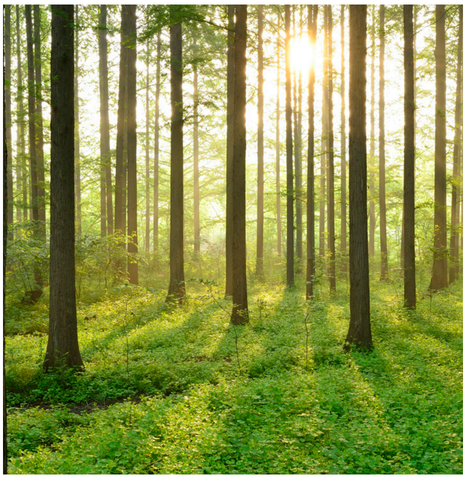
UPGRADING TO MODERN COMPUTERIZED I&C SYSTEMS

REPORT 2016:324



ENERGIFORSK NUCLEAR SAFETY RELATED I&C, ENSRIC

Energiforsk

Upgrading to modern computerized I&C systems

Partial replacement of analog and old computerized equipment to modern computerized I&C

CHRISTOFFER CALÅS, KARIN FERM & TOMMY KROGELL

ISBN 978-91-7673-324-0 |

Energiforsk AB | Phone: 08-677 25 30 | E-mail: kontakt@energiforsk.se | www.energiforsk.se
Coverphoto: Forsmark 3, photo Hans Blomberg

Foreword

Energiforsk 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 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 research is performed by Christoffer Calås, Karin Ferm and Tommy Krogell from Semcon Sweden AB, in close cooperation with the responsible persons from the participating NPPs, Fredrik Bengtsson (Ringhals), Roger Granath (Forsmark), Mauri Viitasalo (Olkiluoto) and Karl-Erik Ericsson (Oskarshamn). The authors would like to thank all persons for taking their time to participate and for their contribution to this report.

Financed by:

ENSRIC, Program Manager Nuclear Monika Adsten

Reference group:

Fredrik Bengtsson, Ringhals

Christer Johansson, Forsmark

Sammanfattning

Användningen av moderna datoriserade Instrument- och Styrsystem (I&C) ökar och kärnkraftsindustrin utgör inget undantag. Denna rapport identifierar och undersöker fallgropar och framgångsfaktorer då äldre I&C-system eller utrustningar ersätts med moderna motsvarigheter.

I september 2016 finns det totalt tretton kärnreaktorer i drift för energiproduktion i de nordiska länderna, som alla har varit i drift i cirka trettio till fyrtio år. Några av de driftsatta systemen eller utrustningen för instrument och kontroll är tekniskt gamla och det finns ett behov av att förbereda för hur systemens funktion skall säkerställas under de återstående åren av anläggningens livstid. Kärnkraftsindustrin är väl medvetna om fördelarna med övergången till modern datoriserad teknik och eftersöker riktlinjer för att göra detta på bästa möjliga sätt.

Denna rapport undersöker en handfull projekt som genomförts på de fyra kärnkraftverken i Forsmark, Olkiluoto, Oskarshamn och Ringhals för att identifiera fallgropar och framgångsfaktorer vid införlivandet av modern datoriserad teknik. Detta uppnås genom en enkätundersökning samt med personliga intervjuer med personal från de olika kärnkraftverken som har varit inblandade i I&C förändringsprojekt. Det sista kapitlet i rapporten sammanfattar ett antal rekommendationer för att framgångsrikt driva I&C förändringsprojekt.

Sammanfattningsvis är alla kärnkraftverk medvetna om fördelarna med den moderna datoriserade tekniken och många av de utmaningar som det innebär. För icke-säkerhetsklassade system och utrustningar, dras slutsatsen att fördelarna och förmånerna med modern datoriserad teknik väger tyngre än risker och nackdelar. Utnyttjande av hyllprodukter har också ansetts viktiga framgångsfaktorer. Alla är överens om att införandet av mjukvara ökar ansträngningarna av verifiering och validering, även om det poängteras att systemets utformning och användningsområde t.ex. i en säkerhetsfunktion, är av större betydelse

I praktiken är det rekommenderat att fokus för utbyte av I&C-system och utrustning skall vara icke-säkerhetsklassade system och utrustning. Användning av hyllprodukter och en leverantör väl medveten om starkt reglerade industriella krav, såsom dokumentation anses också vara en viktig faktor. Mycket tid och resurser ska avsättas för att studera dokumentation och delge leverantören av utbytessystemet, information över hur systemet används i anläggningen. Nyckeln till framgång vid ersättning av I&C system och utrustning anses vara både en god helhetssyn på anläggningen samt djup kunskap om systemet eller utrusningen som ersätts samt det nya som skall introduceras.

Summary

The use of modern computerized systems for instrumentation and control (I&C) is increasing and the NPP industry is no exception. This report identifies and investigates the pitfalls and key success factors when replacing older I&C systems or equipment with modern equivalents.

In September 2016, there are totally thirteen nuclear reactors in operation for energy production in the Nordic countries, which all have been in operation for around forty years. Some of the commissioned I&C systems or equipment are technologically old and there is a need to prepare how the system functions shall be maintained during the remaining years of the plants' lifetime. The NPP industry is well aware of the benefits of transiting to modern computerized technology and seeks a guideline to do this in the best possible way.

This report investigates a handful of projects carried out on the four NPP's in Forsmark, Olkiluoto, Oskarshamn and Ringhals in order to identify pitfalls and keys to success when incorporating modern computerized technology. This is achieved through a questionnaire and with personal interviews with staff from the different NPP's who have been involved in I&C change projects. The final chapter in the report summarizes a set of recommendations in order to successfully run I&C change projects.

Conclusively, all NPP's are aware of the benefits offered by the modern computerized technology and many of the challenges it presents. For non-safety classified systems and equipment, the NPP's conclude that the pros and benefits of modern computerized technology are in favor of the risks and consequences. Utilization of off-the-shelf (OTS) products dedicated to a specific task has also been considered key success factors. All agree that introduction of software do increase the effort in Verification &Validation (V&V), however much more important are the system design and the safety impact of the system or equipment being replaced.

Practically, it is recommended that focus for replacement of I&C systems and equipment shall be non-safety classified systems and equipment. Usage of OTS products and a supplier well aware of highly regulated industrial requirements, such as documentation is also considered a key factor. Much time and resources shall be set aside to study documentation and disseminate information to the supplier of the replacement system. The key to successful system replacement ought to be both good holistic view of the plant, in-depth knowledge of the systems or equipment being replaced as well as of the new equipment to be introduced.

List of content

Terms and abbreviations

DSP	Digital Signal Processing
FAT	Factory Acceptance Test
FKA	Forsmarks Kraftgrupp AB
GAMP	Good Automated Manufacturing Practice
HW	Hardware
I&C	Instrumentation and Control
NPP	Nuclear Power Plant
OKG	Oskarshamnsverkets Kraftgrupp
OTS	Off-the-shelf
PE	Programmable electronics
PLC	Programmable Logic Controller
RAB	Ringhals Aktiebolag
SAR	Safety Analysis Report
SAT	Site Acceptance Test
SSM	Swedish Radiation Safety Authority
STUK	Radiation and Nuclear Safety Authority in Finland
SW	Software
TBE	Tekniska Bestämmelser Elektrisk utrustning
V&V	Verification and Validation

1 Introduction

The use of computerized systems for instrumentation and control (I&C) in industry is increasing and the nuclear power industry is no exception. Due to the high security regulations in this industry, implementation of modern computerized systems to replace older systems is far from easy.

This report identifies and investigates the pitfalls and key success factors for replacing older systems with new computerized systems. This has been realized with interviews and questionnaires of personnel who participated in different upgrade projects performed on the Nordic nuclear power plants (NPP's) in Oskarshamn, Ringhals, Forsmark and Olkiluoto.

Crucial in order to fully grasp the conclusions and findings presented within this report is to be aware of the distinctions made between different types of systems and equipment. Therefore, section 2 has been dedicated to disseminate such information in order to facilitate a correct interpretation and aid in future upgrade projects.

1.1 PROBLEM AND BACKGROUND

As of September 2016, there are thirteen nuclear reactors in operation for energy production in the Nordic countries. Nine of these are located in Sweden (Forsmark, Oskarshamn and Ringhals) and four in Finland (Loviisa and Olkiluoto). Common for all of these reactors are that they were commissioned during the mid-70's to the mid-80's and has served more than half of their intended life span of sixty years.

Many I&C systems have been in duty since the plant commissioning and are technologically old due to the swift development in the computer industry since the first commissioning. Aging tends to tear on all kinds of systems and there is dire need to prepare for how these system functions shall be maintained during the remaining years of the plants' lifetime.

The latest decades of advances in automation and computerized technology has decreased the market demands for the older technology. This is not in favor for the NPP industry since long life cycle is favored. The NPP industry is well aware of the benefits of transiting to modern computerized technology, and seeks a guideline to do this in best possible way.

In order to adapt to the declining knowledge of the old I&C systems and equipment, one solution is to replace the technologically old systems with newer, benefiting from the latest advances in modern plant technology.

1.2 PURPOSE AND RESEARCH QUESTIONS

The purpose of this report is to identify if any and what kind of I&C systems or equipment are particularly suitable to change or upgrade to today's modern computerized technology.

Furthermore, it is of interest to identify characteristics of projects regarding I&C system and equipment upgrades, if the projects were successful or unsuccessful and in either case identify common denominators.

The following research questions will be addressed:

- What are the pros and cons for upgrading to modern computerized I&C?
- Which benefits have been gained during upgrade/conversion?
- What is the lifecycle cost for modern computerized I&C systems compared to older technologies?
- How does software qualification/safety demonstration differ between the two types of systems/equipment and why?
- How does the maintenance perspective of the two different categories differ?

1.3 LIMITATIONS

Focus of this report has been to assess systems and/or equipment which is not considered having a sole safety purpose. I&C systems with connection to the safety systems has previously been assessed in a report from Energiforsk [1].

Each collaborating NPP has freely selected what project to use and also what employees/roles in each project to be interviewed.

The supplier’s way of working is not included in this research.

This report is written in a technical level to suit the target group which is employees who are working with I&C operations at the NPP’s in the Nordic countries.

2 Definitions

This section provides explanations and rationales for the definitions and distinctions used throughout this report. The intentions are to capture and assess in what cases aging I&C systems and equipment successfully can be replaced with today's modern alternatives.

This report focuses on replacing analog or old computerized with modern computerized I&C systems or equipment. Equipment is typically a small device built for a sole and specific purpose, such as a sensor or an actuator. Systems, on the other hand, consist of two or more systems or equipment which is combined to provide a specific function, such as a control system.

2.1 DIFFERENT TYPES OF SYSTEMS

In the NPP industry, there are many types of systems and this subsection suits to clarify the distinction between these types of systems, as seen in Figure 1.

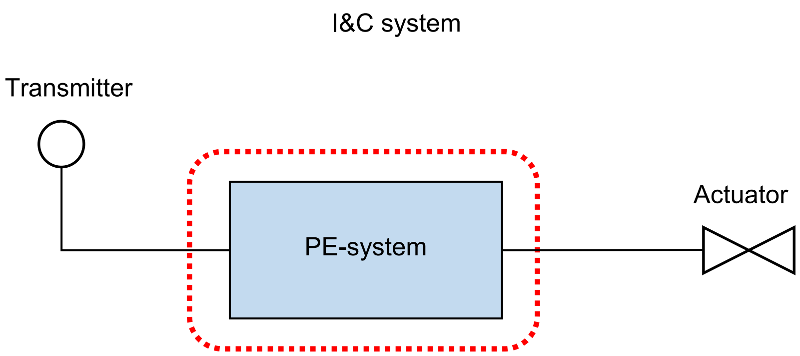


Figure 1. Sensor/transmitter, PE-system, and actuators as part of an I&C system

The terms I&C system, plant system and PE-system used in this report are defined as follows in Table 1, where PE is an abbreviation for *programmable electronics*.

Table 1. Types of systems and their meaning.

Term	Meaning
I&C System	An I&C system can be used for safety reasons as well as for non-safety reasons (and for safety related systems when the IEC categories are used). An I&C system contains the whole chain (from sensor to actuator of a component). The I&C system is often divided into several plant systems since e.g. the sensor and actuator belongs to different plant system. When using the word system in this report it refers to an I&C system.
Plant system	Refers to the systems in the plant configuration such as system 531, 539 and should not be confounded with I&C systems.
I&C platform/ PE-system	I&C platform or PE system refers to computerized I&C implemented in a platform.

Generally, I&C systems are automation systems built to control process variables of a running process based on measurements on the same process. I&C systems can be used for safety reasons as well as for non-safety reasons (and for safety related systems when the IEC categories are used). They contain the entire chain from sensor to actuator of a component and may span several plant systems as sensors and actuators typically belong to different plant systems. As the number of processes within a NPP is vast, so is the number of I&C systems and equipment present in this environment. For the nuclear industry, IEC 61513 [2] states the definition of I&C systems and is presented in Figure 2.

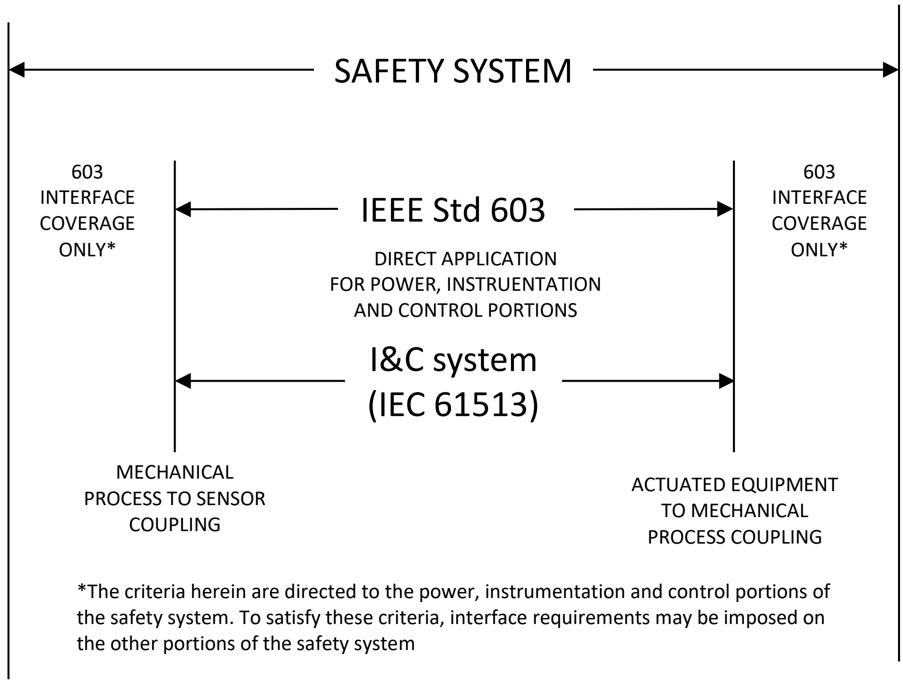


Figure 2. The figure is from IEEE 603 [3] where the definition of an I&C system from IEC 61513 [2] has been added.

2.2 COMPUTERIZED AND ANALOG I&C SYSTEMS

2.2.1 Background

Back in the time of the first commissioning of the NPP's, the control systems were mostly analog, meaning that the signals were processed using analog electronics and logic was implemented using e.g. electromechanical relays. These I&C systems were generally custom built to serve a sole purpose, signals were hardwired and their function was locked once it was implemented and assembled on a component level. Many of these systems are still in operation in the NPP's today due to their robustness, but also the time and effort required when committing a system replacement in terms of verification and validation. However, maintenance of systems, no matter how robust they might be, is inevitable. Sooner or later, a system must be replaced and due to the tremendous technological development since the design of these systems, replacing such a system requires time and resources.

Already from the beginning, the NPP's also were equipped with computerized I&C systems and equipment. At the time of the first commissioning, computers were vastly different than what we are used with today. Above all, the capacity and the capability of today's modern computers have changed the game significantly and computers have been introduced in most industries. This furthermore means that it is also of interest to study how older computerized systems and equipment are replaced by new, modern equivalents.

In the same pace technology advances, so diminish the knowledge of the older, sometimes obsolete technology. This has a direct impact on the effort needed to replace a system.

2.2.2 Nomenclature

Instrumentation and control systems can be distinguished into many categories depending on what properties are used for discrimination. This report will focus on whether a system or equipment is computerized or analog, which is defined based on how its function is realized and the property of signals with which they operate.

The term *computerized* is used rather than *digital* to avoid ambiguousness with terms. While the term digital may be interpreted as a binary state, e.g. on an electromechanical relay, the term computerized implies what is referred to as digital signal processing (DSP). However, the latter uses what is commonly referred to as digital signals, hence the ambiguity. A computerized system is defined to require software to perform some kind of programming at some point in development in order to obtain its function. It shall be noted that a computerized system is also required to work with *logical signals*, meaning that the signal can only take two distinct values (High or Low). This further requires the input signal to be interpreted to give it a useful meaning.

In contrast, an analog system has its function defined directly from the ingoing components' relative connections to each other. As such, their function must not be obtained following programming of an integral component.

This report will due to this use the wording *Analog* versus *Computerized* systems and equipment.

2.2.3 Classification of computerized systems

The logic in computerized systems and equipment can be implemented in a vast number of ways depending on their purpose and additionally, their versatility is high. They can all be classified based on their ability to be configured or altered to serve the intended use and this does have a direct impact on the comprehension of the verification, validation and qualification needed. The pharmaceutical industry has a trade association called ISPE who provides the industry with guidelines. One of these guidelines is the Good Automation Manufacturing Practice 5, GAMP 5. This guideline describes how to validate and put computerized automation systems into operation. Some of their definitions could be adapted also for the nuclear industry and this report has chosen to consequently use the categorization of software in computerized systems provided in the GAMP as shown in Table 2. Hardware is also categorized in a similar fashion, shown in Table 3.

Table 2. Classification of computerized systems according to GAMP 5, based on the ability of customization [4]. The category gives an indication of the customization possible with the system or equipment and ranges from not configurable (category 1) to fully bespoke (category 5).

Category	Name	Brief description
SW1	Infrastructure Software	Layered software upon which applications are built. Examples include operating systems and programming languages.
SW2	Non-Configured Products	Products which allows run-time parameters to be entered and changed, but otherwise immutable. Examples include firmware-based applications and instruments.
SW4	Configured Product	Complex software which can be configured and adapted to a specific intended use. The software source code, however, cannot be changed. Examples include data acquisition systems.
SW5	Custom Applications	Fully bespoke software. The software source code is altered to tailor the software to any specific intended use. Examples are internally developed applications and custom ladder logic.

Table 3. Categorization of hardware according to GAMP 5. The category can be seen as an indicator of risk, ranging from standard hardware (category 1) to custom built hardware (category 2).

Category	Name	Brief description
HW1	Standard Hardware Components	Off the shelf hardware. Installation and connection of components should be verified post installation.
HW2	Custom Built Hardware Components	Bespoke hardware. In addition to the requirements from category 1, this type of hardware requires design specification and must be subjected to acceptance testing.

2.3 SAFETY CLASSIFICATION OF I&C SYSTEMS

Within the nuclear industry, systems are classified based on their impact on safety and this classification is different depending on what standard is followed. The Swedish and Finnish NPP's use different schemes and hence have different classifications. This section clarifies the differences and similarities to simplify comparison between the different classification schemes.

2.3.1 Swedish NPP classification

In the Swedish NPP industry, both the IEC and IEEE standards are used.

The IEC classification used on O1 and R2 divides functions into four different categories based on their relation to safety. The categories are denoted CAT A, CAT B, CAT C and CAT O and corresponds to *Safety functions*, *Safety-related functions*, *Non-safety function* and *General purpose function*, respectively.

In addition, R2 has an additional classification which is CAT B^A"[1], which essentially means CAT B with seismic requirements.

The IEEE classification used on the other plants (F1-F3, R1, R3/4, O2/3) divides functions into either *Safety function* or *Non-safety function*, while equipment is classified as 1E, 2E or 3E where the foremost correspond to the highest classification.

2.3.2 Classification in Olkiluoto

While the Swedish NPP's depend on the IEC and IEEE standards, the Finnish NPP's have their own classification consisting of class 1, 2 and 3. The highest class, Class 1, is only used for mechanical equipment and hence not for I&C and cannot be directly compared to an IEC/IEEE category. Class 2 and Class 3 on the other hand, are comparable to the IEC categories CAT A and CAT B, respectively [5].

2.4 REGULATORY AUTHORITIES

The participating NPP's in Finland and Sweden are under the control of two different authorities respectively, the Radiation and Nuclear Safety Authority (STUK) and Swedish Radiation Safety Authority (SSM). Although the subordinate responsibilities of both authorities are the same, they work differently together with the NPP's.

In Sweden the NPP sends a notification to SSM where they describe the scope of the change and its impact on safety. This is done prior to performing the change in the plant and after the projects are completed, an updated Safety Analysis Report (SAR) is sent to SSM. Additionally, SSM can ask for project documentation and presentation of working methods, however this is made upon request and is not compulsory for all projects. SSM also inspect the working process and are expecting the NPP's to work according to relevant standards when introducing SW in to the plants, e.g. IEC 60880 [6]. This means they could request a safety demonstration as complement to the updated SAR.

For safety systems, STUK on the other hand, is involved during the entire execution of the project and at a more detailed level. STUK also perform documentation reviews and approvals during the project, such as concept documentation, factory acceptance test (FAT)/site acceptance test (SAT) program and commissioning plan.

Since STUK is deeply involved in the project and are reviewing several project documents, the Finnish NPP's need to take this administration into account when performing changes of safety systems in a way that is not necessary for the Swedish NPP's.

[1]CAT B rose to A.

3 Methodology

3.1 RESEARCH DESIGN

This report is performed as a combination of a qualitative and a quantitative research study. Personal interviews with individual project members are the foundation for the qualitative data and questionnaire for quantitative data. These research methods have been chosen to obtain a deeper understanding, to uncover and identify underlying patterns.

The foundation will be based on several projects run by the different NPP's Forsmark, Oskarshamn, Ringhals and Olkiluoto. Several employees from the different NPP's have been interviewed regarding their involvement in the projects in order to assess common key success factors and also to suggest improvements for future upgrade projects.

3.2 PROJECTS FOR INVESTIGATION

The participating NPP's were responsible to select which project to be investigated as well as ensure that employees participating in the projects could be interviewed. Furthermore, it has been actively decided to not include platforms. Interviews were performed on site at the NPP's in Forsmark, Oskarshamn, Ringhals and Olkiluoto while questionnaires were sent by e-mail and performed after or before the interview took place.

3.3 QUALITATIVE DATA COLLECTION

People with various roles in the chosen plant changing projects were encouraged to present their version of the project and their respective roles. The interviews served to give a qualitative overview and to compile information regarding the projects.

All interviews were semi structured with the questions in *Appendix C: Interview guidelines* used as a reference. A summary of all interviews are attached in *Appendix D: Interview summaries*.

3.4 QUANTITATIVE DATA COLLECTION

Quantitative data has been collected by letting employees with different roles in each project fill in a questionnaire where several statements were graded from 1 (strongly disagree) to 5 (strongly agree). As the number of employees, and their roles, differed between the plants, the answers are weighted to a plant level. The quantitative data complements the qualitative data with measurable results.

The statements from the questionnaire can be found in *Appendix B: Questionnaire statements*, together with a summary of the answers.

4 Empirical findings & Analysis

This section disseminates findings and analyses the results emerging from questionnaires and personal interviews. It shall be emphasized that interviews require interpretation and analysis which disfavors objective results. Therefore, the interviews are completed with questionnaires to obtain an objective interpretation as possible. Where needed, a collective perspective has been applied to formalize general findings from all participating NPP's.

4.1 I&C SYSTEMS AND EQUIPMENT

Eleven projects have been studied for this report, and a majority of the new systems and equipment are based on programmable logic controllers (PLC). Key information regarding the projects is listed in Table 4. A more comprehensive list over the studied systems can be found in *Appendix A: Systems studied*.

Table 4. Studied I&C systems at the different NPP's. The hardware column refers to the system which was installed. The GAMP classification considers the HW and SW classification of the installed equipment.

Plant	Project	Substituted hardware type	Installed hardware	Safety class	GAMP category
Forsmark	Radiation measurement	Analog	Mirion	2E	HW1/SW5
Olkiluoto	Radiation monitoring	Analog	Mirion	2	HW1/SW5
Olkiluoto	Turbine automation	Computerized	Siemens Teleperm XP, Siemens S7	No	HW1/SW5
Olkiluoto	Control Rod operating	Computerized	Siemens S7 & PC	No	HW1/SW5
Oskarshamn	Wasteplant control equipment (measurement equipment for all systems in wasteplant)	Computerized	Siemens S7	2E	HW1/SW5
Oskarshamn	Wasteplant control equipment (measurement equipment for magnetic filter)	Computerized	Siemens S7	2E	HW1/SW5
Oskarshamn	Temperature measuring	Computerized	PR Electronics 2289A	2E	HW1/SW4
Ringhals	Temperature measuring	Computerized	ABB AC800M	2E	HW1/SW5
Ringhals	Compensation for vessel level	Analog	H&B TZA4	1E	HW1/SW5
Ringhals	Measure temperatures & calculate limit	Computerized	Eurotherm 6100	1E or CAT A	HW1/SW4
Ringhals	Reactor control system	Analog	WDPF	1E Control HW 2E SW	HW1/SW5

As can be seen in Table 4, many of the systems introduced are based on PLCs, and the same model is used within each NPP. This fact hints a common policy when replacing systems of certain character, namely to use off-the-shelf (OTS) systems and equipment of which they are already familiar with. Although it is not always considered a formal strategy, it is also reflected in the interviews. The NPP's are well aware of the gains from previous installations such as documentation, verification and validation (V&V) and qualifications. It is also emphasized that the supplier in these scenarios are aware of the routines and the expectancy on their delivery, which is inherently positive. Conclusively, this yield more time to focus on the implemented logic (which is GAMP category SW5) rather than the underlying infrastructure (which is GAMP category HW1/SW1).

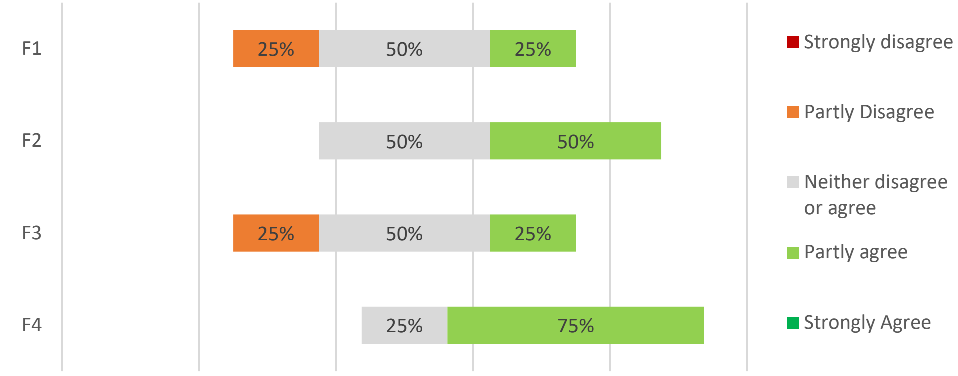
Furthermore, the maintenance departments at the NPP's generally prefer to use a limited assortment of systems and equipment since it is easier to maintain high competence. Another aspect is that the PLC systems chosen are considered state of the art OTS systems and are widely used. This large community is thought to facilitate longer vendor support and spare parts on the market. Young professionals in the field are typically schooled in this type of general purpose equipment, facilitating recruitment of new young professionals with experience of the system.

According to GAMP 5, creating software directly from code is associated with category 5, meaning the highest risk. Therefore, it will significantly impose on the amount of work put into V&V and qualification. This is extra work which arises solely due to the usage of SW, and it is therefore easy to see why SW in some cases is disfavored. However, when utilizing OTS systems, such as PLC, it must be considered that the PLC hardware itself can be classified as HW1. The system which runs the bespoke source code ought to be considered as SW1 (infrastructure software). Together, this shows that the major focus will be on the fully bespoke software, while only a small part must be attributed to the hardware and the interpreting software per se.

As can be seen from the table, 7 out 13 projects have replaced old computerized systems with modern computerized systems based on OTS PLC. In some cases old computerized systems has been replaced with a SW4 category equipment.

4.1.1 Complexity and characteristics

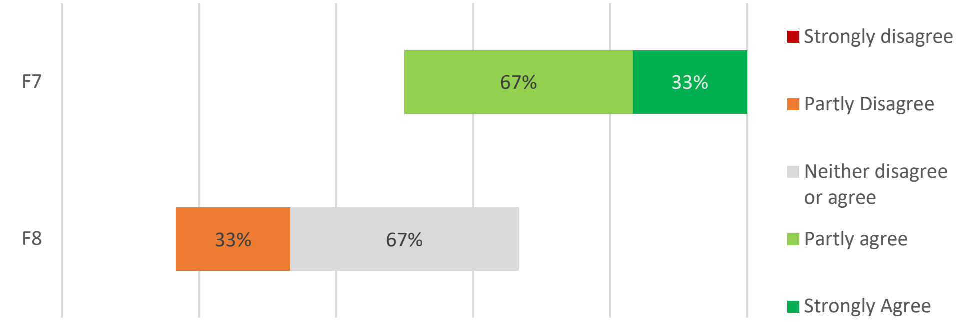
Computerized systems in many cases involve extensive interaction with other systems, expanding the zone of impact, which in turn extends the effort which has to be put in to V&V. This is also supported by the fact that systems with fewer interfaces to other systems and equipment are considered more suitable to be replaced with computerized I&C than systems with many interfaces (F3, F4 in Figure 3). This does not necessarily imply that the issue is regarding the computerized nature itself, but rather a design statement. It is furthermore stated that systems which have one or few well defined functions or tasks are more suitable to replace than systems comprehending more functions (F1, F2 in Figure 3). However, during interviews it was evident that the NPP's are aware that a carefully designed computerized system does not necessarily introduce more interfaces. It is also agreed that computerized systems are not necessarily more complex compared to any other type of system. Complexity and interactions are purely dependent on design, not whether it's computerized or analog. Computerized systems are, however, often perceived more complex, possibly due to their abstract logic implementation, although an analog system might be just as, or even more, complex.



F1: Systems with many functions/tasks are especially suitable to be replaced with digital I&C systems/equipment.
F2: Systems with one or a few well defined functions/tasks are especially suitable to be replaced with digital I&C systems/equipment.
F3: Systems with many interfaces towards other systems/equipment are especially suitable to be replaced with digital I&C systems/equipment.
F4: Systems with one or a few well defined interfaces towards other systems/equipment are especially suitable to be replaced with digital I&C systems/equipment.

Figure 3: Question F1-F4

In fact, systems that handle large data quantities, such as data from multiple sensors, are considered by all the NPP's to be especially suitable to be replaced with computerized I&C (F7 in Figure 4). Conversely, systems or equipment handling small data quantities, e.g. door contacts, is considered the opposite (F8 in Figure 4). This shows that the NPP's have a clear view of where to use computerized systems and equipment.



F7: Systems handling large data quantities (e.g. data from multiple sensors) are especially suitable to be replaced by digital I&C systems/equipment.
F8: Systems handling small data quantities (e.g. door contacts) are especially suitable to be replaced by digital I&C systems/equipment.

Figure 4: Question F7 & F8

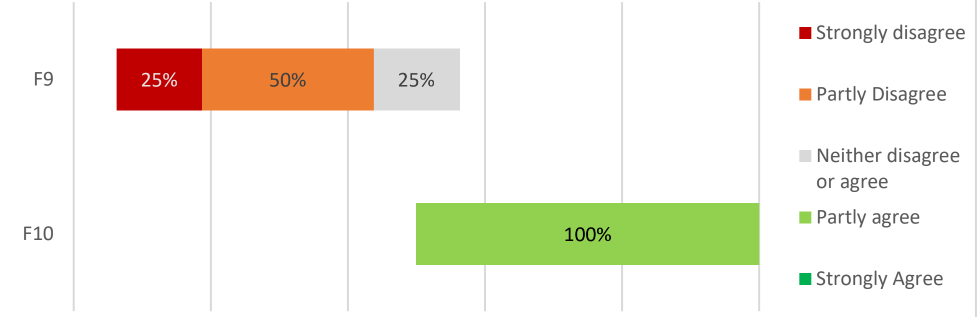
The vastly different characteristics of an analog system and a computerized system may also contribute to the perception of the latter being more complex. Therefore, knowing about such characteristic differences and reasons is of importance to successfully upgrading from an analog system or equipment to a computerized equivalent.

If the same function is implemented both in an analog and in a computerized system, difference in physical characteristic might yield differences in e.g. response time. This can be a problem, especially when it comes to partial replacement of a system or equipment and the characteristic properties of a system are not fully mimicked. Systems well understood, both to function and also how the function was implemented and why, were easier to replace. Compiling the differences and similarities in appearance and features of the old and the new system are considered important when performing future maintenance and changes. This especially comes into mind for future upgrade of the same system where documentation is found to be of paramount importance, see further sections 4.3.3 and 4.4.1.

Qualification of software is generally considered more cumbersome than for hardware, possibly due to the more abstract implementation of the logical function. While hardware is simpler to qualify, it does not offer the same possibility of versatility as software.

4.1.2 Safety classification

The safety classification of a system or equipment plays a major role in whether it is suitable for replacement with a computerized I&C system or equipment. As safety classified systems generally have more comprehensive qualification and V&V procedures, this can be an issue with computerized systems which may require comprehensive work. This is supported by all the NPP's as they do not prefer replacement of safety classified systems with computerized I&C, while on the other hand encourages replacement with computerized I&C in non-safety systems and equipment (F9, F10 in Figure 5). If however, a safety classified system is to be replaced, dedicated equipment and minimal interfaces shall be considered.



F9: Systems with a high safety classification are especially suitable to be replaced with digital I&C systems/equipment.
F10: Systems with a low safety classification are especially suitable to be replaced with digital I&C systems/equipment.

Figure 5: Question F9 & F10

Again, it shall also be noted that the disinclination towards replacing safety classified systems might not be due to the computerized nature, but rather the comprehensive task of replacing that kind of systems. The general impressions during the interviews were that they all see computerized I&C systems and equipment as a part of the future in the NPP industry.

4.1.3 Configuration

The nature of computerized equipment gives the possibility to digitally store configuration parameters. This is in contrast to analog systems, which must be manually set up, and which are hard to precisely control due to their analog nature. Furthermore, changing configuration parameters can be forced to be traced in a computerized environment, whereas this must be handled somewhat manually in other types of systems and equipment.

Modern computerized equipment can also in many cases be programmed using graphical software, which in general might give a more holistic view of the system function. This provides the opportunity for people who are not familiar with software code to review and understand the system logic which is considered inherently positive.

4.1.4 Data handling and visualization

A prominent benefit of digitally storing data is the ability to afterwards easily perform data analysis and also different visualizations of the data. It gets even more advantageous as the different analyses and visualizations do not need to be known prior to data collection. This feature therefore facilitates different uses of the acquired data for e.g. process optimization. However, these features shall be used with care as abundance of information might disfavor overview of critical information. In other words, too much data might in fact inhibit efficient monitoring of the most critical parameters and aggravate the work for operators.

4.1.5 Testing possibilities

Computerized systems are considered easier to test in a simulator environment, compared to analog systems which sometimes require to set-up the entire system. This gives the opportunity to perform more extensive testing prior to commissioning. The V&V procedure, which is tightly related, is considered work well during I&C changes for a majority of the NPP's (SM20 in Figure 6).

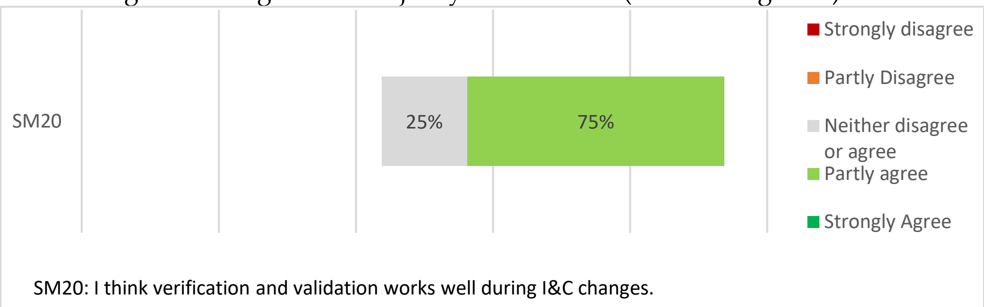


Figure 6: Question SM20

Furthermore, software code run on the simulator can be transferred directly to the production environment without any manual interventions in configuration. Although this gives a very good indication, it is emphasized that it shall not be seen as ground truth that it will perform equally in a commissioned system.

4.1.6 Stability and vulnerability

In contrast to analog systems and equipment, computerized equivalents are not considered to be affected the same way with deteriorating components. The computerized systems are also considered more stable over time and generally require less maintenance, e.g. calibration which can be performed automatically. Furthermore, self-monitoring is present in many modern computerized equipment, which gives an indication of the system's health status. However, it shall also be emphasized that the NPP's state that they cannot fully rely on the self-monitoring functionalities unless they are validated. There are uncertainties regarding how well they actually work, and commonly the self-monitoring functionality is not assessed during V&V.

While storing and loading of configuration parameters mentioned in section 4.1.3 is considered a major strength, it can also be exploited for other purposes. A connected computer used to perform such system maintenance has permission to alter system behavior which also makes it vulnerable for e.g. data viruses. This can in fact be an imminent danger even if the computer in itself is not connected to the Internet, as malicious code can infect via e.g. USB flash drives.

Software has a peculiarity due to its abstract implementation, and it is the possibility of entering a program state from which it cannot recover. Typically, the program enters a loop and the condition to exit the loop is never met and it continues in infinity and therefore cannot operate normally. Such errors can be hard to detect, as the system might give a feasible signal response and therefore appear to act normally.

The ease with which code can be copied has both pros and cons. While it facilitates faster development, error in code which is commonly copied also facilitates the introduction of errors. However, this can generally be handled with a good working process for the software development, which is discussed further in section 4.3.4.

When aging, computerized systems are not considered to deteriorate the same way analog systems do. This deterioration is hard to detect, especially when performing periodical calibration, in which such deviations are corrected for. The NPP's note that there is always a risk when adjusting analog equipment, as there is no way to exactly return to a specific parameter setup which can be done with software.

No matter how stable a system is, failures and breakdowns are eventually inevitable and so also in modern computerized systems. Typically, computerized systems present an error code which points to the failing unit, which is then replaced. The most vital part to fail in such system ought to be the processors, which are fundamental as they implement the logic of the system. Therefore, changing processor is associated with one of the major risks when handling computerized systems.

Stability can in many respects be increased by utilizing multiple distributed computation modules (DCM), to obtain or increase redundancy. The benefit of doing this is that, as they operate as independent islands, not all are required simultaneously to fulfil the function. This gives a higher reliability during operation.

4.1.7 Physical properties and surrounding environment

The physical size of a system or equipment impacts its suitability to be replaced by a computerized I&C system or equipment. The size of systems or equipment is of course limited by the size of their integral components, and when considering computerized systems, these components are generally very small. Physically large systems or equipment are therefore considered more suitable for replacement by a computerized than physically small systems (F11, F12 in Figure 7). However, the difference is quite small, and it might be that older physically large systems do incorporate a higher level of complexity which may impact on the response, see further section 4.1.1. As modern computerized systems are generally smaller than older equivalents due to their integral components, the restrictions of where to place them should not be considered an issue.

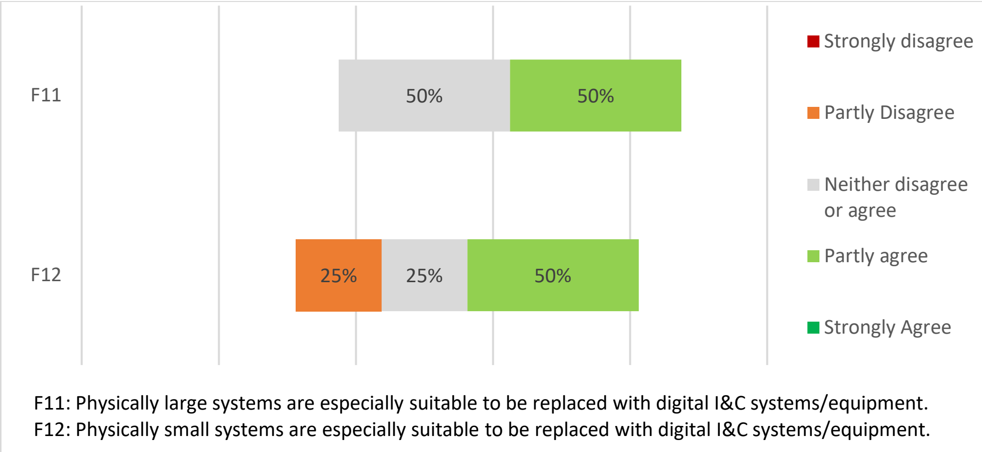


Figure 7: Question F11 & F12

However, locations which are subjected to radiation exposure are not suitable for computerized systems or equipment, as radiation impacts their performance. Without going into detail, radiation is known to cause malfunction of vital integral components and may produce strange measurements and results. This, in turn can lead to an inappropriate control measure due to the interference caused by the radiation.

4.2 STRATEGIES

In general, all NPP's strive to maintain and keep their old systems and equipment for as long as possible and this ambition is stricter if the systems or equipment concern safety of the plant. The originally commissioned Combimatic/Combitrol equipment used within safety systems, are examples of equipment which will be prolonged throughout the entire lifetime of the plant. This is allowed by signing new contracts with the manufacturer to ensure spare parts and support for the remaining time. There is also a strategy to prolong the life time of other already commissioned systems.

Eventually, systems or equipment are subjected for replacement and this typically happens when it is not economically feasible to keep to the older variant. The most common fundamental reason is lack of spare parts and competence.

The general strategy can be summarized as to keep the installed systems or equipment for as long there are spare parts and competence available.

4.2.1 Replacement

The replacement strategies for all the NPP's differ slightly, however they all emphasize the urge to introduce as few new sources of error as possible when replacing a system or equipment. This means that they favor gradually replacing the malfunctioning parts of an I&C system or equipment. The only necessity is that the interface of the system being replaced is mimicked. In essence, peripheral units and any connected systems or equipment must not be affected.

While this is the preferred way of work, it may not always be feasible, if e.g. an entire system is failing. If a system, on the other hand, is preventively procured, it is considered a good practice to install and commission the new system in addition to the other. This increases the diversity, and may facilitate the qualification of the new system, as there is an already installed reference system.

It is preferred that the function of the system or the equipment being replaced is well documented to avoid reverse engineering[2] and the risk it introduces. All NPP's do point out the utter importance of testing the entire system together with the newly installed system or equipment. This is to ensure that the overall system functionality is not altered. As an example it is mentioned that a computerized system might respond quicker than the analog system it suits to replace, even if the output signal should be the same. Such characteristics are considered to sometimes be forgotten when replacing analog systems with computerized equivalents.

Incorporation of new features is also discouraged both to the risk of introducing errors but also to facilitate maximum compatibility. In fact, the NPP's all agree that a modern system should not incorporate more functionality than absolutely necessary. This avoids unreasonably cumbersome V&V procedures and let the focus on the core functionalities. Introducing new features may extend V&V procedure to ensure that these functions do not affect the primary functions. The deep knowledge of the system or equipment shall fall on the supplier, so the NPP can focus on the overall plant function.

There is a consensus that it is favorable if a system can be replaced in several stages, rather than the entire system at once. This is a strategy which is apparent

[2] Reverse engineering in this sense means to recreate functionality without using the original specification and/or drawing.

for all the NPP's, irrespectively of each other and is considered yielding good results in the end.

4.2.2 Preventive upgrades

The NPP in Olkiluoto have a defined strategy when it comes to upgrading of equipment, namely to run upgrading project continuously in preventive purpose. This strategy is considered good to acquire and disseminate competence among personnel, but also contribute to the high availability of the Finnish NPP's, which have the highest availability in the world [7]. Furthermore, for the two reactors at Olkiluoto, there is a preference to keep them as similar as possible. This means that, in general, changes to one of the reactors are normally mirrored in the other afterwards. The benefits of using this strategy are thought to lower the cost for implementing new systems due to that documentation and qualification in many cases need to be done only once.

4.2.3 Maintenance

From a maintenance perspective, all NPP's agree that computerized systems or equipment require less maintenance once commissioned. Self-monitoring and remote surveillance are mentioned as two very positive features to monitor health status. Furthermore, changes in configuration can be traced and a known running configuration can easily be restored to facilitate troubleshooting of a malfunctioning system.

The less maintenance required by computerized systems and equipment and the possibility to read status and parameters from afar, lowers the frequency of physical inspection rounds. This imposes a declination of the knowledge of how a healthy plant behaves when it comes to e.g. sound and vibrations. Such perceptions are of vital importance to discover erroneous behavior if, for example, the computerized system may malfunction or, in fact, conclude that it is malfunctioning.

Other maintenance aspects include the difference in troubleshooting methodology. Computerized systems or equipment generally require an error code or some other indication of the location of the error. Localization of a broken equipment or component in an analog system can generally be accomplished by physical measurements using instruments (e.g. a multimeter). Although location of errors in computerized systems or equipment may be more cumbersome if no indication is given, the impact of troubleshooting methodology may be a matter of habit.

All NPP's are reporting very few or no faults with computerized systems after installation and commissioning. This is attributed to the extensive testing, including comprehensive FAT, of computerized systems and equipment possible prior to installation in the plant. The stability of the systems is also considered a contributing factor to the low number of faults.§1

Competent resources

All resources needed for operation, maintenance and configuration of a system should be tied to the in-house operations. The reason is to ensure that competence

Energiforsk

is at hand even after the supplier's support for the obtained system or equipment have decreased or ceased.

This strategy is also consistent with the fact that most NPP's somewhat agree that they should not outsource more tasks to suppliers (SM6 in Figure 8). Furthermore, there is considered to be enough competence in-house (including consultants), regarding I&C systems and equipment (SM2 in Figure 8). Collectively, this strengthens the interpretation that the strategy is to keep competence in-house.

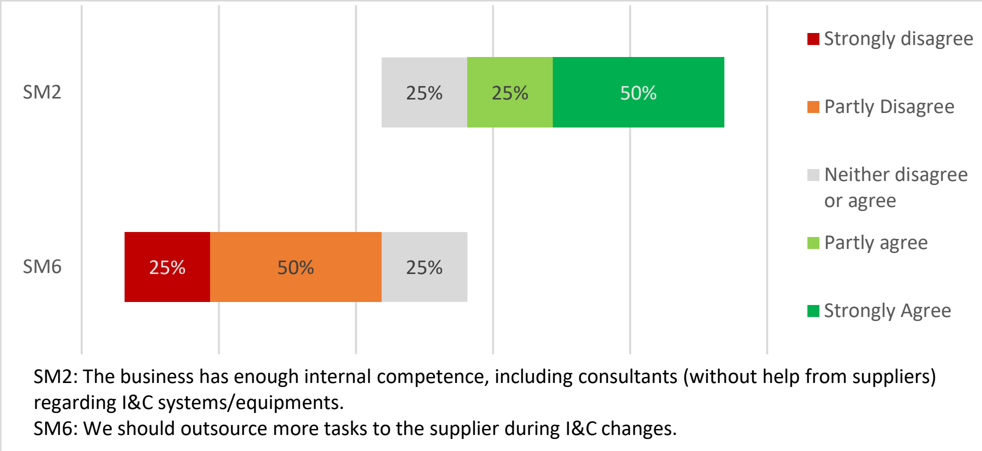
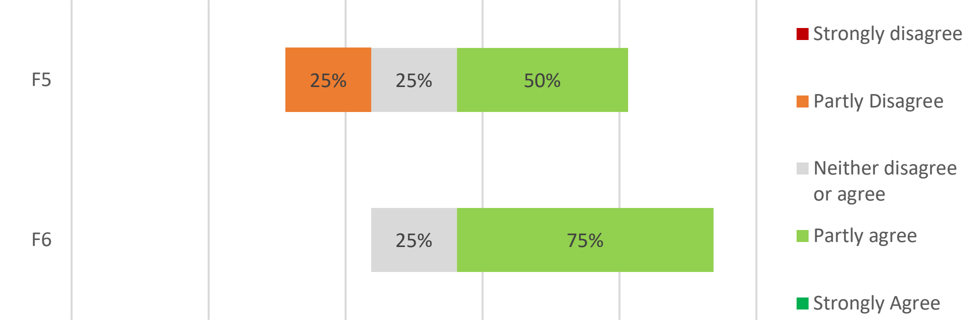


Figure 8: Question SM2 & SM6

The underlying reason for keeping competence in-house cannot be objectively determined, although there are many feasible causes. The area of use for an acquired system or equipment might be unique to the NPP industry making such competences hard to find elsewhere. This is a palpable way of extending the lifetime of a system or equipment after the supplier has ceased their support.

The need of specialist competence for a system or equipment impacts on the NPP's view on suitability to be replaced with computerized I&C. If a system does not require specialist competence, the suitability for replacement of computerized I&C is considered slightly higher (F5, F6 in Figure 9). It is also noted that with lower profitability in the energy market, people leaves the business area. Therefore, specialist competence can be harder to obtain in the future.



F5: Systems requiring specialists for maintenance/updates are especially suitable to be replaced with digital I&C systems/equipment.
F6: Systems not requiring specialists for maintenance/updates are especially suitable to be replaced with digital I&C systems/equipment.

Figure 9: Question F5 & F6

Version control of software and hardware

An issue when introducing computerized systems or equipment is the dire need to track the latest version of both software and hardware for every system or equipment. Generally, a support tool on an external PC is required, and this needs to match the latest configuration of the equipment. This has been resolved by the NPP's by dedicating a specific computer to each system or equipment, running the appropriate software and version. This also implies that an aging support PC might impose as large problem as the system itself. There is also an opportunity to outsource the administration to the supplier, as further discussed in section 4.2.4 under *Role of supplier*.

4.2.4 Life cycle

Computerized systems are generally considered having shorter lifecycle than analog technology and thus the life cycle costs are higher. All NPP's do also impose that the internal components which in general limits the lifetime is the I/O cards and power supply units. Therefore, the life cycle cost is considered higher for computerized systems than for analog equivalents. The typical expected life time for computerized systems and equipment is ten years.

It is generally the case that the number of suppliers, and therefore also systems, are more numerous when it comes to modern computerized equipment. Apart from the monetary benefit of competition for the NPP's as a procurer, this also gives an opportunity to fairly evaluate different systems.

Analog systems or equipment are considered easier to troubleshoot or repair physically broken parts. In computerized systems it is accustomed to replace a failing unit, i.e. an I/O card or processor, instead of repairing them. The cost of such replacement depends on the modularity design of the system as it is undesirable to replace parts which are functioning correctly. However, replacing entire units can make the root cause investigation suffer, as the actual root cause is only traced to the malfunctioning unit.

A majority of post-commissioning changes on the installed systems are related to calibration and parameter changes which are considered minor changes. They do not require revalidation of the system as the logic is not altered. However, since the project time for the NPP's often are several years long , the computerized systems are aging already before they are taken into operation which have already resulted in changes of hardware for some of the oldest of the "new" equipment.

Spare parts and system lifetime

The rapid advances in computerized technology further impose a problem related to availability of spare parts long after commission. This fact is well known and has led to the strategy to procure spare parts for the entire estimated life time of a system when it is installed, together with a service agreement with the supplier

There is also experience with system changes which cost more than a total system replacement, due to the obligation of using a specific supplier in order to maintain the validated state of the system. This shall however be taken into perspective as the time to retain competence in-house over the years also is quite expensive. All NPP's strive to have resources and personnel to perform minor configuration changes to the systems and equipment without involving the supplier. Examples of such changes are to add new algorithms, change parameters and change sampling interval. However the extent of what is performed in house depends on the NPP, and there are no real consensus regarding this.

Changes of major comprehension and complexity due to many system interactions will require comprehensive V&V procedures, and are always performed in collaboration with the supplier.

Role of supplier

Suppliers of systems tend to be involved during major changes such as installation, commissioning and modification of systems. The idea is that the supplier has more in-depth knowledge regarding the system itself, whereas the plant personnel have a better understanding of the plant functionality. This holistic perspective is important when modifying an already existing system or procuring a new system. The NPP may for example supply data to the supplier which then can perform modelling, simulation, calculations and programming prior to FAT. There are also cases where the supplier administers the system which then maintains correct version of e.g. hardware and software or by other means ensure compatibility.

Regular maintenance tasks and minor changes which do not alter the system logic, e.g. changing parameter values, are performed in-house without involving the supplier.

Reason for system replacement

In most cases, replacement of systems was preceded with degrading system performance or an increased difficulty to acquire spare parts, if at all possible. The latter could also be true if the cost for the spare parts were deemed to high compared to the cost for an entirely new system. This is a result of the technological ageing, meaning that the advances in technology have made the systems obsolete and therefore the support of the systems or equipment have ceased. This in combination with poor knowledge and experience regarding the system forces an upgrade to ensure future operation.

The lack of, or decreasing, system knowledge and experience among the personnel together with issues with spare parts was a common factor for all participating NPP's.

4.3 PROCESSES

4.3.1 Standards

Standards that NPP's must comply with when introducing computerized systems, points out the importance of having a structured way of working, from concept to end of use. The working process has phases where verification activities need to take place and be documented after each phase. It means that all verification cannot be performed as commissioning's tests in the plant.

The standards also require a life cycle perspective that forces the NPP's to look beyond the projects that are performing the changes. A plan and a strategy for administration of the computerized system and documentation over time must be utilized when taking the system into operation.

4.3.2 Quality Management System

All NPP's have established a Quality Management System (QMS) and project management methods for performing changes in the plant. All NPP's have identified Requirement Management and Validation as essential areas to succeed with the projects introducing new systems and equipment into the plant. Both RAB and Olkiluoto have pointed out that they are working with different initiatives to improve the process and working methods for Requirement Management and Validation.

4.3.3 Documentation Management

Documentation is of paramount importance, both to operate the commissioned systems, but also for administration over the life cycle. Document management is valuable when preparing system upgrades, since how well the old system is documented is one of the most important factors to succeed with the change. Due to this the working process needs to facilitate so that the necessary information is saved over time and easy to access. All NPP's have the opinion that they have feasible routines for Document Management. It was however mentioned during the interviews that the documentation from the suppliers are not as detailed for the new equipment as it was for the old ones which could lead to struggles for future changes.

When outsourcing parts of projects to suppliers, it is also of interest for the NPP to receive all produced documentation even from the supplier. It can be deduced that a majority of the NPP's considers themselves acquiring good documentation from the supplier (SM9 in Figure 10).

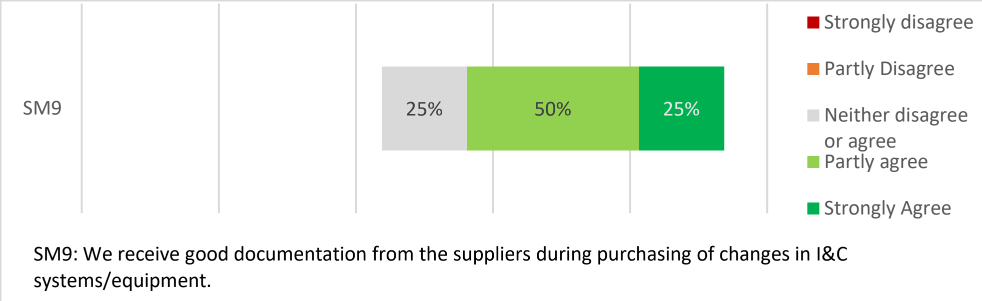


Figure 10: Question SM9

However, when discussing the effort put in to documentation and long-term maintenance, the answers are more spread, and span uniformly from partly disagree to strongly agree (SM7 in Figure 11). This may be a result of pure personal reflections regarding what is considered good documentation.

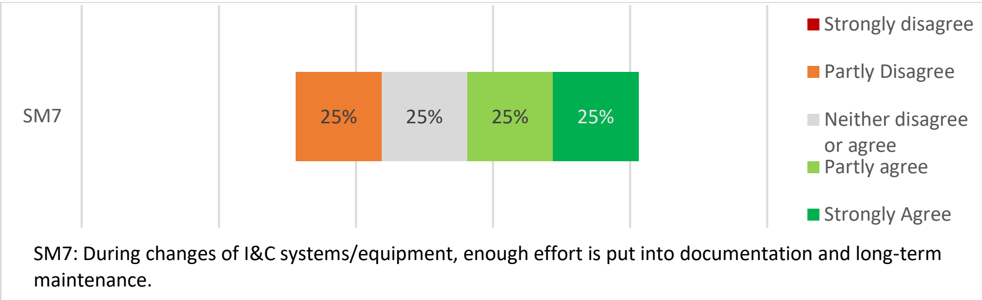


Figure 11: Question SM7

In order to maintain a good knowledge and to further build experience with a system or equipment, the need of regular training is stressed by all NPP's.

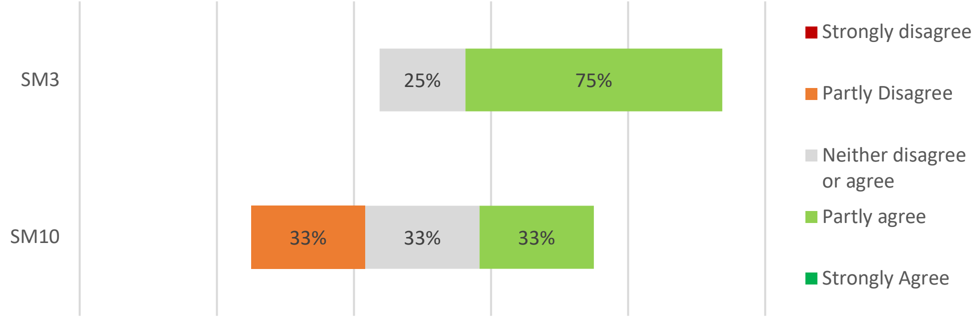
4.3.4 Software development

Agile working methods for SW development are used more and more frequently outside the NPP industry. It is an efficient method to discover faults at an early stage in the projects. RAB is the only NPP who have started to try Agile working methods and one reason for this is that RAB is the only NPP who are performing the programing in-house. It means that RAB both have the development environment and SW test environment in-house which makes agile working methods efficient and feasible.

4.4 PROJECTS

4.4.1 Project planning

As keys to successful projects, enough budget and especially time were of paramount importance, which in essence means good project planning. The importance of this is also well substantiated in the questionnaire, where a majority of the NPP's agree to have good processes to perform replacement of I&C systems or equipment (SM3 in Figure 12). This shall of course also be seen in contrast to the working procedures for requirement management (RM), which span from partly disagree to partly agree, interpreted as deficient RM routines (SM10 in Figure 12).



SM3: The business has well developed processes/instructions to execute replacement of I&C systems/equipment.
SM10: We have good working procedures for requirement management during changes of I&C systems/equipment (replacement and change of existing systems).

Figure 12: Question SM3 & SM10

If the system or equipment which to be replaced was well understood, this significantly improved the final outcome of the projects.

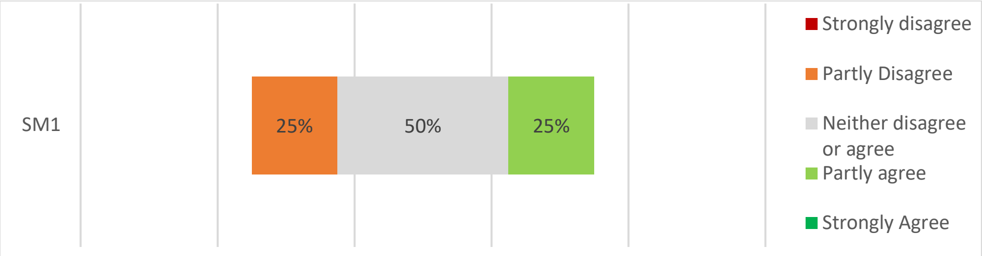
Many successful projects also spent much time of experienced staff to compile essential documentation and to educate the supplier regarding system function and current implementation. Projects which skipped this educational phase experienced more trouble along the way, due to insufficient understanding of the problem. In other words, the supplier solved a problem without enough overall knowledge of the operations. Understanding the purpose, interfaces to, and dependencies on, other systems or equipment in the operations is considered keys to understand the overlying problem and therefore a successful project. All of which can be acquired by thorough documentation over the entire system or equipment, including rationales for the specific implementation.

Experienced staff, good documentation in combination with a well-informed supplier was considered keys to a successful project. Good plant knowledge at the supplier end was of major importance in order to obtain consensus and thereby a good end result. Deep understanding of the functionality and behavior of the plant both during normal operation and other states (e.g. outage) is of value.

When a decision is taken to perform a system replacement, it is considered that suppliers should be chosen based on their familiarity with regulated industries. Higher understanding of such industries tends to be more familiar with special procedures and documentation requirement. Suppliers which were not aware of the requirements within the nuclear industry were in some projects identified as a cause for delay. It is therefore of importance to ensure that suppliers are aware of the time and effort needed to present such information.

4.4.2 Cost

In many cases, the NPP's have associated certain types of systems with certain suppliers. This is considered effective, as the supplier then have a better holistic view of the plant and its equipment than a completely new supplier. It can however also be disadvantageous, as the lack of competition leads to a monopoly which drives the prices up. This duality is also seen in the objective results from the questionnaires, which reveal that the cost effectiveness of I&C projects are inconsistent (SM1 in Figure 13).



SM1: I&C projects works cost effective.

Figure 13: Question SM1

The NPP's all agree that the use of OTS products, present in other industries to perform similar tasks, is very cost-effective. The list of suppliers to choose from is more numerous and thus, competition will be in favor of the NPP. It shall also be stated that there tend to be more suppliers of computerized equipment than for the analog technology. The strategy of using general purpose systems, which are typical OTS products, is a practical example of this strategy.

4.4.3 Safety and Quality

All NPP's state that there are no problems from a technical point of view to change old analog or computerized systems to a modern computerized system. The challenge is in relation to prove the system to be qualified and validated for its intended use in the plant. When using SW it must be proven that only the intended functionality and nothing else is introduced into the plant. This puts an extra dimension to the projects when handling computerized systems and equipment.

Safety demonstration and safety culture

Since the validated state of the plant is affected by a change, a safety evaluation is necessary. Strategies for how to verify the change must be performed and a strategy for re-validation of the plant needs to be evolved. This is applicable for all plant changes but when programed equipment is installed to a NPP an even more structure way of working is required according to the standards. According to e.g. IEC 60880 [6], V&V of software requires a working process, where the SW is verified during the development phases. It means verification can not only be performed as final tests out in the plant. The safety demonstration requires more than only updating of SAR, the authorities would like to see a working process that guarantee a verified and validated functionality. Due to this requirement management and validation strategies are of importance when introducing computerized systems into the plant.

A majority of the NPP's strongly agree that they have a good working security culture when performing I&C changes (SM4 in Figure 14). Furthermore they all are, to various extents, confident with the quality of performed I&C changes (SM5 in Figure 14).

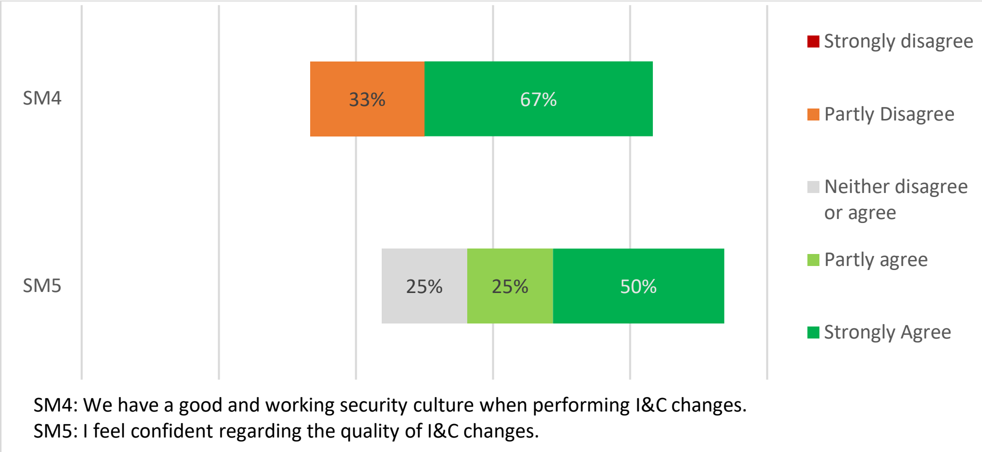


Figure 14: Question SM4 & SM5

Qualification

The Nuclear industries have very high and special requirements which narrow the assortment of equipment and leads to high prices. Today there is no common EU standard for qualification of equipment which means that e.g. Finland not automatically can use a component that are qualified within one of the Swedish NPP's. This applies to both SW and HW, however due to the abstract nature of SW; more emphasis is put on the developing process and the extent of testing. It takes longer time and cost more money. The effort of demonstration is determined by the use for the system, e.g. safety or non-safety in combination with classification (according to e.g. GAMP) of the equipment. Meaning that the high levels of effort is for a class SW5 system (custom application) used within a safety system.

To qualify software for use in safety system application requires a lot of effort from the NPP's. The key to success is to work with a supplier that are familiar with the nuclear industry or other highly regulated industries (e.g. Pharmaceutical industry) and are formally documenting all their aspects of development. The other key factor is to choose dedicated equipment for the specific use in the plant.

Areas in which requirements are set for equipment:

- Radiological environment
- Electrical environment
- Input voltages (acceptable variances)
- Interference
- Function and performance

The NPP's consider the TBE (Tekniska Bestämmelser Elektronik) to be up to date in the respect of computerized systems. The requirement which differ the most comparable with other industries area is the seismic. One feasible way to make the qualification more efficient is to find a supplier who deliveries to e.g. the pharmaceutical industries and use one of their qualified component as a base and add the NPP unique and necessary verification. Further on, most of the NPP's consider themselves as having good working procedures for V&V of I&C systems and equipment (SM11 in Figure 15).

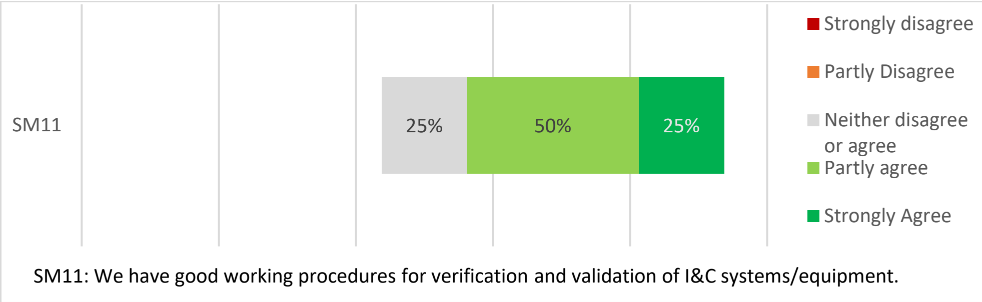


Figure 15: Question SM11

In general, the FAT for a computerized system can be fully performed before installation and commissioning by using a simulator to mimic the power plant environment. This is harder to do when it comes to analog systems or equipment. For all NPP's, both the FAT and the SAT are considered working very well during I&C changes (SM23, SM24 in Figure 16).

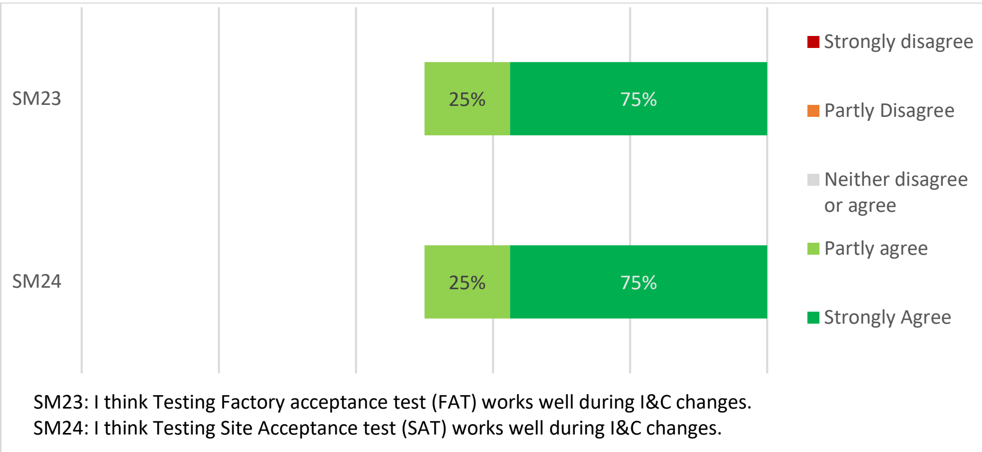


Figure 16: Question SM23 & SM24

5 Conclusions

It is clear that the NPP's have an interest in what the modern computerized technology offers and that they also have a good understanding of the challenges it presents. The overall impression is that the NPP's are aware of the potential gains in utilizing the modern computerized technology.

The view on computerized systems coincides among the NPP's when it comes to the use for non-safety functions. In non-safety systems or equipment the benefits, such as self-monitoring and versatility, are considered to outweigh the drawbacks with the technology, such as the shorter life cycle. Avoiding customized solutions in favor of industry OTS products is also a key in this.

The NPP's do also agree that the complexity of a system or equipment is utterly determined by the design, rather than whether it is computerized or not. The reason for computerized systems generally are perceived more complex is that they do facilitate interactions between systems, although this is not mandatory. Therefore, being restrictive with interactions and use a sparse number of functions for each system or equipment will yield a less complex system and thereby facilitate V&V procedures significantly. It shall however also be noted that introduction of SW will always create extra work during V&V, but it is the system design, system category (according to Table 2) and the safety level that determines how much.

The general conclusions from the report is summarized and compiled in the following subsections. The sectioning follows the research questions listed under section 1.2.

5.1 KEY FINDINGS

This section summarizes and presents some key findings made in the report. It first disseminates general findings, followed by common denominators of systems suitable to be replaced and finally some key properties of an ideal replacement system.

5.1.1 General findings

These general findings presented herein are considered important take home messages which were identified during the analysis of questionnaire and personal interviews. There is an attempt to list the findings in a descending order of importance, although all shall be considered.

- NPP's prefer to keep old systems for as long as possible and extend lifetime of commissioned systems and equipment, if feasible.
- There are no technical obstacles in moving to computerized technology.
- Complexity is a matter of design, classification and its intended use (not whether the system or equipment is computerized or analog).
- Gradual replacement of systems/equipment is preferred.

- Testing of entire system after replacing subsystems or equipment is of vital importance.
- Suppliers should be involved early to learn about system/equipment, the use of it and the plant functionality.
- Suppliers shall be chosen based on familiarity with regulated industries.
- Troubleshooting methodology is different for computerized systems and equipment compared to analog equivalents.
- All resources for maintenance and configuration are kept in-house.
- One extra dimension in V&V, when using SW needs to be taken into account when planning the project.
- Many new systems are based on OTS PLCs where the same type is used for many applications at the NPP.
- Regular training of staff to build experience.

5.1.2 Systems or equipment in focus for change projects

This section compiles common denominators for systems or equipment which have been considered especially suitable for change projects. All which were deemed suitable exhibit one or more of the following properties:

- Is preferably non-safety classified.
- Has comprehensive documentation of function and implementation.
- Has a well understood function and purpose.
- Experienced difficulties in acquiring spare parts.
- Experienced degrading performance.
- Declining system experience and knowledge.

5.1.3 The ideal replacement system or equipment

Some systems or equipment which was considered especially successful after installation did have some common denominators. The following joint properties of these systems or equipment were identified:

- Use a dedicated system or equipment suitable for the task.
- Only incorporate enough functionality to serve its purpose (but no more).
- Only have a few interfaces to other systems and equipment.
- Only have one, or possibly a few, clearly defined functions.

5.2 PROJECT

The I&C change projects deemed successful did exert some key factors which were common for all of them:

- Well planned project in terms of budget and time.
  - × Time to educate supplier.
  - × Time to compile essential system/equipment documentation.
- Participation of personnel with experience of the plant functionality as well as the system or equipment being replaced.
- A good documentation management process (good available documentation).
- Good Requirement Management and Validation process.

5.3 LIFE CYCLE COST

The life cycle of computerized systems and equipment are shorter than for corresponding analog equivalent. Other impact on the life cycle cost is the error frequency, where the NNPs experience lower error frequencies of hardware than for software.

The numbers of suppliers are in favor of computerized systems and equipment which in essence means more options and competition, which is considered favorable for the price. On the other hand the NPP's are to some extent forced to use the same supplier who performed the original installation when changes are required, which could lead to high cost due to lack of competition.

The effort and costs for maintenance are lower due to e.g. self-monitoring equipment and few faults to attend.

The fact that technology rapidly advances can also be disadvantageous, as the systems or equipment are aging more quickly, which impacts the life time and contributes negatively to the life cycle cost.

5.4 QUALIFICATION AND SAFETY DEMONSTRATION

The effort of demonstration is determined by the use for the system, e.g. safety or non-safety in combination with classification (according to e.g. GAMP) of the equipment. Meaning that the high level of effort is for a class 5 software system (custom application) used within a safety system which is determined via risk assessments. If the NPP's are performing the change in a non-safety system the depth of safety demonstration is manageable.

Today there are several qualified computerized I&C equipment available in the market. However, the NPP would benefit if an EU standard for qualification of equipment was introduced.

5.5 MAINTENANCE PERSPECTIVE

Computerized systems or equipment require less maintenance and in many cases also simplifies troubleshooting as they are self-monitoring and can therefore in many cases diagnose themselves.

There are, however, some drawbacks using modern computerized technology, such as the consequence of the fewer physical maintenance rounds. This will have a negative impact on the overall plant knowledge, which in essence means that there is no "feeling" for how a healthy plant behaves.

From a maintenance perspective, specifically the uses of OTS systems are favorable, as it is easier to maintain competence in fewer systems. The NPP's are often using the same PLC for many applications within the plant to minimize the assortment.

Troubleshooting is different in computerized systems and equipment compared to analog equivalents. The former requires some kind of indication of the error, such as an error code, while analog systems more traditional troubleshooting is performed involving measurements with instruments. The latter is considered straight forward, however it ought to be a matter of experience. However, root causes may be somewhat trickier to determine in computerized systems, as error codes are only traceable down to a specific unit.

5.6 PROS AND CONS

This section disseminates pros and cons, i.e. arguments for and against, incorporation of computerized I&C systems and equipment. The identified pros which are in favor of incorporating computerized I&C are, in descending order of

- Easier to test previously to installation in plant e.g. during FAT and the use of simulator environment.
- Stable over time, the signals doesn't change over time due to aging of the equipment.
- Very few (or no) faults when commissioned due to extensive testing.
- Provides error code upon errors/failures.
- Configuration parameters can be traced.
- Adjustments more precise.
- Can preferably be OTS systems (general purpose) rather than customized.
- Require less maintenance e.g. Calibration can generally be performed automatically.
- Physically smaller – require less space.

There are also some identified cons which is in disfavor of incorporating computerized I&C. In order of impact, where the most notable disadvantages on top, these are identified as:

- Short life cycle and consequently higher life cycle cost.
- Sensitivity for tough environment (e.g. radiation gives strange results).
- Version control of both SW and HW as well as for the support equipment (SW adds an extra layer of administration).
- Abstract logic implementation (tougher V&V and qualification procedure).
- Vulnerability to computer viruses.
- Troubleshooting methodology is different (e.g. if an error code is given, computerized systems may be harder to troubleshoot).

5.7 BENEFITS AND RISKS WITH CONVERTING TO COMPUTERIZED I&C

Benefits are considered effects of converting to computerized I&C systems or equipment, from which the entire operations can gain in relation to possible risks.

The benefits for modern computerized I&C, in descending order of impact, was considered to be:

- Well suited for handling large data quantities.
- Digital data storage yields easier post-processing of data.
- Data visualization and analysis capabilities are better.
- Self-monitoring.
- Secure system access to ensure only authorized personnel.

- Traceability of changes using an audit trail.
- Loading of latest running configuration.
- New, graphical software is easier to review even for a non-programmer.

Conversely, there were also identified risks with implementing computerized I&C, in descending order of impact:

- Different characteristics than older systems (compatibility issues).
- New types of error modes (e.g. infinite loops).
- Few rounding out in the plant by Maintenance.
- Overload of data, the important information is hidden in the total amount of information.
- The support PC which is required to manage and configure the system ages.

6 Recommendations

This section summarizes a set of recommendations which ought to simplify the decision whether to upgrade a system or not and also what should be especially considered when performing such changes:

- Focus on replacements of systems or equipment which are not related to the safety of the plant, i.e. non-safety related systems.
- Set aside much time and resources to study documentation and compile information regarding the system to be replaced in order to get a good holistic view as well as in-depth knowledge. Knowing the system, how it works, and design choices (e.g. why a specific design was chosen) are keys in order to have a successful project.
- List all features of the system to be replaced; this is used as input to the design phase of the new system, which shall not incorporate more features than this in order to ensure compatibility.
- The characteristics of old systems and modern computerized systems are different, especially in terms of electrical signals. An analog system may have electrical properties of a low pass filter, which the computerized equivalent has not. This may not be in the design specification of the analog system, but a mere consequence of its implementation. Such differences which are somewhat hidden, must be assessed.
- When choosing supplier, ensure that they are familiar with either the NPP industry or other highly regulated industries, e.g. pharmaceutical industry. The aim is that the supplier shall be aware of the requirements in terms of documentation.
- Invite the supplier to work on site in the beginning, as this facilitates the understanding of the system to be replaced. It also facilitates dissemination of information, which is of interest for the future in-house operations.
- Set aside much time to educate all personnel who are about to work in the project (including suppliers) so that all have the same good holistic view and fully agree upon the scope.
- Allow NPP staff to spend time with the supplier to learn the new system but let the supplier stand for the depth of knowledge of the equipment.
- Invest time in Requirement Management and Validation strategies to optimize the implementation both within the project as well as for the life cycle.
- It is considered a good idea to have a defined general purpose system, which has been observed on many of the NPP’s. This should preferably be a versatile OTS system or equipment.
- Perform training on regular basis to understand the system, alarms etc.

7 References

[1] K. Ferm and D. Klamer, "Experience from asset management of installed safety related programmable platforms/systems in Swedish NPPs," Energiforsk AB, Stockholm, 2015.

[2] IEC 61513, ed2.0, Nuclear power plants - Instrumentation and control important to safety - General requirements for systems, 2011.

[3] IEEE 603, *Standard Criteria for Safety Systems for Nuclear Power Generating Stations,* 2009.

[4] GAMP 5: A Risk-Based Approach to Compliant GxP Computerized Systems, 2008.

[5] CORDEL Digital Instrumentation & Control Task Force, ”Safety Classification for I&C Systems in Nuclear Power Plants - Current Status & Difficulties,” World Nuclear Association, London, 2015.

[6] IEC 60880:2006, Nuclear power plants - Instrumentation and control systems important to safety - Software aspects for computer-based systems performing category A functions.

[7] World Nuclear Association, ”Nuclear Power in Finland,” World Nuclear Association, [Online]. Available: www.world-nuclear.org/information-library/country-profiles/countries-a-f/finland.aspx. [Använd 2 September 2016].

Appendix A: Systems studied

Technical data from all the studied systems are compiled in this appendix.

	Forsmark A	Olkiluoto A	Olkiluoto B	Olkiluoto C	Oskarshamn A	Oskarshamn B	Oskarshamn C	Ringhals A	Ringhals B	Ringhals C	Ringhals D
System	System 552	System 551	System 466	532/533	125530 S504	124434 S462	124433 S421	R1 Accurex	R1 Density compensation of reactor level	Accurex - Core exit temperatures	R3/4 WDPF
What kind of I&C System/Equipment is it?	Radiation measurement	Signal processing unit from Mirion	Siemens Teleperm XP	Siemens S7 and PC	PLC	PLC	Signal Calculator only parameter setting	PLC	PLC	Data logger	PLC
What is the name of the system/equipment? Is it a complete system or an equipment	Mirion	Radiation Monitoring System	Turbine automation	532 Control rod operating system 533 Control position indicating system	Complete system Wasteplant control equipment	An equipment	An equipment	ABB AC800M	H&B TZA4 Single equipment	Eurotherm 6100 Paperless Graphic Recorder	WDPF
To what plant system(s) does the I&C system/equipment belong?	Equipment ta an overall strategy for system 550, to be replaced in phases	Equipment for main steam lines radiation monitoring	Turbine	Positioning & rod control	System 504	System 462	System 421	R1	R1	R2, R3, R4 R1 other cases	R3, R4
What is the main function and application for the I&C system/equipment.	Exhaust system, before chimney. Measures gamma radiation in different areas in plant. Purpose to detect damaged fuel rods. RMS (Radiation Monitor System)				Control of pumps, valves and measuring equipment for all systems in wasteplant	Control of pumps, valves and measuring equipment for magnetic filter	Calculate a temperature signal and present it on an instrument	Leak detection. Measuring temperatures	Compensation for reactor vessel level	Measure core exit temperatures, calculate under cooling limit	Control system for reactor
What is the security classification of the I&C system/equipment	IT-security:Class 2	Finnish Class 2	Non-safety	Non-safety + switch gear device class 2	2E	2E	2E	2E	1E	1E or Cat A	1EC for hardware 2E for software

	Forsmark A	Olkiluoto A	Olkiluoto B	Olkiluoto C	Oskarshamn A	Oskarshamn B	Oskarshamn C	Ringhals A	Ringhals B	Ringhals C	Ringhals D
When was the I&C system/equipment implemented and what did it replace?	2006, analogue equipment from Studsvik to MGP (Mirion)	2010 and 2011, Studsvik to MGPi (Mirion)	2005 and 2006 Turbomat Decontic	2003, Norsk data	2014. Replaced old PLC	2015. Replaced old PLC	2015. Replaced old PLC	2015 Replaced old analog/digital equipment named Acurex TEN.	2002 Replaced old analogue equipment named Kent	2011-2014 Replaced old digital equipment named Autocalc	1994-1997
Which project or projects have been done since the installation, on the I&C system/equipment and when? What was the scope of project(s)?	Reactor containment and scrubber stack monitoring	None	None	Replaced PLC and PC	None	None	None	Parameter changes. Alarm limits.	None	None	Power increase on R3 & R4, new measuring channels for sump levels etc.
Describe the I&C System/Equipment architecture. What are the main components? If possible, provide a schematic of the system/equipment. With architecture, it is considered number of subs, processors, communication links etc.	See attached file of implemented equipment (part of the overall system 550)	Mirion	Siemens Teleperm XP, Siemens S5	Siemens S7 PLC	HP -servers, Siemens S7-417H, Distributed I/O, ET 200	Siemens S7-315-2 DP, Siemens HMI, KPT 1000 Basic color DP panel	PR Electronics Signal calculator 2289A	Standalone	Standalone	Standalone data logger which communicate with a DCS system. Division A and B	Standalone
What kind of spare parts are applicable to the I&C System/Equipment and what is the availability of those spare parts?	Detector and circuit boards, good but the compatibility is not as expected thouth new versions.	Shelf product, available on market during lifetime	Shelf products, system available on market. 10 years from commissioning.	Shelf product, available on market during lifetime	Spare parts for twenty years was included in the delivery. available on site	Spare parts for twenty years was included in the delivery. available on site	The product is available on the market	The product is available on the market	The equipment is obsolete and is no longer supported by the supplier.	The product is available on the market	Store replacement units at own shelf

Energiforsk

	Forsmark A	Olkiluoto A	Olkiluoto B	Olkiluoto C	Oskarshamn A	Oskarshamn B	Oskarshamn C	Ringhals A	Ringhals B	Ringhals C	Ringhals D
What is the supplier strategy regarding commissioning and/or modifications of the I&C System/Equipment? What is performed in-house and what is performed by the supplier?	Mostly changes in -house, valid for both the design and commissioning.	Modification but not programing	Modification but not programing	Modification but not programing	Modifications is performed in house	Modifications is performed in house	Modifications is performed in house	FAT & SAT at Ringhals	The equipment is obsolete and is no longer supported by the supplier.	FAT performed at vendor and SAT at Ringhals	FAT & SAT at Ringhals
What is the availability of resources in-house for performing upgrades and/or modifications of I&C Systems/equipment's?	Good but requires communication with the Supplier for support.	Knowledge to change predefined parameters	Available for non-security related parts	Knowledge exists	resources in-house is available for upgrades and modifications	resources in-house is available for upgrades and modifications	resources in-house is available for upgrades and modifications	RAB have knowledge. The equipment is now part of our standard	Knowledge to change parameters	RAB have knowledge. The equipment is now part of our standard	Changed Power Supply Unit, computer, units and parameters
What is the frequency of maintenance and who performs such actions?	Calibration (see STF) about every 3 month. In house performance	Maintenance department	Maintenance department	Maintenance department	Maintenance department	Maintenance department	Maintenance department	Maintenanc e department	1 year, Maintenance department	Maintenance department	Maintenance department
What is the life expectancy of the equipment?	20 year.	10 years	10 years	10 years	20 years	10 years	20 years	15 years	20 years	20 years	20-30 years
How does the I&C system/equipment interact with other systems/equipment's, i.e. what interfaces and/or communication protocols are utilized?	-	FAT and pre-com with one system installed in the plant but not connected.	-	-	None	None	None	Input is hardwired. Output to screen and to plant computer (RS232)	Input is hardwired Output hardwired	Input is hardwired Output hardwired and data link (OPC/Modbus)	Operator monitoring
How was the I&C system/equipment tested before commissioning and replacement of the old system/equipment?	FAT & SAT1 (delivery control) incl. Channel tests.	FAT	Supplier wrote and qualificated code. Collaboration with STUK for safety related parts	Site testing	FAT test complete system	FAT test complete system	FAT test complete system	Temporary test in plant with ability to change back to the old equipment	SAT	Test environment, FAT	FAT

Appendix B: Questionnaire statements

This appendix comprises the statements in the questionnaire, which is the foundation for the quantitative results presented in the report. Each statement should be graded from 1 (strongly disagree) to 5 (strongly agree). The result from the questionnaire is compiled in the end of this appendix.

Statements SM1-SM11 relates to the general work methods during changes in I&C systems.

ID	Statement
SM1	I&C projects works cost effective.
SM2	The business has enough internal competence, including consultants (without help from suppliers) regarding I&C systems/equipment.
SM3	The business has well developed processes/instructions to execute replacement of I&C systems/equipment.
SM4	We have a good and working security culture when performing I&C changes.
SM5	I feel confident regarding the quality of I&C changes.
SM6	We should outsource more tasks to the supplier during I&C changes.
SM7	During changes of I&C systems/equipment, enough effort is put into documentation and long-term maintenance.
SM9	We receive good documentation from the suppliers during purchasing of changes in I&C systems/equipment.
SM10	We have good working procedures for requirement management during changes of I&C systems/equipment (replacement and change of existing systems).
SM11	We have good working procedures for verification and validation of I&C systems/equipment.

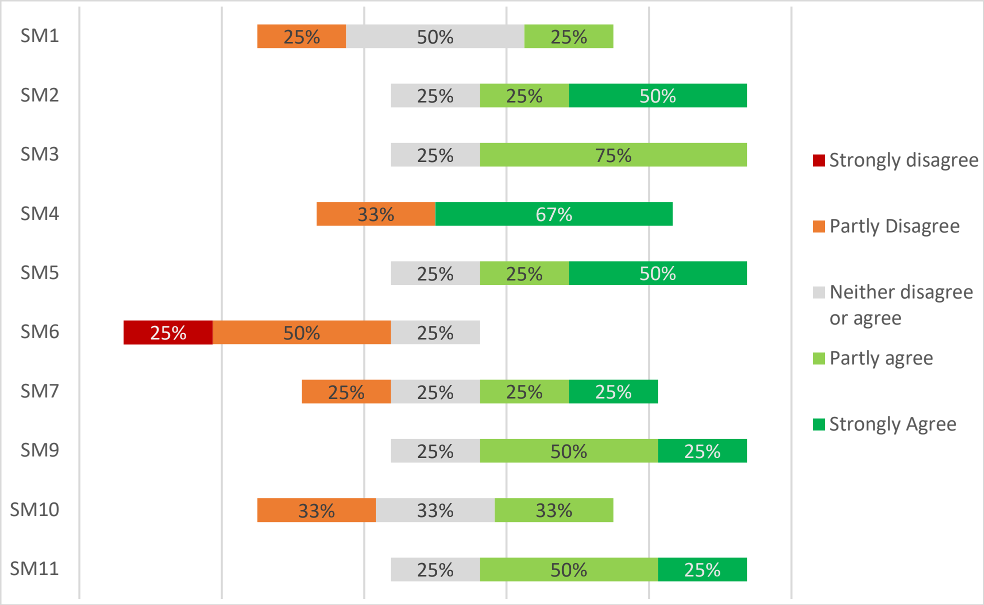
Statements SM12-SM29 covers the specific functions in I&C change projects. It shall be noted that some of these statements are not referenced in the report, as the coverage and results did not affect the focus of the report.

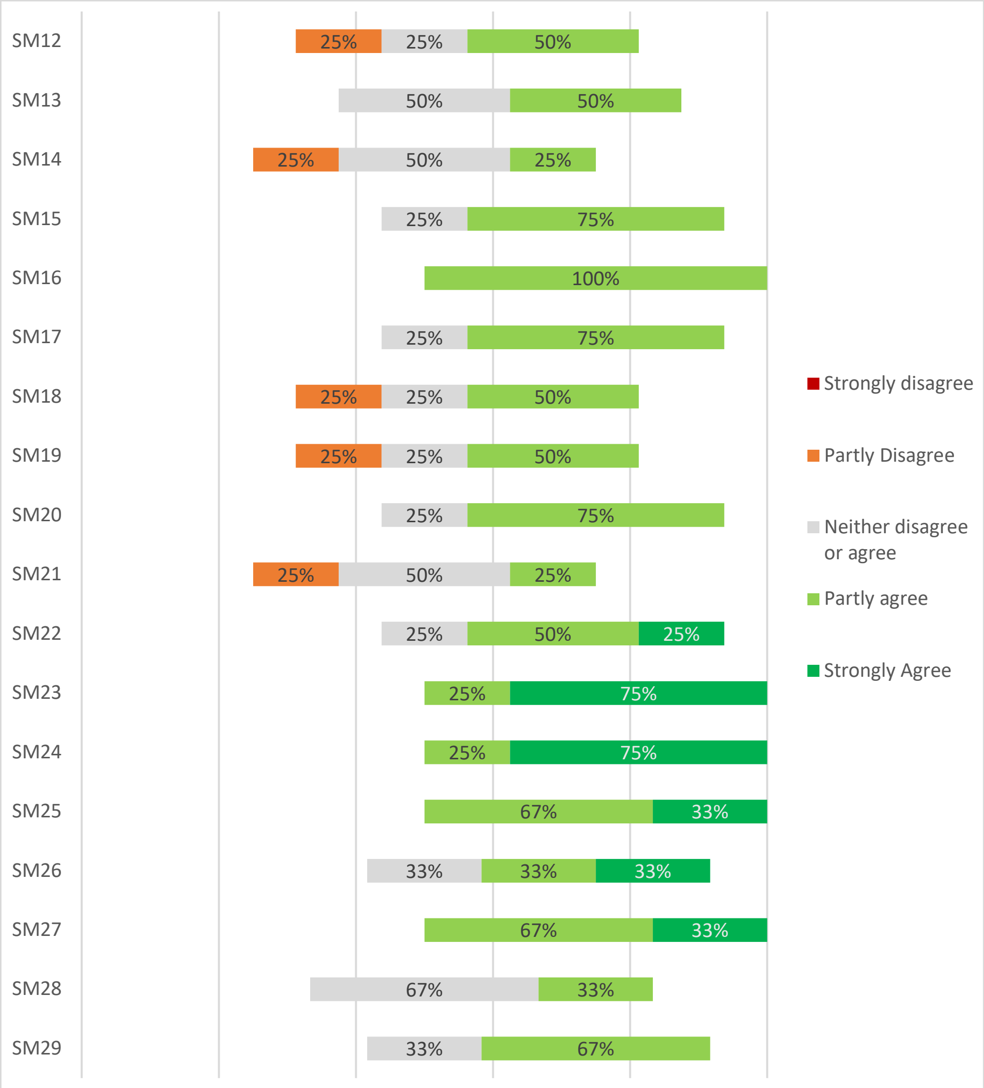
ID	I think that the following areas works well during I&C changes:
SM12	Purchasing/Packaging of projects
SM13	Project management
SM14	Plant design
SM15	System design
SM16	Detail design
SM17	Purchasing of hardware
SM18	Purchasing of software
SM19	Configuration management
SM20	Verification and validation
SM21	Technical risk management
SM22	Human technology interaction

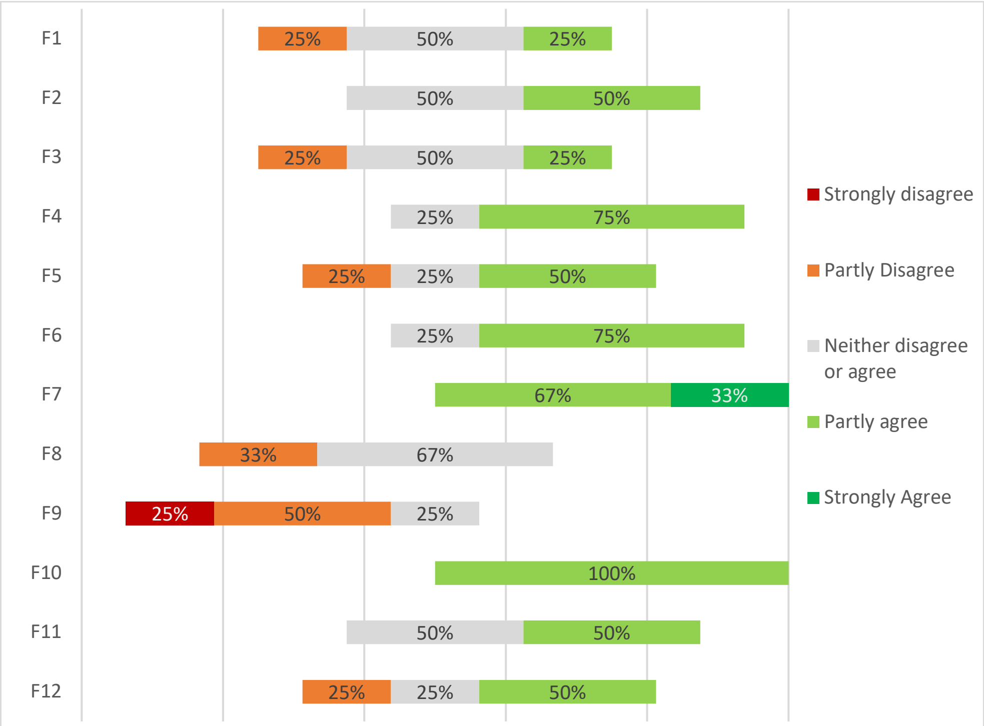
ID	I think that the following areas works well during I&C changes:
SM23	Testing Factory acceptance test (FAT)
SM24	Testing Site Acceptance test (SAT)
SM25	Installation
SM26	Maintenance
SM27	Operations
SM28	PSG
SM29	Contact with authorities (e.g. SSM, STUK)

Statements F1-F12 relates to how the characteristics of the I&C system affects the suitability to computerize them.

ID	Statement
F1	Systems with many functions/tasks are especially suitable to be replaced with digital I&C systems/equipment.
F2	Systems with one or a few well defined functions/tasks are especially suitable to be replaced with digital I&C systems/equipment.
F3	Systems with many interfaces towards other systems/equipment are especially suitable to be replaced with digital I&C systems/equipment.
F4	Systems with one or a few well defined interfaces towards other systems/equipment are especially suitable to be replaced with digital I&C systems/equipment.
F5	Systems requiring specialists for maintenance/updates are especially suitable to be replaced with digital I&C systems/equipment.
F6	Systems not requiring specialists for maintenance/updates are especially suitable to be replaced with digital I&C systems/equipment.
F7	Systems handling large data quantities (e.g. data from multiple sensors) are especially suitable to be replaced by digital I&C systems/equipment.
F8	Systems handling small data quantities (e.g. door contacts) are especially suitable to be replaced by digital I&C systems/equipment.
F9	Systems with a high safety classification are especially suitable to be replaced with digital I&C systems/equipment.
F10	Systems with a low safety classification are especially suitable to be replaced with digital I&C systems/equipment.
F11	Physically large systems are especially suitable to be replaced with digital I&C systems/equipment.
F12	Physically small systems are especially suitable to be replaced with digital I&C systems/equipment.


SM1 25% 50% 25%
SM2 25% 25% 50%
SM3 25% 75%
SM4 33% 67%
SM5 25% 25% 50%
SM6 25% 50% 25%
SM7 25% 25% 25% 25%
SM9 25% 50% 25%
SM10 33% 33% 33%
SM11 25% 50% 25%
Strongly disagree
Partly Disagree
Neither disagree or agree
Partly agree
Strongly Agree


SM12 25% 25% 50%
SM13 50% 50%
SM14 25% 50% 25%
SM15 25% 75%
SM16 100%
SM17 25% 75%
SM18 25% 25% 50%
SM19 25% 25% 50%
SM20 25% 75%
SM21 25% 50% 25%
SM22 25% 50% 25%
SM23 25% 75%
SM24 25% 75%
SM25 67% 33%
SM26 33% 33% 33%
SM27 67% 33%
SM28 67% 33%
SM29 33% 67%
Strongly disagree
Partly Disagree
Neither disagree or agree
Partly agree
Strongly Agree


F1
25%
50%
25%
F2
50%
50%
F3
25%
50%
25%
F4
25%
75%
F5
25%
25%
50%
F6
25%
75%
F7
67%
33%
F8
33%
67%
F9
25%
50%
25%
F10
100%
F11
50%
50%
F12
25%
25%
50%
Strongly disagree
Partly Disagree
Neither disagree or agree
Partly agree
Strongly Agree

Appendix C: Interview guidelines

This appendix comprises the topics discussed during the personal interviews which are the foundation for the qualitative results and analysis in the report:

- Within which area do you see the major challenges with change projects within I&C?
- Which kind of systems/equipment do you think is suitable to replace in favor to digital technology?
- According to you, which are the most important factors which make change projects within I&C successful?
- According to you, what should be improved to ensure more success in change projects within I&C?
- According to you, what are the major cost drivers for both computerized and analog equipment
- According to you, what are the major success factors in your I&C project?
- What has been the major challenges in in your I&C project?
- What would you do different if you had the possibility to do the project all over again?
- What important experiences would you emphasize for future I&C projects to learn from?
- Do you consider the project has had access to the proper resources (competence and amount)?
- According to you, should the supplier be more involved, or less involved, in change projects concerning I&C systems/equipment? (Feel free to provide examples regarding within which parts and how the supplier should be involved.)
- To what extent has changes been performed in the systems/equipment since its installation?

Appendix D: Interview summaries

This appendix is summarizing the conclusion of the received answers from interviewed personal at all NPP's.

Background	Comment
Within which area do you see the major challenges with change projects within I&C?	To understand the original plant functionality burring all type of operations. "I&C is like a spider in the plant; legs everywhere". The challenge to see through all consequences when changing old equipment independent of the new equipment that are chosen. To separate to plant behavior from behavior that is related to the old equipment.
Which kind of systems/equipment do you think is suitable to replace in favor to digital technology?	Everything that are non-safety and safety related equipment. Safety, only if there are no other options. Sometimes also the original equipment are computerized and in these cases there are often no other choices to changes it when it is not possible to repair it any more.
According to you, which are the most important factors which make change projects within I&C successful?	• Understand the plant functionality • Good documentation and skilled staff with high knowledge • Invite the supplier to the plant to learn the plant behavior • Spend time at the suppliers site during design and verification • Use suppliers that familiar with highly regulated industries • Choose dedicated equipment for the task if possible, not to large or complex equipment • Don't add new functionality just because it is easy in a computerized system, it also needs to be maintained and that could be expensive
According to you, what should be improved to ensure more success in change projects within I&C?	• Common EU standard for qualification of equipment. • Spend more time in the beginning of the projects to really understand the task
According to you, what are the major cost drivers for both computerized and analog equipment	• Qualification, if there is no qualified equipment available. Especially for safety functions • Unexperienced staff, both internally and at supplier who are not familiar with the plants behavior • Over the life cycle, the aging. SW needs to be replaced sooner than analog. However analog requires more maintenance over the years

Background	**Comment**
According to you, what are the major success factors in your I&C project?	• Keep the system as simple and isolated as possible • Use systems and equipment dedicated for its task • Enough time to really understand both the plant and the old equipment before replacement • Good documentation over the old system • The use of a supplier who was familiar with the nuclear environment and it's requirements
What has been the major challenges in in your I&C project?	• To get the supplier to understand • Extensive Qualification, Verification and Validation
What would you do different if you had the possibility to do the project all over again?	• Spend more time in the beginning to ensure that the supplier really had understood the task
What important experiences would you emphasize for future I&C projects to learn from?	• Make as few customizations as possible from standard products • Chose the supplier wisely • Spend time in the begging • Use the advantages with SW tools, test environment, simulator etc.
Do you consider the project has had access to the proper resources (competence and amount)?	Yes, but since the energy market is changing, lower prices and people leaving the business, it can be harder in the future.

Background	Comment
According to you, should the supplier be more involved, or less involved, in change projects concerning I&C systems/equipment? (Feel free to provide examples regarding within which parts and how the supplier should be involved.)	It is good to have an involved supplier. The supplier normally knows their equipment best and if they are involved future changes will go smoothly.
To what extent has changes been performed in the systems/equipment since its installation?	Normally there are required some parameter adjustments but not much more than that. After ca 10 years HW needs to be replaced due to aging.

UPGRADING TO MODERN COMPUTERIZED I&C SYSTEMS

This report investigates a handful of I&C change projects on the NPP's in the Nordic countries and identifies common pitfalls and success factors.

Among the findings are that the NPP's have much to benefit from transiting to modern computerized I&C systems and equipment when it concerns non-safety classified systems or equipment. Furthermore, utilization of off-the-shelf products has been identified as a cost-effective way to perform upgrades.

Finally, the importance of experienced and competent personnel in-house and at supplier end, as well as much time spent together with supplier is found to be of paramount importance.