COMPARATIVE REQUIREMENTS, STAKES AND DEPLOYMENT FOR 2 ONGOING MAJOR I&C MODERNIZATION PROJECTS (NPIC2017 - 19956)

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ABSTRACT

Rolls-Royce Civil Nuclear I&C is deploying its safety and safety-related technologies in more than 80 plants, in particular in France, China and Finland.

This paper gives an overview of the context (including regulatory requirements), stakes, objectives and progress as well as of the technology and technical solutions being deployed in two representative I&C modernization examples:

- The modernization of 2 VVER plants in Loviisa (Finland)
- Modernization of 20 PWR plants for EDF in France

While there are many similarities: a tight schedule, the cohabitation of new and old systems, mostly from 3rd parties, both digital and analog, and some additional improvements and modifications, the context of these two projects is very different:

- Fleet Vs "isolated" plants approach
- Different types of reactors (PWR Vs VVER)
- Involvement of a large utility & Integrator (EDF/Areva) Vs a smaller Utility (Fortum)
- Specific safety requirements from well recognized safety authorities (French ASN & Finnish STUK)
- Implementation of specific safety functions with the same Safety platform (Rolls-Royce Spinline®)

From this comparison we will extract the main challenges faced, the solutions implemented and some key success factors for such I&C modernizations. In particular: the licensing, the importance of a proven and adaptable safety platform and the often overlooked aspects such as communication and joint working-organization with all the stakeholders: customer, supply chain and safety authorities.

Key words: Modernization, I&C, Safety, Spinline, Rodline

1 INTRODUCTION

There are currently 60 Nuclear Power Plants (NPP) in construction in the world and more than 200 are planned or projected[1]. The licensing of their safety I&C systems is often regarded as one of the most complex phases of such projects. Most of the nuclear power plants in the world have been in service for more than 30 years and pursue a life extension to at least 60 years. Therefore, the modernization of their equipment, in particular Safety I&C systems, must be achieved in order to preserve or enhance their safety and operating license according to applicable standards, but also improve their productivity.

With more than 50 years of experience in Nuclear I&C, Rolls-Royce has led several major I&C modernization projects in the world, on multiple types of reactors: Dukovany, Czech Republic (4 VVERs), 900 MW PWRs French fleet (34 units), 1300 MW PWRs French Fleet (20 units). More recently Rolls-Royce was awarded the modernization project of the safety I&C systems of two Fortum plants in Loviisa, Finland, based on the same methods proven during 1300MW modernization and the technical characteristics of its modular digital safety platform: Spinline®.

This document presents and compares the rationale, the scope, Rolls-Royce contribution and the results of 2 representative examples of major I&C modernization:

- The modernization of a whole fleet: the VD3 project: modernization of the safety I&C of 20 PWR units in France
- Modernization of 2 VVER units (Russian Design) in Loviisa, Finland

2 MAIN CHALLENGES FOR MODERNIZATION: THE EDF VD3 PROJECT

2.1 Context

EDF operates 58 nuclear power plants in France and generated 541 TWh in 2014[2] from its nuclear fleet. Cumulating 1500 reactor years of experience, EDF's maintenance program is focused on pro-active improvement in long term reliability and plant safety. In France, the reactor life is milestoned by the ten-year inspections (Periodic Safety reviews – PSR) undertaken under ASN, the French safety authority, oversight. Ten-year inspections consist of a comprehensive check-up, which lasts for several months and involves thousands of people. For the 1300MW PWR fleet (20 units) of EDF, the third ten-year inspections are scheduled between 2015 and 2024. The 1300MW fleet is key to french power generation and its original design authorizes: a potential life extension from 40 to 60 years and an up-rate of around 7%.

In 2009, after a comprehensive survey, EDF assessed the health status of the reactor Instrumentation and Control (I&C) systems of its 1300MW fleet. Based on this assessment, EDF CIPN, the EDF engineering department in charge of the nuclear fleet in operation, decided on September 2009 to make feasibility study about the modernization of the reactor I&C of its 1300MW fleet. The result of this feasibility study was the decision of modernizing the reactor I&C systems with the following scope:

- Replace the programmable part of the reactor control and protection system
- Add some ESFAS actuations to improve safety and keep the same technology (hard-wired) for the voting logic
- Add screens to help the operator and bring more valuable information to his attention
- Keep the same instrumentation and actuators

The requirements were to meet the modern safety standards, in particular:

- RCCE[34] 2005 and referenced IEC standards
- EDF CRT 80.C.012.00 (same applied to EPR)
- Up-to-date seismic spectrum for the new pieces of equipment

And demonstrating there was no regression with the original qualification of the equipment, for modifications on installed equipment or additions of cabinets in the original technology (ESFAS).

2.2 Main challenges

The challenges to be met for such large scale (20 units) and long term project (2015-2023 and 20 scheduled outages) were:

- To adapt the new equipment to existing interfaces (electrical features, cabling, room, power supplies, etc.)
- To be licensable in the time-schedule, according to French law: last document to be reviewed by ASN[5] has to be submitted one year before authorization delivery
- To be installed in place of the existing operated equipment
- To be installed and commissioned during the scheduled outages without increase of their durations
- Being able to support and maintain the equipment for the remaining 30-year lifetime of the reactor fleet (till 2053)
- Being able to integrate the modifications requested by a potential up-rate
- Deliver the first unit in 2015 (Paluel 2)

Considering the importance of the stakes for this ambitious modernization program, such management was a key decision driver for EDF CIPN. After a one year basic design, they decided to sign a global contract with Areva as main contractor, and chose Rolls-Royce to deliver the technology for the Reactor Protection System (RPS), Neutron Instrumentation System (NIS) and Rod Control System (RCS). Rolls-Royce proposed to modernize the technology at a cabinet level: replacing old cabinets by new ones enables to meet EMC and seismic requirements, and to demonstrate it to the safety authority easily. Moreover, Rolls-Royce was able to address the documentation challenge: knowing the current document structure, Rolls-Royce calibrated the effort to deliver the 2000 documents required (in French language) in the time scheduled without discrepancy with the existing documentation of the plant.

2.3 Rolls-Royce solutions, progress & benefits

Rolls-Royce was chosen to provide the I&C technology for safety systems such as the Reactor Protection System and the Nuclear Instrumentation System, each underpinned by Rolls-Royce patented Spinline® technology. Additionally, Rodline technology is used to implement the Rod Control System.

Spinline is the latest generation of modular digital technology dedicated to nuclear I&C developed by Rolls-Royce. During its 40 years of accumulated experience, Spinline has been continuously updated to improve reliability/availability and response time performance, make maintenance and operation easier, meet electromagnetic compliance and shorten project development time, becoming thus the world standard for nuclear safety systems digital technology.

Hereafter is the architecture of the original I&C systems:

- Reactor Protection System (RPS) – Gray background
- Neutron Instrumentation System (NIS) - in green background
- Rod Control System (RCS) – in brown background

The solution proposed by Rolls-Royce consists in modernizing, replacing or removing some cabinets. The cabinets in Blue in the diagram below are replaced by new cabinets using the Spinline and Rodline technologies. Cabinets in Yellow are modified using the same technology as in the original system. Cabinets in red are removed.

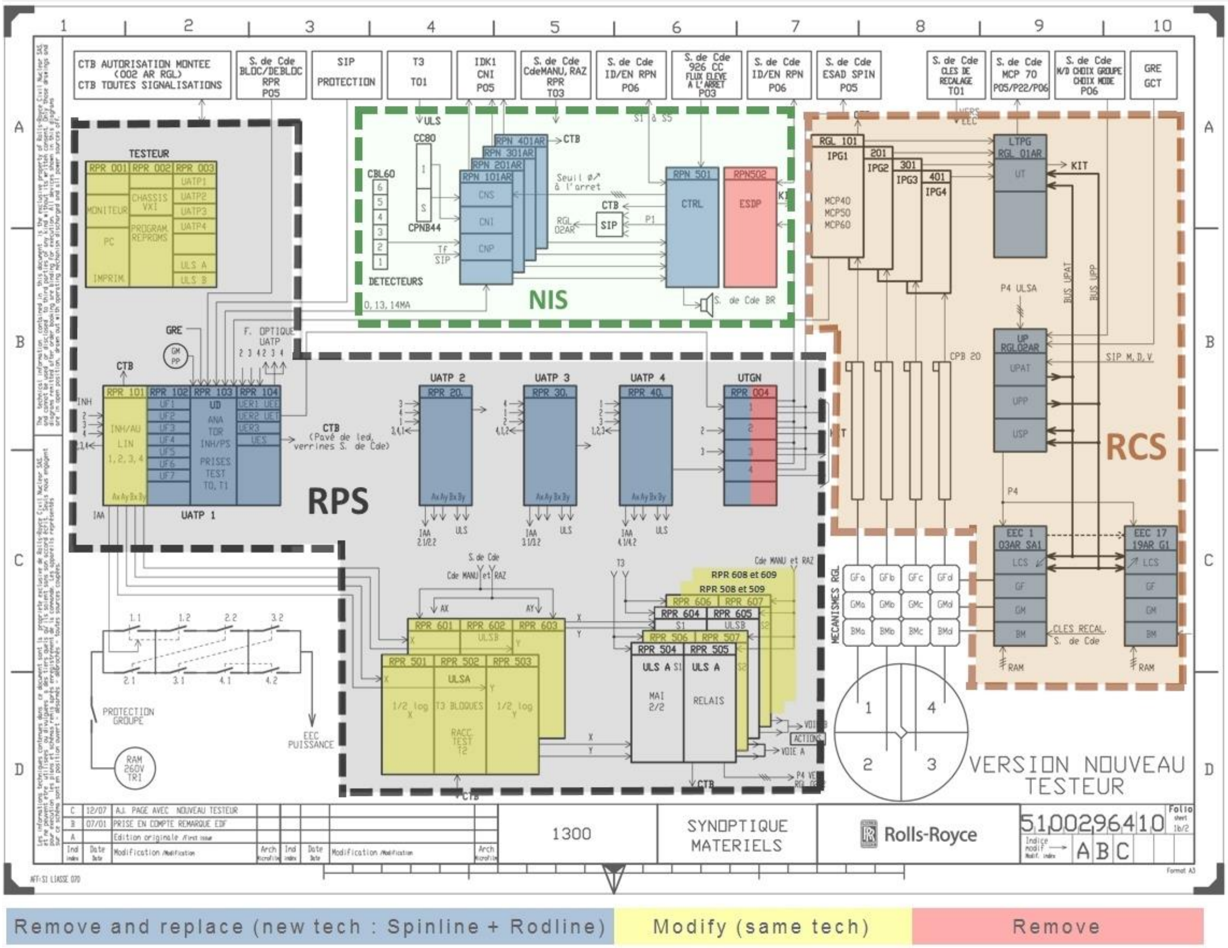

Figure 1: Original I&C architecture of the 1300MW fleet, with equipment to be modernized

The communication between systems and sub-systems will use the advantages of the Spinline technology in particular the use of networks, including NERVIA Safety classified network, between the UATPs.

2.3.1 Adaptation of the new equipment to existing interfaces

Rolls-Royce designed 40 new modules (boards and terminal blocks) to adapt the equipment to electrical features such as:

- Particular signals (instrumentation to measure primary pump rotation speed)
- Specific communications protocol (installed data collection and alarm system)
- Impedance (sharing of inputs between several units)
- Power supply (installed 200 V AC power distribution)

These new designed pieces of equipment required to be specified at an early stage of the project (basic design) so that the first specimen to be manufactured can be qualified through test queues according to the hardware qualification time schedule. It also implies, to manage the risk of this parallel engineering that the data package on existing installations is reliable and the guidelines for new design to be included in Spinline platform are robust to have a high probability to meet the qualification criteria during the tests.

2.3.2 Licensing process and HW qualification

For the licensing process, Rolls-Royce had to support EDF, the licensee, for:

a) The demonstration of Spinline's ability to implement 1E safety classified functions
b) The demonstration of the conformance of the design process of the SW applications with the A safety level of IEC 60880
c) The acceptability of the architecture after the implementation of the modifications

For the first item a), the evaluation was conducted by the safety authority through the following aspects:

- Structure and concepts of Spinline platform (origin, return of experience etc.)
- Design process
- Mechanisms ensuring a conform operation of the Spinline platform, in particular its determinism
- Tools to design applications or systems using Spinline platform
- Technical aspects of the independent V&V of the design of the Spinline platform
- Reliability of the hardware

Rolls-Royce supported EDF by providing documentations (more than 8000 pages), welcoming audits, answering to requests for additional information, and by delivering source codes to be tested against their robustness.

For the second & third items, Rolls-Royce effort included three main axes:

- **Hardware qualification**: a 3 steps process was set to demonstrate that the new Spinline cabinets meet the requirements (seismic, EMC, temperature etc.):
  - A seismic test of a fully loaded cabinet to determine component acceleration spectrum
  - Tests of all type of components used in systems
  - Final synthesis report combining the tests results to demonstrate the conformance with the requirement

This process involved: 370 electronic boards, 33 racks, 18 cabinets (off-the-shelf & Spinline) and more than 12 km of cables set up in 5 different labs during 1 year: 6 vibrating tables (to simulate earthquake), 7 air ovens and 3 EMC test chambers. Also, 150 documents (about 36,000 pages) were released to support, trace and sum up this complete hardware qualification process.

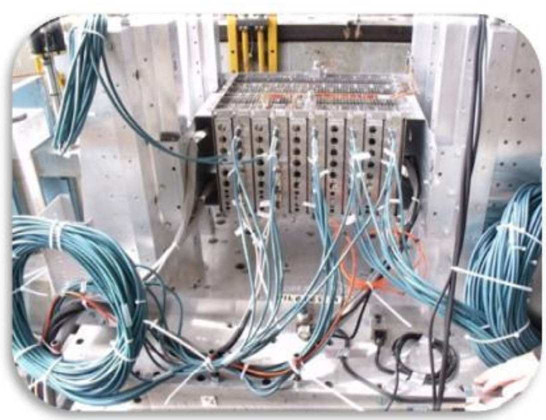

Figure 2: Hardware qualification

- **Software**: design of applications according to IEC 60880, and independent test of robustness of the codes generated, with tools such as Frama C by EDF

- **Systems**: design with respect of IEC 61513 and 62340, supply of a full scope interconnected test platform (53 cabinets interconnected through 30 km of cables and simulators) and support to a 12 month functional test campaign

Figure 3: Interconnected Test platform

2.3.3 Replace existing equipment during a scheduled outage

To assess the feasibility and the duration of the installation and the connection with the existing cables added with new ones (optic fibers for instance), a complete exercise was performed:

- Representative mock-ups of the most complex cabinets were manufactured
- Identical site cables were procured
- Installation staff performed real connections

The results of this full scale exercise were: a complete and detailed map of the cabling inside each cabinet with some slight design improvements of cabinets (additional electrical trunkings, change of some types of terminal blocks) and real measured durations for connecting cabinets.

2.3.4 Progress of the project

The physical progress is as planned in the 2009 EDF baseline schedule according to the following major milestones

- Beginning of feasibility study in Sept 2009
- Initial global frame contract signed in 2011
- Interconnected tests, Qualification and Technology licensing completed in October 2014
- Factory acceptance tests and inspection of 1st unit completed in October 2014
- 3 units installed, 2 already re-started
- Deployment until 2023

2.3.5 Key success factors & Business benefit

The ability of Rolls-Royce to deliver architecture based on the existing one (2 out of 4) with no major changes, but based on modern technology (32bit microprocessor, Nervia network, communication gateways) is valuable in two ways:

- Easier to demonstrate the system is more effective than the existing one and meets at least the same requirements in term of safety

- Easier to interface with modern man machine interface with a guarantee of non-disturbance to safety, thanks to networks, fiber optic, and proper hardware and software architecture

Rolls-Royce knowledge inherited from the almost 40-year support of the existing system benefits EDF CIPN in:

- Quick understanding of the huge amount of detailed requirements during the basic design phase (one year)
- Design of solutions directly embedding the return of experience: an easier, yet secured, process to download parameters each month in the RPS and NIS to take into account fuel ageing, while not removing any boards (saving hours of maintenance and risks of damaging the equipment)

Moreover, the capability to design new specific safety hardware to adapt its Spinline technology to the existing interfaces in the tight time schedule was also a great value: no need to impact/modify the installed equipment and so minimize the risk of a too large scope to be implemented during the scheduled outages.

2.4 Conclusion

This project is the world largest I&C modernization program.

It will contribute to improve the safety, availability and reliability of the 20 nuclear units of the 1300MW French fleet, through the deployment of the latest I&C technologies, systems and components provided by Rolls-Royce. The new systems have been installed and tested on time on 3 units, which shows the importance of a carefully chosen processes and technology than can adapt to existing architecture in order to meet the stringent safety and schedule requirements in modernization projects.

3 MAIN CHALLENGES FOR MODERNIZATION: THE LOVIISA PROJECT ("ELSA")

In 2014, Rolls-Royce signed an agreement with Fortum for the modernization of Loviisa nuclear power plants I&C systems, which covers mainly the nuclear safety and safety related systems. The project, named "ELSA", will be implemented in three phases during 2016-2018. The aim of this modernization is to secure the safe and reliable operation of the 2 VVER reactors until the end of the plants' 50-year operational lifetimes, in 2027 & 2030.

3.1 Context: Objectives, requirements

The Loviisa plant is located on the southern coast of Finland; it has two VVER-440 Russian designed reactors operating since 1977 and 1980. While the major components are from Russian origins, the I&C systems are based on both Siemens technologies, Simatic and Teleperm for Normal operation and safety related systems, and Russian technologies for Reactor Trip, rod control and Neutron Instrumentation systems. To maintain a safe and reliable operation till the end of the operating license and accommodate new safety guides recommendations, it was decided to modernize large parts of the I&C.

The first upgrade project, named "LARA", was awarded in 2005 (to other suppliers) and terminated before the end of the project in 2014[6]. It included the modernization of automation systems, control rooms and Simulators. In 2014, a new modernization project was awarded to Rolls-Royce to update the reactor protection, control and power limitations systems, key safety functions and accident management systems. The new safety-classified systems delivered by Rolls-Royce (including Reactor trip) will be based on the Spinline Digital safety Platform. Rolls-Rolls will also supply a hardwired backups system for accident management, monitoring and normal control systems based on third party PLCs.

3.2 Main challenges

The complexity of such modernization projects[7] results from many aspects, in particular:

- Ensuring the compatibility between the modernized systems and the old systems remaining in place: interfacing between these systems is a key success condition
- The schedule: modernization to take place during 3 regular outages (2016- 2018)
- Modifications management: because the new systems use a different technology compared to the ones they replace (Digital Vs. analog), improvements are possible, while some existing applications cannot be replicated exactly identical
- The modernized systems belong to different safety classes and a strict interfacing policy was put in place to separate the systems of different categories

3.3 Rolls-Royce solutions and progress

To minimize these challenges, a special focus was put on the changes and configuration management, and a very strict phased scheduled was established.

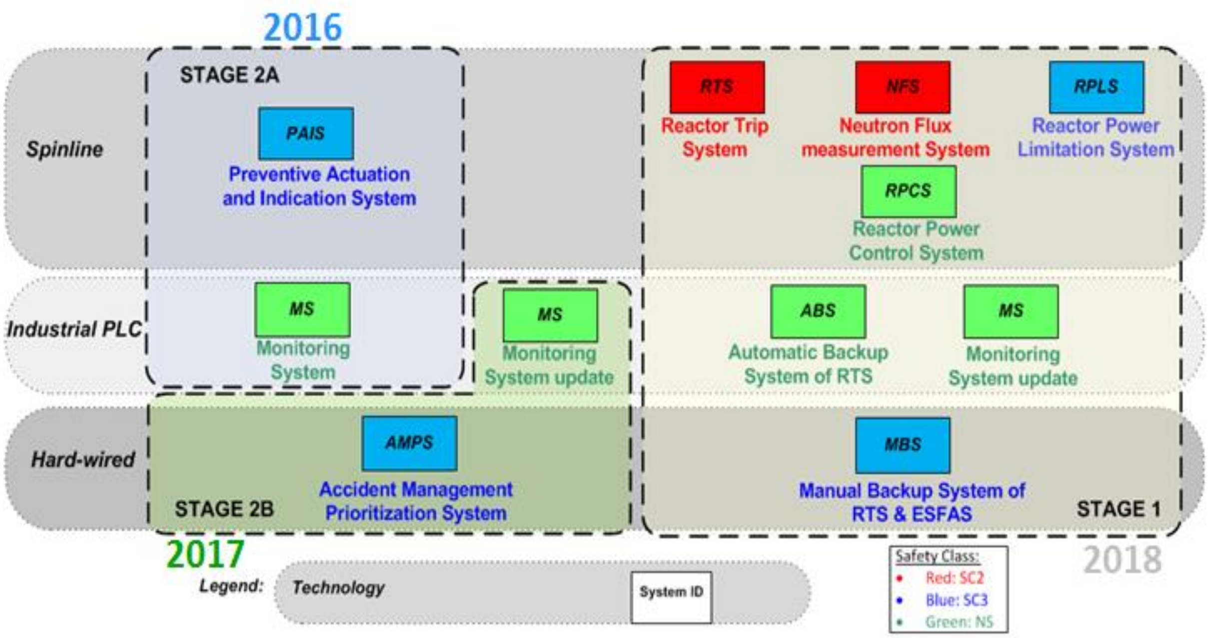

Figure 4: Schedule and systems to be modernized

Key figures:

- 6 safety class systems SC2 and SC3 (approximately equivalent to safety and safety related)
- 3 non-safety systems
- ~10 new developments
- ~100 cabinets
- Over 100 Rolls-Royce employees engaged full time in the support of the project
- 2 dedicated outages (LO1 and LO2) by stage: stage 2A in 2016, stage 2B in 2017 and stage 1 in 2018.

3.3.1 Benefits and key Success factors

In order to guarantee success on this project, Rolls-Royce applied the results of its own experience and the feedback from its customer on the previous project to modernize the I&C. Therefore, a particular emphasis was put on the capability to have an in-depth I&C Engineering dialogue with the End-User and with a very rigorous Safety Authorities, and demonstrate the proposed solution licensability. Rolls-Royce proven capabilities and readiness to manage complex projects, in close cooperation with local partners, and several sub-suppliers is a key advantage in managing such modernizations.

The know-how to define a project set-up / organization, and planning strategy fitting with a constrained project schedule came from Rolls-Royce past experiences in large modernization projects such as Dukovany VVER plants in Czech republic or on the French EDF PWR fleet. Finally, the adaptability of Rolls-Royce safety Digital platform: Spinline® used for the SC2 & SC3 safety classified systems, eased the compatibility challenge with existing systems and was a plus in term of licensability.

3.3.2 Current status

The Elsa project is implemented in three steps:

- 1st step called 'Stage 2A': Renew preventive protection functions to create clear defense-in-depth lines; was successful completed at the plant in 2016.
- 2nd step called 'Stage 2B': Renew accident management prioritization systems; planned for 2017.
- 3rd step called 'Stage 1': Renew reactor control and reactor power limitation system as well as reactor trip system together with manual and automatic back-up system. This stage will also include renewal of the neutron flux measurement system. Implementation is planned for 2018. Fortum: "Elsa started smoothly in May 2014, greatly helped by being able to make use of the Lara *(previous modernization project)* project organization, which was already in place and ready. Fortum engineering team involved nearly 70 employees mainly focusing on I&C (field), HMI and simulator testing".

During the power plant outages 2014 and 2015, interfaces with the existing automation system were investigated enabling to elaborate basic design of ELSA's new systems. Stage 2A equipment has been manufactured and tested, as scheduled in 2014. The firsts ELSA's equipment was successfully installed, connected and commissioned during power plant outage enabling Loviisa unit 1 & 2 to restart successfully on time in September & October 2016. The installation of stage 2A equipment (~16 cabinets) is a major step on the route to ELSA success. Stage 2B and stage 1 basic design concept have been approved by the regulatory authority leading to conceptual design. Design and manufacturing work in support of the second and third steps of the project is under way and the whole project is due to be completed by the end of 2018.

3.4 Conclusion

The challenges of this very complex project were very numerous: a tight schedule, the cohabitation of new and old systems and some additional improvements and modifications. Nevertheless, thanks to a very collaborative mindset and transparent way of working between Rolls-Royce, Fortum and STUK (Finnish safety authority), the project is progressing according to plans. The project is closely monitored with regular management meetings and detailed reporting activities. The results with STUK are still very good and encouraging thanks to regular management meetings (introductory workshops + Project Management Meetings held every 2 months) Fortum recognizes quality as a key project success factor, even if the project is obviously schedule driven. (Official evaluation from Fortum has been received in September 2015; Result is 18/20 of client satisfaction).

4 CONCLUSION

The qualification and licensing are very complex and risky phases in the modernization or deployment of new I&C systems, in particular for safety classified I&C. Any delay during this phase will have a negative and costly impact on the projects that are usually already submitted to extremely tight schedules. Moreover, modernizing existing systems brings additional constraints, in particular the cohabitation between the new systems and the older systems that remain in place, notably when the new equipment is based on digital technology while the rest is analog. Also, other organizational requirements: such as the need for localization, may add complexity to the design, manufacturing, testing, licensing and install of new I&C systems.

The solutions to these challenges and requirements are project specific as demonstrated by the examples in this paper. Nevertheless, several general principles can be drawn from Rolls-Royce experience:

It is a big advantage to use proven and adaptable equipment and technology. To be able to answer each plant and regulation specificities, the technologies used should be flexible enough to fulfill these requirements, without needing to implement major changes that may invalidate the main characteristics of the platform used.

As the communications between all the plant systems is a key point of the defense-in-depth demonstration, mastering the design and implementation of I&C architectures is necessary. On the technical point of view, knowledge of both digital and analog technologies is necessary for the projects mixing systems based on these technologies.

Having a technology qualified and licensed in several countries will also facilitate the licensing process as it may allow speeding up the demonstration process using argumentation. More importantly, the capacity and experience in dialoguing with safety authorities is a crucial asset for the success of the project.

Rolls-Royce has more than 50 years of experience in I&C for nuclear, in particular in safety classified I&C systems. With equipment installed on more than 200 civil nuclear reactors worldwide, Rolls-Royce I&C is currently delivering I&C to 84 NPP simultaneously, on various types of reactors, both for New Builds and Retrofit. With these programs and the related term support, Rolls-Royce technologies Spinline and Rodline will be in operation and ready to be supported until 2053.

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