SUOMEN ATOMITEKNILLINEN SEURA – ATOMTEKNISKA SÄLLSKAPET I FINLAND

ATS YDINTEKNIIKKA

3/2026
Vol.55

YDINJÄTEHUOLTOA SUOMESTA EUROOPPAAN

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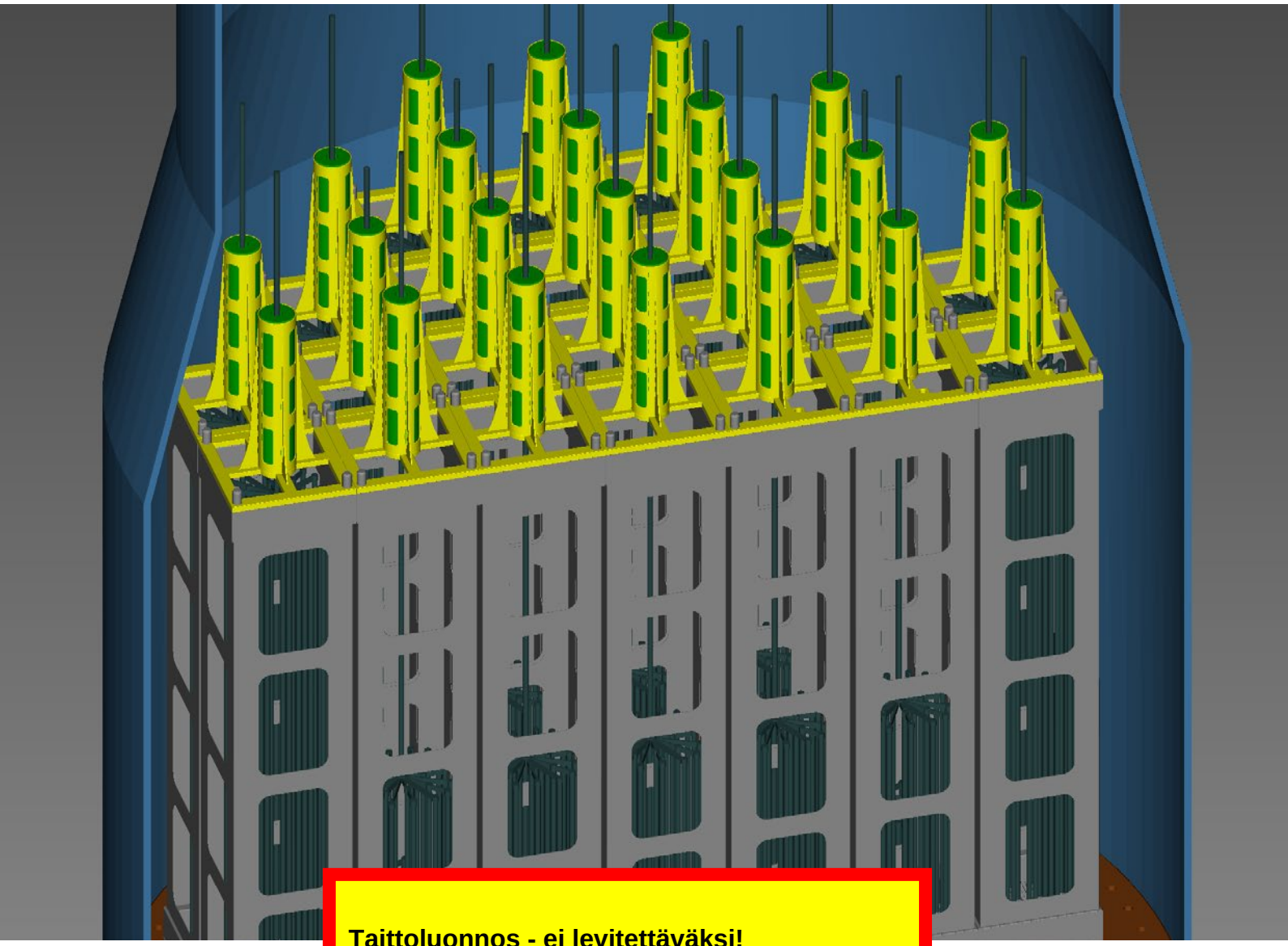

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DIGITAL MODERNIZATION OF VVER-440 SAFETY SYSTEMS AT RIVNE NPP: OPERATIONAL EXPERIENCE AND LESSONS LEARNED

Modernization of legacy safety instrumentation and control (I&C) systems remains one of the key challenges for VVER nuclear power plants as they approach long-term operation. This article reviews the digital modernization of safety systems at Rivne Nuclear Power Plant Units 1 and 2 in Ukraine, focusing on the engineering approach, implementation strategy, and operational experience gained over nearly two decades of operation.

Text and figures: Oleksandr Ivasiuk, Kostiantyn Leontiiev, Roman Tsaturian

Rivne Nuclear Power Plant (RNPP) is one of Ukraine's major nuclear generating facilities, operating four power units with a total installed capacity of 2,835 MW. Units 1 and 2, equipped with VVER-440 reactors, were commissioned in 1980 and 1981, respectively. Their control and safety systems were designed according to 1970s standards and relied on relay-based technology and ageing components.

Following the Chernobyl accident and the subsequent evolution of international nuclear safety requirements, significant attention was directed toward the modernization of safety-related systems at Ukrainian nuclear power plants. One of the key objectives was to support the long-term operation of existing units while improving compliance with updated national and international safety standards.

MODERNIZATION CHALLENGES

The original safety systems at RNPP Units 1 and 2 relied on analogue and relay-based technologies with limited diagnostic capabilities and increasingly difficult maintenance due to equipment obsolescence. In addition, the architecture required extensive cable infrastructure and large equipment volumes.

The modernization program was implemented within the framework of the Energoatom Program for Replacement of Key Components of Process Control Systems at VVER-1000 and VVER-440 Units, originally during 2000–2006 and later extended to 2007–2010. One of the program's principles was the use of domestic engineering and manufacturing capabilities.

SELECTION OF DIGITAL ARCHITECTURE

After evaluating available technical solutions, RNPP selected the digital RADIY Platform to modernize the safety I&C systems. The upgraded systems included the reactor trip system, reactor protection system, engineered safety features actuation system, reactor power control and limitation system, as well as nuclear and conventional island I&C systems.

The new architecture was based on Field-Programmable Gate Array (FPGA) technology and incorporated multi-channel redundancy, extensive diagnostics, optical communication channels, and reduced dependence on conventional cable connections. The use of optical communication channels significantly reduced the



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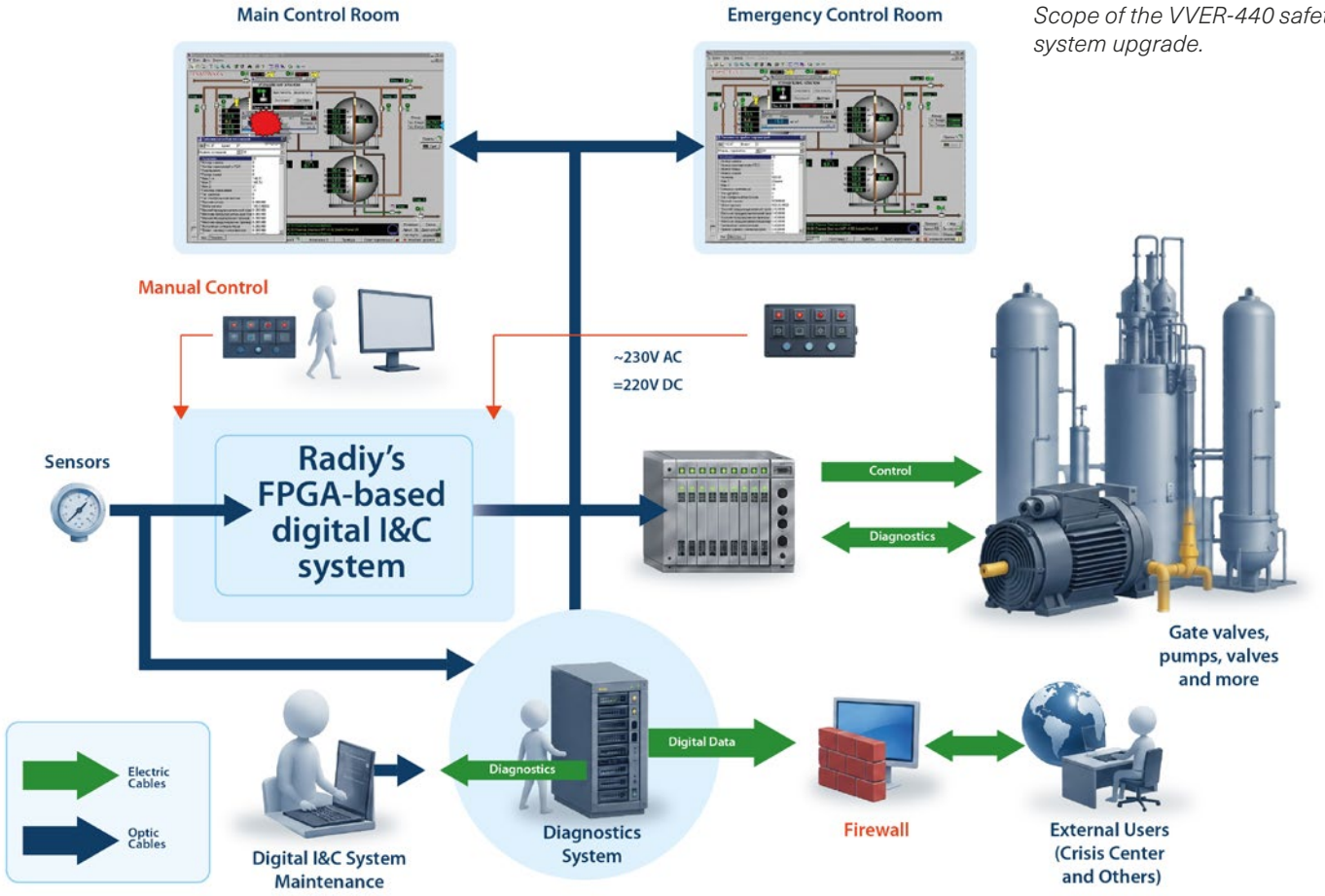


Scope of the VVER-440 safety system upgrade.

amount of copper cabling required within the system architecture.

The platform also provided high diagnostic coverage and supported implementation of I&C systems with key modern nuclear safety principles, including independence, single-failure tolerance, and protection against common-cause failures.

At the time of implementation, the Radiy Platform had already been applied in several safety modernization projects at Ukrainian nuclear power plants, including the emergency protection system at RNPP Unit 4 (commissioned in 2004). Additionally, it had been applied in safety system modernization projects at South Ukraine NPP where ESFAS-3 and ESFAS-2 (Engineered Safety Features Actuation System) were reconstructed in 2005-2006.

WHY WAS FPGA TECHNOLOGY SELECTED?

FPGA-based platforms offer several significant advantages over conventional microprocessor-based architectures. First and foremost, FPGAs provide a high degree of computational parallelism, as they allow hardware modules to operate simultaneously, whereas microprocessors generally execute instructions sequentially. This enables substantially higher performance in applications such as digital signal processing, cryptography, and real-time control systems.

In addition, FPGAs offer exceptional configurability, allowing the hardware architecture to be tailored to specific application requirements without the need to manufacture a new integrated circuit. FPGA-based platforms also provide lower processing latency and improved energy efficiency for specialized tasks because required algorithms are implemented directly in hardware rather than executed as software instructions.

From a cybersecurity perspective, FPGA technology offers a distinct advantage because VHDL (Very High Speed Integrated Circuit Hardware Description Language) code defines hardware logic rather than software executed by an operating system. Once synthesized and programmed into the FPGA, the device functions as a dedicated hardware component with predetermined behavior. This architecture eliminates many of the common attack vectors found in conventional computing systems, including operating systems, file systems, processes, general-purpose drivers, interpreters, dynamic library loading mechanisms, and third-party code execution environments.

No operating system. No software runtime environment. No traditional malware attack surface. FPGA technology implements deterministic hardware logic rather than executing software code, significantly reducing cybersecurity risks and eliminating entire classes of operating-system vulnerabilities.

MODERNIZATION STRATEGY

RNPP adopted a comprehensive modernization strategy involving large-scale replacement of existing safety systems during a single outage period. The approach aimed to minimize long-term operational disruption while implementing substantial

improvements in system architecture and diagnostics.

The project was implemented jointly by specialists from RNPP, Radiy, and several Ukrainian contractors responsible for installation, commissioning, and regulation systems. Reverse engineering methods were applied where necessary to preserve existing plant functionality while introducing new digital technologies.

IMPLEMENTATION AND TESTING

Particular attention was paid to pre-installation testing, which included verification of system functions, diagnostics, communication interfaces, and operational logic under conditions representative of actual plant operation. The testing environment reproduced the final plant configuration as closely as possible, allowing identification and correction of potential issues before equipment delivery to the site.

The modernization also simplified the system architecture. The use of digital communication channels and optimized equipment arrangement reduced the number of internal connections and overall equipment volume compared with the original relay-based systems.

During commissioning and startup activities, the modernization team focused on minimizing operational risks and ensuring compatibility between the new digital systems and existing plant infrastructure. According to operational experience from RNPP personnel, no system failures, false actuations, or significant deviations from expected system performance were observed following implementation.

OPERATIONAL EXPERIENCE

More than twenty years of operation have provided practical experience regarding the long-term performance of the modernized systems. Operational data indicate stable performance of the digital safety systems with high availability and reduced maintenance requirements compared with the previous analogue systems.

One of the most significant technical effects of the modernization was the reduction in cable infrastructure. The transition to optical communication channels reduced the total length of electrical cables from approximately 135 km to 28 km, contributing to lower fire load, simplified maintenance activities, and reduced equipment complexity.

The digital architecture also improved diagnostic capabilities. Continuous automated diagnostics provided maintenance personnel with more detailed information regarding equipment status and system performance, supporting condition-based maintenance approaches and reducing the need for periodic manual inspections.

One of the tangible operational advantages was the availability of a wide range of real-time information to operators and maintenance personnel. The system provided detailed health status information on individual modules and equipment, as well as online monitoring of input and output signal values, improving situational awareness, facilitating troubleshooting, and supporting more efficient system operation and maintenance.

The modernized systems were designed in accordance with key safety principles commonly applied in modern nuclear safety systems, including:

- Redundancy;
- Independence between channels;
- Single-failure tolerance;
- Continuous diagnostics and monitoring;
- Electromagnetic compatibility;
- Protection against unauthorized access.

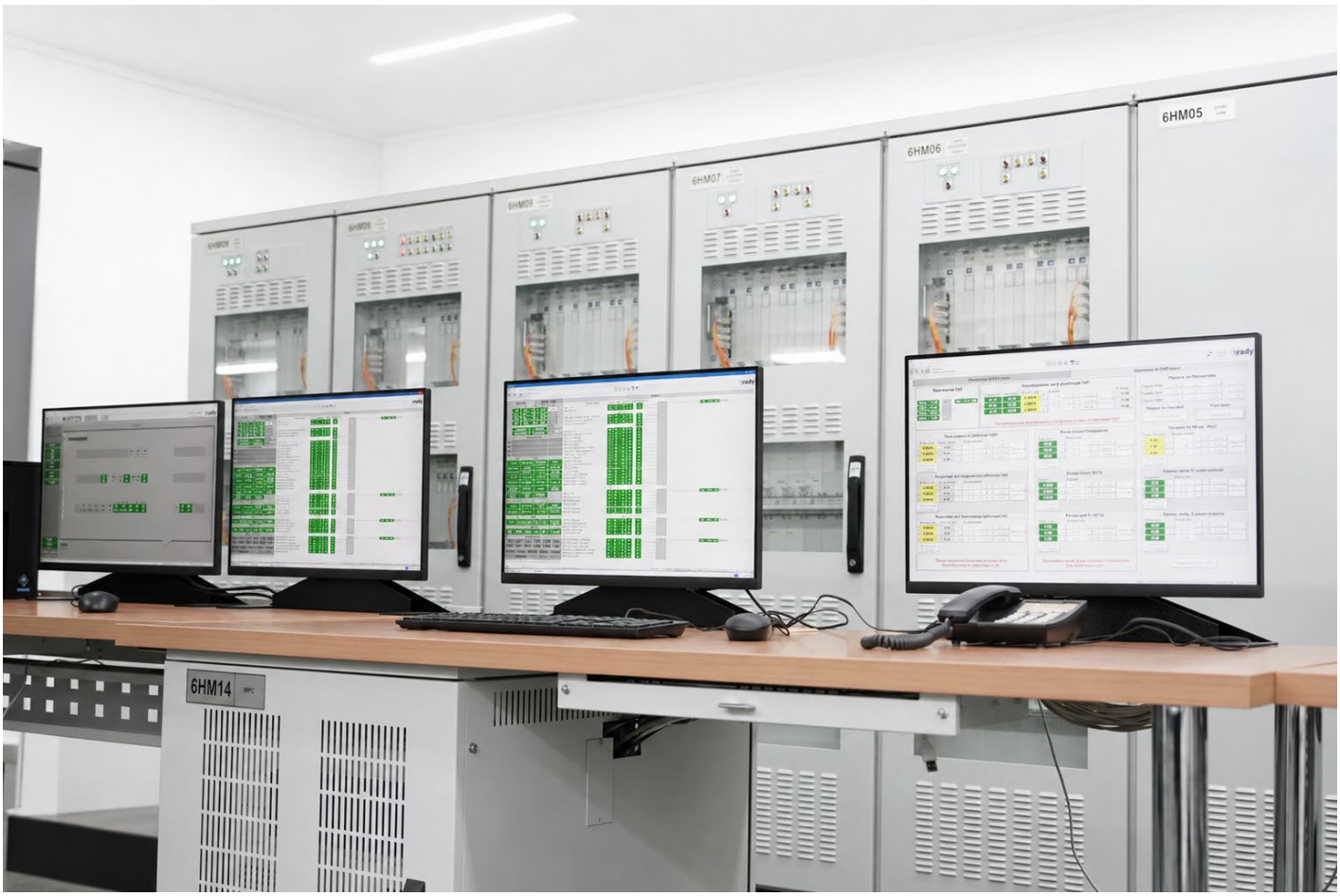
Although cybersecurity requirements in the nuclear industry were less developed at the time of implementation, several protective measures incorporated into the original design remain consistent with modern cybersecurity expectations.

LESSONS LEARNED

The RNPP modernization project demonstrated several important considerations relevant to the digital modernization of



Digital I&C system cabinets installed as part of Rivne NPP modernization program.



Proven FPGA-based I&C technology for VVER reactor modernization.

legacy VVER units. Extensive pre-installation testing significantly reduced implementation risks during outage activities and simplified commissioning. In addition, early integration of plant personnel, system designers, and installation contractors contributed to more efficient resolution of technical issues during implementation.

The project also demonstrated that large-scale modernization can be performed while maintaining compatibility with existing plant systems and operational practices. Reduction of equipment complexity and improvements in diagnostics supported both operational reliability and long-term maintainability.

The use of FPGA-based architecture also provided flexibility for future system modifications and adaptation to evolving regulatory requirements. Despite substantial changes in nuclear safety expectations during the past two decades, the modernized systems continue to support compliance with current Ukrainian and international nuclear safety regulations.

RELEVANCE FOR FUTURE NUCLEAR PROJECTS

Experience gained during the RNPP modernization project remains relevant for ongoing modernization programs at existing nuclear power plants and for future advanced reactor projects. Many nuclear facilities worldwide continue to address equipment obsolescence, lifecycle extension, and increasing requirements for diagnostics and cybersecurity.

FPGA-based digital platforms are increasingly being considered for applications requiring high reliability, deterministic behavior, and long-term maintainability. Experience gained during modernization of VVER safety systems demonstrates the potential of such technologies for both existing reactor fleets and future nuclear projects, including Small Modular Reactors (SMRs).

The RNPP project demonstrated that replacement of legacy safety systems can improve diagnostics, reduce maintenance complexity, and support long-term operation while addressing evolving nuclear safety requirements.

Given the advantages of FPGA technology described above, its versatility, and the extensive experience of Radiy/Radics in developing, manufacturing, supplying, and commissioning equipment that has been successfully deployed across a variety of reactor technologies, there is no doubt that FPGA-based products can be effectively applied to both current and future nuclear power plant designs, including SMRs.

The inherent flexibility, reliability, cybersecurity benefits, and deterministic performance of FPGA technology make it well-suited to meet the demanding requirements of next-generation nuclear facilities. As the nuclear industry continues to evolve, FPGA-based I&C solutions provide a robust and future-ready platform capable of supporting advanced reactor concepts and emerging technologies.