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IMPLEMENTATION OF DIGITAL INSTRUMENTATION AND CONTROL SYSTEMS FOR NUCLEAR POWER PLANT USING FPGA-TECHNOLOGY: BENEFITS AND SOLUTIONS

The paper represents overview of modern instrumentation and control (I&C) systems intended for use in nuclear power plants (NPPs), including their functions and main objectives. Possible application of Field Programmable Gates Array (FPGA) technology for I&C of NPPs is discussed. Experience of RPC Radiy in development and modernization of digital I&C systems is presented, along with implementation of FPGA solutions for NPPs in I&C modernization projects.

Keywords: *I&C, NPP, FPGA, function, safety, performance, measurement, adjustment, protection, technology, solution.*

Introduction

Instrumentation and Control (I&C) systems represent one of several most important parts of each Nuclear Power Plant (NPP). I&C system contains various complex components and subsystems intended for sensing of certain parameters, monitoring of performance, integrating required information, and making automatic adjustments to NPP operations as necessary. However, the main purpose of each I&C system is in responding to failures and any abnormal events within NPP, thus ensuring goals of both efficient and reliable power production and safety.

Nowadays, FPGA technology is widely used by the world industry: from simple and portable personal devices to complex safety-related digital I&C systems for NPP. Various functions, including NPP I&C systems' control functions important for safety, are being implemented on the basis of FPGA technology in reliable and convenient way. 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.

RPC Radiy is the leading Ukrainian developer and supplier of advanced FPGA-based digital I&C systems for NPPs and thermal power stations for more than last 15 years. During that period more than 70 FPGA-based digital I&C systems were commissioned at European nuclear facilities, including NPPs and research reactor. I&C from RPC Radiy can be installed to newly built

NPPs or to NPPs during modernization in a short-term and cost-effective way, and allow to both increase of reliability and availability of NPP I&C systems and minimize the cost of producing power.

General Concept of I&C Systems

Within each NPP, during power generation process, hundreds parameters have to be kept within the design-based limits. In such a way, NPP contains plenty of various electromechanical components like motors, pumps or valves that have to be operated in a well-coordinated, efficient and reliable way. This coordination is explicitly performed by I&C systems [1]. To accomplish this mission, I&C systems measure thousands of NPP process parameters, calculate their deviation from the predefined design conditions, and issue corrective actuation commands to appropriate field devices to either bring the parameters back or to achieve control objectives. During their operation, I&C systems continuously display important safety-critical information, related to actual plant parameters and deviations from set points, through the human-machine interface in order to inform the operator about real status of the NPP to effectively manage power production through the necessary actions and adjustments.

In general case, NPP I&C system performs three primary functions: parameters measurement and sensing, regulation, and protection.

In such a way, measurement and sensing function is intended for implementation of NPP support functions by the personnel in order to continuously monitor and assess plant's actual status. This function allows establishing the direct interfaces between the physical processes of the NPP, the operator and appropriate decision-making applications. If properly planned, designed, implemented, and maintained, such functionality provides accurate and appropriate information to permit required activities during both normal and abnormal NPP operation.

Regulation function of I&C system is intended for implementation of automatic control and regulation for all NPP systems in order to reduce the workload on the plant personnel. As a rule, majority of modern I&C systems contain certain reserved manual actions that can be performed during unusual occurrences as a part of appropriate corrective actions.

I&C system protection function is intended for protection of the NPP from the consequences of any plant systems malfunction or failure, or errors in personnel actions. Under such abnormal plant conditions, protection function provides rapid automatic response to protect both the NPP and the environment.

The variety of additional elements and factors should be taken into consideration during implementation of planning, design, operation, maintenance and decommissioning activities for each NPP I&C system, including, in particular, human factors, information management, simulation, software engineering, system integration, prognostics, and cyber security [1].

The relevance of adequately designed NPP I&C systems toward enhancing the competitiveness of the nuclear option of energy generation involves the following considerations:

– reduce construction costs (reduce cable runs and accelerate acceptance of 'as-built' implementation);

– decrease life cycle costs (allow for modernization/obsolescence management and standardization);

– enable optimized operations by bringing improved technologies to commercial maturity;

– provide investment protection (ensure limitation of adverse conditions and protection against accidents).

FPGA Technology for I&C of NPPs

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 [2].

Physically, FPGA technology is represented by a semiconductor-based complex programmable device, which can be configured to perform a custom-required function. It includes two entities: an FPGA chip, which is a piece of hardware that can be qualified against hardware qualification testing requirements, and the electronic design of the FPGA, which is implemented into FPGA chip, represented by a set of instructions in hardware description language (HDL) that, in turn, can be verified against functional requirements.

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 include the following:

– design, development, implementation, and operation simplicity and transparency;

– 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;

– more reliable and error-free end-product due to reduction in the complexity of the verification, validation and implementation processes;

– relatively easy licensing process of FPGA-based I&C systems due to the simplicity and transparency of system architecture and design process, as well as possibility to provide evidences of meeting licensing requirements 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;

– possibility of reverse engineering via emulation of obsolete central processing unit in FPGA chip without modification of existing software code;

– specific beneficial properties regarding cyber security compared to microprocessors (nowadays, there are no viruses for FPGA) [3].

Experience of RPC Radiy in Digital I&C Systems

RPC Radiy is the leading Ukrainian designer and supplier of advanced digital I&C systems for NPPs and thermal power stations, as well as is one of the leading companies in the world providing FPGA-based solutions to the nuclear industry and seeking new applications where the advantages of the FPGA technology can be utilized. RPC Radiy is a company with the completed cycle of development, design, manufacturing, testing, and equipment implementation [4].

RPC Radiy has a full range of capabilities, which can support the complete development process and can effectively implement and support products life cycles. During projects implementation, RPC Radiy has accumulated and established the best design practices aimed at achieving compliance with the general design and quality assurance requirements for I&C systems having safety roles as given in the leading international standards (e.g., IEC 61508), as well as the specific requirements for nuclear I&C systems as given in IAEA safety standards and IEC standards for nuclear facilities. All processes are performed by RPC Radiy in accordance with IEC, IAEA, national and internal Quality Management System requirements.

RPC Radiy designers have gained an extensive experience in the development of I&C systems for Pressurized Water Reactors, research reactors, as well as CANDU-type reactors. The FPGA design practices of RPC Radiy are based on the company's experiences, continuous improvement processes and the best international FPGA design practices.

RPC Radiy also shares own FPGA-related experience with the international nuclear community to make the FPGA technology and its potentials well-known. Application of only qualified tools from well-known vendors helps avoiding human errors during software and hardware development.

Technical departments and top management of RPC Radiy support the designers' professional development. Trainings of designers are performed on the regular basis to achieve the assurance of the appropriate qualification level for all persons involved in design, development and maintenance activities. All training activities are performed according to internal Quality Management System's standards, guides and instructions. Designers do have not only strong technical skills, but working-level English language skills as well to participate in technical discussions and meetings with foreign customers.

During last 15 years, more than 70 FPGA-based digital I&C systems were commissioned at European nuclear facilities, including NPPs and research reactor. Such FPGA-based digital I&C systems are represented by:

– Reactor Trip Systems;

– Reactor Power Control and Limitation Systems;

– Rod Control Systems;

– Engineered Safety Features Actuation Systems;

– Nuclear Island and Conventional (Turbine) Island Systems;

– Automatic Regulation, Control, Operation and Protection for Research Reactors;

– Switchgear and Controlgear Assemblies.

I&C systems from RPC Radiy can be installed to newly built NPPs or to NPPs during modernization in a short-term and cost-effective way, and allow to both increase of reliability and availability of NPP I&C systems and minimize the cost of producing power.

FPGA Solutions for NPPs

I&C modernization projects are performed in the context and to support the overall NPP goals, objectives, and internal and external commitments. The goals and objectives of NPPs are defined substantially by the utilities long-term and short-term business plans.

In general, generic I&C modernization goals include the following:

– increase of reliability and availability of NPP I&C systems;

– safe operation of NPP units;

– extension of NPP units life;

– ecological and efficient electricity production with minimum cost;

– compliance to safety standards and requirements that have changed with time and technology.

Any I&C modernization project is typically a multi-step process that is performed within the planned durations of existing outages for refuelling and scheduled maintenance work.

RPC Radiy can implement both of two possible approaches to modernization: complete modernization (or system replacement) and partial modernization. In the first case, all the components of old I&C system, including sensors, transmitters, logic solvers, input/output modules, cabinets and communication links, are being changed to modern equipment in a short-term and cost-effective way. The second case implies replacement for only the most critical equipment: in the scope of such option, RPC Radiy provides all necessary interfaces of the new FPGA-based digital equipment to be connected to the remaining components of the existing system, at pin-to-pin level. Moreover, during the design process of the new FPGA-based I&C system by RPC Radiy, independently of the modernization scope, experience of operation of the obsolete system is being taken into account in order to identify its strengths and weaknesses and identify the most appropriate solutions for replacement [5].

In many cases, complete redesign could lead to significantly increased engineering costs and licensing uncertainties. To succeed in such modernization projects, RPC Radiy performs reverse engineering activities. Application of FPGA technology provides with many advantages to its flexibility and possibility to emulate easily the functionalities of any obsolete electronic component.

RPC Radiy has used proprietary FPGA-based platform in I&C modernization projects at various NPPs for a wide range of safety and control functions and systems, such as Reactor Trip System, Reactor Power Control and Limitation System, Engineered Safety Features Actuation System, Rod Control System, Nuclear Island Control System, and Turbine Island Control System. Such applications represented large-scale modernization projects, however, the technology can provide solutions for an even larger variety of applications, such as 'pin-to-pin' or 'like-for-like' type replacement of obsolete circuit board components, reverse engineering, emulation of functions performed by obsolete computers, replacement of components and subsystems, and building complete I&C systems or diverse back-up systems in new NPP designs. FPGAs can implement any safety and control functions that are typical in existing NPPs or in any new designs, therefore providing a technology-neutral implementation tool.

Conclusions

The paper presented a general overview of approach to implementation of digital I&C systems for NPPs on the basis of FPGA-technology, its benefits and possible solutions, as well as related activities and products of RPC Radiy, and their applications.

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

The number of FPGA applications in NPPs in various countries is growing and more applications can be expected, since nuclear utilities and regulators get more familiar with the technology and its advantages.

Nowadays, RPC Radiy is the worldwide frontrunner of FPGA applications in NPP modernization projects, in terms of the number of systems and safety applications installed, and it is ready to extend its applications to other NPP designs and countries.

Unquestionable, FPGA-based technologies will have a significant role in I&C systems of future NPP designs as well, where diverse solutions with high reliability are required. RPC Radiy has extensive knowledge and cutting-edge experiences to design I&C systems for modernization and the brand new build projects.

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ЗАСТОСУВАННЯ ЦИФРОВИХ ІНФОРМАЦІЙНО-УПРАВЛЯЮЧИХ СИСТЕМ ДЛЯ АТОМНИХ ЕЛЕКТРОСТАНЦІЙ З ВИКОРИСТАННЯМ ПЛІС-ТЕХНОЛОГІЙ: ПЕРЕВАГИ І РІШЕННЯ

В.В. Скляр

Стаття представляє огляд сучасних інформаційно-управляючих систем (ІУС), призначених для використання на атомних електростанціях (АЕС), у тому числі їх функції та основні завдання. Обговорено можливості застосування технології програмованих логічних інтегральних схем (ПЛІС) для ІУС АЕС. Представлено досвід компанії «Радій» в області розробки і модернізації цифрових ІУС поряд з реалізацією рішень на базі ПЛІС.

Ключові слова: *інформаційно-управляючі системи, АЕС, ПЛІС, безпека, продуктивність, вимір, регулювання, захист, технології, рішення.*

ПРИМЕНЕНИЕ ЦИФРОВЫХ ИНФОРМАЦИОННО-УПРАВЛЯЮЩИХ СИСТЕМ ДЛЯ АТОМНЫХ ЭЛЕКТРОСТАНЦИЙ С ИСПОЛЬЗОВАНИЕМ ПЛИС-ТЕХНОЛОГИЙ: ПРЕИМУЩЕСТВА И РЕШЕНИЯ

В.В. Скляр

Статья представляет обзор современных информационно-управляющих систем (ИУС), предназначенных для использования на атомных электростанциях (АЭС), в том числе их функции и основных задачи. Обсуждены возможности применения технологии программируемых логических интегральных схем (ПЛИС) для ИУС АЭС. Представлен опыт компании «Радий» в области разработки и модернизации цифровых ИУС наряду с реализацией решений на базе ПЛИС.

Ключевые слова: *информационно-управляющие системы, АЭС, ПЛИС, безопасность, производительность, измерение, регулировка, защита, технологии, решения.*