On-line Monitoring of Enhanced CANDU® 6 (EC6®) Plant Instruments

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Abstract

On-line monitoring (OLM) of Enhanced CANDU® 6 (EC6®) plant instruments will detect the drifts of the instruments in a timely manner. The instrument drift monitoring will be performed by the Plant Display System (PDS) in the EC6 plant design. The PDS collects measurement data from the plant instrumentation for safety systems, reactor control systems, and process control systems. OLM functions will be performed on both safety and non-safety instruments. OLM of the EC6 plant instruments is expected to provide significant benefits to the safety and economics of the plant in operation while incurring only modest additional cost.

1. Introduction

Instrument on-line monitoring (OLM) determines the health status of an instrument using the information from the instrument and other related instruments without taking the instrument out of service. Instrument OLM has been used in nuclear power plants (NPPs) worldwide and proven to provide significant benefits to plant safety and economics [1], [2], [3].

Instrument OLM functions will be designed and implemented in the Enhanced CANDU® 6 (EC6®) plant design. The EC6 is a 700 MWe heavy-water moderated and cooled pressure tube reactor based on the well-proven CANDU 6 design. It incorporates innovative features and technologies that enhance plant safety and economics. The EC6 OLM functions focus on the accuracy of the instruments. Through the detection of the degradation of the instrument accuracy in a timely manner, the OLM functions can be credited to extend instrument calibration intervals [1].

EC6 OLM functions will monitor the accuracy of instruments included in safety systems, reactor control systems, and process control systems. Measurement data from plant instruments will be used. The EC6 safety systems include Shutdown System No. 1 (SDS1), Shutdown System No. 2 (SDS2), Containment System, Emergency Core Cooling System (ECCS), and Emergency Heat Removal System (EHRS). Safety parameters measured by these systems include neutronic and process parameters: the safety neutronic parameters are measured by in-core flux detectors and ion/fission chambers; most of the safety process parameters, including pressures, levels, and flows, are measured by pressure transmitters. In addition, many instruments will be included in the reactor and process control systems, such as Reactor Regulating System (RRS), Heat Transport System

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Pressure and Inventory Control (HTS P&IC), Moderator Temperature Control (MTC), Steam Generator Level Control (SGLC), and Steam Generator Pressure Control (SGPC).

The Plant Display System (PDS) will collect measurement data from plant instruments included in safety systems, reactor control systems, and process control systems in the EC6 plant design. The PDS will use the measurement data to perform drift monitoring.

This paper addresses the incorporation of instrument drift monitoring functions in the EC6 plant design. Instrument on-line drift monitoring algorithms, methods, and practices that have been used in the existing nuclear power plants (NPPs) are investigated. Design and implementation of the instrument drift monitoring functions in the EC6 plant design will be discussed.

The paper is organized as follows. Section 2 discusses the regulatory requirements on instrument OLM. Section 3 provides an investigation on instrument drift monitoring. Section 4 discusses the implementation and applications of the drift monitoring in the EC6 plant design. Section 5 summarizes the conclusions of this paper.

2. Regulatory Requirements on Instrument OLM

The Canadian Nuclear Safety Commission (CNSC) requires that "in order to maintain the NPP within the boundaries of the design, the SSCs (systems, structures, and components) important to safety are calibrated, tested, maintained, repaired (or replaced), inspected, and monitored over the lifetime of the plant" [4].

In France, the French Safety Authority has approved Electricité de France (EDF) to use the drift monitoring of transmitters and temperature sensors to extend their calibration intervals since 1996 [5].

In the US, the Nuclear Regulatory Commission (NRC) has issued a Safety Evaluation Report (SER) regarding using OLM to extend calibration intervals in 2000. The SER identified four inherent deficiencies associated with OLM [6]:

1. It is not capable of monitoring instrument performance for its full range including trip setpoint.
2. It does not have accurate reference, but compares the monitored value to a calculated reference (the process parameter estimate) that itself is less accurate compared to simulated input used in the traditional calibration process.
3. It does not provide accuracy traceable to standards.
4. It does not allow frequent physical inspection of the instrument or allow technicians to observe instrument anomalies.

The SER also specifies 14 requirements on using OLM to extend instrument calibration intervals. Detailed and in-depth discussions on the 14 requirements and how to meet the requirements are provided in the NUREG/CR-6895 Report, Volume 1 [7]. NRC's requirements and the NUREG/CR-6895 reports will be studied and used as guidance in the design and implementation of the EC6 drift monitoring functions.

3. Instrument Drift Monitoring

The Electric Power Research Institute (EPRI) sponsored a research project to investigate the characteristics of the drifts of instrument used in nuclear power plants [5]. The study found that there were three types of drift: a) zero shift drift, which means the amount of drift is the same over the entire instrument span; b) span shift drift, which means there is no drift at one end of the span but the drift linearly increases with the span, and c) nonlinear drift, which is any drift that is not zero shift, span shift, or a combination of the two. Zero shift and span shift could occur either alone or together. Among all observed drift cases, about 75% had zero shift drift, about 50% had span shift drift, and about 8% had nonlinear drift. The study also found that if the value of a process parameter stays at or close to the high or low end of the instrument span, e.g. containment building pressure, the parameter is more likely to have span shift drift.

Though in most cases the drifts at the operating points are close to the drifts at other points of the instrument spans, the existence of span shift drift and nonlinear drift indicates that so-called "single-point monitoring" is an important issue that needs to be addressed [5]. During normal plant operation, most process parameters stay almost constant, thus the drift monitoring system is only able to detect the drift at the operating point. The drifts at other points, including trip setpoints, of the instrument span may not equal to the drift at the operating point. EPRI's proposed measures to address the single-point monitoring issue are a) in addition to on-line drift monitoring, instruments are periodically calibrated throughout their spans using traditional methods, and b) including an associated allowance/penalty in the uncertainty analysis [5].

In addition to the single-point monitoring issue, there is also a common-mode drifting issue, which means instruments drift toward the same direction by same or close amount [5]. The on-line drift monitoring system will not be able to detect such a problem as the process parameter estimate equals the weighted average of all measurements of the parameter. Though common-mode drifting rarely occurs, it is still necessary to rule it out through calibrating at least one instrument out of a redundant group of instruments periodically using the traditional calibration methods [5].

Drift monitoring methods can be divided into redundancy-based and non-redundancy-based. Redundancy-based methods require at least two instruments available to measure the same process parameter. Non-redundancy-based algorithms do not rely on redundancy; instead, they use process models which describe the relationships among process parameters. This paper focuses on the redundancy-based methods as the EC6 plant instrumentation typically has high level of redundancy. There are at least three, in many cases six, and in some cases twelve instruments available to measure an important EC6 plant parameter.

The EC6 plant design will adopt an averaging-based drift monitoring method as it is simpler, more straightforward, easier to understand, implement, and use, and more matured and better-proven at NPPs. Averaging-based methods calculate the weighted average of the measurements of several instruments for the same process parameter, and then compare each measurement against the average. If the absolute difference between the two exceeds a certain threshold, the instrument is considered to have already drifted.

Averaging-based drift monitoring systems have been used in NPPs around the world. The following are a few examples:

1. Transmitter Accuracy Monitoring System (TAMS), which was developed by Atomic Energy of Canada Limited (AECL) as the result of a research project sponsored by CANDU Owners Group (COG) [5]. The system was used at Bruce Nuclear Generating Station (NGS) B, Unit 6 from 1995 to 1997 to monitor the accuracies of pressure, flow, and level transmitters.

2. EDF's calibration monitoring system, which has received regulatory approval as a basis to extend instrument calibration intervals [5]. The system has been used at all 54 of the EDF's NPPs.

3. Instrumentation and Calibration Monitoring Program (ICMP), which was developed in 1993 by EPRI [5]. An ICMP-based system has been used at V. C. Summer NPP as a performance monitoring and troubleshooting tool. Similar ICMP-based systems have also been used at a few other US nuclear power plants.

4. Temperature sensor cross-calibration technique, which was developed by Analysis and Measurement Services Corporation (AMS) [8]. The technique has been used at several NPPs for the cross-calibration of temperature sensors.

In the TAMS algorithm, an instrument will be excluded from the estimation for the process parameter if a) it is identified as not good; b) it is irrational; or c) it does not have a consistent checksum [5]. A consistency check is performed to determine whether an instrument is good. The degree of inconsistency, K_j, is calculated as follows:

$$K_j(t) = \sum_{i=1}^{n} d_{ji}(t) \tag{1}$$

where $d_{ji}(t) = 0$ if $\left|x_j(t) - x_i(t)\right| \le \varepsilon_j$, $d_{ji}(t) = 1$ if $\left|x_j(t) - x_i(t)\right| > \varepsilon_j$, and n is the number of instruments to measure the same process parameter. The range of the value of i is from 1 to n, j is from 1 to n, and K_j is from 0 to n-1. The instruments with the largest K_j will be considered as not good. Then, K_j for all remaining instruments are re-calculated until K_j for all of them are equal. If K_j for all remaining instruments are equal but not equal to 0, the inconsistency is unresolvable [5].

The value of ε_j was originally chosen to be three times the reference accuracy as specified in the Safety Analysis Report if the instrument is previously good, or two times the reference accuracy if the instrument is previously not good. Later, to reduce false alerts, the value of ε_j was increased to six times and five times, respectively, based on the operating experience [5].

If an instrument is good for at least three consecutive time steps, it is considered as good and is used in the subsequent estimation. The parameter estimate, $\hat{x}$, is calculated as follows:

$$\hat{x} = \frac{\sum_{j=1}^{n} x_j(t)}{n_g(t)} \tag{2}$$

where $n_g(t)$ is the number of good instruments. The mean of the differences between x_j and the corresponding $\hat{x}$ over a certain number of time steps is then calculated and compared against the specified accuracy requirements to determine if the *j*-th instrument needs calibration. The experience at the Bruce NGS indicated that the deviations observed by the TAMS matched the corrections made during transmitter calibrations well [5].

The algorithm adopted for EC6 drift monitoring will be similar to the TAMS algorithm, mainly because it was specifically developed for CANDU plants and it has been used and tested in a CANDU plant. The TAMS algorithm will be further assessed and potentially modified to improve the effectiveness of the EC6 drift monitoring.

4. Implementation and Applications of OLM Functions in the EC6 Plant Design

The drift monitoring function will be performed by the Plant Display System (PDS) using measurement data provided by the plant instrumentation for safety systems, reactor control systems, and process control systems in the EC6 plant design. The reactor and process control systems will be implemented using Distributed Control Systems (DCSs). The PDS includes a historical data storage and retrieval subsystem, which stores measurement data from all plant instruments with associated qualities and time stamps.

Figure 1 presents an overview of the instrumentation and control (I&C) architecture for the EC6 plant design [9], which includes the PDS. Measurements provided by both safety and non-safety instruments will be used to implement the OLM functions. The OLM functions will be performed on both safety and non-safety instruments.

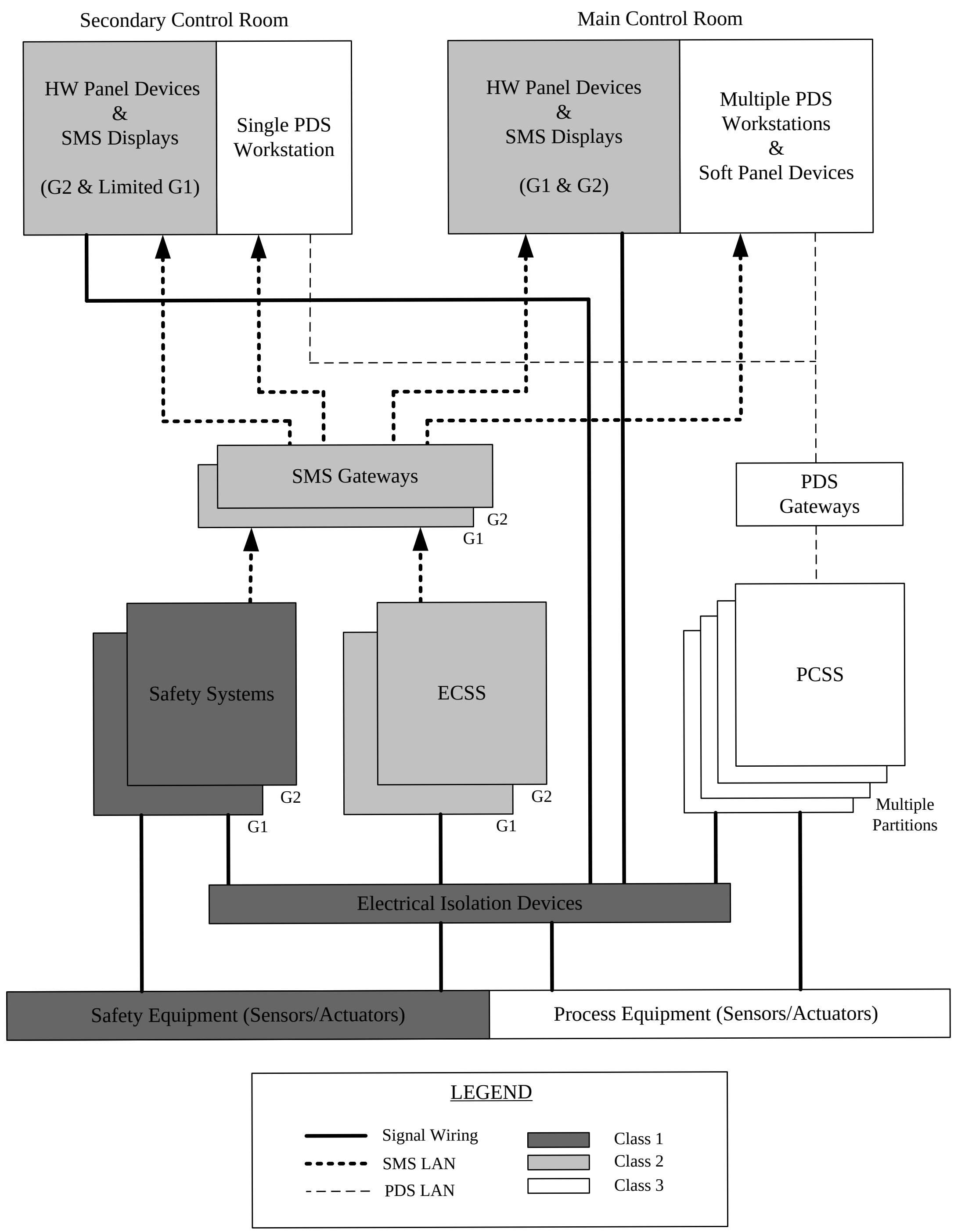

Figure 1 Overview of the I&C Archietecture in the EC6 Plant Design [9]

Time stamps will be applied to the measurement data by the Safety Monitoring System (SMS) gateways and the PDS gateways shown in Figure 1. The clocks of the SMS gateways, the PDS gateways, and the PDS workstations will be synchronized and a Global Position System (GPS) receiver may be used to obtain highly accurate time.

To perform effective OLM, it would be ideal if the measurement data used for comparison could be collected at the same time. Since the measurements data from sensors and transmitters are collected by different systems, as shown in Figure 1, it is important to determine the range of the time needed for measurement data to arrive at the gateways through safety systems, Essential Control Subsystems (ECSS), and Plant Control Subsystem (PCSS), respectively. The OLM algorithms must appropriately address the different time taken by each data transmission path.

The PDS will obtain the data used for EC6 OLM from plant safety, reactor control, and process control systems. The sampling rate, simultaneousness of sampling, resolution, and accuracy of data acquisition will be determined according to the requirements of each plant system. To reduce data storage, typically the measurement data sample of an instrument is stored only when the difference between the present measurement and the previous measurement is larger than a certain threshold or a certain period of time has elapsed. Both the threshold and the period are configurable.

Averaging-based drift monitoring techniques are based on the assumption that the average of the measurements of a sufficient number of redundant instruments is equal to the true value of the process parameter [8]. Such an assumption may not be valid due to a few possible causes [8]:

1. Common-mode drifts;

2. Instability of the process parameter during data acquisition, including fluctuations and drifts; and

3. Non-uniformity among the values of the process parameter at different locations where the measurements are taken.

The instability issue and the non-uniformity issue will need to be addressed if any of the two is considered significant. Data preprocessing can potentially improve the effectiveness of drift monitoring significantly [8].

Since all the data needed for the OLM functions performed by the PDS are readily available, the OLM functions can be implemented with a workstation included in the PDS. As a result, it is expected that the OLM functions will incur only modest additional capital cost but lead to significant operation and maintenance (O&M) improvements.

Potential applications of the OLM functions in the EC6 plant include but are not limited to the following:

1. Alerting operators in the control rooms once significant and sustained degradation of instrument accuracy is detected so that necessary immediate actions can be taken; and

2. Similar to the use of the ICMP at the V. C. Summer NPP [5], system specialists and instrument engineers can use the OLM functions as a performance monitoring and troubleshooting tool to make recommendations on I&C inspection, testing, and maintenance activities.

5. Conclusions

The on-line instrument drift monitoring will be performed by the PDS in the EC6 plant design, which collects measurement data from plant instruments included in safety systems, reactor control systems, and process control systems. The OLM functions will be performed on both safety and non-safety instruments.

Using the OLM functions in the EC6 plant in operation is expected to provide significant benefits to plant safety and economics through detecting instrument drifts in a timely manner. The additional cost incurred is expected to be modest as all the data used to perform the OLM functions are readily available in the PDS.

6. References

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