UPGRADING OF THE FUELLING MACHINE TESTING RIG AUTOMATION SYSTEM IN SUPPORT OF CERNAVODA NPP UNITS U3 & U4

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Abstract

The current paper addresses the analysis, rehabilitation, and commissioning methods of the automation system associated with the Fuelling Machine (F/M) Testing Rig within the Institute for Nuclear Research Pitești. This initiative represents a key step in preparing the testing infrastructure for the acceptance and pre-acceptance tests of the F/M Heads intended to be used at Cernavoda Nuclear Power Plant (NPP) Units U3 and U4. The study focuses on the evaluation of the existing automation system, reducing of electromagnetic interference, and identifying obsolete and unreliable components. Based on this assessment, modern control architectures are proposed, aiming to improve system reliability, flexibility, and performance. Viable hardware solutions are analyzed, considering compatibility with the existing installation, operational requirements, and long-term maintainability. Additionally, the paper presents a structured methodology for project implementation, including system evaluation, hardware and software development, testing, and commissioning phases. The proposed modernization ensures the transition from analog-based control logic to programmable digital systems, enabling improved monitoring, diagnostics, control capabilities and digital signal processing. The results highlight the feasibility of upgrading the Fuelling Machine Testing Rig automation system and its critical role in supporting future nuclear projects, particularly the development of Cernavodă NPP Units U3 and U4.

Keywords: *Fuel Handling System, CANDU, F/M Testing Rig, Automation System, F/M Head*

Introduction

The continuous development of nuclear energy infrastructure requires reliable testing and validation facilities for critical equipment, such as the Fuelling Machine (F/M) Heads. Within the Institute for Nuclear Research (RATEN ICN) Pitești, the Fuelling Machine Testing Rig represents a unique installation designed for out-of-reactor testing of Fuel Handling System components.

The modernization of this testing facility is essential in the context of Romania's strategic objectives to expand nuclear energy production, which include the completion of Cernavoda NPP Units 3 and 4. These developments impose strict requirements regarding safety, reliability, and performance on the F/M Heads, which must undergo comprehensive acceptance and pre-acceptance testing.

The Fuelling Machine Testing Rig, originally developed in the 1980s, has been previously used for testing F/M Heads for Unit 2 at Cernavoda NPP. However, the existing automation system is built on outdated technology, such as analogic control systems and discrete electronic components, which are no longer supported or available [1].

This paper presents the methods used for the rehabilitation and commissioning of the automation system of the Fuelling Machine Testing Rig, focusing on the transition to modern control architectures while ensuring compatibility with current and future operational requirements, as well as advantageous solutions for systems where Hardware (Hw) modifications to the existing architecture are impractical.

Existing Automation System and Identified Limitations

The Control Room is the heart of the Fuelling Machine Testing Rig Automation System, and integrates multiple subsystems responsible for the operation and monitoring of the F/M Heads. These include: Automation System of the Hot and Cold thermo-hydraulic Loops, Control system of the F/M Heads, Operator control panels and Computer-based process control system.

The system receives signals from a variety of sensors and transducers installed on the F/M Heads, including pressure, temperature, flow, and position measurements. These signals are processed and used to control hydraulic systems, actuators, and other auxiliary equipment.

During testing of the installation, a significant limitation was identified within the signal acquisition chain of the Fuelling Machine Testing Rig automation system. The processed analogic signals, originating from the pressure, temperature and flow transducers, exhibited severe susceptibility to electromagnetic interference (EMI).

Localized noise generated by auxiliary actuators operating at 230 VAC, 50 Hz, induced significant power-line harmonics into the measurement loops, compromising signal integrity. A key advantage of switching to the proposed digital architecture is the ability to overcome this limitation through software (Sw).

The existing control logic is based on Systems of Regulation and Automation (SRA) modules organized in modular racks (SRA U1÷U4). These modules perform functions such as: signal conversion (e.g. Voltage-to-Current, Resistance-to-Voltage), minimum/ maximum selection, analog value comparison, relay-based DO (digital outputs). While functional, these systems rely on outdated electronic boards and discrete components, posing major reliability and maintenance challenges.

In addition to SRA modules, the system uses Voltage Comparator Blocks to implement decision logic based on analogic signal values. These comparators operate within the 0–5 V range and generate DO via relay contacts. There are two sorts of comparators: comparators with two inputs (window comparators) and comparators with single input (threshold detection). A large number of such comparators is required, resulting in a complex and difficult-to-maintain architecture.

The analysis of the existing system revealed several critical limitations: obsolete equipment (no longer manufactured), high failure rates due to aging components, limited flexibility and scalability, complex wiring and maintenance requirements, and a lack of advanced diagnostics and monitoring capabilities. These limitations justify the necessity for a complete modernization of the automation system.

The Control System and the Human–Machine Interface (represented by the Control Panels for testing) establish the functional connection between the F/M Head and the F/M Head Control Room, ensuring both the acquisition of technological parameters via the Process Computer and the transmission of operational commands to the auxiliary installations, as shown in Figure 1.

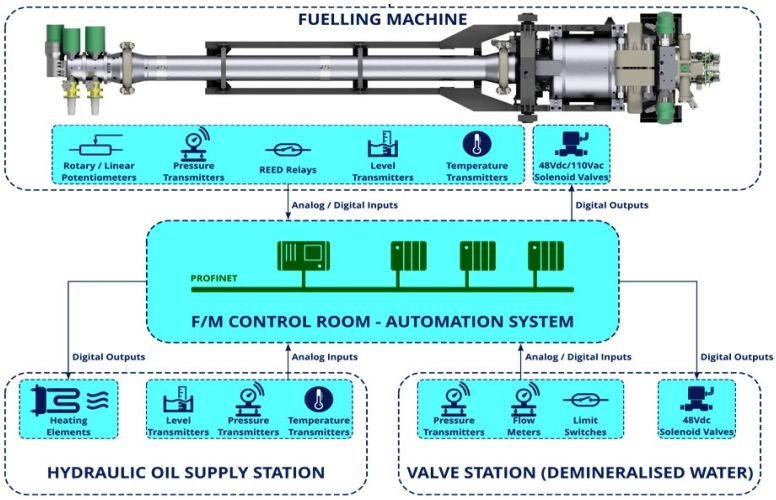


Fig.1. Diagram of interaction between the Automation System and the F/M Head equipment

The F/M Head system integrates sensors and actuators that enable real-time monitoring and control of mechanical and hydraulic processes (see Figure 1). Various process variables, such as the positioning of the RAM assembly, are monitored using rotary potentiometers (fine or coarse), which provide analogic signals proportional to axial displacement [1].

This architecture is planned to be optimized by replacing analog and discrete logic elements with software-based control, resulting in significantly improved modularity and maintainability.

Methodology for Rehabilitation and Commissioning

The Fuelling Machine Testing Rig project, which aims to optimize and modernize a facility and control room, will be carried out following the phased structure highlighted in Figure 2.

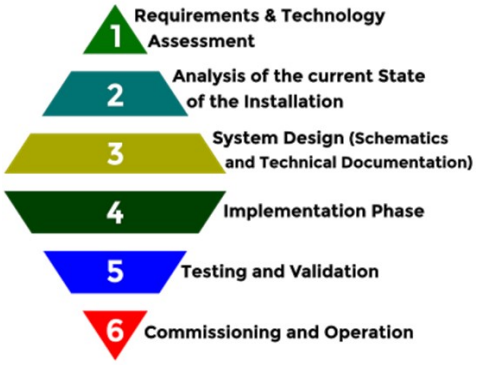


Fig.2. Phase planning of the F/M Head Control Room project

The modernization process follows a structured methodology consisting of several stages, starting with technical analysis and planning, which includes the identification of system requirements. This is followed by the evaluation of the existing system, which includes functional testing of the current equipment, performing electrical measurements, and identifying defective or obsolete components.

The project is currently in process of transitioning from current state analysis to system design.

The system design phase includes both Hw and Sw aspects, such as electrical schematics, final Hw components selection, control logic development, and Sw applications.

The implementation phase focuses on the integrating and configurating the proposed solution within the Fuelling Machine Testing Rig, followed by performance evaluation and validation under real operating conditions.

When the system is ready for operation, no-load campaigns are conducted, either without the Fuelling Machine or using the mechanical simulator, to assure operational continuity until the acceptance/pre-acceptance testing of Cernavoda NPP U3&U4 F/M Head and its auxiliary equipment.

SRA Analog Control Systems & Voltage Comparator Blocks

The computer-controlled system for F/M Heads testing is primarily used for automatic mode testing during the acceptance and pre-acceptance campaigns. It has around 80 AI (analogic inputs), with each analogic-to-digital converter operating at 16-bit resolution.

Considering the technical characteristics of the SRA Racks and Voltage Comparator Blocks used in the Fuelling Machine Testing Rig automation system, a reference architecture for the F/M Control Room has been defined, based on Siemens S7-1500 programmable logic controller, equipped with analogic and digital I/O (input/output) modules.

The proposed architecture, which is based on Siemens SIMATIC S7-1500 automation equipment, provides advanced control and monitoring capabilities such as hot swapping functionality, advanced signal processing using mathematical and time-based functions. Hot swapping is a key requirement during F/M Head testing, as interruption for corrective actions might cause installation difficulties and delays [2].

Figure 3 presents a 3D rendering of the architecture option based on Siemens SIMATIC S7-1500 equipment, which integrates a set of I/O channels, with at least one channel for each signal category. The figure just depicts the equipment required to replicate the SRA functions, although the structure necessary to perform the two types of Voltage Comparators functions is similar.



Fig.3. 3D rendering of equipment based on the Siemens SIMATIC S7-1500 product range

Siemens SIMATIC S7-1500 CPU 1513-1 PN programmable logic controller model was selected from the S7-1500 controllers' class to ensure adequate processing capacity for F/M Head applications [3].

Siemens ET200MP IM 155-5 MF HF interface module model was selected since it is one of the most recent models available, reducing the likelihood of the equipment becoming obsolete in the near future [2].

The equipment of the structure from Figure 3 ensures the minimum technological setup, being a baseline configuration that performs the essential operations to reproduce the functions of the Voltage Comparator Blocks as well as the functions of the SRA boards, enabling the implementation of the "hot swapping" functionality for modules.

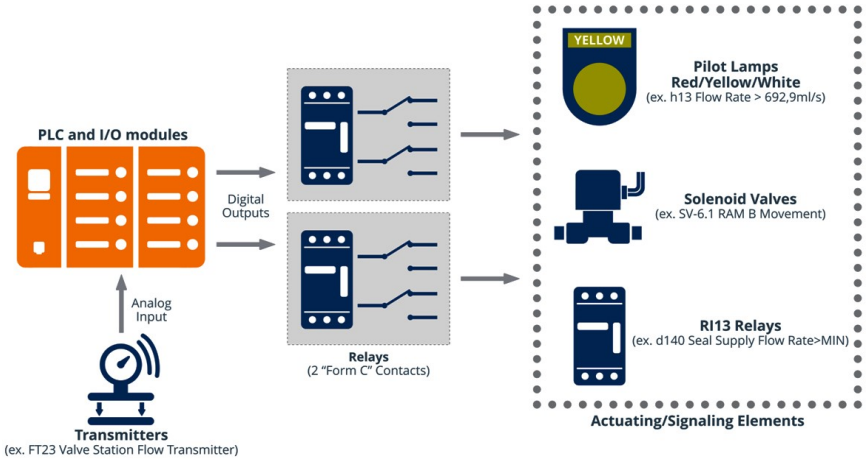


Fig. 4. SRA-U2 Rack Module Interfacing Diagram for PLC, Transducers, Relays, Control and Signalling Elements

Figure 4 show an example of interfacing diagram of the PLC, transducers, relays, actuators, and signalling elements for the SRA-U2 Rack, highlighting AI from Transmitters, controlled relays, and their associated actuation/signalling elements.

The above-mentioned components and signal flows represent only a single functional block dedicated to the RAM assembly movement logic, which functions as part of the overarching control system.

EMI Attenuation through Signal Processing Based

To mitigate the EMI vulnerability that induces significant power-line harmonics into the measurement loops, compromising signal integrity without introducing the Hw complexity associated with traditional analogic filters, the proposed architecture uses software-based signal conditioning within the digital control system. To reduce signal spikes affecting the control logic and the display of process values, data from the sensor is digitally processed by a moving average algorithm used as an adaptive low-pass-filter.

This function computes a continuous moving average governed by a predefined window size of 100 iterations, which defines the buffer capacity. Once this buffer reaches its maximum capacity, the algorithm switches to a FIFO (First-In-First-Out) basis, where each new incoming sample automatically overwrites the oldest recorded value to keep the rolling average.

Figure 5 shows the experimental test setup used to validate the effectiveness of this digital filtering function.

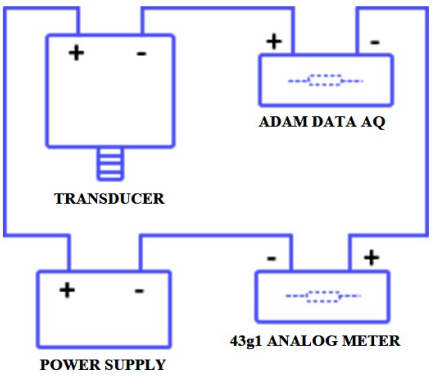


Fig. 5. Experimental test setup

The architecture utilizes a PLC equipped with an AI module, which was specifically configured for voltage acquisition.

The physical setup was designed to measure the voltage drop across the 100 Ω line resistor integrated into the terminal board of the 43g1 analogic indicator, which is part of the F/M Testing Rig control and monitoring system.

Consequently, the PLC AI module receives a 0.4–2 VDC signal, directly corresponding to the standard 4–20 mA current loop output from an RI adapter [4].

Figure 6 depicts the Sw implementation of a digital moving average filter within the TIA Portal environment. To condition the raw temperature signal, Moving Average function continuously smooths the incoming sensor data [5].

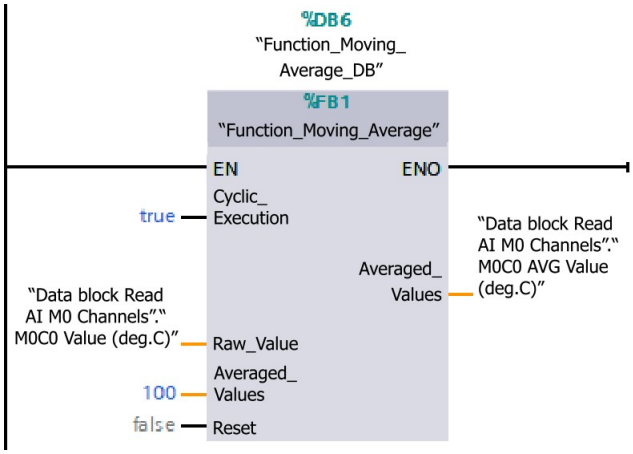


Fig.6. TIA Portal implementation of a digital moving average filter

As shown in Figure 7, the analysis of the system's dynamic response reveals that the raw AI signal (red trace) is influenced by high-frequency noise and EMI, rendering it unusable for accurate regulation. Processing this data through the first stage of the moving average filter (blue trace) successfully eliminates the extreme noise spikes. However, the generated signal still exhibits a transient, stepped profile with suboptimal stability.

The green trace shows the implementation of a cascaded filtering architecture to optimize signal conditioning. By passing the signal through a second, successive averaging window, the mathematical order of the filter is improved. This dual-stage configuration effectively attenuates the 50 Hz harmonic and produces a perfectly smoothed final curve, all while maintaining the low latency required for a highly responsive control loop.

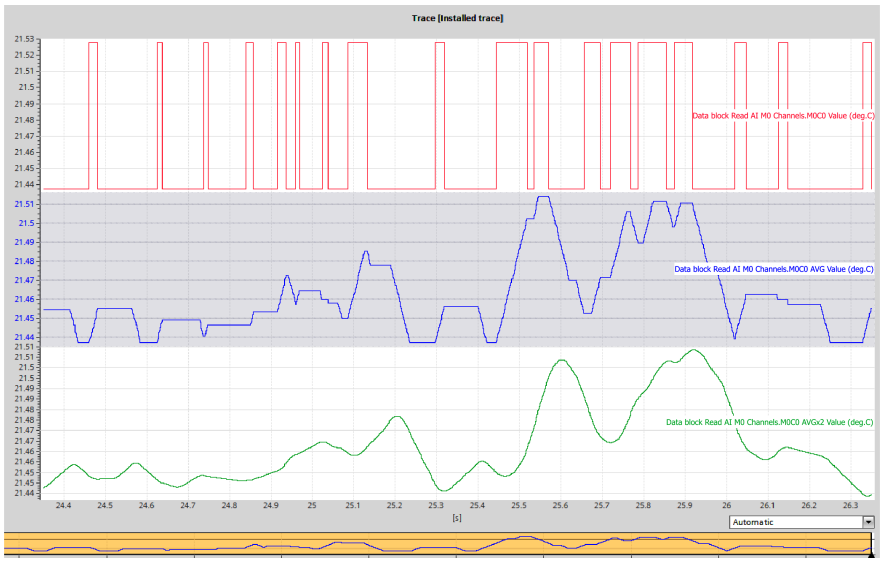


Fig. 7. The signal processed with the averaging function

Conclusions

Implementing modern control architectures within the PLC environment provides a reliable alternative to physical retrofitting. In cases where Hw changes to the existing architecture are not feasible, a digital transition approach and Sw optimization proves to be the best solution for a cost-effective of and highly reliable method of enabling hot-swappable systems, ensuring continuous performance of the Fuelling Machine Testing Rig.

Cascading two Moving Average algorithms creates a higher-order digital filter with a triangular impulse response. This configuration provides better attenuation of the noise and signal smoothing while maintaining lower latency compared to using a single, oversized averaging window.

Following project completion, a modern Hw/Sw system will be installed, capable of replicating the functions of the SRA Racks and Voltage Comparator Blocks while maintaining the required process parameters.

The methodology adopted for this project provides a clear architecture for implementation and validation, allowing scalable optimization for different types of infrastructure in the nuclear sector.

The upgraded testing facility from ICN Pitesti will play a key role in the qualification of F/M Heads, contributing to the safe and efficient operation of future Cernavoda NPP units U3 and U4, as well as providing testing services to other CANDU technology users worldwide.

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