SMART GRID TECHNOLOGIES AND APPLICATIONS FOR THE INDUSTRIAL SECTOR

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Abstract

Smart grids have become a topic of intensive research, development, and deployment across the world over the last few years. The engagement of consumer sectors—residential, commercial, and industrial—is widely acknowledged as a key requirement for the projected benefits of smart grids to be realized. Although the industrial sector has traditionally been involved in managing power use with what today would be considered smart grid technologies, these past applications have been one-of-a-kind, requiring substantial customization. This paper provides an overview of smart grids and of electricity use in the industrial sector. Several smart grid technologies are discussed, with particular focus on the promising topic of automated demand response. Four case studies from aluminum processing, cement manufacturing, food processing, and industrial cooling plants are reviewed. Future directions in the development of interoperable standards, advances in automated demand response, and more dynamic markets are discussed.

Keywords

Smart grids, electricity consumption, demand response, power systems, energy efficiency, Smart Grid Interoperability Panel, electricity markets, ancillary services, OpenADR

Introduction

The term "smart grid" refers to a reworking of electricity infrastructures—encompassing technology, policy, and business models—that is under way globally. Substantial amounts of government investment in several countries and regions have been devoted to smart grid research, development, and deployment.

Smart grids are being pursued in order to address several challenges associated with today's power and energy systems, notably the following:

- *Greenhouse gas emissions and climate change.* Fossil-fuel power stations are responsible for about 30% of all anthropogenic carbon dioxide emissions and about 20% of all greenhouse gas emissions; in both factors power generation is the single largest source (IPCC, 2007). With smart grids, substantially higher penetration of renewable, non-fossil-fuel generation sources is anticipated.
- *Economics.* Utilities and service providers today are sometimes forced to pay high prices for electricity that is imported from grid-connected neighbors at times of shortage or transmission congestion. A recent if extreme example is Texas, where day-ahead wholesale prices had an order-of-magnitude variation in August 2011 (approximately \$60/MWh to \$600/MWh). Smart grids promise an ability to reduce demand in such instances, with financial savings for utilities and ultimately consumers.

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- *Reliability.* Especially in developed economies, transmission infrastructure is aging and new infrastructure investment is lagging the increase in consumption and the addition of new generation. As a consequence, grid reliability is worsening. For example, in the U.S. the number of outages that affected more than 500,000 customers more than doubled in 2005 – 2009 compared to the previous five years (Amin, 2011). Smart grids will bring sophisticated measurement, monitoring, and control to grid operations, improving reliability.
- *Energy security.* The electrification of road transportation (through electric and plug-in hybrid vehicles) is seen as a strategy to reduce imports of foreign oil. The additional load on the grid required, as well as the high charge rates of vehicles as individual loads create additional challenges for today's power systems.

Smart grid investments and developments are covering the entire electricity value chain: generation, transmission, distribution, markets, and, increasingly, consumers. The role of the end-use customer is in particular focus, primarily because the increasing penetration of wind and solar power is necessitating a more active role for energy management in homes, buildings and industries. The intermittency and unpredictability of renewable generation sources is in sharp contrast to traditional power generation. With power coming entirely or almost entirely from the latter assets, system operators have been able to keep the grid balanced by adjusting generation in real-time in response to demand variation. With unpredictability now extending to generation, "demand management" is essential.

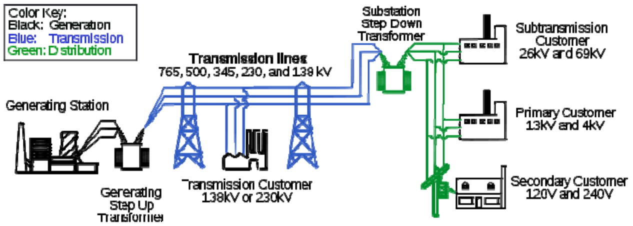

Figure 1. A simple diagram of electricity grids in North America (FERC, 2004)

The customer "domain" of smart grids is not undifferentiated (see Figure 1). Three categories are commonly recognized: residential, commercial (i.e., buildings and multi-building facilities), and industrial. Subdivisions exist within each of these and commercial and industrial facilities are often categorized together as "C&I." Public attention on smart grids has been directed mostly to the residential sector (e.g., smart meters) but C&I has a much larger consumption footprint and in some respects is well advanced in the implementation of smart grid technologies (in many cases these implementations preceded the popularization of the "smart grid" label). Even in C&I sectors, however, implementations have been piecemeal, limited in scope, and often one-of-a-kind.

As suggested above, the smart grid field is diverse and extensive. We limit our attention here to the industrial consumer sector. In the following section, we give an overview of electricity use in industry, including industry-specific considerations regarding electrical power use and the role of electricity markets as relevant to industry. We then describe several smart grid "technologies," discussing their relevance to manufacturing facilities. We highlight the topic of automated demand response, with particular attention to the standardization of communications that is in the process of broadening the scope of the technology. Four case studies are also presented, from different industry sectors. Before concluding we outline some future directions for smart grid developments as relevant for industry.

Electrical power and the industrial sector: An overview

Industrial Electricity Consumption

Industry plants consumer less electricity in the U.S. than commercial facilities or homes, but the total is still substantial. In the U.S., total consumption in 2006 was almost one trillion kilowatt hours (EIA, 2009). Consumption varies widely depending on the type of facility. Table 1 shows the aggregate consumption in the U.S. categorized by type of industry. Chemical plants are the largest consumers with over 200 billion kWh followed by metals. On a per-plant basis, processes/equipment such as machine drives, electrochemical process, and electrical heating are especially electricity-intensive. From a 1999 study, the average power consumption for a single recent-vintage U.S. secondary steel mill was over 250 million kWh (Worrell, Martin, Price, 1999). The approximately 150 refineries in the U.S. consume an average of 323 million kWh annually apiece.

Several distinguishing aspects of industrial electricity consumption are noteworthy:

- As already noted, industrial plants are high consumers. Peak loads of 100s of MWs and annual consumptions of 100s of millions of kWh are not uncommon.
- As a consequence, industrial plants often connect to the grid at high voltage levels—including directly to transmission lines.
- Large manufacturing facilities can have substantial on-site generation. Nationwide industrial generation is almost 150 B kWh, about 15% of net industrial electricity demand. Not all of the generated power is used on-premises; almost 20 B kWh are sold or transferred offsite (EIA. 2009).

Table 1. Electricity consumption by industry (EIA, 2009)

Industry sector	Total electricity used (10^6 kWh)
Chemicals	207,107
Primary Metals	139,985
Paper	122,168
Food	78,003
Petroleum and Coal Products	60,149
Transportation Equipment	57,704
Plastics and Rubber Products	53,423
Nonmetallic Mineral Products	44,783
Fabricated Metal Products	42,238
Machinery	32,733
Wood Products	28,911
Computer and Electronic Products	27,542
Textile Mills	19,753
Beverage and Tobacco Products	17,562
Printing and Related Support	13,089
Electrical Equip., Appliances, and Components	12,870

A basic distinction among industrial loads is that between "production" and "support services." The former include furnaces, motors, pumps, etc. that are part of the industrial process itself; the facility's production would cease without power to these loads. In addition, industrial sites have lighting; heating, ventilation, and air conditioning (HVAC); office equipment; and other loads that are required for site personnel. Support loads can usually be used more flexibly than production loads. The former constitute a smaller proportion of overall consumption than in commercial facilities, where the production-versus-support distinction is also important. For example, for chemicals and primary metals, about 12% and 8% of total electricity is consumed for nonprocess purposes respectively (EIA, 2009).

Needs and Requirements

In part because of the intensity of consumption, industrial consumers have several distinctive needs and requirements for managing their electricity. These desiderata tend to be application-specific; controlling power consumption requires deep domain knowledge about processes involved. We note a few requirements here.

- Some manufacturing processes have critical temporal dependencies; processes and equipment must be scheduled with knowledge about their interdependencies as well as their roles in the overall production. Plant performance as well as safety are at issue.
- All electricity consumers have concerns about the protection of their usage data—for example, access to data from a home can readily be used to determine if the home is currently occupied or not. But for many industrial users, access to load profiles—even the "shapes" of loads—can indicate which equipment is being used at what times, information that is often highly confidential and competition-sensitive.
- Industrial electrical equipment can require high timing precision. In residential and commercial facilities, "near real-time" data—at resolutions of a few seconds or so—is usually sufficient; in many industrial sites, millisecond-scale monitoring and control can be required. Special meters are installed in industrial facilities for this purpose.

Electricity Markets

Market products and rate structures for electricity are a complex and evolving aspect of smart grids. There is considerable regional variation in market mechanisms and in the extent to which different end users can participate in markets. Generally, larger consumers such as large commercial and industrial sites have more options today, and with the growth of aggregation services and broader interests in incentivizing consumers to conserve or otherwise manage their consumption we expect to see electricity markets affecting consumers much more extensively.

Whereas virtually all U.S. residential customers today pay a flat rate for their power— about 11.5 c/kWh, on average across the U.S.—many commercial and industrial users have rates that are nonuniform in one or more respects. Retail pricing programs include the following:

- Time of use (ToU) rates. The per-kWh charge varies depending on the time of day—for example a two-tier ToU rate would have a lower charge for off-peak use and a higher charge for peak use. The times and charges are fixed ahead of time for an extended future duration (often indefinite).
- Critical peak pricing (CPP). A utility can implement a significantly higher rate for a few critical periods in summer. A CPP period would be announced ahead of time, and customers on the CPP rate could reduce their bill by shifting or reducing their loads during these times. In return, demand charges when CPP periods are not in effect are reduced.
- Real-time pricing (RTP). These are similar to ToU rates with the important differences that the price may change several times during a day (e.g., hourly) and the pricing schedule would change daily—the schedule could be announced each day and effective for the following day.

One difference to note is between deregulated and regulated electricity markets. In deregulated competitive retail markets, customers can purchase their power from an energy supplier by entering into special contracts and they may participate in negotiating their rate. In regulated markets, customers sign onto one of the tariffs that are offered by a utility.

In aggregate in the U.S., many industrial facilities already participate in some kind of dynamic pricing programs and can be involved in negotiations with utilities about their rates and consumption. As a result, industrial customers pay about 40% less than residential and commercial customers for their electricity use, on a per-kilwatt-hour basis—although these latter sectors are responsible for 80% of all electricity purchases (Galvin, Yeager, Stuller, 2009).

Large consumers, such as many industrial facilities, can also participate in wholesale electricity markets. An area of particular interest is ancillary services—services required for enabling the transmission of electric power from sellers to buyers while ensuring grid reliability. See (NYISO, 2011) for an overview of one ISO's ancillary services offerings. Table 2 shows the typical products and requirements of ancillary services markets. Loads can participate in spinning reserves, non-spinning reserves and regulation products. Most ancillary services markets have a single regulation product that is symmetrical and covers both regulation up and regulation down services. These products have to start moving within the first minute and follow a ramp rate that is pre-specified. The duration is usually between 15 and 60 minutes. Telemetry equipment at the facility, which records and communicates electricity data every two to six seconds, is required. For operating reserves, the resource has to ramp up in less than 10 minutes for a duration of 30 minutes. The electricity data is captured every 4 seconds but communicated back to the independent system operator (ISO) every minute.

Table 2. Ancillary Services Products and Requirements

Ancillary Services Products	Response Time	Duration	Tele-metry
Regulation Up	Start <1 min Reach limit <10 min	15 - 60 min.	4 sec.
Regulation Down	Start <1 min Reach limit <10 min	15 - 60 min.	4 sec.
Non-Spinning Reserves	< 10 min.	30 min.	4 sec.; every minute
Spinning Reserves	Instant Start Full output <10 min.	30 min.	4 sec.; every minute

Smart Grid Technologies

Industry is a heavy user of electricity in aggregate and many individual plants represent large loads. It may seem paradoxical, then, that the industrial community is not as engaged with smart grid developments as commercial and residential consumers. In fact, many industrial facilities that are large power consumers adopted what today we would call smart-grid technologies many years, even decades ago—since well before the popularization of the term. We note some examples later.

However, these smart-grid-like applications have not been easily replicable. They have typically been done on a one-of-a-kind basis, with customized solutions and little learning from prior efforts. Many ISOs and utilities have crafted their own programs for industry users. The investment required for developing and deploying many existing energy management applications has been bearable for facilities with large loads—the benefits have outweighed the costs—but not for the vast majority of plants. Thus opportunities for economic benefit across the full range of industrial end users and utilities, and for realizing national and societal benefits such as improved grid reliability and greater penetration of electricity from renewable generation sources, have not been realized.

With recent developments, the barrier to entry for smart grid applications is being dramatically lowered. These applications can take a variety of forms; many facilities can take advantage of multiple ones. We briefly describe several salient approaches in this section. The technology we highlight in this paper is automated demand response, discussed more extensively in the following section—automated demand response can in fact encompass many, even all, of the technologies discussed below.

Energy efficiency

Improving efficiency is the "low-hanging fruit" for energy management and has been widely practiced wherever energy costs are significant. Technical advances today facilitate sophisticated energy conservation actions. These advances include low-cost wireless sensors, interconnected control networks, and asset management software. Today's automation systems provide fully integrated "dashboards" that can give managers of smaller facilities their first meaningful access to real-time data on facility operations, previously limited to large energy-intensive and/or high risk manufacturing processes. Efficiency actions can now be undertaken at times of grid stress; teal-time data and granularity of controls provide facility staff with the right tools to respond to stress signals from the electricity grid.

Direct load control

When a utility or a curtailment service provider (CSP) sends control signals to a device at a facility, it directly controls the loads. In its crudest form, a utility installs a switch to control the loads and communicates with the switch without engaging the asset or facility owner. In some cases, the controlling entity can also send control signals to the automation system that can effect the control action.

Direct load control is common in the residential sector in the U.S. Many utilities offer incentives to homeowners in order to install remote control switching systems for central air conditioning units and thereby limit use of air conditioning during peak demand times in summer. Other residential loads can also be directly controlled in similar ways, such as electric hot water heaters.

However, direct load control is rarely useful in industry, especially for production loads. Load adjustment requires deep knowledge of the characteristics of the load and the role the load plays in the production process. Safety considerations also often arise. The industrial load control applications that have been implemented are exceptions that prove the rule; they have been carefully tailored to insure that the operation of the plant is not compromised.

Storage

Electricity supply can be variable in many respects, including availability, price, and quality. In such cases storage can permit the partial decoupling of the purchase or use of electricity with facility operation. What is stored can vary as well.

"Electrical" storage is usually effected with batteries. Electricity can be stored when available inexpensively and used to run loads at a later time. Batteries are being used for utility-scale storage today. With the imminent availability at scale of electric and plug-in hybrid vehicles, there is also considerable interest in using the batteries of these vehicles to service loads in homes and buildings.

Often we use electricity for heating and cooling. "Thermal" storage refers to using electricity for such thermal effects in advance of when the heating or cooling capacity is needed. Building pre-cooling is widely practiced in commercial buildings today, for example. As another example, also principally in the commercial buildings space, rooftop refrigeration units are being used to make ice overnight, with the ice used to provide cooling for the building instead of running an HVAC compressor and condenser.

Finally, with "inventory" storage, intermediate products of a production process can be made in excess of immediate demand. Additional physical storage is required in this case. Inventory storage is especially relevant for industrial facilities.

Distributed generation and cogeneration

Many industrial plants generate some part of their power requirements and often export power too. Traditionally, onsite generation resources have been set up to take advantage of material and energy synergies with the production process. Plants like paper mills produce combustible waste that can be burned and used to drive turbines. Power generation boilers themselves produce heat and steam that can be used in some industrial processes.

Whereas traditional cogeneration has relied on biomass and fossil fuels, today the interest is in distributed generation with renewables (wind and solar). Here too, commercial buildings have been the early adopters. The economics of these installations are not favorable just on the basis of the nominal value of the power that is generated, but incentives are available in many countries—both to offset installation costs and, through feed-in tariffs, to provide guaranteed and attractive purchase terms for supplying renewable power to the grid. Such incentives are available for industrial facilities as well, but rarely availed of today.

In all these cases, the grid connection is important and automation and control are needed. Facility operators need to know costs of utility and site-generated power—both can be variable—over a planning horizon and they need to be able to schedule and control the production process and the onsite generation facility accordingly.

Microgrids

Facilities that have multiple types of loads, onsite generation and storage, and the ability to function off the grid, in whole or in part, are candidates for microgrids, another smart grid technology generating considerable interest today. A microgrid is an electrical distribution network with similar monitoring, control, and optimization as may be found in utility substations. In some respects microgrids may be more complex—they may include direct current (DC) elements and inverters for conversion. DC-inclusive microgids facilitate integration of renewable sources (e.g., solar cells produce DC outputs) and electronic equipment requires DC voltages to operate. Significant conversion inefficiencies have to be dealt with today that could potentially be obviated.

Microgrids are of particular interest where grid supply may be unreliable. In this case the "islanding" capability of a microgrid comes into play. Appropriate load curtailment can be done, storage and generation resources managed, and, in the circumstances, an optimized level of operation maintained.

Automated Demand Response

Through the operational "life" of a facility, its operators engage in demand-side activities such as maximizing production and minimizing energy use (energy efficiency); reducing energy consumption daily during high price periods (daily peak load management); and actively participating in electricity grid transactions with various timescales of response. Of these demand-side activities, those that are directly coordinated with supply considerations and ISO/utility communications (related to the availability, price, and quality of grid power), are referred to as "demand response."

When a facility receives information from the electricity grid, it can respond in one of three ways: manually, semi-automated, or fully automated. Manual response involves at least one person orchestrating changes in energy assets in the facility; the human-in-the-loop element prevents customers from delivering repeatable, persistent and fast response and limits their participation in all markets because of the latency. Semi-automated response is pre-programmed in the automation system but still requires a human to trigger the identified actions. Thus, the reliability of the response depends on the availability of the trigger. When facilities are fully automated, automation systems receive communication signals from the grid and trigger pre-programmed or dynamically developed sequences of operations. Fully automated demand response is both fast and reliable, provided that the automation logic is correctly defined.

Figure 2 illustrates a portfolio of demand-side actions that industrial facilities can undertake relative to their electricity use. For demand response events, the notification time, duration, frequency and quantity of electricity impact the operations of the systems and types of control strategies that may be implemented and require greater granularity of controls. An example is the use of electrical load reductions using variable frequency drives rather than on/off control. Faster response requires faster, more sophisticated telemetry equipment to capture and communicate demand data. As the facility starts engaging in faster demand response activities, which are driven by the necessity of using loads to balance the electricity grid in real-time, automation becomes essential.

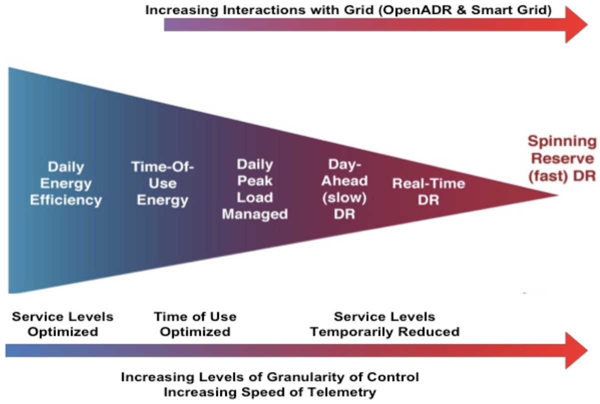

Figure 2. Demand-side-management activities, from energy efficiency to fast DR

Automation also enables the substantial broadening of the scope of what demand-side activities can be subsumed under demand response, and the facility size for which demand response is a feasible technology.

Approaches for Automated Demand Response

The automation of demand response can be accomplished in several architectural ways. A key point of differentiation is where the demand response logic resides. Three scenarios are shown in Figure 3. In large-scale customer facilities, energy management and control systems (EMCSs) are typically available and can host the logic. This is the most common approach for automated demand response today. In some cases loads and local energy resources (LER) can directly implement the logic rules. Finally, for small facilities the demand response (DR) logic can be resident within the utility or in a third-party service provider; in this case automated demand response is effectively being used for direct load control (DLC) commands.

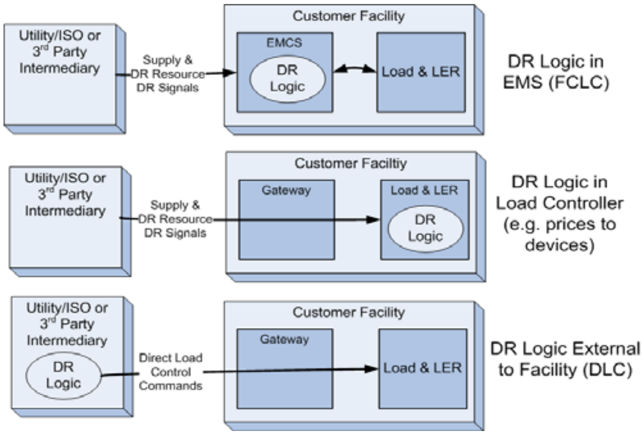

Figure 3. Three scenarios for automated demand response. (Figure courtesy of E. Koch, Honeywell Akuacom)

OpenADR

Regardless of how the facility responds, a low-cost and secure communication infrastructure is needed to support the receipt of signals from an ISO or utility and to respond to these various signals using the controls infrastructure in the facility. Although market designs and mechanisms may change and develop over time, the use of standard information exchange models can diminish the likelihood of stranded demand-side assets. The demand-side automation systems may also evolve; standardization facilitates the continued support of data exchange models to ensure market participation. See Figure 4 for the communications involved in typical current automated demand response implementations.

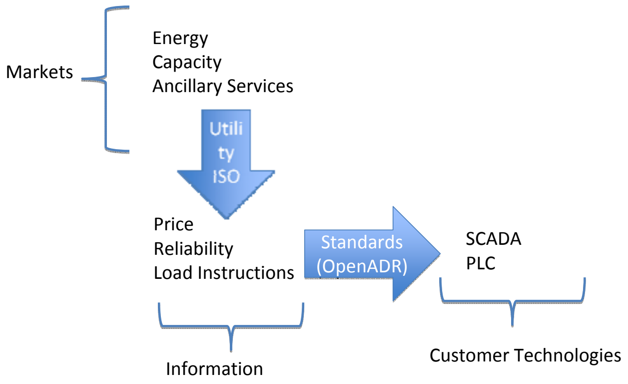

Figure 4. Automated demand response communications

Open Automated Demand Response (OpenADR) is an information exchange model developed to communicate price and reliability information to large commercial and industrial facilities. It was developed for retail price and reliability programs and has been tested for ancillary services markets. The adoption of this standard links markets with facilities. However, it is extensible and loosely tied to markets and loads so changes in markets or demand side technologies do not affect the communication infrastructure investments. Figure 5 shows the OpenADR architecture. This is a client-server infrastructure where a utility or an ISO publishes prices, reliability information, or load instructions over the Internet. Sites equipped with OpenADR clients poll the server periodically to access these signals. The automation systems in the facility take the information and convert it to a set of pre-programmed response sequences. With smaller facilities and facilities with proprietary communication and control networks, aggregators can represent consolidated loads to the utility or ISO and convey OpenADR signals to the aggregators' customers.

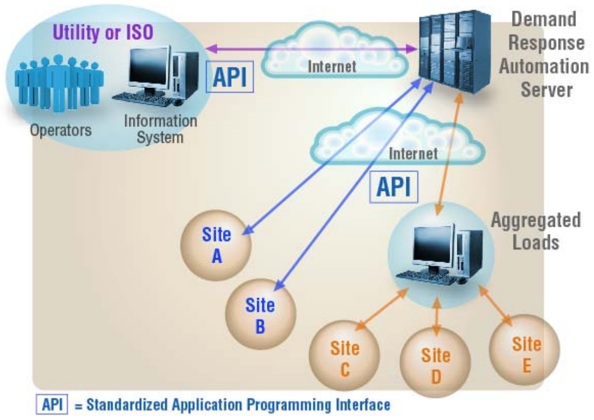

Figure 5. Open AutoDR architecture

OpenADR standardization is now proceeding under the aegis of the Smart Grid Interoperability Panel (SGIP; see later). An application layer standard, OpenADR 2.0, is being developed in partnership with the Organization for Advancement of Structured Information Standards (OASIS) and with industry support. By the end of March 2012, the first OpenADR 2.0 compliant products are expected to be certified by the industry-led OpenADR Alliance and selected testing and certification labs.

Case Studies

We present four industrial case studies in this section: Alcoa, which has been participating in ancillary services markets for about two years, delivering 70 MW of regulation services to Midwest ISO; Amy's Kitchen, a food processing facility participating in Pacific Gas and Electric Company's (PG&E) Auto-DR program since 2008; and two examples from New York State, including a cement manufacturing facility.

Alcoa

Alcoa is a major consumer and supplier of electricity in the US with over 3 GW of demand and 1.4 GW of supply. Alcoa's Warrick, Indiana plant participates in the Midwest ISO (MISO) wholesale market by providing regulation as an ancillary service through control of smelter loads (Todd et al., 2009). Alcoa is reimbursed for load modulation as if the energy was generated. In order to participate in the ancillary services market, Alcoa created Alcoa Power Generating Inc. (APGI), a subsidiary that operates as a load serving entity to supply the smelter loads from the Warrick facility to MISO. Up to 70 MWs of regulation services have been provided (Todd, 2010).

Figure 6 shows an architecture diagram for Alcoa's participation in the regulation products. Regulation is a symmetrical product in the MISO ancillary services market, meaning that a generator commits to a regulation target and has to deliver this target above or below their operations at the time it receives a set-point instruction (load instruction) from MISO. In order to achieve this, the Warrick facility installed an energy management system (EMS), smelter potline load control system (LCPD), and metering and monitoring systems. MISO sends set-point instructions to the facility using three redundant communication channels that use the Inter-Control Center Communications Protocol (ICCP). These MW set-point instructions are received by the EMS, converted to a potline sequence of operations that will yield the targeted set-point instruction, and sent to the LCPD, which executes the developed sequences. Typical DR strategies are cycling the aluminum smelting potline and controlling the voltage to the potlines. Loads are monitored by telemetry equipment, which records loads every 2 seconds. Telemetry data is then sent back to the MISO so as to enable visibility of the load response.

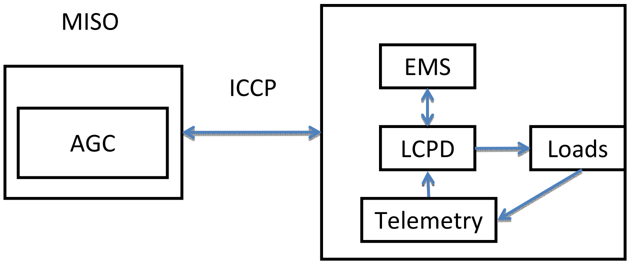

Figure 6. Information and control architecture for Alcoa case study (AGC: automatic gain control)..

The cost of the system including the new software and hardware for communication and controls systems and upgrades was close to $700,000, which was paid back in 4 months[1] with revenues from DR participation. With the capabilities developed with this system and favorable market rules, the facility can participate in multiple markets and gain revenues from each of these markets.

Amy's Kitchen

Amy's Kitchen in Santa Rosa, California has a processing plant that takes raw food and produces packaged vegetarian meals. The facility includes several large cool rooms, freezers, blast freezers and a spiral freezer. In addition to these production loads, there are multiple support loads such as HVAC and lighting loads. In 2008, this facility participated in PG&E's Automated DR (Auto-DR) program using OpenADR (Goli, McKane, and Olsen, 2011). An architecture diagram for how Amy's Kitchen participates in automated demand response is presented in Figure 7.

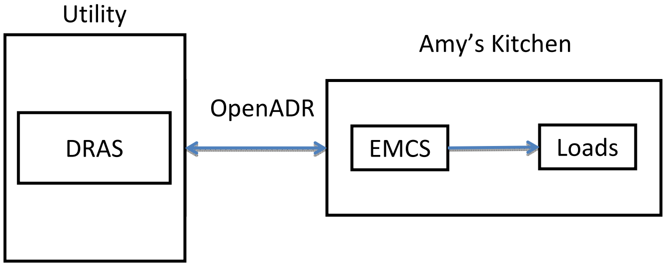

Figure 7. Information and control architecture for Amy's Kitchen case study.

The utility notifies the customer a day-ahead by announcing the DR event period using OpenADR. The facility EMCS, which is connected to an OpenADR client, receives these signals. The facility manager also receives an e-mail notification. The following day, when the DR event starts, the EMCS triggers pre-programmed DR strategies. The facility manager can use a secure, Internet-based portal to opt-out from the DR event after she receives the notification and before the trigger.

At this facility, DR strategies included shutting off some freezers and the battery chargers and raising the set-points on other freezers and cool rooms. The installation of a new EMCS and programming for automated DR cost the facility $160,000. The facility received $139,200 from PG&E. The facility only participated in PG&E's baseline AutoDR program and not in capacity or ancillary services markets. Even so, the payback period for the remaining costs was about one year.

Lafarge Building Materials

In New York State, NYSERDA and NYISO have initiated load reduction and demand response programs that are relevant for industrial facilities. One of the beneficiaries of these programs is Lafarge Building Materials, a cement processing plant (Epstein et al., 2005).

Cement manufacture is highly energy intensive, requiring the crushing and drying of large volumes of rock. On request from NYISO, Lafarge can shut down its rock crushing equipment, shedding 22 MW of "discretionary" load. With its inventory storage capacity, the plant can continue production with stockpiled crushed rock. The load curtailment is calculated and submitted to NYISO automatically and payment is made in accordance with NYSERDA's Peak Load Reduction Program.

Lafarge also participates in NYISO's Day Ahead Demand Response Program. The plant can schedule maintenance on equipment at times when grid prices are scheduled to be high. The program allows Lafarge to sell the energy that it did not use into the market. Demand response revenues of approximately $2 million are reported.

Implementing these programs required investment in equipment and infrastructure, which was supported by NYSERDA. Twenty-six miles of fiber optic Ethernet cable, Internet connectivity for pricing information, and energy management system functionality to centrally monitor and control consumption and loads were required. But the benefits have been substantial: in addition to other financial returns, demand response revenues of approximately $2 million are reported.

Ice storage at an industrial process

Our final example is also from New York State and relates to NYSERDA's Peak Load Reduction Program. The facility is an industrial plant with significant process cooling demand in New York City (Epstein et al., 2005). Because of NYC's poor grid connectivity for power imports, high prices result in peak times. In this plant, ice slurry is created at night with chillers and stored in insulated tanks. This slurry is used during the day to cool refrigerant without running electric chillers. 5,000 ton-hours of cooling capacity is available. Demand reduction of over 600 kW was realized. NYSERDA provided

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[1] http://www.americainfra.com/article/Demand-response-participation-can-change-the-viability-of-industrial-facilities-Brian-Helms-power-markets-coordinator-Alcoa-on-industrial-scale-demand/

financial support for the installation of the ice storage and associated controls.

Future Directions

Standardization and interoperability

Smart grids are "systems of systems." Solutions are, and will increasingly be, integrations of components, often from different sources. The components in question are not just physical products, but also communication protocols, information and data models, software implementations of algorithms, etc. It is thus important that components and subsystems from different suppliers can work together (interoperability), in as close to plug-and-play fashion as feasible and consistent with safety and reliability constraints; and that they are based on open, accessible interfaces and protocols (standardization).

The importance of interoperable standards for smart grids is globally recognized and end-use sectors are a particular focus. In the U.S., a public-private partnership organization, the Smart Grid Interoperability Panel (SGIP), has been established by the National Institute of Standards and Technology "to support NIST in fulfilling its responsibility, under the Energy Independence and Security Act of 2007, to coordinate standards development for the Smart Grid" (NIST, 2011). The SGIP organization includes several "domain expert working groups," including one for industrial end users titled Industry-to-Grid (I2G). I2G is a forum for industry end users, suppliers, and other interested individuals and groups to discuss issues related to smart grid applications in the sector. For further information see http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/I2G.

Market innovation

The grid-of-the-future will have significantly increased penetration of renewable generation, many types of distributed storage technologies, micro- and macro-grids, as well as new technologies that are unforeseen today. These along with new business models will continue to impact policies around how electricity is being produced, sold or used.

Across the U.S., various energy, capacity, and ancillary services markets have a number of different terminologies, rules, and policies. This is largely due to the different generation types, control systems, market sizes, and available resources in each region. Internationally as well, pricing structures and market designs vary considerably. Given structural and societal differences—for example, the relative prioritization accorded to large-scale penetration of renewable generation, improved grid reliability, reduced peak loads, and other benefits promised by smart grids vary considerably across the globe—a uniform market strategy is neither feasible nor desirable. There is much to be learned from the portfolio of approaches and implementations, even though these have often been designed as trial-and-error approaches. Albeit from a primarily residential perspective, Faruqui, Hledik, and Sergici (2010) review and analyze existing work. The authors also highlight the need for rigorous models that are validated by the data available from commercial and pilot applications and that can help policy makers and others in developing rate structures and market mechanisms for technologies such as demand response.

Next steps in automated demand response

Until recently, demand response was employed for general load reductions in response to peak power concerns. New developments are now targeting faster-scale response times and thereby enabling the use of demand response for ancillary services—at up to 4-sec response times, as needed for frequency regulation. Automation, as noted earlier, is essential for such applications. We believe automated demand response can be expanded to cover the full variety of ancillary services. The communication and negotiation protocols, optimization and control algorithms, and measurement and settlement processes are all topics for research.

Another important area for research is related to the assets covered—automated demand response is not just for electrical loads. As distributed generation and storage become more widespread—and industrial processes are leading the way in this regard—the demand management opportunities commensurately increase. Generators and storage devices bring additional complexity; in particular a more holistic approach to automated demand response is needed. For example, the availability of on-site renewable generation and/or stored power can reduce grid draw without curtailing loads, but this flexibility must be exercised in "intelligent" fashion, in cognizance of renewable intermittency and future demands for stored power.

Conclusions

Electricity's role in fueling societal progress is growing—the fraction of U.S. energy needs met by electrical power has increased from 2% at the beginning of the previous century, to 11% in 1940, to 20% in 1960, and to over 40% today (Galvin,Yeager, and Stuller, 2009). With this increasing role has come greater scrutiny—of the impact of electricity on climate change; on the economics of power generation, delivery, and consumption; and on the reliability of power grids. The "business as usual" model for power systems is widely seen as untenable and "smart grid" initiatives have been launched worldwide as a response to these developments.

Industrial facilities, because of their large consumption footprints, are a key stakeholder community for smart grids and in many cases have already benefited from some smart grid technologies (as these applications would now be called—many of them predate the term).

However, the potential of this field on industry is, we believe, not fully appreciated, especially with regard to recent and emerging technologies such as automated demand response, and the industrial sector is less engaged in the definition, standardization, and research activities related to smart grids than other customer sectors. We hope this paper will help raise the awareness of smart grids for industry, with regard to the benefits that can be achieved with today's solutions as well as the research opportunities for realizing further improvements in the capabilities and ease-of-application of smart grid technologies.

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References

Amin, M. (2011). U.S. Electrical Grid Gets Less Reliable. *IEEE Spectrum*, January.

EIA (2009). 2006 Energy Consumption by Manufacturers—Data Tables. U.S. Energy Information Administration. Available http://www.eia.gov/emeu/mecs/mecs2006/2006tables.html. Accessed Nov. 27, 2011.

Epstein, G., et al. (2005). Demand response enabling technologies and approaches for industrial facilities, *Proc. 27th Industrial Energy Technology Conf.*, New Orleans, LA, May.

Faruqui, A., Hledik, R., and Sergici, S. (2010). Rethinking prices: The changing architecture of demand response in America. *Public Utilities Fortnightly*, pp. 30 – 39.

FERC (2004). Final Report on the August 14, 2003 Blackout in the United States and Canada, Federal Energy Regulatory Commission, April. http://www.ferc.gov/industries/electric/indus-act/reliability/blackout/ch1-3.pdf. Accessed 2010-12-25.

Galvin, R., Yeager, K., and Stuller, J. (2009). *Perfect Power*. McGraw Hill.

Goli, S., McKane, A., and Olsen, D. (2011). Demand Response Opportunities in Industrial Refrigerated Warehouses in California. *Proc. 2011 ACEEE Summer Study on Energy Efficiency in Industry*.

IPCC (2007). Climate Change 2007: Synthesis Report, Summary for Policy makers. Intergovernmental Panel on Climate Change. Available http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf. Accessed Nov. 27, 2011.

McKane, A., Rhyne, I., et al. (2008). Automated Demand Response: The Missing Link in the Electricity Value Chain. *In 2008 ACEEE Summer Study on Energy Efficiency in Buildings*, Technical Report LBNL-2736E, Lawrence Berkeley National Laboratory.

NIST (2011). Smart grid interoperability panel site. http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/. Accessed Nov. 17, 2011.

NYISO (2011). Ancillary Services Manual. New York Independent System Operator. Available at http://www.nyiso.com/public/webdocs/documents/manuals/operations/ancserv.pdf. Accessed Nov. 28, 2011.

Piette, M.A., Kiliccote, S., Ghatikar, G. (2008). Linking Continuous Energy Management and Open Automated Demand Response. *In Proceedings of the Grid Interop Forum*, Atlanta, GA.

Samad, T. (2010). Commercial and Industrial Perspectives on Smart Grids. Presentation to Smart Grid Interoperability Panel Governing Board. http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/I2G. Accessed Nov. 27, 2011.

Todd D., et al. (2009). Providing Reliability Services through Demand Response: A Preliminary Evaluation of the Demand Response Capabilities of Alcoa Inc. Technical Report ORNL/TM-2008/233, Oak Ridge National Laboratory., http://info.ornl.gov/sites/publications/files/Pub13833.pdf. Accessed Nov. 27, 2011.

Todd, D. (2010). Alcoa –Demand Response Innovation. FERC Technical Conference on Frequency Regulation Compensation in the Organized Wholesale Power Market. http://www.ferc.gov/eventcalendar/Files/20100526085714-Todd,%20Alcoa.pdf. Accessed Nov. 27, 2011.

Worrell, E., Martin, N., and Price, L. (1999). Energy Efficiency and Carbon Dioxide Emissions Reduction Opportunities in the U.S. Iron and Steel Sector, Report LBNL-41724, Lawrence Berkeley National Laboratory.