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FPGA-BASED I&C SYSTEMS IN NPP NEW BUILDS AND MODERNIZATION PROJECTS

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Abstract

This paper deals with advantages and disadvantages of some of the strategies that could be adopted in the refurbishment of nuclear power plants (NPP) Instrumentation and Control (I&C) systems and the reasons why Field Programmable Gate Array (FPGA) technology provides us with an effective means of meeting most of the challenges faced by operators and designers.

We also include examples of I&C refurbishment and new build projects where FPGA based technology has been either adopted or being considered.

Introduction

One of the main challenges faced by operators and designers involved in New Build and refurbishment of Nuclear Power Plants (NPPs) are to build safe, reliable control and safety systems with minimum licensing effort, resilient to obsolescence, at low capital and operating costs and minimum impact on construction schedule.

In order to meet the above challenges it is necessary to consider all associated contributing factors at the front end of the project so that they can be effectively addressed during the design phase.

The technology adopted for the replacement of existing I&C equipment and systems or their introduction in new builds plays an important role in mitigating the negative impact of the above factors as well as in creating favourable conditions for meeting the above challenges.

1. Factors affecting modernization projects of I&C systems

I&C related technologies are continuously advancing, perhaps faster than any other areas in the industry and those available to the NPPs went through a rapid development in the past fifty 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 using already unavailable digital technology. Although analog I&C systems have performed their functions satisfactorily for decades, a substantial amount of the original I&C equipment already is or soon will be obsolete.

When the lifetime of NPPs is extended and the existing systems cannot continue to support it, modernization is required.

Nuclear power plants, now designed to operate for 60 or more years, could potentially outlive their original I&C systems through various phases, moving initially from analog to digital technology and subsequently to even more advanced versions of digital I&C systems.

Experience from the different approaches taken in the modernization of NPPs I&C systems is now available in the form of cost-benefit analyses and lessons learned covering, among other areas, commercial, licensing, equipment design, selection and qualification, installation and testing and project management processes.

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

The nuclear industry, due to the important role assigned to safety related applications and the absence of sufficient operating data to be able to establish compliance with reliability requirements, has been slower than other industries in adopting digital technology. Now that the digital industry has reached a healthy level of maturity, both in their products as well as in associated Verification and Validation (V&V) techniques it provides operators and designers with an excellent opportunity to improve the safety and efficiency of the plants while helping address challenges posed by equipment obsolescence.

Some of the features that must be considered when selecting a digital I&C system for NPP applications are:

- Higher connectivity among their many components and other systems result in higher complexity than their analog predecessors.
- Their functionality depends on system and application software and as a result, the overall system reliability depends on the quality of the software development process.
- Their potential dependence on digital data networks raises the importance of cyber security.

The first above two features, complexity and software-dependence, introduce new risks of common cause failures (CCF) to the integrated system. In order to mitigate this, various ways and degrees of diversity have to be introduced at selected stages of the I&C system development.

The development and applications of new I&C systems are expected to continue and this will likely result in new solutions and improvements to various areas associated with the design and operation of NPPs. Examples of these are where advanced sensors, detectors, transmitters, and data transmission channels will be needed to meet the requirements imposed by new designs and by the more severe requirements of beyond-design-basis and post-accident conditions. Also, where in order to meet the continuous need to improve the efficiency and safety of NPPs, new approaches to monitoring and diagnostics will need to be developed, making use of on-line condition monitoring techniques, wireless sensor networks and communication, and integrated remote operation.

Regulators should be involved at an early stage of the introduction of new technology so that licensing issues affecting the design could be dealt with at the start of the design process.

2. I&C equipment replacement options

An important issue to be addressed during the project scope definition phase is the approach to be taken in the replacement of I&C equipment. This could vary from system to system and it will depend on factors such as availability of equipment and suppliers, required functionality, impact on HMI, history of operation, outage schedule and economic factors. The options considered in the following sections are based on the assumption that the I&C systems to be refurbished are of the analog or non-programmable types.

Typical replacement options are:

i. **Replacement at the component level**. This consists in replacing components at the integrated circuit/PC board level. The need for replacement could arise as a result of poor design or obsolescence leading to frequent failures and/or problems to obtain spare parts. It frequently involves circuit re-design at the PC boards level. It is rarely adopted as a refurbishment strategy due to the following reasons:

- In most cases circuit re-design exceeds the expertise of utilities
- Subcontracting PC boards redesign tends to be expensive
- The rest of the components continue to be vulnerable to obsolescence
- The reliability of the final product is uncertain.

ii. **Replacement at the module level**. When, as part of the original design strategy of the I&C systems, a large number of modules of the same type were purchased for different applications or when the station could be considering the replacement of some of the modules within I&C systems to be refurbished.

iii. **Replacement at the panel level.** Most of the considerations mentioned under section 2.2 above could be applied to I&C panel replacements. Panel level replacement does not lend itself to the modernization of entire I&C systems unless the same is self-contained within a single panel so we will not elaborate further on this approach.

iv. **Replacement at the system level.** When, in addition to obsolescence, maintainability and reliability problems, there is a need to change the architecture of the system as a result of new licensing or other requirements such as channelization, diversity and Human Factors considerations.

v. **Comprehensive systems modification**. In addition to considerations as those described for system level replacement under section 2.4 above, a comprehensive system modification approach is normally adopted when a decision has been made to replace all the applications with I&C systems based on a specific technology or platform, or, when practical, utilizing multiple/diverse technologies or platforms. This is mostly due to obsolescence problems or the need for additional functionality.

One of the main decisions to be made, mainly as applicable to module and panel replacement levels, is whether the replacements will be of the Like for Like (LFL) or Form Fit and Function (FFF) type. This will depend on cost, reliability, availability of equipment and equipment foot print. These involve the following:

a. **"Like for Like" replacement**. This option involves the replacement of I&C equipment with ones of exactly the same type as that actually installed, at times with minor design changes to accommodate improvements as identified during operation.

   Some of the considerations that would lead to adopting the above solution would be:

   - The installed equipment meets all new safety, functional and performance requirements.
   - The equipment is available in the market at refurbishment time (it may become obsolete prior to the end of life of the station).
   - The equipment could be acquired in sufficient quantities to satisfy the operators' needs throughout the remaining life of the station.
   - The economics justify the above investment.
   - There is sufficient in-house expertise to maintain and operate the equipment.

b. **"Form Fit and Function" replacement.** The substitute equipment in this case involves a different device, most often implemented using a modern technology than the one to be replaced, with exactly the same functionality and external features, such as it will result, from an installation viewpoint, in a simple "box only" replacement.

   Some of the considerations that would lead to adopting the above solution would be:

   - The equipment to be replaced meets all new safety and functional requirements but falls short of performance requirements (e.g. new response time requirements) and/or has a history of frequent failures.
   - There aren't sufficient original spare parts or entire modules available in the market to satisfy the operator needs between refurbishment time and the end of life of the station.
   - FFF replacement of existing equipment can be economically justified

Section 3 below includes a summary of what are generally considered advantages and disadvantages of the different approaches to equipment replacement. Where applicable, a clarification on whether the above refers to LFL or FFF is provided.

3. Advantages and disadvantages of the different options

The following sections include advantages and disadvantages to be considered when evaluating replacement options.

3.1. Replacement at the module or rack level.

Advantages and disadvantages at the module level of replacement depend on whether the same is of the LFL or FFF type.

3.1.1 Advantages of module by module replacement approach (LFL)

- No training of NPP operators and maintainers required.
- Proven design, well known reliability and failure modes.
- No changes to interfaces.
- Same layout and/or footprint, i.e. virtually no installation issues.
- Changes confined to the system affected by module obsolescence
- Easier to commission (same procedures, skills).
- Minimum licensing effort if there are no licensing issues with the originally installed equipment.
- No impact on the HMI and thus no changes required to the simulator.

3.1.2 Disadvantages of module by module replacement approach (LFL)

- Missing out on newer, more reliable technology.
- Obsolescence problem still persists and will most likely worsen as the station reaches its end of life.
- Large initial investment in spares (quantities and price),
- SS suppliers not in abundance and not cheap.
- Lack of flexibility to accommodate design changes and thus requires more engineering effort if above changes were needed.
- Limited parts and services support market.

3.1.3. Advantages of module by module replacement approach (FFF)

- Lends itself to technology updates without much impact on interfaces, i.e. Changes are confined to parts of the system affected by module obsolescence.
- Similar footprint, therefore easy to fit into available space.
- Limited changes to commissioning procedures
- Updated technology provides better safeguards against obsolescence
- Wider available technical support
- Lower initial capital investment in spare parts, particularly if new equipment is reconfigurable and applications are portable
- Lower dependence on SS suppliers, especially if it supports portable applications
- Minimum changes to the HMI and thus little or no impact on simulator.

3.1.4. Disadvantages of module by module replacement approach (FFF)

- Incorporation of new technology is possible but limited to existing system architecture
- Some maintainers training required
- Considerable design effort within tight constraints
- Licensing effort depends on how much regulators decide to involve themselves with the new technology.

3.2. Replacement at the I&C system level.

Depending on the type of changes, whole system replacement could be more economical and efficient to implement than single module replacements. For example when design changes arise from the need to improve diversity, add redundant logic by implementing a channelized architecture or improving the HMI.

3.2.1 Advantages of whole I&C system replacement approach

- Designers and operators are more at liberty to decide on the technology of the new I&C system and as a result optimize system performance
- More amenable to the incorporation of built in diagnostics and redundancy
- Equipment obsolescence no longer an issue
- Easier to achieve full compliance with modern standards

- Changes to the MCR could be simplified by the adoption of technologies suited to modern HMI standards
- More compact equipment and lower number of cables free space and save in equipment, cabling and installation costs
- Amenable to implementations that would allow off- line simulations and optimization of functionality prior to installation, thereby simplifying and shortening post installation tests and commissioning activities
- Flexibility to choose the simplest to license solution
- Easier access to a wide support market

3.2.2. Disadvantages of whole I&C system replacement approach

- Larger training effort for operators, maintainers and system engineers
- Risks associated with the adoption of unproven design
- Larger design and associated monitoring (on the part of the operator) effort
- Changes to one system could ripple into other systems, e.g. HMI.
- Changes to HMI could result in the need to change the simulator
- More prone to late discovery of problems leading to additional design changes and scope creep
- More planning required for installation activities due to different functionality, layout and/or footprint
- Programmable systems subject to more stringent V&V requirements than non-programmable ones.
- Programmable systems could be vulnerable to cyber attacks

3.3. Comprehensive systems modification.

A comprehensive I&C system modification approach across the whole plant is normally adopted when a decision has been made to replace all the applications with I&C systems based on a specific technology or platform as a result of system wide encompassing obsolescence and/or a need for additional functionality that the present systems could not accommodate.

Therefore, rather than covering advantages and disadvantages of this approach, this section deals with issues to be taken into consideration after a decision has been made to undergo a comprehensive systems modification of the NPP I&C systems, after factors such as platform costs, loss of production, etc… have been considered.

- Project implementation plans associated with comprehensive replacement of I&C systems should ensure that plant safety and design basis are maintained. At times, the lack of a properly documented design basis results in severe challenges to designers and operators when trying to define system requirements. For such cases a re-establishment of all or part of the design basis applying, when in doubt, conservative criteria, may be the only acceptable alternative.
- Before committing to a refurbishment scope, a detailed analysis of systems functional, performance and safety requirements must be performed. This will minimize risks of having to change the technology, platform type or suppliers as a result of late discoveries associated with inability of the equipment to meet design requirements.
- Where replacement of safety and safety related systems is part of the scope of the I&C refurbishment, the design and equipment selection process must comply with sound defence in depth, diversity, separation and redundancy criteria as a means to address common cause failures (CCFs), random failures and other plant safety concerns. NUREG/CR-6303, "Method for Performing Diversity and Defense-in-Depth Analyses of Reactor Protection Systems," describes diversity criteria to be used in the implementation of digital safety systems.
- Replacement of analog with digital technology in most cases results in significant changes to the Human Machine Interface. A detailed Human Factors analysis of the proposed platforms should be conducted in order to ensure that the refurbished systems meet requirements. The complexity of the HMI and the associated analysis will increase when different platforms are selected for redundant functions.
- The analysis should include an evaluation of whether manual functions could be automated and thus free operators' time to undertake other activities.
- In addition to higher reliability figures, comprehensive on-line diagnostic capabilities could result in simplified system architectures and reduction in the frequency of periodic testing and thus should be taken into consideration when selecting I&C platforms.
- Where the system will be connected to the corporate network, there will be a need to incorporate means of immunity against cyber attacks. The I&C platforms should allow implementation of the above security means with minimum effort to the designers and maximum reliability to the I&C system.
- Even though a comprehensive V&V of safety related applications is required, the new equipment should be selected among those that are proven to comply with guidelines in international standards such as IEC 61508 or equivalent. This will reduce the effort dedicated to demonstrate that all I&C system requirements are met.
- One of the decisions to be made early in the planning phase is whether I&C components and systems will be replaced during several planned outages or during the refurbishment outage. This will depend on the nature of the affected systems, licensing considerations and the economics associated with loss of production.
- Modern I&C digital platforms are highly reliable and they incorporate comprehensive diagnostics capabilities as well as user friendly interfaces. However, depending among other factors on the technology on which they are based, they are also highly complex and require technical specialization to maintain and incorporate design changes and succeed in the

licensing process. This requires that users and suppliers establish long term and solid business relationships to ensure efficient equipment operation and avoid production losses.

4. Different perspectives of what needs to be done.

Modernization of NPPs involve the participation of people from different backgrounds within the clients, suppliers and licensing organizations and each of these view the project from different perspectives. Examples of these are:

Operators and maintainers tend to prefer solutions that will have minimum impact in the operation of the station, as, for example would be the case with the LFL (and to a certain extent, FFF) replacement of modules and racks.

Plant management would be inclined to adopt options that would result in the lowest installation costs, minimum licensing efforts and maximum production revenues.

Designers gravitate easier towards new technologies and tend to have a more optimistic view of their impact on cost and schedule. Moreover, replacing entire systems with modern platforms could be simpler, from an overall design viewpoint, than, say, a FFF replacement at the module level.

Project Managers preferences reside mainly on solutions that will result in the lowest costs and shortest implementation schedules.

Regulators are interested in the safety aspects of the change.

The final scope of the NPP refurbishment will depend on the input of all above stakeholders.

5. A brief description of FPFA technology

Field-Programmable Gate Arrays (FPGAs) provide an alternative to microprocessor based technology and other types of programmable devices. They have been applied in aerospace and other industries since the 1990s. Although in comparison to other industries NPPs have been slow to adopt the technology, in the latter years there has been an increasing number of FPGA installations in operating NPPs worldwide.

FPGAs are integrated circuits within the broader family of HDL-Programmable Devices, designed to be configured by the user via hardware description languages. They differ in their detail design among different vendors and product lines. Most FPGA platforms share a basic architecture which includes:

- A set of configurable logic blocks (CLBs). These can be configured to implement logic functions via AND, OR, XOR and NOT using simple logic gates, or look-up tables (LUTs). The output of each CLB includes a flip-flop for synchronizing the data flow within the FPGA.
- A set of programmable Input/Output (I/O) blocks. These provide interfaces between the low voltage, low current signals within the FPGA and the higher voltages and currents required by field devices connected to the FPGA. Some I/O blocks include analog-to-digital conversion capabilities.

- An internal interconnection grid. A grid of conducting material via which the application is configured by connecting its intersecting points, thereby linking CLBs to each other.
- Application data memory. Some FPGAs include static random access memory (SRAM) and others, when, for example, used for applications requiring fast power restart and/or resistance to single-event upsets (SEUs) are equipped with non-volatile flash memory.
- FPGA architectures can be equipped with microprocessors linked to the CLBs through the interconnection grid. This could increase the complexity of the FPGA, thereby offsetting some of the advantages that will be discussed below.

6. Advantages and challenges of FPGA-based I&C systems

The sections below include a brief description of advantages and disadvantages of FPGA technology, mainly as compared with traditional CPU based platforms.

6.1. Advantages of FPGA based systems

a) **Lower complexity.** CPU based systems could potentially include a significant amount of relatively elaborate software in the form of operating systems and application programs, Depending on the application, this results in rather complex design, V&V and licensing processes. By allowing the possibility to avoid operating systems and embedded software, FPGA based systems can be made simpler, easier to test and qualify for safety applications.

b) **Applications portability.** Rapid obsolescence of electronic components result in having to undergo comprehensive refurbishments of I&C systems during the life of the station and vendors can seldom guarantee full upward compatibility during the long periods between refurbishments. FPGA technology allows a significant degree of design portability, i.e. only the final steps (synthesis and place and route) are dependent on the particular FPGA circuit chosen. This mitigates their vulnerability to obsolescence.

c) **Longer lasting availability of technical support.** Portability of HDS code helps achieve hardware independent applications. This is expected to result in available technical support throughout the life of the plant.

d) **Fast Response time.** FPGAs can process logic independent functions in a parallel fashion at high clock speeds and are therefore suited for applications that require very short response times.

e) **Simpler Verification and Validation (V&V) processes.** As opposed to CPU based systems, which are mostly general purpose machines, FPGA based systems can be designed to include only the required functionality and without the need for an operating system. As a result, there are no hidden functions that might remain either untested or express themselves in unpredicted ways under certain machine states. This results in lower complexity and thus in simpler V&V efforts..
Figure 1 shows a comparison of how complexity increases with functionality for conventional hardware, FPGAs and microprocessor based systems. The figure also includes three different FPGA architectures, i.e. flat hardware logic, FPGAs with an embedded microprocessor, with and without an operating system.

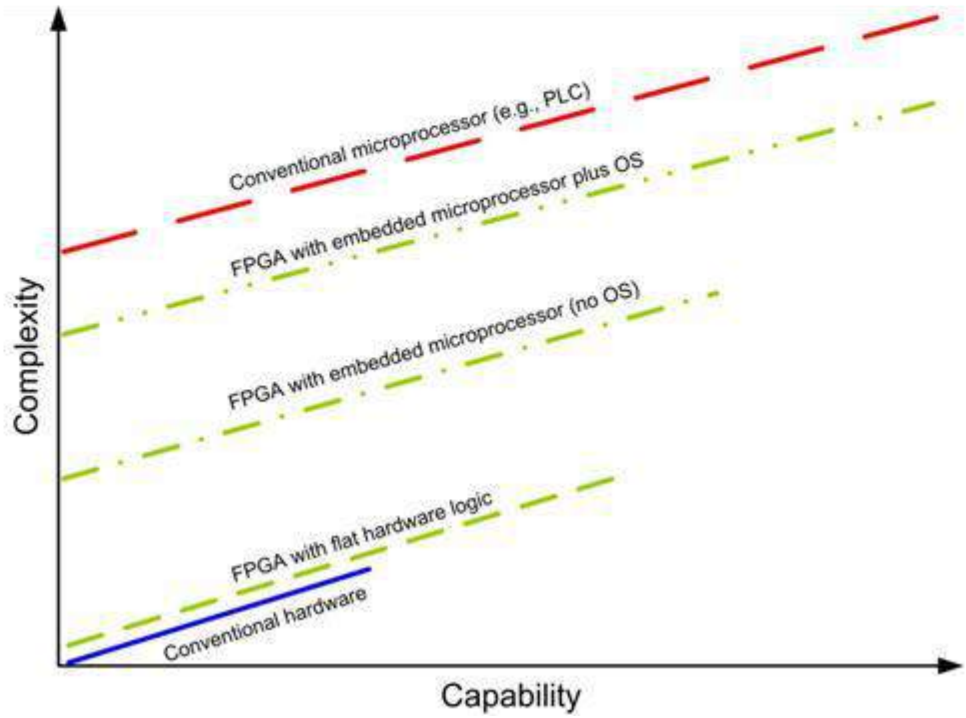

Figure 1. Complexity vs. capability for different I&C technology

f) Segregation of safety and non-safety functions

Support functions, such as self-monitoring and diagnostics and other non-safety functions may be easily physically separated from the main safety functions by placing them in separate FPGA chips. This results in:

- Simpler to design and validate safety related applications.
- Failures of non-safety functions will not result in loss of safety functions and viceversa, thus leading to an overall higher system reliability.
- Easier determination and design of failure modes, thereby further increasing the reliability, decreasing the need for periodic testing and simplifying diagnostic functions

Functional separation can be relatively simple to achieve because of the possibility to design FPGA systems with minimum or no shared resources.

g) Low vulnerability to cyber security attacks

Cyber security in programmable systems is always a concern to be dealt with independently of the adopted technology. FPGA based implementations tend to increase the level of difficulty that would be faced by a would-be attacker due to the following reasons:

- They don’t include high-level, general-purpose components that could be easily tampered with.

- Where cyber security could be a concern, FPGA design could be based on anti-fuse (one time programmable) type of chips.

h) A strong technology of choice when required to comply with diversity requirements

FPGA technology could constitute a viable diversity option between primary and redundant safety functions. Redundant CPU and FPGA based systems must as a minimum meet diversity criteria in NUREG/CR-6303 as follows:

- Design diversity (different technologies and architecture)
- Equipment diversity
- Functional diversity (different ways to achieve the same result)
- Software diversity (different programming languages, design methodologies, software architecture)

i) Cost effectiveness

The following main factors contribute to making FPGA technology an attractive option from a cost perspective:

- Lower design complexity and simpler V&V processes result in shorter development and change implementation times
- Intrinsic robustness to cyber attacks results in simpler measures to protect against malicious tampering with the system
- Portability of applications result in significant cost savings by avoiding the need to maintain and store large quantities of obsolete equipment to ensure availability of parts throughout the life of the plant.

j) Suitable for a wide range of applications

In addition to straight replacement of major systems or the design of I&C solutions for new or existing NPPs as could be achieved with CPU based systems, FPGA technology could be adopted to implement changes to a variety of applications, such as Form, Fit and Function (FFF) replacement of electronic components, reverse engineering and emulation of CPU based applications. This is mostly due to the fact that FPGA based systems are not constrained to a standard architecture as CPU based systems normally are.

k) Other advantages of FPGA technology

- Flexibility to accommodate design changes
- Considerable support market (parts and service)
- Considerable diagnostic capabilities
- Reduced footprint and cabling costs due, for example to FPGA capabilities to segregate safety and non-safety functions and provide redundancy within the same box.
- Allows simulations and optimization of functionality
- FPGA systems could be used to easily prototype solutions that could later be implemented in different technologies

6.2. Challenges normally faced by users when selecting FPGA based I&C systems

This section describes challenges to be dealt with when selecting FPGA technology. These are as follows:

a) Relatively few applications in the nuclear power industry

Although FPGAs have been widely used in the general industry for decades, they have been relatively recently introduced in nuclear plant I&C applications. Therefore, there isn't a large amount of nuclear specific data on which to base reliability analysis required for the safety case. This poses challenges in the safety analysis and licensing effort to be invested by utilities and designers. These challenges are being met by using industry wide related information and providing redundancies and diversity at the chip and module levels to ensure compliance with reliability targets.

b) Limited availability of products and tools

Presently there are only a few qualified suppliers of FPGA based I&C platforms for nuclear power plant safety applications and although sound development methods and tools are available in the market, they have not reached the level of acceptance by developers as that of their CPU based counterparts.

c) Limited access to internal signals

Analysis must be performed during the design phase in order to determine which signals will be accessible to users for activities such as monitoring, testing and troubleshooting. In many cases, this is accomplished through the use of a test access port in the FPGA chip but there are no guarantees that signals whose accessibility were missed during the design phase will be accessible to users through the above access port so this requires an extra effort on the part of the designer and solid communications with those who will be responsible for maintaining the system during plant operation.

d) **Not well suited for complex human-system interface functions**

Even though FPGAs are very well suited for data processing functions involving mathematical calculations and image processing associated with control room displays, they exhibit some user interface limitations, for example, lack of accessibility to functions through window type based interfaces, soft controls, alarm filtering and procedure management.
Complex HSIs tend to require more frequent modifications than control algorithms. Due mainly to development tool availability, these types of modifications are presently easier to implement in software.

7. Examples of projects using FPGA technology

This section provides examples of FPGA applications in different countries, some of them installed or about to be installed in NPPs and others to be installed in the future or under consideration.

7.1 FPGA based systems presently installed in operating NPPs

1. In the Kozloduy NPP, Units 5 and 6 (Bulgaria) [1] , RPC Radiy has installed six FPGA based Category A engineered safety features actuation systems (ESFAS) of their own design as a turn-key projects, i.e. RPC Radiy designed the platform and applications, manufactured, installed and commissioned the above systems.
2. FPGAs are installed in Units 1 and 2 of the Czech Republic Temelin NPP's non programmable logic (NPL) system to provide priority logic arbitration between the microprocessor based primary reactor protection system (PRPS), diverse protection system (DPS) and hard wired control signals. The NPL is also involved in the safety diesel load sequencing and associated automatic test function.
3. The French corporation EdF has replaced obsolete electronic modules for their rod control system (RCS) and their reactor in-core measurement (RIC) systems in their 900 MW plants. They are also using FPGA technology to implement parts of new systems,
4. Japan's Toshiba implemented start-up and power range neutron monitoring systems in some of their BWR plants, radiation monitoring systems in their BWRs, ABWRs and PWRs plants and reactor trip and isolation systems in their ABWR plants, all based in FPGA technology.
5. FPGAs will be used in the design of the engineered safety features for new APR-1400 plants under construction in the Republic of Korea.
6. In Sweeden, FPGAs are used in the component interface module (CIM) of the replacement safety system in Unit 2 of the Ringhals NPP.
7. RPC Radiy has installed FPGA based systems for safety applications in all Ukranian NPP sites. Specifically, 28 reactor trip systems, 10 reactor power control and limitation systems, 18 engineered safety feature actuation systems, and 4 nuclear and conventional island control systems have been installed in the Zaporozhye NPP Units, the South-Ukraine, Rovno NPP, and Khmelnitski NPPs **Error! Reference source not found.**. Replacement of the rod control system in the South-Ukraine NPP with RPC Radiy's FPGA based system is presently in progress. In the reactor trip system of the above plants, the primary and diverse RTS systems are FPGA based from different FPGA-chip vendors.
8. In the US, a Westinghouse FPGA based control system was installed to replace obsolete equipment in the main steam and feedwater isolation system (MSFIS) at the Wolf Creek Generating Station [2]. At the same station, FPGAs are being used as the basis for the replacement of obsolete timing modules in the emergency diesel generators.

7.2 Envisaged FPGA based applications

1. The replacement of the existing special safety systems annunciation for the Embalse NPP in Cordoba, Argentina. This is a Form Fit Fucntion (FFF) type of replacement using FPGA technology.
2. The implementation of a Signal Processing Unit as part of the new SDS2 Main Heat Transport Pump Trip function for the Embalse NPP in Cordoba, Argentina.

Note: Both above systems were successfully Factory Acceptance Tested by RPC Radiy and witnessed by their client, the Toronto, Canada based Candu Energy Inc.

3. Even though the Digital Control Computers (DCCs) have been in use since the early days of Candu plants, they are now experiencing obsolescence and there are plans to replace them with systems implemented using current technology, of which FPGA, given its emulation and other desirable capabilities could be a strong substitute candidate. The same can be stated about other electronic components in Candu Stations, including the shutdown computers.

4. The French corporation EdF is currently developing a CPLD based solution to upgrade the rotational speed measurement system for the primary pumps of their 900 MWplants. In addition, EdF developed and formally verified an FPGA based emulator for the Motorola 6800 microprocessor, currently being used in their 1300 MW plants.
5. The PLC based diverse protection system (DPS) will be replaced with FPGA based logic controllers in Korean power units in the Yonggwang NPP and the Ulchin NPP.
6. In the US, the Westinghouse/CS Innovations FPGA platform is planned to be used in the Diablo Canyon NPP to replace the digital RPS and ESFAS systems. The application is currently under review by the US NRC 0.
7. Candu Energy (CE) is considering using an FPGA based platform for the implementation of special safety systems in their Enhanced CANDU-6 (EC-6) reactor. RPC Radiy is supporting CE in their efforts.
8. The chinese Nuclear Power Engineering Company (CNPE) is evaluating the use of FPGA based safety systems in the advanced version of their CP1000 design **Error! Reference source not found.**.
9. The Chinese Techenergy Company (CTEC) is developing an FPGA based platform, FitRel, to be used in the design of the DAS of Units 5 and 6 of the Yangjiang NPP presently under construction **Error! Reference source not found.**.
10. The Chinese State Nuclear Power Automation System (SNPAS) Engineering Company and Lockheed Martin Corporation (LMC) are developing a safety I&C platform, NuPAC, and the NuPAC based RPS for the China advanced pressurized water reactor (CAP-1400) **Error! Reference source not found.**.
11. Triconex of Invensys Process Systems (now Schneider Electric) is also employing FPGAs for the priority logic modules in new plants being built in China.
12. In Westinghouse's AP1000 design, FPGA based solutions, developed by CS Innovations, are used to implement the safety-related CIM system as an interface between field components, the protection and safety monitoring system (PMS) and the plant control system (PLS). FPGAs also provide prioritization of commands from the safety-related PMS and non-safety related PLS. AP1000's non-safety related DAS provides a diverse backup to the reactor protection system. This is implemented by using CS Innovations' FPGA based ALS platform 0.
13. In Areva's US EPR design, the priority actuation and control system (PACS) is implemented by using PLDs. Programmable electronic devices, such as FPGAs or PLDs are considered as options for implementing DAS 0.
14. In the Combined License Application for Units 3 and 4 of the South Texas Project, it was indicated that the ABWR design's neutron monitoring system and the reactor trip and isolation systems will be implemented based on the I&C platform developed by Toshiba using FPGAs 0.
15. In Mitsubishi's US APWR design, FPGAs are used in the control network interface, bus master, and power interface MELTAC digital platform modules [2].
16. In Hitachi-GE's ESBWR design, a PLD based independent control platform (ICP) will be used to implement several functions within the accident mitigation systems 0.

8. Conclusion

Designer, operators and maintainers of NPPs face different and numerous problems throughout the operation of their facilities and in addition to the challenges exhibited by other equipment, I&C systems have the additional complications of rapid obsolescence which makes replacement parts more difficult to obtain. When I&C systems are inevitably having to be replaced by new technology, lack of operating data makes licensing processes and safety analysis more difficult and time consuming for designers, analysts, utilities and regulators.

The industry has acquired a healthy level of experience in the development of design and V&V processes for digital I&C systems but these are still very time consuming, costly and in some cases difficult to prove that full coverage of all safety, functional, performance and diagnostic requirements has been achieved.

FPGA technology presents a viable option to solve at least partially some of the challenges posed by CPU based technology while introducing some of its own. It is expected that this paper will be able to create the necessary awareness for users and practitioners to take into consideration and decide as to whether an FPGA approach would solve or mitigate some of the challenges that they may be facing in the process of maintaining or refurbishing existing plants as well as designing new ones.

9. References

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