Overview of Monitoring Applications for Retrofit and New-build NPP Projects

Vaughn Thomas and Christopher Black
Westinghouse Electric Company, LLC
(thomasvm@westinghouse.com; blackcj@westinghouse.com)
1000 Westinghouse Drive, New Stanton, PA 15672

Abstract

Westinghouse has provided digital I&C upgrade systems to the fleet of nuclear power plants worldwide from the earliest introduction of such technology to power generation, covering a complete range of applications including systems for protection, control, information, & monitoring. In this context, plant computer and vibration/diagnostic systems have been integral to existing plant retrofits as well as new-build (e.g. **AP1000®** plants). Westinghouse has positioned a set of integrated technologies to facilitate increased efficiency and effectiveness of system engineers relative to maintaining a high level of equipment readiness and reliability by leveraging I&C technology. This presentation provides an overview survey of such technologies and product applications.

1. Introduction

Utilities continually seek ways to avoid forced outages and power curtailments in order maintain a high level of plant availability, and therefore, competitiveness. Challenges to this effort grow as plants near the end of their design lifetime, and often, beyond as lifetime renewals and extensions have become commonplace and even expected for many plants. The burden of these challenges fall most directly upon system engineers who, with aging components/equipment and an array of preventive maintenance programs and strategies in place, often find themselves overwhelmed with an increasing backlog of issues and work orders to be dealt with, while also addressing emergent issues of the day. In recent industry forums, the question has often been posed: Can online process and condition monitoring technologies be effectively leveraged to help proactively identify emerging or slowly developing issues, and help to help focus maintenance priorities? (1) The industry has long sought after a means to identify that components or equipment are going to degrade or breakdown before they actually do. Virtually all operating nuclear units have a plant computer system, the capabilities of which have been viewed as a potential support in this regard; the unblinking eye of the computer which stares 24/7 and never tires of "watching grass grow" relative to slowly developing degradations, and which provides a way of discerning early issues before they become critical; to use a medical analogy - identifying when a process or component is "developing a sniffle before it becomes pneumonia".

Nevertheless, experience with such monitoring using the existing I&C infrastructure has had limitations. The existing infrastructure was designed primarily for protection and control of the unit, and secondarily, for process monitoring. It was not, however, designed for monitoring the condition and operational readiness of components, which requires an expanded coverage of measurements points both in terms of scope and type. Effective component condition monitoring requires handling of high-speed data measurements (e.g. vibration). Adding new wired signals is generally cost-prohibitive; even when introduced on a selective basis, high-speed data would overburden the existing infrastructure and must often be implemented on a stand-alone basis.

Recent evolutions of certain enabling technologies associated with data acquisition platforms and digital I&C infrastructure have introduced potential for dealing with such issues in a manner previously not possible or considered viable. Correspondingly, implementations of related technologies for new-build applications are beginning to point the way toward potential for leveraging such technologies so that effective component condition monitoring may be introduced on a retrofit basis in a cost effective and integrated manner. The following discussion presents a survey of such technology and applications, and identifies considerations for retrofit application to existing operational units.

2. Legacy Monitoring Systems

Traditional implementations of monitoring systems from the earliest days of nuclear power up to the present have generally fallen into two distinct and separate categories depending upon their focus; process monitoring, and component monitoring. Process monitoring was the basis of the original plant computer applications, and largely remains so today, including a number of post-Three Mile Island systems specifically aimed at post accident conditions. Component monitoring began to be introduced later as attention moved from support of the operator in the control room, to support of the engineering/maintenance staff concerned with the details of specific equipment and components within the various systems. The component monitoring applications tended to be introduced on a standalone basis, sometimes in association with upgrades of the related components or equipment. The following provides a brief survey of such systems that Westinghouse has provided, and which are representative of similar systems in the industry.

2.1 Process Monitoring

2.1.1 Plant Computer System

Plant Computers were some of the first systems introduced based upon digital technology, and therefore by necessity, were implemented in parallel to the analog process control and protection systems. Later, as digital infrastructure began to be introduced via retrofit upgrades, mostly for control systems, portions of the plant computer process monitoring function began to be integrated into this digital infrastructure while the remainder was left largely unchanged. The focus of information provided by the plant computer and its nuclear applications largely supports operators in the main control room and immediate support personnel associated with the reactor core.

2.1.2 Alarm/Annunciator System

Similar to the plant computer, alarm/annunciator systems have largely been implemented in parallel to existing analog control and protection systems, with later integration into digital infrastructure as control upgrades were implemented, or less frequently, on a standalone basis. The human-system interface and format for alarm presentation has largely centered upon the tile/window-box approach in which arrays of such tiles, one per alarm condition, are configured into blocks typically placed across the top of the main control board panels. Alarms associated with portions of the infrastructure replaced by digital equipment are capable of being represented in alternate graphic display formats and are supplemented with dynamic electronic listings.

2.1.3 Rod Position Indication

Given the primary importance of reactor control rods relative to changes in reactivity according to changes in position, and due to the unique nature of the positioning devices and the equipment necessary to measure rod position, rod position monitoring and indication has traditionally been handled by a specialized, stand-alone system. Even with the introduction of recent digital upgrades to replace the original analog systems, they have remained largely as stand-alone systems.

2.1.4 Post Accident Monitoring

Following the events at Three-Mile Island in the late '70's, a number of regulatory measures instituted requirements for supplemental, qualified, dedicated monitoring instrumentation specifically targeted to conditions associated with post-accident conditions. An array of monitoring systems, some initially analog but later digital, were introduced and implemented largely as stand-alone retrofit solutions for operating and near-term operating license (NTOL) units. These included functions such as reactor vessel level indication (RVLIS), core-subcooling (CSM), qualified wide-range nuclear instrumentation, core-exit thermocouples, safety parameter display systems (SPDS), and a number of other wide-range measurements associated with post-accident emergency guidelines (ERGs) and procedures (EOPs) designed to respond to accident conditions, mitigate their evolution, and achieve/maintain stable conditions.

2.2 Component Condition Monitoring

As more plants moved into longer term operation and some began in the late '80s to consider life extension (> 40 yrs), and with continuing development of digital instrumentation, systems aimed primarily at monitoring component condition and challenges to structure integrity began to emerge and see deployment.

2.2.1 Turbine Monitoring

As perhaps the largest and most expensive single piece of equipment for most power generation units, and due to its high-speed rotational operation, the main turbine has been the object of some of the earliest component monitoring systems, with a focus primarily upon performance and vibration. Turbine monitoring systems (or so called turbine supervisory systems), are typically introduced as an integral part of any turbine control or protection system upgrade if not already in place and as such, are typically integrated and highly specialized systems. They, in conjunction with smaller scale systems of similar design applied to turbine-driven feedwater pumps, are some of the most widely implemented systems of this type in power generation units and have been the focus of technology, design, and analysis for many years.

2.2.2 Loose Parts Monitoring

Given the potential for damage to fuel rods or related equipment due to existence of loose parts within the reactor coolant system, regulatory requirements have brought about introduction of loose parts monitoring systems to identify such circumstances in order to support detection and response planning. These are generally based upon acoustic measurements, and have been implemented as stand-alone systems.

2.2.3 Leak Monitoring

Leak monitoring systems have various forms and utilized differing technologies, including acoustic as with loose parts. Similarly, they are implemented largely as stand-alone, retrofit applications.

2.2.4 Transient and Fatigue Monitoring

With regard to life extension considerations, it is recognized that plants were designed to a particular set of assumed transient conditions over a specified (initially, 40 yrs) operational life, and that major components were analyzed for such conditions. In order to assess actual operation and transient evolutions, and correspondingly support evaluation of usage relative to the original basis, monitoring systems which incorporate analysis and algorithmic techniques accordingly have been implemented[(3)]. While in many cases making use of existing measurements and indications, these systems can vary as either stand-alone systems, drop-in applications to existing monitoring/plant computer systems, or integral to a larger package of upgrade systems.

2.2.5 Chemistry and Corrosion Monitoring

As a very specialized sort of monitoring, some systems have been implemented with a focus on chemistry and corrosion considerations. Special measurement interfaces are employed, along with usage of existing instrumentation where possible and applicable.

3. New-Build Monitoring Systems

While many of the Legacy Systems mentioned continue forward in application to new-build projects such as the **AP1000** plant, several now incorporate additional capabilities, provide alternate perspectives and supplements to monitoring, and utilize a more current technology base in order to gain from advancements in related areas. The following provides an overview survey of those applications which are in some significant way different from the typical Legacy application.

3.1 Process Monitoring

3.1.1 Digital Display System

For new-build, the entire I&C infrastructure for plant protection and control utilizes digital-based platform technology. In addition, the scope of coverage is not limited to the reactor or nuclear steam supply system alone, but instead encompasses the entire unit, including the balance of plant as well as auxiliary and infrastructure systems. These characteristics make available a wide range of signals and measurement points to support the plant computer function, as well as the human-machine interface for the operators, which is itself a highly integrated, digital-based hybrid of a small number of backup/safety hard-panel devices, and a largely soft-control based set of workstations, displays, and graphic interfaces.

Within this context, the traditional "plant computer system" becomes a set of application servers which support data acquisition, processing, archival, and presentation of operational parameters necessary to support the operators during plant evolutions. It also supports and incorporates such applications as advanced alarming, computerized procedures, technical specufications & limiting condition for operation (LCO) indications, and various advanced core monitoring features.

While this represents a substantial increase in scope and depth of integrated monitoring coverage, it is still largely directed to supporting the operators in the control room from the standpoint of the primary protection and control missions, and relative to process monitoring. There are relatively few and limited aspects which contribute to or directly support component condition monitoring, as concerns the engineering and maintenance staff outside of the control room.

3.2 Component Condition Monitoring

Several subsystems, in relation to similar Legacy Systems, are focused on monitoring the condition of particular components or structural concerns.

3.2.1 Digital Metal Impact Monitoring System

Loose Part Monitoring System (LPMS) for metallic debris detection within the primary loop of PWR (and BWR) plants is based upon the legacy system which has been in use for over 40 years. The current implementation, designated as Digital Metal Impact Monitoring System (DMIMS), incorporates high-speed, high performance signal conditioning and data acquisition technology and is provided to all **AP1000** plant units as standard equipment.

3.2.2 Vibration Integrity Monitoring System

Likewise supplied to all **AP1000** plant units under construction, the Vibration Integrity Monitory System (VIMS) provides rotating equipment monitoring for Reactor Coolant Pumps (RCP) and Control Rod Drive Mechanism Fans, thereby providing machinery protection in accordance with API 670 and ASME OM-S/G part 24. The system supports accelerometers, velocity sensors and proximity probes, and correspondingly, employs associated high-speed, high performance data acquisition, and provides buffered outputs to support other predictive monitoring applications.

3.2.3 Feedwater Vibration Monitoring System

The Feedwater Vibration Monitoring System performs vibration monitoring on the **AP1000** plant main feedwater pumps, using 84 proximity sensors to monitor radial and axial vibration including phase reference channels as an enhancement to legacy systems utilizing a smaller number of monitoring points. As with the above component condition monitoring applications, high-speed, high performance signal conditioning and data acquisition technology are integral components.

3.3 Test Support Monitoring

In addition to the process and component condition monitoring system mentioned, there are a couple of notable test support monitoring systems which respond to requirements associated with first-of-a-kind new-build projects. They have been developed using an architecture incorporating modular data acquisition technology which is referred to as VADE™, an acronym which represents the focus of measurement types for these applications, namely: vibration and diagnostic expansion(4).

VADE™ is built upon a compact, small-footprint, low-power usage, high-speed, high performance data acquisition platform that incorporates a combination of analog & digital I/O, FPGA, & CPU technology. Because aspects are software based, it provides a flexible, open, highly configurable capability for potentially addressing various high-speed data applications, including both process monitoring (e.g. sequence-of-events, transient post-mortem), as well as component condition monitoring (e.g. diagnostics, vibration). It is highly scalable and can expand from on the order of 20-30 channels to thousands of channels.

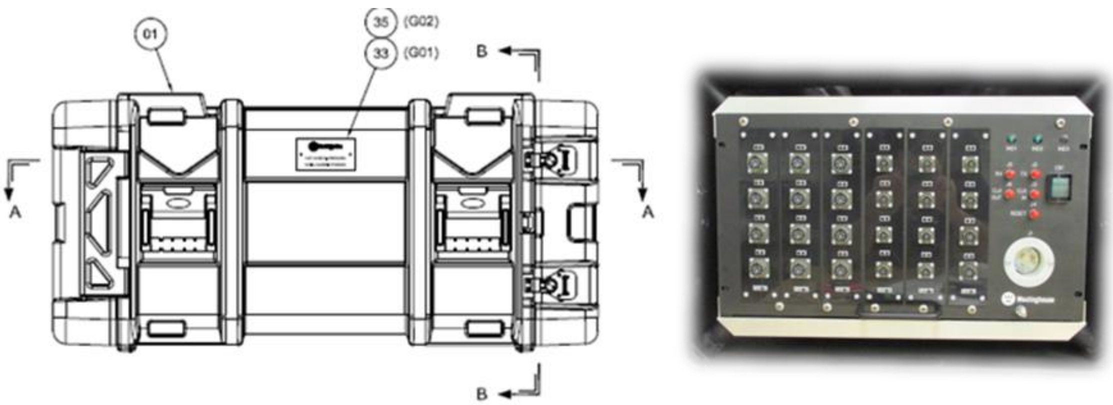

Figure 1 - VADE Packaging and Distribution Hub Front Panel

The VADE™ packaging supports configuration flexibility due to its modularity, and correspondingly, supports install variations, including temporary and permanent, mobile and in-situ. This modular data acquisition technology was developed for **AP1000** plants, and is applied for both of the following applications associated with first-time plant start-up programs.

3.3.1 Comprehensive Vibration Assessment Program (CVAP)

The CVAP system addresses governing regulatory requirements from U.S. NRC Reg Guide 1.20. The system configuration is comprised of an Operator Workstation which addresses the HSI and Processing layers of the system and includes server/storage components. The Distribution Hub provides a Network/Infrastructure layer which provides connectivity between the various sub-assemblies, including a total of six remote data acquisition satellites which comprise the I/O Layer. These six satellites handle in total over 90 individuals sensors and nearly 20 signals as buffered signals from interfacing systems. CVAP equipment is currently being deployed for the **AP1000** plant new-build projects in China.

3.3.2 Thermal Effects, Dynamic Effects & Vibration (TEDEV)

The TDEV system address ASME OM-S/G-2000 Parts 3 and 7 concerning thermal expansion and vibration testing of piping systems. The TDEV configuration is similar to CVAP and is comprised of an Operator Workstation and Distribution Hub, and much larger complement of I/O, having a total of twenty-two remote data acquisition satellites (14 inside containment) which monitor over 430 individual sensors.

For both CVAP and TDEV, fiber-optic interfaces maintain synchronization across the various sub-assemblies via clock signals, a number of which are high-speed vibration channels.

4. Common Monitoring System Technologies & Considerations

As seen from the above overview, it is clear that over time and across a range of applications, dedicated instrumentation for plant monitoring has been added to supplement existing instruments (primarily for plant protection, control, and process monitoring) in order to support other functions and considerations, however, the breadth of scope for such add-ons has remained somewhat limited relative to having a complete, detailed profile of process/component conditions and performance. With the introduction of digital I&C retrofits for existing plants and distributed digital network architectures of new-build, the traditional "plant computer" has become an integral part of the plant I&C infrastructure. It can be seen that, while there is a level of synergy between the process monitoring and control functions, this introduces inherent constraints and limitations with regard to monitoring of process operation/performance, and more particularly, component condition[2]. Alternative approaches generally aim to build upon traditional preventive maintenance strategies by leveraging technology to introduce continuous monitoring and its corresponding advantages. The goal is to be more proactive, with the benefits of doing so being somewhat apparent. The cost of an unplanned, forced outage is significantly larger than the cost of an anticipated, temporary down-power to do a planned repair. Likewise relative to outage planning where the impact of many emergent issues often drives the critical path, whereas with pre-planned work is more directly managed. With these clear benefits, barriers and challenges remain to comprehensive introduction of continuously online condition monitoring.

4.1.1 Monitoring System Challenges and Goals

Process monitoring performed by the plant process computer supports plant operation. The focus for information generated by this system is the operators in the main control room, and to a limited extent, operations support personnel outside of the main control room. Custom graphic displays for plant system/process information (e.g. typically Process Instrumentation Diagram - PID - format) comprise the HSI. Data rates are relatively moderate (1 second updates or longer) with periodic data capture and archival continuously and/or by exception. As described above, the input signals are from a somewhat limited set of instrumentation largely supporting control & protection systems.

Alternatively, component condition monitoring is more focused towards engineering, maintenance, and other operational support personnel outside of the main control room. Associated displays are oriented toward component attributes, and data rates tend to be relatively high (0.001 second updates or shorter) with data capture and archival on a periodic and/or triggered basis. The measurement inputs are most typically new supplementary measurements associated with component or upgrade related add-ons. They are fairly limited in scope and number, as the cost of cabling, field design, installation, etc. can be significant.

While the type of new technologies described above for new-build applications have capabilities which address the requirements of component conditions monitoring, challenges yet remain in the insufficient coverage of measurements points of the necessary type (i.e. high speed vibration data), and the often prohibitive cost of adding new wired signals. In addition, high-speed data can often overburden the existing infrastructure, requiring a stand-alone implementation.

Much interest has been generated with respect to the possibility of leveraging wireless technology to overcome these barriers, however, nuclear power plants have been slow to widely adopt it due to Cyber Security and EMI/RFI considerations. In addition, current wireless sensors and corresponding infrastructure do not deliver raw high-speed data, but instead are based on protocols supporting slower data rates (on the order of 1 sec updates or longer). An alternate, higher performance approach to wireless network infrastructure, and implementation "outside the firewall" to address security would perhaps be enabling in this regard; the remaining concern of EMI/RFI could be reasonably managed through proper survey and design.

4.1.2 Characteristics of an Integrated Monitoring Infrastructure

In view of the above considerations relative to potential retrofit upgrades or modifications to support component condition monitoring, and potentially supplementary process monitoring as well in order to provide value to operations and operations support, a set of overview requirements could be summarized as follows.

1) Expanded scope of & access to plant data and associated calculated parameters (i.e. more new measurements and measurement types)
2) Real-time & historical window to behavior of plant processes (statepoints & transients)
3) Data archival and retrieval capability (supporting post-event evaluations and reporting)
4) Data analysis and performance evaluation capability
5) Expanded support engineering, and maintenance personnel to focus on assessment of plant processes and associated components/systems status, condition, performance, and behavior

Item 5 speaks to the shift in focus toward a much broader 'audience' of personnel to whom the above must be made readily available and/or directly accessible on their desktop.

The need for a scalable approach to architecture is indicated such that small, localized, focused applications could be pursued for specific, targeted issues while maintaining capability to effectively interface and scale to broader system, unit, site, or even fleet-based applications. This could be done in a manner which addresses both process and component condition monitoring within an integrated and common infrastructure such as the type shown in Figure 2. This representative infrastructure incorporates a number of key attributes: an integrated, modular, scalable configuration as well as flexibility and distributed processing capabilities across the various layers of the system (I/O, Processing, Network Infrastructure/Archive, and HSI). The utilization of wireless technology would reduce installation costs and would allow for the introduction of mobile devices as a means to interact within the system, thereby bringing capability for further value-added applications to support personnel, not only during power operation, but also during maintenance outages.

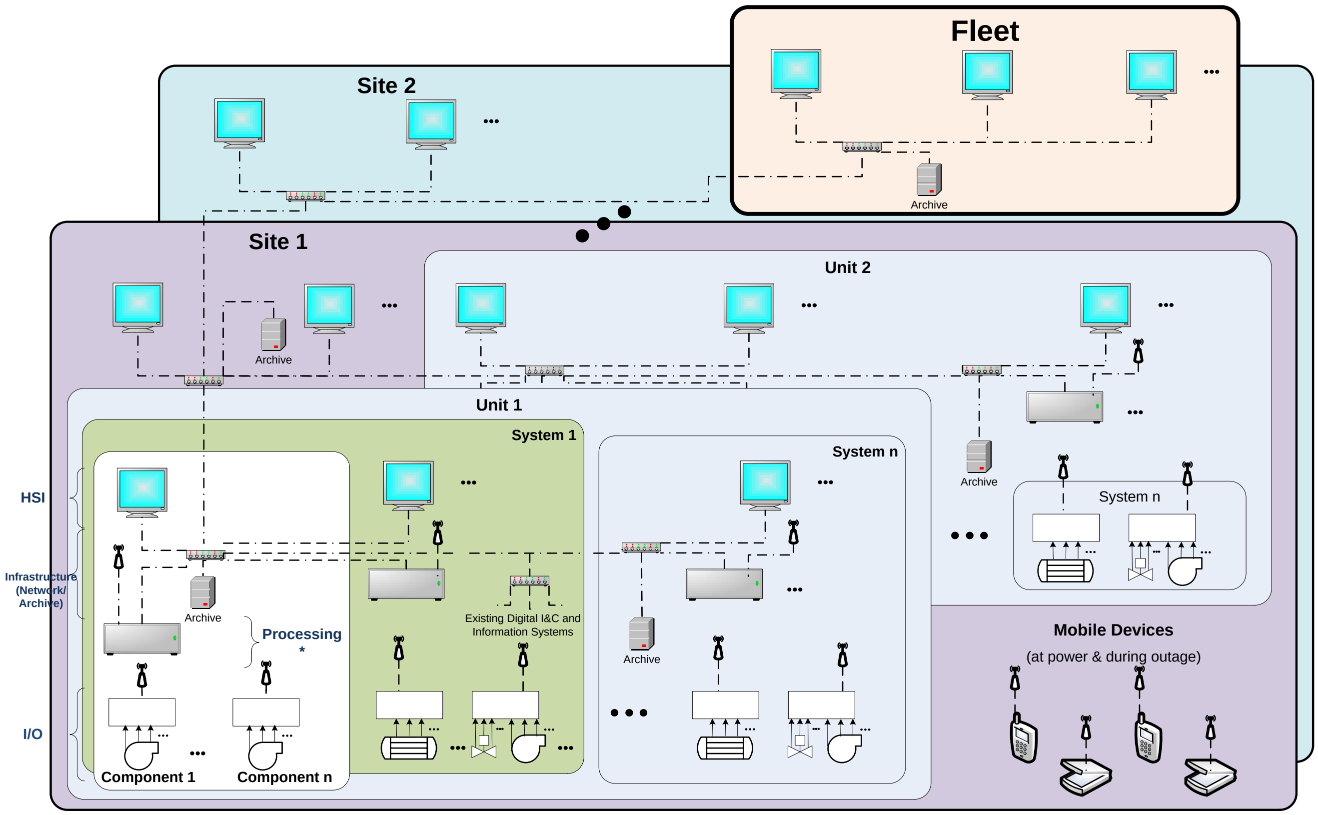

Figure 2 : Representative Overview of an Integrated Monitoring Infrastructure

The new-build technology described above would appear to be well suited for application in support of such an infrastructure given its attributes: support of expanded instrumentation, real-time and historical data access (archival/retrieval), data analysis/display, and ability to extend direct access over a distributed network to the wider set of personnel outside of the main control room (perhaps in an adjacent engineering buildings). Modifications introduced to the front-end and back-end of the system, i.e. the I/O Layer as well as the Processing & HSI Layers, would provide the necessary adaptation for retrofit. For I/O, the temporary installation modules would be repackaged for permanent installation. For the Processing and HSI Layers, capabilities could be evaluated and incorporated on a case-by-case basis according to the application.

5. Conclusion

The range and scope of monitoring applications have evolved from legacy systems to current implementations in a manner which more fully utilizes the capabilities afforded by digital I&C technology. As additional applications were introduced to address particular requirements, they were often implemented as stand-alone upgrades. New-build projects have incorporated updated versions of a number of legacy systems and have exhibited a much more integrated implementation, particular with regard to the traditional plant computer function and other control/protection functions in support of plant operation. However, many of the legacy applications carried forward, particularly those associated with component condition monitoring, remain as largely stand-alone applications.

Some of the technologies being applied in new-build projects with regard to high-speed, high-performance data acquisition systems incorporate features which can, with some moderate adaptation, supplement process monitoring and support component condition monitoring retrofits in existing plants. They are configured with a high degree of modularity, scalability, and integration suitable for meeting various levels of system implementations which could arise for retrofit applications - ranging from component to system to unit, site or even fleet-level. Introduction of wireless technology could assist in addressing challenges related to installation costs and addition of supplementary field instruments in order to obtain the desired benefits, including extended direct access over a distributed network to the wider set of personnel outside of the main control room, including system engineers in adjacent engineering buildings.

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