Energy Storage

A Nontechnical Guide

By Richard Baxter

PennWell®

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Foreword

Electricity is the most useful and flexible of all energy sources. To provide this capability, the power industry in modern industrialized societies developed power stations of various sizes and capabilities to provide a continuous, reliable, and affordable supply of electricity as the demand varied on daily, weekly, and seasonal cycles. Lately however, this centrally organized and controlled market design has become unstable. This has caused investment for new large power stations to become riskier as repaying their development costs can no longer be guaranteed through assured power sales in a highly regulated market.

Solutions to this challenge follow one of two competing strategies. The first is simply to continue extending the power transmission grid in order to open up additional markets for these new generation facilities. The second is to focus on a distributed supply strategy reliant upon smaller and distributed power generation and energy storage resources to provide a more stable and secure electricity supply. Each of these strategies implies a different direction for the future of the power industry. The first strategy represents a continued centralization of power production to offset increasing transmission infrastructure costs, whereas the second strategy represents a focus on local production and management of electricity to avoid excessive infrastructure build-out and grid management costs. This second option is the most promising one as it enables significant progression toward improvements of energy efficiency, leads to enhanced energy security, and—above all—promotes wind and solar power for the electricity supply.

Richard Baxter shows in his book how diverse the possibilities of electricity storage really are. These technologies have been widely overlooked by the power industry for many years as the industry's focus has been fixated on large-scale supply strategies. Through this fundamental book for the energy industry of tomorrow, Richard Baxter has broadened the industry's horizon by showing how it will be revolutionized by energy storage technologies—enabling greater use of renewable energy, and promoting a more flexible, efficient, and stable self-correcting energy infrastructure.

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General Chairman World Council for Renewable Energy
President EURSOLAR
Recipient of the Alternative Nobel Prize
Member of the German Bundestag

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1 STORAGE AND THE ELECTRIC POWER INDUSTRY

The electric power industry has some immense challenges before it—that, we can all agree, is glaringly obvious; the good news is that energy storage technologies offer real solutions to some of the most pressing of these issues. Many of the worst problems stem from issues built into the system through the market structure. One of most vexing is that the current power system is built around a central tenet: Electricity must be produced when it is needed and used once it is produced. This rule necessitates rigid procedures for operating the system—raising inefficiency, lowering reliability, and reducing security. Although radical solutions from pundits abound, most industry veterans understand the sheer scale and interconnectivity of the system mean that change here comes most readily through evolutionary and not revolutionary means. Because energy storage technologies are usually enabling technologies and not disruptive ones, their expanded use will enhance the value of existing assets by providing more flexibility and options—supporting the inherent infrastructure-centric nature of the market.

Although the industry may prefer slow, evolutionary change, it should also be understood that change is endemic in the power industry. In the short-term operation of the electric power market, what happens on a daily basis can take weeks or months in the natural gas market. In the long term, evolving regulatory, economic, and technological forces have affected the market since its inception, and will continue to do so in the future; while some of this change is intended, much is either unexpected or even unwanted. First, it exposes weakness in the market; episodes like the 2003 blackout in Canada and the northeastern United States show that there is a real need for the existing infrastructure to be coordinated in a far more effective manner. Second, change creates a need for new market tools—existing assets are built to perform in certain market conditions, and when these change, some of these assets are simply not readily adaptable. Finally, change also produces opportunities; as the market moves from a tightly controlled structure toward a more open and flexible stance, many market participants can more easily take advantage of innovative business models and technological advances such as storage technologies.

This does not mean that energy storage technologies are a panacea or a solution for every market problem; existing power market assets remain the backbone of providing service to customers. However, the normal operation of conventional technologies propagates the inefficiencies inherent in the industry, which often produce the very situations where the flexible capabilities of a storage asset are most needed. In fact, these instances of system instability frequently produce the greatest cost to the system—cost that can be reduced through greater adoption of energy storage technologies. In the previous incarnation of the market, standard regulatory-led practices lent themselves to capital-intensive solutions in meeting these challenges as the redundant equipment could simply be rolled into the rate base. Although functional, this was an inelegant solution to a chronic problem; in an increasingly competitive market, this inefficient solution is no longer acceptable.

For these and other reasons, energy storage technologies provide an option (often the least costly one) that the industry can call on to solve some of its most difficult challenges. Energy storage technologies break the linkage between electricity production and demand, allowing the storage of power for later use. By maintaining a ready-reserve cache of energy, storage technologies can help industry participants overcome such challenges as:

- Improving low utilization of power facilities
- Relieving transmission congestion
- Improving the market potential of renewable energy generation
- Preventing losses from unreliable power quality for end-use consumers

By absorbing or providing power—even a small amount—at precisely the right time and place, energy storage technologies can relieve significant system stress and costs, effectively acting as a *shock absorber* for the industry.

Misperceptions and Realities

Storing energy is a seemingly simple and familiar concept, yet even electric power industry insiders often misunderstand its real potential. The technology is straightforward—storage technologies convert electrical power into chemical, mechanical, or electrical potential energy and retain the ability to reinject it into the power grid when called on. Unfortunately, the stored electrical power is then viewed simply as a static repository of energy, with any value ascribed strictly to its commodity value. This is a simplistic, one-dimensional view of storage technologies—the deliverability of that energy is another key aspect. The ability to decouple the linkage between power production and power demand allows the industry to use storage technologies as both a sink and a source of energy—and both are valuable resources in a dynamic environment such as the electric power market. As a sink, storage facilities can not only absorb energy slowly from generators to optimize their operations, but also absorb rapid surges, preventing imbalances that can affect the power grid's stability. As sources of energy, storage technologies not only can be used to arbitrage energy between off- and on-peak usage, but they can also be used to adjust the rate of energy production and purchases. The ability to affect the supply/demand balance of energy delivered to customers provides the capability to then reduce ramping stress or otherwise optimize the use of generation and transmission assets, or to prevent consumer equipment damage in the retail market from power fluctuations.

Although treated as a new technology, the electric power industry has actually maintained significant storage capability for quite some time now. Therefore, the issue going forward is rather the rate and type of further adoption—not introduction—of these technologies in the market. From the wholesale to the retail market, firms have recognized their flexibility and have invested significant amounts of capital into these technologies for many years. In the wholesale power market, U.S. utilities began in earnest to build a number of pumped-hydro facilities in the 1970s and 1980s, resulting in 20 GW of capacity by the early 1990s (nearly 3% of all U.S. summer capability at the time). Besides their use for arbitraging off-peak power to peak demand, they have proved very useful for providing much-needed stabilization for the transmission system. In the retail market, commercial and industrial firms drive the $7 billion spent globally on uninterruptible power supply (UPS) equipment to provide enhanced power quality and reliability as the demand for better power quality grows.[1] Even the U.S. power industry itself keeps banks of batteries on hand at each of the estimated 100,000 (or more) substations and every major power facility to run the control equipment in the event of a power outage. Existing applications will continue to grow with the market, and new applications will be enabled through expanding capabilities of existing technologies and the continued commercialization of newer ones. As one sign of a maturing storage technology market, some storage technologies now target existing markets already supported by existing battery technologies.

Therefore, energy storage technologies are not simply a solution in search of a problem—they have real uses both now and in the future. In some instances, they enable applications that generate real revenue, whereas in other applications, they either reduce capital expenditures or prevent losses from damage-process interruptions. As these are all valued roles now, no *paradigm shift* in thinking, market structure, or technological basis is needed for these technologies to expand their presence in the market. As the market continues to change and new demands are put on the industry, these existing and new technologies will enable a more flexible way of operating and provide the real optionality managers need. For this reason, the continued introduction of these technologies will not simply be vendor-driven, but actually demanded by the market. In fact, three broad themes at the core of most corporate and public policy goals will promote the continued deployment and use of energy storage technologies:

1. **Efficiency.** Storage technologies can be used to improve the operations and use of generation and transmission facilities, enabling a more flexible and effective market. Even if their capability is short-lived, so too are the times when they are needed most, such as when the wholesale price of power spikes during times of temporary transmission capacity shortage.
2. **Reliability.** Storage technologies can enhance the ability of utilities to provide electricity service to customers without any of the normal or abnormal fluctuations in the quality of the power impacting their customers by improving the power system's stability.

3. **Security.** Storage technologies can provide a means to blunt short-term disruptions on the power grid before they become large-scale problems by giving system operators the fast-response capability provided by a ready-reserve resource—or they can harness additional resources to support restoration of service once a blackout does occur.

Wholesale Power

The wholesale power market continues to prove far more challenging than envisioned by the architects of its transformation, as competitive power prices have brought both new opportunities and new setbacks. Although recent entrants garner much of the market's attention, owners of the existing $500 billion in generating assets struggle to maintain their profitability as the rules in the market change—changes that reveal that previous operating strategies incurred far higher costs than first imagined.[2] These market changes also affect developers of renewable energy projects who find that while many support the idea of developing these domestic resources, integrating them into the market can be far more difficult than first envisioned.

Facility utilization

The move to a competitive power market has stressed the ongoing operations of many existing coal facilities; improving the utilization of these units is one direct way to markedly improve their profitability. Because coal-fired units provide half of all U.S. power generation, improving their value ranks as a public policy concern. As it stands, ramping down during off-peak hours (nights, weekends) to match the current load leaves these units with appreciable unused capacity. Although generally termed baseload, coal-fired units do not enjoy the must-run status of nuclear units, leaving the fleet average of all coal units around 70%, whereas nuclear units have been able to increase their levels well above 90% (fig. 1–1). Increasing the utilization of these facilities would lower average operating costs—not only increasing overall revenue, but also the profitability of these facilities. The off-peak production cost of power could also benefit (from higher plant utilization), as some market studies point to increases in the heat rate of individual units of anywhere from 5% to 20% when running at low power.[3] Anecdotal evidence even points to some older units whose total operating costs reportedly increase upwards of 40% when operating at half power. Beyond lower operating costs, per-kWh-hour emission levels would also decline, as the power facility is able to operate more closely to full power. Although this overall improvement may not be dramatic, any improvement on this issue in an era of ever-tightening environmental restrictions could prove beneficial.

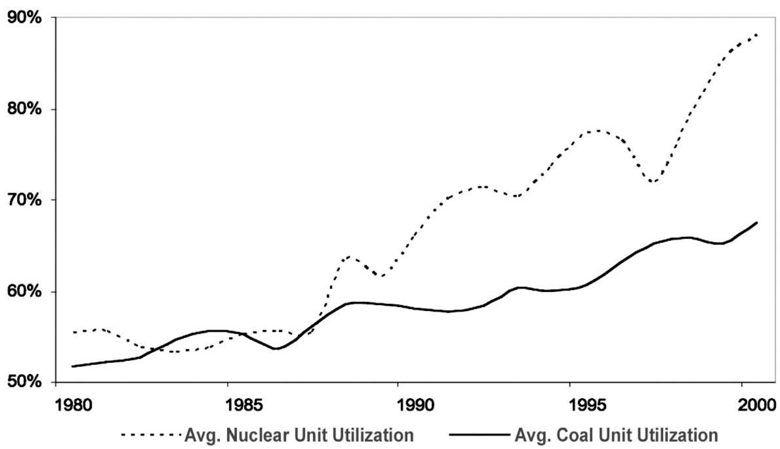

Fig. 1–1. Coal units lag nuclear in utilization improvements (Data: U.S. Department of Energy).

Large-scale energy storage facilities can help increase the utilization of coal facilities—or other units with excess capacity—by acting as an energy sink during energy-usage off-peak periods. Coal facilities with the most to gain would be those with significant excess production capacity as they should have the lowest marginal cost for additional power production. Existing large-scale energy storage facilities (pumped-hydro, compressed air energy storage [CAES]) already operate in this arbitrage role today, and even offset the need for some additional peaking capacity during peak demand. Producing additional power at night can even help daytime air quality, especially during hot summer days prone to ozone warnings, because the emission levels of a CAES facility (and especially those of a pumped-hydro unit) are far lower than those of a peaking combustion turbine unit.

Cycling damage

Matching the changing daily load can also have negative impacts on mid-merit power facilities, and to a far greater degree than previously thought. Recent market strategies have evolved so that older fossil-steam (and even some combined-cycle) units in the mid-merit role are forced to cycle with the load, resulting in many facilities cycling heavily every day—with some even cycling on and off daily . What is becoming better understood is that the cost previously ascribed (and used currently in dispatching decisions) to these activities is significantly below their real value; the true cost of this cycling is much higher—sometimes more than 10 times the previously used value—making the current dispatch decisions far from optimal. One of the leaders in the field of power plant failure/performance analysis is APTECH Engineering Services, which has spent many years evaluating these problems. Based on analysis of real operating data from more than 200 power generating facilities, Steven Lefton, vice president of the firm, notes that if the true cost of cycling was used, an average utility power system could reduce its total production costs by 5% (and increase profitability significantly). This heavy cycling and rapid load following is taking its toll by damaging plant equipment and requiring far larger maintenance costs. Although the older fossil units have proved far more rugged than first thought, the resulting number of warm or even cold starts is far more than first envisioned for these units, especially as some are now older than many of their operators.

Even combined-cycle units—having improved significantly from their first entrance in the market—still find the cycling troublesome. The resulting effect on these units is that the wear and tear is accelerating, resulting in higher operation and maintenance (O&M) costs, longer and more frequent forced outages, higher heat rates, and shorter life expectancies for critical plant components (fig. 1–2).

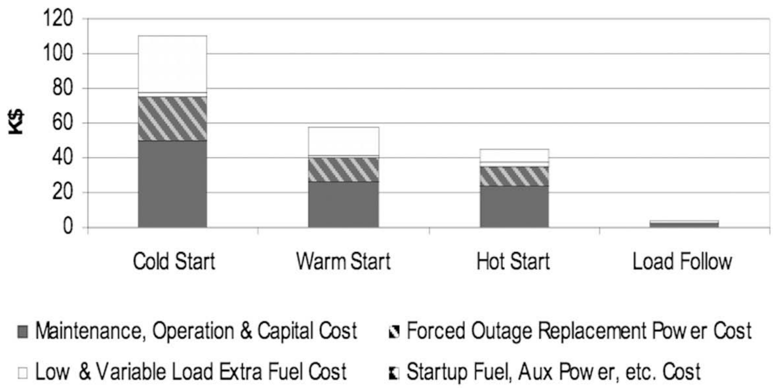

Fig. 1–2. Power generation cycling cost breakdown (Courtesy of Aptech Engineering Services, Inc.)

Large-scale storage facilities can help these mid-merit power facilities in two ways. First, they can provide a sink for energy at night sufficient to keep these plants from shutting down, precluding many of the excessive warm starts that create the costly and cumulative damage to the units. Second, the storage facilities can provide faster-responding load following services so that the demand on power generation facilities is not as dramatic during times of rapidly changing demand, allowing these older units (and combined-cycle facilities) to ramp along their optimal design path rather than what the market demands. Both of these roles would reduce the cyclical wear on the power facility equipment significantly, greatly extending its life and lowering the maintenance replacement costs. Extending their analysis to include this application of energy storage, APTECH Engineering Services estimates that including storage into the mix can improve the performance of a large utility system by anywhere from 10% to 28% from reduced cycling damage and dynamic heat rate effects.[4]

Renewable energy

Increasing the use of renewable resources such as wind is one of the prime goals of U.S. energy policy makers. Not only does wind provide a domestic source of power, it is an environmentally clean source of energy. Wind power in particular has seen dramatic growth, with a total of more than 6,000 MW of wind turbines installed by the end of 2003. Far more is possible, with the American Wind Energy Association (AWEA) estimating that the United States alone has three times the wind power potential compared to its current electricity usage today. However, these new resources face market penetration challenges as they become integrated into the power market. Wind energy production potential is generally noncoincident with peak demand periods; most (roughly two-thirds) of the energy that can be produced from wind turbines is outside of the weekly peak demand (and pricing) periods. In addition, wind resources are variable—making the stable delivery of power from the wind turbines hard to achieve. Most wind resources developed to date have been in remote locations where the existing utility transmission capabilities are generally limited.

Advancements in wind turbine technology have created many new opportunities for even more development, but challenges remain. Although modern wind turbines can now produce power competitively with natural gas combined cycle units, there is a growing realization that the wind energy potential in many areas will remain stymied because of the above-mentioned challenges. Noncoincident production means that much of the power is only sold at off-peak prices. Unpredictable power means that not only is the capacity payment heavily discounted, additional ancillary services are needed to integrate the wind power into the power grid—again lowering the value of the wind energy to the system operators. Much effort (especially in Europe) has gone into extending weather forecasts into *wind-power* forecasts, but weather forecasts have their limits, especially in the time frame required by the power industry. Distant resources mean additional costs for transmission or even the potential loss of sale because the wind energy could be constrained off the power grid during peak demand. Therefore, without addressing these attributes of the wind resource, modern wind turbines may very well be able to turn vast quantities of the nation's wind resources into electrical power, but that wind energy will continue to be penalized or even unusable in the market.

Storage can improve the value of wind energy (and reduce the project risk) by both increasing the value of the wind energy and reducing the current discounting of its output value. At its heart, storage offers a means to decouple the production of wind energy from demand, and to provide that power in a dispatchable and stable manner to the market. These capabilities can directly mitigate the negative aspects of wind resources to improve the value of the wind energy and promote a greater market penetration of wind power. For instance, on small or isolated power grids, wind resources are plentiful, yet the variability of that potential resource could mean additional generating units must be added to stabilize the power grid, actually increasing the overall cost of power. A growing number of wind and storage projects with short paybacks are proving the success of this strategy today. With storage, these small power grids can rely on wind power to a far greater degree, reducing or even eliminating the need for the diesel generator and its expensive fuel needs. In the larger wholesale power market, a number of wind and storage projects are currently being evaluated. Although some will provide a *capacity-firming* capability to support the wind turbine output, others plan to optimize the design