FPGA - Based Technology and Systems for I&C of Existing and Advanced Reactors

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Abstract. Control systems of modern nuclear installations (including water-cooled, WCR) are based on programmable technologies. Most of control systems modernizations which are implemented at operating nuclear installations are also based on application of programmable technologies.

Besides, a range of features and properties is defied for programmable technologies. These features and properties make licensing process more complicated, facilitate appearance of common cause failures, make safety evaluation procedures more complicated, etc. Also it is known that programmable technologies significantly extend the time periods for project realization of new power units construction and modernization of the existing power units, and also it involves rise of its value.

Company RADIY has developed the Platform of digital equipment RADIY on FPGA-based technology. In the article there is a description of the features of FPGA-technology developed and applied by Company RADIY, features of the Platform RADIY and systems realized on its base, which allow to minimize significantly above-mentioned negative features and properties of programmable technologies.

Technology which realized in Platform RADIY allows to solve the whole set of tasks of control (including regulation) and protection of nuclear installations. Platform RADIY is a combination of the best features of traditional programmable technologies and FPGA-technology.

According to the opinion of the authors of this article the technology which is realized in Platform RADIY is the key factor for solving of control and protection tasks of nuclear installations in the nearest future.

1. INTRODUCTION

Modern nuclear installations are basically equipped with control systems based on software technologies. These are digital software technologies. While modernization old-type nuclear installations are also re-equipped using these advanced technologies. This experience is assimilated by operational personnel and is fairly considered the best engineering solution for advanced control systems.

Research-and-production Corporation "Radiy" has designed and developed the technology which is based on FPGA (Field Programmable Gates Arrays). This digital technology is characterized by several unique advantages and reduces or even eliminates negative effects of digital software technologies that are being traditionally used.

The suggested innovative design is really a revolutionary engineering solution for all the stages of control system life cycle: design, manufacture, factory testing, on- site installation, setting operation and commissioning at power unit, further operation and modernization (as the need arises).

RPC "Radiy" started research on programmable logic integrated circuits (PLIC-technologies) to find expert solutions on control and protection of nuclear facilities at the beginning of the 90-s. Based on

PLIC-technology several modules were designed to exchange old control systems using the "module into module" replacement methodology. That was the first generation of equipment based on PLIC technology.

Beginning with 1998, more than 100000 technological modules have been supplied to modernize old control systems and improve plant performance.

Taking into considerations the unique specifications of this technology, RPC "Radiy" has designed the Platform of digital equipment with a minimal component set which can be basis for any control system. Since 2002 we have started development and since 2004 – supply of control systems as hardware-software complexes for nuclear power stations (the second generation of equipment based on PLIC-technology).

"Radiy" Company has a very powerful design capability represented by several design-engineering departments that are specialized in:

- Control systems for technological processes;
- Fireproof automation;
- Forced power supply equipment.

The Company's production line is fitted with up-to-date highly technological equipment, that provides overall production cycle for electronic, electro technical modules and blocks, cabinets and ensures quality control at all production stages.

The Company's Quality Assurance is certified by TUV Rheinland InterCert, Brussels.

2. CONTROL SYSTEM TECHNOLOGY FROM "RADIY"

"Radiy" technology based on FPGA allows to perform all the spectrum of tasks specific for nuclear installation control – regulation, blocking and protection.

Using FPGA technology makes it possible to exclude software to provide safety functions and critically safety functions. All critical functions are provided by electronic FPGA-project.

This technology uses software only to solve ancillary tasks (reception and processing signals, information exchange among the system components, diagnostics, archiving and providing man-machine interface), which do not interfere with the system's main functions (regulation, blocking and protection).

Using this technology allowed to considerably reduce the amount of software products developed for different applications. Consequently, in the process of critical functions realization the probability of common cause failure which is characteristic for software technologies was reduced. And manufacturing input to make verification for software products is significantly reduced.

One more differential feature of this technology is systems' small response time. The response time does not depend on the number of activated work algorithms. The latter quality is especially important for situations when the majority or all the installation parameters are changed and all the system functions are realized simultaneously. For example, transition regimes of the nuclear installation operation, connected with implementation or with deactivating, power level change and also emergency modes. This quality can be reached due to parallel processing of all system's algorithms (instead of circumstantial data processing in traditional digital software technologies).

Another important asset of the technology is its simplicity and short time necessary for making changes to functional work algorithms. The procedure does not require any change in the structure of system's

hardware. Verification process of the modified project and its testing do not require big expenses. While verification all the activities meet the modification safety requirements for nuclear applications, that are prescribed by existing Rules and regulations.

And finally, this technology allows to provide deep multilevel functional equipment diagnostics.

3. RADIY^{TM} DIGITAL PLATFORM

Based on this technology "Radiy" Company designed and developed RADIY^{TM} Digital Platform which consists of hardware and software constituents.

Designers are using these constituents to make control systems with upper and lower levels. Lower level is considered safety critical. Because it is the lower level where all the critical functions are realized (control/regulation algorithms, blocking and protection). One way information flow connects both levels – upward. The structure like this prevents the lower level from upper level impact, as lower level is safety critical level for nuclear installations. Thus, lower level provides workability regardless of the upper level state.

3.1. Hardware

Platform hardware is limited number of cabinets and modules (blocks) of different designation.

Modules (blocks) which realize the lower level functions – critical for safety - are protection forming blocks, input analog and digital signal blocks, normalizing converter blocks, analog and digital output blocks and actuators control blocks. Some blocks have FPGA in their structure.

Of course, the list of blocks given in this article is not complete as this article is aimed at introducing the specific features of FPGA technology that is designed and developed by "Radiy".

To provide diversity-oriented decisions in control systems we use FPGA from different vendors (Actel & Altera).

The scheme given below shows RADIY^{TM} Digital Platform composition and to some extent the way of manufacturing I&C systems based on the Platform (the bold type shows components which realize critical functions):
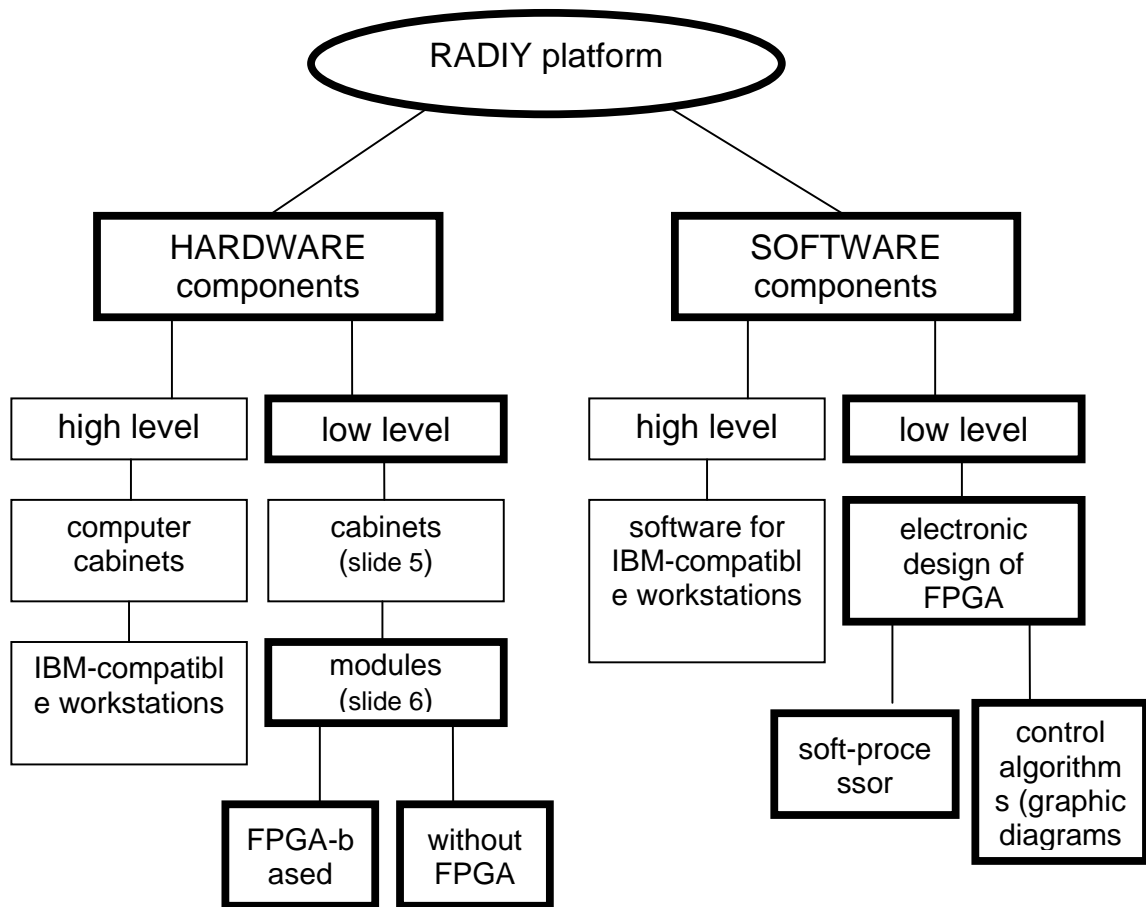
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                          ┌─────────────────┐
                          │  RADIY platform │
                          └─────────────────┘
              ┌─────────────────┐        ┌─────────────────┐
              │    HARDWARE     │        │    SOFTWARE     │
              │   components    │        │   components    │
              └─────────────────┘        └─────────────────┘
       ┌────────────┐  ┌────────────┐  ┌────────────┐  ┌────────────┐
       │ high level │  │ low level  │  │ high level │  │ low level  │
       └────────────┘  └────────────┘  └────────────┘  └────────────┘
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HARDWARE components — high level: computer cabinets → IBM-compatible workstations

HARDWARE components — low level: cabinets (slide 5) → modules (slide 6) → FPGA-based / without FPGA

SOFTWARE components — high level: software for IBM-compatible workstations

SOFTWARE components — low level: electronic design of FPGA → soft-processor / control algorithms (graphic diagrams)

Fig. 1. RADIY^{TM} Digital Platform composition

3.2. Software

Upper level software is designed to receive technological and diagnostic data, to visualize information on every control algorithm work and also diagnostic information on the status of the functional modules components. Software is also in charge of registration, archiving, selection and display of information, necessary for the operation personnel (if necessary in the way of trends and bar charts).

The following principles have been followed while designing the Platform:

- All control algorithms are performed only on FPGAs (Field Programmable Gate Arrays):

•   FPGA-projects have clear and well defined structure;
•   FPGA-projects and schemes of control technological algorithms have direct equivalent;
•   simplification of development and verification processes and decrease of design errors;
•   flexibility of integration and commissioning of digital equipment on NPP with adjacent I&C systems including analog equipment.

- Software and FPGA-projects verification based on multi-components V-shape life cycle;
- Use multi-components distributed data processing structure with heterogenic networks;

- Use of maximal possible quantity of own pre-developed hardware and software with positive service history for design of new I&C systems.
- absence of a direct relationship between computing processes.

RADIY^{TM} Digital Platform meets all requirements of Ukrainian national standards and safety norms for nuclear applications. Ukrainian national safety standards for control systems on nuclear applications corresponds to IEC standards and IAEA recommendations.

4. USING RADIY^{TM} DIGITAL PLATFORM TO DESIGN I&C SYSTEMS

"Radiy" company designed the new FPGA technology and tested it while completing projects and subjected them to verification which is the primary part of control system design. The technology itself is based on the principle that FPGA – chip is a part of hardware that uses CEC and FPGA-project is a software part – it is a set of statement, which is appropriate for implementation in FPGA chip.

The design process for control system based on FPGA consists of the following important stages:

- Development of System requirements, including Customers' requirements on safety;
- Development of technical specification which includes the list of necessary equipment (modules, cabinets), software products, technological algorithms and requirements on safety. Technical specification is verified to see its compliance with System Requirements and is finalized with corresponding report;
- Design including hardware design, software design and algorithms design that uses IDE tools. For example, Libero – for FPGA from ACTEL and Quartus – for FPGA from ALTERA. Software and algorithms are verified to prove their compliance with Technical specification requirements. Verification Plan is designed for this procedure;
- Hardware production, software coding and making electronic FPGA-project. Both software and electronic FPGA-project are tested according to Testing Plan. The latter is a part of Verification Plan. And Verification report is released which contains Testing report;
- Control system integration, validation and qualification testing in accordance with Validation and Qualification Plans to prove their compliance with System requirements and requirements to external exposure immunity. Finalized with Validation and Qualification Report.
- IDE-tools are also subjected to analysis qualification and the Library Components are subjected to testing.

The design process of FPGA- project and its verification is the following:

- Block-diagram according to control algorithms is designed;
- The Program model of control algorithm in IDE (Integrated Development Environment) is developed. The IDE corresponds to FPGA chip (Development of FPGA electronic design (program models of control algorithms) in IDE (Integrated Development Environment))
- The program model received in IDE is verified to see if it corresponds to technical algorithm block-diagram;
- The Program model of control algorithm (electronic FPGA-project) is functionally tested;
- The time delays of library components and IP-cores are checked.

5. RADIY^{TM} DIGITAL PLATFORM AND FPGA-TECHNOLOGY APPLICATION: FINDINGS AND OUTCOMES

RADIY^{TM} Digital Platform has demonstrated high flexibility while designing systems of different designation for different types of nuclear installations.

Beginning with 2003 the following control and protection systems have been designed and installed in NPP:

- Reactor protection systems (there are 22 operating systems with deep diversity: 18 systems for VVER-1000 and 4 systems for VVER 440);
- Reactor Power Control systems;
- Reactor Limitation systems;
- Accelerated Preventative Protection systems (according to operating VVER-1000 project requirements the latest three systems were supplied as complexes, combined in one system. There are 8 operating systems for VVER-1000);
- Engineered Safety Feature Actuation Systems (there are 13 operating systems: 9 for VVER-1000 and 4 for VVER 440).

In March 2008, after profound modernization, a new control and protection system for research reactor was successfully implemented for Research reactor VVER-M of Ukrainian National Academy of Science. "Radiy" Company performed all the scope of work on designing, manufacturing and installing Regulation, Control and Protection System for this research reactor. The installed System is based on RADIY^{TM} Digital Platform elements which were approved in control and protection systems of power reactors VVER-1000 and VVER-440.

The total number of the commissioned systems for power reactors of different types (VVER-1000 and VVER 440) made on RADIY^{TM} Digital Platform is 43. In addition there is a control system for research reactor. Currently a newly designed and developed control system of control-rod actuators has been developed and put into experimental operation in Zaporizhzhya NPP.

All the modernization projects for control systems using "Radiy" Platform-based equipment were subjected to licensing according to the requirements of Ukrainian and Bulgarian National Regulatory committees (power units 5,6 at Kozloduy NPP).

In this part of the article it is appropriate to show the time frames for retrofits.

The reconstruction project experience for ESFAS at Kozloduy NPP has shown the following results:

2nd safety system for power unit #6

- March 2008 – the Contract signed
- May 2008 – the source data for system design received
- August 2008 – Factory Acceptance Test data received
- September 1, 2008 – old equipment dismantling started
- September 5, 2008 – new equipment installation started
- September 22, 2008 – 2nd safety system is put into operation

2nd safety system for power unit #5

- April 18, 2009 – old equipment dismantling started
- May 5, 2009 - 2nd safety system is put into operation

Safety systems for VVER-1000 power units are big enough in terms of the number of equipment units for control systems, the number of actuators and the number of cable connections. The retrofit time frame was so optimistic due to the following factors:

- Availability of Digital "Radiy" Platform with its advantages, including 10-time contact connection reduction, number of cabinet-to-cabinet connection reduction, metrology procedures automation, etc.
- Factory Acceptance Test characteristics: quality, way of organization and intensity.
- "Radiy" Platform- technology flexibility, that provides try-outs of actuators and systems at power units before all the cable connections are done and intellectual part of the system is checked out.
- Cable connection work optimization.

6. CONCLUSIONS

"Radiy" Platform –technology designed and developed by "Radiy":

- Is qualified for complex solutions for nuclear installations of different types
- Is an advanced tool for retrofit and modernization of NPP power units aimed at life cycle extension
- Is able to further licensing process
- Facilitates reducing financial expenses and time for control systems design and development.