MANAGING I&C OBsolescence FOR NUCLEAR POWER PLANT LIFE EXTENSION

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Abstract. Most General Electric (GE) Boling Water Reactor (BWR) nuclear power plants (NPPs) in operation now were built in 1970’s and 1980’s, and majority of them are near the end of 40 years of initial licensed operation life. Part obsolescence for instrumentation and controls (I&C) has been a continuing issue and causes higher cost and maintenance problems. Diminished skill sets also affect the ability to maintain older equipment and systems. However, the pace for I&C upgrade has been slow due to economic and regulatory constraints. Plant life extension changes the economic model for I&C obsolescence issue. The estimated revenue for all GE BWRs for a 20-year life extension is estimated to be $356 billion in today’s dollar. Programs such as Performance 20[TM] are designed for plants to achieve maximum benefits for 20 more years of operation with a possible 20% additional power level output have huge economic benefits for the nuclear power industry. This also brings new incentives and opportunities to deal with obsolescence issues with I&C modernization and upgrade since repair to survive mode would result in higher cost and risk for the upcoming decades. This paper discusses system strategy and some technical practices of GE-Hitachi Nuclear Energy (GEH) around these issues. Six Sigma tools, such as Quality Function Deployment (QFD), can be used to help prioritize I&C upgrades for coming years. The QFD should be developed with inputs from the plant staff including engineering, maintenance, and operations. Possible solutions for each of the system can then be developed. This evaluation will identify the optimal solution for a given system. Potential I&C upgrades that would meet the listed Critical to Quality (CTQs) for a GE BWR are Power Range Neutron Monitor (PRNM), Wide Range Neutron Monitor (WRNM), Rod Control and Management System (RCMS),[1] Turbine-Generator Electro-hydraulic Controls (EHC), Recirculation Flow Control (RFC), Feedwater Level Control (FWLC), etc. Where possible, I&C modernization should be based on a digital system design and application of newer electronic devices with user design ownership and more flexibility for future component replacement or upgrade, such as Field Programmable Gate Array (FPGA). The longevity of the new design must be evaluated to ensure that it can help to improve future obsolescence situations. Continuous evaluation is required to manage obsolescence to ensure the continued operation of the plant for the reminder of its extended life.

1. Overview of GE BWR Nuclear Power Plants

There are 49 GE BWR nuclear power plants currently operating around the world as shown in Figure 1. Their initial licensed lives were about 40 years. Among them, the earliest one is Oyster Creek Generating Station, Unit 1, which started its commercial operation in December 1969. Now its licensed operating life will be expired within less than two years. As shown in Figure 2, the average operated life of these plants has already exceeded 26 years and average

[1] Reference 1 provides additional discussion of these systems.
licensed life left is less than 12 years\(^2\). Most of these plants will go into a process for licensed life extension with 20 more years. Some with take advantage of programs such as Performance 20\(^\text{TM}\) that are designed for plants to achieve maximum benefits for 20 more years of operation with a possible 20% additional power level output to maximize the revenue for the plant. Each nuclear power plant can generate 0.5~1 million dollars revenue per day [2]. Fully operated 49 BWR power plants generate 8.9~17.8 billion dollars revenue per year. If all these plants can extend their lives for 20 more years, the estimated total revenue would be $178~356 billion in today’s dollar value. The economic benefits would be even higher if a nuclear plant seeks to increase its power output level (20% more) by programs such as Extended Power Uprate (EPU). Therefore, the total value of life extension for these power plants is enormous. Since I&C systems are the central part of a nuclear power plant, it will not only directly affect the life extension process and its result, but also will be very critical for plant more reliable and safer operation future plant operation with lower maintenance cost.

\[\text{FIG. 1. Current operating GE BWR NPPs and life status}\]

\(^2\) Some plants are licensed for less than 40 years.
2. Major I&C Obsolescence Issues

These BWR power plants shown in Figure 1 are products of several generations of development and designs. Although some technology improvements have been made and evolved into them for various types of BWRs, major portions of the I&C systems for these plants are still more than 20 years old. The need for I&C upgrade for these plants are well documented [3, 4, 5]. The tremendous development and technology advancement that has occurred in other industries in the last two decades has generally not been implemented into these plants. Following are major issues associated with I&C obsolescence for these plants:

— Technology obsolescence: major design architectures and system communication bus standards and related assembly and manufacturing processes are obsolete. This is inevitable as technology advancement will bring in new products causing existing installed products to be unavailable. Should this happen, a major overhaul of the affected I&C will be required.

— Parts Obsolescence: required parts are no longer manufactured. This happens as manufacturers introduce new products to meet market needs. In most cases, the impact is not severe and alternative parts can be found. However, should the obsolete part be a critical component of a design, then re-design with new parts would be required.

— Diminishing skill sets: knowledgeable plant and supplier staff are lost by attrition or retirement. With technology advancement, the younger plant staff would be more knowledgeable with new technologies, thus leaving a knowledge gap in the plant staffing.

— Regulatory hurdles: In the past, NRC reviews for upgrading safety related systems has made I&C modernization a complicated and costly process. In addition to making the proposed upgrade difficult for a plant owner, the process also makes it difficult for vendors to introduce new products that have not already been approved by the NRC.
While the first three issues are drivers for I&C upgrades, the last is a driver or primary cause for the lack of progress in the I&C modernization for operating plants. In the deregulated environment, plant owners typically base their decision for I&C upgrades on economic benefits or regulatory requirements instead of obsolescence needs or technological advancement. Although the recent advancement in digital technology has been felt in all corners of the world from people’s daily life to all industries, the nuclear industry in general is still in the analog world. The advantages of higher accuracy, less maintenance, higher speed and reliability of the digital equipment are seldom sufficient justification for an major system upgrade without additional drivers or clearly defined costs benefits. As the decision for I&C upgrades is delayed, the obsolescence issues with current I&C system continues to exacerbate. In view of plant life extension, the obsolescence issue eventually will affect plant operation and must be dealt with sooner instead of later. With the current state of affairs, a systematic approach is required to identify and prioritize potential upgrades.

3. GEH Approach to Managing I&C Obsolescence

3.1. Challenges to Managing I&C Obsolescence

The fast pace of technology advancement makes parts obsolescence a daily event. As an I&C supplier, GEH needs to be effective in managing obsolescence to support its customers. The GEH approach to managing obsolescence is shown in Figure 3. There are several challenges in managing obsolescence. These are:

1. Ability to predict when parts will become obsolete - The expected life and reliability of several major components, e.g., CPU, may be evaluated to forecast their future needs. However, the availability of most parts is market driven which makes prediction virtually impossible.

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**FIG. 3 Overview of GENE Approach in Dealing with I&C Obsolescence**
2. Effective Maintenance Program – having an effective maintenance program that also considers parts availability is essential in managing obsolescence. Too often, maintenance programs in operating plants are focused on the short-term need of bringing the plant on line or sustaining plant operation. Such programs rely on the know-how of skilled personnel. However, as the skill set diminishes with the technological advancement and with personnel attrition, this ability would not to meet challenges of growing obsolescence issues. Personnel training and a database for maintenance needs is expected to be essential in managing obsolescence for the long term.

3. New Generation of I&C Development – Both I&C manufacturers and GEH are involved in developing new I&C products. The I&C manufacturers have a market based need for the development. GEH is involved in applying state of the art design for new plant applications, e.g., ESBWR. Introduction of new products that can perform similar functions may cause the existing part to become obsolete. In addition, the new part may not meet the form, fit and function requirements to replace the obsolete part.

4. Industrial and Regulatory Requirements – The NRC and industrial organizations, e.g., EPRI, ANS, IEEE, place various requirements and limitations to the upgrades of the I&C systems. These requirements must be fully addressed during the design and implementation of the upgrade. Therefore, GEH would establish a platform that has been approved by the NRC and expand on it for other applications for future needs. The Nuclear Measurement Analysis and Control (NUMAC) is the approved platform for safety related applications in GE BWRs.

3.2. GEH Approach

The GEH approach in response to these challenges is a multi-faceted program in the design and manufacturing of the I&C products that would minimize the obsolescence concerns. The key elements of the approach are as follows:

1. Apply modular design for both hardware and software so that any changes can be limited to module instead of the entire system. The modular design also allows forward and backward compatibility in case a component or module has been replaced.

2. The design bases for I&C systems must be maintained to facilitate the process for any parts changes or system re-design due to obsolescence. Any new part or new design must meet the original design bases of the system. This allows the designer to have wider options in selecting the new design. In such cases, it would be advantages to select widely used components in other industries and standard communication protocols when possible. Components dedicated for aeronautical, aerospace, and military applications usually not only have higher quality, but also have longer supported life compared with those used in other general areas. These components have a higher priority for design selection in nuclear applications. A standard communication bus or networking protocol are even more widely supported based on opened standards, for example, PCI bus and Ethernet. When a selected component or design architecture is compatible with those standards and supported with multiple
3. supply sources, it is usually readily available for getting long-term supply. Leveraging the design bases can be an important tool in managing obsolescence.

4. Apply advanced simulation and analysis where possible so that the compatibility of any replacement part can be proven prior to design implementation.

5. Maintain the rigor required for the hardware and software design process. For example, the confirmation of the parts or design meeting the design bases of the system is required to ensure that the part can be used. The verification and validation (V&V) process for the software must be applied without any compromise to the integrity of the software.

6. Ensure that any new parts or design being applied would meet the same standard as required, e.g., the new part must meet the EMI or environmental requirements as specified for the original parts. This is in addition to other design requirements and long term viability requirements of the parts.

7. Apply Six Sigma and Lean methodology to optimize the design process and to ensure the quality of the final product.

These elements in the GEH approach have proven to be successful in providing I&C upgrades for various reasons, including power uprate and plant life extension.

3.3. Example of GEH Approach
The Six Sigma and Lean methodology aims to reduce the total number of components for a design to improve quality and reliability. This also reduces concerns for future obsolescence. The advancement in I&C technology provides many opportunities to reduce the number of components and replace them with software. However, the software may be proprietary to the manufacturer which then causes a potential obsolescence issue because the designer and/or system provider do not have any intellectual property ownership in selected components for the final product. With more digitized design and availability of new generation of FPGA devices, the picture starts to improve. A designer can now own a board level design as well as the design inside a processing component. The basic principle of this type of devices is a designer designs all necessary functions and logic, and then programs it into a chip. Therefore the designer has the design ownership of the component.

![FIG. 4 Overview of design flow of FPGA devices](image-url)
This type of components has been widely used in mission and safety critical applications in aeronautical, aerospace, and military areas [6]. Multiple providers and growing development is lowering their future costs. Not only they can be used for a digital based design, partially analogue based devices are also available. Use of one component to replace most or even all components for signal processing on an old generation board is not impossible any more. Figure 4 illustrates a overview design flow of this type of devices. It can been seen that almost all types of traditional digital components can be designed into this type of device, which includes microprocessors, DSPs, bus control logics, and networking components. Those are usually made into IP cores and provided to users. Figure 5 shows a simple application example of a such device in a upgraded design of BWR reactor rod control boards. It is apparent that the simplified design helps to ease concerns for part obsolescence of an I&C system considerably.

![Image of a programmable device](image)

**FIG. 5** A programmable device used to simplify and upgrade a design of BWR reactor rod control board

4. **Six Sigma Methodology**

The GEH approach described above is the implementation approach. In view of the extensive need for I&C upgrade to support plant life extension, a strategic level approach is required to identify and prioritize the needs for the I&C upgrades. In this case, GEH would recommend the application of the Six Sigma methodology to define the plant needs.
4.1. Quality Function Deployment (QFD)

The lessons learned from the GEH experience in various I&C upgrade projects is that a systematic approach is required in the planning of the I&C upgrades to support plant life extension. GE has embarked on the Six Sigma Quality program since 1996. Six Sigma tools, such as Quality Function Deployment (QFD), can be used to help prioritize I&C upgrades for the future. Quality Function Deployment (QFD) is a structured methodology used to identify customers' requirements (voice of customer) and translate them into key design requirements or process deliverables (voice of engineers). The QFD process involves:

- Understanding Customer Requirements – this is also known as identifying the customer’s critical to quality (CTQ) needs for a specific design.
- Quality Systems Thinking – this means initiating a design with quality requirements defined as opposed to adding in quality at the end of the design process.

QFD can be used at many levels to optimize the quality and value of the design to achieve total customer satisfaction. Justification to include or exclude various design features is one of the aspects in applying QFD in the design process.

QFD is usually applied to help designers focus on ways to improve their processes or products to meet or exceed customers' expectations. In this case, QFD can be used to help prioritize the various I&C upgrades to support plant life extension and/or extended power uprate. In such applications, the expectations or voice of the customer are the requirements for plant life extension as defined by the plant staff that is tasked to operate the plant for the next several decades.

4.2. QFD Application for Plant Life Extension

4.2.1. Team Selection for QFD

The success of a QFD depends on two primary factors: the selection of the right team and the correct identification of the CTQ. As noted above, CTQs represent the design requirements and it is essential to have the correct requirements in developing the plan for I&C upgrades. The correct identification of CTQs requires the participation of the right team. The team should be comprised of knowledgeable stakeholders or process owners from various groups. Diversity is a must for group composition to ensure that all necessary inputs are collected. As a minimum, the team should include individuals from engineering, maintenance and operations. The selection of these individuals is obvious as they are involved in the daily activities with the I&C system and equipment. Their input would be vital in identifying the problem areas and other concerns. In addition, quality assurance (QA), outage management, and plant strategic planning staff should be included. The involvement of QA is to identify quality related issues regarding the current or upgraded systems and equipment. Since most of the upgrade would be installed during an outage, the presence of outage management is essential to ensure a seamless integration between the outage team and the installation team. The plant strategic planning staff would be able to identify strategic requirements, such as expanded capabilities to support EPU. Other functional groups, e.g., licensing, may be
required depending on the plant situation. The goal of this diverse team is to produce a comprehensive set of CTQs.

4.2.2. Define CTQ

The team will define the CTQ that are applicable to the plant. Some examples of CTQs are:

(a) Reliability – Each BWR represents a significant source of revenue to the plant owner. Therefore, any upgrade must be able to optimize the plant availability. This CTQ is relatively easy to achieve in the application of modern I&C technology.

(b) Ease of Maintenance – A major complaint of the old I&C system is the burden in maintenance. The high cost of maintenance would need to be eliminated to justify any upgrade.

(c) Ease of Operation – Equipment that is easy to operate would reduce the possibility of human error and would improve plant availability and safety.

(d) Outage Impact – Most upgrades would be installed during an outage. Upgrades that can be installed without impacting scheduled outage duration would be more desirable. As more plants are moving to shorter outages, with 15 days or less being the norm for most US plants, the designers are tasked to design that system that can be installed during this short duration.

(e) Long Term Viability – The purpose of the upgrade is to support plant life extension. Therefore, any upgrade will have to be able to achieve the goal of supporting plant operation for future decades.

(f) ALARA – Most I&C systems are located in low dose areas. However, any upgrade involving equipment inside a high radiation zone will have to be completed with the ALARA goal. Further, any I&C system in the high radiation zone that can be relocated to a low dose area would be beneficial to the plant and plant staff.

(g) Ability to Support Plant Operation (e.g. EPU) – In addition to added years of service, plant life extension and other programs may add other design requirements. For example, additional protection may be required to ensure plant stability due to EPU. More reliable feedwater level control may be needed. These strategic level requirements need to be defined and evaluated for I&C upgrades.

The CTQs are then weighted based on the consensus of the plant staff. The performance of each I&C system can then be evaluated against the CTQ. The result of this evaluation represents the priority of the systems that would require upgrade or other actions. Possible solutions for each of the system can then be developed based on a more specific set of CTQs for a specific system. This evaluation will identify the optimal solution for a given system. It should be noted that an upgrade might not be the optimal solution for all obsolescence issues. For example, if the issue is with a part, e.g. the scram contactor in the reactor protection...
system, it may be more cost effective for the plant owner to team up with other owners to purchase sufficient parts for the rest of the plant life before the part becomes obsolete. The result of the QFD process is presented in a matrix known as the House of Quality. An example is shown in Figure 6. The House of Quality can be expanded until the desired details for the design or decision has been established.

4.2.3. Examples of Potential Upgrades

Potential I&C upgrades that would meet the listed CTQs for a GE BWR are Power Range Neutron Monitor (PRNM), Wide Range Neutron Monitor (WRNM), Rod Control and Management System (RCMS), Turbine-Generator Electro-hydraulic Controls (EHC), Recirculation Flow Control (RFC), and Feedwater Level Control (FWLC). These are all I&C systems that have been upgraded for BWR. The PRNM provides a more reliable and advanced monitoring of the neutron flux in the reactor core. It also provides the stability monitoring function that is required for plant safety. The WRNM provides a simplified design for the neutron monitoring in the startup range that allows the operator to focus on rod movements instead of the potential prompt jump response of the old startup range detector system. The RCMS provides yet another fault tolerant rod control system with advance HMI. These systems are further discussed in Reference [1]. Upgrade of the EHC improves the
availability of the Turbine Generator and the plant. Upgrade of the RFC and the FWLC improves plant availability and safety. The recirculation flow in a BWR has a direct correlation to plant power level. The feedwater level must be maintained to ensure adequate cooling for the core.

4.4 Long Term System Strategy in Managing Obsolescence

The above approach is the first step in managing obsolescence for plant life extension. During the process of the upgrade, it is necessary to continue the systematic approach to manage the obsolescence of I&C systems for the future decades. The current reactive practice is not advisable because obsolescence problems are going to become more difficult in the future. Therefore, it is necessary to develop a strategic plan and system for continuous managing of obsolescence issues. The plant health in terms of equipment performance history and parts availability needs to be evaluated on a continuous basis so that obsolescence issues can be dealt with proactively. The objective is to support NPP customers to achieve minimal outage impact and power output uprate with 20 more years of operation, and safer and more secured and reliable operation.

5. CONCLUSIONS

Plant life extension and power output uprate of current operating GE BWR power plants have huge economic benefits and positive impact on global environment related issues. I&C modernization and upgrade is not only necessary for dealing with aging and part obsolescence problems, but also will keep nuclear industrial more reliable and safer for future operation. The I&C modernization must be executed with systematic planning and with tools such as QFD. The planning must first identify ad prioritize the systems for the upgrade, based on plant experience and projected needs. For this reason, a diverse plant staff is required in the planning to derive an effective upgrade program. Once developed, the upgrade will solve today’s obsolescence issues. Continuous evaluation of plant needs is necessary for managing obsolescence. With more attention and support from both public and governments and available proven new technologies, it’s a great opportunity for those older generation plants to be upgraded. With available new generation of licensed GEH I&C products, decision making, planning, and effective management will be most critical elements for a success of this migrating process.

REFERENCES


