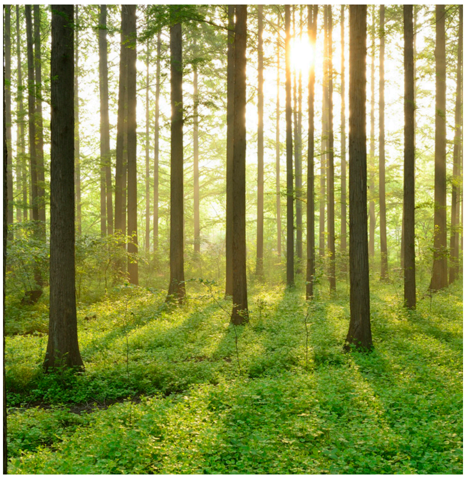
WIRELESS IN NUCLEAR APPLICATIONS IN THE US

REPORT 2020:683



NUCLEAR

ENERGIFORSK NUCLEAR SAFETY RELATED I&C – ENSRIC

Energiforsk

Wireless in nuclear applications in the US

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Foreword

Wireless is by many considered as a prerequisite for digitalization, to enable introducing sensors and other equipment on a wide scale. The nuclear sector has however been reluctant to wireless, given the cyber security and EMC challenges.

U.S. nuclear power plants are fore runners in introducing wireless technology in the sensitive environment in the nuclear facilities. Security challenges have been solved and different technical solutions have been used. R&D program ENSRIC sent a team with experts from the Nordic nuclear power plants, Patrik Larsson Ringhals AB, Samuel Axelsson Ringhals AB, Tobias Hillbom Forsmark Kraftgrupp AB and Petri Pyykko Fortum, led by senior consultant Fredrik Bengtsson AFRY to learn from the U.S. experience.

The activity is included in the Energiforsk Nuclear Safety Related Instrumentation and Control program – ENSRIC. The program is financed by Vattenfall, Sydkraft Nuclear/Uniper, Teollisuuden Voima Oy (TVO), Fortum, Skellefteå Kraft, Karlstads Energi and the Swedish Radiation Safety Authority.

Sammanfattning

Trådlös teknik har generellt inte använts inom kärnkraften för att mäta processvärden dels pga restriktioner kring säkerhet. Osäkerheten kring eventuell påverkan på känslig säkerhetsutrustning från elektromagnetisk kompatibilitet (EMC) har varit den största anledningen. Utvecklingen av trådlös utrustning har varit snabb de senaste åren och används mer och mer inom övrig industri.

En slutsats från tidigare ENSRIC aktiviteter var att kärnkraftverken i USA har kommit ganska långt med att införa trådlös teknik. ENSRIC initierade därför denna studie för att bekräfta detta.

Målet med uppdraget har varit att se och lära av deras erfarenhet inom detta område genom studiebesök till USA.

Under resan besöktes organisationer, energiföretag och leverantörer och gemensamt för alla var att kärnkraftindustrin måste sänka sina kostnader för att vara konkurrenskraftiga på marknaden.

En gemensam nämnare var viljan att digitalisera och att nyttja trådlös teknik. En förutsättning för att nyttja denna nya teknik är att det finns en infrastruktur på plats. Det finns inte en lösning som passar alla företag utan detta måste analyseras utifrån förutsättningar som finns på respektive företag eller anläggning. Olikheter i marknader och vilken infrastruktur som finns installerad kan påverka den tekniska lösningen. En del företag vill nyttja kabelanslutna givare medan andra vill nyttja Wi-Fi eller DAS. Vilken strategi som väljs måste bedömas utifrån förutsättningar och möjligheter som finns på anläggningarna.

Mer mätdata kan innebära att kraftverken kan förändra underhållsarbetet till ett mer tillståndsbaserat underhåll istället för tidsbaserat underhåll.

Etablering av övervakning och diagnostik center, där all tillgänglig mätdata för anläggningen/företaget samlas och analyseras, kan förbättra tillgänglighet och produktionskostnaden.

Elektroniska arbetspaket var ett mål för flertalet av energiföretagen och några hade redan infört detta.

Summary

Wireless technology has traditionally not been used in nuclear applications, mainly due to restrictions in safety and security. One of the major concerns is the impact from electromagnetic compatibility (EMC) and the vulnerability to wireless transmission for safety functions. The development of wireless applications has however been very strong during the last years, and the technology is widely used in other industries.

One conclusion from previous ENSRIC activities was that U.S. NPPs and suppliers of wireless solutions have come quite far regarding implementing wireless solutions in different applications. Therefore, ENSRIC launched this study with an in-depth study of how wireless is used in the nuclear sector in the U.S.

Objectives for the trip was to increase the hands-on knowledge on opportunities and challenges regarding wireless installations by studying U.S. nuclear applications.

During the trip a couple of different suppliers and utilities were visited. Common for all was that the nuclear power plants have to reduce cost in order to be competitive on the market.

A common denominator for all utilities is the digitalization and the use of wireless equipment. Prerequisite for digitalization is the infrastructure the so called enabler. There is not one kind of solution that suite all NPP’s instead this needs to be analysed case by case. Differences in the market where they operate and what kind of infrastructure they have in place today will impact the technical solution for wireless equipment. Some utilities will use more wired sensors and others will use wireless via Wi-Fi or DAS. This strategy must be decided case by case for each plant. Each utility has their own conditions that must be taken into account.

More measurements and data will enable power plants to go from a time based maintenance to maintenance based on condition instead.

The establishment of a Monitoring and Diagnostic centre, where all available plant/fleet data are collected and analysed, could improve the performance and plant efficiency.

Electronic Work Package was another goal for all/many of the powerplants and this was also already implemented at some of the NPP’s.

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1 Background

1.1 INTRODUCTION

Wireless technology has traditionally not been used in nuclear applications, mainly due to restrictions in safety and security. One of the major concerns is the impact from electromagnetic compatibility (EMC) and the vulnerability to wireless transmission for safety functions. The development of wireless applications has however been very strong during the last years, and the technology is widely used in other industries. Lately, wireless has also been used to some extent in the Nordic nuclear power plants (NPPs), in non-safety applications, and mainly in temporary installations during outages etc.

The area of wireless applications in connection to instrumentation and control (I&C) of NPPs is highly interesting, this is why the ENSRIC carried out a feasibility study [8] and an international seminar [9] on wireless in nuclear during 2017/2018. One conclusion from these activities was that U.S. NPPs and suppliers of wireless solutions have come quite far regarding implementing wireless solutions in different applications. Therefore, ENSRIC launched this study with an in-depth study of how wireless is used in the nuclear sector in the U.S.

Objectives for the trip was to increase the hands-on knowledge on opportunities and challenges regarding wireless installations by studying U.S. nuclear applications.

The scope of this work included to identify nuclear power plants, suppliers and organization that had experience of wireless applications in nuclear business within USA.

The field trip to USA was conducted in beginning of March 2020, in the middle of development of the Coronavirus which had impact on the field trip. The visit to North Anna Nuclear plant was cancelled in the last minute.

Following organizations and nuclear power companies were visited and Figure 1-1 shows the location:

EPRI	Charlotte, North Carolina
Duke Energy	Charlotte, North Carolina
AMS	Charlotte, North Carolina
Dominion	Glen Allen, Virginia
Exelon	Kennett Square, Pennsylvania

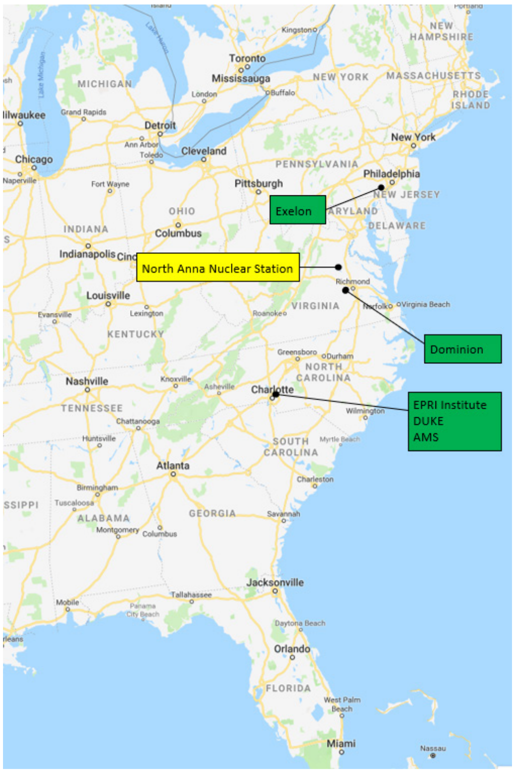

Figure 1-1

1.2 ABOUT ENERGIFORSK AND THE ENSRIC PROGRAM

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:

- LTO of existing platforms and systems
- Safety demonstration and licensing
- Emerging technologies

Information from the program will assist the nuclear industry and the Swedish Radiation Safety Authority when analysing how to replace systems and methods - choosing a new technology or finding a way to stay with the present solution - with maintained safety and promoting a low life cycle cost. Participation of a mix of junior and senior participants in the program is encouraged to facilitate knowledge transfer.

More information on ENSRIC, including the strategy plan of the program, can be found at their web page, https://energiforsk.se/program/karnkraftens-styr-och-kontrollsystem-ensric/.

1.3 SCOPE AND OBJECTIVE

Objective for this field trip was to increase the hands-on knowledge on opportunities and challenges regarding wireless installations by studying U.S. nuclear applications.

2 Abbreviations and acronyms

AOV	Automatic Operated Valve
DAS	Distributed Antenna System
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference
EPRI	Electric Power Research Institute
ISM	Industrial, Scientific and Medical
IT	Information Technology
IoT	Internet of Things
LTE	Long Term Evolution
LTO	Long Term Operation
MOV	Manual Operated Valve
NPP	Nuclear Power Plant
OT	Operation Technology
PM	Predictive Maintenance
RCS	Reactor coolant system
RFI	Radio-frequency interference

3 Field trip USA

3.1 EPRI

EPRI was founded in the early 70ths following The Great Northeast Blackout in New York City in 1965. The energy industry gathered to stop blackouts instead of it should be regulated. EPRI's primary purpose is to conduct research and development relating to the generation, delivery and use of electricity for the benefit of the public.

EPRI is a member organization and the nuclear part has worldwide members. The majority of nuclear members are not from USA.

EPRI headquarter is located in Charlotte, North Carolina.

Nuclear power in USA is facing stiff competition from among other natural gas. Gas plants are cheaper and faster to build than nuclear plants. To address this situation, the NEI[1] launched its "Nuclear Promise" plan.

*"This strategic plan, called Delivering the Nuclear Promise®, strengthens the industry's commitment to excellence in safety and reliability, assures future viability through efficiency improvements, and drives regulatory and market changes so that nuclear energy facilities are fully recognized for their value. In 2018, the initiative transitioned to focus on implementing the most significant savings opportunities in the most efficient manner possible." [*https://www.nei.org/resources/delivering-the-nuclear-promise]

Delivering the Nuclear Promise (DNP) put new focus on Plant Operation. To reduce production loss one way is to increase monitoring and diagnostic of plant components. For fleets a centralized monitoring center could improve plant production and reduce production cost. Additional monitoring requires more sensors in the field and the biggest cost for installing sensors are related to cable pulling. That's were wireless solutions could be a key factor.

EPRI has studied the use of wireless solutions in nuclear business and gain a lot of experience. EPRI research documentation is available for their members or could be purchased. Some of the most relevant documentation regarding wireless technology are included in the reference list, see 7.1.

Future operation requires wireless Infrastructure support. Engineering and IT has traditionally been separated in different organizations but when wireless technology will be implemented there are a lot of synergies and experience that could be used, if cooperation is promoted. Another area that IT department has experience from is cybersecurity. When the nuclear sector lacks experience of this type of technology we should learn from other industries and also capitalize on the consumer market and trends. Another major concern from the NPP is the Electromagnetic compatibility (EMC) which must be taken into account.

Other challenges with infrastructure is that more applications and users will mean more data which means that data capacity could be a bottleneck. There are

[1] Nuclear Energy Institute is the policy organization of the nuclear technologies industry, based in Washington, D.C.

continuously emerging technologies and life span for equipment could be relatively short and that must be taken into account.

Current status of wireless network in USA's Nuclear Power Plants.

- Office areas and workshops have wireless networks and the majority of turbine buildings do have. In the reactor and auxiliary building there are very few installations, but some projects are planned. Few plants have necessary coverage to support moderate plant monitoring, but many plants are looking for solutions. Wi-Fi is currently dominating but they are also looking for solution with DAS systems.

EPRI presented some examples of wireless solutions or initiatives that has been implemented or carried out in the USA so far:

- **Comanche Peak**
  - Largest Permanently Installed Wi-Fi Wireless Network
  - Portable and Fixed Wireless Vibration Monitoring Systems
- **Arkansas Nuclear One (ANO)**
  - Vibration Monitoring of Containment Cooling Fans
  - Vibration Monitoring of Control Element Drive Mechanism Cooling Fans
  - In-Containment Oil Level Detection
- **Diablo Canyon**
  - Voice and Data Communication using Cell Phones and Tablets
  - In-situ Immunity Testing to Reduce Exclusion Zones
- **Callaway**
  - LTE (cellular) throughout the plant (aux, containment, turbine building, offices)
  - Elimination of land lines -> replaced with mobile phones
- **South Texas Project**
  - Over 450 Wi-Fi access points,
    >95% of desired coverage areas including containment
  - Used for Electronic Work Packages
- **Duke Energy**
  - Recently installed Wi-Fi throughout the fleet
  - Used for Electronic Work Packages, part/people tracking, fire carts, and soon sensors

- **Southern Company**
  - Wi-Fi and 900 MHz ISM
  - Vibration monitoring, cameras, Electronic Work Packages
- **Exelon**
  - Wi-Fi installed throughout the fleet, DAS installed at Nine Mile and Ginna
  - Various uses including condition monitoring sensors, refuel bridge monitoring, isolated phase bus, cooling fans, wireless gauges, etc.

3.1.1 EPRI tips for successful wireless infrastructure planning

EPRI presented their collected tips for a successful implementation of wireless infrastructure.

1. Focus on Use cases
   - Invent which applications where wireless technology is desirable.
   - Identify which are most important to the business operation and needs
   - Draft the architecture options for each
   - Engage IT department in the discussion and let them participate in the strategic planning and technology selection
2. Establish a Consolidated Infrastructure
   a. Questions to consider
      - Is there a common denominator for all technologies?
      - Can one network handle all use cases?
      - Can your IT organization support all use cases?
      - What is the installation costs for each approach?
      - Is the network easily upgradable?
      - Can you leverage wiring (e.g. fiber) from one network to reduce costs for another?
      - If separate networks are needed, is 100% coverage needed?

   b. Put down a wireless infrastructure plan
3. Leverage Modularity, if possible
   c. Networks
      - Develop plant frequency management plan – ongoing EPRI project and guide planned to be released 2021
      - Modularity – easier for future upgrades and expansion
      - Ability to implement new technology with minimal hardware changes for example possibility to use the same antennas/access points for other applications.

   d. Sensors & Gateways
      - Standardize on sensor protocols to extent practicable
        - Reduces number of sensor gateways needed
        - Ensures fewer data collisions

- Use modular sensor designs to allow for more flexibility while reducing costs
  - Easier adoption of new technology
  - Leverage consumer IoT applications

3.1.2 EPRI Wireless Network and Installation Research

Wi-Fi

The Wi-Fi technology is continuously evolving and first installations were based upon 802.11a,b and g. Recent installations are based upon 802.11n and 802.11ac with speeds from 300 Mbps to several Gigabits per second.

See section 4.1.1 for more information regarding Wi-Fi.

Distributed Antenna Systems (DAS)

Distributed Antenna Systems (DAS) are used in public society for example football stadiums, complex building. This could be an attractive alternative to Wi-Fi.

EPRI has installed a DAS system in their facility and looking to different scenarios how this could be used in the nuclear business. It is possible to use a DAS system for different applications if it’s modularly built. For example, mobile phone, 433 MHz, 850 Mhz and 900 MHz could use the same infrastructure.

There are also different ways of having control of the data by using public cloud or private cloud, see figure Figure 4-1.

EPRI has produced interesting reports in this area, see reference [2], [3], [4].

3.1.3 EPRI Wireless Sensor

EPRI has studied wireless sensor which is documented in their reports, EPRI Wireless Sensor Survey and General Specification, [6]. Topics covered in this report are for example presentation of various wireless sensor technologies that are commercially available; an overview of EMI/RFI concerns for wireless sensor technology, including laboratory test results for numerous sensors; guidance for specifying and procuring wireless sensor technology to meet a particular equipment condition monitoring application.

EPRI also has guides regarding which measurement that is recommended for continuous On-Line Monitoring for different kind of plant components like pumps, motors, couplings etc.

3.1.4 Wireless Electromagnetic Compatibility

Electromagnetic compatibility (EMC) is the ability of electrical equipment and systems to function acceptably in their electromagnetic environment, by limiting the unintentional generation, propagation and reception of electromagnetic energy which may cause unwanted effects such as electromagnetic interference (EMI) or even physical damage in operational equipment. [Wikipedia]

EPRI has tested different equipment and their immunity against electromagnetic energy such as:

- pressure, level and flow transmitters
- various relays
- seismic instrumentation
- control system
- nuclear instrumentation
- Solid State Protection System

During these tests they have not seen any problem with EMC for frequencies above 1 GHz. Some equipment had vulnerability for some spectrum below 1 GHz.

There are challenges of addressing EMI/RFI and the use of exclusion zones is one way to handle this but it can also result in limiting wireless installations, distances can be more conservative than needed which may add cost to plant or limit the usage of wireless tools. Limited knowledge of plant equipment susceptibility to wireless signals is one concern. Laboratory and in-plant testing has shown most equipment is immune to wireless signals but this should be verified anyhow.

EPRI has developed guidelines for Electromagnetic Compatibility Testing of Power Plant Equipment, see reference [1]. Guidance on how to establish exclusion zones distances is described in this guide. The minimum exclusion zone could be defined by the following equation:

$$d = \frac{\sqrt{30 P_t G_t}}{E}$$

Where:

d = distance from the transmitting device (m)
P_t = output power of the transmitting device (W)
G_t = gain of the transmitting device antenna
E = the field strength of the device at a given distance (V/m)

Emissions data collected under NRC Regulatory Guide 1.180 [10] (issued in January 2000) was integrated within reference [1] to define more pragmatic limits that removed excessive conservatism without compromising nuclear safety.

Reference [1], also gives guidance on how to implement fixed wireless devices operating in the 2.4 GHz band, i.e. what transmitter output power shall be limited to so it is ensured that the field strength is within plant requirement level. The guidance also states what level mobile devices shall be limited to unless exclusion zones are in place.

To protect equipment from EMI grounding, filtering, shielding and administrative control by using exclusion zones could be used. New design should take this into account from the beginning.

EPRI has tested ten wireless sensors with a mix of proprietary and standard protocols (XBee, Wireless Hart, ISA 100, Proprierty 900 MHz, 2.4 GHz, WiFi, Z-Wave, Zigbee). Test was carried out according to guidance in reference [1]. The conclusion from this test is that EMI/RFI levels at one meter distance are well below acceptable levels. Low power sensor devices do not pose a significant risk.

EPRI has evaluated EMI/RFI of Mobile Devices such as common Phones, Laptops, Tablets etc. and documented result in Technical Report Wireless Technology Assessment [7]. Protocols that were analyzed was Bluetooth, Wi-Fi and LTE. The measured radiated emissions were lower in peak magnitude than the theoretical field strengths calculated using guidance in EPRI TR-102323 [1]. Measured field strengths for cellular LTE were higher than for Bluetooth and Wi-Fi.

Conclusion from this study: Wireless Systems Can Be Safely Deployed & Operated at NPP from an EMC perspective.

3.2 DUKE ENERGY

Duke Energy are one of the largest electric power holding companies in the United States, providing electricity to 7.7 million retail customers in six states. They have approximately 51,000 megawatts of electric generating capacity in the Carolinas, the Midwest and Florida – and natural gas distribution services serving more than 1.6 million customers in Ohio, Kentucky, Tennessee and the Carolinas. Duke Energy commercial business owns and operates diverse power generation assets in North America, including a portfolio of renewable energy assets. Duke Energy operates 11 nuclear plants.

Driving factors for innovating and transforming the company is the demand of reducing operating cost in order to be competitive. One area that they focus on is digital solutions.

Duke Energy has installed Wi-Fi throughout the powerplant, "Digital Backbone", which enables the usage of other tools or technologies.

<u>Accomplishment so far at Duke Energy:</u>

- Creation of Mobile Worker Tool

  The aim is to make work efficient by providing true mobility to Nuclear field workers.

- Introduction of indoor drones

  All sites have at least one drone and 4 pilots trained to fly it and used it on several different occasions such as inspection of vertical Fuel Oil Tanks.

- Camera installations to aid in remote area monitoring

  Example that was mentioned was cameras installed around transformers.

- Creation of Fire Watch Cart that can be used for periodic fire watches

  Can be used as a dose savings tool and future revisions will be able to be used for continuous fire watches.

- Installation of Wireless Gauge Readers at all sites

  Initial installations aimed at helping operators with rounds data.

<u>Currently being worked on at Duke Energy:</u>

- Fleet wide advanced remote equipment monitoring project

  Installation of various sensors on important plant equipment and installation of infrastructure to capture sensor data and send to servers. Creation of Advanced Pattern Recognition (APR) models for equipment monitoring.

  Better monitoring/trending will allow transition to condition based maintenance

- Automated Chemistry Sampling/Analysis

  Automating Primary RCS sampling/analysis to extend and/or eliminate frequency of manual grab samples.

- Thermal Performance Automation

  Implementation of Data Validation and Reconciliation (DVR) process to standardize and automate thermal performance monitoring. Models each instrumented piece of equipment (Main Turbines, MSRs, Feedwater Heaters, Condensers, Feedwater Pumps, etc). Greatly reduces uncertainty of the instrumented values and provides a reconciled (true) value for each parameter. If parameter can't be balanced, an alarm is generated to determine if there is an efficiency issue of an instrumentation issue.

- Automated Meter Reading Using Cameras

  Idea is to have one camera that can read multiple gauges on a panel and Data would be sent to servers.

Future plan at Duke Energy:

- Using additional sensors to supplement plant monitoring

  The idea is to make plant/equipment monitoring more efficient by using video cameras, thermal cameras, acoustics, etc.

Duke Energy has developed Installation specifications to ease installation if additional sensors or access points are needed in the plant. This make the work more efficient and reduce cost.

Duke Energy use both wired and Wi-Fi based sensors and the decision is dependent on required data rate, availability of power supply and ethernet switches. Duke Energy are using more hardwired sensors than wireless due to better performance.

3.3 AMS

AMS is a nuclear engineering services company specializing in instrumentation and control system test equipment, training, and services. They provide the worldwide nuclear industry with products and services to measure I&C performance and verify compliance with technical specifications and regulatory requirements.

AMS presented a brief overview of Wireless Sensor Implementations.

- Comanche Peak Nuclear Plant was the first plant to implement a largescale wireless sensor network in USA. 2003 they installed a Wi-Fi network based on IEEE 802.11b with over 400 access points.
- Wireless Monitoring of Arkansas Nuclear One (ANO) Containment Fans. A Wi-Fi network established in containment with copper and fiber communications through the containment wall.
- A cooling tower had experienced several failures with fan motors. Data collection was previously collected once a month and gearbox was not monitored. The solution was a system that routinely collected vibration and ultrasonic data from the fan motors as well as the gearboxes. Collected data was transmitted using 802.11 Wi-Fi from the remote tower location to an engineering workstation for evaluation and trending by the system engineer

The demand of wireless surveillance is increasing all the time especially for motors and pumps.

In USA exclusion zones are widely used to avoid disturbance of sensitive equipment. Exclusion zone distances depend on transmitter power and antenna gain and can be overly conservative and restrictive. Exclusion zone distance can be calculated with mathematic formula, see 3.1.4.

Practical tests has showed that radiocommunication equipment below 450 MHz could impact equipment but frequencies above 1 GHz has not showed any impact. AMS presented a case where a pressure transmitter was tested which showed identified Vulnerabilities.

RF emissions from smartphones and tablet devices were measured to establish typical exclusion distances.

Low signals are most vulnerable for EMI/RFI like Source Range Monitoring (SRM), Power Range Monitoring (PRM).

AMS can provide in-situ susceptibility testing of plant equipment using standard test methods and actual wireless signals.

AMS are engaged in the IAEA work and informed that IAEA is expected to publish a wireless guidance in 2020 which cover

- Codes, standards and regulatory guides
- Wireless technologies for nuclear applications
- Practice, experience and lessons learned
- Potential new applications
- Emerging technologies and challenges

3.3.1 Conclusions from AMS presentation

Nuclear Power Plants are implementing wireless technology and there are numerous applications and benefits for using wireless technology.
Guidance and standards are changing with the evolving technology and operating experience.

Plants need to have confidence that wireless technology will not impact sensitive plant equipment. To be able to minimize exclusion zones distance requires additional testing to verify immunity of plant equipment to wireless signals.

3.4 DOMINION

Dominion operate in 20 states, from Connecticut to Georgia to California with headquarter in Richmond, VA. Dominion operate 6 NPP's at 3 different locations.

Dominion see that most of the daily work are paper reliant and many actions are performed manually such as tracking of equipment health, trending equipment performance, tracking surveillance performance. They also see that equipment are maintained based on time instead of actual condition.

Dominion are looking into how to improve efficiency and lowering production cost like all other power plants. They see that a transformation from traditional working methods towards new improved methods are necessary by using digitalization.

Within 5 year they aim for a paperless environment, automatically track equipment health and surveillance performance and they perform maintenance based on condition instead of time.

To fulfil this transition, they have a portfolio of actions and tools:

Electronic Work Package	This will reduce paper and make it possible to track work progress and completion more efficiently. With Wi-Fi implemented there will be more communication possibilities for the crew like visual support using Augmented Reality and other video applications. Efficiency increase in reduced handling time, improved data tracking and communication.
Monitoring and Diagnostic	With an Monitoring and Diagnostic center they can centralize system monitoring, improve predictive Diagnostics and provide Predictive Maintenance recommendation. Efficiency improvement • 24 hour tracking • Early problem identification • Fleet expertise supported Degradation Identification • Early degradation assessment • Scheduling of corrective maintenance • Reduction in outage and expediting costs On-Line and Outage assessment • Performance driven Predictive Maintenance (PM) • Reduction in Time based PM work

Electronic Surveillance/Procedure	Electronic documentation Efficiency Improvement • Tracking equipment performance • Automatic entry validation • Simplified processing • Easily verifiable performance
Digital Communication	Supporting technology and enhances all digital improvements. Necessary for implementing all other initiatives.
Digital Data availability	Enabling technology for different analysis techniques and will improve predictability.
Electronic Records	Efficiency Improvements –less handling and less manual work.
Vibration Monitoring	Enabling technology that reduce field work and supports eliminating preventative maintenance.
MOV/AOV Monitoring	Enabling technology that reduce field work and reduce vendor support and improve outage efficiency.
Electrical Signature Analysis	Enabling technology that reduce field work and reduce/eliminate preventative maintenance.

Dominion has chosen to use Wi-Fi in their plant and this is installed almost everywhere except for the containment.

3.5 EXELON

Exelon is one of the largest competitive energy provider in USA, with more than 31,000 megawatts of nuclear, gas, wind, solar and hydroelectric generating capacity. Exelon Nuclear, a division of Exelon Generation, operates 22 reactors in the USA. Exelon Generation Headquarters is located in Kennett Square, PA.

3.5.1 Exelon's Wireless experience

Exelon has an "innovation center" where needs and wishes from the NPPs can be taken care of. Exelon described a couple of examples where the use of wireless solutions had been success stories. For example:

- Fire cart

  Quite common due to ongoing work/installations at the plant, fire cells need to be open up and dedicated and manual surveillance is necessary. This used to require a lot of manhours but instead of using labors an automated system, fire cart, equipped with Thermal cameras, fire detection system with wireless smoke detectors could be used. All equipment is powered by battery and information is transferred wirelessly to a monitoring site.

- Integrated Switchyard Monitoring

  Switchyard is monitored by using thermal cameras.

- Different kind of Wireless sensors that Exelon had tested

  Petasense – vibration

  Cypress – wireless gauge

- LTE/Wi-Fi Gateways

  This is a way of connecting wireless sensors without an infrastructure. Sensors that are using Wi-Fi are connected to a gateway that are connected via LTE and in that way could sensor values be transmitted.

Exelon has installed Wi-Fi in the NPPs and also a Distributed Antenna System (DAS) in one plant. Wireless sensors are not allowed today to be connected to the Wi-Fi system because this could be an attack vector to their IT system. Instead their aiming for wireless sensors that are connected via DAS system. Final decision to be made in near time.

Exelon try to use open technology for their wireless sensors so that they don't will be limited to the narrow market.

3.5.2 Monitoring & Diagnostic centre

Exelon has established a Monitoring & Diagnostic centre which the field trip group got to visit. The Monitoring & Diagnostic centre monitor all of Exelon Nuclear power plants located at 11 different sites. Data from each plant are collected and analysed at this centre, see simplified figure Figure 3-1. The centre consists of a crew of 7 people which work daytime. The crew also include Thermal Performance specialists which try to identify performance issues and when found they notify the plant. The Monitoring & Diagnostic centre has not focus on immediate actions/problems instead they focus on a longer time horizon.

They indicate that this surveillance had been efficient and increased the production for the fleet.

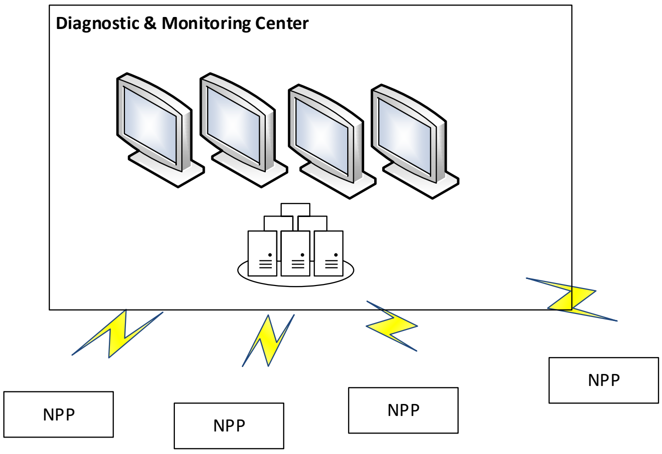

Figure 3-1

Exelon would like to use digitalization in this effort, and they see that the most efficient solution including cost are to use wireless sensors. Most of the cost for additional sensors are related to installation of cables. Collecting data manually isn't a good solution even if data is collected once a day.

Exelon are using commercially available software products for their monitoring and diagnostic centre, which analyses plant performance and identifies plant issues.

The system generates an alarm list which is available for the crew when they arrive in the morning. These alarms are analysed and reviewed. The goal is to identify degradation at the NPPs and initiate actions before an unplanned production loss occurs.

4 Technical areas

This chapter summarizes common technical discussions from the study.

4.1 WIRELESS TECHNOLOGY

4.1.1 Wi-Fi

Wi-Fi is widely used in NPP's. There exist several standards such as 802.11a, b, g, n, ac and also other pending standards as 802.11aj, ak, ax, az ba.

The Wi-Fi technology is continuously evolving and first installations were based upon 802.11a,b and g. Recent installations are based upon 802.11n and 802.11ac with speeds from 300 Mbps to several Gigabits per second.
There are new technologies, not installed yet, based upon 802.11ah which use 900 MHz (license free band) which extend the range. This standard also benefits from lower energy consumption, allowing the creation of large groups of stations or sensors that cooperate to share signals, supporting the concept of the Internet of Things (IoT).

Wi-Fi 6 or 802.11ax is the next standard for Wi-Fi which already is available.

Expected lifetime for Wi-Fi equipment is about 5 years.

4.1.2 Distributed Antenna Systems (DAS)

This is the solution commonly used in the society to enable cellular communication within big arenas or other complex buildings. In some of the Nordic NPP's this is used for cellular and radio communication but not for other applications so far. A distributed antenna system can be implemented using passive splitters and feeders, or active-repeater amplifiers can be included to overcome the feeder losses. Antennas can have a wide band frequency range to be able to work with several applications.

Commercial phone companies connect to a base station and the signal is distributed in the plant via fiber to a remote unit. From the remote unit the signal is distributed to antennas or signal could be emitted with a leaky cable.

Frequency bands might be licensed to operators and not free to use but there are also some frequency bands that are free to use. This changes from country to country and need to be considered.

A DAS system that is designed with modularity could be used for several different applications by using different frequency band. It's important to plan the frequency ranges so that no interference and disturbance occur between the applications. Development of a frequency plan that define different applications frequency band is encouraged. This means that a DAS system could be used for several different applications such as cellular, Wi-Fi, wireless sensors etc. Figure 4-1 illustrate a DAS system with different applications. The coverage in the plant is dependent of the frequency where lower frequency can penetrate better. For example, 700 MHz penetrate 2,5 times better than 2100 MHz. This must be accounted when designing the antenna system.

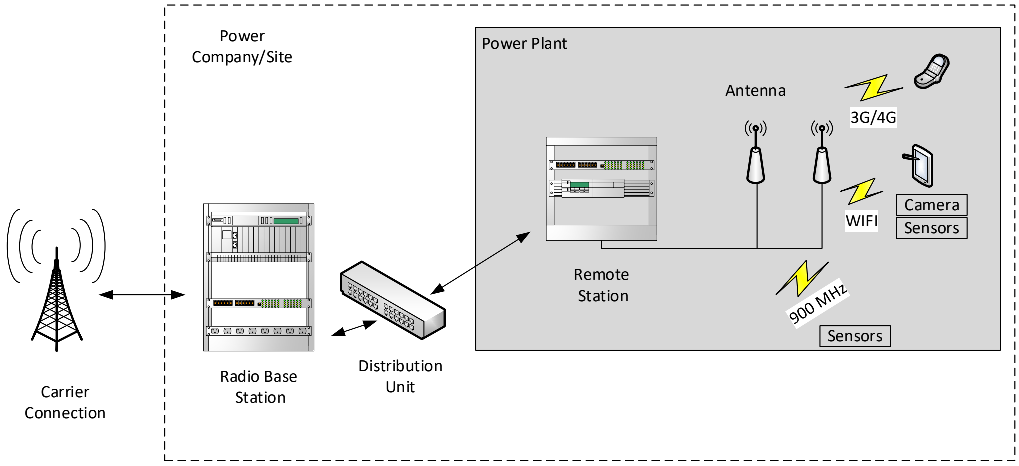

Figure 4-1

4.1.3 Energy Consumption

When using wireless sensors, only powered from battery, there is balance between battery life, range and update rate.

Better range means more energy consumption and less battery lifetime. Battery lifetime is also dependent how often the equipment updates and how much data that are communicated.

These configurations need to be analyzed based upon the process that are monitored or controlled.

4.1.4 Edge computing

When more and more equipment is connected to the network, bandwidth could be a limiting factor. Edge computing is a distributed computing that is performed closer to the location where it’s needed and improve response times and save bandwidth.

5 Strategies

Prerequisite for digitalization is the infrastructure the so-called enabler. There is not one kind of solution that suite all NPP's instead this need to analysed case by case. In the following a way forward is discussed.

Backbone

Regardless of which wireless technology that should be used all solutions are dependent on a backbone and preferably this is done with fiber. A fiber backbone could be used for all kind of systems that's going to be implemented in the future. For example, distributed process control system, video surveillance, different communication system (cellular, "blue light communication" (fire, ambulance) etc.) and wireless solutions. To secure future expansion oversize the backbone because cable cost is minor to the installation cost. With an oversized backbone future projects only need to consider cross connection instead of installing this infrastructure.
Consider redundancy and separation when designing and also power supply for feeding the equipment.

Look into what kind of existing infrastructure could be reused (both fiber and copper) for example old Ethernet cables that could be used for distribution to the local access point. This could reduce installation cost.

Use cases

Identify all use cases and also try to consider future applications. Prioritize use cases and consider lifecycle cost.

Established Consolidated Infrastructure

When the prioritizing is done a consolidated infrastructure could be established which include defining wireless systems and subnets.

Modular Design

Aim to have modular design which allow or make it possible to add more applications in the future.

Ability to implement new technology with minimal hardware changes so that infrastructure could be reused like antennas/access points.

Develop a frequency management plan to align best frequency for applications.

Cooperation with IT

Usually all powerplants has a separate IT department and it's recommended to involve IT since they have experience of network and wireless solution within the company. Combine the knowledge between admin IT and process IT (OT).

There are many different solutions for infrastructure that support Digitalization. Figure 5-1 illustrate different approaches that was discussed and also illustrate that data are collected at a Monitoring & Diagnostic Center. This could be a common centre for one, several plants or a fleet of plants but data must be collected and analysed at some place.

- Process Control and Process Safety system measures and collects a lot of data that is used for operating the NPP's but this data is also useful for others when analysing plant performance and degradation of components. In order to keep the Process Control and Process Safety system "clean" the use of analysis tools should normally be "outside" of these systems. Data need to be exported to Monitoring & Diagnostic Centre.

- Wi-Fi could be used for administrative work like Electronic Work Packages and also for connecting cameras, sensors etc. This data should also be transferred to Monitoring & Diagnostic Centre.

- The DAS system could be used for traditional communication devices but also for connecting different kind of sensors. Data from these sensors could be distributed in different ways to the Monitoring and & Diagnostic Center and Figure 5-1 illustrate this with "Private Cloud" and "Public Cloud". There are solutions for tapping of data within the power plant, to a "Private Cloud". This solution could be desirable for NPP's to ensure full control of the data and also avoiding additional cost for subscription by the carrier.

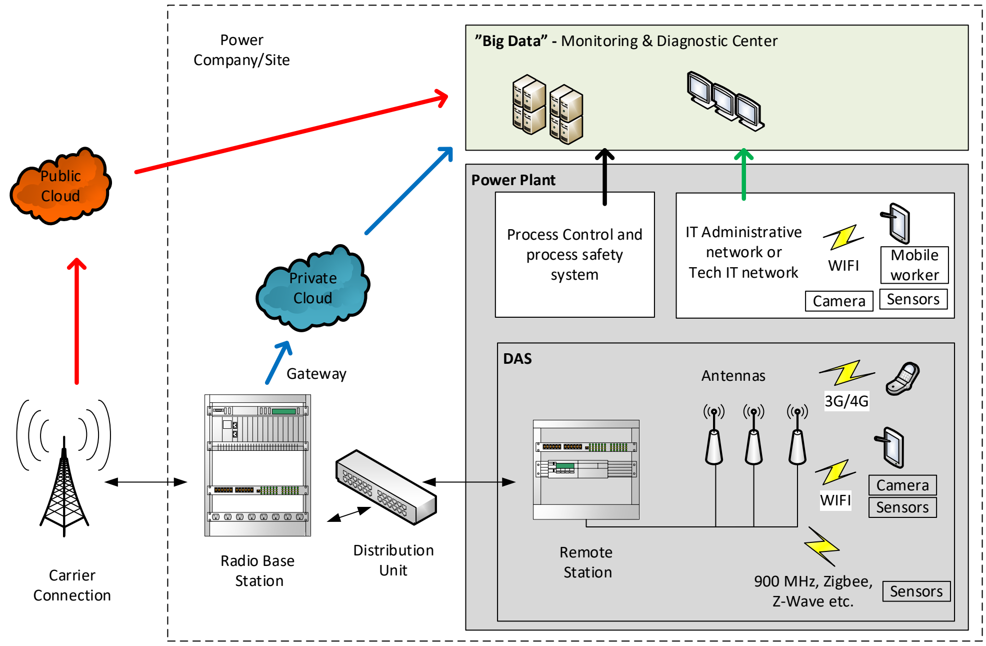
Power
Company/Site
"Big Data" - Monitoring & Diagnostic Center
Public
Cloud
Power Plant
Process Control and
process safety
system
IT Administrative
network or
Tech IT network
WIFI
Mobile
worker
Camera
Sensors
Private
Cloud
Gateway
DAS
Antennas
3G/4G
WIFI
Camera
Sensors
Carrier
Connection
Radio Base
Station
Distribution
Unit
Remote
Station
900 MHz, Zigbee,
Z-Wave etc.
Sensors

Figure 5-1

6 Summary and conclusions

6.1 SUMMARY

During the trip a couple of different suppliers and utilities were visited. Common for all was that the nuclear power plants have to reduce cost in order to be competitive on the market. There are also a differences between the powerplants regarding which market they operate at. Some operate at a regulated and others are not. Powerplants that are operating at the regulated market try to avoid additional running cost which will have direct impact on their production cost. An example that was mentioned is cost related to "subscription" of wireless data via cellular solutions instead of internal Wi-Fi solution or private cloud. This will make impact on the technical solution.

A common denominator for all utilities is the digitalization. But differences in the market where they operate and what kind of infrastructure they have in place today will impact the technical solution for wireless equipment. Some utilities will use more wired sensors and others will use wireless via Wi-Fi or DAS. This strategy must be decided case by case for each plant. Each utility has their own conditions that must be taken into account.

Usually all investment must have a positive business case but to be able to take credit from the digitalization, the infrastructure is needed. The infrastructure will not generate a positive business case itself but it's the enabler for continued digitalization, which have potential for better performance and business. As a utility the whole picture must be considered.

6.2 CONCLUSIONS

Common for all visited companies was that the nuclear power plants have to reduce cost in order to be competitive at the market. The common denominator for all utilities that were visited was the digitalization and the use of wireless equipment. More measurements and data will enable power plants to go from a time-based maintenance to maintenance based on condition instead.
The establishment of a Monitoring and Diagnostic centre, where all available plant/fleet data are collected and analysed, could improve the performance and plant efficiency.

Electronic Work Package was another goal for all/many of the powerplants and this was also already implemented at some of the NPP's.

Prerequisite for digitalization is the infrastructure the so-called enabler. There is not one kind of solution that suite all NPP's instead this need to be analysed case by case. Section 5 discuss a strategy for implementing an infrastructure that also take into account evolving of the digitalization by oversizing the backbone.

Exclusion zones for wireless equipment are used in USA to solve the issue with interference of sensitive equipment. This way of introducing wireless equipment could also be used in the Nordic NPP's.

6.3 RECOMMENDATIONS

This study has the following recommendations for future work within Energiforsk or at corporate level in the energy companies and also recommendations for the Nuclear Power Plants.

6.3.1 Energiforsk and/or corporate level

For Energiforsk or at corporate level the following recommendations are identified for continued work.

Backbone	Prerequisite for digitalization is the infrastructure the so-called enabler and the backbone is one major component in the infrastructure. Investigate good practices and good solution for building backbone.
DAS Solution	There are different ways of designing a DAS network. Investigate good practices in this area.
Exclusion zones	One of the biggest concerns for the NPP’s is to provide evidence that wireless equipment doesn’t interfere with sensitive safety equipment. Investigate if exclusion could be a solution for the Nordic NPP’s as well.
Monitoring & Diagnostic center	One of the main takeaways from this study was the Monitoring & Diagnostic center. Look into how this could be built up and which kind of tools and applications to use.
Big Data – environment, supporting applications	Investigate different applications on the market.
Use case for Motor/Pump application	Look into what kind of measurements that are needed to implement condition-based maintenance and provide guidelines to the NPP’s.

6.3.2 Nuclear Power Plants

For the NPP's the following recommendations are identified for continued work.

Backbone	Build backbone because this could also be used for other applications.
Investigate existing data	Analyze what kind of data that is already monitored and available and how to centralize this data.
Analyze existing data	Analyze how to use existing data to improve maintenance and implement condition-based maintenance.
Fix it now team	The use of "Fix it now" team seemed to be an effective way to take care of new and urgent demands. For example, a team for taking care of new monitoring demands or a team for analyze data.
Competence analyze	There is probably a need for new competences to be able to implement and handle digitalization and wireless technology. Perform a competence analysis.

7 References

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WIRELESS IN NUCLEAR APPLICATIONS IN THE US

Wireless technology has traditionally not been used in nuclear applications, but the technology is widely used in other industries. To introduce digitalization on a wide scale in the nuclear power plants, wireless is needed to facilitate equipping systems and components with sensors and connecting to monitoring systems.

Furthermore, wireless is an enabler to reduce costs, compared to wired solutions. There are however many challenges, cyber security and electromagnetic compatibility being two of the most important.

The U.S. nuclear industry are fore runners in introducing wireless solutions in nuclear applications. A team of Nordic experts visited several U.S. companies and organizations to gain from their experience. This report features hands on information on study has investigated what kind of wireless applications that are implemented in Nuclear Power plants in USA.

Energiforsk is the Swedish Energy Research Centre – an industrially owned body dedicated to meeting the common energy challenges faced by industries, authorities and society. Our vision is to be hub of Swedish energy research and our mission is to make the world of energy smarter!

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