NERC

NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Special Report:

Potential Reliability Impacts of Emerging Flexible Resources

November 2010

to ensure
the reliability of the
bulk power system

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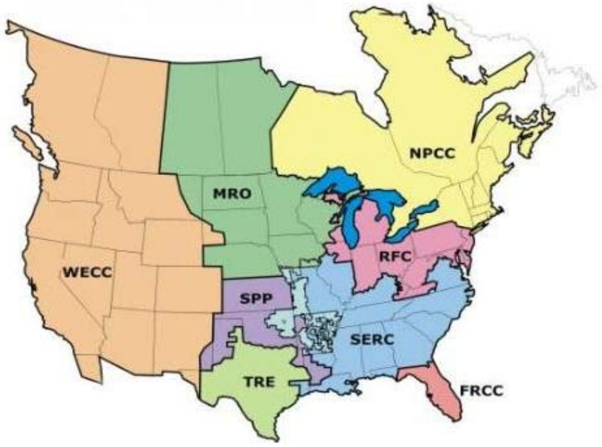
to ensure
the **reliability** of the
bulk power system

NERC's Mission

The North American Electric Reliability Corporation (NERC) is an international regulatory authority to evaluate reliability of the bulk power system in North America. NERC develops and enforces Reliability Standards; assesses adequacy annually via a 10-year forecast and winter and summer forecasts; monitors the bulk power system; and educates, trains, and certifies industry personnel. NERC is the electric reliability organization in North America, subject to oversight by the U.S. Federal Energy Regulatory Commission (FERC) and governmental authorities in Canada.[1]

NERC assesses and reports on the reliability and adequacy of the North American bulk power system divided into the eight Regional Areas as shown on the map below (see Table A). The users, owners, and operators of the bulk power system within these areas account for virtually all the electricity supplied in the U.S., Canada, and a portion of Baja California Norte, México.



Note: *The highlighted area between SPP and SERC denotes overlapping regional area boundaries: For example, some load serving entities participate in one region and their associated transmission owner/operators in another.*

Table A: NERC Regional Entities

FRCC Florida Reliability Coordinating Council	**SERC** SERC Reliability Corporation
MRO Midwest Reliability Organization	**SPP** Southwest Power Pool, Incorporated
NPCC Northeast Power Coordinating Council	**TRE** Texas Reliability Entity
RFC Reliability*First* Corporation	**WECC** Western Electricity Coordinating Council

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[1] As of June 18, 2007, the U.S. Federal Energy Regulatory Commission (FERC) granted NERC the legal authority to enforce Reliability Standards with all U.S. users, owners, and operators of the BPS, and made compliance with those standards mandatory and enforceable. In Canada, NERC presently has memorandums of understanding in place with provincial authorities in Ontario, New Brunswick, Nova Scotia, Québec, and Saskatchewan, and with the Canadian National Energy Board. NERC standards are mandatory and enforceable in Ontario and New Brunswick as a matter of provincial law. NERC has an agreement with Manitoba Hydro, making reliability standards mandatory for that entity, and Manitoba has recently adopted legislation setting out a framework for standards to become mandatory for users, owners, and operators in the province. In addition, NERC has been designated as the "electric reliability organization" under Alberta's Transportation Regulation, and certain reliability standards have been approved in that jurisdiction; others are pending. NERC and NPCC have been recognized as standards setting bodies by the *Régie de l'énergie* of Québec, and Québec has the framework in place for reliability standards to become mandatory. Nova Scotia and British Columbia also have a framework in place for reliability standards to become mandatory and enforceable. NERC is working with the other governmental authorities in Canada to achieve equivalent recognition.

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Executive Summary

The NERC IVGTF Special Report "*Accommodating High Levels of Variable Generation*"[2] identified the need to assess the reliability implications of "*integrating large amounts of plug-in hybrid electric vehicles, storage and demand response programs may provide additional resource flexibility and influence bulk power system reliability and should be considered in planning studies.*" This report addresses this aspect of variable generation integration.

Variable renewable generation such as wind and photovoltaic (PV), introduce additional variability and uncertainty to the power system that system operators must manage. To maintain reliable power system operation as variable energy resources provide a larger proportion of our electric energy supply, additional system flexibility will be required. The installed wind generation capacity in some North American balancing authorities has resulted in 25-50 percent of the instantaneous on-line generation being from variable sources. The additional system variability and the reduced on-line conventional synchronous generation that occurs as more variable energy is delivered presents new challenges for power system operators to manage in the time frames of milliseconds to many days. To maintain the reliability of the bulk power system as more variable generation is integrated and other system enhancements potentially impact the ramp requirements of the system, sufficient and appropriate operational flexibility will be needed to respond to the resulting additional variability and uncertainty.

System flexibility is defined as the ability of supply-side and demand-side resources to respond to system changes and uncertainties. Flexibility also includes the ability to store energy for delivery in the future and the operational flexibility to schedule/dispatch resources in the most efficient manner. Traditionally, much of the system flexibility required to maintain reliability has been obtained from rotating synchronous generators. During periods where more energy is being delivered by variable resources, less synchronous generation may be available. As such, additional sources of flexibility may be more effective and will be needed to maintain bulk power system reliability. This report summarizes the potential contributions that may be obtained in the future from emerging sources of flexibility such as Demand Response (DR), electric and thermal energy storage, and plug-in electric vehicles (PEVs).

As part of this assessment, the capability of each of the identified emerging resources to provide system flexibility/reliability functions and services were qualitatively evaluated for 10 specific characteristics. There are numerous challenges, to quantifying the potential impact of these emerging flexible resources on bulk system reliability including the lack of flexibility metrics, the uncertainty in quantifying future system flexibility needs, and the uncertainty due to the availability of the emerging flexible resources and other conventional resources that can supply flexibility. Consequently, a qualitative analysis of the potential of Demand Response, distributed energy storage, and Plug-in Electric Vehicle technologies to provide the ten specified reliability functions 10 years in the future is provided.

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[2] *Special Report -- Accommodating High Levels of Variable Generation*, NERC, http://www.nerc.com/files/IVGTF_Report_041609.pdf

Although it is difficult to project the capacity of these resources without regard to how they might be used to provide various ancillary services, the best available information is used in the report to provide the existing capacities of these resources and estimate their capacities in the year 2020. These capacities are then used for developing the qualitative assessment of emerging resource reliability contributions 10 years in the future. ***The aggregate reliability contributions presented are not supported by rigorous analysis, but are provided only as qualitative estimates of potential contribution.***

An important conclusion from this assessment is the emerging flexible resources evaluated – Demand Response, distributed energy storage, and Plug-in Electric Vehicles (PEV) – offer the potential to support many of the flexibility-related reliability functions that may be stretched as variable generation levels increase. While many of these technologies have not yet been applied to providing specific reliability functions, in many cases there do not appear to be any technical limitations in doing so. Largely, the potential market penetration of these emerging resources in providing the reliability functions is dependent on commercial and policy considerations that may or may not support development of these capabilities. Furthermore, although a particular emerging flexible resource may be technically capable of providing specific reliability functions, the extent to which it is developed will be influenced by whether it is economically viable relative to other available potential sources.

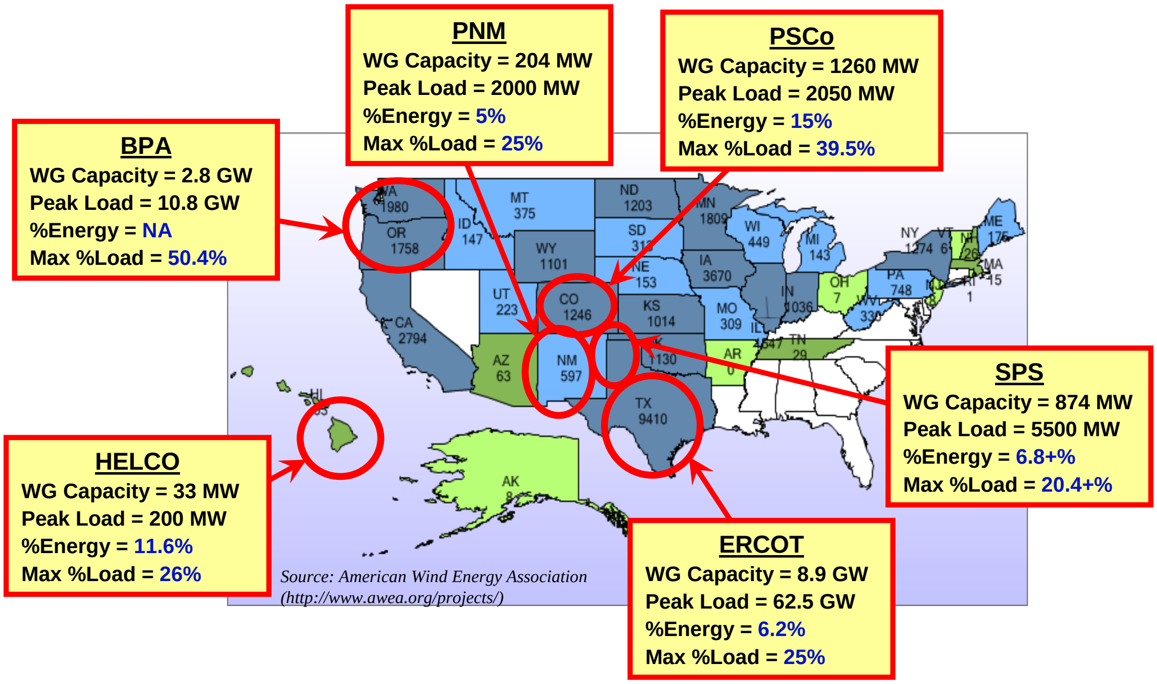
Assuming future commercial and market policy circumstances perpetuate present trends, these emerging resources are most likely to have the most significant impact on the reliability functions that allow for the longest response times and limited duration of response, such as spinning and non-spinning reserves. This is primarily due to the high potential of loads to participate in these reliability services, the growing record of accomplishment of Demand Response already providing these services and the large potential resource base that already exists. The potential aggregate impact on the faster response or longer duration or higher frequency of deployment reliability functions such as regulation or dispatchable energy is more moderate. These characteristics are not as well suited for a wide range of loads to supply. Many energy storage technologies and PEVs are technically capable and suited to provide these services, they are generally either not currently commercially available or there is uncertainty as to whether sufficient development of the resources will occur to have a more significant impact over the next ten years.

The recommendations in this report include the following:

- Adjust regional or federal reliability standards that might limit the deployment of these resources from providing specific reliability functions.
- Development of an operational infrastructure that provides visibility and control (direct or indirect) of distributed resources such as DR and PEVs.
- Consider modifying market rules or non-market rules/procedures that limit technically capable resources from providing flexibility needed to support specific reliability functions and evaluate how adding new resources can add to this flexibility.

Chapter 1: Introduction

Renewable generation resources such as wind generation and solar photovoltaic generation (PV) use weather-based fuel sources, the availability of which can vary over time. Subsequently, the electric output of these resources also varies creating a new class of resource categorized as variable generation (VG). Until recently, North American experience with variable generation was limited, with variable generation making up only a small amount of the total generation within a power system or balancing area (i.e. typically less than ten percent). Large increases in installed wind generation capacity in some balancing authority areas (BAs) have resulted in relatively high penetrations on a regional basis. Figure 1-1 shows a recent state installed wind capacity map from American Wind Energy Association (AWEA) highlighting selected BAs that have a high installed wind generation capacity relative to the BA peak load. For each of these BAs, the following parameters are provided: installed wind capacity (*WG Capacity*), peak BA load (*peak load*), percentage of annual energy derived from wind generation from most recent available data (*percent Energy*), and the maximum instantaneous percentage of load served from wind generation (*Max percent Load*). As the graphic shows, for some BAs in the U.S., wind generation is already instantaneously supplying as much as 25-50 percent of system supply requirements.



Source: American Wind Energy Association (http://www.awea.org/projects/)

Figure 1-1: Selected Balancing Authorities w/Significant Penetrations of Wind Generation

BAs with increasing penetration levels like those shown in Figure 1-1 have already begun experiencing operational challenges,[3] though integration of variable generation typically has

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[3] For example, see NERC's *2010 Summer Assessment*, Regional Reliability Assessment Highlights, at http://www.nerc.com/files/2010%20Summer%20Reliability%20Assessment.pdf

not appreciably affected the reliability of the bulk power system. Anticipating substantial growth of variable generation, NERC's Planning and Operating Committees created the Integration of Variable Generation Task Force (IVGTF) which prepared a report, entitled, "Accommodating High Levels of Variable Generation,"[4] which was released in April 2009.

In addition to defining various technical considerations for integrating high levels of variable generation, the IVGTF report identified a work plan consisting of thirteen follow-on tasks to investigate potential mitigating actions, practices and requirements needed to ensure bulk system reliability. These tasks were grouped into the following four working groups with three tasks each: 1) Probabilistic Techniques, 2) Planning, 3) Interconnection and 4) Operations. This report describes the results of one of three tasks assigned to the Planning activity, providing the results of the task of evaluating the potential improvement to bulk system reliability from integration of large amounts of emerging flexible resources, such as plug-in hybrid electric vehicles, bulk electric storage, and Demand Response programs. There are numerous industry "smart grid" initiatives that are developing infrastructure to facilitate the use of the flexible resources for supporting system reliability. In addition, NERC's Smart Grid task force (SGTF) is characterizing smart grid and developments in North America which can be referenced for more detail on smart grid activities[5].

Overview of Bulk System Operating Impacts of High Variable Generation Levels

Power system planners and operators are already familiar with a certain amount of variability and uncertainty. Power grids are constantly adjusting to fluctuations in demand and generation, as well as changes in the power flow over transmission lines due to maintenance schedules, unexpected outages and changing interconnection schedules. Large-scale integration of variable generation introduces increased supply variability and uncertainty. Geographic diversity and dispersion of wind plant output reduces aggregate variability over large geographic areas. However, operating experience in areas with increasing amounts of wind generation such as BPA's Columbia River basin and western part of the ERCOT system has shown that the variability of individual wind plants' output can correlate with other wind power facilities over distances of a few hundred miles for some large weather systems. Therefore, geographic diversity, while valuable, is not entirely sufficient to avoid weather related ramping of a significant portion of the total wind power capacity within a given BA's footprint over a period of one to several hours.

High levels of variable generation have the potential to affect system operations at the local level, at the Balancing Area (BA) level, and at the interconnection level. At the local level, impacts tend to be related to power quality, voltage control and reactive power management. At the BA level, variability and uncertainty make it more challenging, and sometimes more costly, to maintain balance between load and generation. At the interconnection level, reduced inertia and primary frequency response and the possibility of large-scale changes in generation (due to weather events or propensity to trip off line) could cause stability issues.

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[4] *Special Report -- Accommodating High Levels of Variable Generation*, NERC, http://www.nerc.com/files/IVGTF_Report_041609.pdf

[5] *Reliability Considerations from the Integration of Smart Grid, NERC, November 2010* http://www.nerc.com/files/SGTF_Report_Final_posted.pdf

High variable generation levels can also affect bulk system operations on all operational time scales from seconds-to-minutes, minutes-to-hours, hours-to-days, and beyond. The variability and uncertainty also affect the long-term transmission and resource adequacy planning assessments. For the operations timeframe, however, Figure 1-2 illustrates the time scales on which variable generation creates additional balancing burden, as well as the system flexibility services that are required to maintain reliability. The physical phenomena and control actions associated with these operational time frames, arranged from shortest to longest, are as follows:

- ***Stability:*** System stability is the shortest time scale, ranging from milliseconds to seconds, and although not explicitly shown in Figure 1-2, would be graphically represented as a single point within the regulation time frame. System stability is the extent to which both voltage and frequency are maintained within established tolerances at all times. In this time frame, bulk power system reliability is almost entirely controlled by system inertial response, automatic equipment and control systems such as, generator governor and excitation systems, power system stabilizers, automatic voltage regulators (AVRs), protective relaying, remedial action schemes, and fault ride-through capability of the generation resources.

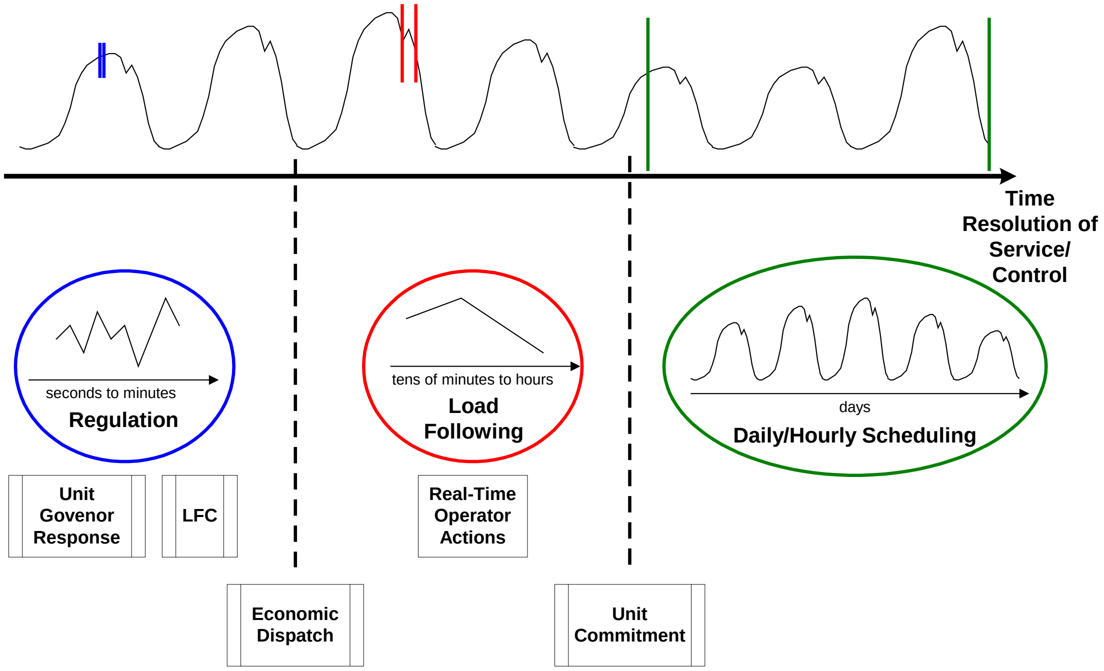

Figure 1-2: Operational Time Frames and Associated Control Mechanisms

- ***Regulation:*** The regulation time frame covers the period during which generation (and potentially load) automatically responds to minute-by-minute deviations in supply-demand balance. Typically, signals are sent by an automatic generation control (AGC) system to one or more generators to increase or decrease output to match the change in load. The frequency regulation control portion of the AGC system is typically called the load frequency control (LFC). Changes in load during the regulation time are typically not predicted or scheduled in advance and must be followed by generation reserve capacity that is online and grid-synchronized.

- ***Load Following:*** The load following time scale covers periods ranging from several minutes to a few hours during which generating units are economically dispatched, subject to various operational and cost constraints to follow the correlated variation of the load throughout the day. Load following is typically provided by dispatching generating units that are already committed or from starting generating units according to a predetermined commitment schedule.
- ***Operational Scheduling/Unit Commitment:*** Unit Commitment covers several hours to several days and concerns the scheduling and, commitment of generation to meet expected electric demand, reserve, and interchange requirements. Generation in this time frame may require several hours, even days, to start-up and increase to the preferred operating level. Similarly, taking a unit off-line may require several hours or days, and the unit may need several hours of cooling before restarting. Therefore, planning the appropriate level of unit commitment is of fundamental importance to economically and reliably operate the system.

Variable renewables can also impact utility operations at times of minimum load. Some large thermal generators (nuclear and coal for example) are unable to cycle on and off easily, have relatively high minimum loads, and typically operate as base load generation. High levels of variable generation occurring at times of low system load can create concerns if the level of variable generation exceeds the net system minimum load (load – minimum generation). The normal utility practice of reducing the generation with the highest marginal cost no longer works once the conventional units are at minimum load. At this point the variable generation must be reduced, the load increased, or some base load generation de-committed to maintain the generation/load balance. Assuring that control capability exists for the variable and conventional generators is a reliability requirement. Having procedures in place for power system operators to select which generators to curtail (or loads to increase) are equally important for reliability.

Mitigation of potential adverse variable generation impacts in all of these time frames is accomplished through ensuring sufficient and appropriate operational flexibility exists to respond to the additional variability and uncertainty. Generally, system flexibility can be defined as the ability of both supply-side and demand-side resources to respond to changes and uncertainties in system conditions. Flexibility also includes the ability to store energy for delivery in future time-periods or the operational flexibility to schedule/dispatch resources in the most efficient way to address variability/uncertainty.

Overview of Required Bulk System Flexibility and Reliability Functions

Traditionally, operators have obtained most of the system flexibility and stability support from the performance capabilities of and specific services provided by traditional generators. The system flexibility/reliability functions and services that are required can be grouped into the following categories:

1. ***Inertial Response:*** Very fast response (cycles to 1-2 seconds) which supports power system stability by constraining the initial rate of change of frequency following a system disturbance. This response is obtained from the inertia inherent in large synchronous generators and from the natural frequency response of motor driven loads. As load and generation technologies change it will be necessary to ensure that sufficient sources of inertial response are available to maintain system stability.

2. ***Primary Frequency Response*:** Very fast response (cycles to 5-10 seconds), traditionally from synchronous generator governor control, that adjusts MW output as a function of frequency to arrest frequency deviations following a disturbance. As with inertial response, it will be necessary to ensure that sufficient sources of primary frequency response are available to maintain system stability as load and generation technologies change.

3. ***Regulation*:** Continuous response (10 seconds to several minutes) of reserves under Automatic Generation Control (AGC) that are deployed to correct minute-to-minute deviations in system frequency or return system frequency to the desired range following a system disturbance. Regulation is a FERC defined ancillary service which is obtained through hourly markets in many locations.

4. ***Load Following/Ramping*:** Slower response (several minutes to few hours) whereby available resources are dispatched to follow system ramping requirements. Load following is not a defined FERC service, but is obtained from intra-hour and hourly energy markets.

5. ***Dispatchable Energy:*** Dispatchable energy is closely related to load following and ramping. The primary difference is that dispatchable energy focuses on the energy consumption at times of peak capacity requirements and minimum load while load following focuses on the rate of change in generation and consumption, i.e., the ramping requirements. Both can be obtained from sub-hourly and hourly energy markets and/or the movements of the marginal generators or loads.

6. ***Contingency Spinning Reserve*:** Generation (or responsive load) that is poised, ready to respond immediately, in case a generator or transmission line fails unexpectedly. Spinning reserve begins to respond immediately and must fully respond within ten minutes (or potentially 15 minutes according to the revised NERC DCS requirement). Enough contingency reserve (spinning and non-spinning) must be available to deal with the largest failure that is anticipated.

7. ***Contingency Non-Spinning Reserve:*** Similar to spinning reserve, except that response does not need to begin immediately. Full response is still required within 10 minutes, however.

8. ***Replacement or Supplemental Reserve:*** An additional reserve required in some regions. It begins responding in 30 to 60 minutes. It is distinguished from non-spinning reserve by the response time frame.

9. ***Variable Generation Tail Event Reserve: Reserves*** that are available to cover infrequent, but large ramps of variable generation. The requirements for such reserves are very similar to conventional contingency reserves in that response is only required infrequently. The difference is that large variable generation ramping events are typically slower than conventional contingencies. While a conventional contingency happens instantly, a large variable energy resource ramp will typically take two hours or longer for the full ramp. NERC reliability rules require contingency reserves to be restored within 90 minutes, making most variable generation tail events too slow to effectively use conventional contingency reserves. A reserve that is able to maintain

response for two hours or longer may be required to respond to large, infrequent variable energy resource ramps.

10. ***Voltage Support:*** Resources that can provide voltage control to maintain system voltage levels within specified criteria.

High penetrations of variable generation will increase the need for the stated flexibility and reliability functions. As such, additional sources of flexibility may need to be used to maintain reliability and/or improve operational efficiency. This report describes the potential of non-traditional, emerging sources of flexibility in providing the reliability functions required to maintain system security and reliability. Specifically, this report describes the potential reliability contributions of the following emerging resources:

- Demand Response
- Bulk system central energy storage
- Distributed stationary energy storage
- Distributed non-stationary energy storage (e.g., electric vehicles)

The report provides an evaluation of the capability of each of these categories of emerging resources to contribute to the reliability services identified in the preceding list.

Chapter 2: Flexible Resource Technology Descriptions

Introduction

The resources examined in this report are Demand Response, stationary energy storage, and non-stationary energy storage in the form of plug-in electric vehicles. Demand Response and several forms of bulk system stationary energy storage have been in use for many years, while smaller distributed stationary storage and plug-in vehicles are relatively new. However, both technological and procedural advances are creating new opportunities for these resources.

Demand Response

Demand Response has been effectively used in the electric power industry for decades. Advances in communications and controls technologies are expanding the ability of all types of consumers to both respond to system operator directives and to respond to price signals. Demand Response is not a single technology. Rather, Demand Response is any technology that controls the rate of electricity consumption rather than the rate of generation. FERC defines the term Demand Response to include "consumer actions that can change any part of the load profile of a utility or region, not just the period of peak usage."[6] FERC goes on to recognize Demand Response as including devices that can manage demand as needed to provide grid services such as regulation and reserves, and changing consumption for the "smart integration" of variable generation resources.[7] There are numerous existing Demand Response technologies. The report focuses on new Demand Response technologies and on Demand Response technologies that are particularly well suited to help integrate variable renewable generation.

Example: Residential Air Conditioning Response

Residential air conditioning (AC) provides an example of an existing demand response technology. Residential AC response programs can provide peak reduction and they can provide contingency reserves. They can also be credited with capacity value. Residential AC can also participate in real time pricing programs. Residential AC response is particularly valuable because it is typically available during peak load times when energy and ancillary services are expensive and when generation is typically in short supply. Residential AC response is not particularly well correlated with wind generation variability, however. This does not mean that residential AC response should not be used to help balance wind but rather that it should be used, along with all other balancing resources, if it is available when a wind ramp event occurs.

Demand Response technologies that meet established performance criteria could provide power system balancing needs including the integration of renewable generation. Different

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[6] National Action Plan on Demand Response, Federal Energy Regulatory Commission, p. 7, http://www.ferc.gov/legal/staff-reports/06-17-10-demand-response.pdf .

[7] National Action Plan on Demand Response, p. 7

technologies will be successful for different applications in different locations, depending on the specific characteristics of the local loads, as indicated by the above example.

NERC and the North American Energy Standards Board (NAESB) characterize the full range of Demand Response options as shown in Figure 2-1 below. Demand Response can be very fast, as with under frequency load shedding, very slow, as with efficiency improvements, or anywhere in between. ERCOT currently obtains half of its responsive (spinning) reserves (1,150 MW of the 2,300 MW total) through a Demand Response product called Loads-Acting-As-Resources (LAARs). These customers have under-frequency relays set to 59.7 Hz so that they automatically trip off-line during under-frequency events. During emergency conditions, these loads will also disconnect upon receiving instructions from ERCOT. ERCOT also has an Emergency Interruptible Load Service (EILS), a separate program of loads that will separate from the system during emergency conditions upon receiving instructions from ERCOT.

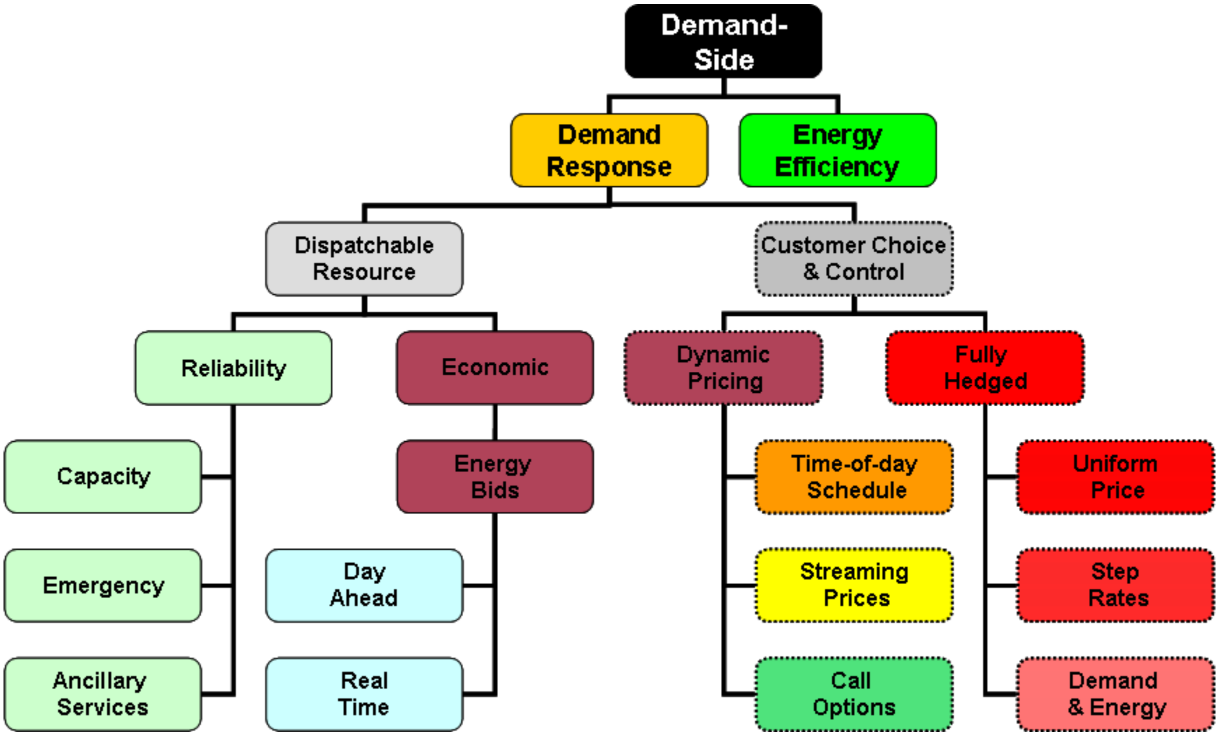

Figure 2-1 NERC and NAESB categorization of Demand Response.

NERC and NAESB characterize Demand Response as either being "Dispatchable Resource" or "Customer Choice and Control". Dispatchable Resources give the power system operator either direct physical or administrative control of the load's power consumption. Customer Choice and Control response is based on the consumer's voluntary response to price signals. Both types of programs can be effective in obtaining reliable response from loads. Figure 2-2 shows the significant amount of Demand Response currently being used in each of the NERC regions.

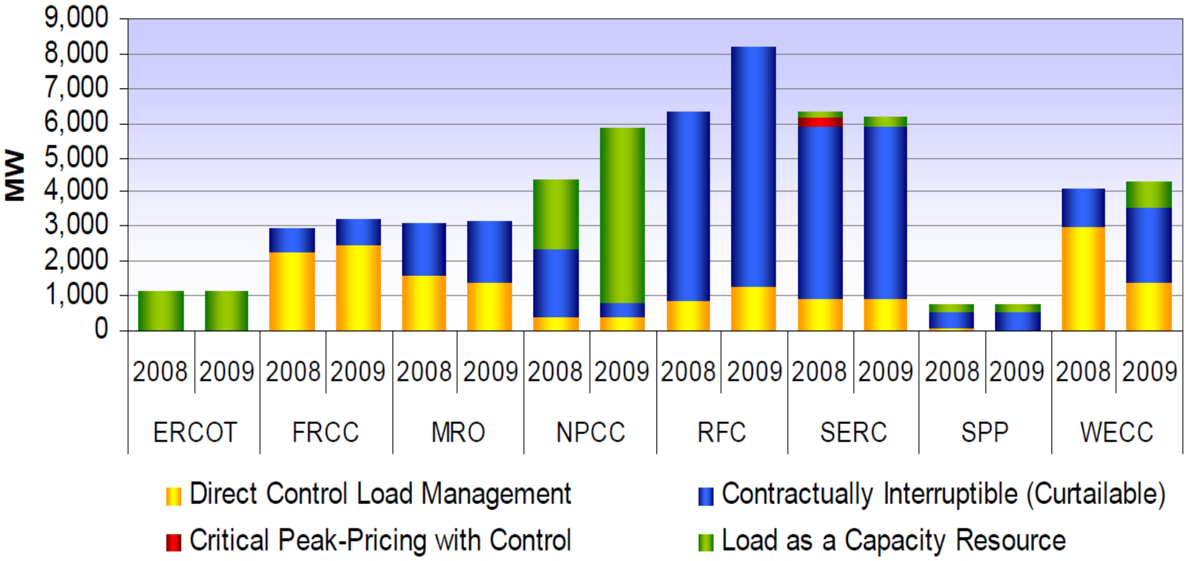

Figure 2-2: Existing Demand Response resource contributions by NERC Region and program type[8]

Using Demand Response as a capacity or energy resource in wholesale electricity markets is a relatively new concept and grid operators are still working out how best to incorporate Demand Response resources for ramping, balancing and regulation. Organizations such as utilities, load-serving entities, grid operators, and independent third party Demand Response providers are developing ways to enable Demand Response to be used more broadly as a resource in energy, capacity, and ancillary services markets. New types and applications of Demand Response are emerging due to technology innovations and policy directives. These advances have made it both technically feasible and economically reasonable for consumer response to signals from a utility system operator, load-serving entity, RTO/ISO, or other Demand Response provider to be deployed to provide reliability services to the bulk system.

From the loads' perspective, in addition to the technical requirements of the reliability function to be provided such as response speed, frequency, and duration, other important characteristics include sensitivity to electricity price and storage capability. Storage of intermediate product or energy at the load's premise is valuable to enable the load to respond to power system needs without hurting the loads' primary function.

The majority of Demand Response programs currently in use are designed to reduce peak demand. Demand Response programs might also provide contingency reserves, as is the case in ERCOT. Most recently, a few loads have started to provide minute-to-minute regulation, providing an example of one extreme of Demand Response capability. Air conditioning loads (residential and commercial, central and distributed) can be ideal suppliers of spinning and non-spinning reserves. Many pumping loads are good candidates (water, natural gas, and other gasses). Any industrial process with some manufacturing flexibility is a good candidate (cement, paper, steel, aluminum, refining, air liquefaction, etc.). For example:

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[8] North American Electric Reliability Corporation, *2009 Summer Reliability Assessment*, May 2009, p. 10, http://www.nerc.com/files/2009_LTRA.pdf

1. **Aluminium Smelter:** Alcoa modified its Warrick, Indiana aluminium smelter to provide regulation when the MISO ancillary service market opened in January 2009.[9] Warrick provides regulation by continuously adjusting pot line voltage in response to MISO AGC signals. Pot line chemistry and temperature must be continuously monitored and controlled in response to the power changes. This is an impressive accomplishment for a process that was designed and optimized to operate at a constant power level. A plant that was designed with regulation in mind from the start could likely provide significantly more response. Alcoa operates ten aluminium smelters and associated facilities in the U.S. with a combined average load of 2,600 MW representing a significant Demand Response potential. Many other industries can provide similar or greater response. At least one other industrial load is preparing to supply regulation to the NYISO.

   Evaluating the potential for a load to provide regulation involves: 1) a technical assessment of the end-use equipment and the underlying process' to determine if control is possible, 2) an assessment of the capabilities of the specific factory where the implementation is proposed, 3) an evaluation of the required communications and control equipment including the equipment costs, 4) an evaluation of any increased process losses and maintenance costs, 5) an evaluation of the lost opportunities when the factory production capacity is switched from making product and is instead used to supply regulation, and 6) a comparison of the expected benefits from selling regulation with the expected costs (including program startup costs) involved in supplying regulation. The physical and economic analyses are heavily intertwined.

2. **Oil Extraction from Tar Sands and Shale Deposits:** On-site heating of oil deposits represents a potentially large and extremely responsive load. There are large deposits of shale oil that may be able to be economically extracted by heating the oil in place before pumping. Two electric power technologies are being tested and show promise of being commercially viable: resistance heating and Radiofrequency (RF) energy. In both cases, electric heaters are placed in the rock formation and warm the oil deposit in about a month. What makes these loads so interesting from a power system perspective is the decoupling of the load's time constant from that of the power system. While the load needs a month of electric heating only the average energy is important. Heater power level can be controlled as rapidly as desired (sub-cycle n the RF heater case) to provide any response that is helpful to the power system. The load will likely be price responsive and avoid consumption during times of generation shortage but it can also supply regulation and contingency reserves when heating. It can also help with minimum load problems and be responsive to wind ramps in either direction. Plant size could be quite large. A 100,000 bbl/day oil shale plant will require 870 MW of average power. Oil shale deposits are estimated to be large enough to support a 10 million bbl/day industry.

Demand Response technologies not only respond to the signals of a load-serving entity or other Curtailment Service Providers, but may also be designed to respond to conditions of the bulk power system, such as a change in system frequency. Competitive market forces enabled by

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the deployment of advanced metering infrastructure and dynamic pricing are expected to continue to support increased Demand Response and greater consumer control over energy use. Demand Response-based energy resources have the potential to support bulk system reliability as variable generation increases the need for certain reliability services. To fully realize the potential contributions from demand response, however, regulatory and institutional barriers need to be addressed, as described in Chapter 4 as part of the *"Demand Response – Timeline for Deployment and Associated Potential Risks"* section.

Stationary Energy Storage

The basis for most of the following description of energy storage technologies is based on EPRI energy storage resources.[10, 11]

Energy storage has the potential to offer much needed capabilities to maintain grid reliability and stability. Other than pumped hydro facilities, however, a limited number of large-scale energy storage demonstration projects have been built. With increasing requirements for system flexibility as variable generation levels increase and predicted decreases in energy storage technology costs, bulk system and distributed stationary energy storage applications may become more viable and prevalent.

Storage may be used for load shifting and energy arbitrage – the ability to purchase low-cost off-peak energy and re-sell the energy during high peak, high cost periods. Storage also might provide ancillary services such as regulation, load following, contingency reserves, and capacity. This is true for both bulk storage, which acts in many ways like a central power plant, and distributed storage technologies.

Figure 2-3 shows compares various energy storage options based on typical device power capacity relative to discharge time. As such, each technology can be categorized as to typical system applications for which they are applied.

Pumped Hydro Storage

Pumped hydro, which has been in use for more than a century and accounts for most of the installed capacity of bulk storage. With approximately 40 pumped hydro facilities operating in 19 states, pumped hydro provides about 22 GW of capacity with 10 or more hours of energy storage. Pumped storage is used on very large scales with most installations sized for more than 100 MW and able to store several hundred MWh of energy. Pumped storage facilities consume energy at low cost periods to pump water from a reservoir at low elevation to another reservoir at higher elevation. The water from the upper reservoir can then be released through hydroelectric turbines to regenerate electricity as needed. Due to the size required to achieve economic viability, pumped hydro plants are built as large transmission interconnected plants. A proven technology with a long track record, pumped hydro offers many benefits, however companies seeking to construct new facilities face obstacles. Pumped hydro is only economical on a large scale, and construction can take more than a decade requiring a number

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[10] *EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications,* EPRI, Palo Alto, CA, and the U.S. Department of Energy, Washington, DC: 2003. 1001834

[11] *EPRI-DOE Handbook Supplement of Energy Storage for Grid Connected Wind Generation Applications,* EPRI, Palo Alto, CA, and the U.S. Department of Energy, Washington, DC: 2004. 1008703

of environmental permits. Therefore, a significant increase in pumped hydro storage capacity is not likely unless bulk storage is incentivized and the full range of benefits are monetized.[12]

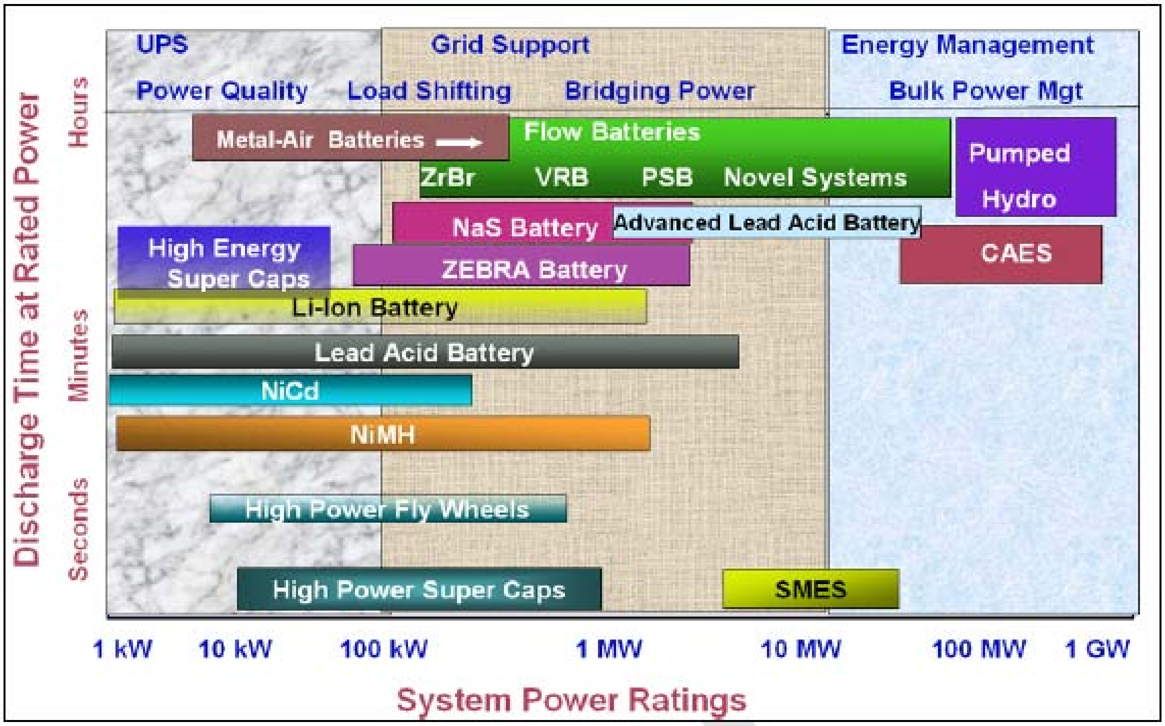

Figure 2-3 Energy Storage Options: Discharge Time vs. Capacity Ratings. [13]

Compressed Air Energy Storage

Compressed air energy storage (CAES) plants consume energy to compress air that is stored in a pressurized reservoir. The compressed air can then be used to generate electricity by heating it and passing it through an expansion turbine. The heat input is often delivered through the combustion of natural gas, in which case, the CAES plant can be considered a simple-cycle combustion turbine for which the compressor and expander can operate independently and at separate times. Like pumped storage, CAES plants are usually designed on large scales, with power ratings in the hundreds of MW and the capability to deliver that power for several hours. Two CAES plants have been built to date, one in Germany and the other in the U.S., but there is currently increased interest in developing CAES in the U.S. with multiple utilities participating in demonstration efforts[14]. CAES plants are well suited for reducing transmission curtailment of wind plants and time shifting the delivery of energy to more valuable time

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[12] *Opportunities in Pumped Storage Hydropower: Supporting Attainment of our Renewable Energy Goals", Miller, R.R. and Winters, M, Hydro Review, July, 2009*

[13] *Energy Storage Program: Electric Energy Storage Technology Options: Primer on Applications, Costs and Benefits*, EPRI, Palo Alto, CA: 2009.

[14] Eric Wesoff, "EPRI on Renewable Energy: Compressed Air Energy Storage," January 14, 2010, http://www.greentechmedia.com/articles/read/epri-on-renewable-energy-compressed-air-energy-storage/

periods. Smaller CAES systems have been proposed that may be suitable for use at the distribution scale, but such facilities are not yet commercial.

Solid Electrode Electrochemical Batteries

Lead-acid, nickel-cadmium, sodium-sulfur, and lithium ion batteries (among others) are rechargeable electrochemical batteries. Electrochemical batteries store energy in chemical form by using input electricity to convert active materials in the two electrodes into higher energy states. The stored energy can then be converted back into electricity for discharge later. Lead-acid batteries are the oldest and most mature form of rechargeable electrochemical battery. Lead-acid batteries use lead electrodes in sulfuric acid electrolyte. They have been in commercial use for well over a century with several applications at both distribution and transmission levels including the Southern California Edison Chino plant and the Puerto Rico Electric Power Authority Sabano Llano plant. Most of the lead-acid battery systems were considered technical and economic successes, but the initial expense of such plants and their uncertain regulatory status resulted in limited follow-up to these projects.

Nickel-cadmium batteries are similar in operating principal to lead-acid batteries, but with nickel and cadmium electrodes in a potassium hydroxide electrolyte. The best-known utility project constructed with nickel-cadmium batteries is the Golden Valley Electric Association Battery Energy Storage System (GVEA BESS), completed in 2003 in Fairbanks Alaska. The GVEA BESS is sized to provide 27 MW for 15 minutes or 46 MW for 5 minutes. It is used primarily for spinning reserve for the Fairbanks region.

Sodium-sulfur batteries are based on a high-temperature electrochemical reaction between sodium and sulfur. The Tokyo Electric Power Company (TEPCO) and NGK Insulators, Ltd., have deployed a series of large-scale demonstration systems, including two 6 MW, 48 MWh installations at TEPCO substations. In 2002, the first NAS battery was installed in the U.S. at an American Electric Power (AEP) laboratory at Gahanna, Ohio. Sodium-sulfur batteries are expected to be considered for peak shaving and load leveling applications at the distribution level if costs decrease.

Lithium ion batteries are relatively new to utility-scale application, despite their dominant position in the portable electronics market. Nevertheless, they have already been deployed in several grid-scale applications, primarily to provide frequency regulation. A 1 MW demonstration system was installed at the headquarters of PJM in late 2008. A 12 MW lithium installation was put into commercial operation in Chile in November 2009 to provide frequency regulation and spinning reserve services[15].

Liquid Electrode Electrochemical (Flow) Batteries

Flow batteries are electrochemical batteries that use liquid electrolytes as active materials in place of solid electrodes. These electrolytes are stored in tanks sized in accordance with application requirements, and are pumped through reaction stacks which convert the chemical energy to electrical energy during discharge, and vice-versa during charge. Flow batteries are attractive for long duration discharge applications requiring energy to be delivered for several

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[15] Megawatt-Class Lithium Ion Energy Storage Systems: Generator Frequency and Voltage Control Services. EPRI, Palo Alto, CA 2009. 1017819

hours. The nature of flow battery systems makes them particularly suited to large-scale systems. Flow batteries are a relatively immature technology and have not yet been tested widely. There are several types of flow batteries of which two types are available commercially: vanadium redox flow batteries and zinc-bromine batteries.

Flywheel Energy Storage

Flywheels store energy in the angular momentum of a spinning mass. During charge, the flywheel is spun to the desired speed by a motor with the input of electrical energy; during discharge, the same motor acts as a generator, producing electricity from the rotational energy of the flywheel. Flywheels are capable of several hundred thousand full charge-discharge cycles and so enjoy much better cycle life than batteries. They are capable of very high cycle efficiencies of over 90 percent, and can be recharged as quickly as they are discharged. Beacon Power Corporation manufactures high energy-density flywheels for frequency regulation applications at the transmission level. Beacon currently has 3 MW of flywheels operating in the ISO-NE market and 60 MW under development in 3 other projects in the NYISO and MISO markets.[16]

Thermal Storage

Thermal storage works by keeping a fluid in an insulated thermal reservoir above or below the temperature required for a process or load. A common application is production of ice or chilled water (or other fluid) for later use in space cooling. Similarly, water or other fluid can be heated for later use in space heating later. Distributed-connected thermal energy storage options are commercially available, and the application is typically peak shaving or demand shifting in response to time-of-day rates. Energy density is much higher when there is a phase change involved (e.g., conversion of water to ice). This method is called latent heat storage, and is offers advantages versus sensible thermal storage (no phase change) when size and weight are an important considerations. Like residential and commercial AC, distribution-connected thermal storage can be cycled over short time-frames to provide regulation and load following. From the bulk system point of view, distribution-connected thermal storage is a form of Demand Response.

Large-scale thermal energy storage is also feasible, and electricity generation is one of the applications. Latent or sensible thermal storage is part of the design of concentrating solar power (CSP) plants. Latent thermal storage, which involves melting a salt or wax into a liquid, is often used in tower-based CSP. The amount of energy storage can be very significant (up to 8 hours). An obvious application of this storage is energy dispatch, with the goal of delivering a significant portion of the solar energy during periods of high load demand. However, large-scale thermal storage can also allow CSP plants to cycle more often and provide power balancing services. Thus, integrating thermal storage with a CSP plant firms the output of the plant allowing the solar plant to be dispatched and provide all of the services of a dispatchable plant. From the grid interface point of view, CSP plants are conventional steam-driven generators, and therefore provide inertia response and voltage support like any other synchronous generator would.

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[16] Chet Lyons, “Application of Fast-Response Energy Storage in NYISO for Frequency Regulation Services,” Presented at the UWIG SPRING TECHNICAL WORKSHOP, April 15, 2010.

Plug-in Electric Vehicles

Policy makers and energy industry professionals foresee the modernization of the electric grid moving forward in partnership with the electrification of the transportation sector. The development and use of the plug-in electric vehicles (PEV) typify this nexus. While PEVs may eventually present a significant new load on the electrical system, they may also provide new opportunities for improved operational management and gird efficiency. PEV can be organized according to three broad categories:

- **Plug-in Hybrid Electric Vehicles (PHEV):** Vehicles that contain an internal combustion engine and a battery that can be recharged through an external connection to an electricity source. They have larger batteries than traditional hybrid vehicles (2-22 kWh) that allow them to be operated in an all-electric driving mode for shorter distances, while still containing an engine, effectively making giving them an unlimited driving range.
- **Extended Range Electric Vehicles (EREV):** PHEVs with larger batteries (16-27 kWh) are capable up 40-60 miles on a single charge—the longest range of all-electric driving options. An EREV's battery can be recharged from an electrical connection or the internal combustion engine providing for unlimited range.
- **Battery Electric Vehicles (BEV):** All-electric vehicles with no supplemental on-board combustion engines. BEVs have the largest of the PEV batteries (25-35 kWh) and require re-charging from an external source of electricity at the end of their driving range, which varies greatly, between 60 and 300 miles depending on the vehicle.[17]

As these technologies mature and evolve, their connection with the electric power system is likely to evolve. While the initial PEV products may simply draw power from the grid for purposes of recharging batteries, future vehicle-to-grid interconnections might allow vehicles to supply electricity back to the grid as needed. Vehicle-to-Grid (V2G) technology would use the stored energy in electric vehicle batteries to contribute electricity back to the grid when the grid operators request it. While, still several years away from any commercial application, there are numerous industry research efforts have been conducted to evaluate the viability and benefits of the concept.

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[17] *Assessment of Plug-In Electric Vehicle Integration with ISO/RTO Systems,* KEMA, Inc and Taratec Corporation, ISO/RTO council, March 2010, p. 13.

Chapter 3: Overview of Related Study Work

Introduction

While still a relatively new effort, the research and analysis related to the integration of flexible resources to address variability and uncertainty in power systems is a growing field. Significant effort is associated with identifying the role that both emerging and established technologies might play in mitigating the supply variability and uncertainty associated with variable generation. This section presents a review of recent research and analysis of Demand Response, bulk system energy storage, distributed stationary energy storage, and distributed non-stationary energy storage. The overview reviews significant work conducted by leading research and policy institutions such as the Federal Energy Regulatory Commission, the International Energy Agency, the National Renewable Energy Laboratory, Oak Ridge National Laboratory, the North American Electric Reliability Corporation, the Electric Power Research Institute, and public-private research partnerships involving major utilities and academic institutions.

Demand Response

A wide range of studies are available on Demand Response approaches, technologies, barriers, and markets. The studies, however, do not often focus on Demand Response as a reliability resource as this is a recent development for this field. As provided by Section 529 of the Energy Independence and Security Act of 2007, the Federal Energy Regulatory Commission is charged with preparing an Assessment of Demand Response, a National Action Plan for Demand Response, and a joint FERC-DOE Implementation Proposal. FERC completed the Assessment of Demand Response in June 2009, including providing a national estimate of the technical potential for Demand Response in five- and ten-year horizons according to four scenarios. Under the full participation scenario, the most aggressive scenario, which assumes national deployment of advanced metering infrastructure and dynamic pricing, the FERC assessment finds the Demand Response potential to be 188 GW by 2019. Under the business-as-usual scenario, the FERC Assessment estimates 37 GW of Demand Response would be achieved by 2019.[18]

FERC submitted its draft National Action Plan on Demand Response for public comment in March 2010. The draft report outlines three categories of strategies and actions to advance Demand Response: Communications Programs, Assistance to States, Tools and Materials.[19] The last category refers to tools for incorporating Demand Response in dispatch, ancillary services, transmission, and resource planning. FERC finds that there is a need for new tools and methods to more directly incorporate Demand Response into dispatch algorithms and resource planning models. Subsequently, the Action Plan contemplates the development of tools to enable Demand Response resources to provide reliability and ancillary services in the electricity markets.[20] Furthermore, FERC issued a Notice of Proposed Rulemaking on March 18, 2010, seeking comment on requiring organized wholesale energy markets (RTOs and

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[18] A National Assessment of Demand Response Potential, Federal Energy Regulatory Commission, Staff Report, June 2009, p. 27. Available: http://www.ferc.gov/legal/staff-reports/06-09-demand-response.pdf

[19] National Action Plan on Demand Response

[20] National Action Plan, pp 75-76.

ISOs) to pay Demand Response providers the market price for energy and whether regional differences among markets justify the wide range of prices available to Demand Response resources.[21]

Recognizing that Demand Response is an important component in the portfolio of resources required to reliably meet increasing demands for electricity, NERC created the Demand Response Data Task Force in December of 2007. To keep up with the growing penetration of Demand Response resources and the power sector's growing reliance on these resources, NERC established a plan to enhance its data collection and reliability assessment process to highlight emerging programs and demand-side service offerings, which can impact bulk power system reliability. [22] The Demand Response Availability Data System (DADS) Phase I & II report was issued by NERC in September 2009. The report lays out the process for moving forward with a data collection effort on Demand Response under the Demand Response Availability Data System (DADS). DADS will be deployed in two phases. Phase I establishes a voluntary Demand Response reporting system as a pilot program to be launched mid 2010. Phase II is a mandatory data collection system for all electricity operators with dispatchable Demand Response resources. The findings of the DADS project and the impact on reliability as measured by NERC's analysis of the data will provide important information with respect to the ability of Demand Response to provide additional reliability and ancillary services.

In Order No. 719, FERC established a number of requirements for RTOs and ISOs, with the express goal of eliminating barriers to Demand Response participation in organized energy markets by treating Demand Response resources comparably to other resources. Among other requirements, Order No. 719 provided that:

> *All RTOs and ISOs must incorporate new parameters into their ancillary services bidding rules that allow demand response resources to specify a maximum duration in hours that the demand response resource may be dispatched, a maximum number of times that the demand response resource may be dispatched during a day, and a maximum amount of electric energy reduction that the demand response resource may be required to provide either daily or weekly.*[23]

The CAISO issued a report on April 28, 2009, *Demand Response Barriers Study (per FERC Order 719*), which includes an analysis of market and regulatory barriers to Demand Response. The CAISO included the *Demand Response Barriers Study* as part of its compliance filing under Order 719. The report finds that Demand Response resources cannot provide the full range of ancillary services as required under FERC Order 719. The CAISO allows Demand Response resources to participate in competitive ancillary service markets to the extent they are able to comply with technical requirements, for example, as non-spinning reserves. Furthermore, although not defined as an ancillary service, Demand Response resources may

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[21] FERC Notice of Proposed Rulemaking, *Demand Response Compensation in Organized Wholesale Energy Markets*, issued March 18, 2010.

[22] Demand Response Availability Data System (DADS) Phase I & II, North American Electric Reliability Corporation, September 1, 2009, pp. 4-5.

[23] *Wholesale Competition in Regions with Organized Electric Markets*, FERC Order No. 719, at P 81.

bid resources into the market for imbalance services. However, the technical requirements of the CAISO Tariff, which reflect the Western Electric Coordinating Council (WECC) operating standards, limit the participation of Demand Response resources for regulation and spinning reserves. WECC standards requiring generation-based ancillary services preclude Demand Response resources from participating in spinning reserve markets.[24] The study on Demand Response barriers finds that the California market has a fairly robust and expanding portfolio of regulatory-driven Demand Response programs that are a mix of price- and reliability-based designs. However, there are barriers for Demand Response resources to be part of Ancillary Services markets, which may limit their use to provide flexibility.

Energy Storage

The Energy Advisory Committee (EAC) provides advice to the U.S. Department of Energy in implementing the Energy Policy Act of 2005, executing the Energy Independence and Security Act of 2007, and modernizing the nation's electricity delivery infrastructure. In December 2008, the EAC submitted a report to Congress entitled, *Bottling Electricity: Storage as a Strategic Tool for Managing Variability and Capacity Concerns in the Modern Grid*. The EAC report identifies five significant benefits of storage technologies:

1. Improving gird optimization for bulk power production
2. Facilitating power systems balancing in systems that have variable or diurnal renewable energy sources
3. Facilitating the integration of plug-in electric vehicle power demands with the grid
4. Deferring investments in transmission and distribution (T&D) infrastructure to meet peak loads (especially during outage conditions) for a time
5. Providing ancillary services directly to grid/market operators[25]

The EAC finds that one source of regulatory uncertainty stems from the fact that energy storage can be related to generation, transmission or demand resources. This regulatory uncertainty hampers deployment of storage technologies. Utilities are unlikely to move forward with deployments of the technologies without assurance of cost recovery, and the private sector is not likely to make significant investments in projects without utility buy-in or partnerships. Rather than invest in an energy storage technology, the EAC finds that a utility is more likely to invest in a generation or transmission project that can achieve the same objective. The EAC suggests that regulators work to define the technologies as a class of assets within the generation, transmission, distribution, or distributed/end-user sectors according to ownership and application. Regulators should then establish appropriate regulations on the use of energy storage and appropriate cost recovery mechanisms. [26]

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[24] California Independent System Operator Demand Response Barriers Study, p. 32.

[25] *Bottling Electricity: Storage as a Strategic Tool for Managing Variability and Capacity Concerns in the Modern Grid*. Report by the Energy Advisory Committee, December 2008, p. 3.

[26] *Bottling Electricity: Storage as a Strategic Tool for Managing Variability and Capacity Concerns in the Modern Grid*. Report by the Energy Advisory Committee, December 2008, pp. 15-17.

Bulk Energy Storage

An Electric Perspectives article reviews some of the operating characteristics of both traditional and modern energy storage technologies. Pumped hydro plants absorb excess electricity produced during off-peak hours, provide frequency regulation, and help smooth the fluctuating output from other sources.[27] CAES, offering shorter construction time and greater siting flexibility, is a leading alternative for bulk storage. CAES appears to be a cost effective storage alternative, with installation costs of approximately $550 per kilowatt and a relatively low per-hour stored cost.[28]

Large batteries, although more expensive, can provide many of the same functions as compressed air energy storage. In addition to providing spinning reserves, regulation and assisting with renewables integration, batteries offer power quality and reliability benefits to customers. Sodium sulphur batteries are well suited for utility applications due to their longer life, better storage efficiency, and lower maintenance. American Electric Power installed a 1.2 MW sodium sulphur battery in 2002 to defer transmission and distribution investments in West Virginia. The battery was operational in the 2006 summer peak season and successfully shifted power demand from on-peak to off-peak periods.[29] Another benefit of batteries is that they can be located at or near end-users providing peak management.

Perhaps the oldest storage technology, flywheels are a proven technology with a fast response and excellent storage efficiencies. Typical applications for flywheels include ride-through or back-up power. Large-scale applications of flywheel technologies include frequency regulation for the power grid, providing ancillary services. In these installations, the flywheels inject or absorb power to and from the grid in response to the grid operator's signals.[30]

The Bonneville Power Administration (BPA) sought the expertise of the Pacific Northwest National Laboratory to evaluate and compare available energy storage options specifically to help better integrate wind power facilities with variable generation resources.[31] The project developed principles, algorithms, market integration rules, functional design and technical specification for the Wide Area Energy Storage and Management System (WAEMS). The project specifically addresses the issue of fast ramps that occur at higher penetrations of variable generation, including wind generation, in the BPA and CAISO control areas. The project team selected a flywheel, pumped or conventional hydro plants, and sodium sulfur or nickel cadmium batteries for further analysis.[32] One pumped hydro plant in the BPA area and a flywheel in the CAISO service area were strategically located, , with shared controllers and communication selected to test compatibility with BPA and CAISO, operating procedures,

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[27] *New Demand for Energy Storage*, Dan Rastler, Electric Perspectives, September/October 2008, p. 35.

[28] *New Demand for Energy Storage*, Dan Rastler, Electric Perspectives, September/October 2008, p. 36.

[29] *New Demand for Energy Storage*, Dan Rastler, Electric Perspectives, September/October 2008, p. 37-39.

[30] *New Demand for Energy Storage*, Dan Rastler, Electric Perspectives, September/October 2008, p. 46-47.

[31] Y.V. Makarov, et. Al, *The Wide-Area Energy Storage and Management System to Balance Intermittent Resources in the Bonneville Power Administration and California ISO Control Areas,* Prepared for the Bonneville Power Administration by the Pacific Northwest National Laboratory, June 2008.

[32] Y.V. Makarov, et. Al, *The Wide-Area Energy Storage and Management System to Balance Intermittent Resources in the Bonneville Power Administration and California ISO Control Areas,* Prepared for the Bonneville Power Administration by the Pacific Northwest National Laboratory, June 2008. P. xv.

technical requirements, market processes and other system protocols.[33] The effectiveness of the energy storage in providing regulation was tested and the cost benefits of the installations modelled. The results found that the WAEMS service could help to reduce the regulation requirement in these control areas by about 30 percent. The Cost benefits analysis finds that both the pumped hydro and flywheel energy storage devices would provide high net present values and were comparable for both technologies. Both technologies should be considered competitive. Alternatively, similar analysis for the battery technologies found that they have a negative net present value, but that the conclusion concerns applications for regulation services only. Other power system applications may be more cost effective. [34]

In a paper presented at the American Wind Energy Association's Windpower 2008 Conference in Houston Texas, Patrick Sullivan, Walter Short and Nate Blair quantify the value that storage technologies might provided to wind power. The analysis makes use of the Regional Energy Deployment System model (ReEDS) and compares a business as usual wind penetration scenario with a 20 percent wind penetration scenario with and without storage technologies. The storage technologies considered are pumped-hydroelectric, compressed air energy storage, and battery storage, primarily used in a bulk storage capacity.

The ReEDS model establishes a business as usual baseline that is based on data provided by the *Annual Energy Outlook for 2006*, representatives from Black & Veatch, who provide cost data for conventional generation, and the *Wind by 2030* report. The business-as-usual case was run with two scenarios, one that allowed for storage, and one that did not. All of the storage built in the model is CAES due to the lower capital cost of the technology. Under the scenario that allowed for storage, an addition 50 GW of wind power was able to be built by 2050. The storage and wind both grow until about 2042 at which point storage grows in support of nuclear generation and not wind (Figure 3-1).

Under the 20 percent by 2030 wind scenario, the model is required to increase development and generation by wind power facilities so that 20 percent of the U.S. electricity supply is coming from wind power from 2030 and beyond. Once again, the model assessed two scenarios, one with storage and one without. In the scenario that allowed for storage the price of electricity is lower by $2/MWh in 2050. The price difference is partially attributed to the reduced need for new conventional capacity, specifically combustion turbines.

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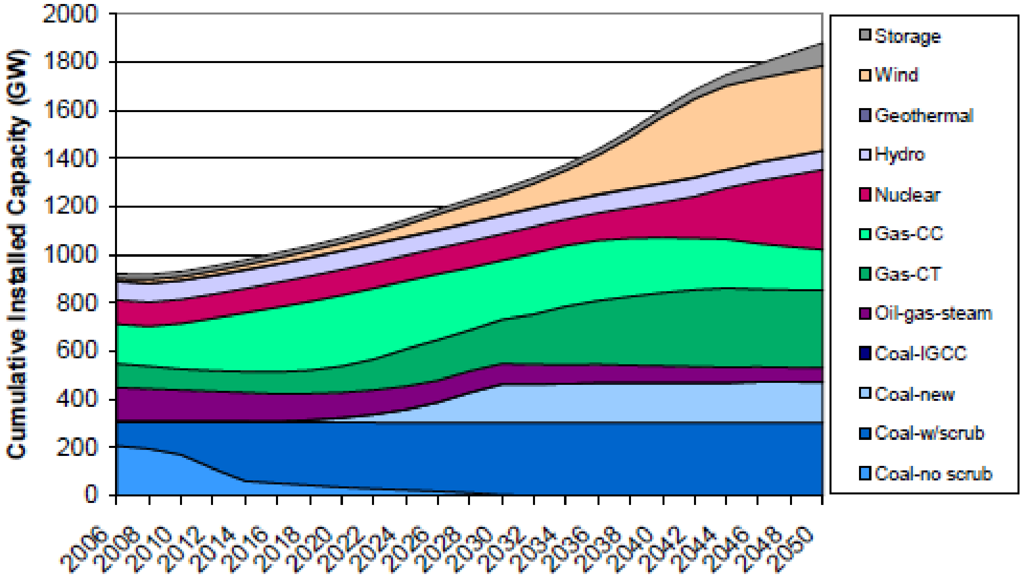
[33] Y.V. Makarov, et. Al, *The Wide-Area Energy Storage and Management System to Balance Intermittent Resources in the Bonneville Power Administration and California ISO Control Areas,* Prepared for the Bonneville Power Administration by the Pacific Northwest National Laboratory, June 2008. p. xviii.

[34] Y.V. Makarov, et. Al, *The Wide-Area Energy Storage and Management System to Balance Intermittent Resources in the Bonneville Power Administration and California ISO Control Areas,* Prepared for the Bonneville Power Administration by the Pacific Northwest National Laboratory, June 2008. P. xxiv.

Figure 3-1: Cumulative Installed Capacity
Business-as-Usual with Storage



Source: Patrick Sullivan, Walter Short, Nate Blair, *Modeling the Benefits of Storage Technologies to Wind Power*, National Renewable Energy Laboratory, presented at the American Wind Energy Association (AWEA) Windpower 2008 Conference, Houston, Texas, June 2008, p. 8.

Comparing the business-as-usual case with the 20 percent wind by 2030 (high wind) case leads Sullivan, Short, and Blair to the conclusion that more storage capacity is built in the high wind case and the storage comes on line earlier. The finding that with more wind on-line, more storage is built, leads researchers to conclude that the storage is providing a tangible benefit to wind specifically, and not simply to the grid(Figure 3-2).[35]

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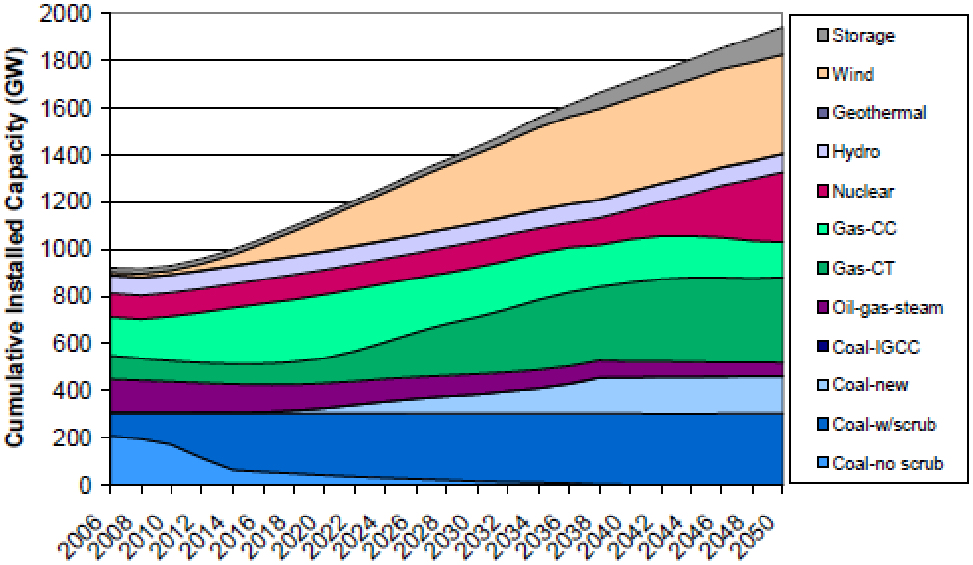
[35] Patrick Sullivan, Walter Short, Nate Blair, *Modeling the Benefits of Storage Technologies to Wind Power*, National Renewable Energy Laboratory, presented at the American Wind Energy Association (AWEA) Windpower 2008 Conference, Houston, Texas, June 2008, p. 12.

Figure 3-2: Cumulative Installed Capacity
20 Percent Wind by 2030 with Storage



Source: Patrick Sullivan, Walter Short, Nate Blair, *Modeling the Benefits of Storage Technologies to Wind Power*, National Renewable Energy Laboratory, presented at the American Wind Energy Association (AWEA) Windpower 2008 Conference, Houston, Texas, June 2008, p. 11.

Distributed Stationary Storage

Researchers with the National Renewable Energy Laboratory examined the way in which storage can be integrated with variable resources such as wind power in a report, *The Role of Energy Storage with Renewable Electricity Generation*. Storage technologies provide flexibility useful for incorporating increasing amount of variable generation into the grid. There are two general types of flexibility discussed in the report:

- Ramping flexibility, the ability to follow the variation in net load included in the second-to-minute timescale needed for frequency regulation, or in the minute-to-hours timescale needed for load following
- Energy flexibility, the ability to increase coincidence of variable generation supply with demand for electricity services[36]

While it is possible for bulk storage technologies to provide the flexibility services described above, the flexibility offered from these resources and the resulting benefits can be accentuated if the resources can be located at various points throughout the grid. Denholm, et al. find that by aggregating distributed storage technologies into the entire net load of a system, including

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[36] Paul Denholm, Erik Eka, Brendan Kirby, and Michael Milligan, *The Role of Energy Storage with Renewable Electricity Generation*, National Energy Renewable Laboratory, Technical Report NREL/TP-6A2-47187, January 2010, p. 35.

all loads, conventional supply, and variable supply, that storage flexibility options can be deployed at the lowest cost and greatest efficiency.[37]

Plug-In Electric Vehicles

A study commissioned by the Independent System Operator/Regional Transmission Organization Council (ISO/RTO Council) and prepared by KEMA and Taratec Corporation examines how PEVs might interact with the grid. The study had five primary objectives:

1. Identify operational, load, and price impacts to the North American electricity grid from light duty PEVs as their adoption increases,
2. Identify potential PEV products and services,
3. Ascertain the market design adaptations that might be necessary to incorporate PEV services into existing markets and provide a standardized approach to mobile loads,
4. Determine key technologies, communications, cyber security, and protocols required to enable PEV products and services, and
5. Determine the types of investments in Information Technology (IT) infrastructure needed to integrate the PEVs, and estimate their costs.

The availability of products and services impacting the electricity markets and operation of the power grid depends on the number of PEVs that come into the marketplace and their geographic distribution. The ISO/RTO Council's report projects the concentrations of PEVs and the ability of the PEVs to provide Demand Response resources. The ISO/RTO Council's report projects the distribution of consumer fleets, and total PEVs for each of the major ISO/RTO regions in Table 3-1. The numbers of vehicles by ISO/RTO is significant, since the ISO/RTO regions are more likely to accommodate the use of these loads as balancing and ancillary services resources.

The ISO/RTO report goes on to consider the types of services and product offerings that PEVs might bring to the electricity markets and ranks each service and product on a scale between 1 and 5 where 1 is easy and 5 is complex. The products and services include: scheduled energy, regulation, reserves, emergency load curtailment, and balancing energy. The ISO/RTO council ranks all of the services, except for balancing, as a 3, indicating that it is somewhat complicated to incorporate PEVs into these markets but with the right equipment (e.g., telemetry, two-way communication equipment) and the assistance of aggregators, PEVS will be able to provide these services and products into the markets. Balancing energy, however, received a ranking of 4 indicating that it is more difficult or complex to integrate PEVs to the balancing market.

The ISO/RTO Council's study, *Assessment of Plug-In Electric Vehicle Integration with ISO/RTO Systems*, like many other studies on PEV integration, assumes that most of the charging of vehicles, 80-90 percent, will take place in the evening and nighttime hours.[38]

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[37] Paul Denholm, Erik Eka, Brendan Kirby, and Michael Milligan, *The Role of Energy Storage with Renewable Electricity Generation*, National Energy Renewable Laboratory, Technical Report NREL/TP-6A2-47187, January 2010, p. 37.

[38] *Assessment of Plug-In Electric Vehicle Integration with ISO/RTO Systems*, KEMA, Inc and Taratec Corporation, ISO/RTO council, March 2010, p. 26, http://www.isorto.org/atf/cf/%7B5B4E85C6-7EAC-40A0-

However, absent a changing of customer utility rate structures to encourage PEV charging during off-peak times and to discourage charging during peak times, it will be difficult to force consumers to charge their vehicles during specific time-periods. Thus, it is important to understand the possible impacts from PEVs, should customers plug-in during the daytime hours.

Table 3-1. Estimated Number of PEVs in the ISO/RTO Region by 2019.

Estimated Number of PEVs in the ISO/RTO Region by 2019			
ISO/RTO	Consumer PEV	Fleet PEV	Total PEV
ISO-NE	50,780	10,294	61,074
NYISO	28,194	15,544	43,738
PJM	103,124	41,048	144,172
Midwest ISO	65,022	29,622	94,644
SPP	18,466	11,993	30,459
ERCOT	27,276	15,493	42,769
CAISO	237,698	29,956	267,654
TOTAL	530,560	153,950	684,510
Source: *Assessment of Plug-In Electric Vehicle Integration with ISO/RTO Systems*, KEMA, Inc and Taratec Corporation, ISO/RTO council, March 2010, p. 25.			

8DC3-003829518EBD%7D/IRC_Report_Assessment_of_Plug-in_Electric_Vehicle_Integration_with_ISO-RTO_Systems_03232010.pdf

Chapter 4: Flexible Resources' Reliability Functions/Capabilities

Demand Response

Capability/Feasibility of Providing System Reliability Functions

Demand Response encompasses such a broad range of technologies that select subsets of Demand Response resources can be identified that are technically capable of providing each of the balancing functions required by the bulk power system. Some services are easier for loads to provide than others and different loads are better suited to provide different responses. Characteristics of concern when evaluating Demand Response technologies include:

- Response amount – MW
- Response speed – MW/minute
- Response duration – hours
- Response frequency – calls per day or week
- Recovery time – hours
- Response availability – based on time of day, season, ambient temperature, etc.
- Required notification – immediate response versus day-ahead notification

As noted in chapter 2, Demand Response programs include dispatchable resource programs and customer choice .programs. Both types of Demand Response can provide a range of response capabilities with the dispatchable resources being required for the fastest regulation and contingency reserve response while the customer choice programs can provide hourly and sub hourly response.

The general capabilities of Demand Response for providing the standard reliability functions identified in Chapter 1 are summarized as follows:

Inertial Response

Large motor loads provide natural inertial response, just like rotating generators. While individual loads tend to be smaller than individual generators, there are more loads. The natural inertial response of loads has been declining over the past several decades, for several reasons: (1) the percentage of large industrial motor loads has been declining relative to commercial and residential loads, (2) the proliferation of variable frequency drives on motor loads which decouple the motor inertia from the power system frequency removing the natural inertial response, (3) the proliferation of higher efficiency commercial and residential air conditioners that are both lighter (lower inertia) and also increasingly controlled through variable frequency drives. While the natural inertial response of motor loads is declining, loads driven by solid-state power supplies could conceivably provide synthetic inertia by deliberately responding very quickly to power system deviations. At this time, however, there is no requirement or incentive for loads to provide inertial response. As such, distributed resources contributions to system inertial response needs is not anticipated to be significant.

Primary Frequency Response

Similar to inertial response, loads driven by solid-state power supplies could provide primary frequency response if there was a requirement or an incentive. Responding to low frequency by reducing load is, typically, more useful for supporting power system reliability and inherently easier for most responsive loads than responding to high frequency by increasing load. Aggregations of individual loads could also provide smooth primary frequency response through under frequency load tripping of individual loads at different frequencies. The aggregation could provide the equivalent of a generator droop curve. Loads that sell spinning reserve or regulation might be required to also be frequency responsive. Generally, however, the potential contribution of DR to system primary frequency response needs is expected to be low.

Regulation

Regulation is typically the most difficult ancillary service for load to provide because of the communications and control requirements. System operators send AGC commands out every 2 to 8 seconds. The load must have the capability to move both up and down rapidly and accurately. A few loads are beginning to provide regulation (see text box). To do so the load must be able to respond to system operator AGC commands to increase or decrease consumption every few seconds. While regulation is a difficult service for loads to provide, advances in communications and control now make regulation response possible. The high price paid for regulation in hourly ancillary service markets provides a strong incentive for loads to develop regulation capability. While this economic incentive will likely result in more loads providing regulation services, a significant increase in penetration will be required in order for DR to contribute significantly to system regulation needs.

Load Following/Ramping

Some loads can adjust their energy consumption in response to system operator commands or to real-time energy prices providing sub-hourly to multi-hour energy balancing. Price responsive load and peak shaving target specific hours when response is desired. Price responsive loads facilitate voluntary response to market price signals. Peak shaving uses direct control commands. Both price responsive loads and peak shaving can be used to address capacity inadequacy caused by a lack of generation or a lack of transmission. Programs that have traditionally responded to periods of peak demand, summer hours, for example, could be redesigned to respond to changes in variable generation. Simply allowing loads (residential, commercial, and/or industrial) to respond to real-time price signals will facilitate load following and ramping response. Based on the potential magnitude of load resource that technically can participate in price responsive programs with relatively low economic barriers, it is anticipated that load may contribute moderately to system load following/ramping needs in the future. This will require, however, that the regulatory and/or institutional barriers discussed subsequently be adequately addressed.

Dispatchable Energy

Load can contribute to dispatchable energy needs through traditional peak reduction. Similar to load shifting, electricity consumers can adjust consumption to support the deliberate use of energy at times of high variable generation output and low system-wide demand. When significant quantities of excess wind generation are forecast to be available there may be an opportunity for certain loads to adjust their consumption to take advantage of the low-cost surplus. Space conditioning loads might heat or cool thermal storage at night and use the stored thermal energy the following day. Industrial loads may change their operations to use night-time energy. The ability to economically use the resource depends on a reliable long-term forecast of the energy availability. Loads that are designed to make use of the surplus could also be designed to be responsive to the variability of the supply. As with Load Following/Ramping, the potential magnitude of load resource and relative low barriers to participation suggest that DR can have a moderate contribution to system dispatachable energy needs (minimum and peak load management).

Contingency Spinning Reserve Service

Supplying spinning reserve is attractive for some loads since the response duration, and therefore the interruption in the load's normal course of business, is limited. Additionally, spinning reserve is called on relatively infrequently. Response speed is critical but not overly burdensome for some loads. Space conditioning from residential and commercial loads can be an attractive source for spinning reserve as can numerous specific industrial processes. Based on the large potential resource from space conditioning and industrial loads and relative low technical barriers to participation, it is anticipated that DR may make a significant contribution to system spinning reserve requirements.

Contingency Non-Spinning Reserve

Appropriately responsive loads are typically allowed to supply non-spinning reserve. Supplying non-spinning reserve is attractive for the same reasons supplying spinning reserve is attractive, namely that the required response is infrequent and limited in duration. Similarly, it is anticipated that DR may make a significant contribution to system non-spinning reserve requirements.

Replacement or Supplemental Reserve

Appropriately responsive loads are typically allowed to supply replacement or supplemental reserve. With additional time allowed for response additional loads are typically able to provide supplemental reserves. As such, it is anticipated that DR may make a significant contribution to system non-spinning reserve requirements.

Variable Generation Tail Event Reserve

Loads that can supply replacement reserve or supplemental operating reserves will typically be able to supply variable generation Tail Event Reserves. Variable Generation Tail Event response is slow enough that market response might be effective. Sufficient time is available to allow an aggregator to obtain the required response from a fleet of individual loads with diverse characteristics. As such, it is anticipated that DR may make a significant contribution to system non-spinning reserve requirements.

Voltage Support

Demand Response is not well suited for supporting system voltage or reactive needs. Reducing loads may have small localized impact on system voltage, but the ability to supply reactive power to support bulk system voltages is limited. It is possible that future scenarios where residential and commercial loads include distributed solar photovoltaic generation that the inverters from the PV might be aggregately dispatched to support bulk system voltage, but this concept is only beginning to be considered. As such, it is anticipated that DR will have a low contribution to system voltage support needs.

Timeline for Wide-Scale Deployment and Associated Potential Risks

As noted in Chapter 3, FERC's 2009 National Assessment of Demand Response Potential provides a national estimate of the technical potential for Demand Response in five- and ten-year horizons. Under the full participation scenario, the most aggressive scenario which assumes national deployment of advanced metering infrastructure and dynamic pricing, the FERC assessment finds the Demand Response potential to be 188 GW by 2019. Under the business-as-usual scenario, which represents a continuation of existing best practices, the FERC Assessment estimates 37 GW of Demand Response would be achieved by 2019.[39]

Given this potential resource magnitude and the technical capabilities summarized in the previous section, Demand Response has the potential to provide a significant fraction of several of the reliability functions required by the power system. There are, however, potential risks to this level of Demand Response deployment and use for supplying reliability functions and services. Institutional, rather than technical barriers are the most significant obstacles to greater use of Demand Response. Loads are prevented from providing response in many areas. While ERCOT currently obtains half of its contingency reserve from responsive load, ERCOT limits the portion of required contingency reserves that can be served by loads to half as current market rules do not allow ERCOT to obtain response at staggered frequency levels. WECC currently does not allow loads to provide spinning reserve. Many state regulators do not allow retail loads to be exposed to real-time prices, effectively blocking balancing energy response. Even jurisdictions that do allow such exposure (e.g., New York, New Jersey) have seen relatively limited customer acceptance of real-time pricing (RTP).[40] Some ISOs co-optimize energy and ancillary service procurement, an excellent practice that helps both generators and the power system maximize efficiency. Unfortunately, it can turn a regulation or contingency reserve offer into a requirement to supply energy for hours. This effectively blocks both storage and responsive loads from offering regulation or contingency reserves. This is beginning to be addressed for storage but is still an effective barrier to Demand Response for reliability services.

It is difficult to predict when or if the institutional barriers that currently limit Demand Response will be addressed. Realization of Demand Response in providing reliability

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[39] A National Assessment of Demand Response Potential, Federal Energy Regulatory Commission, Staff Report, June 2009, p. 27. Available: http://www.ferc.gov/legal/staff-reports/06-09-demand-response.pdf

[40] Barbose et al., Real-Time Pricing as a Default or Optional Service for C&I Customers: A Comparative Analysis of Eight Case Studies, LBNL-57661.

functions to the grid on a large scale will require state regulators, utility managers, and other stakeholders to collectively address non-technical, institutional and/or regulatory barriers to take advantage of these resources.

In addition to the institutional and regulatory barriers, additional technical developments are also needed to facilitate large-scale deployment of DR for providing some of the specified reliability functions. Communications and control requirements are critical elements when determining whether load is capable of providing reliability reserves. Load must be controllable and dispatchable if it is to supply reliability services to the power system as would a generation resource. The controls must be fast and accurate with capabilities to communicate and receive commands from the power system operator. Faster services (spinning reserve and regulation) require an automatic response to system operator commands and in some instances changes in power system frequency. The required response speed and duration depend on the reliability service being provided.

Aggregation of smaller loads and Demand Response participants is an important component for the broad use of Demand Response. It is the combined response of the collection of responding loads that is important for power system reliability rather than the response of an individual load. An aggregator may be able to manage a fleet of loads to provide response that is more certain and predictable than can be provided by any of the individuals.[41] Again, however, this will require the development of a suitable communication and control infrastructure to support aggregator's ability to use the collective resources.

Bulk and Distributed Stationary Energy Storage (ES)

Capability/Feasibility of Providing System Reliability Functions

The suitability of energy storage technologies to provide system reliability functions varies depending on the specific requirements relative to the performance characteristics of the energy storage device. Important performance considerations for energy storage technologies include size (power) requirement, duration (energy) requirement, and frequency (cycling) requirement.

Table 4-1 shows a table based primarily on a recent EPRI white paper[42] that shows typical requirements for specified integration related applications. The following subsections summarize the capability of the various energy storage technologies to provide the nine identified system reliability functions defined in Chapter 1.

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[41] Kirby, 2006, *Demand Response For Power System Reliability: FAQ*, Oak Ridge National Laboratory, ORNL/TM-2006/565, available at www.consultkirby.com

[42] Dan Rastler, Electric Energy Storage Technology Options: Primer on Applications, Costs, and Benefits, December 31, 2009.

Wholesale System and Renewables Integration					
	Description	Size (MW)	Duration	Cycles (/yr)	Lifetime (yr)
Wholesale Markets	Ancillary services, arbitrage	200 MW	6-10 hr	500/yr	15-20 yr
	Frequency Regulation	1 MW	15 min	>8,000/yr	15 yr
	Spin Reserve	10 MW	1-5 hr		20 yr
Wind Integration	Ramp & voltage support	1-200 MW	15 min – 4 hr	5,000/yr	20 yr
	Off-peak storage	100-400 MW	5-15 hr	300-500/yr	
PV Integration	Time shift, support for voltage sag and rapid shifts	1-2 MW	15 min – 4 hr	>4,000/yr	15 yr

Table 4-1. Energy Storage Technology Requirements for Bulk System Variable Generation Integration Applications

The general capabilities of electric energy storage are:

Inertial Response

Pumped hydroelectric plants and CAES plants both interface to the grid through a rotating machine that allows them to provide inertial response just like any conventional synchronous generator. Battery energy storage plants do not include any rotating mass, but rather they interface to the grid through a power electronic front-end. Although there is no known implementation, the power electronic controls should be configurable to provide an emulation of inertial response over very short durations of up to a few seconds much like the controls being offered on some commercial wind turbine generators that have a full or partial inverter interface to the grid. While flywheels are actually first and foremost a rotating mass, they are also coupled to the grid through a power electronic interface that should allow for emulation of inertial response. Thus, all energy storage technologies should technically be capable of providing inertial response to the system with pumped storage and CAES plants require no new control implementation or design to do so. There are nearly 34 GW of pumped storage underdevelopment. However, given relatively low near-term estimates for new CAES installations and the lack of existing activity to alter controls of inverter-based storage for providing inertia response, the contribution of energy storage to system inertia requirements is estimated to be low.

Primary Frequency Response

Similar to inertial response, all energy storage technologies are capable of providing primary frequency or governor response. Pumped hydro plants must be designed with variable pumping control if they are to provide primary frequency response while pumping. This can be done with a variable speed drive (VSD), with an adjustable pump, or with simultaneous operation of the pump and the turbine ("hydraulic short circuit"). Without one of these mechanisms pumping is at a constant load. Primary frequency response is available while the plant is generating. CAES plants provide similar capabilities. The power electronics interface for battery energy storage and flywheels can be controlled to provide an equivalent frequency response. Unlike Demand Response, energy storage is not limited to responding only to frequency decreases, but can also respond to frequency increases by alternating between charging and discharging modes. As with inertial response, the likely contribution of energy storage to aggregate bulk system primary frequency response requirements is estimated to be low.

Regulation

All energy storage technologies are also capable of providing regulation. Pumped hydro and CAES plants can respond to AGC controls in the same manner as traditional hydro and gas turbine plants while generating. As with primary frequency response, pumped hydro plants can provide regulation when pumping if they are initially designed to do so. Flywheels and battery energy storage systems can use their power electronic front ends to accurately respond to AGC signals faster and more efficiently than traditional conventional generators, potentially reducing the total amount of comparable regulating reserve carried on traditional units.[43] As such, it is estimated that energy storage will provide a moderate contribution to system regulation needs in the future.

Load Following/Ramping

Pumped storage and CAES plants can follow system operator dispatch commands to provide sub-hourly to multi-hour energy balancing in the generating mode. As with primary frequency response, pumped hydro plants can provide load following or ramping when pumping if they are initially designed to do so. Battery energy storage systems can also provide dispatched balancing, with flow batteries potentially having the capability to provide the longer duration following needs. While very efficient in the shorter duration response functions, flywheels are not currently designed for providing long-duration energy response. As such, it is estimated that energy storage will provide a moderate contribution to system load following/ramping needs in the future.

Dispatchable Energy

Pumped storage, CAES, and flow batteries are all well suited to provide load-shifting capability to consume more wind generation that might be produced at low load periods and deliver the energy at high load periods. The size limitations on solid electrode batteries such as lead acid and nickel-cadmium make them less suited for such large-scale load shifting applications. Flywheels are not an option for providing this function due to their limited energy capability. Given the expected lack of significant developments of pumped storage and CAES capacities over the next 10 years, the contribution of energy storage to system minimum and peak load management is estimated to be low.

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[43] Lyons

Contingency Spinning Reserve Service

All energy storage technologies except for flywheels are well suited to provide spinning reserve. The fast response can is easily be met by all of the technologies. The amount of response available from a pumped storage plant while pumping depends on the plant design. The only limiting factor for flywheels is the duration of the response required. As such, it is estimated that energy storage may provide a moderate contribution to system spinning reserve needs in the future.

Contingency Non-Spinning Reserve

Because non-spinning reserves do not need to respond as quickly as spinning reserves, all energy storage technologies discussed, except for flywheels, are well suited to provide non-spinning reserve. The only limiting factor for flywheels is the duration of the response required. As such, it is estimated that energy storage may provide a moderate contribution to system non-spinning reserve needs in the future.

Replacement or Supplemental Reserve

Replacement or supplemental reserves do not need to respond as quickly as non-spinning reserves. All of the energy storage technologies discussed, except for flywheels, is well suited to provide replacement or supplemental operating reserve. The only limiting factor for flywheels is the duration of the response required. As such, it is estimated that energy storage may provide a moderate contribution to system replacement reserve needs in the future.

Variable Generation Tail Event Reserve

Because variable generation tails event reserves are similar to replacement or supplemental reserves all energy storage technologies discussed, except for flywheels are well suited to provide variable generation tails event reserve. The only limiting factor for flywheels is the duration of the response required. As such, it is estimated that energy storage may provide a moderate contribution to system variable generation tail event reserve needs in the future.

Voltage Support

All energy storage technologies are capable of providing voltage support.

Timeline for Wide-Scale Deployment and Associated Potential Risks

A recent EPRI study[44] analyzed the potential energy storage application market size based on the current US market for each energy storage application without consideration of the cost effectiveness of the storage application. The study provides an assessment of the technical market potential for a given application (e.g., total ancillary service market), and then determines a feasible market potential by applying energy efficiency and Demand Response

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[44] *Energy Storage Market Opportunities: Application Value Analysis and Technology Gap Assessment*, EPRI, Palo Alto, CA: 2009. 1017813

adoption rates as a proxy for energy storage adoption from the potential technical market. The feasible market is then further narrowed to a high value market by focusing on geographic regions with higher market prices for energy or ancillary services, end-users with a high willingness to pay, and/or where at least two high value applications can be combined. The EPRI study finds that the feasible market opportunities for energy storage in providing wholesale services such as energy and ancillary services excluding regulation is around 9 GW at a price point of approximately $350/kWh and a high-value market size of 5.8 GW at a price point of approximately $400/kWh. If regulation is added to the wholesale services application, the market size decreases but the value or price point increases with the feasible market found to be 3.2 GW at value of $820/kWh and the high-value market size 1.6 GW at a price point of $1,400/kWh.

The flexibility offered from energy storage is attractive, but the limiting factor to wide-scale utility deployment has generally been the lack of long-term revenue streams that have a high level of certainty of the various technologies. Typically, economic justification of energy storage requires capturing benefits across several different applications such as T&D deferral, frequency regulation, and energy arbitrage as was estimated in the EPRI study high-value market size evaluation. It can be difficult, however, to find locations that provide for monetizing all of the benefits to justify applications.

Another barrier to deployment of energy storage is market rules that prohibit non-generation resources from participating in certain markets. As noted, some markets explicitly limit or prohibit non-generation resources, such as Demand Response, from supplying certain market products. Additionally, the requirements for resources to be co-optimized into energy markets can prohibit storage resources like flywheels from supplying regulation service for which they are extremely efficient.

Plug-in Electric Vehicles (PEVs)

Capability/Feasibility of Providing System Reliability Functions

PEVs offer the potential to be ideal contributors to providing most of the noted reliability services. The solid-state chargers can control consumption rapidly and accurately limited only by the charge rates of the battery technology. Communications and controls would be required as well as an aggregator that will manage the large numbers of small-sized responding chargers. The relatively long charging window (eight to twelve hours) when compared with the relatively short charging duration (ninety minutes for a type two charger) provides a great deal of flexibility. Additional capability may exist if vehicle energy is available to be injected into the grid but this added potential capability, but this capability is not considered for the following technical capability assessments. The following are based solely on the ability to vary the charge cycle of the PEV batteries.

The general capabilities of PEVs in providing the standard reliability functions identified in Chapter 1 are summarized as follows:

Inertial Response

The solid-state chargers do not have inherent inertial response since they do not include rotating equipment. The very fast control capability, however, means that inertial response could be emulated through the inverter controls. PEV chargers have the advantage that they can both increase and decrease consumption, providing the opportunity for full inertial response. No communications would be required for the PEVs to provide emulate inertia since frequency could be sensed locally. While this capability appears achievable, there are no known present applications or demonstrations of this capability.

Primary Frequency Response

As with inertial response, the solid-state control capability of PEV chargers makes providing primary frequency response feasible. No communications are required since frequency is sensed locally. Again, however, while this capability appears achievable, there are no known present applications or demonstrations of this capability.

Regulation

PEV solid-state charger control also potentially allows for the provision of regulation. The ability to increase as well as decrease the charge rate improves the ability to supply regulation. Communications will be required to deliver the system operator's automatic generation control signals to the PEV chargers every few seconds. While there are presently very few limited scope applications or demonstrations[45], possible demonstrations are being discussed and are expected to emerge in the near-term.

Load Following/Ramping

PEV chargers can supply load following and ramping response as well. The long charging window discussed above provides the needed response duration. PEVs are better suited for this service if the balancing requirements are more or less neutral and are not in one direction for a sustained period of time, such as when the load or variable generation forecast errs significantly. Communication from the system operator to an aggregator would likely be required to dispatch changes in collections of charging PEVs.

Dispatchable Energy

Dispatchable energy should be very attractive for PEV charging, within limits. The long charging window when compared with the relatively short charging requirement gives significant opportunity to adjust the charging time to minimize charging cost. The only limitation is that charging must be completed before the next driving cycle, typically the morning commute but occasionally by the evening commute. As with load following, communication from the system operator through an aggregator would likely be required to dispatch changes in collections of charging PEVs.

Contingency Spinning Reserve Service

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[45] Willett Kempton,* Victor Udo,† Ken Huber, et. al., "A Test of Vehicle-to-Grid (V2G) for Energy Storage and Frequency Regulation in the PJM System," November 2008.

PEVs could provide spinning reserves and can respond almost immediately after receiving a control signal, particularly by reducing its charging. PEVs not able to modulate charging or pulse charging can provide reserves by simply stopping charges. Reserve capabilities may be limited in certain circumstances such as in the final hours of the night to honor requirements to PEV owners of a full overnight charge. The short duration of typical spinning reserve events tend to mitigate this concern.

Contingency Non-Spinning Reserve

Because non-spinning reserves do not need to respond as quickly as spinning reserves, PEVs can supply non-spin. Reserve capabilities may be limited in certain circumstances such as in the final hours of the night to honor requirements to PEV owners of a full overnight charge. The short duration of typical non-spinning reserve events tend to mitigate this concern.

Replacement or Supplemental Reserve

Because replacement or supplemental reserves do not need to respond as quickly as non-spinning reserves, PEVs can supply replacement or supplemental reserve. Reserve capabilities may be limited in certain circumstances such as in the final hours of the night to honor requirements to PEV owners of a full overnight charge.

Variable Generation Tail Event Reserve

Because variable generation tail event reserves are similar to replacement or supplemental reserves, PEVs are well suited to provide variable generation tail event reserve. Reserve capabilities may be limited in certain circumstances such as in the final hours of the night to honor requirements to PEV owners of a full overnight charge.

Voltage Support

The interface of the PEVs to the power system is through inverters that have the ability to provide reactive power to the grid and support system voltage. The inverters from the PEVs and other inverter-based distributed resources such as solar photovoltaic systems might be aggregately dispatched to support bulk system voltage, but this concept is only beginning to be considered.

Timeline for Wide-Scale Deployment and Associated Potential Risks

Rising fuel costs and environmental concerns, coupled with federal and state policy initiatives have encouraged the development of Plug-in Hybrid Electric Vehicles (PHEVs) or Battery Electric Vehicles (BEV), which are aggregately referred to as Plug in Electric Vehicles (PEVs). The PEV technology as it exists today is in its infancy. The first large scale introductions of PEVs will most likely be the Chevy Volt and Nissan Leaf in late 2010. Innovators and early adopters have experimented with BEV and PHEV technology with favorable results.[46] Figure 4-2 shows a timeline of commercial release of several PEVs that have been announced by various OEMs.

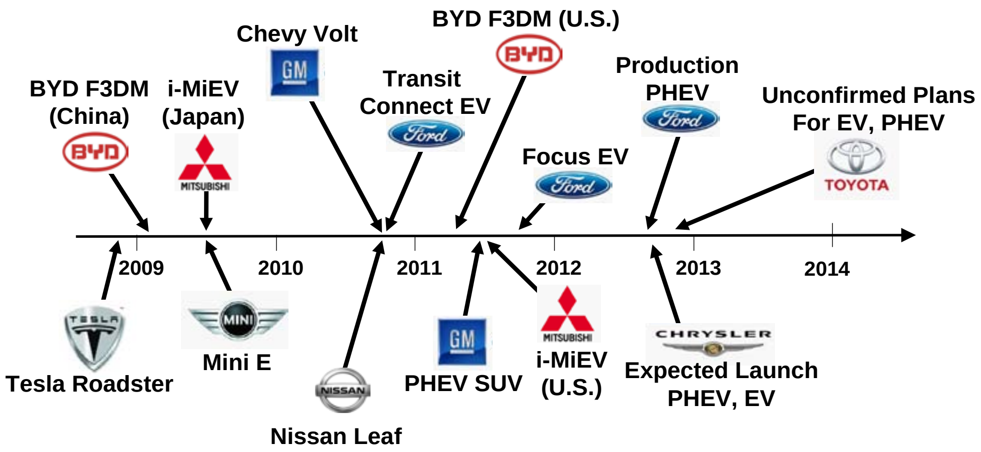

Figure 4-2. PEV Commercialization Timeline[47]

PEV technology has achieved only a miniscule share of the light duty vehicle fleet market as of this writing, though the Obama Administration has set a goal of one million PEVs in the U.S. by 2017. Projected deployment and/ adoption rates vary depending upon the source of information and the industry that is analyzing the data. Reports from the ISO/RTO Council[48] and from EPRI put the potential scope of deployment from 1 to 2.3 million vehicles by 2019. Neither report predicts significant amounts of market growth until after the 2015/16 timeframe when it is expected that vehicles will be widely available from retailers and dealerships.

Several factors will affect large-scale PEV adoption, including regulatory, economic, and market issues, along with technical barriers such as: cost; availability of charging stations; battery life, battery recharge rates, and driving range.

Potential regulatory limitations include the dependence upon the development of Smart Grid standards. Large-scale adoption and use of PEVs for reliability functions will depend in large part on the development of a 'smarter' electric grid. The National Institute of Standards and Technology (NIST) has developed the *NIST Framework and Roadmap for Smart Grid Interoperability Standards*, which identifies 75 existing standards applicable to smart grid development and specifies 15 high-priority gaps and harmonization issues for new or revised standards. NIST notes the smart grid will ultimately require hundreds of standards, specifications, and requirements. NIST will also be developing communication standards which will be critical for PEVs being able to provide reliability services. The communication infrastructure between PEV service providers and the balancing areas and transmission operators must be robust and secure. Another related issue is the privacy of owner information. For PEVs to be used as a reliability resource two-way communication will be required to allow access to PEV data by transmission operators. This issue is common to emerging technologies and the increasing amounts of information enabled by smart grid

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[47] Mark Duvall, EPRI Electric Transportation, Presented at TVA Electric Transportation Forum, April 2010.

[48] ISO/RTO Council. *Assessment of Plug-In Electric Vehicle Integration with ISO/RTO Systems*, March 2010, http://www.isorto.org/atf/cf/%7B5B4E85C6-7EAC-40A0-8DC3-003829518EBD%7D/IRC_Report_Assessment_of_Plug-in_Electric_Vehicle_Integration_with_ISO-RTO_Systems_03232010.pdf

implementation and required by transmission operators to integrate reliability functionality. Policies and standards for information access will need to be developed and issues respecting ownership resolved.

In addition to the noted regulatory and standards issues, several technical and market consideration will need to be considered for PEVs to provide significant contributions to the noted reliability functions:

- Battery life – Using the discharge capability of a PEV battery to reliability functions to the grid may have adverse consequences on battery life. The estimations of PEV capabilities provided in this report are based on varying of the battery charge cycle and not discharging the battery.

- Load forecasting - As the market share of PEVs grows, system operators will begin to see impacts on load profiles, especially in areas with higher PEV penetrations. Load forecasting models may need to be updated in order to provide balancing areas and transmission and distribution operators with more accurate load forecasts.

- Peak versus off-peak charging – Capacity requirements will increase if charging is not performed during low load periods. Markets need to be structured to provide PEV owners information about peak versus off-peak energy prices to ensure that PEV owners charge their batteries at favorable times.

- Another major issue is the risk that consumers may not take the steps necessary to participate in grid operations and service. Therefore, electricity markets will need to provide incentives to compensate PEV owners for reliability services and mechanisms for accessing the relevant markets.

Lastly, PEV proliferation in providing reliability functions will to some degree depend on the associated costs. The PEVs cost relative to conventional vehicles will have to become competitive without subsidies. There are also cost implications to the development of the required two-way smart communications infrastructure and the charging infrastructure.

Chapter 5: Potential Aggregate System Reliability Impact of Technologies

Challenges with Quantitative Assessment of Aggregate Reliability Impact

The NERC IVGTF Special Report "*Accommodating High Levels of Variable Generation*"[49] from which this follow-on work originates states that the report should provide an "order of magnitude impacts" assessment of the influence on reliability of integrating high levels of energy storage, PEVs, and Demand Response. There are numerous challenges, however, to quantifying the potential impact of these emerging flexible resources on bulk system reliability including the following:

1. ***Determining appropriate "reliability" metric(s) to be quantified****:* System reliability generally refers to the ability of the system to serve load and other requirements while maintaining system voltage and frequency criteria under normal and credible contingency conditions. Various metrics are used to measure different components of this broad definition of reliability. Planning metrics such as loss of load probability (LOLP), expected unserved energy (EUE), and planning reserve margin have been used to measure whether sufficient supply capacity will exist to meet demand requirements. Operational metrics such control performance standards 1 and 2 (CPS1 and CPS2) measure the contribution of a given BA in supporting system frequency. There are no established metrics, however, that directly measure aggregate "system flexibility" with all of the aspects reflected in the ten reliability functions identified in Chapter 1. There are several on-going efforts to address the need for such metrics, including one IVGTF work-groups.[50]

2. ***Determining balance of system capabilities and needs:*** The extent to which the emerging flexible resources may aggregately improve system reliability will depend on the baseline reliability or flexibility of the system prior to these resources becoming fully integrated in sufficient capacities to affect the bulk system. Thus, quantifying the change in reliability would require some assumption about the flexibility requirements and capabilities of the system net of these emerging resources. While we can qualitatively describe system flexibility needs and the inherent flexibility of a system consisting of conventional resources, quantifying any of these targets requires detailed planning studies with many sensitivities to address the range of uncertainty.

3. ***Determining portfolio of emerging resources available for a given future scenario:*** Quantifying the aggregate reliability improvements from the use of potential Demand Response technologies/programs, energy storage technologies, and PEVs requires some assessment of the mutual development and market growth of these resources. There are still potential barriers and/or risks to broad deployment and implementation of some of these resources as noted in Chapter 4, and deployment of these technologies will be lumpy, developing at various rates of growth from region to region.

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[49] *Special Report -- Accommodating High Levels of Variable Generation*, NERC, http://www.nerc.com/files/IVGTF_Report_041609.pdf

[50] NERC IVGTF 1-4, "Flexibility Requirements and Metrics for Variable Generation and their Implications for System Planning Studies," May 2010.

Estimates of Future Magnitude of Emerging Resources' Capacity

As noted, it is difficult to quantify the capacity that each of these emerging resources may provide for specific reliability functions in the future. In fact, it is difficult to project the capacity of these resources without regard to how they might be used in various ancillary service markets. Based on the best available information, the following Table 5-1 provides the existing capacity for many of the emerging resource technologies being considered and the potential size of the resource 10 years out.

Table 5-1: Storage Technology and Installed Capacity in NERC[51]

Technology	Installed Capacity in NERC footprint	Potentially achievable cumulative capacity over the next 10 years
Pumped Hydro	**21,900 MW (1)**	**Up to 30,000 MW (2)**
CAES	**110 MW**	**Up to 3,500 MW (3)**
Lead Acid, Sodium Sulfur and other solid electrode batteries	**30 MW**	**Up to 500 MW**
Flow Batteries	**<10 MW**	**Up to 200 MW**
Flywheels	**<5 MW**	**Up to 300 MW (4)**
PHEV	**0**	**3,800 MW (5)**
Electrolysis Loads (6)	**14,000 MW total load** **100 MW controllable**	**Up to 5,000 MW controllable**
Shale Oil	**0 MW total load** **0 MW controllable**	**Up to 1,000 MW controllable**
Demand Response Programs (7)	**40,000 MW**	**135,000 MW**
• Residential	6,000 MW	65,000 MW
• Small commercial/industrial	1,000 MW	5,000 MW
• Medium commercial/industrial	3,000 MW	15,000 MW
• Large commercial/industrial	30,000 MW	50,000 MW

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[51] Reference:

(1) http://www.eia.doe.gov/cneaf/electricity/epa/epat1p2.html. NOTE: pumped hydro accounts for over 99 percent of total energy storage capacity.

(2) FERC has issued and pending preliminary permits for over 30 pumped hydro projects, with total additional capacity of 28,000 MW. Ref.: http://www.ferc.gov/industries/hydropower/gen-info/licensing/pre-permits.asp. Potentially achievable cumulative capacity for hydro reflects permitting challenges and location constraints.

(3) CAES potential was estimated based on planned projects, as follows: 300 MW (CA, ARRA), 150 MW (NY, ARRA), 250 MW (IA), 270 MW minimum/2700 MW potential (OH, see http://www.firstenergycorp.com/NewsReleases/2009-11-23%20Norton%20Project.pdf)

(4) Flywheel potential was estimated on proposed projects and potential market, as follows: There are plans for two 20-MW flywheel plants (ARRA). Future deployment assumes that one to two 20-MW plants per year can be developed.

(5) Assessment of Plug-In Electric Vehicle Integration with ISO/RTO Systems, KEMA, Inc and Taratec Corporation, ISO/RTO council, March 2010, p. 29.

(6) B. Kirby, 2006, *Demand Response For Power System Reliability: FAQ*, ORNL/TM 2006/565, Oak Ridge National Laboratory, December 2006.

(7) Figures are for the US only,. Reference: *A national Assessment of Demand Response Potential*, http://www.ferc.gov/legal/staff-reports/06-09-demand-response.pdf. Potentially achievable estimates correspond to "Achievable Participation" estimate in the report based on the "Best Practices" scenario.

(8)

Qualitative Assessment of Aggregate Reliability Impact of Emerging Resources

Rather than providing a quantitative estimate of reliability improvements, this report presents a qualitative analysis comparing the ability of emerging technologies to provide the ten reliability functions identified in Chapter 1. The qualitative assessment is based on a comparison of the potential of several broad categories of the emerging flexible technologies to provide each of the ten stated reliability functions. This comparison is provided in Table 5-2 where the capabilities of eleven different emerging flexible resource types are mapped against the ten identified system reliability functions. The capabilities are categorized according to one of the following qualitative designations:

1. "A" -- capabilities commercially available today
2. "E" -- capabilities not presently available commercially, but proven in demonstration projects and considered emerging
3. "T" -- capabilities technically feasible, but not supported by present market or level of penetration

For each reliability function listed along the left hand column of Table 5-2, a qualitative assessment of the potential contribution of the emerging resources in aggregate is provided in the next to last column of the corresponding row. The aggregate potential is generally categorized as one of the following:

1. Low
2. Moderate
3. Significant

The potential aggregate reliability impact value is based on a consideration of the technical capability of the individual resources to provide each function and the potential proliferation of the resources based on expected market incentives and commercial considerations. The risks to achieving such aggregate capability are summarized in the "Potential Risks to Achievement" column, with additional insights provides in the subsections following Table 5-2. ***Note that the aggregate reliability contributions presented are not supported by rigorous analysis, but are provided only as qualitative estimates of potential contribution.***

Table 5-2 – Summary of reliability benefits that can be obtained from Demand Response and energy storage.

	Alum. Smelter	Shale Oil Ext.	Res. AC	Comm. AC	Industrial	Pump. Hydro	CAES	Solid Batteries	Flow Batteries	Flywheels	PEV	Potential [1] Aggregate Benefit	Potential Risks to Achievement
Inertial Response		T				A	E	T	T	E	T	**Low**	Storage penetration; Inverter inertia control
Primary Freq. Response		T	T	A		A	E	T	T	E	T	**Low**	Storage/PEV penetration; Comm. & Control
Regulation (AGC)	E	T				A	E	E	T	A	E	**Moderate**	Reg. Storage/Load penetration; Comm. & Control
Load Following/Ramping		T	T	T		A	E	T	T		T	**Moderate**	Disp./Resp. Load/PEV penetration; Comm & Control
Dispatchable Energy		T	A	A		A	E	E	T		T	**Moderate**	Disp./Resp. Load/PEV penetration; Comm & Control
Spinning Reserve	A	T	T	T	A	A	E	E	T		T	**Significant**	Market rules for load; Comm. & Control
Non-Spinning Reserve	A	T	T	T	A	A	E	T	T		T	**Significant**	Market rules for load; Comm. & Control
Supplemental Reserve		T	T	T	A	A	E	T	T		T	**Significant**	Market rules for load; Comm. & Control
VG Tail Event Reserve		T	A	A	A	A	E	T	T		T	**Significant**	Market rules for load; Comm. & Control
Voltage Support						A	E	T	T	T	T	**Low**	Penetration of storage; Comm & Control

Reliability Capability Designations

A	Available commercially
E	Emerging capability in demonstration phase
T	Technically feasible, but not currently being pursued

[1] Note that Potential Aggregate Benefits depends more on market incentives and commercial considerations than on technology capabilities. Stated Potential Aggregate Benefit values based on expected incentives.

Inertial Response

Aggregately, it is estimated that the contribution of the emerging flexible resources considered to bulk system inertial response needs will be "**Low**" for the following reasons. DR is generally not well suited to contribute significantly to system inertial response needs. While there is more potential for energy storage, the estimates for new pumped storage and CAES installations are relatively low, and the lack of existing activity to alter controls of inverter-based storage for providing inertia response does not presently portend significant contributions from inverter-based storage or PEVs.

Primary Frequency Response

Similar to inertia response, the aggregate contribution of the emerging resources to primary frequency response (droop) is estimated to be "**Low.**" Demand Response is again not well suited and potential contributions to droop response from energy storage and PEVs is moderated by the relative low near-term estimates of increases in pumped hydro and lack of present lack of inverter control and communications to aggregate smaller inverter-based resources. However, long-term, increases in pumped hydro are projected to nearly 34 GW.

Regulation (via AGC)

The aggregate contribution of the emerging resources to primary system regulation needs is estimated to be "**Moderate.**" Energy storage, however, has an opportunity to contribute moderately to regulation (AGC) response because they can respond fast relative to conventional generators. Fast regulation is more effective and beneficial to regulate balancing area interchange than an equal amount or response that is slower [Makarov]. Also, the benefits of regulation service from energy storage can be realized at the balancing area level. Regulation is an energy-neutral service over a timeframe of several minutes. Some storage technologies are ideally suitable for this kind of cycling duty. Some loads are also well-suited for providing regulation (aluminum smelters), and there is anticipation that PEVs may also eventually contribute in a meaningful way.

Load Following/Ramping

The aggregate contribution of the emerging resources to system load following and ramping needs is estimated to be "**Moderate.**" The most significant contributor of the emerging resources is expected to be from Demand Response given the potential large penetration of price responsive and load control programs that might be able to respond to dispatch signals. In general, energy storage technologies could also contribute, but to a lesser degree than load due to relative cost and practical penetration levels.

Dispatchable Energy

The aggregate contribution of the emerging resources to system minimum and peak load management needs is estimated to be "**Moderate.**" Load is again the likely primary contributor with space heating and cooling perhaps the most obvious opportunity. Significant benefits could be achieved with direct control or market mechanisms (price signals). The ability of energy storage to contribute significantly would likely depend on the penetrations of pumped hydro and CAES installations. While PEVs might also be attractive if the appropriate communications and aggregation functions are implemented.

Spinning Reserve

The aggregate contribution of the emerging resources to system spinning reserve needs is estimated to be "**Significant**" based on the potential for load participation. Spinning reserves deployment is infrequent, which means that load can provide this service with relatively low risk of interruption or curtailment. Already, responsive load is commonly deployed as spinning reserve. Additionally, energy storage and PEVs are well suited to contribute to system spinning reserve needs. Aggregately, the impact of the three is expected to be sizeable.

Non-Spinning Reserve

The aggregate contribution of the emerging resources to system non-spinning reserve needs is estimated to be "**Significant**" based on the potential for load participation. As with Spinning Reserves, deployment is infrequent and the immediacy of response is less. As such, Demand Response and PEVs are well suited to provide non-spin reserves. As with spin reserve, load is already a contributor to non-spinning reserve requirements in many jurisdictions.

Replacement Reserve

The aggregate contribution of the emerging resources to system supplemental reserve needs is estimated to be "**Significant.**" The reasoning is the same as for spinning and non-spinning reserve as load, storage, and PEVs can all contribute to the longer response time frame without significant concerns of over-deployment that would result in resource fatigue.

Variable Generation Tail Event Reserve

The aggregate contribution of the emerging resources to a new reserve product held for response to infrequent variable generation tail events is estimated to be "**Significant.**" The reasoning is the same as for spinning and non-spinning reserve as load, storage, and PEVs can all contribute to the longer response time-frame without significant concerns of over-deployment that would result in resource fatigue.

Voltage Support

The aggregate contribution of the emerging resources to bulk system voltage support needs is estimated to be "**Low.**" While energy storage technologies can provide voltage support and there is the possibility of PEVs doing so through special inverter controls, their aggregate benefit to the system is deemed to be low due to relatively low penetration levels (as compared with synchronous generators and traditional voltage support equipment). It should be recognized that benefits of voltage support at the local level could be very significant.

Chapter 6: Conclusions & Recommended Actions

Conclusions

Variable renewable generation such as wind and solar PV introduce additional variability and uncertainty to the power system. In order to maintain reliable power system operation as variable energy resources provide a larger proportion of our electric energy supply, sufficient system flexibility will be required. The existing system flexibility varies regionally according to the different supply/generation mixes. Further, the sufficiency/adequacy of the regional and interregional transmission system can greatly impact the overall flexibility of the system by either facilitating or constraining the sharing of flexible resources across a broader footprint. As such, the system impacts of the additional variability and uncertainty associated with wind and solar PV will vary as will the operational and market needs to provide the needed flexibility to accommodate the variable renewable sources. The emerging flexible resources evaluated in this report – Demand Response, bulk and distributed stationary energy storage, and plug-in electric vehicles – offer the potential to support many of the flexibility-related reliability functions that may be stretched as variable generation levels increase.

The various technologies comprised by these three broad emerging resource groups are technically capable of supporting all of the ten specific reliability functions identified and evaluated in this report to varying degrees. Some of these technologies have proven track records of providing specific reliability functions. Pumped storage plants are an example of an energy storage technology where the provision of all ten of the reliability functions has been proven. Other emerging flexible resource technologies are presently being evaluated for providing certain reliability capabilities through prototype or demonstration projects, but do not yet have significant track records of effectively serving these needs.

Many of the technologies have not yet been applied to providing specific reliability functions, but there do not appear to be any real technical limitations in doing so. To a large extent, the potential market penetration of these emerging resources in providing the stated reliability functions is dependent on commercial and policy considerations that may or may not incent development of these capabilities. For example, many of the emerging technologies are technically capable of providing primary frequency response through control modifications on their power electronics interface to the power system. Few of these technologies are presently exploring this capability, however, as there is no financial incentive to provide this function. In fact, in some regions market rules might actually prohibit some of the emerging resources from providing specific reliability functions based on limited acceptable resource definitions that focus on traditional generation resources.

Another significant factor in the potential market penetration of these emerging resources for providing the stated reliability functions is the economic viability and market revenue certainty for financing of the resources relative to other potential sources for providing the services. Despite the fact that a particular emerging flexible resource may be technically capable of providing specific reliability functions, these resources will have to achieve commercial economic viability relative to other potential sources of the reliability functions.

We have provided a qualitative estimate of the potential aggregate impact of these emerging flexible resources in providing each of the ten reliability functions based on a possible future commercial and market policy circumstances that perpetuate present trends. With this view, we generally expect these emerging resources to have the most significant impact on the reliability functions that allow for the longest response times and limited duration of response such as spin and non-spin reserves. This is primarily due to the high potential of loads to participate in these reliability services and the growing track record of loads already providing these services and the large potential resource base that already exists. The potential aggregate impact on the faster response or longer duration or higher frequency of deployment reliability functions such as regulation or dispatchable energy is more moderate. These characteristics are not as well suited for a wide range of loads to supply. While many energy storage technologies and PEVs are technically capable and more suited to provide these services, they are generally either not currently commercially available or there is uncertainty as to whether sufficient development of the resources will occur to have a more significant impact.

Recommendations

The electric power industry should pursue research and development activities to assess the flexibility needs for the regional and interregional systems of North America as well as evaluate the benefits of flexible resources and technologies on their respective systems.

If all resources are provided equal opportunity and information as to power system reliability needs, markets and commercial viability should determine what resources provide specific reliability functions to the grid. If the emerging flexible resources addressed in this report are to play a significant role in providing the additional flexibility needed to accommodate high levels of variable generation, the barriers and limitations identified in this report must be addressed. Limitations related to the resources themselves (e.g., technological limitations or commercial viability) will be addressed to the extent possible by technology developers if those entities determine there is broader economic incentive to do so. Other external limitations, however, need to be addressed in order for technology developers to make decisions on technology investments. To that end, it is recommended that the following be addressed:

- Development of an operational infrastructure that provides visibility and control (direct or indirect) of distributed resources such as Demand Response and PEVs. In order for the emerging distributed resources to be significant contributors to the bulk system reliability functions, appropriate communication systems and methods of aggregating the resources into larger resource blocks are likely needed. System operators will need to understand the operational state and energy capacity available to the system in real-time via full integration into energy management systems (EMS) and market operation systems. This development includes technical, administrative, and commercial aspects. Technical developments are needed to ensure proper communication capabilities and integration into EMS and market operation software platforms. Aggregation of the resources into larger blocks will require developing the administrative processes to aggregate and bid the blocks of resources into the appropriate markets.

- Adjust market rules that unnecessarily limit the types of resources for providing specific reliability functions. Some markets specifically designate some classes of resources as unable to participate in supplying some services. To the extent that there are no technical limitations that would prevent a resource class from reliably supplying a given service, market rules should be adjusted to allow a variety of resource types to participate within stated performance specifications. Resource developers can then determine whether they can package any resource type to meet the performance criteria in an economically viable manner. Thus, market rules should be reviewed in all regions to remove any unnecessary restrictions.

- Adjust regional or federal reliability standards that limit resources that can be used for providing specific reliability functions. Similar to market rules, reliability standards may also limit certain resource groups from providing some reliability functions. For example, the NERC glossary definition of spinning reserve references "unloaded generation" which has been interpreted as prohibiting load from participating. As with market rules, federal and regional reliability standards should be adjusted, if necessary, to allow all resource groups to participate in providing reliability services within specified performance criteria.
- Advances and enhancements that inform all resources of the value of needed flexibility services and incent desired response while discouraging undesired response will be needed. For example, the development of a tariff for PEV owners that would discourages charging during peak hours and encourages charging during off-peak hours.

Abbreviations Used in this Report

Abbreviations	
AESO	Alberta Electric System Operator
AGC	Automatic Generation Control
AWEA	American Wind Energy Association
BC	British Columbia
BEV	Battery Electric Vehicles
BPA	Bonneville Power Administration
CAISO	California Independent System Operator
CAES	Compressed Air Energy Storage
DADS	Demand Response Availability Data System
DR	Demand Resource
DC	District of Columbia
DCS	Disturbance Control Standard
EILS	Emergency Interruptible Load Service
EMS	Energy Management System
ERCOT	Electric Reliability Council of Texas
FERC	Federal Energy Regulatory Commission
FRCC	Florida Reliability Coordinating Council
GVEA BESS	Golden Valley Electric Association Battery Energy Storage System
HQ	Hydro Québec
IESO	Independent Electricity System Operator
IRP	Integrated Resource Planning
ISO	Independent System Operator
IVGTF	Integration of Variable Generation Task Force
LAAR	Loads-Acting-As-Resources
LFC	Load Frequency Control
MISO	Midwest Independent Transmission System Operator
MRO	Midwest Reliability Organization
NAESB	North American Energy Standards Board
NIST	National Institute of Standards and Technology
NPCC	Northwest Power Pool Coordinating Council
NRMSE	Net Root Mean Squared Error
NWP	Numerical Weather Prediction
NYISO	New York Independent System Operator
NYSERDA	New York State Energy and Research Development Agency
EREV	Extended Range Electric Vehicles
PEV	Plug-in Electric Vehicles
PJM	PJM Interconnection
PTC	Production Tax Credit
PV	Photovoltaic
ReEDS	Regional Energy Deployment System
RFC	ReliabilityFirst Corporation

RP	Real time Pricing
RTO	Regional Transmission Organization
SERC	Southern Electric Reliability Corporation
SPP	Southwest Power Pool
TVA	Tennessee Valley Authority
WECC	Western Electricity Coordinating Council

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