EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sensors for Integrated Monitoring, Communication, Command and Control Scoping Study

December 2003

(This scoping study was performed for
CEIDS – the Consortium for an Electric Infrastructure in a Digital Society, the predecessor to
EPRI's IntelliGrid Consortium)

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1 Background

This report is to provide information and input for the decision of funding the next step in technology analysis for sensors, and to suggest scope of the work that is consistent with CEIDS goals to develop concepts and technologies for automated and self-healing power system of the future.

The implementation of infrastructure to support the automated self-healing electric power system of the future starts with the technology to continuously assess current state and anticipate future state of the system, and its components through a combination of sensors, communications, monitoring, and real time state estimation (simulation) tools. Based on the current and anticipated state and operating condition, an intelligent and adaptable control system will continually determine the optimum configuration and operation of the system for efficiency, quality, and reliability and will therefore be able to respond to disturbances that require changes.

The ongoing CEIDS project "Integrated Energy and Communications System Architecture" (IECSA) is developing the specifications for future communications infrastructure. IECSA will develop open, standards-based system architectures for the data communications and distributed computing infrastructure that will enable the integration of a wide variety of intelligent electric power system components.

Sensors are the next essential element of continuous system performance monitoring and are expected to be deployed in large quantities throughout the system as well as integrated with the communications infrastructure. The communication technologies to collect and transport the data to central monitoring and control systems is covered in the IECSA, while communications within sensors and/or sensor systems, in some cases, will be considered as an integral part of the sensor technology development.

This scoping study is focused on identifying the development areas in sensor technology to support self-healing system of the future.

2 Scope of the Study

This scoping study will focus on individual sensors designed to monitor specific parameter, sensors systems to monitor multiple parameters on equipment and/or substation level, and will include communications within sensors systems. Communications and architecture to collect and integrate data on the system level and between substations, for example, is not in the scope of this study.

This study will focus on sensors and communications for transmission and distribution system (T&D), including T&D substations, switchyards at the generating plants, and distributed generating units from the perspective of integration with T&D systems.

Sensors and communications within power plants and for end-user applications are considered to have significantly different requirements and will be address in separate projects.

3 Sensors and Self-healing System of the Future

Self-healing concept assumes real-time, continuous, reliable and accurate conditions and risk assessment of system and its critical components for current and anticipated operating conditions.

This concept will require use of dramatically larger number of sensors to support continuous monitoring of system parameters and to monitor significantly larger number of parameters on the individual component/equipment levels. Sensors will provide data for intelligent automation with response time that will require continuous and fast access to real-time and historical data – often leaving little or no room for human intervention and judgment in emergency situations.

Electric power system will be designed as an integrated system where sensors will be an integral part of system components to provide real-time and continuous stream of data to simultaneously support integrated monitoring, diagnostic, protection, control and operation, including real-time and anticipated risk assessment on component and system levels.

Remote and continuous monitoring will replace periodic inspection, testing, walk-around and other currently standard condition assessment and monitoring tasks. Critical parameters will be continuously analyzed by rule-based and self-learning artificial intelligence systems for current and anticipated operating conditions.

The sensors will likely be intelligent sensors that can perform some local data analysis and filtering. Equipment and system components will be “intelligent” with built-in sensors for local monitoring and diagnostic. Networked sensors will be located on the system and its components to support system performance assessment and system operation requirements.

4 Sensors Requirements

4.1 Two Distinctively Different Set of Requirements for Existing and Future Infrastructure

CEIDS is focused on technology development for "system of the future." Expected life of the existing infrastructure and required capital investment for replacement makes it obvious that "new" and "old" infrastructure will coexist for decades.

The coexistence of new and existing infrastructure requires development of solutions and technologies for two entirely different markets:

- Refurbishment of existing infrastructure to support self-healing system
- New equipment and infrastructure designed and built to support self-healing concept

Requirements for data and parameters to support monitoring and diagnostic of self-healing system will be similar for both markets but constraints and solutions will be entirely different. The rate of investment in new infrastructure is expected to determine interests of commercially driven development projects to support both markets.

Requirements for sensors and sensor systems for "existing" infrastructure will include

- Non-intrusive solutions and sensors are preferred
- No (or minimum) new cabling for field installation required due to cost and environmental/safety/redesign problems

Requirements for sensors for "new" infrastructure will include

- Sensors incorporated and built into component design
- Plug-and-play for additional selected sensors
- Input-output compatibility and interoperability at sensors, equipment and system levels

4.2 Self-healing System Requires Use of Dramatically Larger Number of Sensors

The self- healing system assumes continuous monitoring and forecasting at all levels, from components/equipment to subsystems/substations to system levels.

This concept implies extensive use of one to two order of magnitude larger number of sensors on equipment/component and substation levels and dictates following set of requirements.

- Low cost of individual sensors
- Low cost of installation
- No-maintenance
- Self checking-diagnosis
- Remote programming
- Built-in redundancy
- High level of data security

Use of large number of sensors on equipment/component, substation/subsystem and system levels will require conceptual decisions in the following areas.

- Level of data processing, filtering, archiving at individual sensors, equipment/components, substation/subsystems, and system levels
- Level of data analysis at different levels (sensor/parameter, component/multi parameter, and system)
- Use and development of new diagnostic techniques and new knowledge that will uncover "useful information" in a continuous streams of multi parameter data at various levels and with complex relationships.

4.3 Three Levels of Monitoring

Monitoring and diagnostics of self-healing systems will be a combination of three interactive levels:

- Electric power system level – for control and operation for power flow, transients, power quality, etc.
- Components/equipment and subsystems levels (e.g., individual transformers, load tap changers, bushings etc.)
- Aggregated and integrated "across-system" and "system-wide" monitoring

Parameters and requirements on sensors for these three application levels have to be identified and developed with the following conditions in mind

- Data and systems (protection, monitoring, operation) will be integrated and will support the concept of "one sensor/data – multiple users."
- Some sensors/data will have "local" application (such as condition monitoring of specific component) and some will have "system-wide" application. This will determine communication and archiving requirements.
- Additional sensors/data/parameters may be required for system-wide and across-system monitoring

4.4 New Requirements

Faster Response and Shorter Time-frames for Assessment

Traditionally accepted time frames and response time are in the range of milliseconds for protection, seconds and minutes for operation, hours and days for monitoring, days and months for maintenance, and years for asset management. The self-healing system, however, assumes faster, automated, and intelligent control and operation,

It is estimated that response time and time frames for components and system state/condition assessment need to be shortened to meet requirements of at least one level higher than today's accepted standards.

This will require new and more effective algorithms for condition/state assessment and use of new sensors.

New Technologies for Equipment Internal Condition Assessment

Faster system restoration is critical to the self-healing system of the future and assumes better/faster condition assessment of critical equipment. Internal inspections are essential in assessing condition of critical components and are one of the most expensive and time-consuming tasks in today's condition assessment and maintenance practice.

New technologies for remote, automated, continuous and efficient "internal inspections" of critical system components need to be developed and included in monitoring and condition assessment systems. Use of new technologies in this area will significantly improve availability and reliability of critical components of self-healing systems of the future.

5 Status of Technology Development and "Issues"

This analysis is based on publicly available information about research and development in the area of sensors and communications. Detailed information is available in Appendix A.

Research and development in the field of sensors for electric power applications in the last few decades has focused on incremental improvements rather than on new and revolutionary concepts and technologies. New optical sensors are developed for voltage and current measurement with accuracy as high as 0.2% on a range from under 2 amps to thousands of amps as replacement for traditional electromagnetic instrument transformers. Development of systems for wide-area Phasor measurements is an example of relatively new initiative to provide time-stamped current, voltage, frequency, and phase angles data to support system operation and control. Years of development in the field of detecting and monitoring partial discharges in insulation systems is an example of ongoing work with some results but not for wide applications.

Some progress has been made but monitoring and especially on-line and continuous monitoring is not being widely used.

Cost-benefit ratio is often indicated as a problem for wider adoption of monitoring systems. Existing infrastructure and operation of the systems are not designed to incorporate the latest technology development in the field of sensors, communications and data analysis. This is the area where CEIDS can play a role.

The self-healing system of the future envisions integrated sensors, integrated data and automated data analysis to support continuous evaluation and anticipation for optimized and adaptive system operation.

Development of clear concept, requirements and "specification" for parameters and sensors for component/equipment specific and system level monitoring is critical to defining future R&D investments via EPRI, R&D organizations and commercial industry.

The transition from existing infrastructure to new "self-healing" system will take place over many years and therefore an equally important goal should be to find cost-effective solutions for intermediate steps. Improving and redesigning technologies used for traditional testing and adapting it for on-line monitoring is one of the current approaches. Development of remote sensing and adaptation of "camera-type" technologies is an example. Other "low cost" technologies such as temperature sensitive materials/pains/labels are investigated for monitoring applications as a stand-alone or in combination with the low-cost communications and high technology components ("web/digital cameras" etc).

The area of development that has the highest potential for both existing and new infrastructure is the area of new low-cost, microchip-based, "smart" sensors with "self-networking" capabilities and "built-in" wireless communication. Research and development in this area will be highlighted in more details.

5.1 Smart Sensors and Networks

Sensors systems consist of sensors, data acquisition/conditioning and communications. The latest trend in development is to integrate all three components in a single low-cost chip. Cost of the latest technology is continually declining and is reaching affordable levels.

Wireless radio communication is the preferred option for low-cost sensor systems and networks. Wireless communications eliminates the need for cables. Other advantages include easier installation on existing infrastructure, and small dimensions – for example, a temperature sensor with built-in transmitter is approximately the size of a quarter-dollar coin.

The major areas of concerns and field for "customization" for power system applications are security, interferences and communications with many Line Of Sight (LOS) obstructions (in substations in particular) compounded by the restrictions on antennae installations.

Deployment of large number of self-networking sensors is expected to minimize impact of LOS obstructions.

Security is an issue in wireless communications in general. Research and manufacturers are working on improvements but no bulletproof system is available yet.
This is an area where additional and "customized" development will be needed – some options are already available in the area of combining communications systems (for

example, wireless and optical or powerline carrier), antenna designs, controlled/limited communication range, etc.

Space and military applications is also driving development in this area – sensors for temperature, pressure, acceleration, vibration, electromagnetic field, for example, are already available and ready for customization for power system applications.

The "issues" of power supply at high voltage applications should be addressed in coordination with broader R&D efforts to reduce the power consumption at sensor level and by using smart sensors in a "smarter" way - by taking advantage of built-in processing, for example. Power supply is critical for high potential/voltage applications but is also important for "ground-level" applications to meet low-cost and no-maintenance requirements.

Specification and requirements for sensors for electric power applications should be developed with the goal of using "off-the-shelf" products or components within the system as much as possible. This will be easier to achieve if the requirements are developed having in mind integrated systems and intelligent analysis of data sets, including "pattern recognition," comparative and other more sophisticated technologies. This should help to reduce sensor requirements from the perspective of accuracy, range and ambient operating conditions.

MEMS, or MicroElectroMechanicalSystems is the other area of development that has potential for monitoring applications in electric power systems and should be closely analyzed. MEMS are microscopic structures integrated into silicon that combine mechanical, optical and fluidic elements with electronics.

Low cost of sensors network, energy efficiency, security, ability to function when a part of the system is missing, and adaptation to the environment are issues that are common across applications and are the focus of development by various participants in variety of industries and applications (see Appendix A.)

6 Expected Benefits

Concept presented in this scoping study is revolutionary in its approach of deploying large number of smart sensors across the systems and its components. Concept of integration of "one sensor – many users," combined with low-cost smart sensors and intelligent multi-level data analysis for continuous and anticipated condition assessment will enable fast, informed and intelligent self-healing operation at affordable cost.

7 Proposed Roadmap for future work and Technical Assessment Project

7.1 Assumptions

- Mainstream and basic research and development in the area of new sensors is driven by needs and interests outside of electric industry, including space and military programs.
- Replacement of existing infrastructure and transition to self-healing system of the future will be evolutionary and will take decades.

7.2 Approach

- Close coordination with CEIDS' projects in the area of communication and data analysis.
- Availability and cooperation of experts in two fields of expertise:
    - System operation/control and protection
    - Equipment/components/infrastructure
- Use of "off-the-shelf" technologies with customization of available products and technologies where necessary
- Support technology development in areas with established commercial products/ manufacturers via development of clear concepts and detailed functional requirements and specifications.

7.3 Suggested Scope for the Technical Analysis Project "Sensors for Integrated Monitoring, Communication, Command, and Control"

1. Conceptual Design and High-Level Architecture
   This task will develop high-level design and architecture of the Integrated Monitoring, Communication, Command, and Control system (IMC3) that is consistent with CEIDS vision of self-healing system of the future as well as CEIDS projects such as the aforementioned IECSA.

2. Functional Requirements for New/Future and Existing Infrastructure
   Requirements for new infrastructure will be based on some of the concepts anticipated in this study, including:

    - System components/equipment will be designed for monitoring and remote diagnostics, sensors will be built-in and/or equipment will be designed for "plug-and-play" sensor installation

- Communication infrastructure will be designed for secure data transfer (fiber optic cables within substations, built into overhead and underground cable conductors, etc.)
- Monitoring, protection, control and operation data and systems will be integrated and will share sensors and infrastructure wherever possible from technical and economic perspective

Requirements for existing infrastructure will further develop and evaluate preferred solutions discussed earlier in this study, including:

- Cabling will not be a viable option for most of the applications (substations, etc.)
- Non-intrusive solutions will be preferred
- Wireless communications (no cabling required) and/or wireless in combination with other existing cables will be preferred.
- Smart networked sensors for substations, including data transmission to local database
- Strategies and options toward achieving integrated monitoring, protection, control (for example, use of SCADA and protection data for condition monitoring of circuit breakers)

2.1 Key parameters to monitor ("what" to look for in monitoring/diagnostics)

- Continuous state/condition assessment
- Estimation and forecasting

The analysis will be done for two levels:

- System level (operation and control aspects)
- Component/equipment level (condition and risk aspects)

2.2 Methodology and tools to monitor/assess/diagnose and estimate/forecast ("How")

2.3 Data needed to support current and anticipated state and risk assessment ("Data") with specification (accuracy, frequency of measurements, needs for archiving, etc.)

2.4 Source of data/information ("Source")

- New/future infrastructure of self-healing system data sources will be consistent with concept of integration of monitoring, control and protection data and systems ("one sensor/data - multiple users")
- Availability of data within existing infrastructure will determine optimum strategy for transition from existing to future infrastructure. Development of functional requirements and high-level infrastructure assumes iterative process and teams of experts for system and components aspects in order to determine optimum

solutions and to take full advantage of new technologies and "smarter ways" of extracting information from existing and more conveniently available data

2.5 Monitoring modules

This task will identify logical and functional modules required to monitor system and component level parameters (transmission system, substations, transformers, etc.). This will include

- Requirements and specification for integration of sensors in future designs of individual equipment/infrastructure components
- Specific solutions/technology and targeted cost levels

2.6 Needs for specific sensors

- Functional and technical specification for individual sensors

3. Gaps analysis

4. Development plan
   This task will suggest detailed research and development for CEIDS. Suggested plan will be consistent with the results of gaps analysis and assumptions and approach outlined in this scoping study.

8 Conclusion/Summary

Concept of self-healing system of the future, as envisioned in CEIDS, requires real-time, accurate and continuous assessment of current and anticipated state and operating conditions of system and its components. The latest development in the area of smart sensors and communications, in combination with already attractive cost levels (expected to be even more attractive in the near future) is offering opportunities for revolutionary approach of deploying large number of smart sensors to support automated intelligent system operation and self-healing concepts. A technology analysis of this topic is suggested. Proposed scope of the work assumes "top-down" approach in identifying development projects consistent with CEIDS role and goals.

Appendix A: Sensors and Sensor Systems State-of-the-Art

A-1 Introduction

Sensors are widely used on the power grid to measure electrical and non-electrical parameters. They are becoming cheaper, and innovative solutions in sensors and sensor systems - such as new materials and self-configuring wireless sensors network - have appeared.

This report gives an overview of the research in sensors and sensor systems and a list of the main companies providing customized sensor systems for utilities. The standards organizations performing work in this area are listed.

This report also describes work done at EPRI and in the CEIDS portfolio related to sensors.

A-1.1 Parameters to measure on the power grid

Most sensors measure a physical parameter that is then used for threshold alarming and rate of change alarming.

For the power system, the two main types of parameters are electrical parameters and non-electrical ones. The main electrical parameters are voltage, current, active and reactive power, frequency phasor measurements, harmonics, arks detection, ground impedance, electromagnetic fields and transients.

The non-electrical parameters of interest for the power grid are temperature, humidity, moisture, combustible gas in oil (transformer and LTC), insulation properties (transformers, bushings, CT/PTs, cables), pressure, density, vibration, gases, distance measurements, vegetation, animals presence, lightning, occupancy sensors, motion/speed, pollution, ultrasonic noise, acoustic noise, weather measures.

A-1.2 Interest of communicating sensor systems and smart sensors

Sensor systems are composed of three parts: communications, data acquisition and sensors. It is today possible to have all three parts on a single chip at a low cost. The technologies come from space and military industries but some are now mature enough to be used in industrial applications. The manufacturing cost of the components and the cost of communications are declining.

Sensor systems have extended capabilities and are likely to provide new applications for power monitoring. Wireless communications are also contributing to development of sensor networks as they suppress a lot of installation constraints.

Communicating sensors most often have decisions and information coded on 12 bits and the communication media are designed to handle packets of this size, often on a report-by-exception basis.

Wireless sensors systems
Wireless sensor systems use wireless communications. One or several types of wireless communications can be used in a system.

Wireless communications are nowadays very promising for sensor networks. Their cost is declining. The technology has grown out of the research area and industrial systems and is developing very fast.

Wireless communications of course first suppress the need for communications wires. Other advantages are easier installation, and easier design for existing equipments. For live wireless systems, permit to send data to transceivers at ground level has the potential of not dealing with insulation.

The main available wireless systems are based on TinyOS/WSn, wireless Ethernet (IEEE802.11b at 2.4Ghz), BlueTooth and ZigBee. See performances in Doble report. Laser may be an option. Security is improved; lasers are more expensive but must be compared to wired solutions. Short-range wireless links are 10-60 feet, long-range area 100-1500 feet.

Ad-hoc networks are networks that have the ability to self-configure. There is no need for configuration at installation. The sensors detect each other and build the wireless network. This technology can today be used in industrial applications.

Other wireless communications like cell phone technologies are less likely to be used in sensor systems because of their high cost, although they may be used for transmitting data from point-to-point on the network such as from a substation to a control center. Power line carrier can also be considered as wireless in the sense that they do not require additional wires.

Smart sensors are sensors that process data at the sensor site. **MEMS**, or MicroElectroMechanical Systems are the microscopic structures integrated onto silicon that combine mechanical, optical and fluidic elements with electronics. They are typically no bigger than a grain of sand. Part of the decision is then delegated to the sensors.

Implementation of sensor systems
Complex solutions can be designed depending on the application. Sometimes it may make more sense to process some data before sending results, other times it will be more efficient to gather a lot of data at a central point before analyzing them.

Another choice to consider is customizing standard sensors, which are easily found and relatively cheap, and develop the data analysis, or developing an on-chip system. This choice too is highly dependant on the application and on the number of devices to be deployed.

A-1.3 Challenges for research

Security is an issue in wireless communications. Research and manufacturers are working on it but there is no bulletproof system available. For substations, the area can be controlled and then security can be improved. For other installations on the network, the problem remains. The interference and security issues exist also in the other industries. Electromagnetic fields may be worse in our case than in others.

Power supply
Power supply is a challenge for several reasons. At ground potential it implies cabling. Power supply has to be chosen in relation with the required operations. Some devices need to be always-on, some can have periods of dormancy.

Another parameter is the communications needs. Communications can be one-way or two-way, always-on or on-demand, and this modifies the power needs and the power consumption. Choices include batteries, wired power-supply, and solar energy. Innovative developments in universities try to reduce the power needed for processing an instruction. Power supply has a significant impact on the price of the sensors system.

Energy efficient sensor systems
Sensor webs consisting of nodes with limited battery power and wireless communications are deployed to collect useful information from the field. Gathering sensed information in an energy efficient manner is critical to operating the sensor network for a long period of time. The energy used depends on data exchanges and also on the distance for transmission. Several research projects address these topics in universities.

Interest of combined sensors
Combined sensors may be an interesting way to explore. Measuring different data at the same point simplifies the problem of installation and power supply but data management becomes more complex. An interesting type of sensors is the pressure/temperature sensor.

Reducing the number of sensors by estimation methods and computation of non-measured data
Algorithms can reduce the number of sensors required to monitor a physical phenomenon. These algorithms can easily be incorporated in a chip at low cost. More basically a general idea is to measure at one point and then reuse the data. Data fusion is another related field. Its aim is to unify huge volumes of data.

Use of Artificial Intelligence (AI)
Implementing artificial intelligence in sensor systems can be a way to improve the performance of the system and to enable it to manage itself. The system becomes able to adapt to a changing environment and its aging. Fuzzy logic provides a way to deal with imprecise data and data which are partial. The research in this field is led by Universities.

Cost
Sensors in general are becoming cheaper, as are communications. The cost of manufacturing of ASIC and MEMS is declining. Parameters that have an impact on the price of a sensor system are the number of sensors, the power supply choice, the communications nodes, the communications capabilities (one-way, two-way, always-on or not). The cost will depend on the field implementation.

A-1.4 Difficult operating conditions specific to the power grid

Operating conditions
Electrical inferences disturb the communication methods as discussed earlier. The operating temperature range is in most of the cases the outdoor temperature range, -30°C to +65°C. This can be worse in certain configurations, e.g. sensing on the top of a transformer tank in a desert. Security and tampering have to be to be considered.

Communications
The communication bandwidth in existing equipments may not support enhanced security and more frequent needs for data. These systems have often been designed to transmit 12-bit information and the refreshment rate is lower than required by new generation applications.

In all cases, either for existing or new equipment, the problem of the report-by-exception mechanism has to be considered. This mechanism means that sensors report information when there is a problem. This will induce heavy traffic if the number of sensors multiply and it will not be possible to handle even in new systems. Data may have to be processed and filtered before transmission.

Another major problem for wireless communication on the power grid is Line Of Sight (LOS) obstructions. Substations in particular have a lot of metallic parts that cause problems for wireless communications, compounded by the restrictions on antennae installations.

Other issues in communications are interference and security

- Interference means noise on the transferred data and possible errors. There is a need for fault-tolerant protocols.
- Security is critical on the power grid

Installation issues
Installing new systems on equipments has to comply with environmental regulations, for antenna, material, chemical content. Installation on existing equipments and maintenance of all sensors systems should not require an outage. Calibration is required in certain cases and should be performed without disturbing the operation of the equipment.

Backup requirements
Some equipment are critical for the grid and will impose backup systems for their sensor systems.

System management
Sensor systems are complex with numerous sensors with data processing and communications. The system management functions should be embedded as much as possible in the system. The system should be self-configuring, able to self-diagnose. Remote programming and configuration should also be available.

A-1.5 Leaders and players on the market

The leaders in research are the aerospace and defense industries.
They have important programs on developing new architecture to enable more applications for sensor networks. Their concerns are security, ability to function when a part of the system is missing, and adaptation to the environment. Their solutions may be very interesting for industrial applications.

Universities work in collaboration with these industries. Many universities also work on non-invasive, innovative material and sensors and sensors chips manufacturing in advanced laboratories. Optimizing the whole sensor requires new architecture, new operating systems, new assembly language. This research is led by universities, and the aerospace and defense industry. Energy efficiency is critical. Some projects also aim at developing robots from commercial off-the-shelf (COTS) components, using the innovative architectures.

Manufacturers of sensors and sensors systems are numerous. The document lists them in part 2, as well as the **main companies customizing systems for the power industry**.

EPRI's work on sensors is presented briefly.

A-2 Research on sensors and sensors systems

This partially lists leading research organizations and universities, as well as manufacturers, of sensors and sensors systems.

A-2.1 National organizations

Department Of Energy (DOE)

Main activities related to sensors: sensors for fuel cells, sensors and systems, WAMS demonstration project

Home url : www.doe.gov

Description:
DOE has four main goals: defense, the promotion of reliable and affordable energy, scientific progress to guarantee security and environmental protection.
In DOE, the Office of Industrial Technologies (OIT or formerly ITP)) works in partnership with U.S. industry to develop and deliver advanced technologies that increase energy efficiency, improve environmental performance and boost productivity.

Main projects:
The Sensors and Automation (S&A) Program of OIT serves as the lead in developing and delivering measurement and control technology solutions in support of the industry sectors in the Industries of the Future (IOF) Program. S&A has an important portfolio for the control of manufacturing processes but nothing specific to energy (steel, glass, forest,..). There is particularly an important work on sensors for fuel cells.
The Sensors and Controls program is part of the $12.3 million project for Energy Efficient and Clean Energy Projects. This program deals with process optimization, emissions reduction and sequestration, extreme environments (FE applications) to building systems integration. Embedded sensors could benefit from projects in this area.
The WAMS demonstration project
DOE has launched the Wide Area Measurement System (WAMS) Project in 1995 with Pacific Northwest National Laboratory (PNNL). WAMS is described in paragraph 3.2 under Bonneville Power Administration.

Other related activities: Work on fuel cells

Argonne Lab

Main activities related to sensors: sensors development

Home url : www.anl.gov

Url for sensors work: http://www.et.anl.gov/sections/sinde/research/index.html

Description:
Argonne is a DOE laboratory operated by the University of Chicago.
The Sensors, Instrumentation, and Nondestructive Evaluation (SI&NDE) Section conducts research and development related to instruments and NDE techniques for characterization of materials and system parameter determination for energy systems under development for several DOE offices, including Fossil Energy (FE), Energy Efficiency and Renewable (EE), Environmental Management (EM), and nuclear technologies.

Main projects:
Advanced Sensors for Real-Time Control of Advanced Natural-GasReciprocating Engine Combustion
This was a new project that started in FY 2000. The objective of this project is to develop advanced sensors for real-time combustion monitoring of advanced natural-gas reciprocating engines. The proposed development includes sensors to measure NO_x emissions and fuel composition. The sensors will then be integrated into an engine-combustion control system that can optimize engine performance and control NO_x emissions
Use of Principal Components to Detect Sensor Failures
Argonne has used principal component analysis to determine if the sensors in a system are working properly. This analysis is used to generate the Mahalanobis distance, which is then used as an input to a sequential testing procedure based on the sequential probability ratio test (SPRT). The website has a list of the projects in Sensors, Instrumentation, and Nondestructive Evaluation.

SANDIA National Laboratories

Main activities related to sensors: sensors, sensors arrays, and failure analysis

Home url : http://www.sandia.gov/

Description:
SANDIA National Laboratories are funded primarily by the U.S. Department of Energy and are managed by the Lockheed Martin Corp. They employ about 7,900 people and manage about $1.8 billion of work a year and partner with a variety of other government, industry, and academic institutions to accomplish our work.

Main projects:
Sandia's Microsensors Science and Technology Department develops discrete sensors and sensor arrays based on piezoelectric, fiber-optic, micro-optic, electrochemical, biochemical, and microimpedance devices. The lab also works with other organizations

to construct on-chip sensors, integrated with electronics, using microelectronic fabrication techniques.

Other related activities: cross-cutting capabilities in failure analysis

NASA

Main activities related to sensors: sensors and advanced sensors systems

Home url : http://www.nasa.gov/externalflash/NASA45th/index1.html

Description: NASA has been established in 1958 as a national agency. Its has multiple missions but they share the common goal of having a better knowledge of the universe.

Main projects:
The Sensors and Electronics Technology Branch conducts research and development programs in sensing concepts, sensor technology, high temperature electronics and related areas such as materials and materials processing techniques. Emphasis is on developing advanced capabilities for measurement and control of aeropropulsion systems.

Temperature sensors
The John H. Glenn Research Center at Lewis Field is developing high temperature thin film thermocouples for use in aerospace applications. Also, other specialized wire type thermocouple probes are being developed to meet specialized applications.

- Thin film thermocouples
- high gas temperature probe
- dynamic gas temperature measurement system
- optical pyrometers

Strain sensors

- Thin film gages
- Wire strain gages

Heat flux sensors

- Thin film gage
- Minature plug type gage

Silicon Carbide High Temperature Integrated Electronics and Sensors
The NASA Glenn High Temperature Integrated Electronics and Sensors (HTIES) Team is developing silicon carbide (SiC) as a material for advanced semiconductor electronic device applications. SiC-based electronics and sensors can operate in hostile environments (600 c = 1112 f glowing red hot!) where conventional silicon-based electronics (limited to 350 C) cannot function. Silicon carbide's ability to function in high temperature, high power, and high radiation conditions will enable large performance enhancements to a wide variety of systems and applications

SensorWeb
This projects aims at developing architecture for a sensor network that is robust and plug-and-play.

Sensor Webs collect information and interact with the environment based on what they detect. Much as intelligence in the brain results from the myriad connections among dendrites, the Sensor Web derives its functionality from a parallel-type architecture as sensor data are passed, and locally interpreted on the fly, from pod to pod.

PNNL

Main activities related to sensors: sensors, WAMS

Home url : http://www.pnl.gov

Description:
Pacific Northwest National Laboratory (PNNL) is one of nine U.S. Department of Energy multi-program national laboratories. Its mission is to develop science and technology to meet key national needs. We also apply our capabilities to meet selected environmental, energy, health and national security objectives, strengthen the economy, and support the education of future scientists and engineers.

Pacific Northwest is managed by DOE's Office of Science, but perform work for many DOE offices as well as other government agencies. Battelle has operated Pacific Northwest for DOE and its predecessors since 1965.

Main projects:

Sensors development

- Physical sensors

Temperature, for example Non-contact Temperature Measurement (134)

- Developed innovative "Active Millimeter-Wave Pyrometer" (which won R&D 100 Award)
- Demonstrated low-cost, video-based molten glass temperature measurement using IR emissions
- - Employed IR imaging for near and remote spatial temperature data

- Macroproperty measurement

Develop intelligent "tools" to provide automated component diagnostics and identify prognostic issues, for example On-Line Detection of Key Equipment Failure (105)

WAMS (see paragraph 3.2)

Other related activities:
DSOM®, which stands for Decision Support for Operations and Maintenance, can reduce a facility's life-cycle O&M by as much as 25 to 50 percent.

Mitre

Main activities related to sensors: Sensors systems, sensors fusion, secure wireless

Home url : http://www.mitre.org

Description:

The MITRE Corporation is a not-for-profit organization chartered to work in the public interest. This national resource applies its expertise in systems engineering, information technology, operational concepts, and enterprise modernization to address sponsors' critical needs.

MITRE manages three Federally Funded Research and Development Centers (FFRDCs): one for the Department of Defense (known as the DOD Command, Control, Communications and Intelligence FFRDC), one for the Federal Aviation Administration (the Center for Advanced Aviation Systems Development), and one for the Internal Revenue Service (the Center for Enterprise Modernization).

MITRE also has its own independent research and development program that explores new technologies and new uses of technologies to solve our sponsors' problems in the near-term and in the future

Main projects:

Sensors

MITRE has more than four decades of experience and expertise in sensor systems, signal processing, and exploitation technologies. Sensor experts provide systems engineering and conduct research in technologies that detect, identify, characterize, and monitor the environment, terrain, weather, and targets. Our staff works in the areas of undersea, ground-based, airborne, and space-based intelligence, surveillance, and reconnaissance systems**.**

The main research areas are:

- Sensor Systems Engineering
- Systems Integration
- Global Positioning Systems
- Signal Processing
- High-Performance Computing
- Multi-Sensor Fusion
- Antennas and Electromagnetics
- Advanced Wireless Electronics

Making Wireless LAN secure
This project deals with the complexity of implementing a secure WLAN capability, specifically one that conforms to IEEE 802.11b (see sidebar below), while meeting user needs. This phase-one pilot architecture demonstrates secure WLAN connectivity but also that use of the current virtual private network (VPN) servers significantly reduced user acceptance of the WLANs. MITRE is examining new approaches for securing WLANs.

NSF CENS

Main activities related to sensors: embedded network sensing

Home url : http://www.cens.ucla.edu/

Description:
CENS, a NSF Science & Technology Center, is developing Embedded Networked Sensing Systems and applying this revolutionary technology to critical scientific and social applications. Like the Internet these large-scale, distributed, systems, composed of smart sensors and actuators embedded in the physical world, will eventually infuse the entire world, but at a physical level instead of virtual. ENS systems will form a critical infrastructure resource for society--they will monitor and collect information on such diverse subjects as plankton colonies, endangered species, soil & air contaminants, medical patients, and buildings, bridges and other man-made structures. Across this wide range of applications, Embedded Networked Sensing systems promise to reveal previously unobservable phenomena.

Main projects:
Adaptive Self Configuring Wireless Systems
The Self-configuration and resource management sub-area encompasses projects that focus on the development and understanding of new algorithms, protocols, and platforms for essential design, deployment, and run-time functions. Such functions include timing synchronization, node localization, topology management, sensor calibration, sensor network monitoring, coverage, exploitation of hierarchy, energy management, etc. Key to the approach is exploiting concepts such as distributed localized adaptation, spatial redundancy etc., and techniques to develop effective solutions to these problems. Significant successes todaya are the development of multi-hop time synchronization techniques that achieve approximately 20 microsecond relative timing synchronization per hop using low-end sensor nodes, distributed node localization and ranging techniques capable of centimeter level localization accuracies, development of techniques for distributed in-situ calibration, and techniques for monitoring aggregate statistics of the health of the sensor network.
Micro/Nano Sensor Technology
Small, low-cost, robust, reliable, and sensitive sensors are needed to enable the realization of practical and economical sensor networks. Although there are a large number measurands that are of interest for sensor-network applications (e.g., seismic, temperature, light, sound, magnetic, chemical, etc.), appropriate commercial sensors exist for many of these measurands. However, one prominent exception is the fact that appropriate chemical sensors are not available. It is for this reason that the sensor technology effort within CENS is researching the design, fabrication, and implementation of chemical sensors that have the specifications needed for sensor networks.
In order to have a targeted effort to develop chemical sensors for sensor networks, the focus is on one sensor-network application, namely monitoring soil contamination / habitat monitoring

DARPA

Main activities related to sensors: sensors systems

Home url : http://www.darpa.mil

Description:
The Defense Advanced Research Projects Agency (DARPA) is the central research and development organization for the Department of Defense (DoD). It manages and directs selected basic and applied research and development projects for DoD, and pursues research and technology where risk and payoff are both very high and where success may provide dramatic advances for traditional military roles and missions.

Main projects:

MEMS
The primary goal of the DARPA MEMS Program is to develop the technology to merge sensing, actuating, and computing in order to realize new systems that bring enhanced levels of perception, control, and performance to weapons systems and battlefield environments.
Sensor Networking SenIt
DARPA Sensor Information Technology (SensIT) Program is developing adhoc networking of fixed and mobile devices, methodologies for micro-databases to collect, store, and process data in the sensor network, methods to compile and execute queries and tasks, and mechanisms to deliver the results to end users, who may be mobile.

Defense Information System Agency

Main activities related to sensors: sensors networks architecture

Home url : http://www.disa.mil/

Description:
The Defense Information Systems Agency (DISA) is a combat support agency responsible for planning, engineering, acquiring, fielding, and supporting global net-centric solutions and operating the Global Information Grid to serve the needs of DOD under all conditions of peace and war.

Main projects:
Joint Technical Architecture
The DoD Joint Technical Architecture (JTA) provides the minimum set of standards that, when implemented, facilitates the seamless flow of information among DoD's sensors, processing and command centers, shooters, and support activities to achieve dominant battlefield awareness and move inside the enemy's decision loop. The JTA:

- Provides the foundation for interoperability among all tactical, strategic, and combat support systems.
- Mandates IT standards and guidelines for DoD system development and acquisition that will facilitate interoperability in joint and coalition force operations.

- Communicates to industry DoD's preference for open system, standards-based products and implementations.
- Acknowledges the direction of industry's standards-based development.

The goals continues to be to "reach a consensus of a working set of standards" and "establish a single unifying DoD technical architecture that will become binding on all future DoD C4I acquisitions" so that "new systems can be born joint and interoperable, and existing systems will have a baseline to move toward interoperability."

A-2.2 Universities

BERKELEY

Main activities related to sensors: WSN, Smart dust

Home url : http://www.berkeley.edu/

Description:
The Berkeley Sensor & Actuator Center (BSAC) is the National Science Foundation Industry/University Cooperative Research Center on Microsensors and Actuators.
Some Current Major BSAC Multi-Project Programs (selection):

- Integrated wireless microwatt transceiver
- Wireless communicating microsensors
- Tunable micro capacitors and inductors
- Adaptive optical micromirror arrays
- MEMS-based steered free-air laser communication system
- Silicon Carbide harsh environment MEMS processing
- CAD for MEMS

Main projects:
Smart dust finished in 2001
The goal of this project is to develop an ultra-low energy integrated circuit that will form the core of a self-contained, millimeter scale sensing and communication platform for a massively distributed sensor network. The integrated circuit will contain an integrated sensor, an A/D converter, microprocessor, SRAM, communications circuits, and power control circuits. The IC, together with the sensors, will operate from a power source integrated with the platform.

NEST Project deals with low-power consumption. NEST has developed an ultra-low energy microcontroller that is targeting <1 pJ/instruction, which is an order of magnitude less than the best published processor core.
The research area is an Open Experimental software/hardware Platform for Network Embedded Systems Technology that will accelerate the development of algorithms, services, and their composition into challenging applications dramatically. Small, networked sensor/effectors nodes are developed to ground algorithmic work in the reality of working with numerous, highly constrained devices.

Other related activities:

Other projects with the industry : http://uc-industry.berkeley.edu

MIT

Main activities related to sensors: Ultra Low Power WSN

Home url : www.mit.edu

Description: Massachusetts Institute of Technology

Main projects:
Ultra Low Power Wireless Sensor Project, with DARPA
The objective is to investigate and develop new design methodologies and technologies for ultra low power wireless sensor systems. There are **no publications yet.**
This effort offers a unique vehicle for research advancements in power reduction. There are a broad range of circuit types: sensor interface, data conversion, digital signal processing, RF transceivers, and power electronics which will be studied. Each type of circuitry offers research opportunities for power reduction both in isolation and in conjunction with other types (e.g., variable power supply voltages).

The prototype image sensor system will be capable of wirelessly transmitting a wide range of data rates (1 bit/sec - 1 megabit/sec) over a wide range of average transmission output power levels (10 microwatts - 10 milliwatts) will be designed, fabricated, and characterized.

LEACH (Low Energy Adaptive Clustering Hierarchy) is designed for sensor networks where an end-user wants to remotely monitor the environment, with the following objectives

1. Use 100's - 1000's of nodes
2. Maximize system lifetime
3. Maximize network coverage
4. Use uniform, battery-operated nodes

SPIN is a family of protocols used to efficiently disseminate information in a wireless sensor network

State University of New York at Stonybrook

Main activities related to sensors: NY Center of Excellence on sensors with LIPA

Home url : http://www.sunysb.edu/

Description:

Main projects:
Stony Brook runs a Center for Advanced Sensors Technologies. No information on the website. Related article : http://www.lipower.org/pdfs/commercial/rfp_rdexpo02.pdf.
The new Center of Excellence is a partnership between LIPA and Stony Brook , designed to develop wireless technologies that will be used in the transmission and distribution (T&D) of power on Long Island. LIPA has committed $1 million to the Center to

enhance our T&D system, and improve reliability and customer service by using new wireless technology

Virginia Polytechnic Institute and State University

Main activities related to sensors: Wireless technologies

Home url : www.vt.edu
Description: Virginia Polytechnic Institute and State University, Blacksburg, Va.,

Main projects:
The Center for Wireless Telecommunications (CWT) is an interdisciplinary research center, with faculty and students from five different colleges at Virginia Tech. These are the Colleges of Science, Liberal Arts and Human Sciences, Natural Resources, Business, and Engineering. CWT was designated a Technology Development Center (TDC) of Virginia's Center for Innovative Technology (CIT) in 1993. The primary mission of CWT is to help client companies develop new products and services using wireless technologies, and to provide a learning environment for graduate students that prepares them for jobs in wireless communications

University of Twente, Netherlands

Main activities related to sensors: Sensors and actuators, MEMS

Home url : http://www.utwente.nl/

Description: University of Twente, Netherlands

Main projects:
The Transducers Science and Technology Group (better known as "micmec"), conducted by Prof. Dr. Miko Elwenspoek, is part of the MESA+ Research Institute at the University of Twente, The Netherlands. It is one of the leading groups in the world in the field of Micro System Technology (MST). Research is focused on the design and fabrication of MicroElectroMechanical Systems (MEMS).

Texas A&M

Main activities related to sensors: sensors and WSN

Home url : www.tamu.edu

Description: Texas A&M University

Main projects:
Biometrical sensors , at the The Laboratory for Applied Biotelemetry & Biotechnology at the Department of Marine Biology at Texas A&M University Galveston.
The aim of this lab is to to pursue specific questions and hypotheses related to basic science, conservation and management of marine living resources. The lab studies sensros technologies such as sensors for swimspeed (velocity), motion (accelerometers), Bioelectric Impedance Analysis (BIA), feeding detectors such as stomach-temperature

and oesophagus-temperature sensors, and heart-beat or ECG detectors. They also use commercially available sensors suitably modified for our application needs, such as the Heat Flux Sensors (HFR).

Other related activities:
sensors for transportation and railroad and Wireless Sensors Networks

PSERC

Main activities related to sensors: wireless sensors systems

Home url : http://www.pserc.org

Description:
PSERC is an initiative of several universities working with industry to find innovative solutions to challenges facing a restructured electric power industry and to educate the next generation of power industry engineers.
The team is about 40 graduate students and partners are Industry and utilities.
PSERc is working for CERTS (19 researchers).

Main projects:
The program has a part on T&D, involving monitoring and real-time assessment of the network. A report has been published on **wireless equipments in substations** (accessible to members only).

A-2.3 Private companies

Many sensors are relatively easy to find on the market. Huge manufacturers as Analog Devices, Honeywell coexist with small companies focused on innovative solutions.

Honeywell

Main activities related to sensors: sensors manufacturer

Home url : http://content.honeywell.com/sensing/products/sensors/

Description:
Honeywell is a diversified technology and manufacturing leader of aerospace products and services; control technologies for buildings, homes and industry; automotive products; power generation systems; specialty chemicals; fibers; plastics and advanced materials.

The company is committed to providing quality products, integrated system solutions and services to customers around the world. Honeywell products touch the lives of most people everyday, whether you're flying on a plane, driving a car, heating or cooling a home, furnishing an apartment, taking medication for an illness or playing a sport. Based in Morris Township, N.J., Honeywell employs approximately 100,000 people in 95 countries. Its shares are traded on the New York Stock Exchange under the symbol HON, as well as on the London, Chicago and Pacific Stock Exchanges. It is one of the 30

stocks that make up the Dow Jones Industrial Average and is also a component of the Standard & Poor's 500 Index.

Main products
Wide range of current sensors, pressure, and temperature sensors. Offer a bus for smart distributed systems.

Analog Devices, Inc.

Main activities related to sensors: sensors and MEMS manufacturer

Home url : http://www.analog.com/index.html

Description:
Analog Devices, Inc. (NYSE: ADI) is a world-leading semiconductor company specializing in high-performance analog, mixed-signal and digital signal processing (DSP) integrated circuits (ICs). Since ADI was founded in 1965, its focus has been to solve the engineering challenges associated with signal processing in electronic equipment. ADI's products play a fundamental role in converting real-world phenomena such as temperature, motion, pressure, light and sound into electrical signals to be used in a wide array of applications ranging from industrial process control, factory automation, radar systems and CAT scanners to cellular base stations, broadband modems, wireless telephones, computers, cars and digital cameras.

Main products
Wide range of sensors, sensors networks, MEMS.

National Semiconductor Corp.

Main activities related to sensors: sensors manufacturer

Home url : www.national.com

Description:
National Semiconductor is the premier analog company driving the information age. Combining real-world analog and state-of-the-art digital technology, the company is focused on analog-based semiconductor products, which include stand-alone devices and subsystems in the areas of power management, imaging, display drivers, audio, amplifiers and data conversion. The company targets key markets such as wireless, displays, PCs, networks and a broad range of portable applications. With headquarters in Santa Clara, California, National reported sales of $1.67 billion for its most recent fiscal year.

Main products
Range of sensors, wireless solutions
Bus technology : SensorPath™ Interface Technology

NVE

Main activities related to sensors: First GMR sensors

Home url : www.nve.com

Description:
NVE is a manufacturing leader of sensor products incorporating Giant Magnetoresistance (GMR) materials.

Main products
They are the first company to market a line of GMR based sensors. GMR is used in Magnetic Couplers.

OMEGA

Main activities related to sensors: sensors manufacturers

Home url : www.omega.com

Description:
OMEGA, created in 1962, has grown from manufacturing a single product line of thermocouples to an established global leader in the technical marketplace, offering more than 100,000 state-of-the-art products for measurement and control of temperature, humidity, pressure, strain, force, flow, level, pH and conductivity.
OMEGA also provides customers with a complete line of data acquisition, electric heating and custom engineered products.

Main products:
Line of sensors products, including temperature labels, reversible and non-reversible.

PARC

Main activities related to sensors: control technology, architecture

Home url : http://www2.parc.com/spl/projects/ldc/

Description:
The Palo Alto Research Center (PARC), a subsidiary of Xerox Corporation, conducts pioneering interdisciplinary research in physical, computational, and social sciences. Building on our three-decade tradition of innovation, PARC works with Xerox and other strategic partners to commercialize technologies created by our renowned scientists.

Main products:
Distributed Smart Matter Control
This research project aims to develop control technology for systems with large numbers of networked actuators, sensors, and controllers. The goal is to provide a principled, generic approach to the design and implementation of distributed large-scale control. In particular, PARC focuses on model-based approaches using constraint technology.
Work on MEMS

MICROCHIP

Main activities related to sensors: Digital Signal Controllers

Home url : www.microchip.com

Description:
Microchip Technology has focused its resources on delivering innovative semiconductor products to the global embedded control marketplace

Main products:
Line of sensors products
DSC sensor Family: Low-cost, high-performance devices, 18 and 28-pin packages designed for space constrained applications and Critical peripherals needed for sensor applications. Multiple serial interfaces including CAN, UART, SPI, and I2C

SOFLINX

Main activities related to sensors: Secure wireless monitoring system

Home url : http://www.soflinx.com

Description:
Soflinx is a wireless sensor network (WSN) company, provides software and complete system integration services for the design, implementation and effective management of "smart" wireless sensor networks. Soflinx enables organizations to more effectively collect, analyze and take action on data from sensor networks, as well as cost-effectively manage those networks.

Main products:
Soflinx Defender is a powerful wireless monitoring and control system that provides perimeter security for commercial, industrial, and government locations. Although publicly available for the first time, Soflinx Defender is currently employed by the U.S. government for the detection of hazardous explosive, nuclear, radiological and chemical warfare agents. Press release **09/2003**

Sensor synergy

Main activities related to sensors: integrated web-server

Home url : www.Sensorsynergy.com

Description:
Sensor Synergy, Inc. is a U.S. corporation founded in October 1999 to help industry simplify the task of connecting sensors and actuators to the Internet and local networks. Many manufacturing and commercial enterprises have identified communication barriers within their organization due to sensors lacking connectivity or incompatible interfaces. In order to facilitate the process, Sensor Synergy has developed unique software and hardware tools to implement low-cost sensor-to-Internet interfaces. These products can be used for monitoring and control of industrial processes, environmental control or other monitoring applications, through standard internet-connected Web browsers

Main products:

The Network Enabled Equipment Monitor (NEEM) can be viewed as a miniature data acquisition system with an integrated micro-Web server.

A-3 Projects and experiments for utilities

This part lists companies that supply utilities with customized solutions and describes several on-going experimentations in utilities.

A-3.1 Systems customized for utilities

NxtPhase

Main activities related to sensors: high voltage monitoring optical sensors

Home url: www.nxtphase.com

Description:
NxtPhase works in the areas of technical innovation in power technology, all focused on improving reliability of the power system: fiber optic measurement of current, fiber optic measurement of voltage, and digital protection equipment
It is a Fortune 500 company.

At Honeywell, a spin-off research team had the insight to apply the very same fiber-optic gyro technology developed for demanding civil and military navigation applications to the measurement of current. NxtPhase acquired Honeywell's current sensing technology, to benefit from nearly $100 million spent on development and manufacturing over the past decade, plus the ongoing contribution of 10 engineers, managers and technologists. Then NxtPhase, UBC and BC Hydro partnered to develop a voltage sensing technology; significant technological breakthroughs led to an extremely accurate optical voltage transducer that avoids the environmental concerns of alternative optical or conventional technologies.

Most recently, NxtPhase has acquired a well-established group specializing in digital protection and monitoring solutions for the global electric utilities market. The NxtPhase relay and recorder team design and manufacture leading-edge disturbance fault recorders and protection relays. Our advanced relay and recorder technology will be a key element enabling NxtPhase to lead the way in digital interfaces between sensors and other protection, monitoring and control devices.

Main products:
NxtPhase develops **digital and fiber optic solutions** for the high-voltage electric power. Their patented optical sensing products offer more accurate digital information, broader dynamic range, wider bandwidth, improved safety, and environmental benefits compared with conventional technologies.

NxtPhase is actively seeking interested customers for 115 kV, 230 kV, 345 kV, & 500 kV installations for the NXVT, NXCT, & NXVCT.

Their relay and recorder line provides smart, easy-to-use protection and monitoring of electrical power systems. These products include digital signal processor (DSP) and microcomputer based relays for protection and control of electrical systems, multi-channel recorders for monitoring electrical systems, and data management system software for analysis and optimization of electrical systems.

AIRAK

Main activities related to sensors: Optical sensors

Home url : http://www.airak.com/

Description:
Airak, Inc. designs and manufactures state-of-the-art optical current transducers that are used in medium-voltage or high-current monitoring applications. Airak's patent-pending optical current sensor enables customers to monitor current, magnetic fields, and ambient/conductor temperature in high-power applications with increased safety, isolation, and lower installation costs than conventional technologies. Applications range from integration of the transducers into utility-scale power converters/inverters to provide intrinsic isolation between the distribution lines and the control electronics to monitoring load conditions (current, temperature) on distribution power lines.

Main products:

The main products are

- Advanced Power Inverter Development
- Modular Inverter Development
- Optical Voltage Sensors, from a few hundred volts to 6000VAC.
- Optical Partial Discharge Sensors
- Hybrid Power Electronics Modules
- Optical Oxygen and pH Sensors

Airak has worked with DOE.

Siemens

Main activities related to sensors: Novel sensors for Voltage and current, Transformer monitoring system

Home url : www.siemens.com

Description:
http://www.siemens.com/index.jsp?sdc_p=dpo1026939fcls6mnt4u&sdc_sid=28421128512

Main products:
Novels sensors developed for voltage and current
These novel sensors have low voltage output that can be used with low power microprocessor based technology.

Different sensors for Gas Insulation and air insulation (TBD)

SITRAM+
SITRAM+, Siemens' second-generation on-line monitoring system, allows digital monitoring of transformers. Such monitoring goes far beyond simply taking measurements and achieves greater efficiency in the early detection of faults, in maintenance and in repair. This all results in greater availability and longer service life for power transformers.

Components from the SIMATIC range of automation products make the system both reliable and flexible. 40 measures, system can be used for old and new transformers

TRENCH

Main activities related to sensors: HV low power output VT and CT

Home url : http://www.trenchgroup.com

Description:
Trench is a world leader in power engineering and the design of specialized electrical products- serving customers in the utility and industrial markets around the globe. Our major product categories include air core reactors, instrument transformers, earth fault protection, bushings, line traps, relay communications and protection and control equipment.
Trench has more than 1800 employees and a world wide sales network.

Main products:
High voltage Current transformers and voltage transformers
One LOPO® current transformer covers currents from 50 A to 5000 A and meets both measuring and protection requirements

Luna iMonitoring

Main activities related to sensors: WSN for asset monitoring

Home url : http://www.lunaimonitoring.com/

Description:
Spun-off from Luna Innovations in Summer 2002 and acquired by IHS Energy in October 2003, Luna iMonitoring is providing remote asset management through wireless sensing devices integrated with software and Internet accessibility. This technology enables opportunities in providing information decision makers, operations managers, data analysts, and other staff with real-time or near real-time information derived from data collected from a suite of remote sensors

Main products:
Luna Imonitoring offers a suite of intelligent, solar-powered, wireless telesensors (flow, temperature, humidity, dew point, level, vibration, strain, pressure, electrical power) that are small and low cost. Bi-directional communications provides field configurability and upgradeability with intelligence for diagnostics and prognostics. A communications

bridge enables Internet accessibility to remote information via a WAN link using satellite/cellular communications.

Crossbow

Main activities related to sensors: MEMS Smart sensors, WSN, TinyOS from Berkeley

Home url : www.xbow.com

Description:
Crossbow is a dynamic Silicon Valley company built on a clear and compelling vision of the future of sensing technology.
Crossbow develops, manufactures and markets a broad range of inertial sensors including gyros, accelerometers, tilt, and magnetic sensors. They offer sensor-based analog and digital subsystems.

Crossbow sensors integrate silicon micro-electro-mechanical systems (MEMS) with digital signal processing and communications technology. Crossbow is the industry leader in using low power radio technology to create low-cost wireless sensor networks with global connectivity. Its integrated, intelligent sensing solutions are based on industry standards and require no external components or signal conditioning
Crossbow's sensors are integrated solutions.

Main products:
Crossbow's sensor networks allow for monitoring water-based systems. Water chemistry, flows, conductivity, can all be monitored and managed via information gathered from wireless sensors.

One novel approach is using wireless sensors as an extension of the traditional SCADA system. In order to facilitate this, Crossbow has developed software that allows a desktop PC to bridge sensor network data on Modbus - a common protocol for SCADA systems. The result is that the wireless sensors look exactly the same as traditional sensor hard wired into the SCADA system.

Foster-Miller

Main activities related to sensors: Sensors manufacturer, solutions for utilities

Home url : www.fosmiltech.com

Description:
Foster-Miller Technologies is a division of Foster-Miller,Inc. They develop technology to help save lives; light, heat, and cool the environment; improve industrial processes; and keep defense systems on line and at peak performance.

Main products:
Foster-Miller Technologies has a line of biomedical devices, machinery systems, and measurement and diagnostic systems.

Other related activities:

Gridcom – Designers and manufacturers of voltage and current sensors.
Gridcom is a telecommunications infrastructure company providing wireless and fiber solutions to communications companies and private industry
GridCom is a subsidiary of National Grid USA
Gridcom offers a wide range of infrastructure solutions on managed sites including:

- Communications towers (Multi-Operator)
- Electricity transmission towers (Multi-Operator)
- Electricity distribution poles (Multi-Operator)

Gridcom works with EPRI and ConEd.

DOBLE

Main activities related to sensors: Systems for monitoring transformers

Home url : http://www.doble.com/

Description:
Doble Engineering Company, created in 1920, is a supplier for specialized testing equipment and engineering services to the electric power industry.

Main products:
Systems for monitoring transformers (EPRI report, ConEd experiment)

- Insulation Analysis
- Circuit Breaker Test Systems
- Power System Simulators
- Moisture-in-Oil Sensors
- On-Line Diagnostics

EMBER

Main activities related to sensors: WSN solutions, AMR

Home url : www.ember.com

Description:
Based in Boston, Massachusetts, Ember Corporation was founded by MIT graduates. Ember is expert in embedded wireless networking. The company offers a family of low-cost, low-power, and high performance radio chips enhanced with EmberNet™ embedded networking software. Optimized for sensing and control applications, this self-organizing, self-healing, wireless mesh technology is uncompromisingly robust, secure and easy to use.

Main products:
Wireless network sensors solutions: temperature monitoring and Automatic meter reading. http://www.ember.com/products/solutions/index.html

KINECTRICS

Main activities related to sensors: T&D monitoring systems

Home url : http://www.kinectrics.com

Description:
A Member of the AEA Technology Group, Kinectrics is an established, independent company. Kinectrics offers over 90 years of proven expertise and experience founded on solving the most demanding technical challenges for Ontario Hydro, one of North America's largest and most reliable utilities.

Kinectrics' specialists in generation (hydro, fossil, nuclear), transmission, distribution, industrial energy services, and environmental technologies use innovative science and engineering to help clients improve business performance. Kinetrics offer comprehensive services worldwide, in a broad range of technical disciplines across the energy sector.

Main projects:
http://www.kinectrics.com/index_ht.cfm
The company develops monitoring systems for Transmission and Distribution. No technical details on the website.

SmartSignal

Main activities related to sensors: WSN for the power industry

Home url : www.smartsignal.com

Description:
SmartSignal Corporation is a privately held technology company founded to commercialize early-warning predictive technology originally developed in the nuclear power industry.

The University of Chicago founded SmartSignal to make this revolutionary technology commercially available on March 17, 1999. SmartSignal has products for predictive maintenance, equipment health monitoring and early warning of pending equipment failures across multiple industries ranging from Aviation and Commercial Transportation to Energy and Power Generation.

Main products:
Equipment Condition Monitoring™ software provides the earliest possible warning of potential problems at every site and on all equipment assets you operate, regardless of OEM. You can manage your fleet better than ever before, making repairs on your own terms and getting the most out of your plants.

IREQ HydroQuebec

Main activities related to sensors: Power industry monitoring systems

Home url : www.ireq.ca

Description:

Ireq is the Research Institue of HydroQuebec. It works with the subsidiary TransEnergie http://www.hydroquebec.com/transenergie-tech/index.shtml

Main projects:
http://www.ccfm.ireq.ca/index.html

STARTRAK

Main activities related to sensors: Wireless system and control

Home url : http://www.startrak.com

Description:
StarTrak, LLC, a Delaware Corporation is based in northern New Jersey and has been providing wireless data solutions to a variety of industries for over 5 years. The company's focus is on delivering advanced monitoring solutions to the rail, mobile refrigerated, specialty freight, and petroleum industries. The company's current products are improving freight operations on mobile refrigeration equipment, performance and utilization on rail cars, barges, bulk transport trailers, containers, generators, compressors and chassis, and improving reporting capabilities for numerous fixed-site customers in oil & gas applications. The company has a broad base of installed units currently operating in North America, Australia, Africa, Europe, and Australia.

Main projects:
GeoLink, Wireless Measurement & Control

- Fixed site or mobile
- Full Logistics- location, speed, etc.
- Always-On™ instant poll response
- Complete coverage throughout North & Central America
- Fully Web-Enabled
- Solar powered
- Programmable Applications Processor
- Connects to any sensor or serial device (analog, modbus, digital, strain, etc.)

Numerous applications available (tank level, cathodic protection, flow, etc.)

Serveron

Main activities related to sensors: sensors systems for transformers

Home url : www.serveron.com

Description:
Serveron provides technology and services that continually monitor the performance of electric utility assets. Homes and industries rely on billions of dollars of electric utility assets to deliver electric power. Reliable, efficient operation of that equipment is paramount to the operation of the digital economy. And -- in a deregulated world -- to the ongoing profitability of the utilities themselves.

Main products:
Serveron's products and services continually monitor the operating condition and changes in performance of critical transmission and distribution equipment. Our comprehensive, proprietary technology and high-speed communications immediately send information on developing problems to the appropriate utility personnel. This information helps avoid dangerous and costly failures while optimizing maintenance schedules.
Serveron provides complete online monitoring products and services for electric power substation reliability. Serveron's technologies address asset characteristics that have traditionally been difficult or impossible to measure.

- **Full-service, turnkey asset monitoring**
- **TrueGas™ transformer gas analyzers**
- **Battery and Cell Management (BCM) monitors**

Works with EPRI, EDF

GE HARRIS

Main activities related to sensors: sensors systems with fuzzy logic for the power industry

Home url : www.harris.com

Description:
Harris Corporation (NYSE: HRS) is an international communications equipment company focused on providing product, system, and service solutions for commercial and government customers. The company's five operating divisions serve markets for microwave, broadcast, network support, secure tactical radio, and government communications systems. With more than 10,000 employees, including 4,000 engineers and scientists, Harris is a technology powerhouse.

Main projects:
GE HARRIS is a provider of innovative, real-time information technology solutions to the electric utility industry.
GE HARRIS works on data fusion and fuzzy logic in sensors platforms.
GE HARRIS develops systems for substation monitoring.

A-3.2 Utilities projects

WAMS

Main activities related to sensors: Advanced Monitoring system for transmission

Home url :

Partners:
PNNL, BPA, DOE

Dates: began in 1995

Description:
Bonneville Power Administration (BPA) has pioneered the development and implementation of the Wide Area Measurement System (WAMS). This system is capable of detecting and reporting phase angle swings and other critical transmission system changes over a wide geographical area. By constantly monitoring conditions throughout a wide-area network, WAMS can detect abnormal system conditions as they arise. BPA currently is expanding on the capabilities of WAMS by implementing a Wide-Area stability and Control System (WACS) that will provide a flexible platform for rapid implementation of generator tripping as well as reactive power compensation for voltage support and stability. The system will provide improved voltage security through better preventive and corrective countermeasures. It will also automate the actions of an experienced operator.

BC Hydro

Main activities related to sensors: Optical current and voltage sensors demonstration.

Home url : http://www.bchydro.com/business/investigate/investigate978.html

Partners:
BC Hydro, NxtPhase

Dates: Began in 2000

Description:
This project verified the performance of NxtPhase corp. optical sensors in a substation environment.

ConEd/Doble project on substation monitoring

Partners:
EPRI, ConEd, Doble

Dates:

Description:
EPRI has conducted a demonstration project to demonstrate the utility of WSN for monitoring in a substation. The results are available in a EPRI report.

A-4 EPRI work

Some sensors have been developed for generation. Most of the work in other areas is customizing existing sensors and systems, and providing guidelines.

A-4.1 Substations

Prototype Fiber-Optic Acoustic Partial Discharge Sensor: Lessons-Learned Documentation and Field Test

Project number: 1001768

Project manager Luke van Der Zel

Contributors

Dates 2002

Project description:
The most effective technique for signaling imminent failure in electrical apparatus is detecting and measuring partial discharges (pd). There are several pd parameters that can be measured; however, the signals are very small and high levels of interference exacerbate the problem of measurement, particularly in the field. This report describes development of a new sensor for measuring acoustic pd in transformers. The technique is particularly suited for field measurement since the sensors are mounted inside the transformer tank, thus eliminating much of the external acoustic noise. The report also gives the results of the first field trial in an operating transformer.

The objective is to develop a cost-effective, reliable, fiber-optic acoustic sensor for realizing the quantitative detection of pd in transformers and to model pd acoustic propagation in transformer windings.

Results:
Sensor frequency response and sensitivity have been optimized. A high-performance signal processing circuit has been redesigned and optimized for high gain, wide and flat band frequency response, and ultra-low noise. A controlled thermal bonding technique has been developed to improve sensor manufacture, lower temperature dependence, and give higher yield. Two- and three-dimensional models simulating the mechanism of the pd acoustic wave and its propagation characteristics have been built and validated with field measurements.

Machine Vision

Project number - Not found

Project manager Luke van Der Zel

Dates

Project description
The business drivers for owners and operators of substations are to reduce maintenance costs, improve reliability and improve security of the substation. The proposed opportunity helps meet all three of those key drivers. Continous, cost-effective monitoring of all substation equipment from just a few camera locations will enhance condition-based maintenance decisions - hence reducing maintenance costs. Early warnings of developing problems will improve reliability as timely preventive action can be taken. In addition to those benefits, the same cameras will perform double-duty as intelligent perimiter and internal monitoring devices - improving substation security.

State of the Art Decision Making Tools for GIS (Gas Insulated Substations)

Project number: 1008301

Project manager Luke van Der Zel

Contributors

Dates April 2003, Project Opportunity

Project description:
The objective of this project is to provide participants with detailed practical information about methods and instruments available for assessing the condition of GIS stations. Effective GIS diagnostics are vital for informed decisions on refurbishment or replacement. In addition, early location of problem areas could help prevent in-service failures. Instead of each participant investigating and testing all the available tools on their own, this project provides an effective method to perform a complete field examination of all techniques at a fraction of the cost.

The project will critically examine both portable and permanently installed GIS condition monitoring systems at three GIS stations of differing age and type.

GIS equipment normally includes air entrance bushings, power cable connections, transformer connections, SF6 gas insulated bus, circuit breakers, disconnects, current and voltage measuring devices, and surge arresters. The focus of this project is the SF6 gas insulated bus portion, since diagnosing tests for most other components are more commonly used. For example, the circuit breakers used in GIS systems are generally very similar or identical to those used in air-insulated stations (AIS).

Insulation failures have been the largest source of GIS problems. Insulation breakdown causes include partial discharge within solid insulators, particles that are free to move within the SF6 gas insulation, partial discharge caused by electrically floating components, partial discharge caused protrusions, high resistance at sliding or bolted connections, and excessive electrical stress during disconnect operations.

Partial discharge monitoring systems specifically designed for GIS, based on UHF

electromagnetic emissions, acoustic emissions, and SF6 chemical analysis, are commercially available for on-line or periodic testing.

The direct cost to repair a flashover is at least four times higher than the cost to prevent it. Diagnostic tools can provide an effective means to reduce in-service failures and thus improve equipment reliability. These instruments can normally provide ample warning of problems. However, the levels of testing difficulty vary, depending on access availability and characterization of signatures.

Well-designed diagnostic testing and maintenance recommendations can help optimize GIS life cycle costs. This research activity is designed to improve the quality of recommendations. Improved diagnostic testing can help provide cost-effective alternatives to replacement of problematic GIS. The cost to replace old GIS inventory is relatively high. Life extensions should be an attractive alternative to replacement for at least part of older GIS inventory.

The second most serious GIS problem that utilities have reported is SF6 gas leaks. This project will include recommendations about leak detection.

Utility Investment in Optical Voltage and Current measurement Technology- Five installation case studies

Project number: 1001964

Project manager R. Lings

Contributors : HarGil group, H. Gilleland

Dates : December 2001

Project description:
In late 1999, EPRI polled utility members asking them what optical sensor projects EPRI should work on in 2000 and 2001. One recommendation was to develop a series of case studies on utility experiences. This report documents five installation case studies involving optical voltage and current measurement technology

Wireless Sensors and Communications for Application in Transmission Substations

Project number 1001787

Project manager Predrag Vujovic

Contributors

Dates

Project description
Over the last few years, EPRI has been working with member utilities to improve the cost-benefit ratio for on-line monitoring and diagnostics in transmission substation

applications. Wireless RF sensors and communications are on the list of candidate technologies offering the potential for cost savings by circumventing the need for traditional cabling. Avoided cable installation saves utilities the associated costs of meeting environmental requirements and conducting testing required prior to installation of new cables in existing substations.

Smart Substations: A Preliminary Assessment

Project number: 1001965

Project manager Luke van Der Zel

Contributors: Michael Lebow, PE

Dates: December 2001

Project description
The Smart Substation project objective is to assess the significance of the latest developments in materials, sensors, communications, monitoring, diagnostics, and data analysis to substations and equipment design. The most promising concepts for new substation equipment and technologies will be identified and pursued. Reliability, cost, operation, and maintenance aspects will be addressed. New solutions to substation and equipment design issues will be analyzed and developed. The report represents the initial phase of the project and will serve to identify and direct future project work.

Intelligent Substation

Project number: 1008821

Project manager:B darnsky

Contributors: P Kaptain, J Work

Dates: May 2003

Project description:
The research objective of the Intelligent Substation Project was to develop a combined sensor and data acquisition system, artificial intelligence, automatic control techniques, expert experience, and firmware that will enable on-line diagnostics and predictive maintenance. This intelligent monitoring system will prevent catastrophic failures of large power transformers, which cost millions of dollars each, and will eliminate the present unneeded/scheduled maintenance. The greater reliability this system can provide will also be a benefit for the power grid.

The Intelligent Substation project created a self-automated, distributed system that can detect failures and issue warnings without human interference. This system can prevent the catastrophic failures in substation equipment and eliminate the unneeded maintenance that currently occurs due to the method of scheduling tests on a set interval.
The developed diagnostic system combines on-line sensor monitoring with a neuro-fuzzy network in order to interpret the mass amount of data that will be received from the

sensors. The system will be distributed and consist of five major nodes: sensor, signal conditioning, data acquisition and storage, data analysis, and user interface. The most crucial of the nodes is the data analysis node, which will include the neuro-fuzzy engine. This engine will serve as a non-linear system identifier, output observer, and fault detector. After the data analysis is done, warnings would be sent to the maintenance supervisor, who could then dispatch the needed personnel to correct the problem. In doing this, the diagnostic system eliminates all need for scheduled maintenance and enables the utility to take only the actions that are needed at the time.

A-4.2 Transmission & Distribution

Sensor Networks for Advanced Distribution Automation

Project number: S124.006

Project manager Frank Goodman

Dates : Destinations 2004

Description: This multi-year project will develop the technology for sensor networks for advanced distribution automation (ADA). This network concept will be comprised of (1) measurement capabilities embedded within existing and new distribution system components; (2) low-cost sensors that can be easily deployed on lines, cables and other system sites; and (3) communication capabilities to collect the data and transport it to central monitoring and control systems. A development roadmap for the sensor network technology will be prepared and implemented. This roadmap will encompass development of the overall network concepts and components. Where suitable technologies exist, they will be assimilated into the network. Where gaps exist, the necessary sensors or other components will be developed to fill the gaps. A sponsor review panel will be organized to review and guide the work.

Load Model Development Based on On-line Measurements

Project number: 107471

Project manager: Ram Adapa

Contributors:

Dates: November 2002, project opportunity

Project description:
In an effort to utilize their transmission asset to the greatest extent possible, utilities rely on dynamic simulations. Such simulation studies are also used to design proactive control systems to minimize the impact of disturbances.
Simulation results are critically dependent on the choice of load models. The increasing detail of network modeling makes it both possible and desirable to represent load using physically based models, i.e., a combination of lighting load, motors, etc.

In the past, such models have been derived from load inventory surveys, but implemented as functional models. Recent work suggests that the physical inventory of load can also be estimated from measurement-based methods. Promising results have been obtained at the Public Service Company of New Mexico (PNM) from load measurements.

In the PNM load modeling project, data acquisition systems were installed at several distribution substations in the PNM service area. The load on each feeder was considered to be a combination of incandescent and discharge lighting, small and large motors, electronic loads, etc. A method was developed to derive the percent composition of each load type from test and disturbance data for each feeder. Results appear to be consistent with the type of load served by the feeder.

The project will obtain and catalog distribution level test and disturbance data from a number of utilities. Where possible, information on load inventory from load surveys will also be cataloged. Needed extensions will be made to the identification procedure and models will be developed for each data set.

The results will be compared for consistency. Prescriptive guidelines for modeling and implementation will be developed. At the same time, models will be implemented in a large-scale simulation program. The validity of the models will be assessed by simulating disturbances for which on-line measurements are available.

The project will provide participating utilities with first-hand information on how to develop, implement and maintain "practical engineering" load models with a high degree of confidence.

Advanced Sensor System Assessing Vulnerability of Power Systems— Phase 1

Project number: 1009125

Project manager: Aty Edris

Contributors:

Dates: September 2003, project opportunity

Project description:
Transmission networks are complex interactive systems in Transmission owners and operators will benefit from the development and implementation of advanced sensors that detect abnormal changes in grid transmission parameters. Sensor data can then be processed and used to calculate the real-time values of a set of indices that determine the grid's vulnerability to major failure as well as its overall security level.

However, the presence of sensors in a transmission network raises significant security and operating concerns. First, through their connection to data-collection devices, sensors may provide a window of accessibility into the power grid that could be deliberately exploited unless safeguards are implemented. Therefore, any plan to add sensors to a grid

must thoroughly address the physical vulnerabilities that may be introduced. Second, on some parts of the grid, installing sensors may be cost-prohibitive or present other obstacles. In these cases, transmission entities would benefit from the development of "virtual" sensors, which use data collected from other sensors to accurately estimate the values of parameters that cannot be easily measured.

EPRI proposes to undertake a phased approach to developing advanced sensors and sensory networks (for example, transducer, detectors, and data transmission paths) for use in transmission networks. In the first phase, EPRI will evaluate the transmission grid to assess the current availability of sensor data, determine generic locations that would benefit from enhanced monitoring capabilities, and identify which kinds of sensors would be most appropriate. EPRI will develop implementation guidelines for the addition of advanced sensors to transmission networks, as well as data interpretation guidelines. The project will complement the efforts of the Wide Area Measurement System (WAMS) project that is being implemented by a range of public and private entities in the Western Interconnection.

The benefits of advanced sensor systems for transmission grids include the following:

- Enhanced reliability— Better data collection and analysis methods will enable more effective grid operations, improving power reliability and reducing the possibility of outages.
- Reduced maintenance costs— Data gathered from advanced sensors will support condition- or information-based maintenance, ensuring the strategic application of resources.
- Informed decision-making for capital expenditures— Armed with detailed information about a transmission system's physical vulnerabilities, planners can make effective decisions regarding equipment additions, upgrades, and replacements.

Work Station (IBDW) for Power Electronics-Based Controllers (PEBC)

Project number: S38.007

Project manager: Aty Edris

Dates: Destinations 2004

Project description:
A Power Electronics-Based transmission & distribution Controller (PEBC) is a sophisticated structured system. The PEBC consists of a number of elements: solid-state switching valves, magnetic components, control system, and cooling system. The operation of a PEBC is a series of reliable and controlled interactions between these elements. A malfunction of any of these elements results in unavailability of the controller.

The objectives of the project are to develop an intelligence-based diagnostics tool predicting the “proper” state risk degree for a malfunction of any of the PEBC elements, and developing a corrective action plan. This prediction will be based on collected

performance data, recorded state data, inspection-based data (visual, acoustics, and other inputs), and integration of these data into an intelligence-based workstation.

Fiber Optic Point Temperature Sensors for Thermal Management

Project number: 1007781

Project manager: Ram Adapa

Dates: project opportunity, February 2003

Project description:
During 2002, under the EPRI base funded project on Novel and Low Cost Temperature Sensors for Lines, Transformers, and Cables, a literature survey was performed on the application of low cost temperature sensors for transmission systems. The results of this base project are encouraging. The goal of this supplementary project is to develop prototype sensor systems and apply them at utility test sites. It is important to note that sensor systems are key in implementing dynamic ratings for transmission systems. The results from the field trials will also be documented in the EPRI base funded project document, the "Increased Power Flow (IPF) Guidebook."

Power transmission components must operate below a critical temperature. Active feedback from real time temperature data in transformers would enable current flow to be optimized to increase line capacity. This project will test existing fiber optic temperature point sensors from FISO Inc. and Luxtron for transformers and substation equipment and develop new temperature monitoring systems based on the existing sensors.
FISO's sensors are designed to operate in the harsh environment of a transformer to monitor oil and winding temperature and up to a temperature of 350 degrees Celsius. The electronics are capable of operating up to 196 sensor points, making it possible to monitor the temperature distribution in a large volume of space. Luxtron sensor systems have similar specifications.

This project will test FISO and Luxtron fiber optic temperature sensors in transformers at a test center / laboratory such as EPRIsolutions' labs to test the feasibility of retrofitting existing facilities. In addition, their reliability will be tested and algorithms for finding hotspots based on measurements from several point sensors will be developed. The project will provide participating utilities with information on the specifications of such sensors and information on how they can be installed and used to increase the power throughput of the existing transmission facilities

Reactive Power Management of Transmission Grids

Project number: 1009124

Project manager: Aty Edris

Dates: project opportunity, September 2003

Project description:

Owners and operators of transmission facilities need to ensure grid reliability as well as improve power transfer capabilities to meet increased demand. Meeting these goals economically requires effective grid management strategies, including the efficient management of reactive power in the transmission system.

Because reactive power is required to support power flow, it is an indispensable element of AC transmission grids. Improving the management of reactive power within the grid can increase the system's overall power transfer capability, enabling the transmission of more power over the existing infrastructure. By contrast, inefficient reactive power management can result in transmission bottlenecks, voltage instability, and outages resulting from voltage collapse.

Developing an effective reactive power management strategy requires analyzing a transmission system to identify "load pockets," or buses that lack sufficient reactive power to support increased load. These load pockets are likely to experience voltage instability if equipment outages or additional power transfers increase the load that they carry. The addition of voltage control and reactive power supply devices to these areas can mitigate the conditions that cause voltage collapse.

Load pockets may occur in "families," where each load pocket is part of a successively larger set of buses. For families of load pockets, voltage collapse can be avoided through load shedding, or by application of voltage control and reactive power supply devices to provide reactive power support to the entire load pocket family. In addition, applying hierarchical preventative controls to a load pocket family can help contain voltage instability and loss to specific areas, reducing the likelihood of cascading outages.

EPRI proposes to apply a technical and economic approach to reactive power management in participating companies' specific transmission systems. EPRI will assess reactive power flows at various operating conditions and transmission contingencies, identify load pockets and families, and determine the availability of reactive power generating resources. When the assessment is complete, EPRI will recommend the location, magnitude, and type (switched or dynamically controlled) of reactive power supports to relieve transmission bottlenecks and improve power transfer capabilities, for each participating company's system.

For each studied transmission grid at a funding company, EPRI will undertake the following tasks:

- Evaluate the grid's baseline performance and map the limiting phenomena. This task includes quantitative analysis of steady-state power frequency performance under various power transfer scenarios, transmission contingencies, and availability of generating resources for reactive power.
- Identify remediation options for the grid, including conventional system upgrades and/or adoption of new technological measures.
- Perform an economic evaluation to calculate the potential benefits of the remediation options. This task provides a cost-benefit analysis comparing effective reactive power management to other kinds of remedial measures.

A-4.3 Generation

Smart Sensors and Digital Fieldbus: Market/Product Surveys and EdF's Experience Feedback

Project number: 1003564

Project manager J. NASER

Contributors: EDF

Dates: July 2002

Project description
This report presents results of a survey and a set of experiments with smart sensors and digital field buses. These technologies are capable of supporting improved plant performance through functional gains and economic savings. Experience with these technologies by Electricite de France (EdF) on test loops and at three fossil fuel plants is described.

TEAM work program

Project manager Marty Bridges
The TEAM work program for 2003 is available at
http://www.epri.com/attachments/261577_16team2.pdf .
Several parts are related to sensors.

Among them, Wireless Smart Sensors for Nuclear Plant Maintenance.
EPRI's Technology for Equipment Assessment and Maintenance (TEAM) group has been involved with wireless applications since 2001 in the areas of smart sensors and electronic performance support systems (EPSS). Smart sensors imply a finite number of components monitored. By its very nature, EPSS encompasses a much more complex set of condition monitoring and equipment to human interface(s). In this effort, TEAM works with other targets in EPRI, including the Nuclear Maintenance Applications Center (NMAC), Instrumentation & Control, (I&C), and Plant Maintenance Optimization (PMO).

Centrifugal Charging Pump Gearbox Smart Sensor Development

Project number: 1006694

Project manager: TEAM

Contributors: Duke Energy's Catawba Nuclear Station.

Dates Feb 2003

Project description

This report covers background information on condition-based maintenance and signal processing techniques used to develop diagnostic and prognostic technology for gearbox health monitoring.

Condition-based maintenance can provide significant benefits to the utility industry by reducing maintenance costs, minimizing the risk of catastrophic failures, and maximizing system availability. With the smart sensor system developed in this project, changes in the condition of a gearbox are monitored through the collection and analysis of vibration data. After trending these changes, a health tracking assessment is computed, which estimates the remaining useful life of the gearbox.

This tool enables personnel to more efficiently manage equipment condition. Likewise, the successful implementation of a wireless communication system for equipment enhancements enables plant personnel to avoid the additional cost of through-wall wire penetrations.

Results: This project successfully demonstrated the use of a smart sensor for gearbox health monitoring as well as the use of current communication technologies for wireless data transfer. With the latest developments in the processing power of embedded smart sensors, it is possible to incorporate enough intelligence into a small package to enhance an existing platform while reducing data flow requirements

Wireless Sensor Application Survey in Power Plants

Project number: 1004428

Project manager: Ramesh Shankar

Contributors

Dates: March 2003

Project description
Wireless technology has become attractive for power plant applications. It expands the ability to provide instant communication on corporate enterprise information as well as to monitor engineering data from equipment for diagnostics and prognostics. This Tech Progress report provides a background of wireless technology in use today at fossil and hydro plants based on a survey completed in 2002.

A-4.4 Sensors and sensors systems

EPRI Wireless Sensor Application Guideline

Project number 1004387

Project manager

Contributors

Dates: December 2002

Project description

This guideline discusses the different wireless technologies in use today. Before wireless technologies were available, all the sensory connections and user interfaces in nuclear power plants had to be hard-wired. This was a limiting factor in developing a world-class condition-based maintenance (CBM) program. The wire runs were very expensive, and some equipment was in a remote or inaccessible location. With wireless technologies, adding continuous monitoring to equipment is often easy and inexpensive. In areas where walk-around data are gathered, a facility can now have real-time data available from equipment and networks.

A-5 CEIDS

A-5.1 IECSA

Task 1: application domains

Consumer Domain Applications

- Customer EMS manages building environment, based on preset parameters (security settings, temperature, appliances, lighting management, etc.), to provide energy management expertise and supervision to customer purchased energy management equipment
- Customer status/control of building environment locally and/or remotely by modifying parameters function , in order to provide secure access to customer site through managed network
- Offsite premise management, for remote access and monitoring to remote sites
- Weather function, for access to real-time and historical weather data
- Lightening and severe weather alert notification
- Appliance performance monitoring, to provide advanced analysis to customer sited sensor data to achieve proactive maintenance and performance analysis
- Monitoring of in-building sensors, to support performance requirements for indoor air quality and facilitate conflict resolution in disputes related to air quality in buildings
- Calculation of home R factor function, Dynamically calculate the heating "R" factor of a home

Requires
Sensor configuration information
Customer sensor network
Sensor confirmation tree
Sensor connectivity over disparate networks

Distributed resources

- Meter Data Management Agents (MDMAs) for retrieving DR meter data to manage meter readings and usage profile
- Statistical data on operational conditions are collected and calculated, in order to infer statistically significant information such as end-user's load demand profile
- DR owners analyze operational conditions: e.g. load forecasts, weather conditions, energy prices, DR maintenance requirements, DR capabilities and capacity, etc , in order to evaluate energy capture (wind systems) and availability And to Maximize productivity and anticipate revenue potential from the resource

Requires
Automatic reading from remote sensors
"on-demand" readings from remote sensors over WAN

Federated services

- Security policies and techniques for determining requirements and implementing physical security countermeasures
- Intrusion detection, mitigation, and recovery plan and techniques
- End System/Application Support and Management

Requires

Fiber optic vibration sensor, motion sensor and others

Alarm system (sensors and control panels)

Transmission

- Schedule maintenance operations - predictive, based on data and models
- Planners/operators perform load analysis of substation equipment based on data, to determine which substation equipment can be temporarily overloaded in order to facilitate the planned outage
- Predict and prevent failure of equipment while online; optimize usage of equipment, Based on predictive models driven by real-time data

Problems

Sensors in place have low communications capabilities

Existing sensors are compute-constrained; existing software may not be prepared to take condition-monitoring data, as input

Task 2 : assessment of existing technologies

Size of the Addressable Population

As digital intelligence migrates to the basic sensor level, the address space for these devices will expand exponentially. A future “smart building” may have 500 to 1000 addressable devices. Extending this to the 115,000,000 homes in the US (independent of industrial, commercial, government, and public facilities), an address space in excess of 115,000,000,000 will be required – over 25 times the present Internet address range.

A-6 Standard organizations work

A-6.1 Existing standards and need for interoperability

Standard language
A need for standard language appears with communicating devices. Some systems already implement standardized languages, UCA or CIM.

Accuracy
There are several standards on accuracy for measures on the electrical.
IEC 61000, IEEE EN Standard exists for accuracy (IEC, IEEE, EN in Europe).

Synchronization
If the measures have to be sent, most of them will need to be time-stamped. This can be done before sending or at the receiver depending on the application. Synchronization and accuracy of the time-stamp is an issue in both cases.

Stamp with GPS
There is a need for Geographic information in today's information systems. Then data sent could be GPS-stamped.

Addresses
The multiplication of communicating sensors will raise a need for a huge number of addresses. These addresses will be crucial for all the applications and today's protocols may not support so numerous addresses.

Standardized outputs
Standard outputs or Analog-To-Digital converters (ADC) are mainly today are 4-20mA loops and serial ports.

Protocols/standards
Standards are arriving for ad-hoc networking.

Need for open standards
Most sensors-based systems were in the past proprietary systems but the market is moving towards more open platforms.

Open technologies are yielding unprecedented opportunities for connectivity. Another reason is the long life of most system on the grid. Replacement of parts and maintenance would be easier and less costly if based on open standards.

What is more, sensors for a specific purpose will often have to be integrated in a platform. In a substation, for example, it is likely that all IED's, sensors, meters,.. will have to communicate using common standards.

A-6.2 IEEE

Wireless standards: http://standards.ieee.org/wireless/

Technical Committee on Measurement Sensor Technology (TC9)

URL: http://ewh.ieee.org/soc/im/index.html, searchforTC-9

Description:
The purpose of TC-9 is to develop, promote and support standards in sensor-related communication technology, user applications and industry senor interface needs; To evaluate and, where appropriate, amend existing sensor standards; To review sensor interfaces and their application in user, government and industry segments of technology; and to maintain liaison with other societies and organizations working in the same or related areas.

IEEE 1588 Standard for A Precision Clock Synchronization Protocol for Networked Measurement and Control Systems

URL: http://ieee1588.nist.gov

Description:
From the "Scope" section of the standard: "This standard defines a protocol enabling precise synchronization of clocks in measurement and control systems implemented with technologies such as network communication, local computing and distributed objects. The protocol will be applicable to systems communicating by local area networks supporting multicast messaging including but not limited to Ethernet. The protocol will enable heterogeneous systems that include clocks of various inherent precision, resolution and stability to synchronize. The protocol will support system-wide synchronization accuracy in the sub-microsecond range with minimal network and local clock computing resources. The default behavior of the protocol will allow simple systems to be installed and operated without requiring the administrative attention of users." It is intended to address time synchronization requirements not met by other technologies such as the Network Time Protocol (NTP) or Simple Network Time Protocol (SNTP). It defines an architecture of time servers and time gateways, some of which may be embedded in networking devices such as switches and routers. Published as IEEE1588-2002.

IEEE 1451 Standard for a Smart Transducer Interface for Sensors and Actuators

URL: http://ieee1451.nist.gov

Description: The objective of this project is to develop a smart transducer interface standard, where a transducer is defined as a sensor or an actuator. This standard is intended to make it easier for transducer manufacturers to develop smart devices and to interface those devices to networks, systems, and instruments by incorporating existing and emerging sensor- and networking technologies. There are four working groups, each addressing a different area:

- P1451.1 - Common object model for smart transducers along with interface specifications for the components of the model. Published as IEEE 1541.1-1999.

- P1451.2 - Smart transducer interface module (STIM), a transducer electronic data sheet (TEDS), and a digital interface to access the data. Published as IEEE 1451.2-1997.
- P1451.3 - Digital communication interface for distributed multidrop systems. In progress.

P1451.4 - Mixed-mode communication protocol for smart transducers. In progress.

IEEE 802.11 – Wireless AdHoc Networks

Description: When a wireless LAN does not have a base station or access point controlling its nodes, it becomes an ad-hoc network. Because of the potential ease of deployment, there are many expected uses of ad hoc networks: home-area or personal-area networks, battlefield, search-and-rescue operations, environmental monitoring and mobile robotics. Sensor networks are extensions of wireless AdHoc Networks. The technical challenges of this technology include routing that must be solved dynamically as the nodes may be mobile and the network topology may change frequently. Node mobility, battery power limitations, low bandwidth of the wireless links and their path loss characteristics make the problems more challenging.

Zigbee

Url: www.zigbee.org

Description:
The ZigBee Alliance is an association of companies working together to enable reliable, cost-effective, low-power, wirelessly networked, monitoring and control products based on an open global standard."
ZigBee is an emerging standard being introduced as IEEE802.15.4. It has the following design requirements:

- Data rates of 250 kb/s, 40 kb/s and 20 kb/s.
- Star or Peer-to-Peer operation.
- Support for low latency devices.
- CSMA-CA channel access.
- Dynamic device addressing.
- Fully handshaked protocol for transfer reliability.
- Low power consumption.
- Frequency Bands of Operation
- 16 channels in the 2.4GHz ISM band
- 10 channels in the 915MHz ISM band
- 1 channel in the European 868MHz band.

LonWorks bus

Url: www.lonmark.org

Description:
LonWorks control networking technology is part of the new IEEE 1473-1999 standard for train communications. LonWorks is used for braking, propulsion control, destination signage, locomotive control, fault monitoring, climate control, and wayside signaling worldwide

UCA

URL:
http://www.nettedautomation.com/standardization/IEEE_SCC36_UCA/about_uca.html

Description:
The Utility Communications Architecture (UCA) was developed under the sponsorship of the Electric Power Research Institute (EPRI) through a process of broad industry involvement. The objective has been to allow for **seamless integration** across the utility enterprise using off-the-shelf international standards to reduce costs.
UCA differs from most previous utility protocols in its use of **object models** of devices and device components. These models define common data formats, identifiers, and controls for substation and feeder devices such as measurement unit (see figure 1), switches, voltage regulators, and relays. The models specify standardized behavior for the most common device functions, and allow for significant vendor specialization to allow for future innovation. The models have been developed through an open process including broad vendor and utility participation. These standardized models allow for multivendor interoperability and ease of integration. Modern protocols (such as those found in UCA) make use of the reduced bandwidth costs and increased processor capabilities in the end devices to carry **metadata**: standardized names and type information for the most common device information which can be used by applications for on-line verification of the integration and configuration of databases throughout the utility.

The UCA object models are defined in terms of standardized types and services. These services (such as **reporting by exception** and **select before operate** controls) are defined in abstract terms, then mapped to messages in the underlying application layer protocol. UCA Version 2.0 application layer services for data acquisition and control functions in all of the profiles are provided by ISO/IEC 9506: Manufacturing Message Specification (MMS). The use of the standardized service definitions above MMS allow for 'future-proofing', in that new innovations in application layer protocols can be incorporated into future versions of UCA without disturbing the object model definitions.

Distributed Network Protocol or DNP 3 (IEEE Std 1379)

Url: www.ieee.com

Description:

A uniform set of guidelines for communications and interoperations of remote terminal units (RTUs)and intelligent electronic devices (IEDs)in an electric utility substation is provided.A mechanism for adding data elements and message structures to this recommended practice is described

A-6.3 IEC

IEC 61850

Url: www.iec.ch

Description
The UCA Version 2.0 models, services, and protocols for substation devices are currently being used as the basis for IEC 61850. The initial committee drafts of IEC 61850 will be distributed to IEC member countries for balloting in mid 2000.
IEC 61850 is part of the work of IEC TC57.
IEC 61850 is developed for substation automation systems. The standard defines the communication between intelligent electronic devices in the substation and the related system requirements

Profibus

Url: http://www.profibus.com/

Description:
The PROFIBUS communication is specified in IEC 61158 Type 3 and IEC 61784. IEC 61158 Type 3 includes the entire range of PROFIBUS, consisting of the versions DP-V0, DP-V1 and DP-V2. IEC 61784 specifies the properties of the Communication Profile Family CPF 3 which is PROFIBUS

IEC 60870

Url: www.iec.ch

Description:
Protocol developed by the IEC TC57 for power system control and associated communications.
IEC TC57Working Group 3 was one of the first organizations formed with the goal of developing a common protocol for the utility industry. It initially focused on producing an extremely reliable data link layer protocol for slow serial links. This data link layer was designed to be used in either *balanced* point-to-point links or *unbalanced* multi-drop links, with several levels of reliability which were thoroughly characterized in the annexes of the following two specifications:

- 60870-5-1 Transmission Frame Formats
- 60870-5-2 Link Transmission Procedures

The next three specifications from WG3 described in general terms the most common utility application protocol functions used by proprietary protocols at the time. These functions included such features as initialization, select-before-operate and direct controls, accumulator freezing, report-by-exception, periodic reporting, remote parameter setting, and file transfer.

- 60870-5-3 General Structure of Application Data
- 60870-5-4 Definition and Coding of Application Information Elements
- 60870-5-5 Basic Application Functions

These specifications defined the protocol in general terms only. For the details of the protocol implementation, WG3 defined several *companion standards*, each designed for a different application area, and selecting different a subset of features from the earlier five standards.

- 60870-5-101 Telecontrol (referred to as SCADA in North America)
- 60870-5-102 Load Profiling (energy measurement through accumulators)
- 60870-5-103 Protection Equipment (monitoring and control of relays)

These companion standards were three-layer serial protocols only, with no networking capabilities. With the advent of WANs in distribution automation, WG3 developed a standard mechanism for implementing IEC 60870-5-101 over Internet protocols:

- 60870-5-104 Telecontrol over TCP/IP

Although the 60870-5 companion standards can technically be used within a substation, TC57 has designated IEC 61850 (Working Groups 10, 11 and 12) as the primary standard within substations, while 60870-5 is to be used for telecontrol (to remote sites) only. WG3 recently released a revised edition of the original 101 companion standard and is currently investigating security solutions for the IEC 60870-5 protocols along with Working Group 15.

A-6.4 ISO

CAN and DeviceNet

URL: http://www.can-cia.de/can/

Description:

The attributes of a Controller Area Network (CAN) are:

- the multi-master capabilities that allow building smart and redundant systems without the need of a valuable master,
- the broadcast messaging that is the first piece of the guarantee for 100% data integrity as any device within the network uses the very same information,
- the sophisticated error detecting mechanism and the retransmission of faulty messages which is the second piece of the guarantee for 100% data integrity,

- the availability of more than 50 controllers from low-cost devices to high-end chips from more than 15 manufacturers,
- and the availability of CAN for the next 15 years as its use within the European automotive industry and the decision for CAN from the US and Japan automotive industry is guaranteed."

CAN is a ubiquitous protocol devised for monitoring and control in automotive applications. However, due to its small footprint and other technical attributes, it has found applications in many areas requiring interaction between sensors and controls. Virtually every manufacturer of embedded micro controller provides devices with built-in CAN interfaces. In this regard it is probably only second in commonality to a UARTs and I2C as a means of device communications.

DeviceNet is a related and similar protocol that differs in higher layers from CAN
CAN has also been standardized as ISO 11898.

A-6.5 CENELEC

WorldFip

Url: http://www.worldfip.org

Description:
WorldFIP technology provides a standardized specification, plus hardware chips and software, with everything you need to implement and use the Fieldbus with optimum performance:

- Single communication technology for both time critical data and unscheduled messages of any kind
- Specification complies with EN50170 vol3 including IEC compliant physical layers
- Complete range of chips to suit from large PLC/DCS down to low end non intelligent sensor/actuator
- Single communication technology to serve each level of control architecture

Software tools/libraries for easy development

A-6.6 Others

CIM

Url: http://www.dmtf.org/standards/standard_cim.php

Description:
Common Information Model (CIM) is a model for describing overall management information in a network / enterprise environment. CIM is comprised of a Specification

and a Schema. The Specification defines the details for integration with other management models, while the Schema provides the actual model descriptions

Bluetooth

URL: http://www.bluetooth.com/

Description:
Bluetooth wireless specification includes both link layer and application layer definitions for product developers which supports data, voice, and content-centric applications.

Establishing a standard means integrating well tested technology with the power efficiency and low-cost of a compliant radio system (about the Specification). Establishing a standard also means a group of industry leading promoter companies who drive the specification forward (about the Bluetooth SIG). Bluetooth technology works because it has been developed as a cross industry solution that marries a vision of engineering innovation with an understanding of business and consumer expectations.

Bluetooth wireless technology is supported by product and application development in a wide range of market segments, including software developers, silicon vendors, peripheral and camera manufacturers, mobile PC manufacturers and handheld device developers, consumer electronics manufacturers, car manufacturers, and test and measurement equipment manufacturers.

CDPD

URL:
Description:
Cellular digital Packet data (CDPD) is a wireless digital packet that may meet security requirements appropriate for WSN on the energy grid.
CDPD is a data transmission technology developed for use on cellular phone frequencies. CDPD uses unused cellular channels (in the 800- to 900-MHz range) to transmit data in packets. This technology offers data transfer rates of up to 19.2 Kbps, quicker call set up, and better error correction than using modems on an analog cellular channel.

Fieldbus

Url: http://www.fieldbus.org/

Description:
Foundation Fieldbus is a three-layer protocol suite plus object model specifications, known as “function blocks” defined above the application layer. It includes self-description in the form of “Device Description” (DD) files that use a standard (non-XML language specific to Foundation Fieldbus.
The data link layer is listed among several technologies complying IEC 61158: “Digital Data Communication for Measurement and Control – Fieldbus for use in Industrial Control Systems”. The data link layer uses a “deterministic bus scheduler” to control

access to the bus using token passing. The application layer, the Fieldbus Message Specification (FMS) uses a publish/subscribe model and resembles the Manufacturing Message Specification (MMS) that is the core of IEC 61850.

X10 (PLC)

URL: http://www.x10.com/

Description:
X10 is the pioneering manufacturer of the most ubiquitous home and building automation technology in history. Developed in the 1970's, X10s power line carrier technology can be purchased and installed for less than $20. A subsequent development added a one-way RF technology for remote controls and wireless sensors.
X10 is significant in that there are existing millions of nodes deployed for everything from home automation, to commercial facility management, to industrial control. The protocol has fallen into the public domain after patent expiration. It is manufactured by X10 and dozens of other companies. Its principal limitation is the inherent one-way nature of most implementations, and, its slow message rate ~1/second. The protocol has been extended to achieve two-way guaranteed delivery messaging, analog inputs and outputs, and extension of the address space beyond the initial 256 end points.

SensorML (Standard language)

URL: http://www.sensorsmag.com/articles/0403/30/main.shtml

Description:
Standard language developed by the members of the Open GIS Consortium, Inc. (OGC), including NASA, the National Imaging and Mapping Agency, and EPA. SensorML is a standard XML encoding scheme for metadata describing sensors, sensor platforms, sensor tasking interfaces, and sensor-derived data.

Adherence to a common schema makes it possible to search for sensors and sensor data with more precision than is available with text searches using a search engine. For example, searching for particular kinds of sensors and data in a particular geographic region, with data collected within a particular time window, will be easy. This has significance for science, environmental monitoring, transportation management, public safety, disaster management, utilities operations, industrial controls, facilities management, and many other activities.

SensorML and sensor Web enablement activities are a major milestone in the advancement of sensor applications. Because OGC is the world's authoritative source for standards related to geo-processing interoperability, and because xOGC has strong international industry and government support in domains that depend on sensors, it's likely that SensorML will quickly become established in all areas where such a standard can be of use.

Editor's Note
OGC is an international industry consortium of more than 230 companies, government agencies, and universities participating in a consensus process to develop publicly available geo-processing specifications. Additional information can be found at www.opengis.org.