Importance of modern instrumentation and control systems in nuclear power plants

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Abstract: This paper presents some of the issues the nuclear power plant (NPP) industry is facing in the area of instrumentation and control (I&C) systems. In addition, the paper discusses the advantages of a technology that is an alternative to the computer-based solution, the Field Programmable Gate Arrays (FPGAs) and its applications in NPPs. Finally, the paper discusses some aspects of the international information exchange in the I&C industry, with special emphasis on the I&C related activities of the International Atomic Energy Agency (IAEA).

Keyword: nuclear instrumentation and control systems; digital I&C; FPGA;

1 Introduction

Distributed I&C systems are deployed throughout nuclear power plants (NPPs) and they are used to monitor the status of the plant, control its operation, adjust its process variables, support plant operation and maintenance, and start up and shut down the plant.

I&C systems are vital parts of normal, abnormal and emergency operations. The overall I&C system of a typical NPP unit has thousands of sensors and detectors, thousands of kilometers of I&C cables, and hundreds of actuators distributed over a large area in the plant.

NPPs have both main and secondary (emergency) control rooms from which most I&C systems are operated. Some I&C functions are critical for assuring nuclear safety (*e.g.* reactor shutdown systems, containment isolation, emergency core cooling). Others influence safety to varying degrees. And still others, which are more related to production and maintenance, may have less impact on nuclear safety, but they are important for high reliability and availability in production.

2 Instrumentation and control systems

2.1 Sub-systems and functions

In general, the sub-systems and functions of I&C systems include the following:

- Sensors and detectors directly interfacing with the physical processes of the plant and continuously taking measurements of plant's physical variables, such as neutron flux, temperature, level, pressure, and flow, as well as discrete signals (open/closed). The technologies used for sensing and measuring physical variables in the plant are analog, but digital components are increasingly used as imbedded parts of detectors, transmitters, and communication lines.
- Information processing and control/safety logic systems that process the above measurement information for the purpose of managing plant operation automatically by generating and sending control and command signals to actuators. Traditionally, the control and safety logic has been implemented with analog components (relays, comparators, switches), however these functions are being taken over by digital technologies in modernized I&C systems of operating NPPs or in new NPP designs.
- Actuators (*e.g.*, valves, pumps, and motors) that receive control and command signals from the above control/safety logic systems and directly interact with the physical processes in the plant to adjust the plant's state. The purpose of this function is to optimize plant performance and keep the plant in a safe operating envelope, or shut the plant down and place it in a safe state, if the plant leaves this envelope. Actuators also include digital technologies for their control, diagnostics, and power supply.
- Communication systems for data and information transfer through wires, fiber optics,

Received date: December 15, 2013
(Revised date: December 24,2013)

wireless networks or digital data protocols, connecting sensors, detectors, control/safety logic systems, actuators, human-system interfaces, and information systems.

- Human-system interfaces for information display and interaction provision for plant operating personnel in the main and secondary control rooms. Most of the world's NPPs have hybrid technologies in their control room where analog and digital I&C systems and human system interfaces are employed.
- Status indicators of actuators (*e.g.*, whether valves are open or closed, and whether motors are on or off) providing information for controlling these actuators automatically and manually.
- Surveillance and diagnostic systems that monitor the operation and fault-status of all systems and components mentioned above.

2.2 Modernization

Perhaps faster than any other parts of nuclear power plants, instrumentation and control systems are continuously advancing. I&C technologies available in the NPP industry went through a remarkable and rapid development in the past 50 years. Yet the majority of instrumentation and control equipment in operating NPPs were designed more than 30 years ago with analog and relay components, and in some cases rudimentary digital technology. Although analog I&C systems have served the above functions satisfactorily for many decades, a substantial amount of this original I&C equipment already is or soon will be obsolete.

When the lifetime of NPPs is extended through license renewal processes, and the existing systems cannot continue to support the plant, modernization is required.

Nuclear power plants that may operate for 60 or more years, could outlive its original I&C system by a factor of three, shifting first from analog to digital I&C systems, and then subsequently to even more advanced digital I&C systems. Experience from the various ways of modernizing I&C systems of operating NPPs are now widely available. Such experience covers cost-benefit analyses, bidding processes, design and selection of equipment, installation and testing, licensing requirements, qualification methods and project management.

No accurate and globally comprehensive statistics are available on the numbers of NPPs with fully analog, fully digital or hybrid I&C systems. However, approximately 40% of the world's 435 operating nuclear power reactors in 30 countries have had some level of digital I&C upgrade to systems important to safety. The 71 new nuclear reactors, currently under construction around the world, will have either completely digital I&C technology for their control and safety systems, or a modern hybrid system of digital and analog components.

2.3 Challenges of Digital I&C Systems

Digital I&C technologies with improved performance and reliability has had an important influence on I&C systems design in many major industries. However, in nuclear power plants digital technology has been adopted more slowly, especially for safety I&C systems. For good reason, the nuclear industry has an inherently conservative approach to safety, and substantial effort is required to provide the necessary evidence and analysis to assure that digital I&C systems can be used in safety applications.

For NPP applications and regulatory approval, digital I&C systems have several distinctive features:

- A digital I&C system has more connections among its many components and other systems, and it is simply more complex than its analog predecessor.
- Digital I&C systems are more dependent on system and application software, and their reliability and correctness are impacted by the quality of the software development process.
- The overall dependence on computers digital data networks raises the importance of cyber security.

The first two of these features, complexity and software-dependence, introduce new possibilities for common cause failures (CCF) of the whole system. In order to avoid that, various ways and degrees of diversity have to be introduced at all stages of the I&C system's life cycle.

The development and applications of new innovative I&C systems are expected to continue as an area of rapid technological development. Future designs of NPPs may require new solutions in sensing technologies, communication and in digital control. Advanced sensors, detectors, transmitters, and data transmission lines are needed to meet the requirements imposed by the operating conditions of new designs (*e.g.*, high temperatures and high flux) and by the harsh environment of 'beyond design basis accidents' and post-accident conditions. Additional monitoring and diagnostic systems will need to be developed, making use of on-line condition monitoring techniques, wireless sensor networks and communication, and integrated remote operation.

An important emerging technology in the NPP industry is the Field-Programmable Gate Arrays (FPGAs), providing an alternative to microprocessor based technologies and other types of programmable devices.

3 Digital I&C based on Field Programmable Gate Arrays Technologies

3.1 Advantages and challenges

FPGA-based I&C systems have been developed and applied in aerospace and process industries since the 1990s. Although the use of FPGAs in NPPs has lagged behind in the past, compared to other industries, there is an increasing number of FPGA installations in operating NPPs worldwide.

FPGAs are semiconductor-based programmable devices which can be configured to perform custom-designed functions. It includes two entities: FPGA hardware components that can be tested against hardware qualification requirements, and the electronic design, represented by a set of instructions in hardware description language (HDL) to be configured into the FPGA hardware and that can be verified against functional requirements.

There are two main FPGA chip architectures: fine-grained and coarse-grained. The coarse-grained FPGAs have very large logic blocks (macrocells) with sometimes two or more sequential logic elements, and the fine-grained ones have very simple logic blocks.

Another architectural difference is the technology used to manufacture the FPGA chips. The most common technologies are:

- EPROM/EEPROM/Flash based chips are re-writable types (they allow reprogramming of the FPGA) and non-volatile (no data or logic is lost in case of power losses);
- SRAM based chips are re-writable, but volatile;
- Anti-fuse based chips are non re-writable and non-volatile.

The development process of FPGA applications is typically composed of requirement specification, design, implementation and integration along with the associated verification and validation (V&V) activities.

The objective of the requirements specification phase is to define precisely all the requirements that apply to the FPGA platform and associated application. These requirements are usually derived by following a top-down approach whereby each system component is allocated functional and safety requirements and interfaces among them are defined.

The most critical phase of the FPGA overall development process is the design phase. Errors made in this phase will dramatically affect all subsequent stages. The development process includes architectural and detailed design activities.

The architectural design defines all functional blocks and their interfaces, as well as other information required for the detailed design development process. Reliability, traceability and design verifiability requirements are defined at this stage.

The output of the architectural design requirements definition process is the textual or graphical description of the design partitioning of the above requirements among the system components. Upon completion of this design activity, a design review is performed, which may result in creating a modified design partitioning or correction of the initial requirements.

The detailed design phase refines the architectural design and translates it into an FPGA electronic design description. The detailed design should implement the functions of the FPGA electronic design. The forms of design inputs typically used to implement detailed design are HDL coding (such as VHDL or Verilog) and schematic representation.

One of the reasons why FPGA technology is gaining acceptance for nuclear applications is that some I&C functions requiring short response times (for example, some safety functions within boiling water reactor systems and reactor overpower protection in CANDU reactors) could not be easily implemented using microprocessor based platforms. FPGAs allow the possibility of implementing functions requiring faster response times than those provided by microprocessor based systems. Other FPGA attractive features are:

- Simpler and, therefore, more reliable technology, partly because it doesn't include an operating system and any kind of embedded software;
- Parallel processing inside the FPGA chip and its integrated circuit. This contributes to the above described shorter response time.

In addition to large-scale modernization projects, the technology is suited to implement solutions to a variety of applications, such as:

- 'Pin-to-pin' and 'like-for-like' or Form, Fit and Function (FFF) replacement of obsolete electronic components;
- Reverse engineering of existing components;
- Computer emulation;
- Straight replacement of components and/or systems;
- Design of I&C systems for new NPPs;
- Providing diverse systems in order to reduce the possibility of common cause failures in safety systems.

FPGAs can be used to implement any of the typical safety and control functions presently found in any NPP designs, be it PWRs, PHWR, or BWR reactors. In that respect, FPGAs are technology-neutral.

The application of FPGA technology has significant advantages that can be utilized both in I&C modernization projects of existing NPPs and in I&C designs for new NPPs. These advantages are the following:

- Design, development, implementation, and operation simplicity and transparency;
- Easy portability of algorithms and possibility of re-programming, if algorithms or technology may change in the future, but the hardware stays the same;
- Reduction of vulnerability of the digital I&C system to cyber attacks or malicious acts due to absence of any system software or operating systems;
- Faster and more deterministic performance due to capability of executing logic functions and control algorithms in a parallel mode; due to advantage of hardware parallelism, FPGAs are able to process more data, provide faster input and output response times and execute more instructions per clock cycle than digital signal processors; More reliable, testable and error-free end-product due to reduction in the complexity of the verification and validation (V&V) and implementation processes;
- Relatively easy qualification process of FPGA-based safety systems due to the simplicity and transparency of system architecture and its design process and possibility to provide evidences of meeting qualification requirements, such as independence, separation, redundancy and diversity, in an easier and more convincing way;
- Resilience to obsolescence due to the portability of the HDL code between different versions of FPGA chips produced by the same or different manufacturers: even if the FPGA migrates to the next generation, the HDL code remains unchanged;
- Possibility of implementing the results of reverse engineering via emulation in FPGA of obsolete central processing units (CPU) without modification of existing software code;
- Specific beneficial properties regarding cyber security compared to microprocessors (no viruses for FPGA);
- Reduction of development efforts due to adoption of ready-to-use components called IP-cores (intellectual properties), such as network interfaces and memory controllers;
- Possibility of operation in harsh industrial environments (for example, the Cyclone FPGAs from Altera are qualified for an operation temperature of -40 to +85 °C).

Therefore, FPGAs have much in their favour. From the preceding it may be deduced that they have adequate capabilities for most of the typical safety and control I&C applications in the nuclear power industry. It's an increasingly accepted opinion that FPGAs have potential advantages over the currently more commonly applied microprocessor-based digital I&C systems.

However, there are challenges that affect the application of FPGA technology:

- Even though the technology doesn't differ significantly from the well-established Programmable Logic Devices (PLD) technology, and the HDL language used for configuring FPGAs is a very well established language, FPGAs are still considered as a relatively new technology and not widely known in the nuclear power industry;
- With the exception of IEC 62566:2012, which provides requirements for "HDL-Programmed Devices" for use in Category A I&C systems , there is a lack of normative documents for the utilization of FPGAs in nuclear I&C applications. Lack of regulatory experience in licensing FPGA-based I&C safety systems is also a challenge;
- Limited accessibility to signals in FPGA-based systems: special effort may be required at the design stage to provide access to important internal signals for monitoring, testing and troubleshooting activities.

The above described disadvantages are not intrinsic to the technology; rather they are the results of there not being a large number of applications. These disadvantages will diminish as FPGA-based systems gain more acceptances in larger numbers of nuclear applications.

The number of FPGA applications in NPPs in various countries is growing and more applications can be expected as nuclear utilities and regulators become more familiar with the advantages that can be obtained by adopting this technology. FPGA-based applications will play an increasing role in NPPs as new designs are expected to meet more stringent diversity and reliability requirements.

The FPGA technology has not only a significant potential to provide a diverse alternative to the widely used microprocessor-based digital I&C systems, but it is already a mature technology on its own for safety and control system applications, proven in use for operating NPPs.

3.2 International Experience with FPGA Applications in NPPs

The degree to which FPGAs are used in operating NPPs varies significantly from country to country. Countries that have installed FPGA components or systems in their operating NPPs are: the United States, Ukraine, Canada, Czech Republic, Bulgaria, Japan, France, Republic of Korea and Sweden. Moreover, several countries have started R&D activities, aimed at additional implementation of FPGA technology in safety system applications of new NPP designs, have been started in some of the above countries, as well as in China and Taiwan.

In the United States, the first FPGA-based control system was installed in 2009 to replace obsolete equipment in the Main Steam and Feedwater Isolation System (MSFIS) at the Wolf Creek Generating Station. In addition, the FPGA-based platform ALS from Westinghouse/CS Innovations will be used to replace the digital RPS and ESFAS systems in the Diablo Canyon NPP.

In Ukraine, modern FPGA-based systems have been installed in safety applications in all operating NPPs, as well as in a research reactor, using the RPC Radiy's platform. In the past ten years, 30 Reactor Trip Systems, 10 Reactor Power Control and Limitation Systems, 18 Engineered Safety Features Actuation Systems, and 8 Nuclear and Conventional Island Control Systems have been installed in all four Ukrainian NPP sites.

In Canada, FPGA technology is being considered for the emulation of obsolete PDP 11 computers used in several non-safety and safety related systems and utilities are evaluating the replacement of analog and computer based I&C systems with FPGA-based applications. RPC Radiy and CANDU Energy have entered into a cooperation agreement, for the development of FPGA applications for safety-critical functions to be incorporated in their Enhanced CANDU-6 (EC-6) reactor design. In the last year, RPC Radiy has won two Candu Energy bids for the design and manufacturing of FPGA based safety related systems to be installed in the Embalse NPP in Argentina.

In China, China Nuclear Power Engineering Co. (CNPE) is evaluating the use of FPGA-based safety system applications in their new ACP1000 design. The above applications are being considered for the Reactor Protection Systems, Diverse Actuation Systems, Engineered Safety Features Actuation Systems and Post-Accident Monitoring System. In addition, China Techenergy Co. (CTEC) is developing an FPGA-based platform, FitRel, to be used in the design of the Diverse Actuation System for two CPR-1000 units, presently under construction (Units 5 and 6 of the Yangjiang NPP). China's State Nuclear Power Automation System (SNPAS) Engineering Company and Lockheed Martin Corporation developed a safety I&C platform, NuPAC, and the NuPAC-based Reactor Protection System to be installed in the China Advanced Pressurized Water Reactor CAP-1400. The above two companies are jointly pursuing the generic approval from both the U.S. NRC and the Chinese nuclear regulator, NNSA for the installation of the NuPAC platform in the CAP series of NPPs. Triconex of Invensys Process Systems is also employing FPGAs for the priority logic modules in the new Fuqing and Fangjiashan NPPs being built in China.

In the Czech Republic, FPGAs are used in the Non-Programmable Logic (NPL) portion of the Temelin NPP I&C systems. The NPL is used in priority arbitration between the microprocessor-based Primary Reactor Protection System (PRPS) and its Diverse Protection System (DPS), and the hard wired controls. Other functions of the NPL are to ensure safe failure of the system in the event of a discrepancy between the PRPS and the DPS as well as the Safety Diesel Load Sequencer and associated automatic testing.

In Bulgaria, Units 5 and 6 of the Kozloduy NPP, Company RPC Radiy has installed a total of six FPGA-based Engineered Safety Features Actuation Systems.

In Japan, Toshiba has supplied the following FPGA-based safety and non-safety systems to operating Japanese NPPs: Power Range Neutron Monitoring for BWRs, Startup Range Neutron Monitoring for BWRs and Radiation Monitoring Systems for both BWRs and PWRs. In addition, Toshiba has developed Reactor Trip and Isolation Systems for ABWR-type plants.

In France, EDF initiated in 2009 the replacement of obsolete electronic control and interface modules in several non-safety systems in their NPPs with FPGA equipment, EdF is currently developing an application based on complex programmable logic devices (CPLD) to upgrade the primary pumps rotational speed measurement system. They also developed an FPGA-based microprocessor emulator to perform a number of I&C functions, including safety-critical reactor protection functions in their 1300 MW series of plants.

In Korea, FPGAs are used in operating NPPs to perform diagnostic functions in their CPLD based system initialization, bus interface, control of input/output signal transfers, memory control, and peripheral channel control functions. The Korean NPPs are also planning to use FPGAs in the implementation of component control functions for their engineered safety features.

In Sweden, FPGAs are used in the Component Interface Module (CIM) of the replacement to the Unit 2 safety system in the Ringhals NPP. The CIM acts as the interface between the microprocessor-based primary safety actuation system and the actuator and responds to signals from the independent Diverse Actuation System (DAS) as well as to operator commands.

In Taiwan, FPGA-based designs are considered as a possible replacement for microprocessor-based protection systems.

3.3 Information sharing on the applications of FPGAs in NPPs

The series of international workshops was established in 2007 by a group of industry participants interested in FPGA applications in NPPs. As the interest in the workshop grew, a committee named Topical Group on FPGA Applications in NPPs (TG-FAN) was established with the mandate of managing and organizing the international workshops. TG-FAN organized workshops have been held annually in the past six years.

This year, the 6th International Workshop on the Application of FPGAs in NPPs concluded on October 11, 2013. The workshop was hosted by RPC Radiy in Kirovograd, Ukraine, in cooperation with the International Atomic Energy Agency (IAEA) and SunPort SA.

110 participants from 20 countries attended the workshop, representing 14 nuclear utilities, 18 vendors & suppliers, 14 technical support organizations, 5 nuclear regulators, 4 universities, 2 government organizations, and 1 international organization. The agenda included:

- 24 presentations,
- Technical demonstration by Radiy on their design and V&V techniques and tools for FPGA-based applications,
- Panel discussion on regulation and standards,
- Panel discussion on certification and verification,
- Development of the IAEA Draft Report on "Application of Field Programmable Gate Arrays in Instrumentation and Control Systems of NPPs" in four breakout groups, and
- Technical tour of Radiy's design, production, and testing facilities.

The presentations and discussions covered the following technical areas:

- Benefits and challenges encountered in FPGA applications;
- Methods and tools for application development;
- Methods and tools for verification and validation;
- Lifecycle of FPGA-based platforms, systems, and applications;
- Regulatory perspectives on FPGA technology, licensing and standards;
- Specific standards for FPGAs;
- Qualification and certification;
- Diversity provided by FPGA-based systems;
- FPGAs as prototyping tools;
- Cyber security;
- Operating experience;
- FPGA-based modernization of I&C systems and components;
- FPGA-based systems installed in operating NPPs;
- Potential future applications in operating NPPs and in new NPP I&C designs.

The workshop built on the success of previous ones held and hosted as follows:

- 2008 Chatou, France, hosted by EdF;
- 2009 Kirovograd, Ukraine, hosted by Radiy;
- 2010 Hamilton, Ontario, Canada, hosted by AECL/McMaster University;
- 2011 Chatou, France, hosted by EdF;
- 2012 Beijing, China, hosted by CNNC/CNCS.

The 7th International Workshop on Application of FPGAs in NPPs will be hosted by the Electric Power Research Institute (EPRI) at EPRI's offices in Charlotte, North Carolina, USA on October 14-17, 2014.

4 I&C related programs at the IAEA

4.1 IAEA technical reports

Information exchange has been taking place at much higher scale under the auspices of the International Atomic Energy Agency (IAEA). The Agency has recognized the importance of reliable I&C systems in the safe operation of NPPs, and has launched an ambitious program of I&C related technical meetings and conferences; coordinated research projects; workshops and training courses, and review missions. These activities resulted in number of technical reports [1-16] and review mission reports.

4.2 IAEA Independent Engineering Review of I&C Systems

The IAEA review mission titled "Independent Engineering Review of I&C Systems" (IERICS) in Nuclear Power Plants (NPPs)" was established in

2009 with the aim of conducting peer reviews of I&C design documents, implementation processes, prototype I&C systems, and actual systems already deployed in operating NPPs.

The IERICS mission is conducted by a team of international subject matter experts from various complementing technical areas. The review is based on appropriate IAEA documents, such as Safety Guides and Nuclear Energy Series, and the mission's findings are summarized in a mission report, including a list of recommendations, suggestions, and identified good practices.

The key objectives of the IERICS mission are to:

- Assess the design approach, principles, and procedures of the development process of the system under review, and identify existing or potential design, operational, and licensing related issues or concerns along with proposed measures to address these issues;
- Identify any outstanding good practice that could be a benefit to other organizations, such as nuclear utilities, regulatory bodies, design organizations, technical support organizations;
- Facilitate exchange of experience and to provide key staff of the counterpart organization (the organization that has requested the IERICS mission and the beneficiary of the review mission) with an opportunity to discuss their practices with international experts.
- The review is performed based on the following information:
- Advance Information Package provided by the counterpart before the review meeting;
- Presentations and clarification discussions during the review meeting;
- Visits at design, production and testing facilities.

The review is not intended to be a regulatory inspection or an audit against international codes and standards. Rather, it is a peer review aimed at improving design and implementation procedures through an exchange of technical experiences and practices at the working level. The IERICS mission is applicable at any stages of the life-cycle of I&C systems in NPPs, and it can be initiated by a formal request through official IAEA channels from an organization of a Member State.

The IERICS process is divided into three main phases, each with its own purpose and goals:

- The preparatory phase in which the scope of the review, all conditions and boundaries are defined at a formal meeting between representatives of the IAEA review team and the counterpart team. This meeting may take place 4 to 6 months prior to the review meeting and it produces a detailed Term of Reference. The Advance Information Package is also prepared by the counterpart and sent to the IAEA at this stage;
- The review phase which is the actual review meeting lasting for a week at the facilities of the counterpart organization;
- The follow-up phase in which the status of the action items (recommendations and suggestions) identified during the review will be discussed and closed. The follow-up meeting produces the final mission report. This report is classified as confidential, but can be de-restricted on the counterpart's request.

Organizations in IAEA Member States, such as nuclear utilities, regulators, R&D organizations, vendors, manufacturers, and technical support organizations can benefit from I&C technical reviews through requesting IERICS missions that provide a detailed technical assessment on I&C systems, as well as recommendations for improvement.

The formation of the IERICS mission, as a review service by the IAEA, is based on the recommendation of the IAEA Technical Working Group on Nuclear Power Plant Instrumentation and Control (TWG-NPPIC). The recommendation came from the recognition that the IAEA should play an important role in the independent assessment and review of NPP I&C systems in terms of their compliance with IAEA safety standards and guides.

The technical document IAEA TECDOC 1662, titled "Preparing and Conducting Review Missions of Instrumentation and Control Systems in Nuclear Power Plants", has been published recently, providing guidelines, a basic structure and common references across the various areas that can be covered by an IERICS mission.

The document describes in detail all steps and processes that should be followed during the preparation, implementation and closing phases of the review mission by members of the review team and the counterpart organization. Publications referenced in these guidelines could provide additional useful information for the counterpart while preparing for the IERICS mission. A template for the mission report is also given in the report's Appendix.

4.3 Implemented IERICS Missions

The first IERICS review mission was performed in February 2010 in Yongin-si, Republic of Korea at the request of the Doosan Heavy Industries and Construction Company. The subject of the review was the prototype version of Doosan’s advanced I&C system designed for the APR-1400 NPPs. This system is developed based on the results of a seven-year R&D project titled Korea Nuclear Instrumentation and Control System (KNICS, 2001-2008). The KNICS project team included participants from Doosan, KAERI, KEPCO, KERI, POSCON, and Woori Tec. In order to demonstrate the suitability of this system in terms of performance, operability and reliability, Doosan established an "Integrated Performance Validation Facility” for further system development and testing. Doosan’s goal was that the mission would provide them with a basis for improving the acceptance and reliability of the I&C system by implementing the recommendations and findings of the mission and also would assist in meeting the requirements of the on-going Shin-Ulchin Units 1 and 2 design project. It was also expected that the report would assist in developing a firm design basis for projects in the domestic and international markets.

The second IERICS review mission was performed in December 2010 in Kirovograd, Ukraine, on the Field Programmable Gate Array (FPGA) based safety I&C platform and systems developed by the Research and Production Corporation (RPC) Radiy for nuclear power plants. RPC Radiy completed the development of its FPGA-based digital platform in 2002 which was designed for building I&C systems for reactor protection, control, and monitoring functions in NPPs. These modern digital systems, which were used in I&C modernization projects of operating NPPs, can also be integrated into new NPP designs.

The company has already completed the successful installation of these systems in more than fifty modernization projects in a total of five operating NPP sites in the Ukraine and Bulgaria. The systems included:

- Main and Secondary (diverse) Reactor Trip System (RTS)
- Engineered Safety Feature Actuation Systems (ESFAS)
- Reactor Regulating and Power Limitation System (RPCLS)
- Reactor Rod Control Systems

The IERICS activities consisted of a series of formal presentations by Radiy staff supported by plant personnel from the South-Ukraine NPP and the Bulgarian Kozloduy NPP, clarification discussions between the review team and the designers, as well as a tour of the South-Ukraine NPP to see how the new system operates.

The third IERICS review mission was performed in December 2012 in Moscow, Russia, on the VNIIAES computerized process control system for AES-2006 (VVER-1200) NPPs. The VNIIAES I&C platform is intended to perform safety and safety-related, as well as normal operational functions in NPPs. The system mainly applies microprocessor-based technology for signal processing, logic, and self-diagnostic functions.

VNIIAES has already achieved a successful implementation of parts of the system or its subsystems in several NPP applications. In order to demonstrate the suitability of this system, VNIIAES established different test and performance validation facilities, which also constituted parts of the review. The review areas covered:

- Systems important to safety (*e.g.*, reactor shutdown system, engineered safety features actuation system, reactor instrumentation, control and diagnostics system);

- Reactor control systems for continuous normal operation;
- Computer-based platforms for the above systems;
- Upper level control system including the human-system interface of the main and emergency control rooms.

The fourth IERICS mission was implemented in Severodonetsk, Ukraine, in April 2013 at the SRPA "Impulse" organization. The subject of the review was the digital computer I&C system (MSKU 3M) important for NPPs' safety, designed using standard technical solutions by SRPA "Impulse". The scope of the review included:

- Safety control system: engineered safety features actuation system and support features systems.
- Normal operation control systems for NSSS: process control system and closed loop control systems and the associated human system interfaces.
- Both hardware and software platforms were evaluated.

The MSKU 3M I&C platform is intended to perform safety and safety-related, as well as normal operational functions in NPPs. The system mainly applies microprocessor-based technology for signal processing, logic, and self-diagnostic functions. SRPA "Impulse" completed the development of the system in 2011. They have already successfully implemented large parts of the system in the Zaporizhzhya NPP in Ukraine.

In all four IERICS missions, the IAEA review teams confirmed that extensive engineering work of high quality has been performed to develop the advanced I&C systems, and in general the reviewed areas met the requirements of the relevant sections of the IAEA Safety Guide NS-G-1.3. Specific issues, identified as areas for further improvement, were listed in the issue sheets of the mission report, as suggestions and recommendations. Good practices were also identified, serving as commendable engineering examples for other NPP I&C system design projects.

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