FPGA APPLICATIONS IN I&C MODERNIZATION PROJECTS

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Connecting Forward

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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
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OPTIONS

- 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

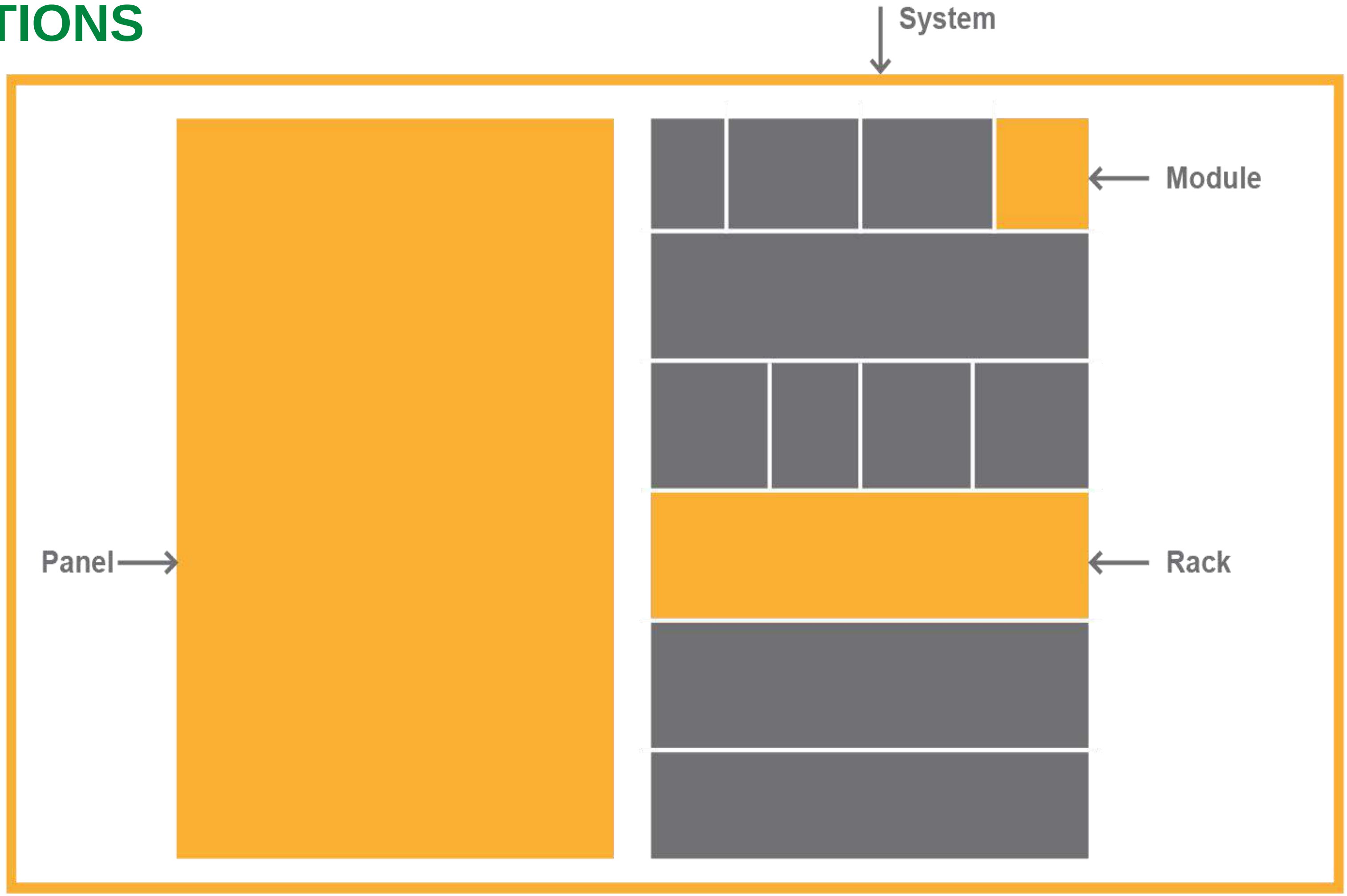
- **Component level replacement. Not practical, very rarely done**
- **Module or rack level replacement**
    - **Same technology ("like for like" replacement)**
    - **Updated technology (Form Fit Function replacement)**
- **Panel level. Also rarely done, unless dealing with a single panel system (covered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

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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

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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

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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

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WHO PREFERS 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**

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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

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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**

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FPGA VS. CPU BASED CONTROLLERS

Criterion	FPGAs	Microcontrollers
Parallel data processing	Some	No
Typical response time	~10ms	~100ms
Deterministic behavior	Yes	No
Design complexity	Lower	Higher
Complexity of V&V	Lower	Higher
Emulation capabilities	Yes	Yes
Application experience in safety critical domains	Yes	Yes
Licensing efforts and risks	Acceptable (decreasing in the future as regulators become more acquainted with the technology)	Acceptable
Average time for I&C system design	6-12 months	14-24 months
Automated design and verification tools	Yes	Yes
Remote modification of control logic	Not Possible	Possible
Cyber security vulnerabilities	At the present time there are no known viruses or malware affecting FPGAs	Vulnerable

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FPGA APPLICATIONS IN THE NUCLEAR INDSTRY

- ***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**

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FPGA VS. CPU BASED CONTROLLERS

Nuclear Plant	Radiy Supplied Equipment	Quantity of Installed Systems	Supply Date
Zaporizhzhia NPP, Ukraine **South Ukraine NPP**, Ukraine **Rivne NPP**, Ukraine **Khmelnitsky NPP**, Ukraine	**Reactor Trip System**	**24**	**2004-2009**
Zaporizhzhia NPP, Ukraine **South Ukraine NPP**, Ukraine	**Fire Alarm System and suppression system**	**5**	**2008-2011**
South Ukraine NPP, Ukraine **Rivne NPP**, Ukraine	**Nuclear Island Control System**	**2**	**2011**
Zaporizhzhia NPP, Ukraine **Rivne NPP**, Ukraine	**UKTS-based Reactor and Turbine Control System**	**15**	**1998-2004**
South Ukraine NPP, Ukraine **Rivne NPP**, Ukraine **Kozloduy NPP**, Bulgaria	**Engineered Safety Feature Actuation System**	**18**	**2005-2010**
Zaporizhzhia NPP, Ukraine **South Ukraine NPP**, Ukraine **Rivne NPP**, Ukraine **Khmelnitsky NPP**, Ukraine	**Reactor Power Control and Limitation System**	**8**	**2004-2008**
Kozloduy NPP, Bulgaria	**Power Supply for Rod Control System**	**2**	**2007-2008**
Nuclear Research Institute, Ukraine	**I&C system of Research Reactor**	**1**	**2006**

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Modernization of the Engineered Safety Features Actuations System (ESFAS)

General Information

- **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**

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Modernization of the Engineered Safety Features Actuations System (ESFAS)

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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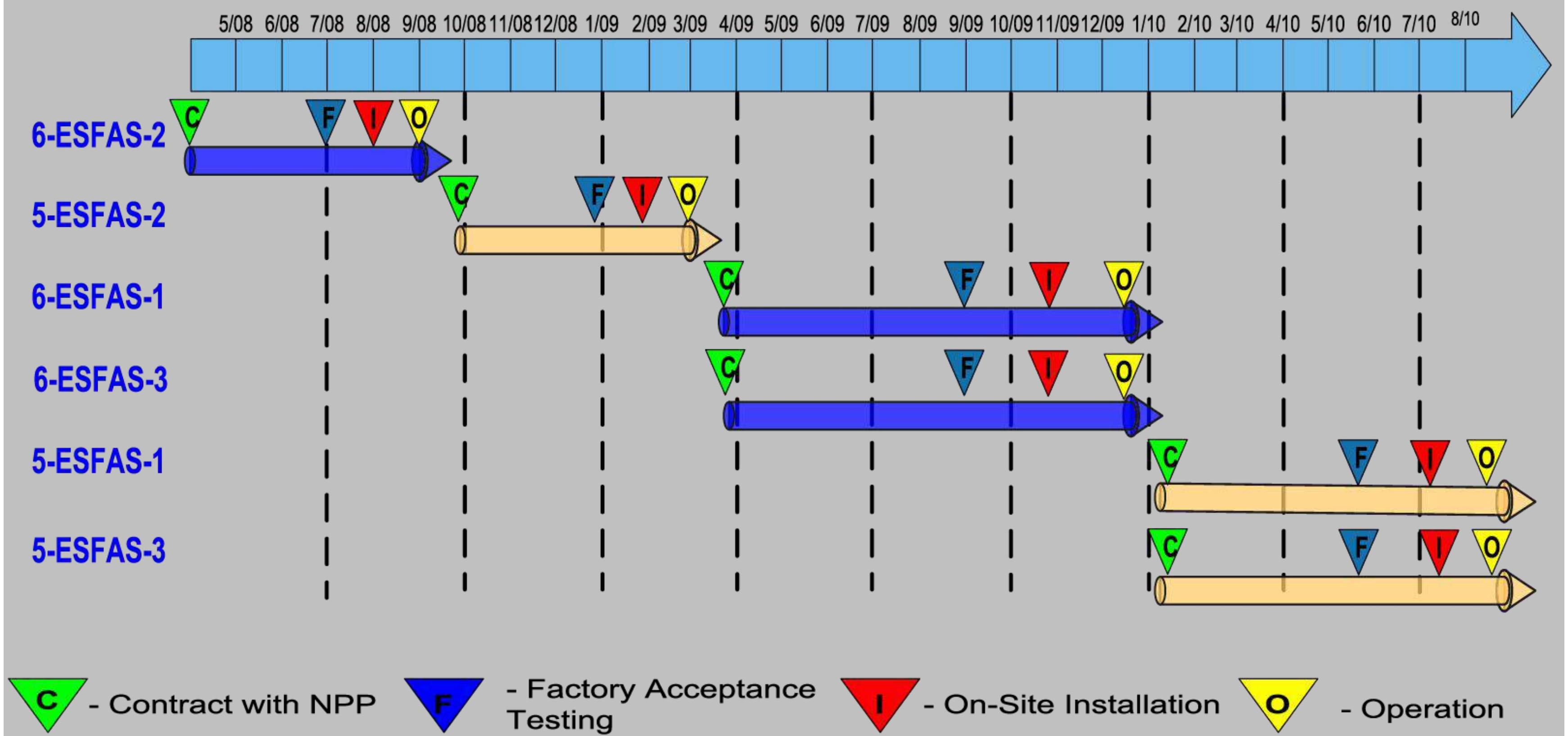
Modernization of the Engineered Safety Features Actuations System (ESFAS)

Duration of Main Modernization Activities



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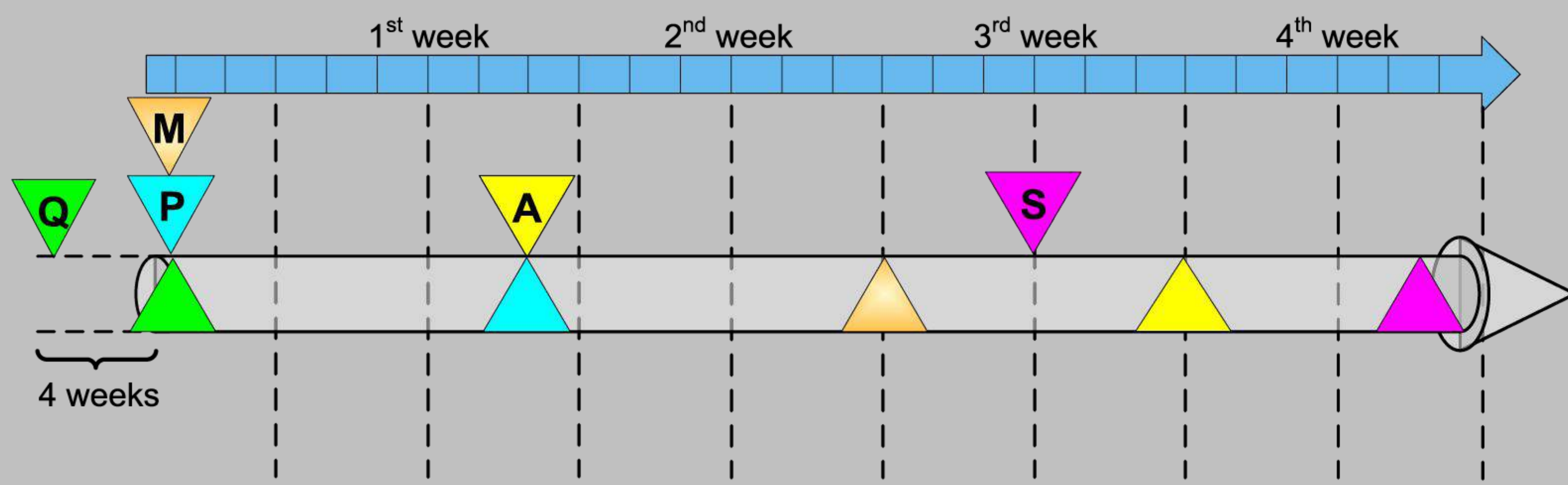
Modernization of the Engineered Safety Features Actuations System (ESFAS)

Installation Time Schedule



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

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Modernization of the Engineered Safety Features Actuations System (ESFAS)

Installation Activities

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September 18, 2008

Day 17

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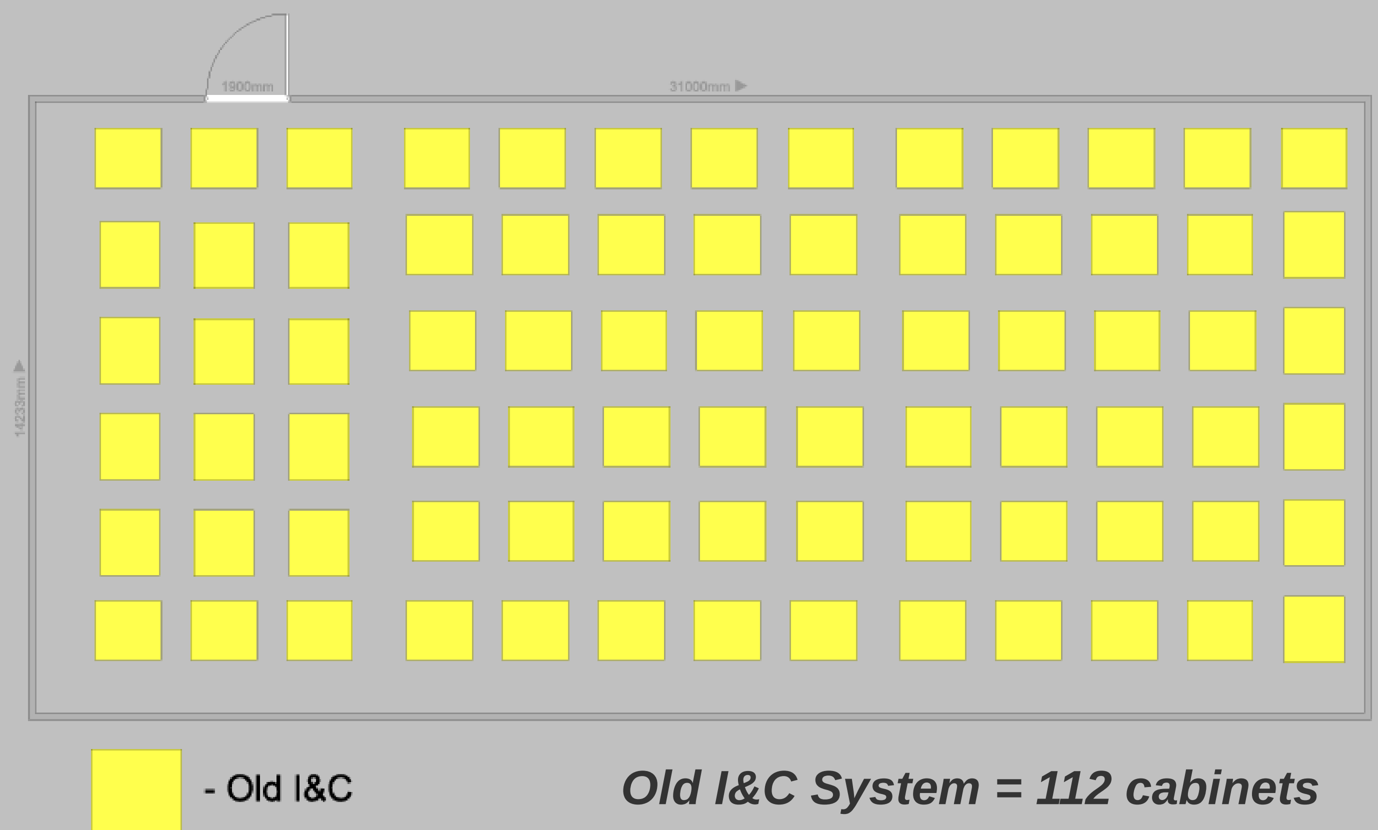
Before Installation



Old I&C System = 112 cabinets

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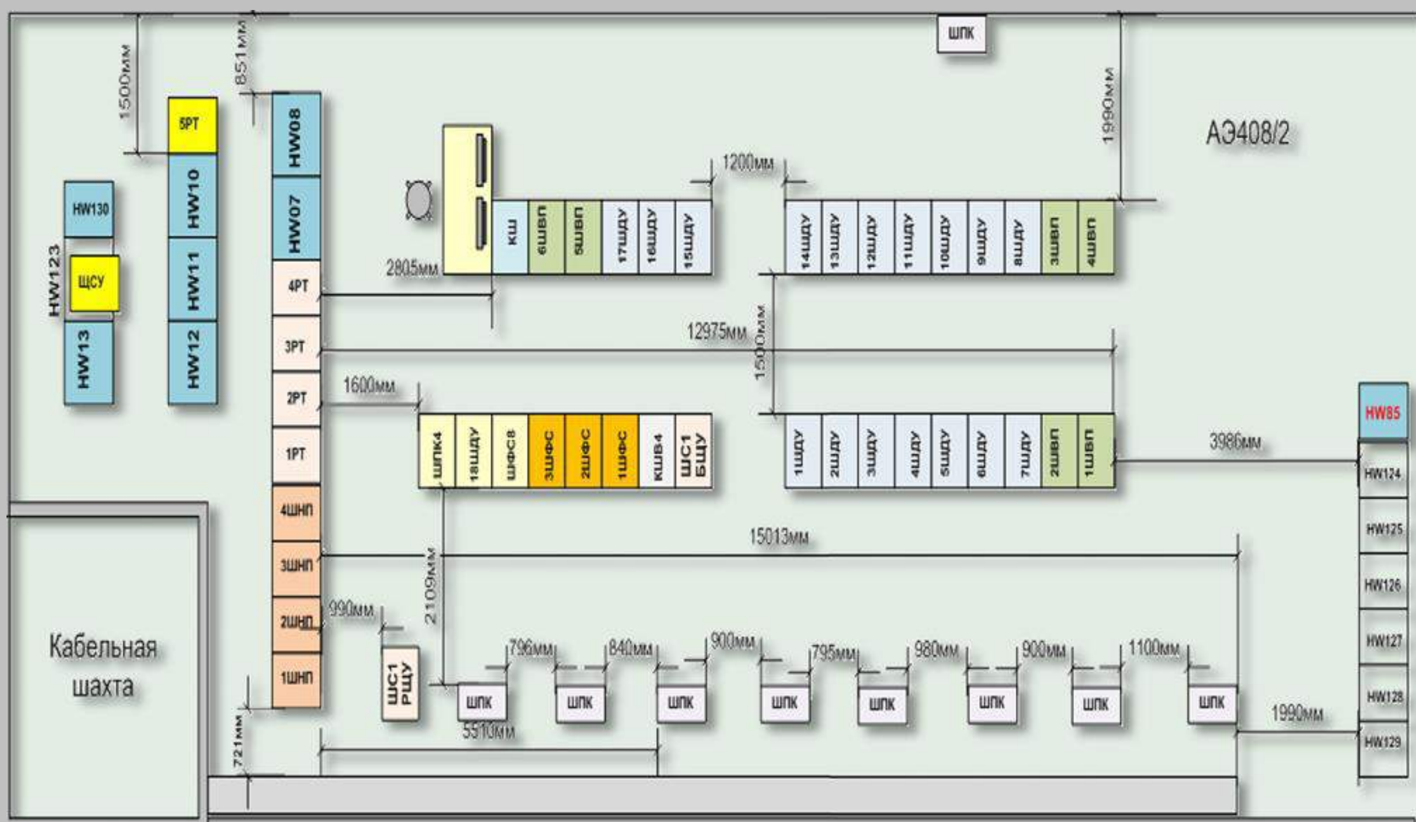
Modernization of the Engineered Safety Features Actuations System (ESFAS)

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?

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