ON-LINE MONITORING FOR STATIC AND DYNAMIC PERFORMANCE VERIFICATION OF I&C SYSTEMS AT SIZEWELL B NUCLEAR POWER STATION

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ABSTRACT

Plant operations and maintenance (O&M) activities account for nearly 75% of the generation cost of a modern nuclear power plant (NPP). This is largely due to time-based maintenance strategies that are expensive, time-consuming, prone to error, and sometimes detrimental to plant equipment. In contrast, condition-based maintenance via on-line monitoring (OLM) can reduce costs, increase equipment availability, and improve safety. OLM uses signals from existing plant sensors to verify the performance of plant instrumentation and equipment while the plant is operating.

The Sizewell B nuclear power station in the United Kingdom, a four-loop pressurized water reactor (PWR), uses OLM techniques for several condition-based performance verification activities including pressure, level, and flow transmitter calibration monitoring, resistance temperature detector (RTD) cross calibration, and dynamic performance monitoring of pressure, level, and flow sensing systems. The implementation of OLM has enabled the plant to extend the calibration intervals of its pressure, level, and flow transmitters from 18 to 54 months and has significantly reduced the amount of critical path time needed to perform RTD cross calibration testing (up to 36 hours). Dynamic performance monitoring of its pressure, level, and flow transmitters with OLM has enabled the plant to monitor transmitter and sensing line response degradation while the plant is operating at 100% power and has dramatically reduced testing time versus the traditional hydraulic ramp testing method.

The Sizewell B OLM implementation provides valuable insights into on how to overcome the technical and regulatory challenges for widespread OLM adoption by the nuclear industry. This paper describes the technical and regulatory aspects of this implementation and includes detailed examples of static and dynamic performance testing results to demonstrate the types of capabilities of OLM. Analyzing existing signals with OLM technologies can provide significant cost and safety benefits for the existing fleet of nuclear power plants.

Key Words: online monitoring, calibration extension, dynamic performance monitoring

1 INTRODUCTION

Process instrumentation in nuclear power plants (NPPs), including sensors and transmitters, are subject to performance degradation as they age. Historically, instrument calibrations, response time measurements, and other plant surveillance activities have been labor-intensive activities that require significant amounts of manpower, equipment, and time. Now, these measurements can all be automated and analyzed with on-line monitoring (OLM) technologies which passively assess the accuracy and reliability of process instrumentation while the plant is operating. OLM technologies provide plants with the information needed to evaluate instrumentation and control (I&C) sensors and systems with applications focused on identifying drifting instruments, alerting plant personnel of unusual process conditions, and predicting impending failures of plant equipment [1].

As an early adopter of OLM technologies in the nuclear industry, Sizewell B, a single-unit, 1200 megawatt Pressurized Water Reactor (PWR) has demonstrated the benefits that implementing OLM solutions can provide to operating reactors. The plant is located in Suffolk, England, and is operated and maintained by a staff of about 400 on-site personnel. Sizewell B's plant protection architecture includes both a digital Primary Protection System (PPS), and a complete and independent analog backup protection system known as the Secondary Protection System (SPS). The PPS and SPS each have their own set of process sensors for measurement of temperature, pressure, level, and flow. As such, Sizewell has more than twice as many process instruments as other PWRs. The small number of personnel working at the plant and its large number of instruments makes Sizewell B an ideal candidate for automated maintenance of the plant equipment. To date, Sizewell B has taken advantage of in-situ testing and OLM for a number of applications, including cross calibration of Resistance Temperature Detectors (RTDs) and core-exit thermocouples (CETs) during cool-down and/or heat-up, online calibration monitoring of pressure transmitters, and noise analysis for response time of pressure transmitters.

This paper summarizes the OLM methodologies that Sizewell B has employed to perform automated monitoring of its temperature and pressure instrumentation. In addition, the paper presents a summary of how Sizewell B addressed regulatory issues in order to implement OLM technologies for condition-based maintenance of its plant instrumentation.

2 ONLINE MONITORING (OLM) BACKGROUND

The term *on-line monitoring* (OLM) describes methodologies for evaluating the health and reliability of nuclear plant sensors, processes, and equipment from data acquired while the plant is operating. Nuclear power plants employ a number of sensors to measure the process parameters for control of the plant and protection of its safety. In addition to providing a means for control and protection, the outputs of the existing sensors can also be used to verify the performance of the sensors themselves, and establish the health and condition of the plant. The types of OLM applications that can be used by nuclear power plants are in large part determined by how fast the outputs of the sensors can be sampled. Static OLM applications such as cross-calibration and transmitter calibration monitoring, typically require sample rates up to 1 Hz, while dynamic analysis OLM applications, such as automated response time, use data sampled in the 1 kHz range. Figure 1 lists examples of OLM applications that can be used in nuclear power plants versus the required data sampling frequency [1]. Section 3 provides details on how Sizewell B employs OLM methodologies to implement pressure transmitter calibration monitoring, dynamic response of pressure, level, and flow transmitters, and RTD cross-calibration.

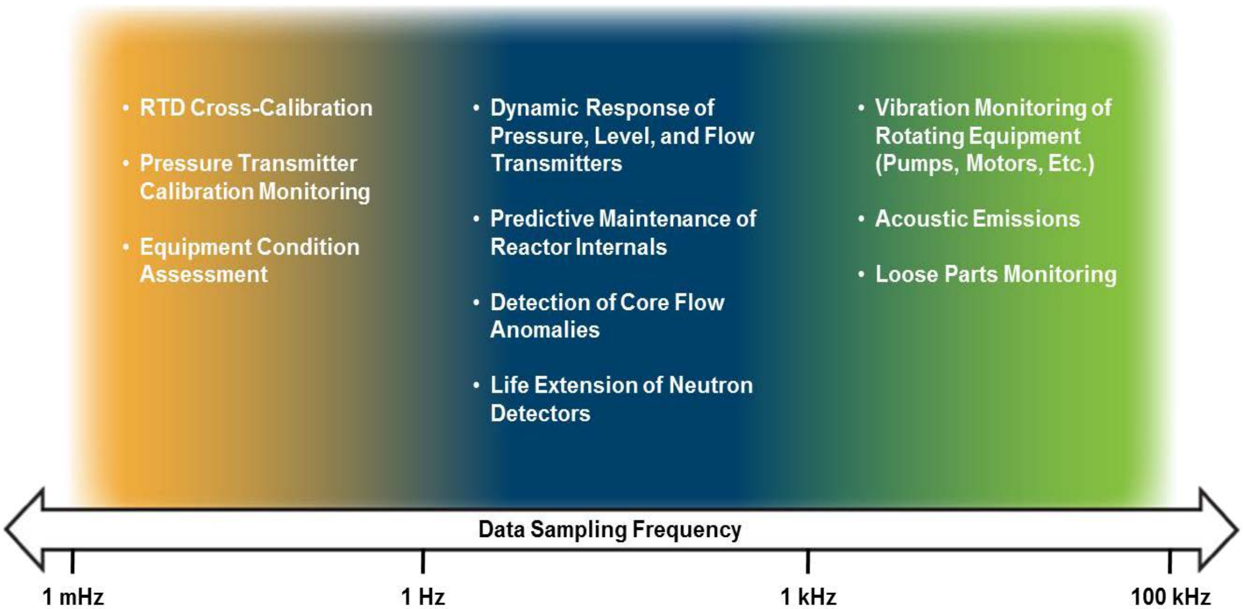


Figure 1. OLM Applications Versus Data Sampling Frequency

3 IMPLEMENTATION OF OLM AT SIZEWELL B

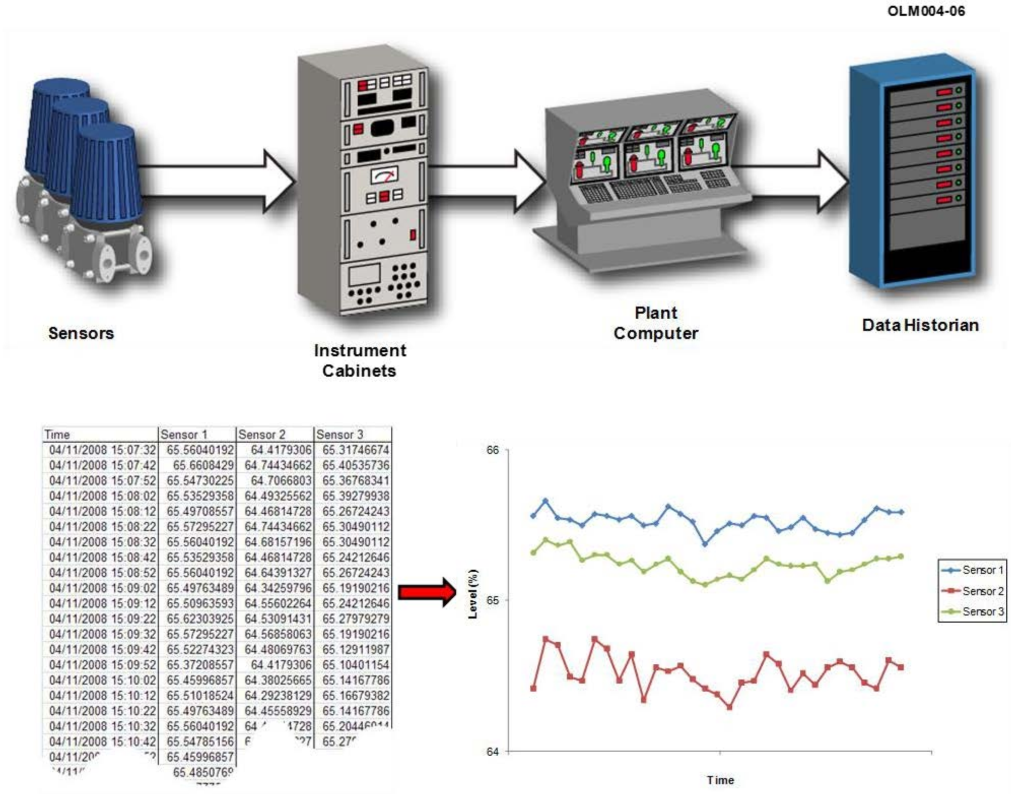
Sizewell B has taken advantage of OLM technologies to help alleviate much of the maintenance burden of verifying the health of its pressure and temperature sensors. This section provides summaries of how Sizewell B implemented OLM applications for online calibration monitoring, online response time testing, and RTD cross-calibration, and the benefits that these technologies provide the plant.

3.1 Online Calibration Monitoring

NPPs are typically required to calibrate their safety-related pressure, level, and flow transmitters on a periodic basis, normally once every refueling cycle (approximately 18 months). This requirement has been in place for decades, dating back to when commercial nuclear power plants began operations. However, based on calibration data accumulated over this period, it has been determined that the calibration of some instruments, such as pressure, level and flow transmitters, do not drift enough to warrant calibration as often as once every fuel cycle [2]. This led the nuclear industry to develop methodologies to determine the calibration status of pressure, level, and flow transmitters by analyzing the data stored from these transmitters on the plant computer as shown in Figure 2.

As shown in Figure 2 , data from the plant sensors is sampled (typically at a rate of 1Hz), and stored in the plant computer or plant historian. The data is extracted from the plant computer or historian, and analyzed with specialized algorithms to determine if any of the transmitters are exhibiting drift in their calibrations. At Sizewell B, data from periods of startup, shutdown, and steady state operation are analyzed to determine the calibration status of approximately 200 transmitters per operating cycle (Figure 3).

The result of the online calibration monitoring process is a listing of transmitters with their calibration status of either ‘Good’ or ‘Bad’ as shown in the example for 12 transmitters in Table I. Sizewell B typically performs this analysis during the mid-point of the fuel cycle to facilitate outage planning in determining which transmitters will need to be calibrated during the outage. At shutdown, the data is analyzed again to confirm or modify the results of the mid-cycle analysis.



Time	Sensor 1	Sensor 2	Sensor 3
04/11/2008 15:07:32	65.56040192	64.4179306	65.31746674
04/11/2008 15:07:42	65.6608429	64.74434662	65.40535736
04/11/2008 15:07:52	65.54730225	64.7066803	65.36768341
04/11/2008 15:08:02	65.53529358	64.49325562	65.39279938
04/11/2008 15:08:12	65.49708557	64.46814728	65.26724243
04/11/2008 15:08:22	65.57295227	64.74434662	65.30490112
04/11/2008 15:08:32	65.56040192	64.68157196	65.30490112
04/11/2008 15:08:42	65.53529358	64.46814728	65.24212646
04/11/2008 15:08:52	65.56040192	64.64391327	65.26724243
04/11/2008 15:09:02	65.49763489	64.34259796	65.19190216
04/11/2008 15:09:12	65.50963593	64.55602264	65.24212646
04/11/2008 15:09:22	65.62303925	64.53091431	65.27979279
04/11/2008 15:09:32	65.57295227	64.56858063	65.19190216
04/11/2008 15:09:42	65.52274323	64.48069763	65.12911987
04/11/2008 15:09:52	65.37208557	64.4179306	65.10401154
04/11/2008 15:10:02	65.45996857	64.38025665	65.14167786
04/11/2008 15:10:12	65.51018524	64.29238129	65.16679382
04/11/2008 15:10:22	65.49763489	64.45558929	65.14167786
04/11/2008 15:10:32	65.56040192	[illegible]	[illegible]
04/11/2008 15:10:42	65.54785156	[illegible]	[illegible]
[illegible]	65.45996857		
[illegible]	[illegible]		

Figure 2. OLM Data Acquisition Process

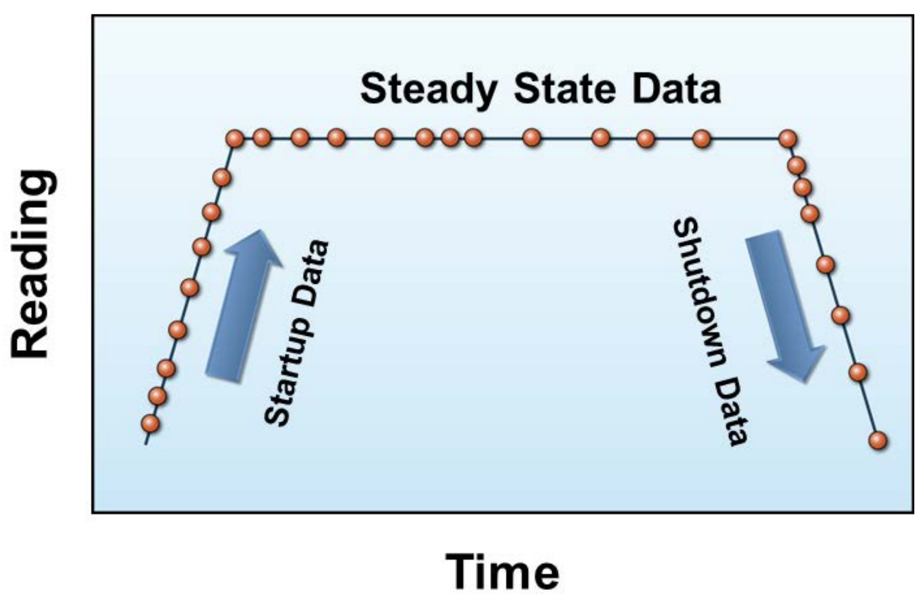


Figure 3. OLM Data Acquisition at Startup, Steady-State, and Shutdown

Table I. Example OLM Calibration Results for 12 Transmitters

Item	Group Name	Tag Name	Result
1	MAIN STEAM PRESSURE LOOP 1	TAG 1	Good
2	MAIN STEAM PRESSURE LOOP 1	TAG 2	Bad
3	MAIN STEAM PRESSURE LOOP 1	TAG 3	Bad
4	MAIN STEAM PRESSURE LOOP 1	TAG 4	Good
5	STEAM GENERATOR A LEVEL NR	TAG 5	Good
6	STEAM GENERATOR A LEVEL NR	TAG 6	Good
7	STEAM GENERATOR A LEVEL NR	TAG 7	Good
8	STEAM GENERATOR A LEVEL NR	TAG 8	Good
9	MAIN FEED FLOW TO SG A	TAG 9	Good
10	MAIN FEED FLOW TO SG A	TAG 10	Good
11	MAIN FEED FLOW TO SG A	TAG 11	Good
12	MAIN FEED FLOW TO SG A	TAG 12	Good

Typically, around 90% of the transmitters analyzed by OLM each cycle do not exhibit drift, allowing the plant to spend valuable outage resources on other activities instead of calibrating pressure transmitters.

3.2 Online Response Time Testing

In addition to calibration monitoring, Sizewell B also employs online methodologies to determine the response time of its pressure transmitters during each cycle. Unlike conventional response time testing methodologies that require inputting pressure ramps with hydraulic test equipment, Sizewell B uses the OLM technique known as noise analysis to determine the response time of its entire pressure transmitter sensing system that includes both the transmitter and its sensing lines [3]. The noise analysis technique involves acquiring 1kHz data from pressure transmitter test points in instrumentation cabinets while the plant is online, and analyzing the data in both the time and frequency domains. Data acquisition for the noise analysis technique can be performed simultaneously on multiple transmitters, which significantly reduces the amount of test time needed to perform the testing compared to conventional methods. In addition, because noise analysis is a passive technique, the assessment of the dynamic performance of transmitters can be performed throughout the fuel cycle to help the plant periodically monitor for degradations in transmitters or sensing lines. Figure 5 shows and example of a clogged pressure transmitter sensing line that was detected by noise analysis in various degrees of degradation over a fuel cycle. As shown in Figure 5 , after the clogged sensing line was detected, it was cleaned, and the dynamic response of the transmitter returned to normal.

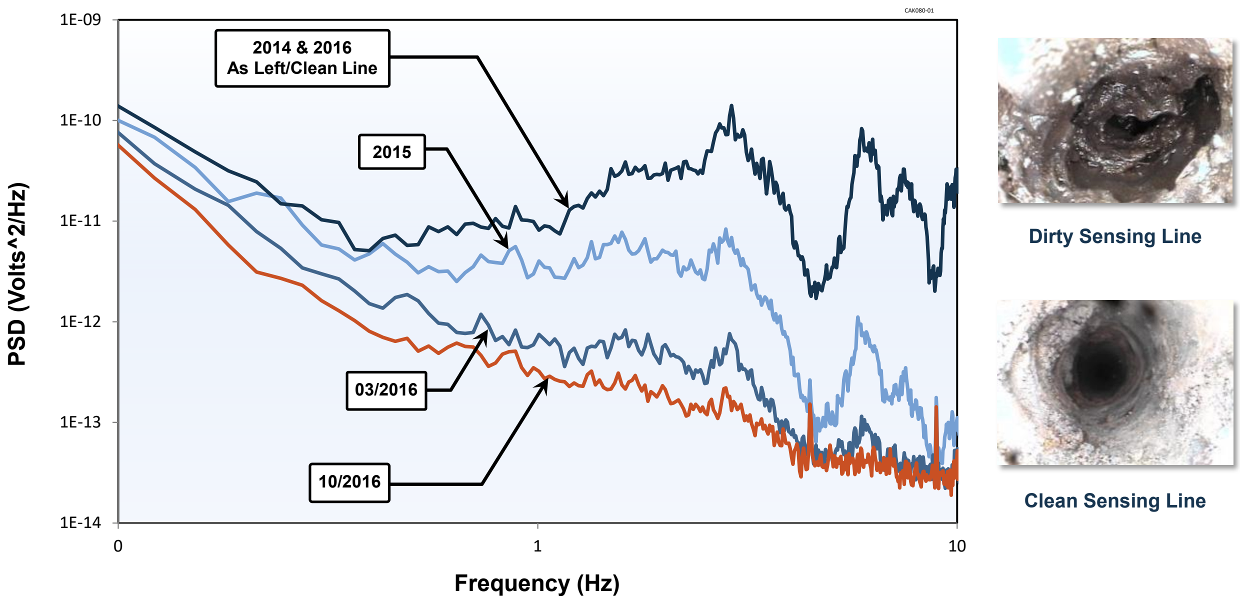


Figure 5. Example of Clogged Sensing Line Detected by Noise Analysis

3.3 Cross Calibration

Sizewell B employs a number of resistance temperature detectors (RTDs) and core-exit thermocouples (CETs) to monitor the fluid temperature in the reactor coolant system (RCS). The temperatures measured by the RTDs and CETs are used by the plant operators for process control and to assess the safety of the plant. Because the measurements of RTDs and CETs play a critical role in the evaluation of the plant's operating status, the calibrations of the RTDs and CETs are normally evaluated at least once every refueling cycle. Each RTD and CET measurement must meet specific requirements for the plant to continue to produce power according to its design specifications.

Similar to other PWRs, redundant RTDs and CETs at Sizewell B help to minimize the probability of failure of any one RTD or CET having a serious effect on the operator's ability to safely and efficiently operate the plant. This redundancy of temperature measurements is the basis for a method of evaluating the calibration of RTDs and CETs called *cross calibration*. In cross calibration, redundant temperature measurements are averaged to produce an estimate of the true process temperature. The measurements of each individual RTD and CET are then compared with the process estimate to determine if the RTDs and CETs are in calibration.

Traditionally, cross calibration data has been acquired using data acquisition equipment connected to test points in the instrumentation cabinets. The traditional cross calibration method, while highly accurate, requires the plant to lose indication when the data is being acquired, and costs the plant time during shutdown and/or startup to defeat and restore the temperature indications. However, at Sizewell B, the RTD and CET measurements are acquired by the plant computer, and these measurements are used by specialized analysis software to provide cross calibration results without requiring the plant to lose indication. A screenshot of the software used to provide the cross-calibration analysis at Sizewell B is shown in Figure 6.

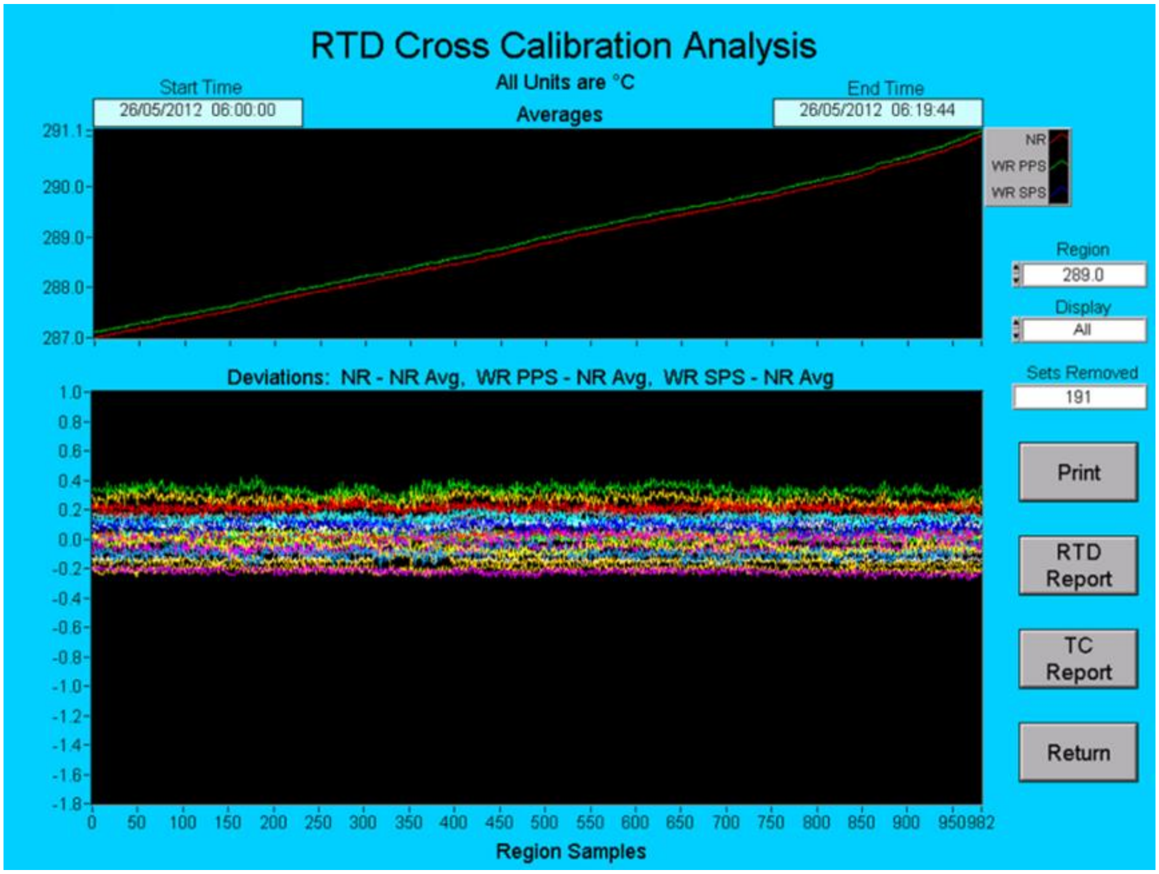


Figure 6. RTD/CET Cross Calibration Software

At Sizewell B, cross calibration data is taken and analyzed on over 50 RTDs and 50 CETs during shutdown. This enables any problems with RTD or CETs to be addressed during the refueling outage. At startup, the cross calibration data is taken again to verify the calibration of the RTDs and CETs. If any problems with the calibrations of the RTDs are found, new calibration coefficients can be calculated and applied to the RTDs.

4 REGULATORY ASPECTS OF OLM IMPLEMENTATION AT SIZEWELL B

Before seeking approval for pressure transmitter calibration interval extension, Sizewell B first examined their existing safety case. Historical plant data needed to be gathered in order to perform a transmitter drift analysis to determine whether the transmitters did in fact drift over an operating cycle. Also, they had to examine the impact that calibration interval extension would have on plant safety and reliability. Sizewell, like all nuclear facilities in the United Kingdom (UK), is regulated by the Office for Nuclear Regulation (ONR), the UK equivalent to the NRC in the U.S. The ONR had many questions and concerns regarding the implementation of calibration interval extension using OLM technologies. In order to extend the calibration intervals, an acceptable methodology had to be provided, along with evidence that it would actually monitor the calibration of the instruments. To this end, Sizewell B personnel worked with the Electric Power Research Institute (EPRI) and Analysis and Measurement Services Corporation (AMS) to provide the analysis and evidence required to justify pressure transmitter calibration extension. This evidence, as well as details regarding the regulatory aspects of implementation is presented in several EPRI report volumes which are summarized in [4].

5 CONCLUSIONS

The Sizewell B plant in the UK has taken advantage of OLM methodologies to transition several of their maintenance activities from traditional time-based to condition-based methodologies. Transmitter calibration extension, facilitated by OLM, has allowed the plant to save up to 75% of their safety-related calibrations per outage, which in turn, has freed valuable resources during the outage to perform other work. In addition, RTD cross calibration has enabled the plant to perform temperature sensor verification without affecting plant shutdown and startup processes, saving critical path time and allowing problems to be addressed without affecting plant operation. In-situ response time with OLM has enabled the plant to verify the response times of their pressure transmitters, and provided indication of degraded pressure sensing systems while the plant is online so that maintenance can be scheduled efficiently. The implementation of OLM at Sizewell B can be used as a template for other NPPs to begin benefitting from the advantages of OLM and transition from time-based to condition based maintenance.

6 REFERENCES

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