Energy Storage Concepts for a Restructured Electric Utility Industry

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This paper examines the potential uses and impacts of electric energy storage in the restructured electric utility industry of the future. Restructuring is changing the rules by which utilities will operate, it is creating new entities and market players, and it is changing the very nature of utilities themselves. As the forces of competition and deregulation open the doors to new business concepts, opportunities for innovative storage applications will emerge. A clearer and more detailed vision of how storage technologies fit into the energy systems of the future will amplify those storage opportunities.

The approach in this paper utilizes scenario analysis to postulate plausible future industry structures, and evaluate how storage may be used in those situations. First, a “Core Scenario” is developed, describing a utility industry basically much like today’s:

- Electric utility industry restructuring continues state by state.
- Performance based rates (PBR) for the regulated wires utilities are more the norm than the exception.
- Federal restructuring lags rather than leads state actions.
- Open transmission access exists with an open market for ancillary services.
- Generation is a merchant function, separated from the wires businesses of utilities
- Many utility holding companies form Energy Service Companies on their unregulated sides, competing with other energy service providers and customer aggregators.
- Competitive forces become more important.
- Electric prices are more volatile than in the past, with summer peak electric shortages and competitive wholesale electricity markets causing substantial spot price peaks.
- More mergers occur between electric utility companies.
- Technologies continue to improve steadily; viable, proven storage technologies continue to come into the market with somewhat lower costs and improved performance.
- Large combined cycle gas fired power plants dominate new central generation additions.
- Natural gas is inexpensive, available, and is the fuel of choice for new power plants.
- Renewables continue to expand into the market place at a gradual pace.
- There are many technology competitors to storage.

The core scenario yields a discussion of the full range of “baseline” applications and benefits of storage for the near term. Typical applications include: demand smoothing for bulk generation and renewables; deferral of and enhancement to transmission and distribution systems; reliability and power quality based applications for customers and industrial processes; and integration of applications for multiple stakeholder (shared) benefits. Figure 1 shows how storage may be located within an electric power system to achieve these benefits.

Eight “stretch” industry scenarios are developed, based on dramatically different (yet plausible) sets of assumptions about regulatory regimes, legislative/societal imperatives, and storage technology capabilities.

Funded by the DOE Energy Storage Systems Program.

A. Very Inexpensive and Efficient Storage Scenario

If energy storage systems were free and nearly 100% efficient, they would be used throughout the electric system in three ways, all of which would ultimately reduce the cost of electric service:

- To level loads throughout the system, from generation to end-use,
- To enable renewables and other non-dispatchables, or
- To condition power, preventing disruptions from reaching customers.

Load Leveling

A major application for energy storage is to level loads throughout the electric system. This includes generation, transmission, substations, distribution and customer end-use. (See Figure 1.)

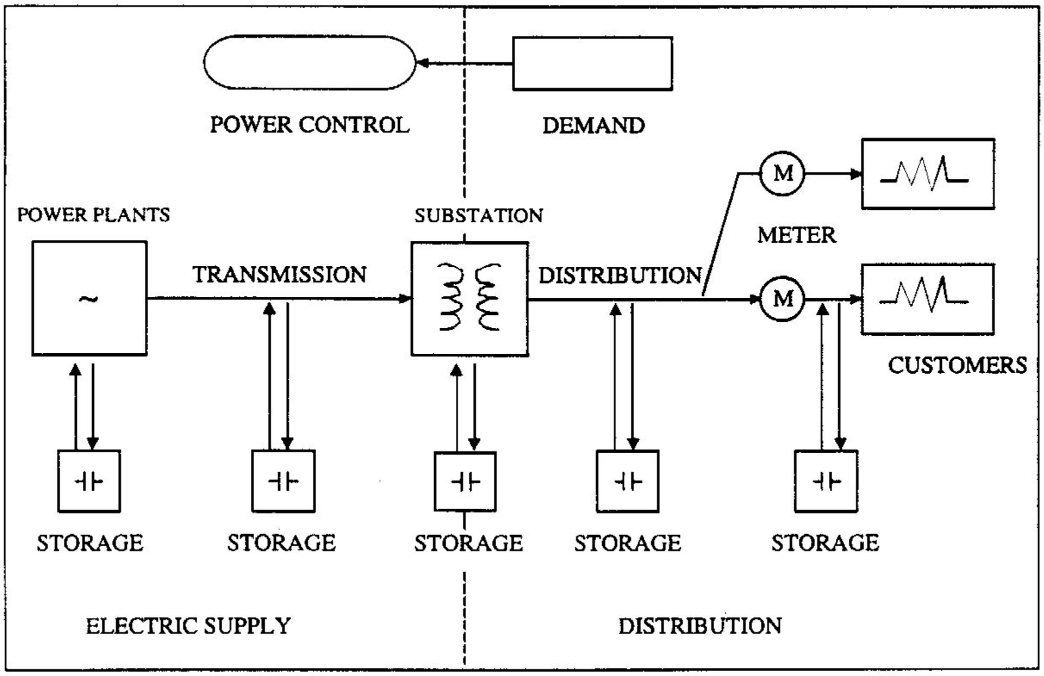

Figure 1. Energy Storage Used for Load Leveling Within the Electric System

The results would be that all generation would run at constant rating all day and night, with the amount of storage sized to meet the varying load demand (including seasonal). This would result in minimum generation capacity, and minimum cost of electricity ($/kWh).

Some of the storage could be placed along the transmission system for stabilization, voltage and VAR control, and to enable increased transmission system utilization. Such systems would require only small amounts of storage, with fast dynamic or transient control.

Alternatively, storage could be located at the distribution end of the transmission system to buffer transmission lines from variations in load. This would result in minimum transmission capacity. Oversizing would be prevented, and minimum transmission system cost would result. Transient and frequency instabilities would also be avoided.

Storage would be incorporated into substations to insure stable operating conditions and power flow control. Storage would also be integrated into the distribution system to provide peak shaving and to optimize power flow among feeders, thus reducing all distribution system (wire, substation, transformers, O&M, land, etc.) costs. The result would be a minimum cost distribution system. In an ideal system, the need for distributed generation decreases as the use of storage increases.

Storage would also be placed at the customer end to level peaks, absorb transients, and provide continuous service. Storage would also reduce electric bills where customers pay extra for peak usage.

Following this scenario's logic, if storage were very inexpensive and efficient, storage should be moved to the customer sites to level each individual load as in Figure 2, thus leveling the load on the distribution system. Constant power flow through the distribution system would result in a minimum cost distribution system. In principle, this is the overall minimum-cost system since the storage is free and the rest of the system runs always at constant power, i.e., no oversizing.

Enabling Renewables and Other Non-dispatchables
Free, efficient energy storage is a perfect companion to intermittent renewable resources. Storage systems could be matched with photovoltaics, solar central receivers, wind and hydro, to meet local or regional loads

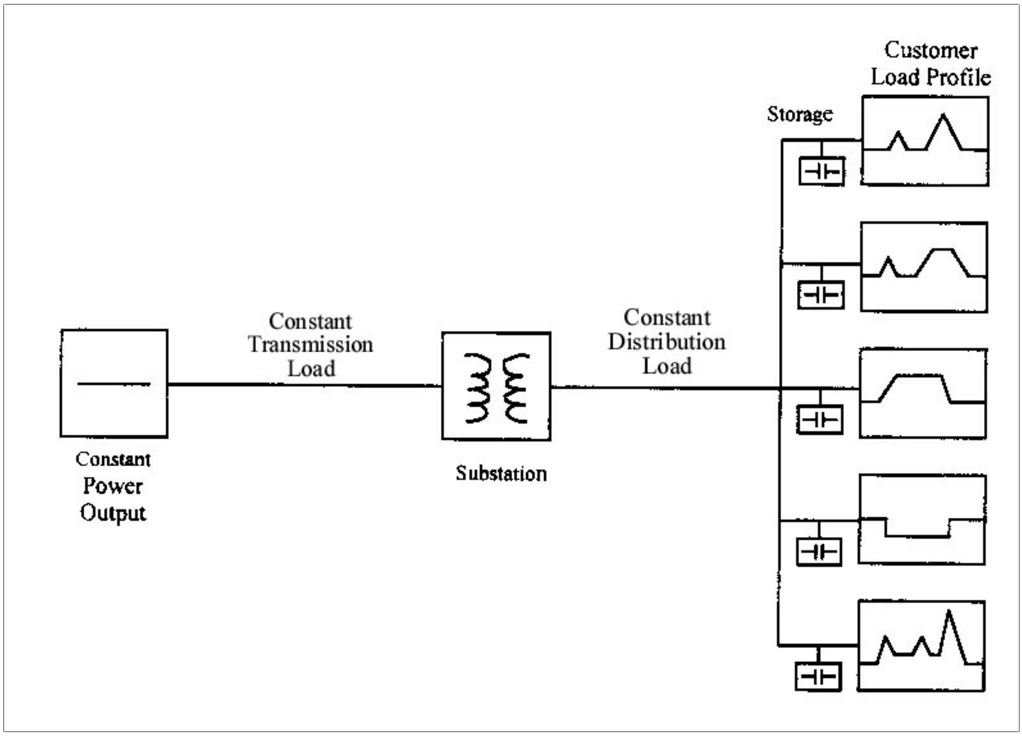

Figure 2 Storage Sited at Each Customer Location

with minimum generating capacity. Some storage might be located at the generation site and some at the load. The optimum location would be selected so that transmission equipment could be sized for as steady a load as possible

Cogeneration, similarly to renewables, has an unpredictable supply profile. Cogeneration facilities are designed primarily for thermal processes and electricity is a by-product. If either thermal and/or electric forms of energy storage were included within a cogeneration system, the operation could be optimized around the thermal requirements. Then electricity would be generated and used as needed, with power flow controlled through the storage system.

Power Conditioning and Power Quality
Energy storage has another ideal application in ensuring reliable, high quality power for customers. Some end-users are particularly sensitive to outages or variations in power flow characteristics. Energy storage systems can buffer these disruptions, such that customers' loads are isolated from them. In this application, depending on the source of the disturbance, storage can be sited at customer locations, within the distribution system at key locations, or at the transmission level, if necessary.

B. Environmental Emergency Scenario
In this scenario, global warming or some other circumstance forces utilities and customers to rethink the way they make and use electricity. Clean air, i.e. local air pollution, concerns are best addressed by moving to cleaner or more remote energy production. Global warming is probably caused by CO_2 emissions; remediation will require primarily the use of less carbon-based fuels. Taken together, energy storage could be used in the following ways to address such an environmental imperative:

- Reduce emissions at the generation point by: operation of the plants at optimum environmental settings, improving overall system efficiency, or changing generators to cleaner sources
- Enable renewables and thus reduce fossil fuel generation contributions to pollutant emissions. Because of the intermittent nature of renewable resources, storage is a valuable enabling companion
- Smooth the output from cogeneration facilities and make efficient use of that resource
- Reduce emissions from distributed generation by coupling with storage

- Reduce industrial emissions by improving process operations and more use of electro-technologies
- Reduce emissions from electric generation used for heating/cooling by using thermal energy storage
- Reduce vehicle emissions by greater use of electric vehicles, recharging stations or transit
- Accelerate the use of hydrogen as an energy carrier, thus eliminating CO_2 emissions

C. Fluctuating Electricity Price Scenario
In this scenario, the daily, weekly, or annual level of energy and delivery prices of electricity become unpredictable. Prices may rise or fall on average, but their extreme variability is the only certainty in this scenario.

These types of customer price variations were seen in the Summer of 1998 in the Midwest and Northeast. In some cases the cost of spot electricity rose to near $10.00 per kWh for several hours. The debate continues as to the real cause and whether such variations in electricity prices are healthy market indicators or a symptom of something wrong with the market. We do not concern ourselves here so much with their causes, but only how such wild variations might present opportunities for the storage community.

If the fluctuations occur over a long time period (say eight hours), storage will have a difficult time entering the market to address the need. Storage systems with long durations and which are used very infrequently have poor economics. However, if the fluctuations have a duration of an hour or less, the market for storage could be substantial. For central storage, utilities or energy brokers may choose to install more short-term storage. Their goal would be to serve this very high value spot market when it occurs.

To look at a specific example let us assume twenty periods of high price fluctuations per year, each one hour long, and each valued at $10 per kWh. This yields a gross income of $200/kW-year. Since the premium is on availability of the power not the efficiency of the storage system in this market scenario, the storage system efficiency becomes irrelevant. Even if the energy to charge the storage system were bought at a pessimistic ten cents per kWh and the storage system roundtrip efficiency were as low as 20%, the charging energy would cost only $10/kW-year; this is negligible with respect to income. Continuing with this hypothetical example, if the owner of this storage unit were to finance it such that the length of the loan, interest rates, etc. yielded a pessimistic 20% per year carrying charge (most utilities currently would say 12%), the net $190/kW-year income could support an installed cost of one hour of storage of approximately $950/kW.

If a new technology could be designed specifically to meet this scenario it would have moderate to low capital cost, fair reliability, any efficiency (above 10%), any reasonable variable operating costs, and low fixed operating costs; unattended operation capability would be helpful. Rapid response to discharge commands and quick draindown capability would be important, while fast recharge rates would be unimportant.

D. Demanding Customer Scenario
In this scenario, customers become very demanding on their suppliers of electricity. Under these conditions, more options are wanted, better and/or tailored services are requested, lower costs are demanded, or new load types are connected. As customers become accustomed to being selective and demanding about cost and performance from their energy providers, storage will become an enabling technology for improving customer service. The possible functions are described in this section. They focus on reducing electric bills and providing high-quality-of-life service.

Some areas where energy storage may help serve these customers are:

- Power Quality and reliable (continuous) service
- Reliable supply in a financially-driven market
- Direct customer cost reduction through customer peak shaving, where demand charges apply
- Overall reduction in the cost of electricity due to efficient use of resources
- Remote locations, either at the end of a feeder, or completely off the grid
- Enabling or enhancing transit capacity in urban/suburban corridors
- Promoting electric vehicle use and construction of its infrastructure
- Using energy storage to enable and promote the use of electro-technologies in the industrial and agricultural sectors
- Synergies with nano-technologies

E. Storage Packaging Breakthrough Scenario

Two characteristics of energy storage, which are often considerations, are energy density (kWh/m^3) and power density (kW/m^3). These parameters relate to the size of a system and therefore the space required to house it. A related parameter is footprint, or the floor area required. Current technologies vary widely in these characteristics. In addition, some technologies also require "auxiliary" space, such as a keep-out zone for the magnetic field surrounding a SMES unit, or the safety containment for some flywheels.

Some current technologies also have scaling characteristics that make them less attractive in smaller, modular units. Economies of scale are an advantage for large applications, and a disadvantage for small applications. In this scenario, we consider the use of energy storage that is modular, has high energy and power density, and no environmental or safety constraints. A fictitious analogy could be a storage "paint."

If energy storage were more convenient (i.e. modular, compact, safe and environmentally benign), even if not free and not 100% efficient, it could be used in all of the circumstances described previously in the Core Scenario: for load leveling, for transmission stabilization, or for providing power quality. For many applications (e.g., large scale load leveling), space is not necessarily a concern, however, and a new, more costly technology would not penetrate there as much as if it were free. The likely place for insertion would be on the smaller end of the scale (substation, distribution, customer end-use), where space is limited.

A particularly exciting development would be if innovative configurations became available that could easily fit within typical customer work or living spaces. Some small-scale batteries are currently being made to fit hand-held appliances. Another innovation that could reduce system and operating costs would be to eliminate wiring by charging storage components inductively.

F. Gas and Electric Industry Convergence Scenario

In this scenario, through a series of mergers and acquisitions and because better gas-conversion technologies arise, the gas and electric industries become nearly indistinguishable. These dual energy companies will probably not care which form of energy they sell; they are capable of converting natural gas into electricity where and when it is needed, for example with on-site generation. There are no business boundaries separating these two energy forms, only a question of maximum profitability and service quality (both gas and electric).

Depending on the economic details of the conversion process of natural gas to electricity (primarily heat rates and capital costs) the electricity can be created where it would be most profitable. Depending on the cost to serve each customer, the local business regulations and practices, new and old customers could be served by electric only, gas only, or both (as we now do).

This could lead to abandonment of wires in some cases in favor of bringing only gas service to a customer. In this scenario electric energy storage will have shrinking market opportunities, since gas is much less expensive to store than electricity; it is also more efficient to store natural gas than electricity. If gas service reliability were to deteriorate, then electricity storage would become a more important factor.

In areas where natural gas becomes the preferred energy delivery choice, only the very modular, very short duration storage technologies would have many applications, mostly in tandem with on-site generation units to help short-term ridethrough or power quality. In areas without natural gas access, electric storage markets would be unaffected.

G. Energy Security Scenario

In this scenario the electric and/or gas infrastructure becomes fragile or is threatened with possible demolition. National action is needed to come up with alternatives to counteract this problem. Could storage technologies play a large role in this situation?

If only the electric system were at risk, the gas system could be designed to provide substantial support via local generation. Electric storage would have very high value, but massive amounts of storage would be needed to solve the major long term outages which might occur.

If both the gas and electric systems become weakened, the mutual support of these energy delivery industries is just as important, but now electric storage becomes even more valuable. The best hope might be simple home storage units rechargeable from an automobile's alternator, an unattractive alternative for many reasons such as safety, excessive gasoline use, inefficiency, wear and tear, etc.

Distributed storage (i.e. storage placed throughout the distribution system) would be a help during relatively brief outages (several hours).

H. Extreme Deregulation and Competition Scenario
In this scenario regulators (state and/or federal) nearly dissolve the utility monopoly for the wires in addition to the open market for bulk electricity assumed in the "Core Scenario". The (former) utilities have little choice but to run their businesses as non-monopolies with a few important exceptions still in the overwhelming public interest such as lifeline rates and minimal reliability and power quality standards.

Nearly every function the wires companies now serve would be unbundled and priced at rates set by the marketplace, not a Commission. We would expect to see customer-specific (or at least location-specific) electric rates priced near or above the margin to serve each customer (or location). Retail rates would be offered in many different packages and forms to meet customer needs: hourly spot prices, curtailable rates, risk-free long term rates, power quality adjusted rates, reliable service guarantee adjustments, group discounts, green pricing, etc.

Such a scenario offers many new opportunities for storage. On a retail level customers may choose to use storage to hedge against temporarily high spot electricity prices, or buffer sensitive equipment from poor power quality events. The degradation of service quality, lack of firm and uniform pricing, and locally poor reliability will lead some customers to hire ESCOs to solve many of their problems, sometimes with storage solutions. Utilities more in tune with customer needs may offer such storage-based solutions themselves.

Locational pricing will eliminate the averaging and locational cross-subsidies now employed by utilities. If locational pricing is coupled with near real time cost of power, extreme needle peaks in rates will occur frequently, making storage a critically important and valuable technology in this scenario.

Conclusion
This report has attempted to go "outside the box" by assuming several extreme situations. These assumptions have allowed us to explore the full range of potential storage applications and describe electrical systems which take maximum advantage of storage. This work should encourage storage developers and potential users to more closely examine near-term applications of energy storage technologies, expedite pathways to the longer-term applications outlined herein, and accelerate the market development of the technologies. Only time will tell as to which of these innovative storage applications will become reality.

In each scenario, both traditional and innovative storage applications are analyzed, and utility trends and potential market opportunities are evaluated. The implications of the scenarios are then synthesized to produce general conclusions about the potential trends for utilities and for uses of storage technologies, and to develop recommendations for potentially profitable storage technology research directions. Key conclusions are:

- Storage is more likely to be installed in conjunction with customer installations rather than coupled to central power plants.
- Increased interest in environmental issues would accelerate market entry of storage technologies; expanded use of storage is completely consistent with cleaner energy.
- Packaging and ease of use, rather than efficiency or energy density, are the key technology factors in several major opportunities.
- Regulatory structures that allow more freedom to solve problems with innovative approaches would be more likely to lead to increased use of storage.