Electricity Advisory Committee

MEMORANDUM

TO: **Honorable Steven Chu, Secretary**
Honorable Patricia Hoffman, Assistant Secretary for Electricity Delivery and Energy Reliability

FROM: **Electricity Advisory Committee**
Richard Cowart, Chair

DATE: **October 28, 2011**

RE: **Estimating the Value of Electricity Storage Resources in Electricity Markets**

Purpose

The purpose of this report is to assist the U.S. Department of Energy (DOE) in 1) establishing a framework for understanding the role electricity storage resources (storage) can play in wholesale and retail electricity markets, 2) assessing the value of electricity storage in a variety of regions or markets, , 3) analyzing current and potential issues that can affect the valuation of storage by investors at the wholesale and retail level, and 4) identifying areas for future research and development for electricity storage technologies and applications.

This paper focuses on electricity storage technologies that result in electricity being delivered back to the grid at later times. We recognized that many of the benefits of storage-- e.g., peak load reduction, taking advantage of off-peak/low-emissions resources, congestion relief-- are also provided by energy storage systems such as thermal systems and "managed charging" of electric vehicles. Those topics will be addressed by the EAC separately.

Background

In the future, it is likely that significant variable energy resources (such as wind and solar and other new technologies) will be interconnected to the grid. In addition, variable loads (such as micro-grids or DR resources), will be able to present both variable demand and supply to the grid. Other changes to the power system could also increase the need for reserves, such as the introduction of large conventional generators or an increased reliance on resources that are prone to common mode failure. Grid operating practices are likely to evolve over time to accommodate additional variability, but it is also likely that as the penetration of variable energy resources increases, grid operators may need to hold additional reserves, regulation, and balancing services to ensure that the grid operates reliably. It may also be necessary for grid operators to specify additional services, such as load following services, or specify more stringent performance characteristics within existing services. This increased need to specific services will likely cause a demand for more responsive resource performance, which should be reflected through the wholesale electricity market designs (in the case of "organized wholesale markets"), or through utility integrated resource planning (in the case of regions that have not restructured). Electricity storage resources are one form of responsive resource, in addition to demand response resources and flexible generators such as dispatchable fossil and hydroelectric generators and curtailable renewable resources. Storage resources have physical limitations on the amount and duration of the energy that they can supply to the grid; therefore, they fall into the category of Limited Energy Resources, or Limited Energy Generation, such as a pumped hydro facility, flywheel, or battery array. This paper discusses the challenges and opportunities that deployment of electricity storage resources have on system operations and provides recommendations to DOE on its role in helping to solve some of those challenges. A core assumption underlying the recommendations to DOE is that: 1) historical, transparent prices exist for specific energy products and ancillary services and 2) studies of future conditions under different generation portfolios that can be used as a basis for forecasting demand and projecting prices of these products and services also exist.

When storage is simply another resource providing an existing market product (typically regulation capacity or reserve- payments), its value can be appraised by either looking at historical annual revenues per unit and extrapolating forward or by using published studies of forward ancillary prices. However, there are several considerations that can make this more complex:

- Over time, electricity service product definitions and the basis of payment for those services change. For example, the current Federal Energy Regulatory Commission's (FERC's) Notice of Proposed Rulemaking on frequency regulation for compensation in organized wholesale power markets (Docket # RM11-7-000) revises its regulations to remedy any undue discrimination by requiring a uniform price for regulation capacity paid to all cleared resources and a performance payment for the provision of frequency regulation. Another consideration is the different market definitions of zero energy or scheduled energy regulation resources (designed for storage technologies providing regulation services) used on a case by case basis by the various Regional Transmission Organizations (RTO) or Independent System Operators (ISO). Other complexity considerations include defining “ramping” as a product in some markets and the possibility of lowering the minimum duration times for reserve products to better exploit demand- and storage-based resources.

- Over time, market prices change due to new resources entering the market. For example, demand response can be used to provide ancillary services.
- The Future revenues may not be as lucrative if a high penetration of resources, such as storage, have low operating costs (for some technologies) and high capital costs, and prices decrease with penetration.
- Evaluating the economics of new technologies, such as life cycle characteristics and self-discharge losses:
    - Some technologies have well-understood life expectancies in terms of charge-discharge cycles; however, some newer technologies do not. In many cases, the depth of discharge and the rate of charge-discharge will affect the life cycle. Different storage technologies have different life cycle characteristics. Many electrochemical technologies have non-linear electrical loss characteristics during charging and discharging, which can make the energy efficiency calculations in some applications difficult.
    - Some technologies have self-discharge losses that are significant over time and may be a factor in “standby” applications, such as reserves, where actual duty cycles are infrequent. In addition to self discharge (which is usually less than 1– 2 percent/month for most electrochemistries), there may be parasitic energy costs associated with these technologies, such as heating the application’s fluid media or cooling its power electronics .

Electricity Storage Resources in Restructured Wholesale Electricity Markets

Storage of electricity allows a shift in time of energy use —charging at one point in time and discharging at another. This storage capability provides the electric service provider the ability to shift or lower its peak prices as has long been the practice with pumped hydroelectric facilities. Using historical or projected prices for electricity provides a straightforward way to estimate hourly energy prices or arbitrage revenues on a diurnal or other cycle basis.

How storage energy arbitrage is handled in wholesale markets varies from RTO to ISO today. ISOs that manage output from pumped hydroelectric facilities have developed protocols for including these facilities in the markets and using them for energy and ancillary services. Some of the ISOs have filed tariffs with FERC for including fast zero net energy facilities. As electricity storage penetration increases in the system and storage operators permit time arbitrage in addition to ancillary services provision, several possibilities for incorporating storage facilities into the market arise:

- The storage facility can self schedule (as a price taker) or bid into the market
- The ISO can co-optimize when the storage facility charges and discharges and can compensate the storage facility as either a price taker or on the basis of bids.

In some regions, changes in the generating fleet may cause an increase in power system variability that may need to be accommodated by increased levels of reserves. . There are at least two or three market design paths to achieve this goal:

- Require the need for additional load following (in one case, a "fast ramping" product is under discussion) to drive prices up and attract the entrant of resources—such as storage—to provide this capability
- Conduct capacity auctions or other capacity planning/fulfillment processes that would incorporate resources required to meet system needs. This capacity planning/auction process could be a means of maintaining faster conventional resources as well as attracting storage resources.
- FERC has recently issued an NOI exploring the question of whether the market and system costs of variability can or should be allocated to the resources causing the variability. Without commenting on that question, we observe that such a paradigm change would alter the economics and market incentives for grid connected storage. These need to be explored and understood as part of such a new direction.

Electricity Storage Resources in Traditional, Cost-of-Service, and Vertically Integrated Utility Regions

In a perfect world, the economics and the valuation of storage resources for bulk power market functions as described above would be identical in a region in which regulated, vertically integrated utilities operate. The one major difference between market-based analysis and vertically integrated/regulated analysis is that in a deregulated and restructured environment, conventional units that lose revenue streams and become non-viable are retired and the owner bears any capital write offs. In regions where vertically integrated utilities operate and are regulated, the capital basis of the conventional units that are "used less" is still included in the rate base; that is, it is still funded by ratepayers and a write off that is not funded by ratepayers is unlikely. This changes the overall economic evaluation of investing in new electricity storage resources. Without a roadmap for financial retirement of existing assets, storage is unlikely to displace conventional generation in regions with vertically integrated structures. However, a path forward may open if certain aging plants are retired due to environmental regulation. Therefore, it may be worthwhile to examine how storage can

be part of a "new" portfolio of resources in an environment of retiring base load units. If accompanied by higher renewable penetration, this may be logical.
There have been numerous studies of the costs of integrating high renewable penetrations[1] and there are preliminary claims made about the cost of retiring older coal plants. Vertically integrated utilities should evaluate the value and role of storage through an integrated resource planning model that considers high renewable portfolio standards, coal plant retirements, and the exploitation of grid-scale storage.

Distribution Applications

It is important to include discussion of the role electricity storage resources can play at the distribution level. Electric distribution systems are still based on regulated, cost-of-service models and are regulated by state public utility commissions. The benefits of any electric power technology services at the distribution level fall into the following categories:

- Reduced losses
- Capital deferral
- Reduced operating and maintenance costs associated with outage restoration and maintenance
- Reliability Improvement

Today, distribution systems are planned and maintained to sustain or marginally improve existing system reliability. However, rural distribution feeders or feeders/locales served by single (radial) sub-transmission can also benefit from storage as a reliability enhancement tool.

Energy storage can improve distribution systems by:

- Facilitating distributed generation (especially renewables) integration
- Facilitating demand response penetration and utilization
- Facilitating electric vehicle integration

All these additional areas will produce benefits that fall into the four basic categories, but it is worth calling them out as they all create new kinds of engineering and valuation issues.

Distribution planning is more formulaic than transmission planning (and operations). Many distribution planners rely heavily on accepted methodologies, most of which are supported by popular software tools. Ease of integrating large volumes of asset and load data from other data bases is critical.

[1] For more information, see: North American Electric Reliability Corporation (NERC) webpage access to reports on reliability of the North American bulk electric system, "Assessments & Trends: Reliability Assessments" http://www.nerc.com/page.php?cid=4|61

Reports from utilities that are facing high distributed generation (DG) penetration indicate that new distribution engineering problems are posed and that accepted methodologies and tools fall short in dealing with these engineering problems. Following are the problems associated with high distributed generation penetration that use of electricity storage resources may be able to help solve:

- High DG penetration and off-peak load can cause excessive backfeed into the system. This potential backfeed violates the principle of radial flow of electricity, causing issues with planning analytics and protection design. Storage may mitigate this by capturing excessive backfeed.
- DG resource variability can cause voltage fluctuations. Voltage fluctuations can cause early failure of voltage control capacitors not designed for multiple operations per day. Storage can mitigate this problem by maintaining voltage with its potential for dynamic control of system inverters.
- High DG penetration can increase short circuit duty for some fault locations. It is unclear whether storage offers any solutions to this problem.
- Current interconnection standards for DG focus on limiting harmonic content and providing for disconnect upon lack of energizing voltage to the circuit; that is, the inverter cannot itself maintain circuit voltage. However, recent experience with very large DG installations (e.g., 2–6 MW of PV in one installation) shows that the fault response of the inverter can momentarily boost feeder voltage before the inverter detects a lack of energization and disconnects. Also, under a high-penetration scenario, a transmission fault could result in the disconnection of a substandard quantity of DG in an affected area while the transmission fault clears—transforming a cleared transmission fault into a generation outage, with unknown impacts on system reliability. (It is unclear whether storage offers a solution to this problem.
- High nighttime loads from electric vehicle charging impact distribution transformers. Storage can help this problem if it is on the secondary distribution line and local to the electric vehicle charging sites.
- Voltage fluctuations propagate from the feeders into sub-transmission substations. Substation storage and inverter controls may be one way to buffer this problem.

Distribution energy storage can play a role in mitigating many of the issues outlined above, as well as improving reliability by providing local (secondary based) back-up power supply. However, until the costs of integrating these new technologies and the methodologies for analyzing their impacts are well understood and accepted, the starting point for valuing the benefits of storage as a mitigation option is in question. Some considerations for increasing the understanding of the benefits that storage can play in distribution systems include:

- Improving reliability locally is a target area for storage applications (typically in distribution/sub-transmission substations). Targeted storage deployment can be used to improve localized reliability for targeted clusters of customers who experience annual outages measured in hours. Such targets may not affect the overall system average interruption duration index (SAIDI) statistic for a large utility, but it can dramatically improve the SAIDI experienced by the affected customers. There is no formal way to value this improved reliability for the customer in terms of regulatory/political goodwill today; SAIDI improvements can be valued only in comparison to traditional construction alternatives and only when the utility is ordered by its public utility commission to "do something."
- Distribution system circuit and/or substation power transformer upgrades that are driven by peak load that occurs only a few days a year are too expensive to normally justify since the upgrade is utilized so infrequently. . Storage resources utilized for peak load management can defer this expenditure until the utilization need is higher.
- Use of fast storage smooths out the intermittency effect of variable energy resources on the system , enhancing system performance. Fast storage is also used at the distribution or customer level to reduce reliance on spinning reserves. A method and incentives are required to quantify the extent of its use and subsequent reduction in carbon emissions and pass this benefit to the ultimate owner. Incentives for utilizing fast storage are needed so that renewables can be deployed, resulting in lower carbon emissions. The benefits of lower carbon emissions should be given to those utilities which can achieve this goal using storage resources.
- Utilities need to have certainty for investment recovery. Since storage applied at the distribution and customer level can have multiple value streams, stakeholders need to understand the approval process, jurisdictional boundaries, and incentive mechanisms to provide certainty for recovery. This certainty needs to be developed to attract investment.
- Market benefits of energy arbitrage, frequency regulation, and generation capacity can potentially be realized by aggregating the effects of distribution and community-based storage. The process and responsibilities for aggregation and the priorities for battery operation need to be determined.

Electricity Storage Resources at the Consumer Level

As investments in electricity storage resources are made by the customer, not the utility, the presumption is that customers (or the customer's energy service provider, photovoltaic system (PV) installer, etc.) understand the economics and are making a decision based on their circumstances and values. However, energy storage blurs the divide between customers and utilities, posing the following questions:

- Should energy delivered to the grid via storage as opposed to directly from PV be qualified for feed-in tariffs?
- Should utilities provide incentives to encourage local storage in conjunction with PV, other DG, or other technologies to mitigate some of the DG impacts described above?
- If a group of customers served on the same secondary drop wish to co-invest in storage as a source of back-up power or for time shifting PV production, how can that be accomplished? Are they then in effect a micro-grid?
- Can this be extended beyond a single secondary for a case of extended virtual net metering?

Distribution systems are generally designed assuming the power flows in one direction. As batteries (and other distributed generation sources) become more prevalent as storage resources, what are the technical challenges to designing and protecting a system with multi-directional power flow? What tools and technology are required to plan and operate safely?

From the customer's perspective or their energy service provider's perspective, transparency of the value of benefits is needed to make decisions about pursuing community-based storage technology. Answering the following questions will provide the necessary information to help customers make this decision:

- How do they get value for deferring transmission and distribution capital investments? How often will the battery be called upon to operate for such benefits? What is the implication to the life of the battery?
- Because the battery is close to the customer's load, their reliability and system efficiency can improve. To what extent will the level of service reliability improve after the battery is installed as compared to the level of service before the installation? Is the incremental reliability enhancement more cost effective through actions taken on the customer side of the meter or on the utility's system? How are the alternatives compared and incented?
- At present, system losses are passed along to customers. If batteries are installed that mitigate utility system losses, who should benefit from this?
- What are implications to the power bill? What tools are needed to align the customer load shape with the battery capacity to minimize demand charges?
- As customers contemplate using batteries, what are the technical interconnection requirements and the cost to comply? Are there special cyber security requirements? Who has control of the battery; what is the priority for operations if it is being used for multiple value streams?

Recommendations for Evaluating the Value and Role of Electricity Storage

There are a number of questions and challenges facing policy makers, grid operators, and market participants as they seek to enable the modernization of the nation's grid. DOE can be helpful to the transformation of the grid by conducting analysis of and providing detailed answers for policy makers, grid operators, market participants and end-use consumers to the following questions:

1. What are the operational and reliability implications for grid operators arising from high penetrations of variable energy resources and from other changes in the generating fleet? (Also see question (4) below.) How would the impact of these changes be mitigated by changes in grid operating procedures that allow greater amounts of variability to be accommodated with existing levels of reserves?

2. What are the consequent market design implications?

3. What incentives could policy makers and regulators create for certain technologies? How can stakeholders better understand the impact of different resource mixes on wholesale production costs and emissions? How can policy makers, regulators, and market participants/investors better understand the relative economic viability of different resources, including different storage technologies, both between technologies and in the context of differing resource mixes? DOE could provide useful, decision-making information by performing "scenario analyses" in which different future resource mixes are modeled (including at least one future that contains a high percentage of electricity storage resources) and production costs, emissions profiles, and infra-marginal revenue contributions to different resource types are analyzed.

4. Will the current state-of-the art in power system modeling and power system management software (including the optimization software inherent in unit commitment and economic dispatch) be sufficient to cope with a future grid that has to support a significant penetration of variable and limited energy resources? What are the constraints that operators and participants should be aware of and what additional research and development should be done in this area? DOE should perform analysis on specific modeling and software optimization tools as a basis for defining and performing a detailed simulation of the real-time performance of the power system under differing operational conditions. This analysis by DOE will lead to recommendations for further improvements in power system modeling and power system management software and will also inform operators and participants as to where the system stability constraints exist.

5. Regulated utilities have a crucial role to play as investors in and portfolio managers of the wide array of integration solutions (including storage) that are

needed to accommodate variable output resources and loads. What will regulated utilities need for creating performance-based incentives associated with this crucial role, in addition to the recovery of prudently incurred costs? DOE should lay out these alternatives to help provide guidance to state utility regulators and investors.

6. What is the potential market value and what are the returns to storage under different scenarios, including high renewable penetration, retirements of older/less efficient generation, and the likely effects of future market services resulting from impending FERC rulings? DOE should conduct economic analysis that complements the operational and market design analysis described above.

7. What are the potential effects of storage deployment on reducing emissions from conventional generation? Several published papers) have analyzed the impact of using storage for regulation services on reduced emissions from conventional generation. This reduction of emissions is due to a combination of 1) altered dispatch that requires fewer reserves from conventional resources and 2) potential heat rate improvements by reducing the amount of rate of change imposed on conventional generation. Other authors have speculated that the dispatch impacts of using storage to accommodate system variability could actually shift generation from gas-fired resources to coal-base-load units, thereby increasing emissions. Sandia National Laboratory (Sandia) has recently begun a project to re-assess the emissions benefits of storage used for regulation services. Sandia is not, however, examining the value of those emissions savings in economic terms. One possibility to be examined by DOE would be to identify the compliance costs improvements, if any, by reduced regulation duty on conventional plants.

8. What is the role of storage at the distribution level?
    - DOE should survey available distribution planning tools for 1) their ability to consider storage resources on the feeder; 2) their ability to optimally locate same; and 3) their use of assumptions in the planning process and comparison of alternatives as storage is applied to adjust load shapes, increase system utilization, and defer capacity upgrades
    - DOE should monitor results from Community Energy Storage ARRA projects to better quantify the economic benefits and barriers for entry
    - As an enabler for storage, DOE should assess the effectiveness of the "Perfect Power Seal of Approval" objectives (Galvin Institute), which establish a reliability rating system, certification utilizing a seal of approval, education to effectively communicate advanced practices and

applications, and an engagement between the provider and users to reveal significant gaps in performance

- Define and resolve federal/state regulatory “gaps” and “overlaps” to increase investment certainty for financing storage projects, DOE should develop analysis that provides better understanding of the costs and benefits that drive rate recovery for storage located on the distribution system

9. What are the barriers, incentives, and technical challenges to aggregating distribution and community-based storage facilities?
   - DOE should conduct analyses on the role of storage “behind the meter” (BTM); determine the distribution system benefits of storage on the customer side of the meter; and
   - determine the technical challenges caused by significant penetration of BTM variable energy resources and loads, including PEVs, solar panels, wind turbines, micro-grids, etc.

These recommendations were approved by the Electricity Advisory Committee at its meeting on October 20, 2011.