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EXPERIENCE OF I&C SYSTEMS MODERNIZATION USING FPGA TECHNOLOGY

Ievgenii Bakhmach, Vyacheslav Kharchenko, Alexander Siora, Volodymyr Sklyar, Anton Andrashov
RPC Radiy
Geroyev Stalingrada Str. 29, Kirovograd, Ukraine, 25006
bakhmach@radiy.com, v.kharchenko@khai.edu, marketing@radiy.com, v.sklyar@csis.org.ua, a.andrashov@csis.org.ua

ABSTRACT

The following are results of applying an advanced RADIY™ platform for modernization of Instrumentation and Control (I&C) systems at Nuclear Power Plants (NPP) sights. RADIY™ platform was designed and developed by Research and Production Corporation (RPC) Radiy, located in Ukraine. The main feature of the platform is the use of Field Programmable Gates Arrays (FPGA) as programmable components for logic control operations. FPGAs are widely used for safety-critical applications, which include safety systems at nuclear installations. These circuits are advantageous as they use Hardware Design Languages (HDL) for electronic design development. Our experience in developing, installing and operating FPGA-based I&C systems, is important for the international nuclear community, as it gives an example of state-of-the-art modernization of nuclear reactor units. The following points will be discussed: European experience of applying RADIY™ platform for modernization of I&C systems; time schedule of I&C system design; time schedule of I&C system implementation; time schedule of I&C system commissioning.

Key Words: Modernization, Instrumentation and Control systems, Field Programmable Gates Array.

1 INTRODUCTION

The objective of this paper is to present experience of Ukrainian Research and Production Corporation (RPC) “Radiy” in area of modernization of Nuclear Power Plants (NPP) Instrumentation and Control (I&C) systems.

NPP I&C systems designed and manufactured by RPC “Radiy” are based on the Field Programmable Gates Arrays (FPGA) technology. Application of FPGAs as programmable components instead of programmable logic controllers (PLC) is an advanced solution which provides decreasing of software impact on potential common cause failures (CCF) [1-3].

The Digital Safety I&C RADIY™ platform consists of upper and lower levels. The upper level is represented by industrial workstations. The software for the upper level of RADIY™ platform was developed by Company “Radiy” and has been installed on the workstations. The lower level of the RADIY™ platform composed of standard cabinets which includes the following standard functional modules:

– Input signals processing modules,

– Logic control modules,

– Output signals modules,

– Actuators control modules,

– Diagnostics modules.

Application of the RADIY™ platform with the use of FPGA technology provides different opportunities such as [4-6]:

– To implement control and other safety-critical functions in the form of FPGA with implemented electronic design, without software,

– To reduce a volume of software verification and validation activities,

– To process all control algorithms in parallel way within one cycle, thus ensuring high performance of the system, etc.

RADIY™ platform has been applied to implement following NPP I&C systems which perform reactor control and protection functions [7,8]:

– Reactor Trip System (RTS),

– Engineering Safety Features Actuation System (ESFAS),

– Reactor Power Control and Limitation System (RPCLS),

– Power Equipment for Rods Control System (PERCS),

– Regulation, Monitoring, Control, and Protection System for Research Reactors (RMCPS).

Figure 1 depicts RPC Radiy profile on implementation of NPP's I&C systems modernization projects. Totally fifty three FPGA-based I&C systems have been supplied to the customers and the maintenance of that systems is ongoing. All the modernization projects have been completed within their schedule and budget. It is important to highlight that modernization projects have different scale and complexity level. For example, FPGA-based RTS consists of four cabinets only, while ESFAS comprises more than sixty cabinets (about forty five cabinets include FPGA-based modules). One of the complexity issues connected with modernization projects implementation is in necessity of establishing the interfaces between old analog I&C systems and new digital ones. Application of FPGA-based Input\Output modules of RADIY™ platform allows implementing such interfaces with less efforts, saving time and recourses.

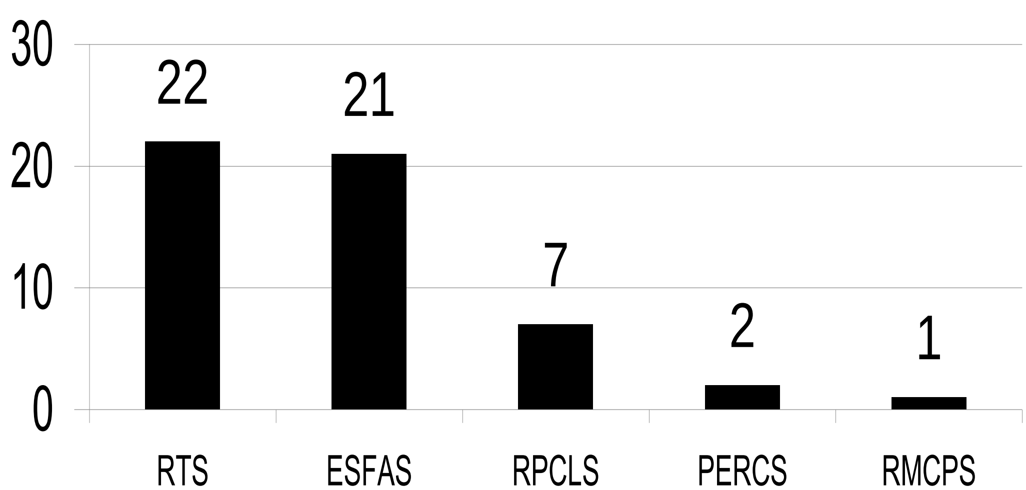


Figure 1. Radiy profile on implementation of NPP's I&C systems.

So the management processes of RPC Radiy are quite flexible and could successfully be applied to multiple scales projects. Application of Radiy™ platform reduces the modernization projects complexity.

Consideration of design and implementation stages for modernization of I&C systems by RPC "Radiy" includes the following [9]:

– Time schedule of I&C system design, implementation and commissioning,

– Time schedule of I&C system implementation,

– Time schedule of I&C system commissioning.

2 EUROPEAN EXPERIENCE OF APPLYING RADIY™ PLATFORM FOR MODERNIZATION OF I&C SYSTEMS

Figure 2 represents year statistics concerning implementation of modernization projects. RPC Radiy have non-stop experience in implementation of NPP's I&C systems modernization projects since 2003. In 2008 RPC Radiy started to perform modernization activities outside the Ukrainian market. One can note, that all the time several modernization projects are implementing simultaneously. In 2007, sixteen I&C systems have been supplied to the customers. It is possible to make a conclusion that productive facilities of RPC Radiy allow to implement modernization projects of any scale.

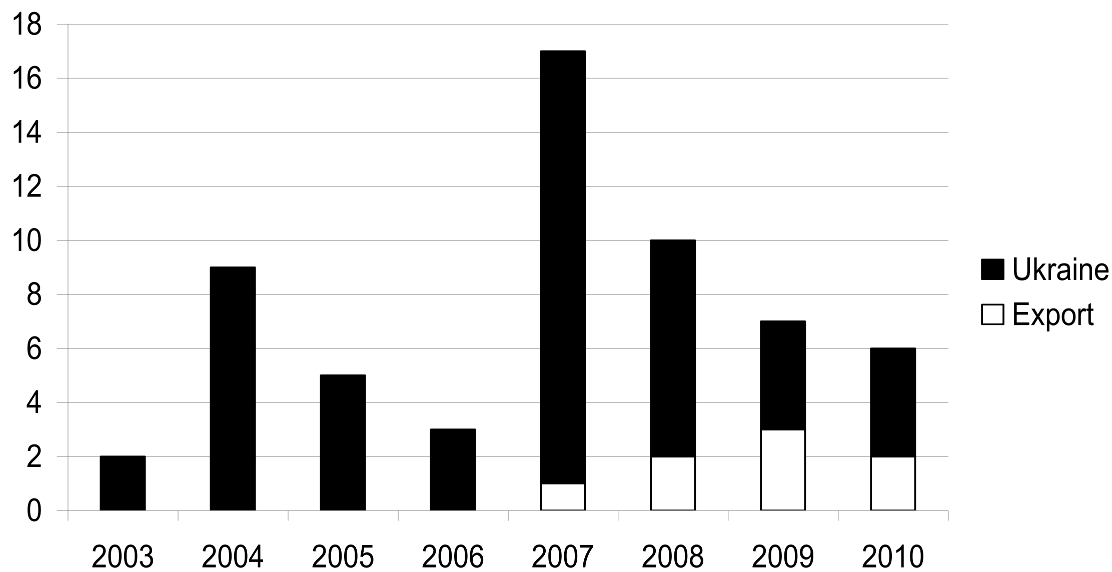


Figure 2. Quantity of I&C systems installed by RPC Radiy since 2003.

For better understanding of both applied efforts scale and collected experience connected with modernization projects implementation activities, lets us consider the detailed data concerning the quantity of programmable complex electronic components (FPGA-chips and configuration devices) that have been used in modernization projects.

Figure 3 represents total operating time for Altera FPGA-chips and configuration devices used in I&C systems by RPC Radiy.

Total quantity of FPGA-chips and configuration devices used is 17992. Total operating time is $3{,}36 \cdot 10^8$ hours. No FPGA-chips and configuration devices failures were detected during this period.

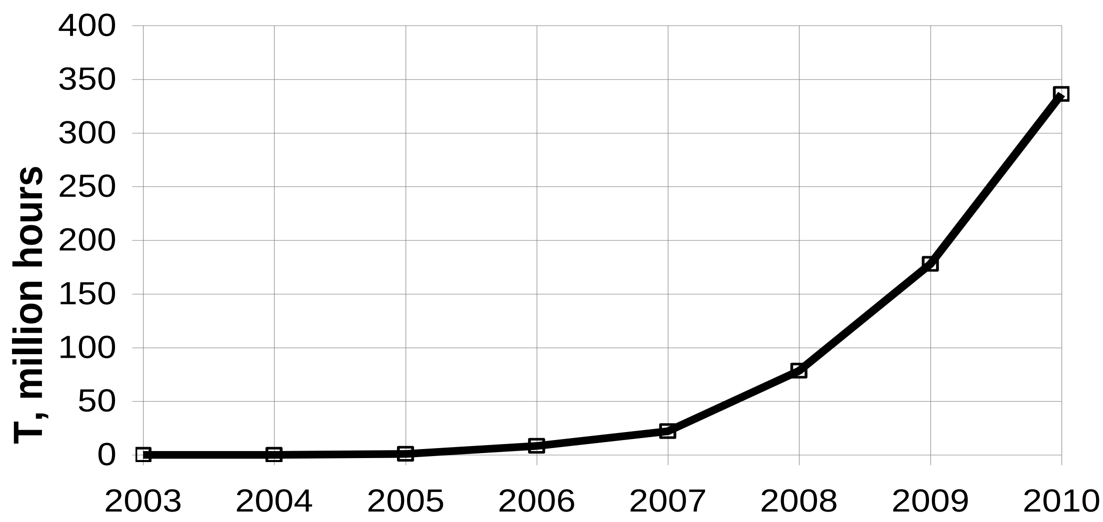


Figure 3. Total operating time for Altera FPGA-chips and configuration devices used in I&C systems by RPC Radiy.

The largest project completed by RPC "Radiy" is modernization of six ESFAS for Bulgarian NPP Kozloduy (three ESFASs for Kozloduy-Unit 5 and three ESFASs for Kozloduy-Unit 6). ESFAS based on RADIY™ platform performs the following control functions [8,9]:

– Forming and outputting process safety and interlock signals for automatic control of actuators in accordance with process algorithms.

– Forming and outputting discrete signals for automatic control of actuators when the monitored process parameters exceed their limit values in accordance with prescribed algorithms.

– Remote control of actuators from the Control Room in accordance with process algorithms.

– Transmission of discrete signals to other systems.

The following outlines mounting and commissioning timelines for Bulgarian NPP:

– August to September 2008 – ESFAS-2 for Kozloduy-6,

– April to May 2009 – ESFAS-2 for Kozloduy-5,

– August to September 2009 – ESFAS-1 and ESFAS-3 for Kozloduy-6,

– April to May 2010 – ESFAS-1 and ESFAS-3 for Kozloduy-5.

The first ESFAS for Kozloduy NPP successfully passed Factory Acceptance Testing (FAT) in July 2008. Mounting of the first ESFAS at the site (ESFAS-2 at Kozloduy-6) started in August 2008. Installation prior to commissioning has been finished in an extremely short period (about one month). The six commissioned ESFASs are now successfully operating.

3 TIME SCHEDULE OF I&C SYSTEM DESIGN

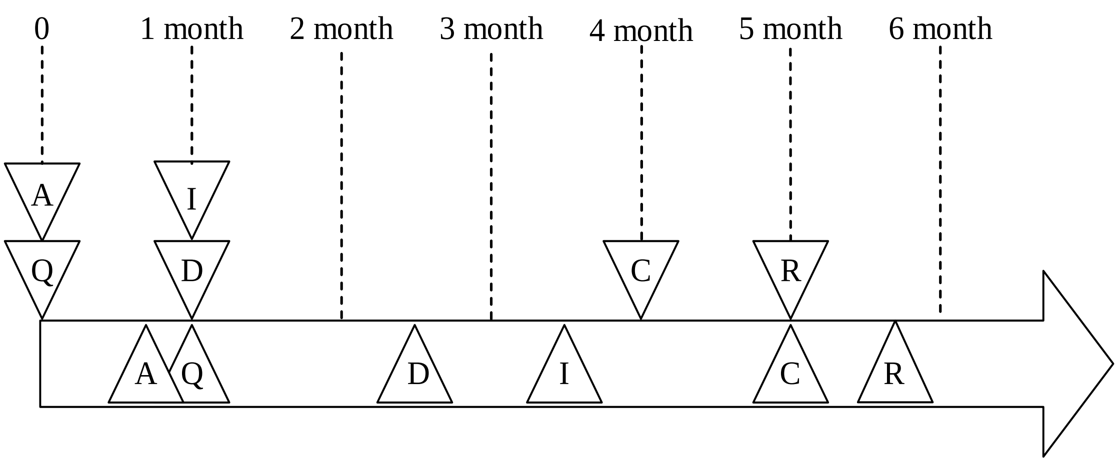
The above mentioned modernization project for Kozloduy NPP is characterized by accomplishing the ESFAS' design, production, acquisition and commissioning in extremely short time, representing Radiy's strong managerial practices. Figure 4 displays design, implementation and commissioning schedule for ESFAS. The life cycle of the below I&C system excludes the operation process. All steps are generally completed within six months. The main components of I&C system life cycle processes are discussed below. Quality Assurance (QA) program entails the following:

– Organizational structure of QA participants, stating their subordination connections,

– Structure, processes, stages and tasks of I&C life cycle and its components, with sequence descriptions of stages and tasks within the processes framework,

– Duties and responsibilities of participants responsible for quality assurance of I&C life cycle,

– Order and scope of I&C life cycle processes documentation.



Processes	Start	Finish	Processes	Start	Finish
Quality Assurance Program Development	Q	Q	I&C Implementation	I	I
Basic Data Acquisition	A	A	I&C Commissioning	C	C
I&C Design Devel-opment	D	D	Documentation amendment	R	R

Figure 4. Design, implementation and commissioning schedule of I&C system.

Basic data is provided by the customer in a standardized log book (questionnaire) containing:

– A list of input and output analog and discrete signals,

– A list of existing actuators,

– A list of existing cable connections,

– A list of existing alarm elements.

4 TIME SCHEDULE OF I&C SYSTEM IMPLEMENTATION

The supplier provides technical specifications that are subject to independent expert assessment. I&C system is generally implemented in four months. Implementation consists of the following processes (see Figure 5):

– Development of equipment composition, design, operational and program documentation,

– Manufacture of I&C system equipment and development of FPGA electronic design and software,

– Development of Factory Acceptance Testing plans,

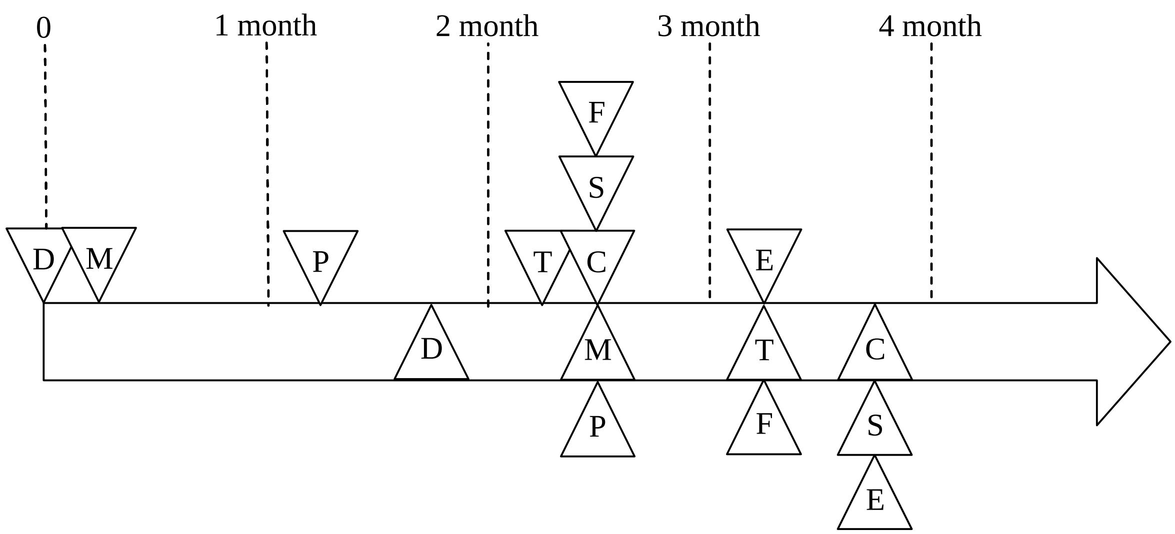
– Training of NPP specialists on equipment operation, maintenance and repair,

– Development of start-up and adjustment programs,

– Development of preliminary Safety Analysis Report (SAR),

– Factory Acceptance Testing of I&C system,

– Commissioning of I&C system.



Processes	Start	Finish	Processes	Start	Finish
Development of equipment structure and documentation	▽ D	△ D	Development of start-up and adjustment programs	▽ C	△ C
Manufacturing of equipment, development of software	▽ M	△ M	Development of safety analysis report	▽ S	△ S
FAT plan development	▽ P	△ P	FAT	▽ F	△ F
Utility's personnel training	▽ T	△ T	I&C commissioning	▽ E	△ E

Figure 5. Implementation schedule of I&C system.

5 TIME SCHEDULE OF I&C SYSTEM COMMISSIONING

I&C system is generally commissioned in twenty five days. Commissioning consists of the following processes (see Figure 6):

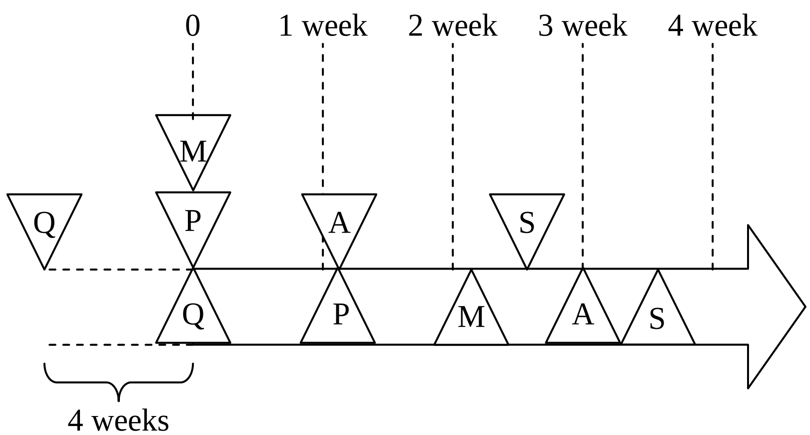
– Development and settlement of Quality Assurance program with the customer during installation,

– Preparation of mounting site, dismounting of old equipment,

– Mounting of equipment and cable routes,

– Equipment adjustment,

– Site Acceptance Testing (SAT).



Processes	Start	Finish	Processes	Start	Finish
Installation Quality Assurance Program Development	▽ Q	△ Q	Equipment Adjustment	▽ A	△ A
Preparing On-site Premises, Dismantling of Old Equipment	▽ P	△ P	Site Acceptance Testing	▽ S	△ S
Cable routing, Equipment Mounting	▽ M	△ M			

Figure 6. Commissioning schedule of I&C system.

6 CONCLUSIONS

Our experience shows that successful implementation of NPP safety-critical I&C systems needs the following:

– Thorough preparation of basic data for designing,

– Precise definition of the procedures and persons responsible for their execution,

– Project execution progress control (in the beginning, in the middle and at the end of each phase),

– Precise coordination of activities between departments which perform equipment installation,

– Application of FPGA-technology for build-up of NPP safety-critical I&C systems allows to decrease manufacturer's risks related to: violation of designing process requirements, violation of verification process requirements, violation of common-cause failure requirements, violation of time characteristics requirements,

– Optimal decision for Customer is installation of the system «on a turn-key basis» by the Manufacturer,

– This approach allows to reduce Customer's risks related to non-execution of separate project stages during realization of works by different executors.

Taking into account flexibility and commonality of the Digital Safety I&C RADIY™ platform, it is possible to make conclusions about readiness of the RADIY™ platform for modernization of power units at North American market [6,9].

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