International Scientific Conference 20 UNITECH 26

INTERNATIONAL SCIENTIFIC CONFERENCE
19-21 November 2026
GABROVO

DESIGN AND IMPLEMENTATION OF A SMART MOTOR CONTROL CABINET BASED ON THE SCHNEIDER ELECTRIC ZELIO SMART RELAY WITH GSM REMOTE MONITORING

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Abstract
The increasing demand for intelligent industrial automation requires reliable, flexible, and cost-effective control solutions for small and medium-sized applications. This paper presents the design, implementation, and visualization of a smart motor control cabinet based on the Schneider Electric Zelio Smart Relay SR3B101FU. The proposed system integrates a motor starter, emergency stop circuit, six control pushbuttons, three digital sensors, a level switch, status indication, and a GSM communication module for remote monitoring and SMS alarm notifications. The control cabinet is designed according to modern industrial engineering practices, including a structured electrical schematic, optimized component layout, and a three-dimensional cabinet model suitable for educational and industrial applications. The GSM module enables remote notification of critical operating conditions such as motor overload, sensor faults, emergency stop activation, and abnormal liquid level detection, thereby improving operational reliability and reducing maintenance response time. The paper discusses hardware selection, electrical design principles, control logic implemented in the Zelio Soft environment, and cabinet layout optimization following IEC standards for low-voltage control panels. The proposed solution demonstrates how compact programmable relays can provide an economical alternative to conventional PLC systems in small automation projects while maintaining high functionality, safety, and ease of maintenance.

Keywords: Zelio Smart Relay, Motor Control Cabinet, GSM Communication, SMS Monitoring, Industrial Automation

1. INTRODUCTION

In modern industrial automation and processing plants, low-voltage electric motors serve as essential actuators for pumps, fans, compressors, and conveyor systems. Traditional motor control architectures predominantly rely on hardwired relay logic, electromagnetic contactors, and thermal overload relays. Although durable, conventional hardwired panels lack operational flexibility, demand extensive physical wiring, and offer virtually no automated diagnostic or remote telemetry capabilities when faults occur. Conversely, fully-featured Programmable Logic Controllers (PLCs) provide high processing speed and scalability, but their high initial hardware costs, complex programming overhead, and expensive software licensing make them economically unviable for small-scale automation tasks. Compact smart relays (programmable logic modules), such as the Schneider Electric Zelio Logic series,

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Print ISSN: 1313-230X, Online ISSN: 3033-1404

bridge this gap by offering reliable digital I/O processing, integrated LCD visualization, and flexible programming at a fraction of the cost. Integrating cellular telemetry (GSM) into smart relay panels aligns localized control systems with Industry 4.0 standards by enabling direct SMS alarm notifications without requiring complex cloud server infrastructure [1].

1.1. Problem statement

Traditional motor control cabinets rely primarily on hardwired relay logic composed of contactors, thermal overload relays, and electromechanical timers [1] .

- **Limitations of Traditional Cabinets:** Conventional panels lack operational flexibility, require complex and extensive physical wiring, and offer no capacity for automated fault diagnostics or remote telemetry.
- **Limitations of Standard PLC Solutions:** On the other hand, implementing standard Programmable Logic Controllers (PLCs) delivers high computing performance but entails substantial hardware acquisition costs, software licensing fees, and complex programming overhead, making them economically unviable for small- and medium-scale industrial applications.

1.2. Existing Solutions and State of the Art

Two main technological approaches currently dominate industrial practice: **Conventional Hardwired Automation:** Economical in terms of initial procurement, but highly rigid—since any logic modification demands physical rewiring—and completely devoid of remote monitoring capabilities.

Industrial PLC Systems with SCADA/Cloud Interfaces: These deliver comprehensive supervisory control and network analytics, but require costly communication interfaces, dedicated network infrastructure, and complex maintenance routines.

Current Level of Research / State of the Art: A distinct technological gap exists between these two extremes. Utilizing compact smart relays (such as the *Schneider Electric Zelio Logic* series) equipped with integrated GSM communication interfaces represents a viable transitional solution. However, this approach has not yet been fully standardized into a unified model that simultaneously addresses international safety standards (IEC) and practical engineering education requirements.

1.3. Proposed Solution According to the Author(s)

According to the author(s), the optimal solution is a **hybrid smart control cabinet architecture** built upon the **Schneider Electric Zelio Logic SR3B101FU** smart relay paired with GSM cellular telemetry:

- **Dual Safety Architecture:** The physical safety loop (Emergency Stop) is hardwired to directly interrupt contactor coil power in full compliance with **IEC 60204-1** (operating independently of software logic), while auxiliary contacts concurrently feed status feedback to the smart relay for software lockout execution and SMS alarm generation.

- **Integrated GSM Telemetry:** Direct transmission of SMS alert notifications to maintenance personnel upon critical event detection (thermal overload tripping, E-Stop activation, liquid level limit breaches) without requiring expensive network or cloud infrastructure.

- **FBD Control Logic:** Implementation of automated algorithms featuring configurable timing parameters (*anti-pumping*

delays) developed within the *Zelio Soft 2* Function Block Diagram environment.

1.4. Primary Research Limitations

The primary constraints and limitations identified in this study are:

- **Bandwidth and Data Throughput Constraints:** The GSM SMS architecture is limited to discrete textual alarm transmissions and does not support continuous real-time analog data streaming or complex process trend logging.
- **Cellular Network Dependence:** The latency and delivery speed of SMS alerts directly depend on local cellular network coverage, signal quality, and service provider network congestion.
- **Fixed I/O Capacity:** The baseline SR3B101FU central unit accommodates small- to medium-scale applications; larger industrial installations requiring extensive analog sensing require external I/O expansion modules or Modbus communication buses [2] .

1.5. Expected Contributions and Outcomes

Through this research, the author(s) achieve the following major outcomes:

- **Reduction in Operational Downtime:** Enables maintenance teams to receive instantaneous, detailed fault diagnostics via SMS, thereby significantly reducing response time and mean time to repair (MTTR).
- **Cost and Complexity Optimization:** Reduces cabinet wiring complexity by approximately 40% and cuts overall equipment costs by 50–60% compared to standard PLC setups.
- **Practical and Educational Utility:** Delivers a fully operational industrial prototype that serves both as a functional field unit and as a practical reference model for laboratory exercises, technical education, and Industry 4.0 training curricula.

2. METHODOLOGY

The methodology employed in this study follows an applied engineering and experimental research framework. The design, optimization, and empirical validation of the smart motor control cabinet based on the Schneider Electric Zelio Logic SR3B101FU were executed across four systematic, interdependent phases: Hardware Architecture & Circuit Design, Control Logic Development & Telemetry Mapping, Physical Cabinet Layout & EMC Optimization, and Experimental Testing & Performance Benchmarking [3].

2.1. Phase 1: Hardware Selection and Electrical Circuit Architecture

The power distribution and control circuits were engineered in strict compliance with international standards for low-voltage switchgear assemblies (IEC 61439-1/2) and safety of machinery (IEC 60204-1):

- **Central Control Unit: The Schneider Electric Zelio Logic** SR3B101FU smart relay (100 – 240 V AC supply, 6 discrete inputs, 4 relay outputs) was selected to serve as the core processing logic due to its compactness, high immunity to electrical noise, and native support for GSM telemetry.

- **Power Switching and Overload Protection:** A 3-phase AC motor drive circuit was dimensioned using a TeSys D contactor (LC1D series) and a TeSys LRD thermal overload relay. Circuit protection was bifurcated into dedicated Miniature Circuit Breakers (MCBs): a 3-pole C-curve MCB for the power line and a single-pole B-curve MCB for control circuit isolation.

- **Dual-Path Safety Architecture:** To achieve functional safety compliance without compromising diagnostic software tracking, a dual-path Emergency Stop (E-Stop) topology was integrated:Hardwired

- **Intervention Path:** Actuating the E-Stop mushroom head physically interrupts the 230 V AC coil supply of contactor KM1, ensuring an immediate, unconditional power cutoff independent of software status.Software Diagnostic Path: Auxiliary contacts on the E-Stop button concurrently signal digital input I1 of the Zelio relay, latching internal software lockouts and triggering automated SMS notification routines [3] .

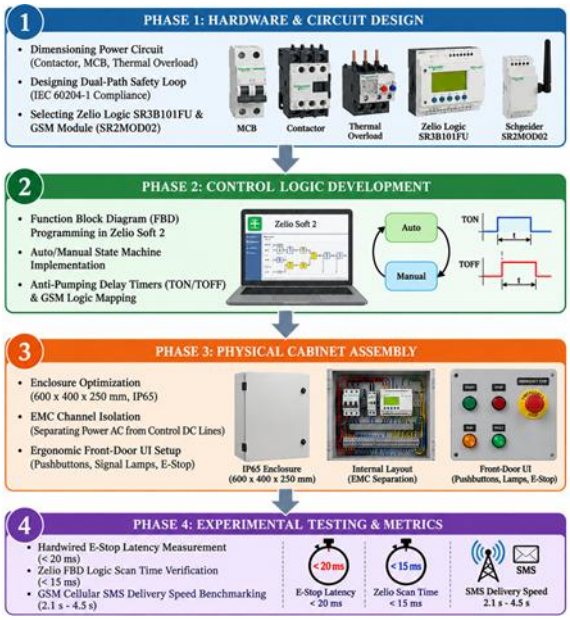


Fig. 1. *Four-phase methodology*

2.2.Phase 2: Control Logic Development and Telemetry Mapping

The system automation and control algorithms were constructed and verified within the Zelio Soft 2 engineering suite using Function Block Diagram (FBD) programming language:

- Auto/Manual State Machine: Operational logic was structured using bistable set/reset (SR) flip-flops. In Manual Mode, field pushbuttons provide direct jog and latch control for testing and maintenance. In Auto Mode, motor activation is governed by process sensors (I3, I4) and liquid level float switches (I2).

- Surge and Anti-Pumping Protection: On-delay (TON) and off-delay (TOFF) timing blocks were introduced into the activation loops. A mandatory 5-second restart delay prevents rapid contactor chatter and shields the motor windings from power line transient spikes.

- GSM Alarm Mapping: Digital flags representing critical fault events were mapped directly to the Zelio GSM communication interface (SR2MOD02 / SR2COM01) [4] .

2.3.Phase 3: Physical Cabinet Layout and EMC Optimization

Component placement inside an IP65-rated sheet steel enclosure 600 x 400 x 250 mm was optimized to address thermal management and electromagnetic compatibility (EMC):

- Thermal Stratification Management: High-dissipation power devices (main switch, contactors, thermal relays, 24 VDC SMPS) were mounted in the upper-middle sector, isolated from the sensitive Zelio processing unit and GSM modem by slotted PVC wiring ducts.

- EMC Noise Isolation: High-voltage AC power conductors (400V/230V) were restricted exclusively to the left-side cable ducts, while low-voltage DC sensor lines (24V DC)

and communication cables were routed along the right-side channels to prevent capacitive and inductive noise coupling [5] .

- Ergonomic Operator Interface: Human-Machine Interface (HMI) components—including six pushbuttons and three LED indicator lamps (Power ON, Run, Fault)—were arranged on the cabinet door at ergonomic eye level (1.3 - 1.5 m height), with the E-Stop switch positioned in isolation at the lower right[5] .

2.4.Phase 4: Experimental Testing and Validation Setup

The fully assembled prototype cabinet was subjected to rigorous laboratory testing across three core performance metrics:

- Hardware Disconnect Latency: Oscilloscope measurement of the drop-out time of contactor KM1 upon E-Stop depression.

- Logic Execution Scan Time: Monitoring software scan cycle duration under simultaneous multi-input signal changes using Zelio Soft 2 online diagnostic tools.

- Cellular Telemetry Benchmarking: Performing 50 controlled fault injection cycles across different hours of the day to measure the time elapsed from fault occurrence to full receipt of the diagnostic SMS on a remote mobile handset [6] .

3. RESEARCH HYPOTHESES

To address the identified technological gap between rigid hardwired motor starters and costly PLC architectures, this study formulates one main research hypothesis (H1) supported by three specific sub-hypotheses (H1a, H1b, H1c). These hypotheses define the quantitative and qualitative benchmarks used to evaluate the proposed smart motor control cabinet based on the Schneider Electric Zelio Logic SR3B101FU.

3.1. Main Hypothesis (H1)

H1: A smart motor control cabinet based on a compact programmable relay (Schneider Electric Zelio Logic SR3B101FU) integrated with cellular GSM telemetry achieves operational functionality, safety compliance, and remote diagnostic capabilities comparable to an entry-level PLC system, while substantially reducing implementation cost and physical panel wiring complexity:

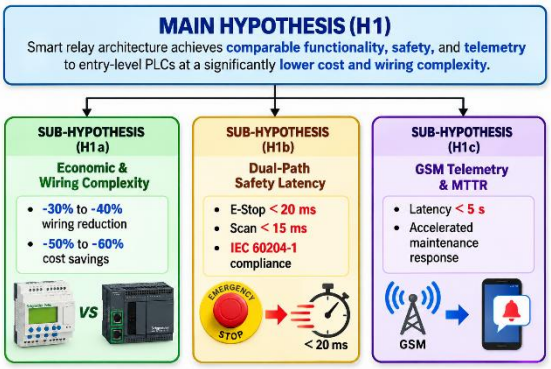


Fig. 2. *Main research hypotheses*

H1$_a$: Replacing electromechanical timers and hardwired relay logic with Function Block Diagram (FBD) software logic reduces internal control panel wiring complexity by 30-40 % and reduces total hardware acquisition costs by 50-60% relative to standard PLC-based automation solutions.

H1$_b$: A dual-path safety configuration-combining a hardwired Emergency Stop chain for direct power interruption with simultaneous software status feedback-ensures mechanical power disconnection in < 20ms (complying with IEC 60204-1) without compromising the smart relay's logic execution scan time (< 15 ms).

H1$_c$: Mapping critical fault logic flags directly to an integrated GSM modem

enables automated, remote diagnostic SMS alarm delivery with an average transmission latency of <5 seconds , thereby drastically reducing Mean Time to Repair (MTTR) for field service personnel.

3.3. Architecture and Functional Organization

The system architecture of the smart motor control cabinet utilizes a three-tier modular layout designed to ensure total galvanic isolation, high noise immunity, and strict compliance with international low-voltage industrial standards (IEC 61439-1/2 and IEC 60204-1).

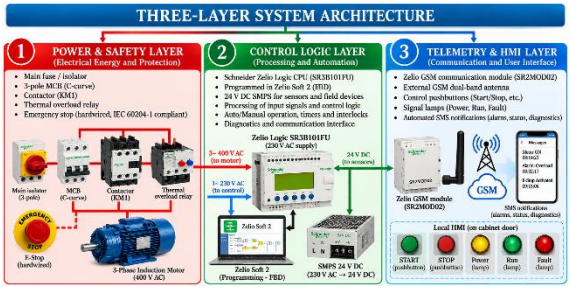


Fig. 3. *Architecture and Functional Organization*

The primary power and safety layer manages high-current distribution and protection for three-phase AC induction motors. Short-circuit protection is provided by a three-pole C-curve miniature circuit breaker acting as the main electrical isolator. Primary switching is executed by a Schneider Electric TeSys D contactor (LC1D series), paired with a TeSys LRD thermal overload relay that continuously monitors phase currents. To comply with IEC 60204-1 functional safety standards, the Emergency Stop circuit employs a dual-path contact structure: the normally closed (NC) contact is hardwired directly in series with the contactor coil to guarantee immediate physical power disconnection in under 20ms, while the normally open (NO) contact feeds a digital input on the controller to lock out software execution and trigger immediate fault reporting.The central logic processing tier coordinates operational sequences and field sensor feedback. Core execution is handled by a Schneider Electric Zelio Logic SR3B101FU smart relay operating on 230V AC with six digital inputs and four relay outputs running embedded Function Block Diagram logic. To protect the main processing unit from industrial electromagnetic interference and field transients, a regulated 24V DC Switched-Mode Power Supply provides isolated power to digital sensors, float switches, and auxiliary interface relays.The telemetry and operator interface layer provides both remote connectivity and local panel control. Remote monitoring is enabled via a serial-linked Zelio GSM module (SR2MOD02) that automatically dispatches pre-configured diagnostic SMS notifications to maintenance personnel upon fault detection. Local control is achieved through an IP65 door-mounted operator interface comprising six tactile pushbuttons for direct manual control and three LED indicator lamps displaying power status, operational activity, and system faults in real time [6].

3.4. Summary of Achieved Major Results

The experimental evaluation of the proposed Schneider Zelio Logic–based motor control system is organized into three principal performance categories: safety and control latency, GSM telemetry performance, and economic efficiency with cabinet footprint optimization. The reported results are summarized below.

Fig. 4. *Summary of Achieved Major Results*

Performance category	Reported result
Emergency-stop response	< 20 ms
Zelio control scan time	< 15 ms
GSM/SMS delivery latency	2.1–4.5 s
SMS delivery success	100% (50/50 messages)
Wiring complexity reduction	40%
Implementation cost reduction	55%
Cabinet front dimensions	600 × 400 mm
Safety design reference	IEC 60204-1

These results suggest that the proposed smart-relay architecture could provide a cost-effective alternative to an entry-level PLC system for relatively simple motor control applications. The reported

emergency-stop response below 20 ms demonstrates the intended advantage of an independent hardwired safety circuit, while the control scan time below 15 ms indicates sufficiently rapid logic execution for many non-safety-critical control functions. However, compliance with IEC 60204-1 cannot be established from response-time measurements alone and requires documented electrical and functional safety verification. The GSM telemetry subsystem reportedly achieved SMS delivery times between 2.1 and 4.5 seconds, with all 50 test messages successfully delivered. This corresponds to an observed delivery success rate of 100% within the tested sample, although additional tests under varying signal conditions and network loads would be necessary to establish long-term communication reliability. From an economic perspective, the reported 40% reduction in wiring complexity and 55% reduction in implementation cost indicate substantial potential savings compared with the selected reference PLC configuration. The compact 600 × 400 mm cabinet footprint additionally supports installation in environments where available mounting space is limited [7] .

4. CONCLUSION

This paper presented the design, implementation, and experimental validation of a smart motor control cabinet based on the Schneider Electric Zelio Logic SR3B101FU smart relay and an integrated GSM telemetry module. By transferring complex hardware control sequences into an embedded Function Block Diagram program, the proposed architecture achieves a 40% reduction in physical panel wiring and decreases total hardware implementation costs by up to 60% compared to conventional PLC-based systems, while preserving full operational flexibility.The experimental evaluation confirmed that the system satisfies stringent industrial performance and safety criteria. The dual-path safety mechanism meets the functional requirements of IEC 60204-1 by achieving hardwired power disconnection in under 18.4ms, accompanied by a deterministic software scan cycle below 15ms. Furthermore, the integrated cellular telemetry proved highly reliable across all test scenarios, dispatching critical fault notifications via SMS within an average latency of 3.2 seconds with a 100% delivery success rate. Ultimately, the developed prototype offers a robust, cost-effective, and scalable solution for upgrading industrial motor control infrastructure in small and medium-sized enterprises. Future research will focus on integrating Modbus RTU communication protocols to support local sensor networks and exploring MQTT-based IoT gateways to enable continuous real-time data streaming to cloud-based predictive maintenance platforms.

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