Implementation of an on-line monitoring system for transmitters in a CANDU nuclear power plant

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Abstract. Many transmitters (pressure, level and flow) are used in a nuclear power plant. It is necessary to calibrate them periodically to ensure that their measurements are accurate. These calibration tasks are time consuming and often contribute to worker radiation exposure. Human errors can also sometimes degrade their performance since the calibration involves intrusive techniques. More importantly, experience has shown that the majority of current calibration efforts are not necessary. These facts motivated the nuclear industry to develop new technologies for identifying drifting instruments. These technologies, well known as on-line monitoring (OLM) techniques, are non-intrusive and allow focusing the maintenance efforts on the instruments that really need a calibration. Although few OLM systems have been implemented in some PWR and BWR plants, these technologies are not commonly used and have not been permanently implemented in a CANDU plant. This paper presents the results of a research project that has been performed in a CANDU plant in order to validate the implementation of an OLM system. An application project, based on the ICMP algorithm developed by EPRI, has been carried out in order to evaluate the performance of an OLM system. The results demonstrated that the OLM system was able to detect the drift of an instrument in the majority of the studied cases. A feasibility study has also been completed and has demonstrated that the implementation of an OLM system at a CANDU nuclear power plant could be advantageous under certain conditions.

1. Introduction
In a nuclear power plant, it is required to calibrate transmitters on a time-directed basis to assure that they are operating correctly, in particular for those having a significant importance for plant operating safety. These manual calibrations are time consuming, can lead to instrument degradation and may cause personnel radiation exposures. Industry experience has shown that almost 90% of these calibration efforts are not necessary [1]. These and other considerations have motivated the development of on-line monitoring (OLM) technology to check for transmitter drift to determine when a calibration is needed.

In the nuclear power industry, the use of the OLM technologies to extend the calibration interval of transmitters has received regulatory approval in France (1996), the United States (2000) and the United Kingdom (2005) [2,3]. This approach is currently implemented at the Sizewell B nuclear power plant in the United Kingdom [3] and in the nuclear power plants in France [2,4], but no United States plant is using this method for calibration reduction [1]. Some studies have been performed in...
the CANDU (CANada Deuterium Uranium) industry, but no OLM system has been implemented permanently yet [2,5].

This paper presents the results of a research project performed in a CANDU 6 plant in order to validate the implementation of an OLM system aimed to extend the calibration interval for transmitters (pressure, level and flow). An application project, based on the ICMP (Instrumentation and Calibration Monitoring Program) algorithm developed by EPRI, has been carried out in order to evaluate the performance of an OLM system. A feasibility study has also been completed to evaluate the costs and benefits associated with OLM. Data collected from a 25 years old CANDU 6 plant located in Quebec, Canada were used for this research. This research is limited to the use of redundant algorithms because of the complexity of the non-redundant algorithms and the efforts required for developing and validating the models.

2. Application Project

An OLM system, based on the ICMP algorithm, has been developed. This algorithm was prepared by EPRI and the basis for the method was completed in 1993 [6]. It was chosen for the present research because it's a redundant algorithm that is well known and documented. It has also been tested in some plants in the United States [2,7]. The methods used in Sizewell B and in the French reactors are very similar to the ICMP technique [3,4].

Four case studies were analysed. Table 1 presents these cases. All the transmitters are Rosemount 1152 serie and are used for the Shutdown System 1 (SDS1) or 2 (SDS2). These two CANDU special safety systems provide diverse ways of achieving reactor shutdown if predetermined process or nuclear setpoints are exceeded. SDS1 actuates the control rods and SDS2 actuates chemical injection to shutdown the reactor.

| Case | Transmitter | System | Function | Model | Calibrated span |
|------|-------------|--------|----------|-------|-----------------|
| #1   | 68241PT2D   | SDS1   | Low steam generator feedline pressure | GP8   | 1.91-5.41 MPa   |
|      | 68241PT2E   |        |          | GP8   |                 |
|      | 68241PT2F   |        |          | GP8   |                 |
| #2   | 68333PT1G   | SDS2   | Heat transport high pressure | GP9   | 5-13 MPa        |
|      | 68333PT1H   |        |          | GP9   |                 |
|      | 68333PT1J   |        |          | GP9   |                 |
| #3   | 68337LT1G   | SDS2   | Low pressurizer level | DP5   | 0-15 meters     |
|      | 68337LT1H   |        |          | DP5   |                 |
|      | 68337LT1J   |        |          | DP5   |                 |
| #4   | 68334PT4G   | SDS2   | Low Core Differential Pressure | DP7   | 0-2 MPa         |
|      | 68334PT4H   |        |          | DP7   |                 |
|      | 68334PT4J   |        |          | DP7   |                 |

The data were retrieved from the plant acquisition system and cover plant operations from January 2010 to June 2011. It is recommended that the sample period for OLM ranges from 10 to 60 seconds [8]. For this application project, a sample period of 60 seconds was used during steady-state periods and a sample period of 10 seconds was used during start-up and shutdown periods. For all the cases,
the results of manual calibration and OLM methodologies were compared. This comparison is presented in Table 2. The terminology that is used to present these results is defined as follows: “good” and “bad” mean the method identified the transmitter as being respectively in calibration and out of calibration.

| Case | Transmitter | OLM system | Manual calibrations | Reason for calibration |
|------|-------------|------------|---------------------|------------------------|
| #1   | 68241PT2D   | Good       | Good                | ---                    |
|      | 68241PT2E   | Bad        | Bad                 | Zero and span shift    |
|      | 68241PT2F   | Good       | Good                | ---                    |
| #2   | 68333PT1G   | Good       | Good                | ---                    |
|      | 68333PT1H   | Good       | Good                | ---                    |
|      | 68333PT1J   | Good       | Good                | ---                    |
| #3   | 68337LT1G   | Bad        | Bad                 | Zero shift and nonlinear drift |
|      | 68337LT1H   | Good       | Bad                 | Zero shift             |
|      | 68337LT1J   | Good       | Good                | ---                    |
| #4   | 68334PT4G   | Not applicable | Bad            | Zero and span shift    |
|      | 68334PT4H   | Not applicable | Good            | ---                    |
|      | 68334PT4J   | Not applicable | Good            | ---                    |

The manual calibration and OLM results align well with each other, except for the third case. The fourth case study presents a limit of the ICMP algorithm. These specific cases are discussed further below.

Figure 1 illustrates an example of the results obtained by the OLM system for the first case study.
In the third case study, the result obtained by the OLM system is not as conservative as manual calibration result for the 68337LT1H transmitter. The term “not as conservative” is used to describe a situation in which OLM identifies a transmitter as good but manual calibration identifies the transmitter as bad. Figure 2 illustrates the OLM system analysis for this case study. Note that this data acquisition was done after the 68337LT1G transmitter manual calibration. It explains why its signal is between the OLM acceptance limits. The 68337LT1H transmitter signal is really close to the upper OLM acceptance limit and exceeds it a few times (black arrows). However, these peaks are not long enough to generate an alarm. Only one isolated alarm is generated (red arrow). Manual calibrations and OLM will not necessarily give the same results. This may be explained by the fact that manual calibrations cover the transmitter alone, whereas OLM covers the transmitter plus the channel instruments and the plant acquisition system. The acceptance limit for these two methods is also established differently. For the manual calibration method, the transmitter uncertainty is used. For the OLM limit, the uncertainty of the algorithm associated with the process estimate is subtracted from the combined transmitter, channel instruments and plant acquisition system uncertainties. Consequently, the results of the two techniques should not be expected to match perfectly.
In the fourth case study, the signals of the transmitters present a high level of noise and are not correlated with each other. In this case, the ICMP cannot calculate a process estimate because each transmitter’s consistency is null for most of the time. Figure 3 illustrates these uncorrelated signals.

In this case, the ICMP algorithm is not an appropriate method for drift detection, and alternate methods need to be used.

The analysis of the different case studies has shown that for the most of the transmitters that were found out of calibration, the deviation was present since the last manual calibration. This observation is coherent with a study realized by the NRC (Nuclear Regulatory Commission) that demonstrates that human errors are the most significant cause of reported failures of pressure sensing systems (transmitters, sensing lines and circuits) in nuclear power plants [9]. Figure 4 shows the results of this study.
3. Feasibility study

Some cost benefit studies have been realized by the nuclear industry [3,10,11]. Since the benefits may vary from plant to plant, an evaluation of the costs and the benefits has been completed for a CANDU 6 utility. This evaluation is based on the following assumptions:

- An acquisition system and a data storage system are already installed.
- The data analysis is not performed on a real-time basis.
- There is no interface between the data storage system and the data analysis software. The data is entered manually into the data analysis software.
- A redundant algorithm is used. Thus, no cost associated with models development has to be considered.
- About 150 transmitters are suitable for calibration monitoring.

There are about 800 transmitters in this CANDU plant. About 500 are connected to an acquisition system; the others are used for local indication only. Among these 500 transmitters, about 150 are redundant with at least 2 other transmitters; the others are not suitable for OLM because redundant algorithm is used.

3.1. Costs

Two different cases were evaluated. In the first case, the data analysis is performed by an outside vendor. In the second case, this analysis is performed by the utility itself. Tables 3 and 4 provide a summary of anticipated expenses.

The costs associated with the feasibility study, the preparation for regulatory approval, the maintenance procedures changes and the OLM program review and documentation are the same for the both cases. In the first case, the cost associated with periodic analysis is based on primary discussions with a vendor and should only be considered as a preliminary estimate. Given that the analysis is performed by the utility staff in the second case, it is evaluated that the personnel needs more training than for the first case.
Table 3. OLM costs (case #1: analysis performed by an outside vendor).

| Cost element                                | Cost (CAD) |
|---------------------------------------------|------------|
| **Initial costs**                           |            |
| Feasibility study                           | $68 000    |
| Data analysis software configuration        | $25 000    |
| Personnel training                          | $5 000     |
| Preparation for regulatory approval         | $5 000     |
| Preventive maintenance procedures changes   | $8 000     |
| **Total**                                   | $111 000   |
| **Recurring annual costs**                  |            |
| Data analysis software maintenance          | Not applicable |
| Periodic analysis                           | $25 000    |
| OLM program review and documentation        | $5 000     |
| **Total**                                   | $30 000    |

Table 4. OLM costs (case #2: analysis performed by the utility itself).

| Cost element                                | Cost (CAD) |
|---------------------------------------------|------------|
| **Initial costs**                           |            |
| Feasibility study                           | $68 000    |
| Data analysis software (development or purchase) | $75 000    |
| Personnel training                          | $10 000    |
| Preparation for regulatory approval         | $5 000     |
| Preventive maintenance procedures changes   | $8 000     |
| **Total**                                   | $166 000   |
| **Recurring annual costs**                  |            |
| Data analysis software maintenance          | $3 000     |
| Periodic analysis                           | $5 000     |
| OLM program review and documentation        | $5 000     |
| **Total**                                   | $13 000    |

3.2. Benefits
The benefits of an OLM system include direct benefits from a reduction in manual calibrations, and indirect benefits including improvements in equipment performance.

It has been determined that the cost of a manual calibration is approximately $930. This estimate includes the resources, the materials and ALARA costs. The ALARA costs are estimated to be about $40 per calibration. The direct dose per calibration is about 4 man-mrem and cost of $10 000 man-rem was assumed and considered to be acceptable according to other studies [10,12,13]. About 50 manual calibrations are performed each year. To evaluate the number of calibrations that may be deferred each year, the following requirements have to be considered [2]:

- At least one redundant transmitter will be calibrated each maintenance cycle.
- Transmitters that are identified as out of calibration by OLM will also be calibrated as necessary.
Based on these considerations, the number of deferred calibrations is estimated to be about 35 per year, and the anticipated savings are thus $32 550.

The use of OLM techniques would reduce the number of traditional instrument calibrations thus decreasing the potential for plant trips or transients. However, in the plant of study, no trip or transient due to human error when performing calibrations has been reported. Even if it remains a real concern and another justification for the use of OLM technology, this saving is difficult to quantify and considered negligible.

The use of OLM applications allows Sizewell B to reduce its outage from 25 to 20 days, resulting in savings of over $5 million per operating cycle [3]. The reduction in outage time for other plants will vary according to a variety of factors, and in some cases, the result might be no reduction. In the case of Sizewell B, lessening the number of calibrations leads to direct critical path time savings due to the number of calibrations that must take place inside containment during the outage. In the case of a CANDU 6 plant, many calibrations are performed while the plant is at power and this maintenance task doesn’t represent the critical path of an outage. Consequently, this benefit is not considered.

3.3. Cost benefit analysis

Table 5 presents a summary of anticipated costs and benefits.

|                      | Case #1 Analysis performed by an outside vendor | Case #2 Analysis performed by the utility staff |
|----------------------|-----------------------------------------------|-----------------------------------------------|
| Initial costs        | $111 000                                      | $166 000                                      |
| Recurring annual costs | $30 000                                      | $13 000                                      |
| Annual benefits      |                                               | $32 550                                      |

Figure 5 shows the financial present value results for different discount rates.

![Figure 5. Financial present value results.](image-url)
The first case may never have a positive net value while the second case may have a payback period of 10 to 25 years depending on the discount rate.

4. Conclusions
The application project reveals that the ICMP algorithm is useful for redundant transmitter groups exhibiting high correlations in their data. For redundant signal where data are weakly correlated, it is suggested to apply other algorithms like non-redundant techniques.

The feasibility study shows that the benefits are strongly affected by the number of transmitters being monitored. CANDU 6 plant design dates from the 1970s. It is likely that the use of OLM system in newer design plants that are more instrumented may be more profitable. Certain costs, like the ones associated with software development or with the preparation for regulatory approval, could also be shared between different CANDU plants to increase the profitability of the project.

This study was limited to the use of redundant algorithm. This choice limits the number of transmitters suitable to OLM. The use of non-redundant techniques may increase this number to about 500. It is suggested to evaluate the costs and benefits associated with the use of these techniques for a CANDU plant.

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