ENSRIC report

Emerging systems and Life time extension

Elforsk rapport 14:39

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ELFORSK

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Preface

ENSRIC, Elforsk Nuclear Safety Related Instrumentation and Control, is a research program focused on safety related I&C systems, processes and methods in the nuclear industry. The three focus areas of the program are emerging systems, life time extension and I&C overall. Information from the program will assist the nuclear industry and the Radiation Safety Authority when analyzing how to replace systems and methods - choosing a new technology or finding a way to stay with the present solution - with maintained safety and promoting a low life cycle cost. The program is financed by Vattenfall, E.ON, Fortum, Skellefteå Kraft, Karlstads Energi and the Radiation Safety Authority.

This report summarizes the findings of two mapping projects carried out within ENSRIC, "Emerging systems and technologies" and "Life time extension of present systems. The aim of these two projects was to find background information and material within these areas for the steering group of ENSRIC, to assist them in their process to develop further research projects within ENSRIC.

Summary

ENSRIC - Elforsk Nuclear Safety Related I&C Program, should contribute to safe and robust I&C systems that promotes low Life Cycle Cost. This report is the first phase of ENSRIC and has identified different strategies and plans used by suppliers and plant owners worldwide in the nuclear business to extend the life of safety related I&C.

Due to analogy I&C for nuclear applications have been designed in the 1960's and early 1970's. Together with regulatory constraints reflecting in rules and regulations handmade for the analogue technology. Have the obsolescence of the analog equipment becomes a major problem.

Transitions to digital microprocessor based safety I&C have been carried out at a high implementation- and life cycle cost. But there exists successful and consistent I&C upgrade plans and strategies worldwide, such as the one developed by GE Hitachi (Attachment 4). These are particular cases of a more general set of principles regarding the I&C upgrades. These principles have been developed and gathered in guidelines by international organization among which, EPRI has a leading position.

Therefore, it is strongly recommended that the Nordic countries, considering the similarities between the fleets, to develop a common strategy for I&C upgrades (like, for example, the one developed by GEH) based on the EPRI collection of standards in this area.

ÅF’s recommendation for the next phase of ENSRIC would be to create a set of guidelines supporting a common Nordic approach for I&C upgrades. These guidelines would support decision making regarding what and how to upgrade the safety I&C.

Content

Attachment List:

Attachment 1: Manfred Märzendorfer (NPP Leibstadt Switzerland – KKL), Presentation”Country Report Switzerland 2011

Attachment 2: IAEA-TECDOC-1016, ”Modernization of instrumentation and control in nuclear power plants”, 1998

Attachment 3: Patrick Salaun (EDF R&D), Presentation ”I&C status in France & recommendations to IAEA”, IAEA TWG-NPPIG meeting, May 2013, Vienna

Attachment 4: IAEA-CN-155-075, ”Managing I &C obsolescence for Nuclear Power Plant life extension”

Attachment 5: Invensys, brochure ”Invensys Modernization Assessment”

Attachment 6: Westinghouse, brochure ”Instrumentation and Control system modernization”

Attachment 7: IAEA-TECDOC-1389, ”Managing modernization of nuclear power plant instrumentation and control systems”, 2004

Attachment 8: Janos Eiler (NPES, NENP), Presentation ”Report of the TWG scientific secretary on IAEA activities in the field of I&C engineering”, May 2013, Vienna

Attachment 9: Oszvald Glöckler (NPES, NENP), Presentation ” Report of the Scientific Secretary on IAEA Activities in the Field of NPP I&C – 2009-2011”

Attachment 10: USA patent no US 8,156,251 B1 of April 10, 2014 for ”Advanced Logic System”, assignee: Westinghouse Electric Company LLC

Attachment 11: Rolls-Royce, brochure ”Spinline”

Attachment 12: AREVA's TELEPERM XS operating experience and clients list

Attachment 13: US-NRC letter in March 19, 2008 referring HFC 6000 platform (DOOSAN)

Attachment 14: Mitsubishi Heavy Industries Ltd, US-APWR Topical Report MUAP-07005-NP RO, "Safety System Digital Platform – MELTAC"

Attachment 15: Mitsubishi Heavy Industries Ltd, US-APWR presentation "Digital I&C key licensing issues", August 16, 2010

Attachment 16: YOKOGAWA, brochure "ProSafe SLS"

Attachment 17: EPRI, TR-107980, "I&C Upgrades for Nuclear Plants - Desk Reference 1997", December 1997

Attachment 18: EPRI, TR-108831, "Requirements Engineering for Digital Upgrades - Specifications, Analysis and Tracking", December 1997

Attachment 19: EPRI, TR-108831-V1, "Instrumentation & Control Life Cycle Management – Plan Methodology, Volume 1: Manual", August 1995

Attachment 20: EPRI, TR-108831-V2, "Instrumentation & Control Life Cycle Management – Plan Methodology, Volume 2: Workbook", August 1995

Attachment 21: EPPRI, TR-107980 "I&C Upgrades for Nuclear Plants Desk Reference 1997 Final Report", December 1997

1 Background

ENSRIC is a research program focused on safety related I&C systems, processes and methods in the nuclear industry. The three focus areas of the program are emerging systems, life time extension and I&C overall. Information from the program will assist the nuclear industry and the Radiation Safety Authority when analysing how to replace systems and methods - choosing a new technology or finding a way to stay with the present solution - with maintained safety and promoting a low life cycle cost.

This report describes a high-level investigation of *emerging safety systems and technologies* and *life time extensions of existing systems*.

The report is a continuation of the report 6027068-01, intending to provide a high level overview of the actual status on the I&C upgrades market for Long Time Operation of the NPPs. The report intends also to provide preliminary recommendations on how to address the strategy for performing an I&C upgrade, based on the actual configuration and trends of the nuclear automation market.

2 Configuration of the actual nuclear automation market, result of nuclear I&C historical evolution

2.1 Objective

The main objective of this report is to provide a high-level overview allowing understanding the actual configuration and trends of the nuclear automation market and the reasons leading to them.

The results can be used when assessing whether new technologies are a realistic alternative in future investment programs within the next 5-10 years in respect to the feasibility of their implementation.

2.2 Background and history to the nuclear I&C

The nuclear power industry started at a time when analogue control was dominant and condition monitoring was not an established discipline. Analogue I&C for nuclear applications have been designed in the 1960's and early 1970's and was applied and certified for both safety and non-safety systems.

Since the beginning the plant operators faced some deficiencies of the analogue I&C such as:

- Time consuming calibration and surveillance test procedures.
- Extensive maintenance time for troubleshooting and repair.
- Difficulty in maintaining equipment qualification.
- Difficulty in maintaining an adequate spare parts inventory.
- Lack of expansion space to install hardware for functional upgrades and plant improvements.

Even so, the analogue technology was largely used for the nuclear applications because a new “credible” (enough operating experience to demonstrate its reliability, deterministic approach, etc.) technology for replacing it, was not available at that time - digital I&C became a “credible” option later on (the application of digital technology into I&C systems for NPPs had begun in the 1980’s).

The period 1970 – 1980 was a period of intensive development of the nuclear power industry and the plant owners pushed to operate the plants at high capacity levels. This has resulted in requirements such as power uprates, work to shorten refuelling and maintenance outages, etc.

To cope with this demand, I&C suppliers have begun to fabricate more suitable analogue equipment for upgrading the existing I&C, interchangeable with the one already in operation. An example of the adaptation of I&C suppliers to the market demand is the case of Westinghouse:

- 1965 – 1972 - the Foxboro H-Line for process protection equipment
- 1970 - 1973 - Westinghouse 7100 Series for process protection equipment
- 1973 – 1983 - Westinghouse 7300 Series for process protection equipment

As mentioned above, in this period there were no mature technologies representing alternatives to the analogue technology available. Also, the fast development of the digital technology to the point to be used in the nuclear application was not foreseeable.

In addition, the “conservatism” safety principle applicable in the nuclear power industry lead to regulatory constrains reflected in rules and regulations tailored for the analogue technology. This has hindered the introduction of alternatives to analogue technology, such as digital technology, especially for safety applications.

2.2.1 Nuclear I&C upgrades

As result of the above, in this period, there was no large scale I&C upgrade projects (e.g., by changing the overall architecture or functional redesign of I&C). The eventual upgrades have been limited to individual I&C systems (partial or total upgrades) and, in most cases, limited to the equipment level keeping I&C functional architecture “as originally designed”.

The eventual upgrades in the mentioned period were considered on case-by-case basis and mostly lead and engineered by the plant owners' internal organizations with the support of the selected I&C equipment’s suppliers. In addition, in most cases, I&C upgrades have had low priority when scheduling the plant’s upgrades.

As result of these conditions, at the beginning of the major I&C upgrades projects after 1980, there was a diversity of I&C configurations developed regarding the “as-designed” I&C, in the NPP’s across the globe. This was reflected especially to the “instrumentation” part of I&C (e.g., in CANDU 6, in Romania, the “in-core” neutron flux detectors are of “coil” SPFD type in Cernavoda Unit 1 while at Cernavoda Unit 2 are of HESIR type, etc.).

However, at the end of this period, as digital technology advanced, and breakthrough developments were achieved, few of these advancements made their way into nuclear power plants (They were only used in non-safety applications to begin with).

In addition, due to the automation market demands for other industries, the automation suppliers diminished the production of analogue equipment and digital equipment developed rapidly.

As a result, the obsolescence of the analogue equipment rapidly became a major problem. Therefore, the nuclear power industry was obliged to consider migrating to the digital technology.

The suppliers adapted to the new situation and have provided kits to adapt the analogue I&C to the digital technology.

An example of what the suppliers could offer is the Westinghouse Eagle 21 platform which was developed as a modular microprocessor-based upgrade system for replacing the existing analogue process protection equipment. It was a digital form, fit, and functional replacement for the existing analogue equipment. All system inputs (from plant sensors) and system outputs (reactor trip logic, engineered safety features logic, indication and control) were preserved so that the installation of Eagle-21 process equipment would not affect the existing external interfaces. Also, Westinghouse has developed a hybrid analogue-digital protection system composed of analogue and digital circuits. The Eagle Family 21 was applied, for example, to the Sizewell B NPP.

Others suppliers advanced in the same way: AECL developed a programmable digital comparator (PDC) and applied it to the CANDU-6 NPP. Siemens developed a protection system, TXS, and it was applied to the Parks NPP in Hungary. In South Korea, the safety grade PLC named POSAFE-Q was developed through the Korea Nuclear Instrumentation and Control System (KNICS) project.

In the last years, plant upgrades for extending the operational life has become a better alternative to nuclear new-builds.

As maintenance of analogue systems have become increasingly difficult in recent times, both from a trained personnel perspective (try to find a college that still teaches analog systems) as well as an obsolete parts perspective, migrating I&C from analog to digital technology as a part of the plants upgrade for Long Term Operation (LTO) has become absolutely necessary.

Progress in electronics and information technology has created incentives to replace traditional analog instrumentation and control (I&C) systems in nuclear power plants with digital I&C systems, or systems based on computers and microprocessors. About 40% of the world's operating reactors have been modernized to include at least some digital I&C systems (IAEA). From another perspective, 90% of all digital I&C installations have been modernization projects at existing reactors; 10% have been at new reactors.

As the development of IT industry involved a high degree of international standardization (e.g., IEC, IEEE, ANSI, etc.), the new digital technology presented a high interconnectivity of digital equipment of different suppliers, allowing the development of nuclear I&C systems with a higher maintainability at lower costs.

The above condition complemented by the increasing analogue I&C maintenance costs due to the market realities, made the migration from analogue technology to the digital technology as a unique solution for extending the operational life in an efficient manner.

2.2.2 Migration from analogue to digital I&C

Migration from analogue to digital I&C required significant reviews, validation, education, and acceptance, as well as regulatory approval. In addition, the complexity of the digital technology due to its software part requires additional efforts for the safety demonstration of I&C reliability and credibility. Therefore, new rules and methods to enhance plant safety and performances were necessary to regulate the approaches to I&C upgrades projects involving digital technology.

To support the plant owners' efforts for the modernization of the I&C and migration to the digital technology, international organizations in the nuclear and automation area such as IAEA and EPRI have developed detailed guidelines for these activities. The references section of this report list several IAEA and EPRI documentation providing guidelines in the I&C upgrade area.

To support the transition from analogue to digital technology and to be in line with the market demand, nuclear I&C to replace the existing one as part of the NPPs refurbishments for LTO, the automation suppliers and the traditional NPPs EPC suppliers have adapted their offer. For example, engineering services for developing customer solutions has been introduced as a part of the qualified platforms (hardware and software) that could be used for nuclear I&C applications,.

Also, as the migration to digital I&C is a trend in the nuclear power industry, the traditional suppliers of plant I&C developed hybrid solutions for I&C upgrades or ensures capabilities of their digital platforms to cope with analogue equipment. This allows partial upgrades or adaptation of existing analogue equipment to a main digital I&C system.

Since there has been many I&C upgrade projects involving digital technology during the last decade, the suppliers are continuously gaining experience and provides upgraded equipment with each new opportunity (e.g., see the evolution of the SIMATIC series / TELEPERM of AREVA or Eagle 21 / common Q / ALS of Westinghouse). A brief preview of experience with the new platforms is provided in the appendix to this report.

2.2.3 Semiconductor-based digital I&C systems

The introduction of the semiconductor-based digital I&C systems (FPGA, CPLD, etc) adding to and occasionally replacing the microprocessor-based digital I&C systems (e.g. PLC), can serve as an example of the rapid technological development of recent years.

This emerging technology, depending on the way of its use, can be considered close either to the analog technology (e.g., One Time Programmable FPGAs, etc.) or to the software based digital technology.

However, even if not worldwide accepted, this emerging technology combines the advantages from both analogue and software-based digital technologies. In addition, with its development and the increase of operating experience in nuclear applications, this technology will facilitate the safety demonstration of the I&C systems and, implicitly, of the NPP using it.

In addition, the application of this emerging technology will allow to increase the diversity of the digital I&C overall systems. For example, the I&C of APR1400 supplied by KEPCO, provides a high diversity level using diverse technologies for each Defence in Depth lines: a DCS for normal operation, a safety qualified PLC platform, individual loops controllers and FPGA-based back-up systems.

2.2.4 Challenges of today

Due to its complexity, an important requirement when dealing with the digital technology, either for upgrade of existing or for the new I&C for NPPs, is the necessity of a systematic “top-down” approach for its development, especially for its safety part. This approach is necessary especially for safety demonstration of I&C reliability and credibility.

The above approach involves substantially higher engineering and planning efforts than before for both I&C upgrades or for new developed I&C. Methods like I&C lifecycle models or Quality Management tools (e.g., Six Sigma) are promoted at international level to support the engineering and management efforts for nuclear I&C modernization projects.

In addition, since the new rules and regulations, at national and international level, for the digital technology for nuclear application are still not completely defined (e.g., the rules for using FPGA in nuclear applications), worldwide there are a large diversity of the upgraded I&C configuration.

During the initial operation period of the nuclear fleet, when the analogue technology was predominant, each plant owner had its own strategy for I&C upgrades and maintenance. This has led to a large diversity of the baselines for the actual I&C upgrades for LTO.

This has resulted in the necessity of a case-by-case approach to each I&C upgrade project - see Attachment 1 for one detailed example and the Appendix of IAEA TECDOC 1016 in Attachment 2 for the status in the year 1998 of the I&C development in the nuclear countries.

Only owners of large “standardized” fleets of nuclear power plants such as EDF France could promote unitary and large scale plans for I&C upgrades to their entire fleet (Attachment 3) that could represent a reference for other owners of smaller fleets.

2.2.5 International solution to challenge

To cope with this situation, the international organizations in this area have promoted the systematic approach based on a lifecycle model for I&C upgrades and migration to the digital technology.

Among others EPRI developed in its Technical Report TR 105555 a methodology to systematically address I&C refurbishment projects based on a lifecycle approach.

The key element of this method is to start the refurbishment with an analysis of existing I&C and to identify “what is to be changed or modified” and “when”, “what can be efficiently improved”, “how to maintain what is to be kept”, etc. In this way both the existing plant safety level can be maintained and even improved for a LTO at reasonable costs.

This approach is also present in the support, provided by the automation suppliers to the plant owners for their efforts to upgrade the plants for LTO. For example:

- Attachment 4 is presenting the approach to I&C modernization of GE based on Six Sigma tools and which start with the evaluation of the existing systems to design a customized solution.
- Attachment 5 is presenting the same evaluation that is part of the services provided by Invensys.
- Attachment 6 presents the recommendation of Westinghouse for the modernization of I&C which are reflected in their projects.

2.2.6 International implementation strategy

In principle, if adopted the strategy described above – evaluation of existing I&C / design of a customized solution / implementation -and the approach to the I&C modernization can be either coordinated by the plant's owner with external support from different specialized organizations and different suppliers for the I&C or can be delegated to an EPC supplier.

Either one of these two approaches – owner's coordination and EPC projects – has advantages and disadvantages such as:

- Usually the engineering companies or traditional automation suppliers providing EPC services demonstrate the trend of using their own equipment or equipment well known by them. This may lead to poor economic efficiency of the project and of limited diversity of the I&C.
- The plant owners knows the process better and their effective needs (functions, equipment features, etc.) so that, under the owner's coordination, the customization of various solutions existing on the market is smoother, faster and better suited to the plant's further operation.
- If the owner is coordinating the modernization project, its personnel assimilates the new I&C better (learning by doing)
- The integration of the I&C modernization project into the overall plant upgrade schedule is better.
- The licensing issues can be better controlled by the owner than a supplier and the safety demonstration will be consistent with the overall plant one. For example, a better diversity could be obtained by acquiring I&C systems from different suppliers or to use different technologies.
- The owner's engineering and planning efforts will be higher if the owner will coordinate the project than in the case of an EPC supplier.

However, in both situations, a permanent interaction between all the involved parties should exist to ensure the suitability of the final product for its purpose.

In the last years, due to the amplitude of the I&C refurbishment activities worldwide, IAEA developed a unitary strategy to support these projects. The aim of this strategy is to ensure an accessible knowledge background in the I&C area to enhance the safety of the new or upgraded NPPs.

Attachments 8 and 9 provide information on the IAEA initiative. Also, at this link http://www.iaea.org/NuclearPower/Downloads/I-and-C/TWG_NPP_CI_2009_05/Start.htm can be downloaded the presentations on the meeting in Vienna in 2009 addressing various countries' experiences with nuclear I&C.

3 Conclusions / Recommendations

3.1 Conclusions and observation on present I&C market and its trends

3.1.1 Causes of the excessive conservative attitude versus the I&C upgrade in the nuclear industry

Over the entire period of nuclear power industry evolution, a general attitude versus I&C upgrades can been observed. Usually the upgrades were and still are driven by economic benefits or regulatory requirements instead of obsolescence needs or technological advancement.

Also, it can be observed that by now, the tremendous development and technology advancement that has occurred in other industries in the last two decades has generally not been implemented into 1970-1980 NPPs.

This was and it still is generated by the inherent conservatism of the nuclear activities resulting from safety principles as “proven engineering” and also due to the high costs of the automation satisfying these requirements (e.g., proven reliability, credibility levels, etc. involving costly tests, etc.). In addition to that, the high reliability performance at which the automation for nuclear applications originally have been manufactured allows “old” equipment to perform properly for longer periods than expected. This fact has additionally enforced the plants’ operators and owners' reluctance to change.

3.1.2 Necessity for the “migration” to digital I&C in the nuclear industry

However, due to the dramatic changes in the automation market in the last period generated mostly by adaptation of the automation suppliers to the request of the other industries, maintaining “in-service” of the I&C based on analogue technology as initially designed for LTO, is no longer a reasonable approach from both an economical (high costs) and a safety (shortage in supply chains) point of view.

In addition, the actual enhanced safety requirements in the nuclear power industry require upgrades of I&C systems which, actually can only be done by adopting the worldwide trend to implement digital technology in the nuclear I&C upgraded applications. These safety enhancements are reflected especially in respect to its reliability (increased redundancies, shortage of the response time, self-testing facilities, etc.) and maintainability (availability of the supply chains, implementation of the symptom-based operating procedures, In-service Inspection and Maintenance, etc.).

It can also be observed that the factors “feeding” the reluctance of the plant’s owners due to the high costs and safety uncertainties involved in the previous period have been solved in the last period. For example, below are listed several “cost drivers” which, even using a high level evaluation of them, shows a considerable cost reduction:

- Licensing,
    - New I&C architecture
    - New safety analysis
    - Using software is now a predicable path and should not be an issue if safety case approach is applied
- Operation and maintenance phase of system.
    - Possible benefits by using modern PDM-systems, can easily be a disadvantage if no adjustments are applied.
    - Adjusted plant organization and processes to handle changes in the new I&C systems
- A straight control system change can't be that expensive even if qualification of a new platform is included in the calculation.

In conclusion, the digital technology with its two forms – "software" and "semiconductor" based logic – remain the single option for the parts of an operational I&C that should be upgraded for a LTO.

3.1.3 Open issues related to the digital technology for nuclear applications

The "software-based" digital technology (e.g., PLCs, computer-based, etc.), even at maturity, has shown some licensing difficulties in respect to the safety demonstrations.

These can be solved through accepting emerging technologies such as "semiconductor-based" digital technology (e.g., FPGAs, etc.), at least as diverse back-ups for the main "software-based" digital I&C.

Efforts are made worldwide to solve all the potential licensing issues with emerging technologies as the "semiconductor-based" digital technology (e.g., FPGAs, etc.) to rush their acceptance as an alternative for the nuclear power industry.

3.1.4 Comments on the recent years upgrading and modernization programs

There is no specific general "recipe" for how to upgrade any given plant due to different I&C-designs implemented by the plant suppliers at the plants´ inceptions. This is also due to the diversity of the baselines for the actual I&C upgrade projects for LTO generated by previous I&C updates and past operating specificities.

Also, the diversity of offers in the existing nuclear automation market (digital based technology) as well as the rapid technological development (e.g., introduction of emerging digital equipment as FPGA, new powerful computing software products, etc.), make each I&C upgrade project unique with regard to the local specific licensing and economic conditions (one offer may be more attractive in one country than in the other) and of the moment in time when the project is run.

Concluding, each actual I&C upgrade project should be treated individually as a self-standing "green-field" project, taking into account, only the specific conditions of it and the worldwide experience at that time as reflected in standards. The worldwide experience with similar upgrades should be considered only as far as this is satisfying the projects specific conditions (e.g., licensing requirements, etc.).

The single "red-line" identified among the existing I&C upgrade projects which is due mostly to the migration from analog to digital technology (the impact on the I&C and plant safety demonstration induced by the I&C software non-deterministic behaviour) is the necessity of a "stepwise", "top-down" and "systematic" approach to the I&C upgrades. This approach identifies two main parts:

- evaluation of the existing I&C to determine the feasibility of upgrade of I&C various parts and to plan it
- Implementation of identified upgrades

It shall be also note that, actual I&C upgrading projects involving "migration" to digital technology require a high degree of interaction between the involved parties (owner, supplier, designers, etc.). The coordination of such projects requires substantial efforts for planning and scheduling and can be done only if a systematic approach to the project is adopted (so-called "lifecycle" approach).

3.2 Recommendations

3.2.1 Generic strategy for I&C upgrades in Nordic countries

For the old NPPs operated in the Nordic countries (Sweden, Finland) requiring upgrade work for LTO, a series of similarities or common aspects of the factors influencing the nuclear I&C projects can be identified, such as:

- Common or similar legal requirements and re-licensing processes, allowing implementation of unitary strategies and methods for performing the I&C upgrades. In addition, this will allow shortening the NPPs upgrade periods by shortening the I&C licensing process period.
- Common market for the nuclear automation, allowing the development of well-established supply chains, increasing the reliability of the I&C (shortage of the supplies, higher maintainability of the I&C through availability of the critical parts, availability of the latest updates that reduce the aging factors, etc.)
- Common or similar operating experience and practices, allowing shorter implementation of the "lessons learned" and increasing the expertise of the I&C system operators, increasing implicitly the NPPs safety levels.

All the above similarities or common aspects of the factors influencing the nuclear I&C projects of the old NPPs operated in the Nordic countries allow and recommend the development of a unitary approach to the I&C upgrades for this geographic area. This will bring both a safety- and economic benefit.

A generic strategy for initiating and conducting the I&C upgrade and modernization, including the corresponding methods and tools can be developed and implemented in the Nordic countries. This will allow each plant's owner to develop further its own specific

I&C upgrade plan consistent with the plans of the other operators. In this way, a common database of the upgrade projects can be developed and maintained for the Nordic countries. This would summarize the benefits and experiences gained during development of these projects and will increase the reliability and operating period of the Nordic NPP fleet.

An example in this respect is the COG (CANDU Owner Group) who has maintained a worldwide similar activity for many years by now. This has allowed the CANDU NPPs fleet to have impressive safety, reliability and performance results - no major incidences, high availability factors, reduced ageing factors maintaining CANDU 6, for example, as a reference plant for more than 30 years. For reference see the link http://www.candu.org/index.html.

A strategy that takes into account the complexity of I&C refurbishment in the actual nuclear automation market conditions and the economic efficiency it is a 3-step strategy coordinated directly by the plant's Owner. The main phases of this strategy are:

- Define the I&C upgrade project strategy. As a suggestion, this strategy can be based on the lifecycle approach described in EPRI TR 105555.
- Performing an analysis of the existing I&C to identify "what is to be changed or modified" and "when", "what can be efficiently improved", "how to maintain what is to be kept", etc.
- Implementation of the I&C configuration based on the previous analysis and initiation of an ageing management program for it (e.g., by contracting various parts of the I&C to be refurbished to different suppliers, etc.).

NOTE: As the analysis on step 1 is determining the future actions of step 2, it is recommended that planning and scheduling of the two steps is made successively and not in parallel.

EPRI has issued a set of guidelines that can sustain the development of a strategy for I&C refurbishment, for example, EPRI TR-107980 (Attachment 17) and the subsequent referenced EPRI reports referenced in it. As one of the most complete sets of publications in the area of I&C upgrades, it is strongly recommended to be considered as a basis for planning strategies and individual projects.

3.2.2 Benefits of Owner's coordination versus EPC suppliers for the I&C upgrades

It is also recommended that the plant owner performs this analysis either with internal resources or involving a specialized organization (Owner's engineering) with sufficient knowledge of the nuclear plant's technology and on the automation market as well.

The involvement of potential automation suppliers in this analysis will limit the I&C refurbishment options. The suppliers have deep knowledge of their own equipment and they are likely to analyse the existing equipment from the perspective of upgrading it with their own equipment and for this reason it is not recommended as a principal option for approaching this step of the project.

Another recommendation is that the owner assumes overall I&C design (through internal resources or by attaching a specialized organization that is independent from the potential suppliers) and is a part of the coordination of the entire project if the above mentioned 3-step strategy is adopted. This is because this part of I&C lifecycle is dealing with particular issues where the owner has greater expertise than an automation suppliers such as the plant's process, licensing issues, etc.

The EPC approach is efficient only if applied to individual I&C systems for which the detailed specifications could be clearly and unambiguously defined.

3.2.3 Introduction to the I&C refurbishment of new digital technologies

It is recommended to consider the emerging technologies such as FPGA-based automation ("semiconductor-based") into the upgraded I&C overall configuration either as diverse digital technology or as replacement of the hardwired components (OTP PLDs).

This is also sustained by the current trend on the nuclear digital automation market which considers the PLDs as a further alternative to "software-based" digital automation (e.g., PLCs).

3.2.4 Final recommendation

Even if worldwide exist successful and consistent I&C upgrade plans such as the one developed by GE Hitachi (Attachment 4), these are particular cases of a more general sets of principles regarding the I&C upgrades.

These principles have been developed and gathered in guidelines by international organization among which, EPRI has a leading position.

Therefore, it is strongly recommended that the Nordic countries, considering the similarities mentioned above, to develop a common strategy for I&C upgrades (like, for example, the one developed by GEH) based on the EPRI collection of standards in this area.

4 AF suggestion for further actions under ENSRIC program

Considering the commonalities of the I&C upgrade projects in Nordic countries, one of the most important output of a program at national level such as ENSRIC, would be a set of guidelines supporting a common approach to the I&C upgrade for all the utilities in the Nordic area.

This can be contained in a set of guidelines based, for example on EPRI guidelines (e.g., TR 107980, I&C upgrades for Nuclear Plans – Desk Reference, and TR 1055555, I&C life cycle management, plan methodology).

The guidelines should provide the recommendations on the methods to be used as well as to propose tools for supporting the I&C upgrades of the interested utilities.

Also, the strategy should consider developing and maintaining a database of the projects and alternatives accessible to all the interested parties.

A training program can be developed to support the implementation of the mentioned strategy.

For clarification purposes, the figure in Annex 2 sketch how this strategy could be used by an interested utility.

5 References

[1] IAEA TECDOC 1016 – Modernization of instrumentation and control in nuclear power plants

[2] IAEA TECDOC 1066 - Specification of requirements for upgrades using digital instrument and control systems

[3] IAEA TECDOC 1389 – Managing modernization of nuclear power plant instrumentation and control systems (Attachment 7)

[4] IAEA NP-T-1.4 - Implementing digital instrumentation and control systems in the modernization of nuclear power plants

[5] EPRI TR-1003090 – I&C Upgrade – Implementation, Experience and perspective

[6] EPRI TR-1005555 – Instrumentation & Control Life Cycle management – plan methodology

[7] EPRI TR 107980 – I&C upgrades for Nuclear Power Plants

[8] EPRI TR 108831 – Requirements Engineering for digital upgrade

Annex 1 - Brief overview of the experience with the main safety I&C platforms

Note: this presentation does not consider separately the "software-based" and "non-software based" components of a digital platform

5.1 WESTINGHOUSE

[1] Foxboro H-Line

- analog process protection equipment
- Implemented between 1965 and 1972 in 25 NPPs

[2] 7100 series

- analog process protection equipment
- Implemented between 1970 and 1973 in 13 NPPs

[3] 7300 series

- analog process protection equipment
- Implemented between 1973 and 1983 in 44 NPPs

[4] Eagle 21

- modular microprocessor based upgrade system for replacing the existing analog process protection equipment and to preserve the existing analog external interfaces
- most representative applications:
    - Watts Bar NPP 1 & 2 in 1989
    - Sequoyah NPP 1 & 2 in 1990

[5] Common Q

- Safety grade "microprocessor-based" digital platform
- Implemented in 22 NPPs in Europe, Asia and USA

[6] Advanced Logic System (ALS)

- hardware-based platform based on FPGAs as "key" components
- The first ALS platform application was installed in 2009 at a generating station
- It is patented by Westinghouse under the no. US 8.156.251 B1 (see Attachment 10)

5.2 ROLLS ROYCE / SCHNEIDER ELECTRIC

SPINLINE platform

- modular digital platform PLC-based dedicated to developing and/or upgrading safety I&C used in NPPs implementing any 1E and category A functions (see Attachment 11)
- Implemented in 80 NPPs of PWR and VVER type. Most relevant:
    - Actual contract with EDF for modernization of the safety I&C in 20 NPPs in France (1.300 MW type)
    - 70% of the safety critical and core control in NPPs in China
    - Refurbishment of the safety I&C in Duchovany NPP

5.3 INVENSYS

TRICONEX

- modular digital platform 3 redundant PLC-based dedicated to 1E safety applications
- inception in 1983
- more than 4,000 Tricon systems in use in industrial control, including nuclear applications and more than 140 million safe operating hours

5.4 AREVA

TELEPERM XS

- Qualified digital software-based platform including FPGA-based components
- The experience of AREVA's TELEPERM XS is presented in Attachment 12

5.5 DOOSAN

The following are a family of I&C equipment, still available and interconnected (e.g., using same software applications)

[1] HFC 6000

- Qualified digital PLC-based platform (see Attachment 13) for 1E safety applications. It is an evolved system based on EFC 1200 and AFS 1000 formerly manufactured by Forney Corporation)
- Implemented in 30 NPPs and with over 10.000 implemented controllers. Main customers:
    - Yonggwang NPP
    - Ulchin NPP

- o Kori NPP
- o KEDO NPP
- o Shin Kori Nuclear Power Plant Shin Wolsong NPP
- o APR1400 projects
- o Automatic Seismic Trip System (ASTS) All Korean Nuclear Sites

[2] ECS 1200

- Distributed Control System (DCS) used primarily for multi-loop Plant Control System (PCS) applications. It is the predecessor of HFC 6000
- Relevant safety nuclear application – normal operating I&C for APR1400 projects

[3] AFS 1000

- Digital platform used primarily for applications involving single-loop control of field equipment with local I/0 modules library. It was used mostly for boiler control applications but is also suitable for nuclear safety applications. It is the predecessor of HFC 6000
- Relevant safety nuclear application –I&C for APR1400 projects

5.6 MHI

MELTAC (see Attachments 14 and 15)

- Standard qualified digital platform suitable for NPPs complete I&C applications (safety and non-safety) both for new build and for partial or full upgrades
- Starting with 1991, 5 operating plants use MELTAC for non-safety applications in Japan. In 2009 implemented in 3 operating plants for I&C/HIS upgrades

5.7 ZAT CZ

ZAT 2000 MP

- Digital qualified PLC-based platform
- Implemented mostly in Czech Republic and Ukraine NPPs (information at this link http://www.zat.cz/en)

5.8 TOSHIBA

TOSMAP

- General purpose qualifiable digital platform developed for plant control ((information at this link http://www3.toshiba.co.jp/power/english/thermal/products/iandc/tosmap)

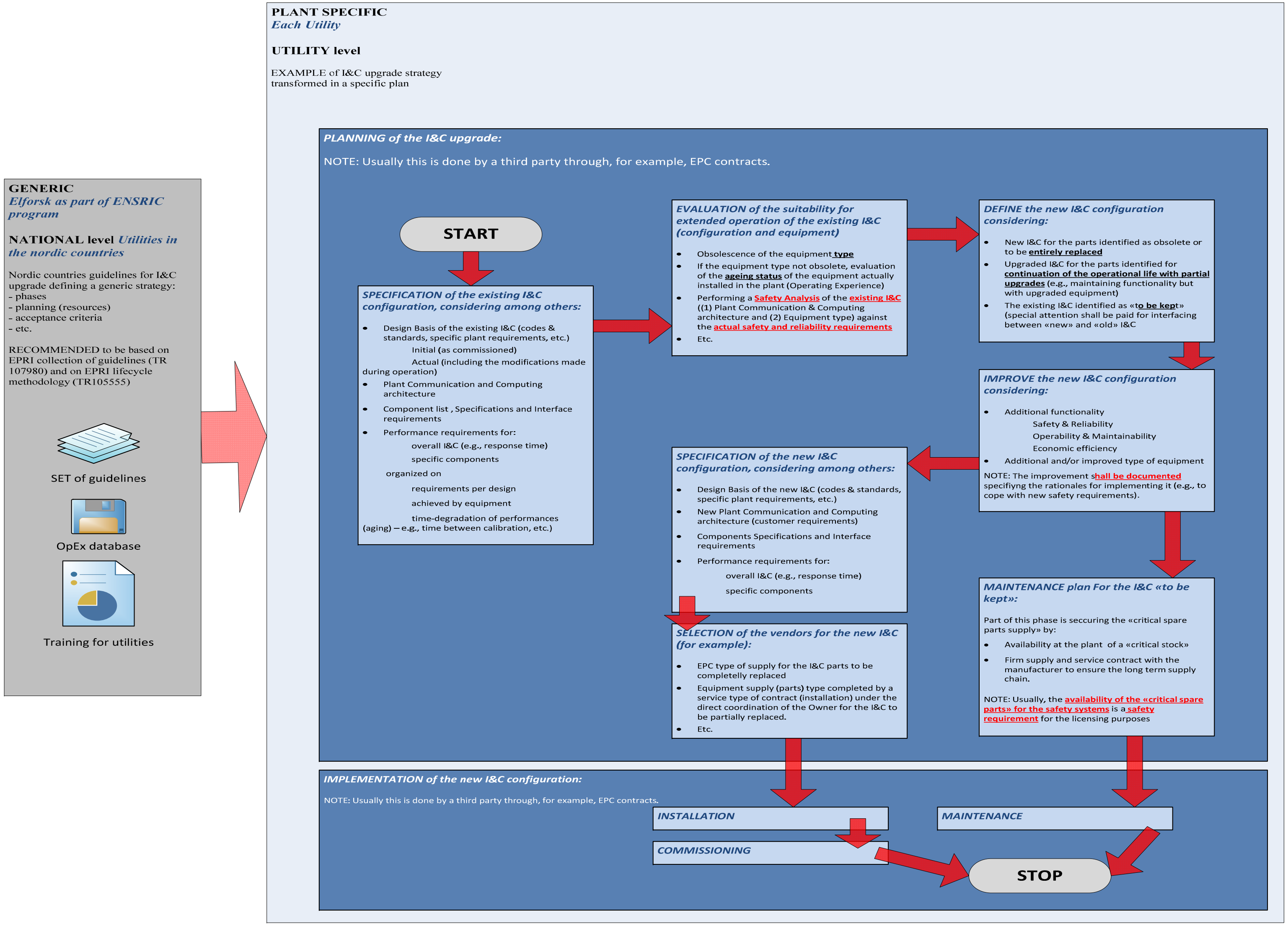
- Use in the nuclear projects of Toshiba

5.9 Yokogawa

ProSafe – SLS (see Attachment 16)

- General purpose platform for industrial safety application SIL 3 and SIL 4, including nuclear power industry (qualifiable I&C systems). It is based on solid-state elements processing functional logic
- It has multiple industrial applications but it is not particularly developed for nuclear applications.

6 Annex 2 – Common strategy for addressing the I&C upgrades in the Nordic countries



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