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PLANT-WIDE INTEGRATED EQUIPMENT MONITORING AND ANALYSIS SYSTEM

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ABSTRACT

A nuclear power plant equipment monitoring system monitors plant equipment and reports deteriorating equipment conditions. The more advanced equipment monitoring systems can also provide information for understanding the symptoms and diagnosing the root cause of a problem. Maximizing the equipment availability and minimizing or eliminating consequential damages are the ultimate goals of equipment monitoring systems. GE Integrated Equipment Monitoring System (GEIEMS) is designed as an integrated intelligent monitoring and analysis system for plant-wide application for BWR plants. This approach reduces system maintenance efforts and equipment monitoring costs and provides information for integrated planning. This paper describes GEIEMS and how the current system is being upgraded to meet General Electric's vision for plant-wide decision support.

INTRODUCTION

The benefits and basic designs of a plant-wide integrated system for monitoring the plant operations and equipment conditions was presented at the EPRI Conference (Reference 1). A plant-wide integrated system provides (1) flexible integration of variety of products for monitoring multiple machines of different types, (2) consistent user interface uniting various state-of-the-art application hardware/software, and (3) availability of data for plant-wide maintenance planning. In addition to specific benefits resulting from individual monitoring products, these advantages lead to minimizing the costs associated with functionality expansion and incorporation of evolving technology in plant monitoring. The basic data processing designs include (1) latest networking and digital communications, (2) open standards, (3) graphical user interfaces supporting multi-national languages, and (4) intelligent distributed signal processing. The essence of this design is currently being implemented through the next generation of GEIEMS. Efforts are being made to achieve the architectural and performance goals of the plant-wide monitoring system vision so that the result becomes a standard baseline.

GEIEMS BACKGROUND

General Electric (GE) Integrated Equipment Monitoring System (GEIEMS) is one of the installed GE's plant monitoring applications (Table 1). GEIEMS currently provides continuous on-line monitoring of BWR recirculation pumps and Reactor Pressure Vessel (RPV) feedwater nozzles. The recirculation pump monitor is an application of condition monitoring that not only checks and reports signal and data abnormality but also diagnoses the problem through an on-line expert system. An on-line rotating machinery vibration analysis tool is also incorporated into this system for use by the maintenance engineer to further examine the various data in detail. The feedwater nozzle thermal cycle fatigue monitor is an application of predictive maintenance monitoring, which performs the required calculations automatically, predicting the remaining time before the component must be serviced.

Table 1 GE Plant Monitoring Applications

3D Monicore	Core Monitoring
BOP	Balance of Plant Performance Monitor
EOPT	Emergency Operating Procedure Tracking
GEIEMS	Equipment Condition / Predictive Maintenance Monitoring
GEPAC+	Plant-wide Data Acquisition and Monitoring
SPDS	Safety Parameter Display System
TRA	Transient Recording and Analysis

A typical use of GEIEMS for meeting condition monitoring and predictive maintenance needs can be illustrated with its Recirculation Pump Monitor. GEIEMS uses plant sensors (over ten vibration sensors per pump and additional plant process signals) to acquire non-safety related data in real time. This data is converted into processed signal data representing plant and vibration parameters in both the time and frequency domain. A single vibration sensor may yield more than twenty processed data items. The On-Line Monitor portion of the system checks for data abnormality by comparing against the signal and processed data's high and low limits. Its expert system further correlates and evaluates these data by applying the expert rules for diagnosing the condition of various components in recirculation pumps. A diagnostic message indicates which pump has a problem, the category of the problem, and the degree of concern. The condition of individual components and the status of all implemented problems (e.g., unbalance, cracked shaft, bearing problems) are continuously updated and displayed. On-line vibration analysis and dynamic graphs are an integral part of the system for investigating the condition in detail.

To meet our plant-wide application objectives, GEIEMS is undergoing modification of its computer system architecture and other integration support such that the system will be easily expandable to include additional applications and be installable on a variety of computer hardware platforms (e.g., HP, Sun, DEC, IBM workstations, etc.) depending on the plant configuration and preferences.

QUALITY DECISION SUPPORT

GE's plant monitoring system vision is *to provide monitoring systems that increases plant reliability while lowering operations and maintenance costs through the use of advanced technology and on-line decision support.* To attain these objectives, the system must meet the concept of *Quality Decision Support.* The data processing to support this concept for equipment condition monitoring will require the on-line processing illustrated in Figure 1. Access to all sensor data that are needed to derive quality information on plant equipment condition is required. It should be followed by solid validation of data and conversion of raw data into much more readily analyzable processed data. The processed data will be analyzed on-line and presented to the user. *Quality Decision Support* can be achieved in a timely fashion through proper implementation of an expert system, neural network, and various modeling such as predictive and deterministic models for diagnosing the current conditions and predicting component remaining life. Good sets of data analysis tools can be used to further investigate the quality information in detail to analyze root causes. Such quality decision supports timely actions, which lead to maximizing performance and reducing the overall operation and maintenance costs. These decision making processes should not be limited to individual plant equipment in an independent manner but should consider plant-wide information through all phases of plant operation (e.g., startup, operation, maintenance, and shutdown).

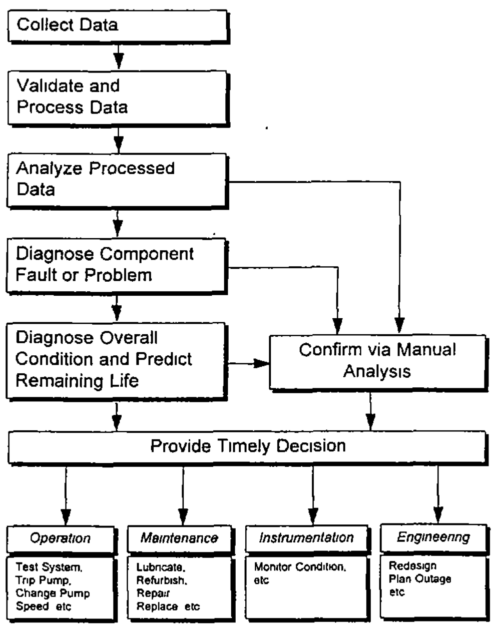

Figure 1 On-Line Equipment Condition Decision Support Process

For a successful decision support, a system requires, in addition to the sound engineering knowledge, easy access to integrated quality data which can be analyzed rapidly. The core computer technology advances that enable this concept include:

- Digital information storage technology which enables on-line access to large amounts of data.
- Artificial intelligence technology, including expert systems, neural networks, and belief logic, which enables on-line diagnosis and recommended action.
- Network communication technology which enables high performance information distribution and sharing.
- Digital signal processing technology which enables intelligent data processing at the smart front-end processors.
- Native language character technology which enables localization of the user interface to the user's language.
- Open standards which enable integration, expandability, compatibility, and multi-platform availability.

The integrated system architecture is being built to incorporate all these advances.

INTEGRATED SYSTEM ARCHITECTURE

The system architecture centers around a distributed processing model, using the latest network technology. This distributed system uses hardware and software modules connected by an Ethernet network. Fiber Distributed Data Interface (FDDI) or emerging Asynchronous Transfer Mode (ATM) will expand overall system performance when high data transfer bandwidth is required. A distributed relational data base allows standardized data accesses from any process on the network, allowing for the processing modules to be resident on different processing units, depending on specific plant configuration requirements. The system's open architecture approach allows accommodation of new technology and incorporation of existing systems that follow standards. The application can be installable on different platforms by using application development tools, available on multiple platforms from various vendors. The user interface supports window applications and graphic display capabilities. For worldwide application, graphical user interfaces that allow multi-language screen displays are utilized. Data acquisition is provided through a set of networked smart data concentrators under the control of a central data server computer. Functions such as signal conditioning, data processing, alarm triggering, and monitoring are performed by these smart data concentrators. In addition, expert systems and neural network applications can be incorporated. If a plant-wide system is not required, the minimum configuration consisting of local smart data concentrators with a display terminal can provide the basic limit checking and alarm capabilities.

Hardware/Software Architecture Characteristics

- Multiple Platform Availability

  The architecture follows OPEN and COMMON standards so that the system can accommodate new technology as well as work with other available systems which follow this standard. The operating systems and supporting software that comply with the standards will be used. The standards that are currently applicable are:

  •Operating Systems -- POSIX 1003.1,
  •Windowing Environment -- X11 and OSF/Motif,
  •Network Communication -- Internet protocols including TCP/IP or OSI,
  •Network Computing -- OSF/DCE with NFS and RPC.

  Additionally, usage of available commercial off-the-shelf (COTS) tools on multiple platforms provides added freedom in implementing the monitoring software on different platforms.

- System Expandability

  The design approach will use Object Oriented methodology and a distributed processing system. Object Oriented methodology allows a design that can be modularized for distributed processing and production of reusable modules, which can then be utilized efficiently for system expansion and for reduction in software maintenance cost. The core of this distributed system is the use of smart data concentrators (SDC). which are unique hardware/software that process signals and transmit the processed data to applications on the network. Industry standard communication supports the communication among distributed processes.

- Localization of User Interface

  Support for European languages on workstations and personal computers has been available for many years. Recently, X11 and especially Motif 1.2 support on many workstation platforms has made available the multi-byte character processing, which is needed for languages with thousands of characters. By conforming to Motif 1.2 and the use of COTS software tools, the system can incorporate user displays in the user's native language and in a standard manner across all applications.

This architecture is designed to accommodate system expansion and future technology advances. The full configuration, as depicted in Figure 2, consists of SDCs, a high-speed network, and high performance workstations. The actual installation can be scalable to adapt to particular plant requirements such that if a plant-wide implementation is not needed, a single workstation-SDC pair may be installed, or even a smaller configuration of a portable computer connected at the SDC.

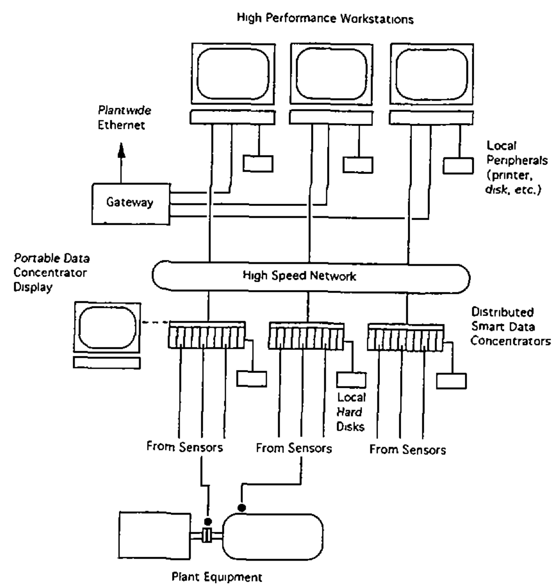

Figure 2 Plant-Wide Equipment Monitoring System Configuration

Smart Data Concentrator

Much of the monitoring, signal processing, and alarm checking is moved down to SDCs, which include an analog-to-digital (A/D) converter, digital signal processor, signal filter and conditioners, multiplexers, and controllers in its local bus. At this level, SDC may be specific to the type of the signals being tapped and its processing speed and complexity may vary depending on the signal processing needs of a particular monitoring application. Due to this localized processing power, the computation burden on the workstation is freed up from the usual data acquisition functions. However, raw data can still be requested by the workstation unit for snapshots and archiving data for off-line analyses. The current prototype will perform limit checking and FFT at the SDC level, but future applications can utilize digital signal processors to perform functions such as spectral analysis, local expert system, curve fitting, etc. to increase the front-end intelligence. The SDC will normally be placed close to the signal sources so that the length of signal cables from the sensors is minimized. The SDC will communicate data continuously to the workstation via digital communication network.

Communication

The data transmission between SDC and workstation will depend on the bandwidth of the network technology. The current prototype of the recirculation pump vibration monitor uses Ethernet. However, the volume of data required to be transferred over the network determines the type of network technology. FDDI is an established network standard that provides rates up to 100 Mbps. Other emerging technologies such as ATM is said to be capable of data transfer rate close to 2 Gbps. The communication design uses high level Internet Protocols to allow changes in underlying physical layers from Ethernet to FDDI to ATM without requiring software modifications. The high bandwidth allows periodic and on-demand transfer of raw data to the workstation from the smart data concentrator and removes many restrictions on the location of various modules to allow distribution of programs and data storage.

Applications

In modularized distributed software architecture, application modules will perform the monitoring functions and interface with distributed Smart Data Concentrators to receive data and communicate with user interface modules, such as screen display programs. These are specific application programs that are platform independent. In contrast, Data Acquisition System (DAS) software will be specific to the DAS hardware and the user interface will be specific to the display platform and software tools. The separation of applications layer from the DAS and the user interface enables easier adaptation of different applications to different platforms. Some of GEIEMS product offerings for diverse predictive maintenance applications are listed in Table 2, which shows those already installed at plants and those at various development stages.

Table 2 Equipment Monitoring Applications

Condition Monitoring	Recirculation Pump Recirculation Piping Turbine Driven Feedwater Control Rod Drive Hydraulic Reactor Water Clean Up Pump
Predictive Maintenance	RPV Feedwater Nozzle (Thermal Cycle) Main Steam Turbine/Generator Diesel Generator Motor Operated Valves Operability Air Operated Valves Operability Solenoid Operated Valves Operability
Performance Monitoring	Plant Thermal Efficiency RPV Pressure and Temperature Limits

User Interface

The common look-and-feel of the user interface across different environments in the monitoring applications and on various workstations is the aim of the new architecture. X11 and OSF/Motif have been selected for the UNIX workstation's window environment, where high performance graphic user interfaces (GUI) can be supported on different platforms. The use of COTS GUI tools enables the implementation of the same GUI on different platforms. In this environment, localization of displayed text becomes natural through Motif's multi-byte text character processing.

PROTOTYPING

As a practical step after the plan/design of the "integrated" plant-wide monitoring system that incorporates the current state of technology, the development of a prototype system has been initiated. The prototype is being built using the GEIEMS technology that is already in use (i.e., the Recirculation Pump Vibration Monitoring system). This prototype does not simply mimic a user interface which must be discarded once the concept has been demonstrated. Instead, the prototype is targeted for a development into a fully functional system. The current generation of the GEIEMS system architecture has been analyzed using object oriented analysis and design techniques and converted to a new architecture that conforms to the plant-wide monitoring system architecture, such that it can be expandable to the plant-wide monitoring system.

The initial phase of the prototype is a small system that contains all the data processing capabilities required to demonstrate the significant system features. The system diagram is illustrated in Figure 3. It incorporates a localized user interface using multi-byte text character processing that allows world-wide adaptability, a "must" for Asian language displays.

The second phase of the prototype will result in the fully functional engineering model that can be installed in a plant for close observation and fine tuning. The prototype will include expert system diagnosis and report generation. The user interface for on-line monitoring is targeted for the plant operator with simple and easy-to-use display screens, while the vibration analysis function is targeted for experienced engineers. With full analyzer capability, it can be used to analyze on-line signal data as well as archived and retrieved off-line data.

The initial prototype is to be operated as an independent platform with data signals being input from recorded tape. The recorded sensor signal data can be played back through cables and directly input in real time to the smart data concentrator, which performs most of the signal processing and data conversion in a VXIbus based controller. The UNIX workstation provides an operator interface with data processing being distributed between the workstation and the smart data concentrator. The prototype unit is not a run-time unit for demonstration but is a full development platform, where software modification can be effected to meet rapid prototyping needs in a self-contained environment. To develop the better user interface, the prototype will be enhanced through user-feedback. One of the duplicate units will be located at a customer site to facilitate the user involvement in the rapid prototyping. Although the architecture allows easy updates for prototyping different ideas, a video recording capability is provided for capturing the workstation monitor images in real time to exchange user interface information quickly and effectively between the customer site and development site. Thorough specification and implementation of system functionality and user interface are the purposes of the prototyping effort.

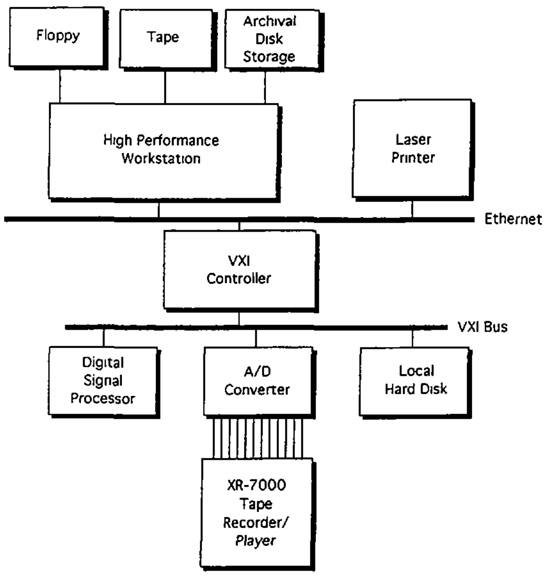

Figure 3 Prototype.System Diagram

CONCLUSION

The system architecture, which is based upon industry standard interfaces, distributed processing, and user interface localization, permits maximum flexibility for site configuration requirements, system expansion, and incorporation of technology advances. The GEIEMS prototype is being used to ensure that new architecture is practical and monitoring performance and functions are what the utilities needs to automate monitoring tasks to reduce plant operation and maintenance costs.

REFERENCE

1. T.A. HUNTER and C.H. SATHRUM, Sathrum, "Integrated Plant-Wide Monitoring", *EPRI Conference* (1992).