# CERTIFICATION OF RADICS FPGA-BASED PLATFORM UNDER US NRC REQUIREMENTS

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## ABSTRACT

The paper discusses approach, applicable to certify digital instrumentation and control (I&C) platform under US Nuclear Regulatory Commission (NRC) requirements. Currently, Radics LLC is certifying its Field-Programmable Gate Array (FPGA)-based RadICS Platform using Platform-based test specimen. The Platform has been recently certified under IEC 61508 to meet Safety Integrity Level (SIL) 3 requirements.

Up to now Radics LLC has developed a number of FPGA-based I&C applications based on RadICS Platform. Those applications include applications based on customer's specification and reverse engineering applications (Fit, Form and Function reproduction of existing equipment). The lifecycles of applications include independent verification and validation of FPGA-based I&C systems/components, Commercial Grade Dedication of components for FPGA-based I&C systems, turnkey implementation of I&C project, supply of hardware, engineering tools and application design process.

The paper also describes in details certification approach, which is based on Digital I&C-ISG-06 and includes the following stages: general agreement with the US NRC, Topical Report submittal, timely responses and successful audits, and timely issuance of approved Topical Report. Such approach is supported by 10 CFR 50 Appendix B Quality Management System, which is also discussed in the paper.

In addition, an overview of RadICS Platform Topical Report is presented, including its overview and structure, certification scope and obligatory appendixes.

*Key Words*: certification, FPGA, US NRC, RadICS, platform

## 1 INTRODUCTION

Certification of modern safety-critical systems is a complicated multi-staged process, which reviews and assesses variety of system's features and applicable requirements considering underlying technologies. A lot of attention should be paid to the systems, which are built with application of different types off-the-shelf (OTS) components, and, first of all, commercial-OTS (COTS) components.

One of the most promising modern trends in I&C systems design and implementation at Nuclear Power Plants is in application of FPGA technology. FPGA technology is now being widely used by the world industry and more often for safety-critical I&C systems designed for various areas due to its attractiveness from the point of view of its convenience and reliability in implementation of required functionality. FPGA-based I&C systems are complex systems that consist of hardware modules and software components [1, 2].

Certification of modern complex I&C systems, taking into account their functionality, underlying technologies and inherent properties, is a challenging and continuously evolving problem, which can be resolved in different ways. This paper represents results achieved in an ongoing certification case.

## 2 CERTIFICATION OF FPGA-BASED PLATFORM UNDER US NRC REQUIREMENTS

### 2.1 US NRC Certification Strategy

Certification strategy of the United States Nuclear Regulatory Commission is based on Digital I&C-ISG-06 document. [3].

Overall review process consists of the following subsequent steps:

– Phase 0;

– Phase 1;

– Phase 2;

– Phase 3.

Brief description for each of the steps along with appropriate certification activities is presented below.

Phase 0 consists of implementation of Pre-Application Activities. The goal is to reach general agreement with the US NRC that:

– The conceptual design is acceptable;

– Equipment qualification plans are appropriate;

– Commercial grade dedication strategy is acceptable;

– Document submittal plans are understood;

– Overall project schedule is reasonable.

During Phase 0 certification activities should be the following:

– Topical Report preparation;

– Equipment qualification plan development;

– Commercial grade dedication plan development;

– 10 CFR Part 50 Appendix B Quality Assurance Plan certification and implementation [4].

A Topical Report is a document that addresses a technical topic related to Nuclear Power Plant (NPP) safety, which the industry submits for review and approval by the US NRC before publishing it for reference in the licensing process by other NPP licensees.

A Topical Report allows for a single US NRC review and (if appropriate) approval of a safety-related topic that may apply to multiple NPPs. In that way it increases the efficiency of the licensing process and reduces the burden on licensees by minimizing the time and resources that both industry and the US NRC staff could expend on redundant reviews of the same topic [5].

Phase 1 is a Topical Report Submittal. The goal is to have application accepted for review and get early feedback on acceptability of Equipment Qualification Plan including the following documents:

– Topical Report;

– Equipment Qualification Plan;

– Commercial Grade Dedication Plan;

– DI&C-ISG-06 Phase 1 Submittals.

Certification activities that are expected at Phase 1 are the following:

– Topical Report review support;

– Equipment qualification plan implementation;

– Commercial grade dedication plan implementation;

– Respond to the US NRC Round 1 requests for additional information;

– Prepare Phase 2 Documents for submittal.

Phase 2 involves Pre-Application Activities. The goal is to provide timely responses and have successful audits performed. The scope of the documents includes the following:

– Equipment Qualification Summary Report;

– Commercial Grade Dedication Summary Report;

– DI&C-ISG-06 Phase 2 Submittals.

Certification activities during Phase 2 are the following:

– Topical Report review support;

– Support US NRC audits, as necessary;

– Respond to NRC Round 2 requests for additional information;

– Prepare Final Topical Report Update;

– Review draft safety evaluation report for proprietary information.

Phase 3 involves Pre-Application Activities, when the goal is to provide timely issuance of approved Topical Report that covers the final revision of the Topical Report.

Successful implementation of the above phases should result in the issuance of a document by the US NRC that approves the proposed digital I&C system upgrade.

## 2.2 RadICS Platform Overview

RadICS Platform designed by RPC Radiy consists of a set of general-purpose building blocks that can be configured and used to implement application-specific functions and systems. The RadICS Platform is composed of various standardized modules (Fig.1), each based on the use of FPGA chips as computational engines.

**Figure 1. RadICS FPGA-based Platform modules and a chassis with 7 modules inserted.**

RadICS Platform includes extensive on-line self-surveillance and diagnostics at various levels, including control of FPGA power, watchdog timer, cyclical redundancy check (CRC) calculations and monitoring of the performance of FPGA support circuits, Input/Output modules, communications units, and power supplies.

The development process of RadICS Platform-based application includes the configuration of Platform's modules, chassis and cabinets to perform the required functions. The hardware design is reduced to choosing the required amount and type of cabinets, chassis and modules in accordance with the system requirements specification.

Most RadICS Platform based applications are used in the most critical and high-reliability demanding NPP applications such as Reactor Trip, Power Control and Limitation, Engineered Safety Features Actuation, and Rod Control systems. Other examples include nuclear and turbine island control systems, and Automatic Regulation, Control, Operation and Protection of research reactors. Proven technologies and

approaches used in the FPGA-based platform produced by RPC Radiy have been confirmed by more than 70 critical NPP I&C systems installed to date.

Recent assessments performed by independent assessor of Function Safety has confirmed that RadICS Platform complies with the IEC 61508 standard meets functional Safety Integrity Level 3 (SIL3) requirements. Typical SIL certification process includes the following items:

– Product reliability;

– Process execution;

– Human factor;

– Functional safety assessment.

The basic US certification strategy is to demonstrate that the generic RadICS Platform and the associated quality and software life cycle processes comply with US nuclear safety requirements.

## 2.3 10 CFR 50 Appendix B Quality Management System Development and Implementation by Radics LLC

One of the most important features of the licensee is to have Quality Management System based on 10 CFR 50 Appendix B requirements.

Radics LLC is an engineering company providing FPGA-based NPP I&C solutions based on RadICS Platform for international market. In 2015 the company started the formal process of Platform certification for the US and other markets that follow the requirements of 10 CFR 50 Appendix B.

In the scope of certification of RadICS FPGA-based Platform under US NRC requirements, Radics LLC developed and implemented its QMS to comply with 10 CFR 50 Appendix B requirements. Some features, related to the developed QMS, are presented below:

– Hybrid Quality Assurance Manual. The Manual incorporates requirements of 10 CFR 50 Appendix B, NQA-1 and ISO 9001:2015;

– The Manual considers more than 51 mandatory references (including IEEE, EPRI, IEC and others);

– The Manual determines control over 14 main processes (design, procurement, testing, training, modification, installation and others);

– The Manual includes 42 Quality Procedures and 47 Work Instructions.

After successful implementation of the developed QMS, the US-based company performed on-site audit of Radics LLC QMS. The scope of such audit was to verify the adequacy and implementation of the QMS for US Nuclear Safety Related Services incorporated.

After several months, the same company conducted a follow up Desktop Audit of QMS, which covered Quality Manual, 42 Quality Procedures and several most significant Work Instructions. The target was to assess the adequacy of Quality Assurance Program documents and their compliance with the requirements of 10 CFR 50 Appendix B, 10 CFR 21, ASME NQA-1-1994, NQA-1-2008, and NQA-la-2009. The evaluation performed by the auditing company came to conclusion that the Quality Assurance Program of Radics LLC is comprehensively documented and compliant with declared commitments.

## 2.4 RadICS Platform Topical Report Overview

Within the scope of Phase 0 certification activities, Radics LLC prepared Topical Report [6], which is an umbrella document for US certification activities. RadICS Platform Topical Report has the following features:

– There are 350 pages including descriptions, diagrams, etc.;

– There are 120 supporting documents submitted and available for audit;

– There is a mapping of process requirements to RGs and IEEE standards.

The structure of the RadICS Platform Topical Report is the following:

– Chapter 1 – Introduction;

– Chapter 2 – RadICS Development and Operational History;

– Chapter 3 – Quality Assurance;

– Chapter 4 – RadICS Commercial Grade Dedication Plan;

– Chapter 5 – Regulations, Codes, and Standards;

– Chapter 6 – RadICS Platform;

– Chapter 7 – RadICS Platform Development Process;

– Chapter 8 – Electronic Design Development;

– Chapter 9 – Equipment Qualification and Analysis;

– Chapter 10 – Diversity and Defense-In-Depth;

– Chapter 11 – Secure Development and Operational Environment;

– Chapter 12 – Compliance Summary for Key Regulations, Codes, and Standards;

– Appendix A – RadICS Platform Application Guide;

– Appendix B – DI&C-ISG-04 Compliance Matrix;

– Appendix C – RadICS Electronic Design Documents.

Chapter 1 Introduction provides the reader with general information about the document, its idea and structure, and contains such subsections as Background, Objectives and Scope of the Report, Structure of the RadICS Topical Report, Definitions, Acronyms and Abbreviations, etc.

Chapter 2 RadICS Development and Operational History describes in sufficient details the evolution of RPC Radiy's (developer of RadICS FPGA-based Platform) products, from the first generation and up to recently developed designs. Such description includes explanation of underlying technologies for the equipment, principles of system design and operation, as well as existing cases of Platform-based applications, covering Reactor Trip System, Engineered Safety Features Actuation System and Rod Control System. This chapter also includes a summary of nuclear I&C references since the time when the first generation I&C system has been installed.

Chapter 3 is devoted to quality assurance aspects. It presents RPC Radiy and Radics LLC quality assurance programs, that cover companies' organization (available facilities and departments for life cycle activities implementation, their roles, responsibilities and achievements). For the Radics LLC, more emphasis is made towards 10 CFR 50 Appendix B based QMS, its structure, specific aspects and activities (including Corrective Actions, Problem Reporting, Safety Evaluation, etc.)

Chapter 4 deals with the Commercial Grade Dedication strategy and describes a set of applicable guidances, developed methodology and overall process for the FPGA-based Platform.

Chapter 5 represents a summary regarding US NRC regulatory requirements and acceptance criteria for safety-critical I&C systems along with the defined scope of the regulatory requirements and acceptance criteria applicable to RadICS FPGA-based Platform and to project-specific features.

Chapter 6 is a comprehensive description of the RadICS FPGA-based Platform. The following aspects of the Platform are provided: Platform overview and its possible configurations, general attributes of the Platform, safety concept, maintainability and operability, ideas for FPGA technology application and their benefits, Platform features at different levels, overview of module and interface types, their operation, interaction and diagnostics.

Chapter 7 is completely devoted to the detailed description of RadICS Platform Development Process. There is an overview of underlying safety standards, requirements for life cycle stages implementation, activities for the RadICS Platform development process (including verification and validation), configuration management process and trainings.

Chapter 8 describes approach used to develop one of the most important and challenging components of FPGA technology – electronic design (ED). ED is a set of FPGA configuration files that are installed (loaded) into the RadICS hardware modules. The description covers ED design process, development and verification of ED's components and Application Function Block Library.

Chapter 9 represents the approach to equipment qualification and analysis used by Radics LLC. It describes two issues:

– Equipment qualification. It includes, in particular, descriptions for the scope of equipment testing and types of qualification tests;

– Equipment analysis. It covers the following generic analyses performed: board/device-level predictive reliability and safety analyses, which includes FMEDA; setpoint analysis support; limited life parts analysis; radiation susceptibility analysis.

Chapter 10 deals with the problem of common-cause failures (CCFs) and describes protective strategy against CCF for the RadICS Platform. Digital I&C systems can be vulnerable to CCFs caused by software, firmware, or programmed logic errors, which could defeat the redundancy achieved by hardware architecture. CCFs are of particular interest for a digital I&C system designed to use in nuclear safety-related projects.

Chapter 11 Secure Development and Operational Environment discusses the RadICS Platform secure development environment, the RadICS Platform vulnerability assessment and implementation of the secure development and operational environment controls.

Chapter 12 is a compliance summary for key regulations, codes, and standards. It contains a summary of the key NRC regulatory requirements and acceptance criteria for safety-critical I&C systems identified in Chapter 5 for the RadICS Platform and associated with development processes. The description is presented in four topics: Quality Assurance, Technical Requirements, Software Development Processes, and Secure Development and Operating Environment.

Appendix A RadICS Platform Application Guide provides a summary of the guidance how RadICS Platform can be applied for NPP I&C systems classified as safety-related. The application guidance is introduces as a separate document (RadICS Product Safety Manual), which meets the requirements for the application guide documentation described in EPRI TR-107330.

Appendix B contains facts that confirm compliance of the RadICS Platform with the DI&C-ISG-04 requirements in a matrix form.

Appendix C contains a list of RadICS electronic design documents that are identified for submittal with a license amendment request.

## 3 CONCLUSIONS

Certification is a very important and complicated process required for each product that enters a specific market, especially for those products that are designed to protect people and environment. Modern

I&C systems are complex, they consist of many components of different nature and use various technologies that have to interact with each other.

Observations, which are introduced in this paper, give an example of the certification results achieved by Radics LLC for RadICS FPGA-based Platform under US NRC requirements. Such case covers development and implementation of QMS that is NQA-1 compliant, its auditing process by the third party, as well as consequent preparation and submission of the Topical Report to the US NRC.

## 4 REFERENCES


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