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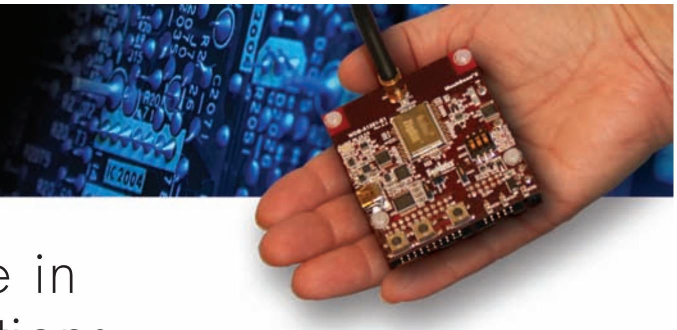

Smart Sensors and their use in Demand Response Applications

Sensors are ubiquitous in the utility industry; these are used to monitor various aspects of power generation, transmission, distribution and use such as voltage, current, real and reactive power, equipment faults, service interruptions, lighting strikes etc. Increasingly these sensors are becoming more sophisticated and can provide significant data in real time to improve the service of feeders and substations.

Now that utilities are migrating toward a "Smart Grid" architecture where automation is moving to and past the meter, advanced sensor and control technologies are emerging to enable advanced demand-side management (DSM) programs. Such programs provide improved management of the grid, enhanced efficiency for customers and better utilization of the transmission and distribution assets. What makes this possible is the development of the "Smart Sensor" and the networks that connect to the end user.

This technology brief covers the current state of smart sensors and how the technology is used to enhance energy utilization and demand-side management programs.

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Technology Overview

Definition of a "Smart Sensor"

Sensors respond to real-world stimulus such as heat, light, motion, etc., and generate analog or digital signal that measures the state of the stimulus. A sensor may need a power supply and a transducer to process and transmit the signal that can be read by a monitoring device or can be displayed on instrumentation. The signal may be converted to a digital format and analyzed and processed in application software, which may simultaneously receive and process signals from multiple sensors and generate control signals for actuators. Traditionally, the sensor, transducer, data processing and controls components were physically separate and connected with wires. However, recent advances in technology have allowed many of these components to be integrated on a single chip.

As illustrated in Figure 1, a smart sensor is a complete system-on-a-chip (SOC). In one package, the smart sensor samples the measured parameter, processes the data, and communicates with other processes on the network. Recent advances in semiconductor manufacturing techniques in miniaturization of hardware, increase in processing power on the chips as well as communication standards and networking have made it possible to build these 'smart' devices that can now be cost-effectively applied to a multitude of existing and new applications.

Prior to the 1990's, the calibration and accuracy of sensors were difficult due to drift in sensors. However, advances in analog and digital processing, software, and embedded systems have led to the integration of calibration algorithms into sensors and made them quite reliable. This feature has

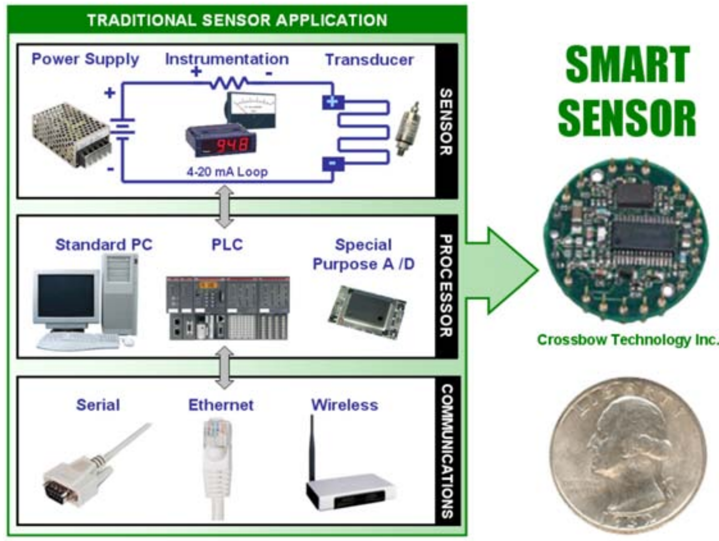


Figure 1. Composition of a Typical Compact Smart Sensor

enabled automatic self-calibration and self-correction, which minimizes errors related to thermal drift, calculation, and measurement. The overall accuracy of these advanced new sensors could be 1,000 times more repeatable than older technologies. The self-calibration features combined with networking and communications functions of smart sensor technologies also provide cost-effective means to verify and calibrate remotely.

A smart sensor has at least three and often four of the following attributes to varying degrees:

- Sensing elements with embedded logic to convert raw signals to readable engineering units and digital format.
- Data processing computational capacity and memory to program logical instructions to process the signal data and analyze it locally with varying degrees of complexity in instructions including input data from the central application processor or other sensors and actuators on the network.
- Communications and sensor networks to communicate the data to the central applications processor or other networked sensors and actuators in digital format.
- Actuators to control devices based on output signals from local processing of sensor data for distributed controls, or remote processing of combined data from other networked sensors or application processors for collaborative control.

Communications and Sensor Networks

The greatest enhancements to smart sensors have been in its ability to communicate with other sensors and actuators and share data on a local network as well as on a broader Internet network. The sharing of data in digital format and increased data processing capacity embedded within smart sensors have increasingly allowed data analysis and decision making to be distributed to the sensors.

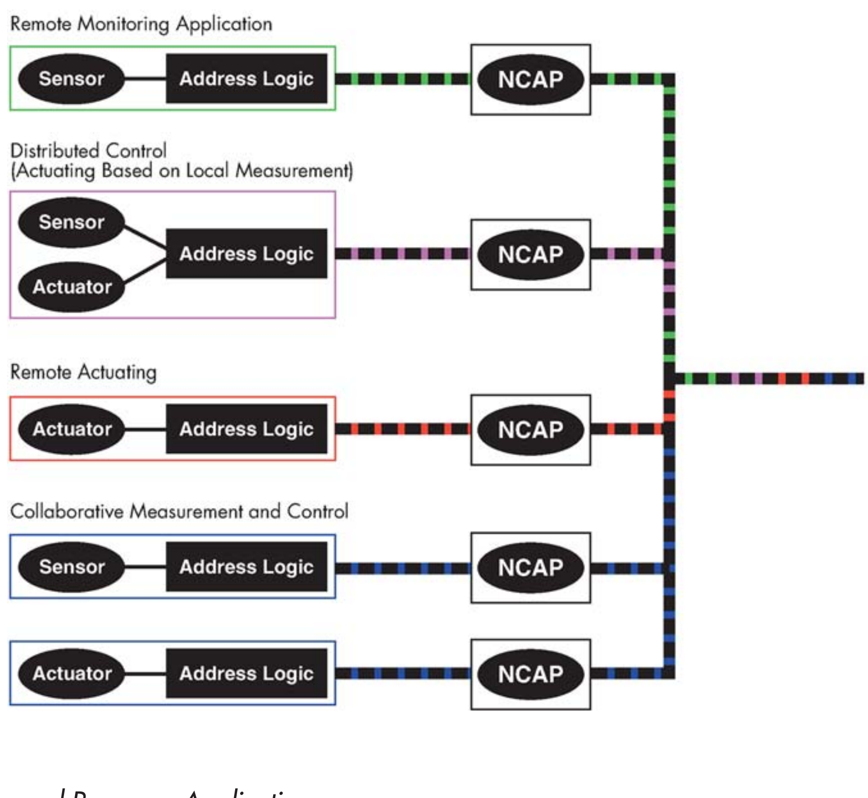
Therefore, the cost of distributed controls has declined rapidly. Additionally, the smart sensors can also communicate with network enabled application processors anywhere on the network. This has created an unprecedented ability for power utilities to send signals for control of power demand by equipment and appliances even if these devices are on the customer side of the power meter. However, this requires accepted communications protocols for sharing and transfer of data between different sensors, network enabled application processors and device actuators.

There are, however, several proprietary networks and field-bus implementations in the industry, and sensors and devices that can communicate on one network may not be able to communicate with devices on other networks. Interfacing the smart sensors to the different networks with different supporting protocols can be daunting. However, use of digital communications schemes can eliminate a large number of lengthy parallel analog wires to accommodate different networks and associated costs. The communication schemes need to keep the data set small so as not to clog the communication networks and yet create open protocols that generally require more overhead data to be transferred. The high cost of wiring the sensors in the field is also prompting the use of wireless sensor networks. Open protocols and communications standards are necessary for interoperability of devices from different manufacturers, to communicate effectively with each other, and uniformly interpret a set of common instructions. A schematic of a smart sensor and controls network is shown in Figure 2.

Demand Response Applications Using Sensor Networks

Smart sensors provide an unprecedented ability to interface with outside world signals over broader networks. Some sensors may be programmed with intelligence on board that can discern signals

Figure 2. Network Capable Application Processor (NCAP)



Traditional load shedding causes power outages or controlled rolling blackouts.

from trusted sources, verify its authenticity and initiate a set of actions. It is these advanced capabilities of smart sensors and communications networks that the utilities would like to leverage for controlling its power demand.

The electric utility industry manages ever-changing demand on its grid with power supply in real time by keeping a certain power generating capacity in spinning reserve and bringing other generating assets on and off line. When power demand exceeds supply, such as in extreme weather conditions when demand exceeds generation or distribution capacity, or in the event of a power loss from one of its generating assets, the utility has to shed demand to keep the grid from overloading. Traditional load shedding causes power outages or controlled rolling blackouts for its customers, which could have a devastating effect to customers' operations as well as the health of the economy. The utilities are obviously reluctant to resort to this option and are looking for innovative ways to manage its customers demand with minimal impact to customers' core business operations.

Requesting customers to temporarily curtail demand is one of the options utilities often use to stabilize the grid. The utilities have used public service announcements and other communications means in the past to inform consumers. But these require advanced notification and isn't always practical. It has also used direct communications with some large consumers about impending power curtailment; it even offers preferential rates if it could curtail power to the consumers at a short notice. However, the ability to communicate directly with energy management systems and other power using devices directly opens up a lot more opportunities than simply communicating of critical shortages and requesting power curtailment; it can help utilities better manage its demand and optimal utilization of is power generating and distribution assets.

Demand response is a term often used by utilities as a means to manage demand by communicating to consumers or directly to smart end-use devices on the consumer side of the meter. It is generally initiated by a power company or energy service provider that sends a signal to the customers' meters, energy management systems or directly to the 'demand response enabled' smart appliances (subject of a complementary technology brief), which can initiate a set of pre-programmed actions to curtail power demand selectively, often unobtrusively, with minimal impact to consumer operations. It provides an additional resource to the utilities to optimize use of its power generating and distribution assets. Since building of new generating assets that need to work only for few peak hours a year are very expensive, utilities find it economical to offer incentives to consumers to manage demand during such critical periods. This is a win-win scenario for utilities and consumers; the utilities avoid building expensive generating assets which reduces its cost of service to its consumers in general, and the participating consumers benefit from incentives that reduce its overall power costs.

Utilities are encouraging demand response by its consumers by several means, which generally fall in the following two broad categories: 1) increasing power tariffs during periods with high demand and low supply; and 2) providing incentives to consumers for each unit of avoided demand during such periods.

Power tariffs designs are aimed to reflect the real cost of generating and distributing power at any given time. Therefore, during peak hours when supply is constrained and expensive, the power rates should also be high. The pricing schemes that reflect the changing cost of power are often termed as

AMI/AMR is emerging as a key device that will monitor power use and provide a gateway to communicate with smart devices on the other side of the meter for demand response.

dynamic pricing or real time pricing (RTP). Time-of-use pricing that is now common in the industry is not truly a RTP, but it does reflect average costs during defined peak, part-peak and off-peak hours. The argument for RTP support is that it could truly reflect procurement price, and high prices during peak hours will encourage users to reduce demand during the expensive price periods. However, technology has not evolved to the point where RTP is yet practical in the industry. It requires smart power meters that can record and communicate power use profile for each hour of the day for the entire billing period. New power meters are emerging that would be able to provide such data and several utilities have embarked on Advanced Metering Infrastructure (AMI) initiatives that could provide such level of detailed data. In addition, the RTP signal should be communicated to the user who can take action to reduce demand, which is the primary reason for communicating the signal. Designing rate structure for RTP is challenging and still emerging.

Providing incentives for avoiding demand during peak hours is another approach to reward users to reduce demand. However, the measurement of the 'avoided demand' can be very challenging. Several utilities in California and members of PJM, a Regional Transmission Organization on the east coast have been experimenting with different RTP structures to manage their peak demands. Critical Peak Pricing (CPP) is one such rate schedule that is being tested in California since 2003. In one such rate schedule the utility declared an event a 'day ahead' and published a rate schedule its server as well as broadcasted the signal over the Internet to special Gateways installed on customer premises. Alternately, the client Energy Management and Control System (EMCS) frequently queried the event status from the server. Once the signal was confirmed by the EMCS, it could schedule a set of actions for the following day. In the 'day ahead' schedule, the customer had lead time of a day to take action. Later, a 'day of' version of the CPP was also tested in which the lead time was just four hours instead of a day. An average demand savings of 8% with maximum of 56% were reported in the California pilot automated demand response tests from 2003 to 2005 (LBNL, 2006).

AMI is emerging as a key technology platform that will not only monitor power use, but can also provide a gateway to communicate with smart devices on the other side of the meter for demand response. These can also assist in asset tracking, dynamic pricing, tamper notification, outage management, supply automation, load profiling and network diagnostics. A complete implementation could include power line communication to the electricity meter for usage data reading and setting dynamic prices, and low power wireless communication from the electricity meter to the major loads in a home/business (heating, ventilating and air conditioning equipment, appliances such as water heaters and refrigerators, etc.), other utility meters such as water and natural gas, as well as added features like prepayment.

However, even if the consumer is aware of the demand response event or real-time price, it is not realistic for them to always be available to manually decrease demand in a timely manner. This is why automation is needed to effectively and efficiently manage demand. Automation and smart sensor networks can be used to turn certain equipment off, limit other equipment to run at part load, turn off some lights or dim others by a certain amount, as well as adjust the Heating Ventilating and Air Conditioning (HVAC) temperature set point. A smart device or sensor can receive either a demand response event command or real-time price signal from a utility and initiate a set of processes that can temporarily reduce demand. Automated demand response programs are gaining popularity

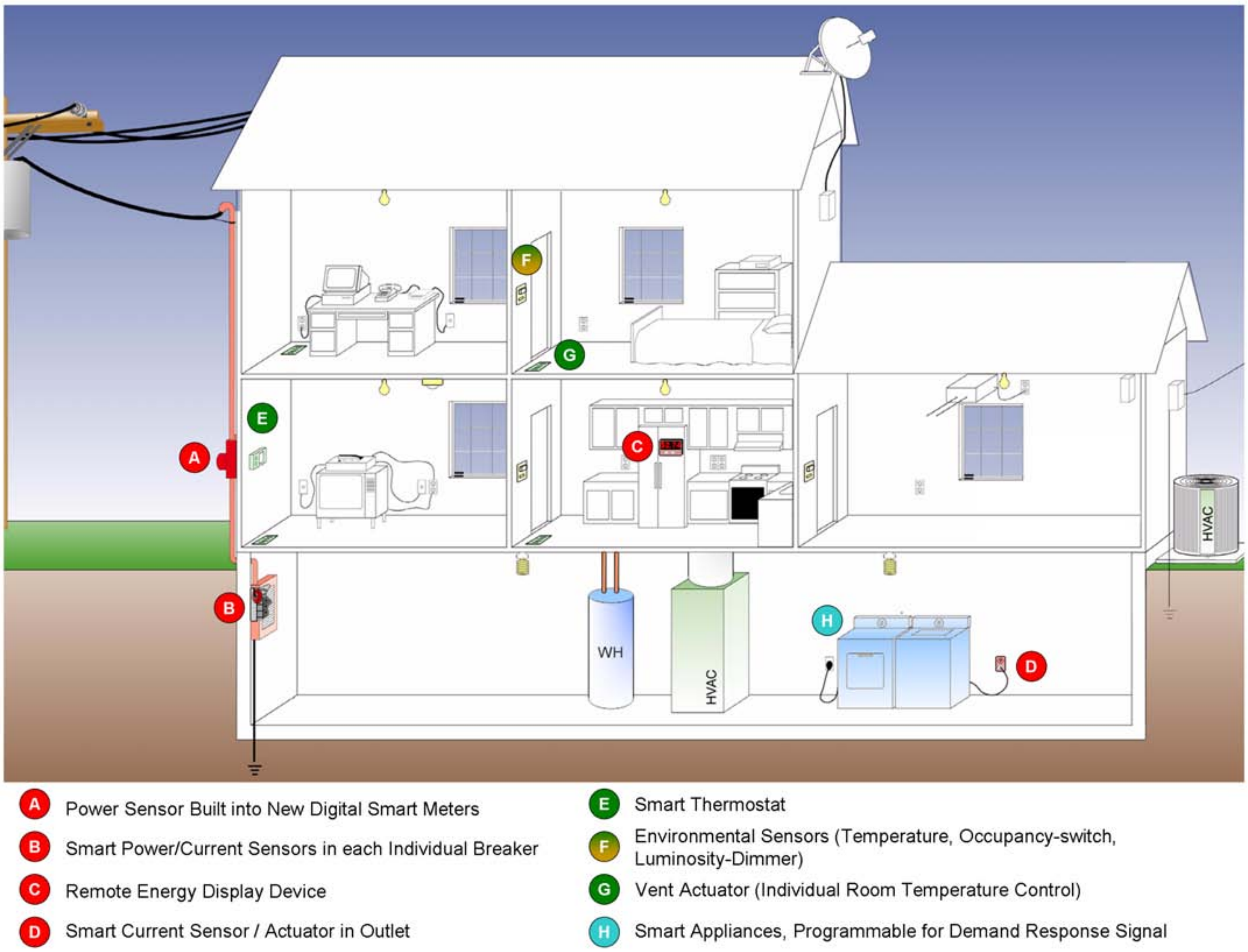


Figure 3. Potential Wireless Smart Sensor Devices for Residential Demand Response

because these can be applied ubiquitously without user intervention. Communications network and protocols for communicating utility signals to the meter and to smart sensors and control devices on the consumer side of the meter either directly or through the meter are emerging.

A schematic of a residential home along with potential end-use applications of smart sensors are illustrated in Figure 3. A demand response signal to a home can be delivered through an AMI using any of the communication technologies, though power line carrier technology is gaining some acceptance. The communication to equipment and devices within a home can be on its own network contained within a home that connects smart devices through remote appliance controllers, programmable communicating thermostats, and in-house displays along with other digital devices, from multiple computers and their peripheral devices to telephones, VCRs, televisions, video games, home security systems, fax machines and other digital devices.

Communication advances in EMCS systems allows sharing data in a digital format among different devices.

Though the concept is the same, demand response in the commercial facilities is done somewhat differently. Many commercial consumers have internal building automation, energy management and lighting control systems with varying degree of sophistication. Generally the indoor lighting control system is a stand-alone system that controls different lighting levels and scenes for different occasions or time of day but does not have the ability to shed loads selectively to demand response control signal. The building automation system (BAS) or energy management and control system (EMCS) typically controls the building heating, ventilation and air conditioning system, but may also control scheduling of some peripheral equipment such as exterior lighting, fountain pumps, etc. Some buildings also have independent fire alarm monitoring system and security and building access control systems. Generally, these systems are independent and rarely communicate and share information with each other. If these systems could communicate and share data among each other and different devices on the controls network, the opportunities for cost effective energy management could be enormous. For example, if a building access control system could communicate to the EMCS and share data on which areas are occupied in the building, the EMCS could only light and conditioned those areas. Some systems are emerging but use proprietary communication protocols, though there has been a movement in the industry to develop open source standard communications protocols.

In a simplest form of demand response in a commercial building, a signal may be sent to the BAS that can initiate a series of pre-programmed actions to curtail power demand by its equipment, lights, and HVAC systems. The signal could be communicated in many different ways; in automated demand response, however, the signal needs to be communicated ubiquitously. In one experiment, the Demand Response Research Center at LBNL worked with PG&E to create a gateway and a device that can receive an Internet-based demand response event message behind a company's firewall and initiate a dry contact, which can be monitored by the building automation system. Through use of Internet-based open standards, the demand response event message can be sent to the building automation or energy management systems without requiring additional hardware.

Since commercial consumers have large loads, a control signal to commercial equipment has a larger potential to reduce demand, which could be more cost effective than control of smaller residential equipment. However, when demand response is needed, the commercial consumers need the power supply for business operations and are less likely to curtail demand, unless it is made ubiquitous. On the other hand, when demand response is needed, many of the home consumers may be away at work, and could easily let its equipment be controlled, though each control signal to the smart equipment has potential to produce smaller demand savings. Therefore, though the potential of demand reductions from individual equipment from residential consumers may be small and its cost effectiveness lower, but the flexibility of load curtailment and size of the overall market may be quite large. With development of home area networks and reduced costs from open source standard devices, it may be possible to get larger and cost effective savings from a large number of connected equipment on a home network with a single demand response signal.

HVAC

HVAC is one of the largest power users in a home during utilities peak hours when demand response is desired. Utilities have been offering some form of air conditioning direct load control to its customers for several decades. In its simplest of forms, a utility installs a circuit breaker and a relay in the power feed to the air conditioning equipment. The relay can be cycled off and on remotely with radio signals. This only offers the opportunity to cycle the power off to the cooling equipment for a certain period, such as 30 to 45 minutes out of an hour. In return, utilities offer monthly incentives on its electric bills to its customers. The utilities create several groups or blocks of individual customers, and rotate the block periodically. Such schemes have certain limitations—it may turn off power to the equipment which is not in operation and does not provide expected demand reduction, and the utilities see an immediate recovery of power loads on its circuits as soon as the relays restore power to air conditioning equipment because of the pent up unmet demand during the period when air conditioning equipment was powered off. Some of the air conditioning equipment, especially the newer ones with on board electronic and digital controls, do not like the power off cycle. The utilities are exploring alternative methods for shedding air conditioning systems. A smart programmable communicating thermostat offers this opportunity.

The utilities have used a similar approach as above to curtail power demand from other large residential power loads such as water heaters, dishwashers, clothes dryers, pool pumps, etc. With home area networks, the demand response from these devices can be more intelligent. For example, a dish washer, clothes washer, or dryer may be started by the consumers, but it can let the network decide when the cheapest power is available for running it, which may be at a different time than when the appliances are loaded and turned on.

Smart sensors and controls will be effective and embraced more quickly by the consumers if it also provides some benefits to them rather than simply providing benefits to the power company in managing demand. The digitization of controls has the potential to provide immense opportunity to smartly control its equipment and appliances. For example, the programmable communicating thermostat can be programmed for different temperature settings for different times of the day and days of the week. It may be possible to control the equipment from a remote signal if the consumer can get access to its network remotely such as through the Internet or mobile network. If the equipment manufacturer is allowed access to its smart equipment, it can diagnose its health remotely and thus lower the cost of maintenance. Once a common open communications network is established for home area networks, the possibilities are endless. It will provide huge energy savings and environmental benefits to the society.

It is obvious that the security of the network will be paramount and it must authenticate the users with rigor to prevent unauthorized access to the network, and yet it has to be easy to use so the consumers are not discouraged by its complexity. There also needs to be uniform and open protocols for communications and data sharing.

Lighting

Lighting is another important load to control and a big opportunity for smart sensors. Occupancy sensors are one of the most cost effective solutions for improving energy utilization. In a demand response application, the smart sensor can be integrated into the dimmer or switch and be configured to decrease load when price or demand limits are exceeded or demand response signals are detected. Illumination sensors, integrated into smart dimming sensors, can be used to measure the amount of natural ambient light and adjusts the light levels to the minimum amount needed to maintain a programmed luminosity level. The demand response from the lighting loads is relatively small in residential customers; however, it has a greater potential in commercial facilities.

Demand response capabilities for lighting in commercial buildings are still evolving. Most of the lighting in existing commercial buildings uses on/off switch control, with lights often circuited in such a way that it is not practical to turn circuits on/off and achieve partial light levels in a working area; either all fixtures are on or off. Rewiring the circuits so as to allow lamps in individual fixtures to be split on two power circuits is expensive and often cost prohibitive. Therefore, it is harder to achieve demand response savings from interior lighting in many existing commercial facilities. However, newer facilities may have split circuits in lighting fixtures that may allow one of the circuits to be turned off in response to a demand response event signal and still have lower light levels in the area. It is, however, possible to use AC phase control for dimming on a complete lighting circuit. But, it may create power factor and harmonic imbalances and could lead to power quality problems, which has limited its use. Other solutions using power line communication such as X-10 have not picked up because of its lack of robustness and one-way communication protocol.

Digital Addressable Lamp Interface (DALI) communication protocol has evolved and is supported by many manufacturers. It has been adopted as a standard in Europe (IEC-929) and though many ballast manufacturers are supporting the concept, it has not been adopted as a standard in North America. The protocol provides two-way communications and can report operational parameters and lamp status information back to a controller. It allows individual ballast control through individual addressing as well as provides the ability to configure groups for common operations. However, the initial costs are high due to higher ballasts costs, controls configuration and commissioning. DALI could make lighting systems easier to respond to demand response signals.

A different kind of lighting demand response has been used in European countries to control streetlights in winter to manage its winter peak demand at night. The primary drivers for some of these lighting programs appear to be more than just demand response; it includes the ability to report the status of lamps and ballast faults to facilitate proper maintenance. Once the bi-directional communication was envisioned to query the light and fixture status, a lot more features could be included cost effectively such as measurement and reporting of power interruptions, control of the on/off timing of the lamps or a group of lamps, dimming of lamps based on local motion and photometric sensors, recording history of the on/off switching times including manual intervention, etc. Power line carrier, wireless cellular phone technology as well as separate communication wiring have been used for such applications. In one of the applications, a friendly user interface is also provided where a user can dial into a portal through his or her cell phone and request certain lights to be turned on prior to walking on the street. Significant energy savings, from 25 to 40% and even more, have been reported along with environmental benefits from reduced green house gases emissions and reduction in light pollution in the night sky.

Energy Feedback Display Devices (In-Home Displays)

Studies have shown that customer awareness can help reduce energy usage by as much as much as 15%. Consumers do not need to wait for the utilities to install a smart meter to be aware of their demand. Smart sensors can be networked with display devices, resulting in real-time feedback. The display devices could be stand alone such as a light that changes color to indicate a low or high price signal or a demand control event. Or the display could be on home television, or a computer screen or a dedicated system's screen. Sensor networks like ZigBee are designed to send text messages specifically to be displayed on an in-home display. Any means of communication of the price signal or demand response event to the consumer could voluntarily change the consumers' behavior and reduce demand.

A complementary technical brief on residential energy display devices (EPRI Report 1016972) was published by EPRI in June 2008.

Standards in Smart Sensor Design

IEEE 1451

Many different standards indirectly support smart sensor development; however, one set of standards that is specifically developed for interfacing smart transducers, i.e., sensors and actuators, is IEEE 1451. The work on this set of standards started in 1993 with the intent is to make it easier and cheaper 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. It addresses communications interface between main components of a smart sensor.

Figure 4 illustrates the structure of an IEEE 1451 standard device. The two main sections consist of the Network Capable Application Processor (NCAP) and the Transducer Interface Module (TIM). A TIM is a module that contains the interface, signal conditioning (e.g., analog-to-digital and/or digital-to-analog conversion) and in many cases, it also contains the transducer, i.e., a sensor or an actuator. A TIM can range in complexity from a single sensor or actuator to a module containing many transducers including both sensors and actuators. Included with the conditioning is a Transducer Electronic Data Sheet (TEDS) that contains information about a given transducer and its interface. It can also include manufacturer information such as identification, range, accuracy, and calibration data. The NCAP simply processes data for the application and provides a gateway function between the TIMs and the user network or host processor through various network communication functions so that it can communicate

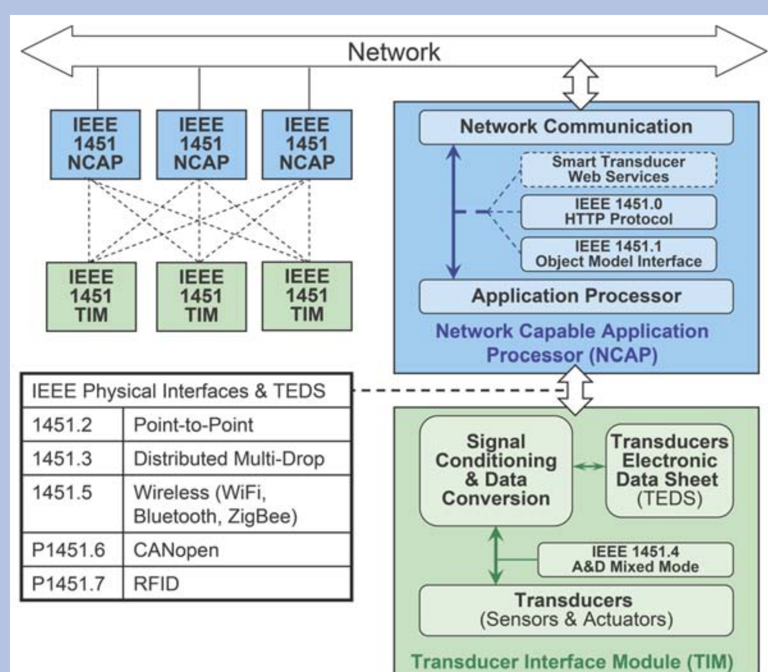


Figure 4: Illustration of IEEE 1451 Smart Transducer Interface Standard

with other TIMs, NCAPs or other processors on the network. Between the NCAP and TIM is a set of the standards that deals with the communications types between the two modules. The types of communications include point-to-point serial configurations, multi-drop wired array, wireless, CANopen, and RFID systems. The NCAP mediates between the TIM and a higher-level digital network. The NCAP may also provide local intelligence.

Overall, the IEEE 1451 standard provides the idea of plug and play and interoperability for smart sensor networks. The standard provides for TIMs that can be plugged into a system and be used without having to add special drivers, profiles or make any other changes to the system. This is referred to as plug and play operation. The primary features that enable plug and play operation are the TEDS and the basic command set. A TIM may be added to or removed from an active transducer interface media with no more than a momentary impact on the data being transferred over the bus; this feature is referred as hot swap.

IEEE 1451 set of standard consist of the following:

- IEEE 1451.0 – This portion of the standard defines the structure of the TEDS (Transducer Electronic Data Sheets) the interface between .1 and .X, message exchange protocols and the command set for the transducers.
- IEEE 1451.1 – Specifies collecting and distributing information over a conventional IP network.
- IEEE 1451.2 – Wired transducer interface –working on a revision, which will put IEEE 1451 on RS- 232, RS-485 and USB.
- IEEE 1451.3 - This is the information to make multi-drop IEEE 1451 sensors work within a network.
- IEEE 1451.4 – This portion of the standard specifies the requirements for TEDS (Transducer Electronic Data Sheets). This is software only.
- IEEE 1451.5 – This section of the standard specifies information that will enable 1451 compliant sensors and devices to communicate wirelessly, eliminating the monetary and time costs of installing cables to acquisition points. The IEEE is currently working on three different standards, 802.11, Bluetooth and Zigbee.
- IEEE 1451.6 – This is the information required for the CAN (consolidated auto network) bus.

Programmable Communicating Thermostat

Heating Ventilation and Air Conditioning (HVAC) loads are the largest sources of peak demand in the Residential and Commercial sectors. Smart sensors have greatly improved the efficiency and network connectivity of HVAC systems in both the residential and commercial sectors. Programmable Communicating Thermostats (PCT) is the quintessential example of a smart sensor. For buildings that do not have an energy management system, the PCT is the next most important smart sensor capable of receiving demand response event notifications or RTP directly. California Energy Commission's Public Interest Energy Research program recently published a reference design guide for programmable communicating thermostats to be compliant with CEC title 24-2008. EPRI's Tech Brief 1016253 Residential Programmable Communicating Thermostats details the differences between different technologies and their uses in demand response applications.

Figure 5. Programmable Communicating Thermostat (PCT) Deployed by Gulf Power, GoodCents(R) Select Program

Beyond the Meter Applications

Smart sensors used today in Commercial and residential buildings are much more then the simple sensors that were designed to only measure the state of a variable like temperature or current. The microprocessors within these smart devices can be programmed to perform some logical control task based on inputs from the sensing element and data from the network. For example, demand response applications are using the Smart Sensor to open and close high current carrying contacts that can interrupt power to loads like water heaters, HVAC compressor motors, pool pumps, lights and many others, as shown in Figure 6.

Smart sensor, like the one shown in the above figure, is equipped with a current transducer which could be used in the logic of the controller to not open the solid-state relay (SSR) if current is present or can switch on or off at zero cross. This type of control feature can prolong the life of the switch and load. The voltage transducer could be used for feedback to verify that the SSR actually opened and did so when expected. On the networking side, both the voltage and current transducers could be used to calculate real-time demand and share this information with an energy management system or an Energy Service Provider (ESP) that can use this data from the sensor to; calculate the estimated real-time load shed potential, execute demand limiting control algorithms, load profile trending and fault detection.

Enabling Demand Response Sensor Networks

As discussed earlier, one of the most important portion of the smart sensor network used by utilities for demand-side management programs today is the advanced meter (or AMI). AMI follows the same architecture of the smart sensor illustrated in Figure 6. The difference between an AMI and the above sensor architecture is that an AMI has two communication modules, also called Network Interface Cards (NIC). One communication card allows the utility to connect to a meter while the second allows the meter to connect to a local area network inside the building. The local area network inside a residential home is referred to as a Home Area Network (HAN), which is a communication infrastructure that enables the connectivity of multiple sensors in the home. The goal

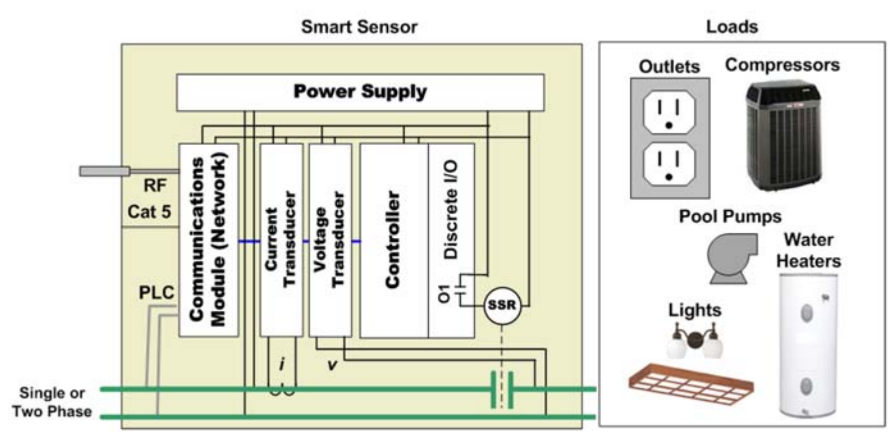


Figure 6. Example Smart Sensor Configuration Used in Residential Demand Response Applications

of most utilities is to offer programs to residential customers where the home owner's HAN could receive demand response commands, text messages or real-time pricing so that smart sensors could respond to these commands resulting in a change in demand.

Barriers

Currently, there is no standard communication protocol used in the commercial or residential sector. Compared to the residential sector, the commercial sector is much further along in that most of the protocols used in this sector use TCP/IP based protocols like BACnet, LonWorks, Modbus etc. Communication protocols in the residential sector currently consists of many different types of Wired, RF or PLC based protocols. Examples include, IEEE 802 Family of wired and wireless, ZigBee, Z-Wave, and HomePlug, X-10 (PLC) and INSTEON(PLC and RF). EPRI's Technical Update 1016113 (Automation & Control Protocols in Residential & Commercial Buildings) provides details of protocols in both residential and commercial sectors.

All protocols have their advantages and disadvantages when compared to one another for use in Demand Response applications, however the current trend is moving in the direction of RF and Power Line Carrier, with the major players being ZigBee and HomePlug. The majority (70-percent) of HAN sensors in use today comply with INSTEON, X-10 or Z-Wave standards. The challenge to utilities and energy service providers is to identify or develop methods to communicate with HAN sensors to help customers automate demand-side management and energy utilization programs.

Current Efforts

In January 2008, ZigBee Alliance completed the development of a public application profile called the Smart Energy Profile (or SEP 1.0). The ZigBee Smart Energy Profile is an application, developed to support AMI, demand response, load control, pricing and customer messaging. SEP 1.0 is designed to provide control for devices such as in-home displays, programmable communicating thermostats, water heaters, lighting, smart appliances, and plug-in electric vehicles, in addition to interface with energy management systems and access to energy service providers. SEP 1.0 has set a benchmark for demand-side management control applications.

Another standard that is actively used is HomePlug, a PLC standard consisting of over 20M compliant devices in six countries. Currently, the ZigBee Alliance, HomePlug and utilities are all working together to develop an expanded smart energy profile application that will run on HomePlug certified components. The result of this effort would be a single application to interface both ZigBee SEP and HomePlug SEP sensors, called SEP 2.0. With one application defined for both protocols, the number of object models at the AMI head-end would be greatly reduced.

Even though some utilities are working together to manage different HAN protocols and ZigBee-HomePlug applications, they are interested in a single object model that could be used with demand-side management programs in any HAN. Since there are so many different protocols and devices already in the marketplace, researchers are looking into ways to communicate with all sensors protocols. One way to enable interoperability among different protocols is at the application level using common objects models. EPRI's AMI/HAN group has taken steps to bring together various electric utility stakeholders to help make the integration and control of smart grid technologies transparent to the back-end applications. The objective of this group is to provide a public arena where utilities, manufacturers, standards organizations and researchers can discuss current efforts, success stories, solutions and research gaps as they relate to AMI/HAN integration.

There are more than 3,000 global sensor and automation equipment manufacturers with a market of $50 billon a year. Many are exploring and creating products for all or parts of smart sensors, actuators and networks. In addition to the traditional manufacturers, the prominent role of networking, communications and applications software as well as system-on-chip silicon technologies, new and established manufacturers with expertise in these areas are entering the market.

Conclusions and Research Opportunities

The implementation of the smart grid to and past the meter has uncovered a wide range of system integration challenges, like compatibility, interoperability and security, to name a few. Utilities, energy service providers, manufacturers, standards organizations are coming together to address each challenge. In fact, most are enthused to address these challenges as is reflected in the development of SEP 2.0 user application and the overwhelming support shown through the large number of participants in EPRI's AMI/HAN Group. In August 2008, the OpenHAN Task Force released the "UtilityAMI 2008 Home Area Network System Requirements Specifications," (UtilityAMI 2008 HAN SRS) which provides basic security requirements for the AMI/HAN. Another group focused on security is the UCAIug AMI-SEC Task Force, which is a collaborative effort with the goal of delivering specifications that could be used by utilities to procure and test security functions related to home area networks.

EPRI has also initiated projects under its IntelliGrid program that aims to support development of open source standard protocols for gateways that will make integration of demand response, building automation, energy management systems, and home area networks cost effective.

A major area that needs to be addressed is the use of smart sensors in end-use equipment, like HVAC, hot water heaters, refrigerators, washers/dryers, lighting, and other like equipment that could participate in demand response applications. Steps are being taken to make the HAN protocol irrelevant to upper level applications; however this approach doesn't help equipment manufactures who want to build and sell equipment compatible with demand response programs throughout the U.S. Equipment manufacturers are looking for a single HAN protocol for use in all U.S. and preferably worldwide utilities so that smart sensor technology can be manufactured into their equipment, sold throughout the U.S. and the world and easily integrated into AMI/HAN programs. The term used for off-the-shelf equipment compatible with demand response programs is "DR-Ready." Research efforts should be applied to enabling DR-Ready end-use equipment. It is to be noted that a complementary technology brief on IP-Addressable Appliances (EPRI 1016080) is being concurrently released.

Current efforts seem to be focused on network connectivity and basic utility requirements for demand response and customer feedback applications. The full use of smart sensor technologies should be investigated and demonstrated in conjunction with demand response applications. Smart sensors are cross-cutting technologies that enable not only demand response, but many other energy management applications. In fact, sensors and controls play an essential role in meeting DOE's 2025 goal of 70-percent energy reduction to achieve "net zero" energy use in new residential and commercial buildings. Use of smart sensors and controls in net zero buildings should be investigated to assure that the direction now taken by utilities in AMI/HAN configurations will support the ideal configuration and use of smart sensors in net zero net energy buildings.

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Principal Authors:

Chuck Thomas, Senior Electrical Engineer, EPRI
Mukesh Khattar, Energy Efficiency Consultant
Thomas Cooke, Technologist, EPRI

Technical Reviewers and Contributors:

Ammi Amarnath, EPRI

Graphics and Layout:

Nanette Jones, EPRI

For further information, please contact:

Ammi Amarnath, Technical Lead, Energy Efficiency
email: aamarnath@epri.com
phone: 650.855.1007

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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