

Modernization of the Central Alarm System at Krško NPP

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ABSTRACT

The existing central Alarm System (AS) has been in operation since 2004, with upgrades implemented in 2008 and 2018. Increasingly frequent faults such as system unresponsiveness, insufficient processing power, and loss of communication within the system components have reduced the overall reliability of the AS system. Due to the lack of technical support and the limited availability of spare parts, replacement of the existing alarm system was required.

The upgrade was carried out during the 2025 outage and covered the entire system, from the input terminals, which remained unchanged and defined the project boundary, up to and including all alarm panels (ALBs) on the main control board (MCB). The system is integrated with a modern distributed control system (DCS), and designed with two redundant channels. The new system allows live replacement of all vital components (“hot-swap”), ensuring maximum system availability in the event of failures. Owing to the redundant two-channel design, if one channel fails, the other maintains full system functionality and enables uninterrupted plant operation. The new alarm panels on the main control board are LED-lit and digitally connected to the main system via a redundant MODBUS protocol. This allows the use of network cabling, easy reconfigurations and significantly shortens installation time compared to the old hardwired ALBs. The system was fully assembled and configured at the manufacturer’s facility, enabling comprehensive Factory Acceptance Testing (FAT). Such approach reduced testing activities during the outage and increased reliability during system startup and operation.

This impressive modernization project, covering nearly 2,000 digital inputs and controlling 33 ALBs (1,260 alarm windows), was fully installed under design modification 1282-AS-L [1] and tested in only eight days with no major issues.

Keywords: Alarm System (AS), Distributed Control System (DCS), Redundant architecture, Alarm Panel (ALB)

1. INTRODUCTION

Alarm systems in nuclear power plants play a critical role ensuring safe and efficient operation. At Krško NPP, the central AS is one of the most important human–machine interfaces in the control room, providing immediate notification of abnormal conditions, deviations, and equipment failures across the plant. Since the annunciator is among the first information sources operators consult during transients, the system must be highly available, deterministic in behavior, and intuitive to interpret under time pressure.

The previous AS, deployed in 2004, had reached the end of its operational life. Despite partial upgrades in 2008 and 2018, the system increasingly exhibited internal communication faults, unresponsiveness during high-load conditions, and processing constraints. Spare parts and vendor

support were becoming unavailable, and configuration changes demanded disproportionate effort. These factors adversely affected reliability, maintainability, and confidence in long-term performance.

In response, NEK initiated a comprehensive modernization under Modification 1282-AS-L, executed as a turn-key project by Tecnatom S.A.U., a Westinghouse Group company. The goal was to replace both hardware and software while preserving operator-facing functions, existing panel locations, and established alarm logic. The design integrates a new digital redundant architecture, LED annunciators with digital communications, an enhanced ground-fault detection concept, and a reengineered power and communication distribution. This paper describes the background, architecture, implementation, testing, and results of the replacement performed during the 2025 outage.

2. BACKGROUND AND MOTIVATION FOR MODERNIZATION

The legacy AS platform (Figure 1) faced three major challenges. First, obsolescence: original replacement modules and support services were increasingly unavailable, which extended repair times and elevated operational risk. Second, performance limitations: the growing number of scanner cards and the associated internal traffic periodically produced communication dropouts and sluggish response, especially during maintenance and testing. Third, limited functionality: diagnostic visibility was minimal, and modern alarm management practices [2] (grouping, prioritization and systematic suppression) were not feasible or very complex to use on the old platform.

From an operational perspective, the annunciator is central information to plant oversight during startup, power operation, and shutdown. Any degradation in processing speed, communication integrity, or availability introduces additional cognitive load for the operating crew and can complicate decision-making during plant transients. From a maintenance perspective, the lack of hot-swap capability and the unavailability of spare parts created extended intervention windows and increased the risk that a single failure could propagate to wider functionality issues. These combined factors justified a full system replacement.

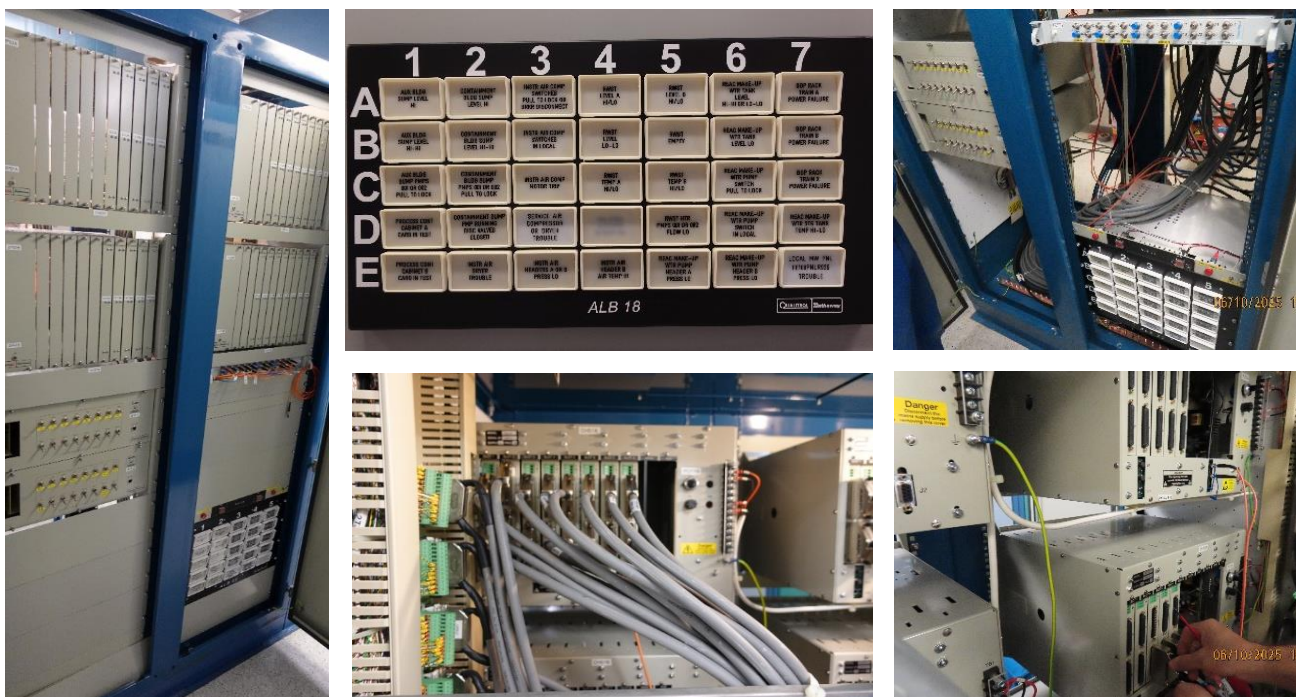


Figure 1: Legacy AS (cabinet, scanner and annunciator)

3. PROJECT SCOPE AND LIMITATIONS

The modernization encompassed the complete replacement of the main Alarm System from the terminal block interface inward, while explicitly excluding all field cabling and field contacts (i.e., the actual process signal inputs from plant instrumentation). These boundaries were deliberately selected to ensure that no modifications were made to the plant-side instrumentation or to the extensive cabling system. By maintaining the original plant field wiring, cabling, and input contact design, the project avoided any impact on validated signal routing and ensured that no unwanted errors or degradations were introduced that could cause a potential extension of outage activities.

Within these defined limits, the project replaced all AS processing equipment, including every chassis, module, communication interface, and termination component located inside both the MCR and the cable spreading room. All wiring internal to the AS system including inter-cabinet cables, cabinet-to-annunciator cables, and internal harnessing were replaced to support digital communications and ensure consistent cable quality and labeling. In addition to the processing hardware, all ALBs and operator pushbuttons were replaced with modern LED-based, digitally driven equipment. The modernization further introduced two new system cabinets: a dedicated AS server cabinet (ASELAL01A08) and a new main chassis/power distribution cabinet (ASELAL01A09) to house the redundant field-contact power supplies, ground-fault detection modules, Ethernet switching, and the header chassis.

The physical execution required coordinated work across multiple areas: the Main Control Room - ventilation control boards, electrical control boards, the switchyard control board, the fire protection cabinet, and the cable spreading room. Interconnecting cables between these locations was renewed also due to the new RS-485 MODBUS communication topology and revised grounding system, while all field wiring remained intact and continued to terminate at the original marshalling terminals. Design documentation (DMP – design modification package) was prepared in accordance with NEK procedural requirements (ESP-2.602), and execution was planned for a restricted outage window, relying on pre-fabrication and factory testing to compress on-site activities.

4. SYSTEM ARCHITECTURE

The new AS is implemented as two fully redundant trains (Train A and Train B), each capable of supporting complete annunciation functionality. Field signals are split at termination modules and routed to matching DI cards in each train. Each train comprises multiple CPU chassis distributed across existing cabinets. Power is provided from independent 118 VAC inverters to dual supplies in each chassis, supporting hot-swap of modules without service interruption.

A Centralized redundant design (Figure 2) was selected to simplify logic distribution and improve determinism. In this model, remote chassis processors acquire all digital inputs and timestamp changes with 1 ms resolution for SOE. The node processors host the Boolean logic that drives annunciator windows, perform inter-train signal validation, manage MODBUS/serial registers and communication for ALBs, and interface with the AS Plant Management System (PMS). Because the node processors have direct access to signals across all paired sub-chassis, no peer-to-peer sharing logic is needed, reducing engineering and lifecycle complexity.

Annunciator communication is also provided by MODBUS cards, each offering four RS-485/RS-232 serial ports at 1200–115200 baud and supporting hot-swap. Annunciators installed on the same control board are additionally connected by a synchronization link that enforces uniform blink behavior across all windows in a group. Groups are arranged as follows:

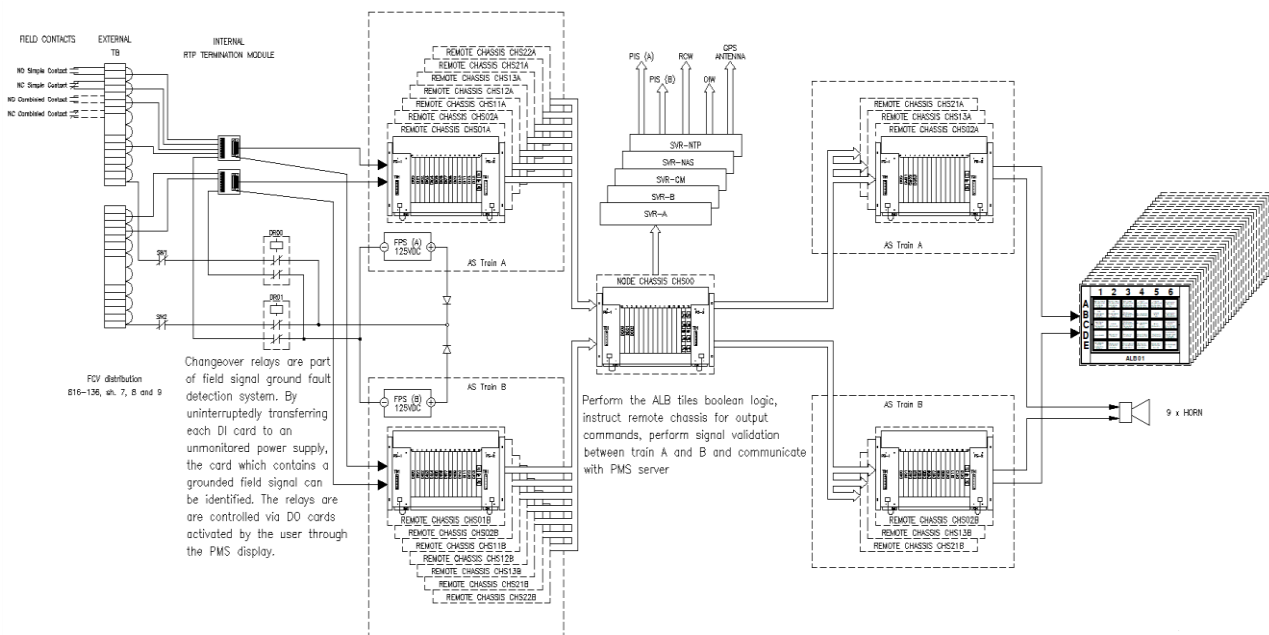


Figure 2: Block diagram of new AS

Main Control Board (ALB01–ALB19), Emergency Control Board and Switchyard Control board (ECB-A/B/X/Y and ALB-E01 to ALB-E03), VCB (PC100CME001–PC100CME006) and the fire protection panel (PC100CME007).

The ground-fault detection subsystem is centralized in cabinet ASELAL01A09 and employs a special state of the art detectors to monitor three major signal groups (VCB & FP, MCB, and ECB & SY CB). Unlike the previous system—which could only detect ground-faults at a coarse, bigger group-level resolution—the new design provides a dedicated detection point for every individual DI card, enabling ground-fault localization down to 32 input points per detection node. Higher-resolution dramatically improves diagnostic accuracy and reduces troubleshooting time.

From the PMS interface, maintenance personnel can selectively toggle dedicated relays to switch any monitored signal group from supervised power to an isolated supply. Importantly, this diagnostic process is performed without interrupting power to the field loops and without activating or suppressing any alarm window, a significant improvement over the legacy system where ground-fault searching often triggered unintended annunciations or temporarily disabled alarm visibility.

This non-intrusive troubleshooting capability represents a major advancement for maintenance efficiency and plant reliability. It eliminates historical challenges where fault-finding required intrusive disconnection, increased operator workload, or temporary alarm impairments. Instead, the new design enables systematic, safe, and accurate ground-fault isolation through a software-guided workflow, significantly reducing maintenance effort and the potential for human error.

To support this improved functionality, all signals associated with a given DI card share a common positive potential, with corresponding modifications implemented in the marshalling cabinet terminal distributions. This ensures consistent ground-fault monitoring conditions and guarantees that each DI card behaves as an independent, diagnosable segment within the overall system.

Time synchronization for complete AS system is provided by a new GPS antenna/receiver chain feeding an NTP server installed in ASELAL01A08. The NTP server distributes time to both

DAQ and HMI networks, ensuring that PMS servers and all RTP components maintain common time bases for SOE correlation and event analysis. PMS also provides a software representation of the alarm panels and diagnostic pages that supersede the legacy ALB22 display and maintains redundant communications with the Plant Information System (PIS).

5. HARDWARE

The acquisition platform is based on a main CPU chassis (Figure 3) with connected DI cards (Figure 4), which provide 32 optically isolated inputs at 125 VDC and support 1 ms time stamping for SOE. Cards connect to termination modules via 37-pin D-sub cables; termination modules - interface to field terminations. Each 19 inch CPU chassis is equipped with two power supplies, each fed from a different inverter source, and a remote processor. Up to 14 I/O or communication cards are supported per chassis.



Figure 3: 19" CPU chassis

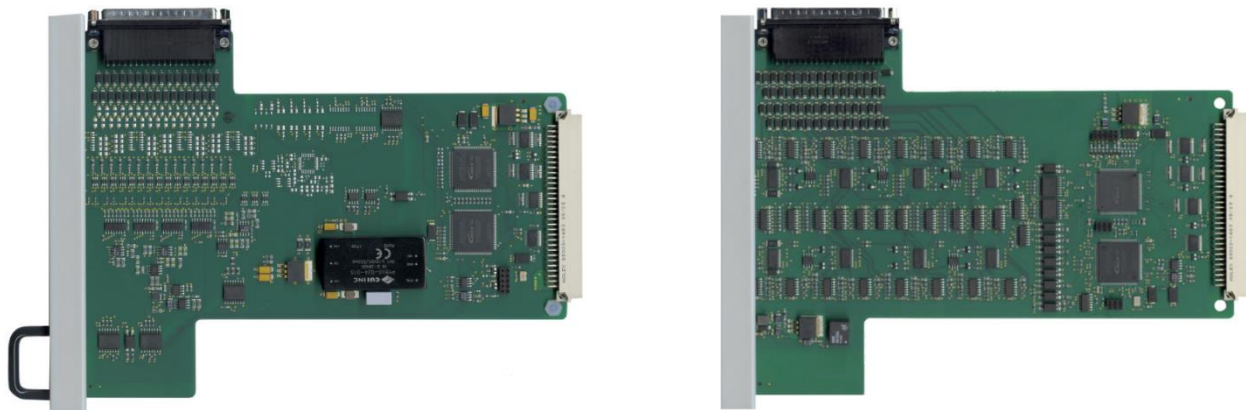


Figure 4: Hot-swappable I/O cards

Existing AS cabinets were reused where practical: CB103RCKK802 (ventilation and fire protection); ASELAL01A04 (MCB-related signals); ASELAL01A05 (ECB and SY CB

connections); and ASELAL01A07 (primarily switchyard signals). Cabinet ASELAL01A06 was removed. A new cabinet, ASELAL01A09, houses the header CPU chassis with dual node processors, the DO cards used for the ground-fault system, Ethernet switches for internal CPU chassis network distribution, and the 125 VDC field-contact power distribution including supervised/unsupervised supplies, diode modules, and ground-fault detection equipment. The server cabinet ASELAL01A08 in the DEH room contains two DAQ switches, two HMI switches, a KVM, three AS servers, a NAS storage server, an NTP server, and cyber-security equipment.

Horn activation is performed by DO cards located in CB103RCKK802 (one per train). An Automatic Transfer Switch provides power source redundancy. Field loop power is supplied from six supervised and six unsupervised 125 VDC supplies mounted in ASELAL01A09 (three per train for each signal group). Signal groups are organized by termination locations (CB103RCKK804 for VCB & FP; ASELAL01A01–A03 for MCB; EIT358/359/CB102BRDK503 for ECB & SY CB), with each group monitored by a dedicated ground-fault detector.

A special approach was applied for the replacement of the annunciators. The main goal was to reproduce the existing annunciator behavior, particularly regarding the HMI representation, so that the operator would not notice any difference after replacement (see Figure 5).

Therefore, an HFE (Human Factors Engineering) revalidation was performed to confirm that the new annunciators are fully acceptable and introduce no adverse impact on operator performance or system operation. For this purpose, a 3D model and a mock-up were prepared prior to the manufacturing process (Figure 6) to review and confirm all changes and details.

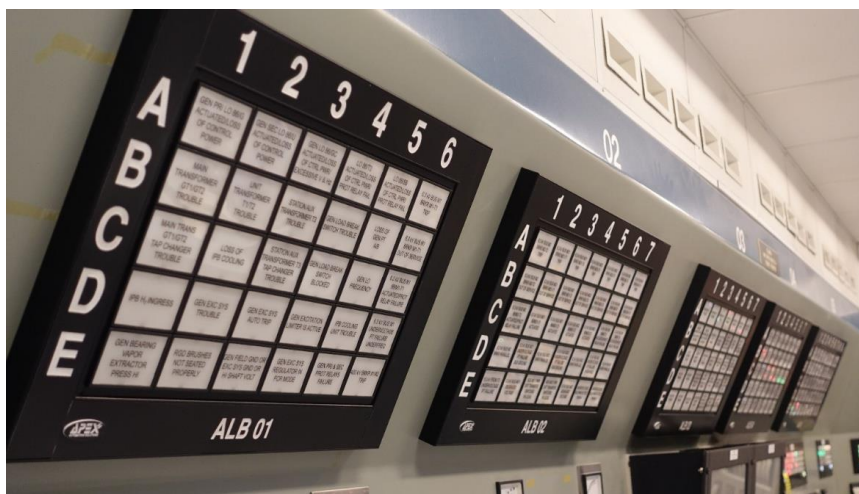


Figure 5: New Annunciators (installed)

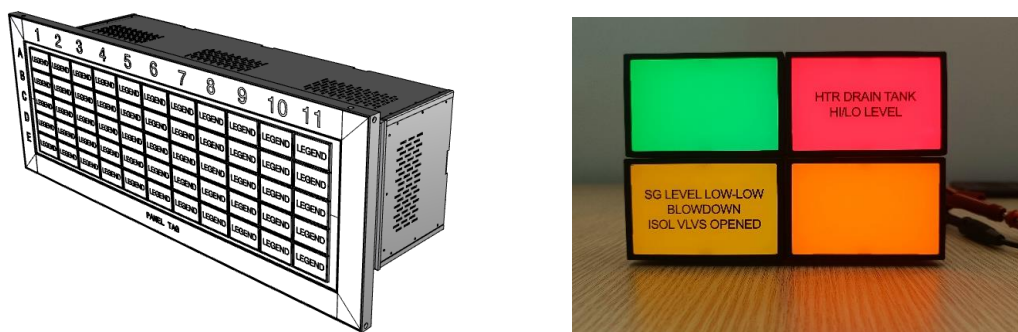


Figure 6: 3D model and mock-up

6. SOFTWARE ARCHITECTURE

All required logic that converts field inputs into annunciator commands resides in the CPU layer. Manufacturer supplied software is the primary engineering tool used to configure I/O, implement Boolean logic, and map MODBUS communications with the ALBs. This software is also used to configure controller IP addresses, subnet masks, redundancy behavior, and startup parameters. System maintains the centralized point tag database and propagates definitions as the project is built.

Remote CPU chassis processors record SOE input changes at 1 ms resolution and push updates to PMS at scan intervals down to 15 ms. PMS renders operator HMI displays that replicate ALB states, present SOE lists, provide diagnostics (including functions previously associated with ALB22 – which has been removed), and host the Ground-Fault System interface for relay control and detector feedback. PMS also maintains redundant communications with PIS to ensure plant-wide visibility of annunciation states.

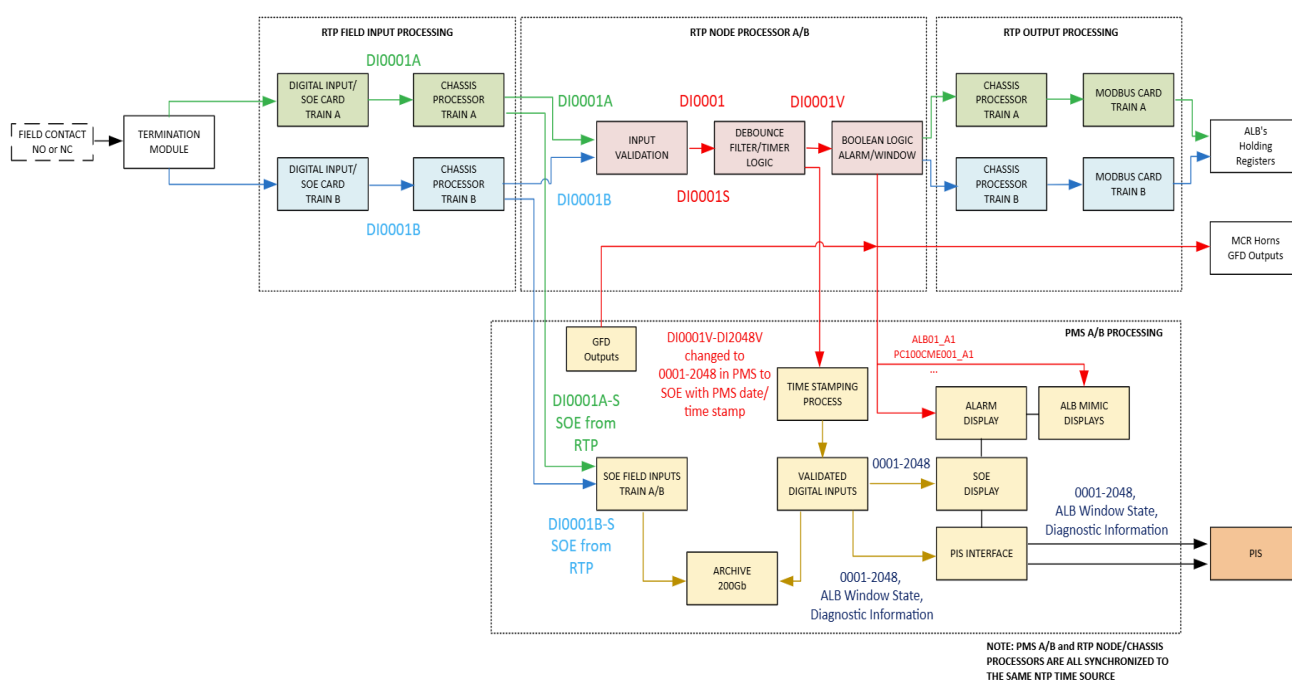


Figure 7:Dataflow

7. IMPLEMENTATION AND OUTAGE EXECUTION

Major preparation activities were completed prior to the 2025 outage. The completely new AS was assembled and configured at the manufacturer’s facility to enable comprehensive FAT. Installation crews underwent indoctrination and qualification, and a temporary alarm system was installed to maintain annunciation while the legacy system was being replaced. Selected activities—such as GPS antenna installation, server cabinet placement in the DEH room, and new conduits in the cable spreading area—were performed ahead of the outage to reduce critical-path work.

During the outage, work proceeded in a tightly sequenced manner: removal of existing equipment from AS cabinets, installation of new CPU chassis and power distribution, replacement of all annunciators, rerouting and termination of new cabinet interconnects and cabinet to ALB communications, configuration loading, and site testing.

Although nine days were allocated for installation and testing, and there was understandable concern due to the highly compressed outage schedule, the work was completed exactly as planned, without major issues. This achievement ensured an on-time startup and demonstrated excellent coordination and execution across all involved teams (Figure 8).



Figure 8:Field works

8. TESTING AND COMMISSIONING

FAT validated the assembled system end-to-end, including I/O termination paths to termination modules, annunciator logic and window mapping, MODBUS communications, blink synchronization behavior, 1 ms SOE performance, PMS HMI rendering, and ground-fault system functionality (Figure 9). Exercising the complete build at the factory reduced integration risk and allowed defect remediation before shipment.

Site Acceptance Testing (SAT) verified approximately 2,000 digital inputs, annunciator behavior and synchronization, communication failover, single-train loss tolerance, horn activation logic, and ground-fault localization via PMS relay toggling. SAT confirmed that system behavior matched design intent and operator expectations and that selected redundancy goals were achieved.



Figure 9: Factory Acceptance Test

9. TRAINING

The training covered general system overview, operator use of PMS displays (ALB replication, SOE interrogation, diagnostics, and relay toggling), and maintenance procedures for CPU chassis, termination modules, power distribution, and ground-fault detection equipment. Training materials and practical exercises were tailored to ensure that operations and maintenance personnel could assume ownership immediately after turnover.

10. CONCLUSION

Modification 1282-AS-L successfully replaced the aging AS platform with a fully redundant digital DCS architecture that preserves operator familiarity while improving reliability, maintainability, diagnostics, and availability. Hot-swap capability, dual-train design, LED annunciators with MODBUS networking, enhanced SOE and diagnostics, and a robust ground-fault detection concept collectively reduce lifecycle risk and outage workload. This impressive modernization project, covering nearly 2,000 digital inputs and controlling 33 ALBs (1,260 alarm windows) was completed within an eight-day installation/testing window during the 2025 outage and is positioned to support NEK's long-term operation and future alarm management enhancements.

REFERENCES

- [1] Westinghouse/Sipro, NEK Modification 1282-AS-L Project Documentation
- [2] Bill Hollifield and Eddie Habibi, Alarm Management – a comprehensive guide – Second Edition