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Smart grid demos provide guidance on integrating DER and RES into the distribution system with consideration of transmission impacts, market signals, and technologies

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SUMMARY

The process to develop selection criteria and strategy for planning and deployment of smart grid technology is the focus of this paper. Demonstrations under the US Department of Energy (USDOE) and Electric Power Research Institute (EPRI) Smart Grid programs, individually and as a group, provide experience with new smart grid technology. Industry knowledge of Distributed Energy Resources (DER) and Renewable Energy Sources (RES) will be expanded to learn how the distribution grid can interact with DER and RES for planning as well as real time analysis, control, and situational response.

Programs include the USDOE Renewable and Distributed Systems Integration (RDSI) and the EPRI Smart Grid Demonstration Program to assess technology as well as how DER and RES can be integrated and operated to lower the carbon footprint. Reactive power supplied by inverter based DER and RES is included in research conducted by Oak Ridge National Laboratory (ORNL) working in concert with the USDOE. A unique state-of-the-art Distributed Energy Communications & Control (DECC) laboratory has been created at Oak Ridge. The DECC lab is being utilized to study reactive power supplied by DER and RES. ORNL owns the electric distribution utility for the laboratory campus and can configure the distribution system to provide opportunities for testing reactive power from inverters and control methods for reactive support. This provides a key advantage for demonstrating the methods and value of integrating DER and RES into the transmission or distribution system.

Programs include the use of responsive load to provide ancillary services such as regulation and spinning reserve. Ancillary services can be supplied more accurately from responsive load than by conventional generation, and the location of the service supply point – near load centers – provides large advantages.

The RDSI program includes integration of renewable energy, distributed generation, energy storage, thermal technologies, and demand response. This integration targets a 20% reduction in peak loads by 2015. The program will also address new value-added services such as differentiated power quality and enhancing asset use. RDSI projects will identify and address barriers for using DER and RES and explore business models to incorporate these technologies into capacity planning and demand-side management.

In addition to project management assistance, EPRI tasks include development of analysis tools, integration technologies, lab and field demonstrations, and technology transfer. The EPRI Smart Grid Demonstration program identified six critical elements that help utilities define how the demonstration projects are selected and assessed:

1. Integration of Multiple Distributed Resources
2. Connect Retail Customers to Wholesale Conditions
3. Integration with System Planning & Operations
4. Critical Integration Technologies & Standards
5. Compatibility with EPRI's Initiative and Approach
6. Leverage other Funding Sources

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KEYWORDS

EPRI, Smart Grid, Distributed Energy Resources (DER), Renewable Energy Sources (RES), U. S. Department of Energy (USDOE), Oak Ridge National Laboratory (ORNL), Renewable and Distributed Systems Integration (RDSI), Load Responsiveness, Voltage, Var Schedule, Ancillary Services

USDOE RDSI Program

The USDOE RDSI Program focuses on integrating renewable energy, distributed generation, energy storage, thermally activated technologies, and demand response into the electric distribution and transmission system. This integration is aimed toward managing peak loads (20% reduction by 2015), offering new value-added services such as differentiated power quality to meet individual user needs, and enhancing asset use. Nine projects are being carried out under the RDSI Program to conduct integration development and demonstrations. RDSI projects will identify and address technical, economic, regulatory, and institutional barriers for using renewable and distributed systems.

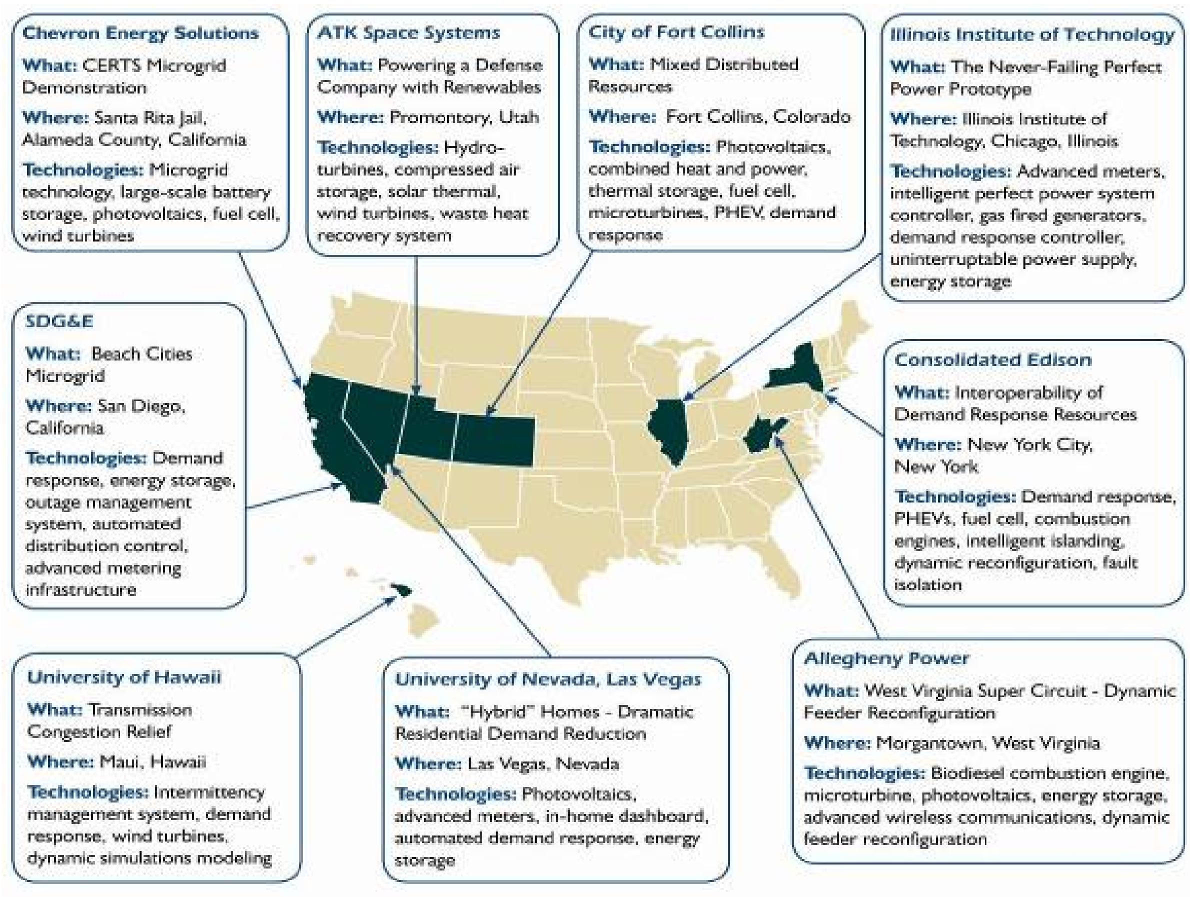

Figure 1 DOE RDSI Projects

In addition to operational issues, the integration will establish viable business models needed to incorporate these technologies into capacity planning and demand-side management. RDSI development attempts to:

- reduce carbon emissions and other pollutants through increased use of renewables and clean DG

- increase asset use through integration of distributed systems and customer loads to reduce peak load and thus price volatility
- support achievement of renewable portfolio standards
- enhance reliability, security, and resiliency from microgrid applications in critical infrastructure protection, constrained areas of the electric grid, etc.
- improve system efficiency with on-site, distributed generation and improved economic efficiency through demand-side management
- support and enable plug-in electric vehicle (PHEV) operations with the grid

The USDOE RSDI program consists of nine projects carried out throughout the US as shown in Figure 1. The nine RDSI projects were selected in 2008 via a competitive solicitation and the nine projects were selected from nearly 200 applications submitted in response to the DOE solicitation. The DOE will provide funding of $55 million over five years and the total value of the RSDI program will exceed $100 million with cost share funding from the participants. The primary goals of the projects were to show how at least 15% peak load reduction, could be accomplished through integrating distributed energy resources and demonstrating the concept of the microgrid that must be capable of operating in both grid parallel and islanded modes.

The RDSI projects are expected to demonstrate the following benefits:

- ✓ Increased grid reliability
- ✓ Address vulnerability of critical infrastructure
- ✓ Manage peak load and defer T&D investment
- ✓ Lower emissions and use fuel resources more efficiently
- ✓ Help customers manage energy costs

DOE RDSI Project #1: ATK Space Systems -- This is a five year project with $1.600M Federal funds matched with $2M non-Federal funds. Project partners include ATK Space Systems, P&E Automation, and Rocky Mountain Power. The purpose of the project is to demonstrate diverse renewable energy generation with an intelligent system to reduce substation demand on peak by 15%. Control system capabilities include load aggregation, fault detection, remote monitoring and control, two-way customer interface (web enable) real-time visibility to and renewable generation production.

DOE RDSI Project #2: City of Fort Collins – This is a three year project with $3.9M Federal funding and $7.2M industry/non-Federal funds. Project partners include Ft. Collins Utilities, Colorado State University, Advanced Energy, Brendle Group, Eaton Corporation, InteGrid Laboratory, New Belgium Brewing, Spirae, Inc, and Woodward Governor Company. The purpose of the project is to demonstrate a mix of resources and reduce peak loads by 20-30% on several feeder locations while increasing penetration of renewables and delivering improved grid reliability/asset utilization.

DOE RDSI Project #3: Illinois Institute of Technology – This is a five year project with $7MM Federal funds matched with $5M industry and non-federal funds. Project partners include Illinois Institute of Technology (IIT), Galvin Energy Initiative, Excelon, S&C, Schweitzer, and Endurant Energy. The purpose of the project is to demonstrate the performance that results from self-healing, learning and self awareness as expected of a Smart Grid. The IIT demonstration will need to identify and isolate faults, reroute power and to accommodate load changes and generation.

DOE RDSI Project #4: Consolidated Edison (ConED) of NY -- This is a three year project with $6.8M Federal funds matched with $1M state funds and $6.0M industry funds. Project partners include ConED, Innoventive Power, Verizon, and Infotility. The purpose of the project is to demonstrate the performance of a demand response command center to aggregate multiple customer-owned and customer-sited generation and demand resource facilities including fuel cells, combustion turbines, and diesel engines. A large part of the demand response capability comes from generation sources at 29 telecom facilities accomplished by changing AC set-points, rectifier voltages and variable frequency drive speeds. DER resources will be dispatched under tariff-based and market-based programs for the electric distribution company and the regional transmission operator.

DOE RDSI Project #5: Allegheny Power – This is a 4.5 year project with $5.5M in Federal funds and $4M in non-Federal funds. Project partners include Allegheny Power, SAIC, West Virginia University (WVU), WVU Advanced Power & Electricity Research Center, North Carolina State University, Augusta Systems, Inc, and Tollgrade Communications. The purpose of this demonstration project is to create a circuit that improves performance, reliability and security in its delivery of power with integration of advance distribution technologies and distributed resources.

DOE RDSI Project #6: University of Nevada –This is a five year project with $7M Federal and $13.9M industry funding. Partners include University of Nevada, Pulte Homes, and NV Energy. The purpose of this demonstration project is to show a decrease in the peak demand for a new housing development by as much as 65% as compared to a similarly conventionally built to code development. Technologies include roof integrated PV Systems of 1.76-2.43 kW, battery storage at the substation, advanced wireless mesh network technology, AMI and a multiple energy efficiency technologies, such as tankless water heaters.

DOE RDSI Project #7: University of Hawaii -- This is a three year project with $3.9M in Federal and $7.2M industry/non-Federal funding. Partners include Hawaii Natural Energy Institute, University of Hawaii, Maui Electric Company, GE Global Research, Sentech, Inc, Hawaii Electric Company, and GE Energy. The purpose is to demonstrate reduced peak load substantially while achieving a high level of integration of “as-available” renewables. The demonstration uses distribution automation solutions to integrate dispatch of distribution and bulk power assets to achieve system-level benefits.

DOE RDSI Project #9: Chevron Energy Solutions – This is a three year project with $7M Federal funds matched with $7M non-federal funds. Partners include National Renewable Energy Laboratory, Lawrence Berkley National Laboratory, University of Wisconsin, and Alameda County. The demonstration will be the first commercial implementation of CERTS (Consortium for Electric Reliability Technology Solutions) microgrid technology that combines large-scale energy storage and renewables. Many existing renewable and non-renewable distributed energy sources already exist, including 1 MW fuel cell, 1.2 MW solar PV, two 1.2 MW emergency generators. New technologies include “CERTS Microgrid” control logic which includes fast static disconnect for islanding, a 2 MW NaS battery for demand offset, TOU pricing, and two wind turbines.

The EPRI Smart Grid Demonstration RDSI Program

The roll of EPRI is to develop the collaborative environment for technology development, integration and application. At the heart of the EPRI Smart Grid Demonstration program, are six critical elements that define how the host site projects are defined, planned, deployed and assessed. These six elements are detailed in a project proposal for each individual Smart Grid demonstration site. The proposals are reviewed in sequence by an EPRI technical review team, a peer review team, and finally a review by the EPRI board of directors prior to acceptance as an EPRI Smart Grid demonstration host site.

The Six Critical Elements:

(1) Integration of Multiple Distributed Resource Types – The project must include multiple resources types at both system and consumer levels. Both generation and load-side resources must be connected with communications and controls. Resources may include technologies such as demand response, storage, distributed generation and renewables.

(2) Connect Retail Customers to Wholesale Conditions – Going beyond just traditional retail rates, the Smart Grid Demos require a direct dynamic correlation between the customer rate and wholesale conditions. This provides a means for customer participation in markets and enables assessment of effectiveness of customer incentives.

(3) Integration with System Planning & Operations – Full utilization of DER enables additional value when it can be utilized across system planning and operations. Host utilities are encouraged to demonstrate integration into operations and planning at both local and system levels. For example, DER should be utilized for both real-time reliability concerns as well as economic optimization and managing the life expectancy of the assets involved.

(4) Critical Integration Technologies & Standards – Integration of existing and emerging technologies and standards to integrate distributed resources help identify issues and gaps in current standards. Planning, developing and implementing interoperability will reveal readiness or harden the critical integration in preparation for standard industry practice.

(5) Compatibility with EPRI's Initiative and Approach – The Smart Grid will anticipate business scenarios and respond more smartly due to the pre-considered anticipation and defined requirements to carry out such scenarios. The demonstration projects leverage EPRI's IntelliGrid methodology in the development and employment of use cases and business models that reflect a wide-range of conditions to be met by the demonstration project.

(6) Leverage other Funding Sources – Multiple sources of funding reflect the vision, goals, and desires of various parties to achieve a more robust implementation of the Smart Grid. Funding from government sources can reflect visions of a Smart Grid at the local and federal level. Private and industry funding reflect confidence in areas such as use and integration of certain technologies and viable system requirements.

Under the EPRI Smart Grid Demonstrations, six unique demonstrations have been identified with an anticipated total of 8-12 domestic and international projects selected by August 2010. When these demonstrations are carried out, results will further the power industry's understanding of:

1) how to create greater interoperability when applying DER and RES
2) how to more easily and reliably integrate DER and RES into the local delivery system in both planning and operational functions
3) how to apply technologies and accelerate the development of standards for DER and RES.

In addition to the demonstrations, foundational research will support the industry as a whole in areas such as smart grid architecture design, best practices, technology evaluation, cost benefit analysis, standards development, and cyber security.

Each host site in the EPRI Smart Grid demonstration is unique in some respects, yet common in others. A graphic has been created for each site. Figure 2 is an example of the Electrcité de France (EDF) project graphic. The graphic enables a quick comparison, or memory refresh, to identify the components of each project. The demonstrations are international in scope to address global needs for integration of new resources and flows of information between all components including the customer. The projects, in total, cover a variety of landscapes, densities, and conditions faced to serve customers and balance the smart system. Additional graphics and information is updated regularly at the project site at http://www.smartgrid.epri.com.

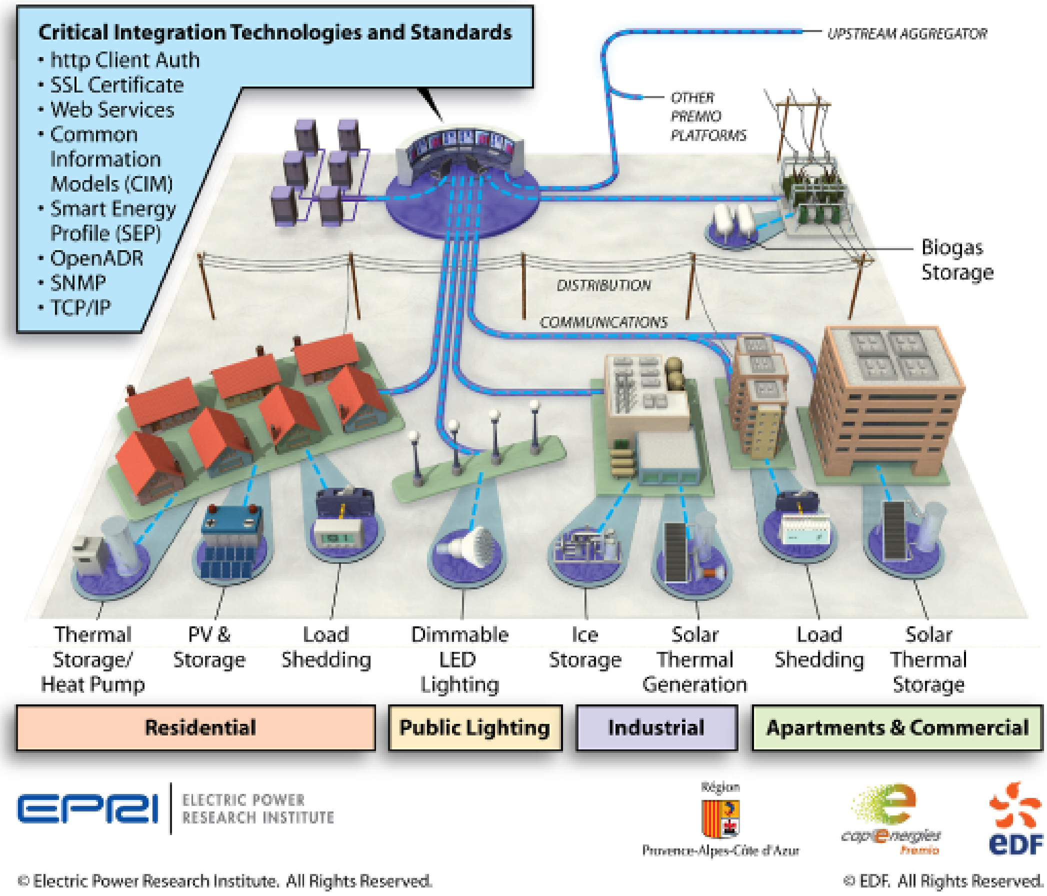

Figure 2 EDF EPRI Smart Grid Demonstration Host site

Oak Ridge National Laboratory (ORNL) – Smart Grid R&D

The Smart Grid will enable control of electric load. As background, the electric power system has one requirement that must be continuously satisfied to maintain system stability: the need to maintain a constant balance between generation and load. If load is greater than generation, frequency will drop. If generation is greater, frequency will rise. However, in a large power system it is difficult to control this balance by simply controlling generation based on deviations in frequency. Instead, the system operator constantly performs a bookkeeping function to ensure that load and generation are balanced. The operator measures generation and load every few seconds and controls the balance in his balancing area. The exactness of the balance is known as Area Control Error or ACE The adjustment of generation to maintain this balance is known as regulation. The system operator sends a signal to specific generators called Automatic Generation Control (AGC) which instructs them to ramp or ramp down to maintain the balance. These generators perform the service of regulation.

Responsive loads can provide the regulation service as well. Reference 4 describes opportunities for an Aluminium Smelter to provide reliability services. An aluminium smelter in Indiana is now using load response successfully to provide 20 MW of regulation to the Midwest Independent System Operator. Responsive loads can supply regulation, contingency reserves, and dynamic reactive support to the power system.

With the proper communications and market systems, responsive load could be available now from commercial and residential customers. Responsive load holds great promise in load pockets (urban areas) and can relieve stress (increase capacity) on the transmission system by providing reliability services locally. With the development of the Smart Grid, responsive load has the opportunity to play a larger role in system operation.

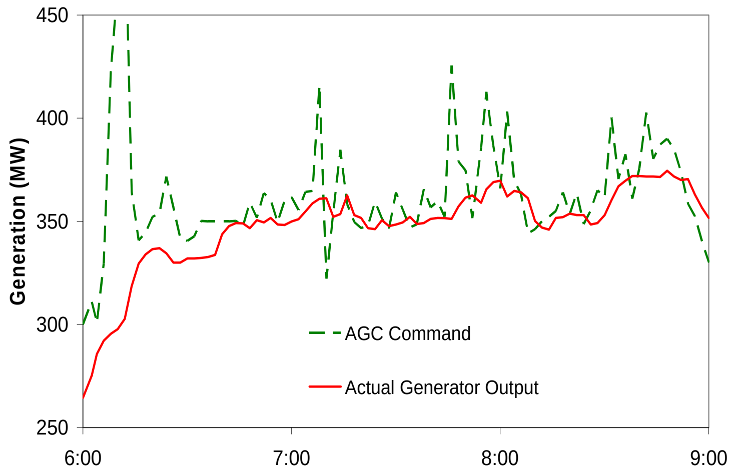

Figure 4 Conventional turbine generators sometimes follow AGC commands poorly.

Figure supplied courtesy of Brendan Kirby [4]

Responsive load can be controlled to turn off and on at the command of the system operator. Just like the generators that provide regulation, responsive load can provide regulation to balance the variability of renewable energy sources such as wind and PV. Wind and PV are well known for being highly variable. When the wind dies down or a cloud shades the photovoltaic cells, the generators that perform regulation make up the difference in power generation. In the future, large numbers of small responsive loads will provide reliability services.

Another type of reliability service is spinning reserve. Spinning reserve is provided by generators that are running and connected to the grid and ready to provide power immediately if there is a contingency such as a loss of a transmission line or generator. Responsive loads can also supply this service.
There are basically five different types of responsive load, as follows. [4]

1. Energy Efficiency programs reduce electricity consumption and usually reduce peak demand as shown in Figure 4.
2. Price Response programs move consumption from day to night. (real time pricing or time of use).

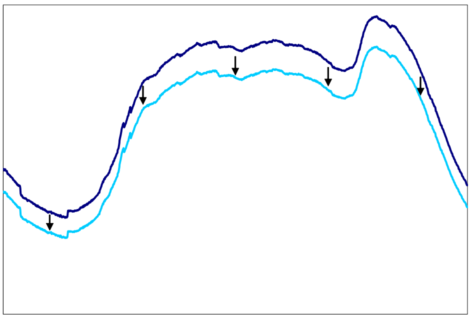

Figure 5 Morning and Afternoon Peaks in Load With Reduction due to Efficiency
(Y axis Load in MW, X axis 24 hours)

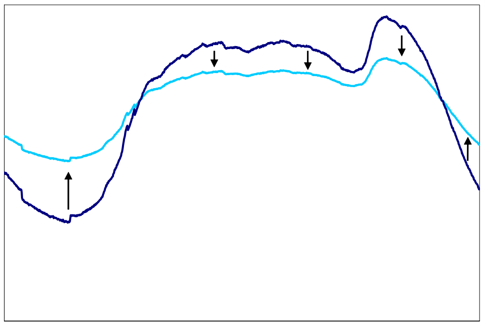

Figure 6 Peak Shaving Programs Can Move Load From Day to Night

3. Peak Shaving programs, as shown in Figure 4, require more response during peak hours and focus on reducing peaks every high-load day.

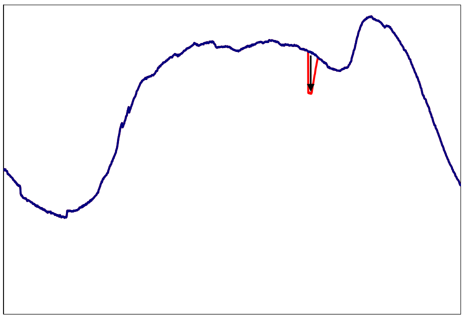

Figure 7 Spinning Reserve is Only Needed for 20 Minutes

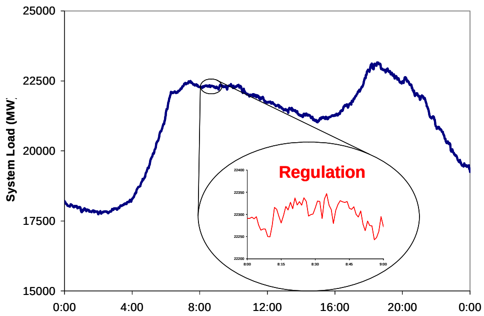

Figure 8 Regulation Is the Response to the Minute by Minute Fluctuation in Net Load

4. Reliability Response (contingency response or spinning reserve) requires the fastest, shortest duration response. Response is only required during power system "events". As illustrated in Figure 7, a response may only be needed for 20 minutes, which makes it ideal for loads to provide. If the air conditioner is off for twenty minutes, the temperature will only change by a degree or so. The Smart Grid is enabling ancillary services such as spinning reserves via load response from industrial, commercial and residential loads. The use of responsive load for spinning reserve is growing. At this time, one half of the spinning reserve is supplied by responsive load for ERCOT. (See http://www.ercot.com/services/programs/load/).
5. Regulation Response, shown in Figure 8 continuously follows the power system's minute-to-minute commands to balance the aggregate system – This is very new and may have the potential to dramatically change electricity costs.

Independent System Operators presently operate ancillary service markets that make it easy to see the value of the various services such as regulation or spinning reserve. This also provides a method for alternative service suppliers, like responsive load, to perform and be paid for providing the service. Responsive load is now providing the regulation service in the MISO. This is being done with a very large load. In the Smart Grid, it may be possible to provide regulation from hundreds of thousands of small loads. Interestingly, when regulation is provided more accurately, much less is needed, and the service is worth more. The MISO now has a separate market for accurately supplied regulation which has a higher value than regulation supplied from conventional turbine generators. Responsive loads can supply regulation very accurately. [4]

When responsive load is used to provide reliability services instead of generation, more generation can be used for supplying energy. This will reduce cost because less generation will have to be held in reserve. This will also reduce cost because it will reduce congestion on transmission lines and reduce emissions. Not only does generation have to be held in reserve for contingencies, transmission capacity also has to be held in reserve. When the contingency response is supplied by load, the transmission capacity is freed up. This allows more low cost energy to be supplied to urban centers.

It is important, as we design the smart grid, to ensure that the communication and control hardware being installed is equal to the task of supplying spinning reserve and regulation from responsive load. In the near future, hundreds of thousands of hot water heaters could be controlled to supply regulation. To do this accurately, a control time of perhaps 4 seconds from dispatch to load response would be required.

In some areas, the basic criteria for the functions of spinning reserve and regulation, that is, how much do we need, how fast, and how do we measure it, have never been determined by a rigorous system analysis. Instead, these criteria have been developed as guidelines, and passed down over the decades as good practices, without a design basis evaluation. [5] This too, needs to be corrected as the smart grid is implemented. We need to know exactly how much we need of each service, how fast it is to be supplied, how it is to be measured, and what our margins are.

Use of local reactive power support to improve efficiency and reliability

Local, accurately supplied reactive support can reduce losses in the distribution system and optimize efficiency. In the future, when high levels of photo voltaic (PV) cells are installed, the PV inverters will be able to follow a volt var schedule supplied by the utility. The PV inverter can supply reactive support much more accurately than capacitors can, and, the inverter is purchased and installed with the PV system. The NIST smart grid standards presently under development are considering this option of a "Smart Inverter." The inverter would be instructed by the system operator to operate in a particular mode. One mode would be to provide a set amount of reactive support, another would be to follow a volt var schedule, and another would be to simply provide an output power factor of 1.0.

Local reactive support from inverters can not only reduce losses in the distribution system, but someday it will reduce losses on the transmission grid as well. Today, voltage support for transmission lines is provided primarily from conventional generators. That is, voltage support is generally provided only from the high side. In the future, voltage support will be supplied from two directions, from the generators, and also from the substation. This will reduce losses on the transmission lines as well. This is practice is already starting in some areas; the advent of the Smart Grid will enable more precise control at more locations with resulting reliability and efficiency improvement.

Local reactive support can also improve load efficiency. A heavily loaded motor will typically operate at a higher efficiency when it is operated at rated voltage as opposed to operation at 95 or 90% voltage. Operating a heavily loaded induction motor at reduced voltage will increase slip, increase losses, and reduce power factor. This causes greater heating in the motor, shorter motor life, and greater losses on the distribution and transmission system. In addition, it reduces the margin to voltage collapse. Many utilities are now experiencing a phenomenon on hot summer days known as fault induced voltage collapse. This occurs when heavily loaded air conditioning motors stall during fault clearing when the voltage may dip to 70%. They stay stalled under the thermal overload trips, and pull down the voltage on the whole circuit, a sort of micro voltage collapse. The voltage collapse events are starting to lump together and there is a concern that they could grow into a major event. With high penetrations of photovoltaic inverters on a distribution circuit, enough reactive reserves may be available to rapidly support voltage and prevent the motor from entering a stalled condition. This is discussed further in [6].

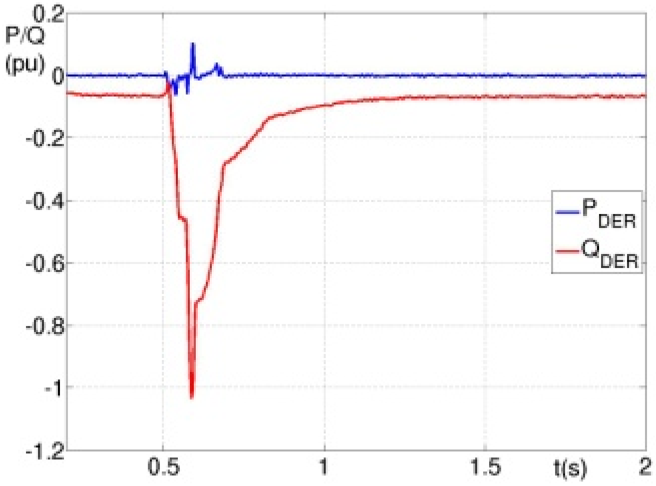

Figure 9 Local Voltage Support to Prevent a Motor from Entering a Stalled Condition [6]

Another benefit to local reactive support is that it can "free up" transmission line capacity. As a rule of thumb for a major West coast utility, every Mvar supplied locally, in a large urban area, translates to one MW of transmission line capacity that could be used to transport low cost hydro power from the North. The exact relationship is provided in [7]. All these benefits add up to a significant value for the service of local reactive support. In the future, there will be a payment for local reactive power supply. This will help to defray the cost of PV systems.

All this must come about with the Smart Grid. The Smart Grid will supply the local intelligence needed to regulate voltage and provide reliability services from load. This will greatly improve power system efficiency and reliability, and reduce emissions from generators that are now run just to provide reliability services. The Smart Grid effort must also be tied into a parallel effort in Net Zero Energy buildings so that the inherent energy storage in buildings can be maximized for use in improving grid efficiency and reliability. Appliance manufacturers must also be tied into the discussion on optimal voltage, so that appliances can be designed to provide maximum efficiency at the voltage levels the Smart Grid will maintain.

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