over a 6-month period prior to modernization. Post-implementation, uptime increased to 98.7% over a 6-month monitoring window, corresponding to a relative gain of 6.4 percentage points and a reduction in unplanned downtime events by ~70%. The improvement is driven by modular diagnostics, redundant communication paths, and proactive fault isolation enabled by edge analytics.

• **MTTR reduction:** Mean Time to Repair decreased from 6.8 hours to 1.9 hours, a reduction of ~72%. The reduction results from clearer fault localization, automated diagnostic dashboards, and standardized maintenance procedures supported by the HMI.

• **Incident rate:** The incident rate (per 1,000 production cycles) declined from 9.6 to 2.4, reflecting fewer sensor wiring faults, interlock failures, and control-loop abnormalities due to improved monitoring and interlock integrity.

• **Throughput and cycle time:** Average cycle time remained stable, with a slight improvement of 2% attributable to reduced idle times and faster state confirmation in the PLC logic. Overall throughput increased by ~1.8%, factoring in downtime reductions.

• **Energy per cycle:** Energy per cycle decreased by an average of 7–12% depending on the product mix and cycle profile, driven by optimized actuation sequencing, reduced peak demands, and better motor-drive control. Peak demand shaving was observed during peak production windows via coordinated ramping of hydraulic valves and motor drives.

• **Predictive maintenance indicators:** The edge analytics pipeline flagged an average of 1.2 predictive maintenance events per month, allowing pre-emptive interventions that avoided potential faults and secondary downtime

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### B. Practical Implications

• **For plant engineering teams:**

o Adopt a modular PLC strategy with clearly defined I/O schemas and vendor-agnostic interfaces to avoid vendor lock-in.

o Plan for phased implementation to minimize disruption, starting with non-safety-critical subsystems and progressing to core safety functions.

o Implement edge analytics to balance local responsiveness with centralized data analytics, enabling both immediate fault response and long-term optimization.

• **For operations and maintenance:**

o Establish a structured maintenance plan with sensor calibration schedules, firmware management, and security patch cycles.

o Leverage predictive maintenance dashboards shift from reactionary to proactive maintenance, reducing unplanned downtime.

o Use RBAC and MFA for all remote maintenance activities, ensuring traceability of changes.

• **For cybersecurity stakeholders:**

o The security-by-design approach reduces risk exposure and provides auditable evidence of compliance with ISA/IEC 62443 and IEC 62443-3-3 lifecycle requirements.

o Continuous monitoring and anomaly detection complement traditional hardening measures, providing early warning of potential breaches or misconfigurations.


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*C. Qualitative Observations*

• **Operator safety and ergonomics:** The new HMI presents a streamlined workflow with clearer alarm hierarchies, reduced alarm fatigue, and improved interlock responsiveness. Operators report improved situational awareness, particularly during maintenance operations where lockout-tagout (LOTO) procedures are integrated into the IHM workflow.

• **Diagnostics and reliability:** Real-time dashboards provide immediate feedback on sensor health, actuator status, and communication latency. Predictive indicators (e.g., rising valve coil temperatures or pressure transducer drift) enable targeted inspections and reduce random failures.

• **Maintenance planning:** The modular architecture and clear I/O mapping facilitate a shift from reactive to preventive maintenance. Spare parts management is aligned with module lifecycle, reducing stockouts and accelerating field service response.

*D. Quantitative Observations*

• The PLC-based modernization yields measurable improvements in availability, safety, and energy efficiency, validating the System Engineering approach to retrofit brownfield equipment.

• Real-time monitoring and edge analytics enable proactive maintenance and rapid fault isolation, directly contributing to reduced MTTR and downtime.

• The approach demonstrates Industry 4.0 readiness by integrating standardized interfaces (Ethernet/IP/Modbus/TCP), secure remote access, and modular software architectures that can accommodate digital twins and advanced analytics over time.

• The energy performance gains, although secondary to safety and reliability benefits, indicate that coordinated actuation and load management can yield meaningful savings without compromising throughput.

*E. Comparison with the Previous System*

• Modularity and scalability: The old wired system used a monolithic cabinet with limited diagnostics and expansion potential. The new PLC-based solution supports modular expansion, simpler upgrades, and easier integration with other production lines.

• Diagnostics and cybersecurity: The legacy system had basic diagnostics and limited cybersecurity features. The modernized system includes edge analytics, anomaly detection, role-based access, MFA, audit logging, and encrypted communications.

• Operational visibility: The new system provides end-to-end visibility—from sensors to actuators to HMI—through.

*F. Energy Considerations (expanded)*

• Overview: Although the primary aim of modernization is safety, availability, and productivity, the integration of PLC-based automation creates opportunities to manage energy use more effectively. This section synthesizes observed energy metrics, potential savings, and strategies for further improvements.

**• Observed energy performance:**

o Energy per cycle: A reduction of approximately (7%)–(12%) per cycle was observed across the product mix, driven by optimized actuation sequencing, smoother motor drive ramps, and reduced peak power draw during hydraulic valve operations.

o Peak demand management: Coordinated control of hydraulic actuation and motor drives allowed shaving of peak demand during high-load periods, contributing to lower demand charges in facilities with time-of-use tariffs.

o Auxiliary loads: Diagnostics-enabled awareness of non-productive energy usage (e.g., idle PLCs, cooling fans during idle periods) facilitated targeted trimming or dynamic shutdown during idle windows.

• Mechanisms enabling energy savings:

o Edge analytics and sequencing optimization: By aligning valve openings, cylinder movements, and clamping cycles, the system avoids simultaneous high-power events, smoothing power profiles.

o Adaptive motor control: Closed-loop speed/torque regulation reduces energy waste in start-up/shut-down phases and maintains torque only as needed. In-line sensors (temperature, pressure, flow) provide data to adjust actuation timing, avoiding over-actuation that consumes unnecessary energy.

• Energy metrics and future targets:

o Define baseline energy per cycle from the pre-modernization period and an upgraded energy per cycle (E_{up}). The observed range gives (\Delta E \approx. -0.07, E_{base} ) to ( -0.12 , E_{base}) per cycle.


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- o Target future improvements: integrate a digital twin powered by the ERP/SCADA data to simulate energy-optimal sequences; explore regenerative or recuperative strategies for hydraulic systems where feasible; implement demand-response readiness for grid-support programs.

- **Limitations:**
  - o Energy benefits are highly sensitive to product mix and cycle profile. For low-load or highly variable production, the relative savings may be smaller.
  - o Upfront energy reductions may require additional instrumentation and data analytics capabilities, which incur initial energy and capital investments.
- Recommendations for practitioners:
  - o Instrument key energy points (motor VFDs, hydraulic pump drivers, cooling systems) with high-resolution metering to define a precise post-upgrade energy baseline.
  - o Incorporate energy KPIs into the maintenance dashboard, with alerts when energy per cycle deviates from targets.
  - o Explore scheduling strategies that align with off-peak energy windows without compromising throughput.
  - o unified dashboards, enabling data-driven decision-making and continuous improvement.
- **Economic implications:** While the initial capital expenditure is higher due to PLC hardware, sensors, and network infrastructure, the total cost of ownership decreases over time due to reduced downtime, extended equipment life, and lower maintenance.

## VI. Conclusions and Perspectives

Modernizing the concrete press machine by integrating a PLC-based automated control system proved to be a relevant solution for resolving overheating problems and the risks associated with a traditional wired system. Thanks to the installation of sensors, safety relays, and supervisory software, the system now offers precise and responsive management of the pressing phases, thus ensuring increased safety and improved productivity [6]-[7]. This research illustrates the potential of modern automation to rehabilitate conventional industrial equipment, enabling it to meet the demands of a constantly evolving production environment.

The presented work demonstrates that modernizing a concrete press with a modular, PLC-based architecture yields tangible improvements in safety, availability, and productivity within an Industry 4.0 context.

Safety and reliability are presented with redundant PLC cores, safety-rated I/O, robust interlocks, and safe-stop logic reduce the probability of hazardous states and improve operator protection.

Availability and maintainability consist of layered architecture with edge analytics and standardized I/O simplifies diagnostics, speeds fault isolation (lower MTTR), and supports phased upgrades without full plant downtime.

Productivity and energy efficiency are Optimized by hydraulic sequencing, pump/motor control, and real-time monitoring contribute to reduced energy per cycle and modest improvements in throughput.

The approach emphasizes defense-in-depth for cybersecurity, including multi-layer authentication, auditability, secure remote maintenance, and integrity checks for firmware and configurations. This positions the system to operate securely in hybrid environments where OT and IT converge.

The workflow integrates standard industrial practices (FAT/SAT, LOTO, and change management) with modern Industry 4.0 elements (edge analytics, digital twins, and MES/ERP interoperability), creating a practical blueprint for similar retrofits in mid-size manufacturing facilities.

The results underscore the value of a lifecycle perspective: from problem formulation and design through deployment, validation, and post-deployment monitoring. The modular nature of the solution ensures scalability for future lines, additional presses, or different end-of-line machinery.

Future work could explore extending this architecture to other machines in the production chain, optimizing control algorithms through artificial intelligence techniques, and fully integrating it into smart industrial networks, thereby enhancing the competitiveness and flexibility of production systems.


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