FPGA APPLICATIONS IN I&C MODERNIZATION PROJECTS

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OUTLINE

1. **Factors** affecting the scope of life extension projects
2. I&C equipment replacement **options**
3. **Advantages** and **disadvantages** of the different options
4. Different **perspectives** on what needs to be done
5. **Example** of a modernization project using FPGA technology
1. FACTORS
2. OPTIONS
3. ADVANTAGES & DISADVANTAGES
4. PERSPECTIVES
5. EXAMPLES
FACTORS

► End of Life
► Obsolescence
► Regulatory requirements
  ► Integrated safety review (ISR)
  ► A comprehensive assessment of plant design and operation performed in accordance with the IAEA’s Periodic Safety Review of Nuclear Power Plants – Safety Guide
► Maintenance/ operational difficulties
1. FACTORS
2. OPTIONS
3. ADVANTAGES & DISADVANTAGES
4. PERSPECTIVES
5. EXAMPLES
An important issue to be addressed early in the project (scope definition phase) is at what level to perform equipment replacement.

The extent of the change is mainly dictated by availability of equipment and suppliers, outage schedule and economic factors.

“Like for Like” or FFF replacements not always possible.

Replacement of obsolete equipment with 2nd source versions often not a good solution.
OPTIONS

- Component level replacement. Not practical, very rarely done
- Module or rack level replacement
  - Same technology (“like for like” replacement)
  - Updated technology (Form Fit Function replacement)
- Panel level. Also rarely done, unless dealing with a single panel system (covered below)
Options

- System level replacement
- Comprehensive systems modification. Extremely difficult to justify, mainly due to impact on initial investment

Replacement strategy subject to cost/benefit, technical and safety related considerations, e.g. drastic reduction of panels and plant real estate usage vs. operator/maintainers training.
OPTIONS

1. Factors
2. Options
3. Advantages & Disadvantages
4. Perspectives
5. Examples
1. FACTORS
2. OPTIONS
3. ADVANTAGES & DISADVANTAGES
4. PERSPECTIVES
5. EXAMPLES
ADVANTAGES
Module/ rack level replacement, same technology (Like for Like)

► No training of NPP staff required
► Proven design
► No changes to interface design
► Same layout and/or footprint, therefore easier to install
► Changes confined to the system affected by module obsolescence
► Easier to commission (same procedures, skills)
► Minimum licensing effort
DISADVANTAGES
Module/ rack level replacement, same technology (Like for Like)

► Missing out on newer, more reliable technology
► Obsolescence problem still persists and will most likely worsen
► Large initial investment in spares (quantities and price), also SS suppliers are not cheap
► Lack of flexibility to accommodate design changes and thus more engineering effort if above changes were needed
► Limited support market (mainly parts and service)
► SS equipment may not be available in sufficient quantities
ADVANTAGES/ DISADVANTAGES
Module/ rack level replacement, updated technology

➤ Middle of the road between module and system level replacement
➤ Incorporation of new technology is possible but limited to existing system architecture
➤ Some maintainers training required
➤ Some changes to interface design
➤ Same footprint, therefore easier to install
ADVANTAGES/ DISADVANTAGES
Module/ rack level replacement, updated technology cont’d

► Changes confined to the affected system
► Some changes to commissioning procedures
► Updated technology safeguards against obsolescence
► Lower initial investment in spare parts, particularly if equipment is reconfigurable and applications are portable
► Independence from SS suppliers if it supports portable application
► Considerable design effort within tight constraints
► Licensing effort depends on how much regulators decide to involve themselves with the new technology
ADVANTAGES
Replacement at the system level

► More at liberty to decide on the technology, allows designers to optimize system performance
► A good opportunity to take advantage of the following:
  ► Include built in diagnostics and redundancy to increase reliability
  ► Cater to equipment obsolescence
  ► Compliance with modern standards
  ► Simplification of changes to the MCR by adopting technologies that are more suited to modern HMI standards
  ► Free space and save in equipment and cabling costs
  ► Adopt solutions that would allow easy simulations and optimization of functionality prior to installation
  ► Choose the most “licensing friendly” solution
► Wider support market
DISADVANTAGES
Replacement at the I&C system level

- Larger training effort for operators, maintainers and system engineers
- Risk of adopting unproven design
- Larger interface design effort
- Changes could affect other systems (though it may simplify already changes to HMI)
- More planning in the installation due to different footprint
- Programmable systems subject to more stringent V&V requirements than non-programmable ones
- Programmable system could be vulnerable to cyber attacks
1. FACTORS
2. OPTIONS
3. ADVANTAGES & DISADVANTAGES
4. PERSPECTIVES
5. EXAMPLES
WHO PREFERENCES TO DO WHAT?

- **Operators and maintainers** generally prefer to replace modules and racks.
- **Plant management** would like to go with what’s faster, cheaper to build, install and operate with minimum licensing effort and loss of production.
- **Designers** prefer to replace systems, panels, racks or modules (in that order).
- **Project managers** would rather replace what’s faster and cheaper to build and install.
- **Regulators** are interested in the safety aspects of the change.
WHY FPGAs?

FPGA based systems retain most of the advantages and minimize impact of most disadvantages listed above.

► If multiple systems replacement, same layout and/or footprint for all of them simplifies installation
► Reliable technology
► High resistance to cyber attacks
► Configurable without the need for an operating system or embedded software
► Excellent solution to diversification requirements
WHY FPGAs?

► Faster than CPU based systems
► Amenable to portable applications
► Medium to low initial investment in spares
► Flexibility to accommodate design changes
► Considerable support market (parts and service)
► Considerable diagnostic capabilities
► Reduced footprint and cabling costs
► Allows simulations and optimization of functionality
► Simpler design process allows reduction of effort necessary for development and V&V
► Some regulators are familiar and taken an interest in the technology
WHY FPGAs?

- Parallel functionality results in reduced response time
- Suitability for reverse engineering of analog and digital equipment makes this technology very attractive for refurbishment applications
- FPGA systems could be used to test solutions that could later be implemented in a different technology
GENERAL CHARACTERISTICS OF FPGA BASED DESIGN

► FPGA technology presents a suitable (in some cases desirable) alternative to CPU based technology
► FPGAs can implement a wide variety of logic and processing functions, including microprocessor emulation
► Programmed by using well established languages (HDL)
► Depending on chip selection, applications could be reprogrammed
► Once programmed, FPGA chips are as close to a hardware device as could be achieved with a programmable device
<table>
<thead>
<tr>
<th>Criterion</th>
<th>FPGAs</th>
<th>Microcontrollers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallel data processing</td>
<td>Some</td>
<td>No</td>
</tr>
<tr>
<td>Typical response time</td>
<td>~10ms</td>
<td>~100ms</td>
</tr>
<tr>
<td>Deterministic behavior</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Design complexity</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Complexity of V&amp;V</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Emulation capabilities</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Application experience in safety critical domains</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Licensing efforts and risks</td>
<td>Acceptable (decreasing in the future as regulators become more acquainted with the technology)</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Average time for I&amp;C system design</td>
<td>6-12 months</td>
<td>14-24 months</td>
</tr>
<tr>
<td>Automated design and verification tools</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Remote modification of control logic</td>
<td>Not Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Cyber security vulnerabilities</td>
<td>At the present time there are no known viruses or malware affecting FPGAs</td>
<td>Vulnerable</td>
</tr>
</tbody>
</table>
1. FACTORS
2. OPTIONS
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FPGA APPLICATIONS IN THE NUCLEAR INDUSTRY

1. Factors
2. Options
3. Advantages & Disadvantages
4. Perspectives
5. Examples

► **Wolf Creek Plant** – USA Main Steam and Feedwater Isolation System Replacement

► **Advanced BWR** – Japan, Power Range Neutron Monitoring System

► **Kozloduy Units 5 & 6** – Bulgaria, Modernization of Engineered Safety Features Actuation Systems (ESFAS)

► **EDF 900 MW Series** – France, Rod Control System – Slave Logic Units
<table>
<thead>
<tr>
<th>Nuclear Plant</th>
<th>Radiy Supplied Equipment</th>
<th>Quantity of Installed Systems</th>
<th>Supply Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zaporizhzhia NPP, Ukraine South Ukraine NPP, Ukraine Rivne NPP, Ukraine Khmelnitsky NPP, Ukraine</td>
<td>Reactor Trip System</td>
<td>24</td>
<td>2004-2009</td>
</tr>
<tr>
<td>Zaporizhzhia NPP, Ukraine South Ukraine NPP, Ukraine</td>
<td>Fire Alarm System and suppression system</td>
<td>5</td>
<td>2008-2011</td>
</tr>
<tr>
<td>South Ukraine NPP, Ukraine Rivne NPP, Ukraine</td>
<td>Nuclear Island Control System</td>
<td>2</td>
<td>2011</td>
</tr>
<tr>
<td>Zaporizhzhia NPP, Ukraine Rivne NPP, Ukraine</td>
<td>UKTS-based Reactor and Turbine Control System</td>
<td>15</td>
<td>1998-2004</td>
</tr>
<tr>
<td>South Ukraine NPP, Ukraine Rivne NPP, Ukraine Kozloduy NPP, Bulgaria</td>
<td>Engineered Safety Feature Actuation System</td>
<td>18</td>
<td>2005-2010</td>
</tr>
<tr>
<td>Zaporizhzhia NPP, Ukraine South Ukraine NPP, Ukraine Rivne NPP, Ukraine Khmelnitsky NPP, Ukraine</td>
<td>Reactor Power Control and Limitation System</td>
<td>8</td>
<td>2004-2008</td>
</tr>
<tr>
<td>Kozloduy NPP, Bulgaria</td>
<td>Power Supply for Rod Control System</td>
<td>2</td>
<td>2007-2008</td>
</tr>
<tr>
<td>Nuclear Research Institute, Ukraine</td>
<td>I&amp;C system of Research Reactor</td>
<td>1</td>
<td>2006</td>
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</table>
Modernization of the Engineered Safety Features Actuations System (ESFAS)

There are a total of 6 units (4*VVER-440, 2*VVER 1000)
First unit started operation in 1974
Only the 2 VVER-1000 units remained in operation as of 2007
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Modernization of the Engineered Safety Features Actuations System (ESFAS)

Main Modernization Objectives

► To comply with updated regulatory requirements by:
  ► Increasing the safety of the station
  ► Improving the HMI to meet latest standards
  ► Improving separation between safety divisions

► To increase NPP availability
► To address equipment obsolescence
► All of the above while keeping field changes to a minimum
Refurbishment Scope Basis

► Conformance with national and international regulations, standards and recommendations (IEC, IAEA)
► Objectives were met due, to a great extent, to the adoption of FPGA technology
► Reasons for the adoption of FPGA-based technology:
  ► Radiy’s extensive experience with the technology
  ► Easy to operate & maintain
  ► Off site preparation work favoured schedule compression
  ► Safety and functional advantages of FPGAs for the application
  ► Amenable to the replacement of obsolete equipment at all levels (module, rack, panels, systems)
  ► Design more resilient to obsolescence due to HDL code portability
  ► Most suitable technology for the replacement of hardware based systems
► Formal development process suitable for safety applications
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Modernization of the Engineered Safety Features Actuations System (ESFAS)

Duration of Main Modernization Activities

- Contract with NPP
- Factory Acceptance Testing
- On-Site Installation
- Operation
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Modernization of the Engineered Safety Features Actuations System (ESFAS)

**Installation Time Schedule**

<table>
<thead>
<tr>
<th>Processes</th>
<th>Start</th>
<th>Finish</th>
<th>Processes</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation Quality Assurance Program Development</td>
<td>Q</td>
<td></td>
<td>Equipment Adjusting</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Preparing On-site Premises, Dismantling of Old Equipment</td>
<td>P</td>
<td></td>
<td>Site Acceptance Testing</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>Cable routing, Equipment Mounting</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Diagram showing the time schedule with different processes and their timelines.
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Modernization of the Engineered Safety Features Actuations System (ESFAS)

Installation Activities
September 1, 2008
Day 1
September 6, 2008
Day 5
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September 24, 2008
Day 23

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Modernization of the Engineered Safety Features Actuations System (ESFAS)

Before Installation

- Old I&C

Old I&C System = 112 cabinets
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Modernization of the Engineered Safety Features Actuations System (ESFAS)

After Installation

ESFAS Based on RadICS Platform = 45 cabinets
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Modernization of the Engineered Safety Features Actuations System (ESFAS)

Contributing Factors to Project Success

► Effective planning of activities with clear responsibilities assigned to supplier clients and owner;
► Highly skilled workmanship;
► System designed taking into consideration installation, commissioning, maintenance and operational factors;
► Involvement of the customer in review meetings performed at each phase of the project;
► Significant reduction in equipment quantity due to adoption of FPGA technology;
► Effective training of maintainers and operators;
► Maximization of in-house activities;
► Regulator involvement early in the project.
THANKS FOR YOUR ATTENTION!

QUESTIONS?