Energy Storage Forum

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The Future of Energy Storage

Meeting the Challenge: A Snapshot of Asia

Bottling electricity. The question is not “Can it be done?” as energy storage solutions exist in the electric power industry, but “How much will it cost?” In the era of low fuel costs, little time was given considering different storage methods. Even as new capabilities came to market, costs remained high. If the cost of doing nothing with – wasting – generated electricity is lower than the cost of adopting storage technologies, waste wins.

But as fuel prices escalate, many planners are looking for answers in energy storage applications. Waste has become painful – and costly – enough to warrant new solutions. And many more storage options are available.

As Jillis Raadschelders of KEMA (a large, multinational energy consulting company) says, “Storage is an integral part of every logistic chain… except in the electricity sector. By using energy storage, you can separate the generation of energy from its use – both in time and in space – without sacrificing quality at any level.”[1]

With the trend toward renewable energy sources, energy storage technologies must also come to the forefront.

After fuel sources, generation, transmission, distribution and delivery, energy storage is often considered a sixth – missing – component of the electric power market. With storage, utilities need only to anticipate a heavier than normal load, but can run existing equipment at a higher level, leading to a greater return on investment (ROI). Rather than replacing the existing system, energy storage technologies can serve in a supplementary role, yet greatly improve efficiency and utilization.

And what about the connection to renewable energy sources? Between 2000 and 2008, global renewable energy installations have tripled.[2] But most experts agree that intermittent sources of power will never reach true market penetration without storage. Why? Utilities need assurance that the power supply will be there when the demand hits.

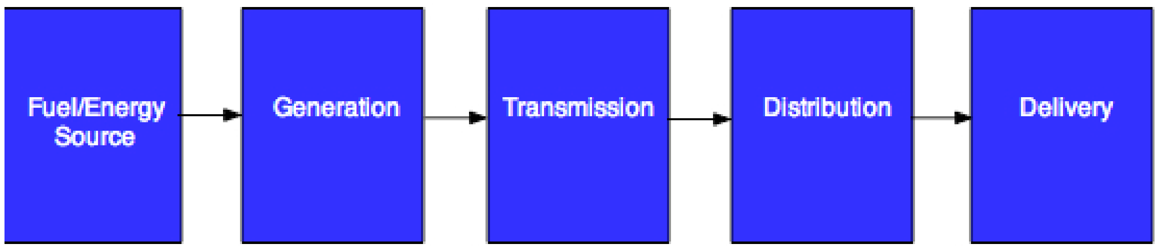
This paper will discuss the challenges and ultimate benefits of implementing energy storage technologies in the utility industry. It includes a synopsis of the current status of the most promising technologies and discusses policy considerations when implementing a new asset class. It focuses on the many ways that energy storage adds value to the utility industry.

Links in the Electrical Power Market Chain

Traditionally, the electrical power market has five components:

1. Fuel or energy sources

   Resources capable of generating energy include non-renewable sources such as coal, petroleum, natural gas and uranium used for nuclear power and renewable resources such as solar, hydro, wind and hydrogen.



"Traditional" Electrical Power Market Chain

2. Generation

   Currently, industrialized countries generate most of their electricity in large centralized facilities. These plants have excellent economies of scale, but usually transmit electricity long distances and can negatively affect the environment. Power quality can also be affected.

   Distributed generation is another approach. Defined as the generation of energy close to the point of use, it reduces the amount of energy lost in transmitting electricity. Using advanced battery technologies, utilities can now store electricity in large batteries located in substations – with capacities on the order of several megawatts – for a few hours.

3. Transmission

   Electric power transmission is the bulk transfer of electrical energy. A power transmission network typically connects the generation facility to multiple substations near populated areas. The grid interconnects generators and loads and generally provides multiple paths among them. Electric power transmission allows distant energy sources to be connected to population centers where consumers live.

   Multiple lines – with redundant paths – between points on the network allow power to be routed from any power plant to any load center, through a variety of routes, based on the economics of the transmission path and the cost of the power. Electricity exits the transmission grid at the substations, where transformers reduce the voltage to a lower level for distribution to commercial and residential users.

4. Distribution

   The modern distribution system begins as the primary circuit leaves the sub-station and ends as the secondary service enters the customer's meter socket. As discussed above, distributed generation can reduce the size and number of power lines that must be constructed. For regions where many people live a long way from the electrical distribution system – and it would be prohibitively expensive to extend distribution lines to each structure – distributed generation is often the best and only option.

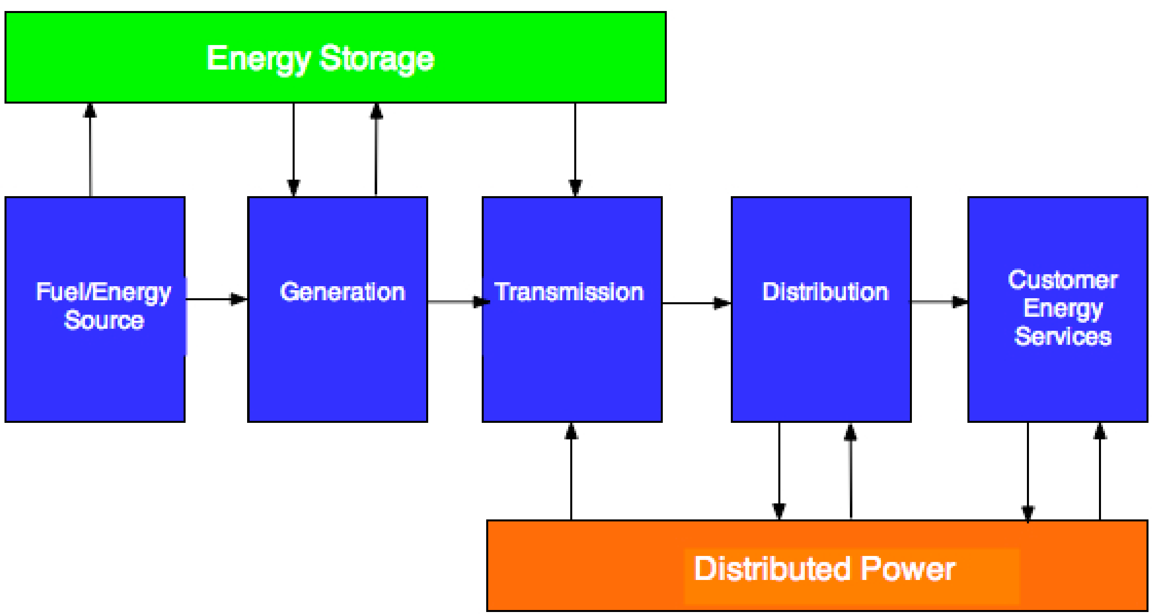
5. Delivery

   Delivery is the interaction between the end user (customer) and the local utility. Electrical services are priced based on the cost to the utility and users charged (generally a flat rate) for electrical usage.

   What the current system lacks is a two-way flow of information. Utilities know when power usage will be more expensive and conversely when it is cheaper, but don't have simple ways of giving this information to their customers. And since the price of electricity can fluctuate day-to-day, hour-to-hour, even minute-to-minute, the information from a Monday afternoon might not be useful by the following Friday morning.

Energy storage connects to the electrical power market as the sixth essential link in the chain, after fuel, generation, transmission, distribution and delivery.

So where does energy storage connect to this chain? Many experts see storage as the sixth essential component of the electrical power market. Storage capacity would improve the reliability of the electrical supply, increase the efficiency of existing generation and transmission facilities and reduce the investment in new and existing facilities. In his book, *Energy Storage*, Richard Baxter says, "Energy storage technologies break the linkage between electricity production and demand, allowing the storage of power for later use."[3]



Electrical Power Market Chain with Energy Storage

Energy storage helps to synchronize energy supply and demand. Customers have the electrical power they want and need – at reasonable prices - while utilities have an easier time forecasting power usage and can reduce their own costs and potentially increase profits. Sources of power that fluctuate based on the natural environment can be integrated successfully into this network.

Challenges Facing the Electrical Utility Industry

The utility industry faces five primary challenges:

1. Volatility (referring to both energy availability and price)

   Power shortages and times of surplus cause wide swings in price and physical availability. During times of high power demand, high-cost peaking plants must cycle on and off, with corresponding high fuel costs, often from natural gas. And when less power is needed, plants must continue to run, often at much less than capacity.

2. Low utilization of power facilities

   Since the electrical grid operates much the same as a huge just-in-time electrical production and delivery system, transmission and distribution systems must be sized to accommodate the maximum or "peak" rather than a calculated average. This ensures that power facilities will be underutilized. Experts estimate that peak loads occur just 400 hours per year. And the capital assets ramped up to meet peak demand are often some of the most costly to build.

3. "Dirty" power

   A report of the Intergovernmental Panel on Climate Change (IPCC) has clearly indicated that most of the global warming observed over the past 50 years is likely induced by the increase in concentrations of greenhouse gases (GHGs), such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), due to human activities.[4] Electricity generation is the largest source of greenhouse gas emissions in the world.

   No single technology can achieve the goal of carbon reduction. By improving overall system efficiencies and embracing the use of renewable energy sources in conjunction with energy storage, industry professionals can plan for and react to a future in which carbon emissions are constrained.

4. Transmission congestion

   Electrical transmission systems are a real-time balancing act. As electrical power flows from power plants to end users, conditions on the grid are always changing. Loads turn on and off, disruptions occur, and wholesale power moves across the network.

To counterbalance these changes, utilities follow the load by ramping power plants up or down, second by second, to meet the demand. Increasing power needs cause more congestion, requiring utilities to increase spending on stabilizing equipment. And these global power needs will only continue to rise.

5. Security

   An element of economic security based on national and worldwide events plagues the utility industry. Decreasing global fuel supplies, dependence on volatile nations as suppliers and rising fuel costs combine to present more questions than answers for many countries. Problems in one section of the power grid can spread within seconds. Lack of backup systems offer more chance of system disruption from unforeseen failures.

Energy storage technologies, when applied in conjunction with current utility practices can diminish the threat of each of these problems. Ready power availability during shortages and the absorption and storage of excess power will smooth peaks in both price and physical availability. Greater utilization of existing assets will prompt private investment that in turn will increase the quality and availability of power supplies.

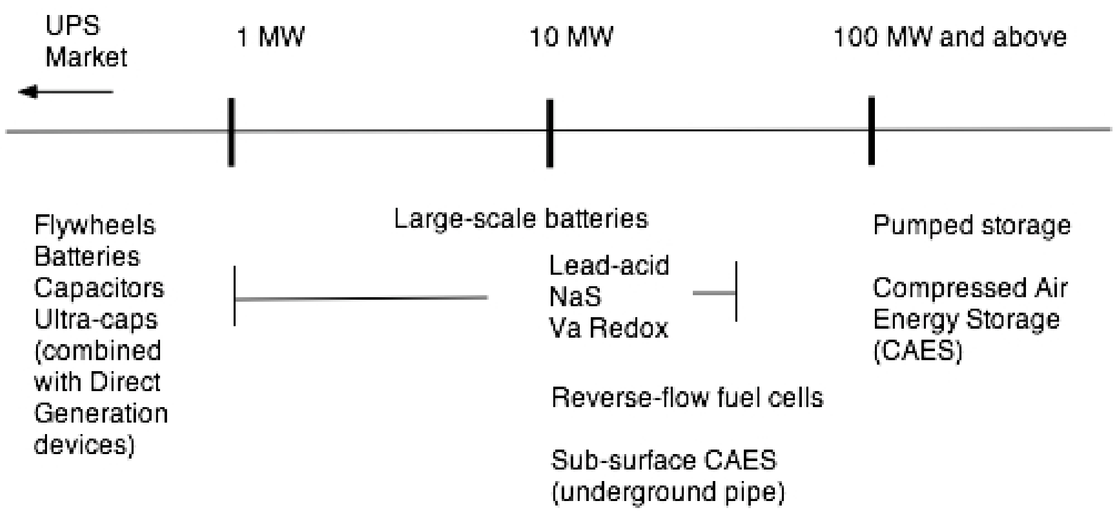
Renewable energy sources combat the production of greenhouse gases and help meet carbon constraints. Distributed generation using renewables can solve both congestion and security problems by reducing dependence on global fuel supplies and locating generation sources at or near where energy is consumed.

The 9 Most Promising Energy Storage Technologies for the Power Grid

Storage technologies are generally divided into three major categories based on utility application. **Energy management** provides a way to shift the consumption of energy into the future, often by many hours. Typically this is known as load leveling, where power generated when energy costs are low is consumed during higher rate periods. **Bridging power** is used to ensure continuity of service when changing from one source of energy generation to another. These storage applications are needed anywhere from several seconds to a few minutes at a time. **Power quality** storage media is needed for a few seconds or less with the goal of continuous quality power.

Most storage technologies will function optimally in just one of these categories. Other considerations include energy density (based on size and weight), the total cost of ownership (including equipment lifetime, operations and maintenance costs) and the efficiency and cycle life of the device (yielding a per-cycle cost) useful in comparing storage media with hundreds or thousands of charge and discharge cycles.

Below is an example of the capacity range of various types of storage media.



Storage Technologies By Capacity[5]

The storage methods below show the most promise and in most cases have been demonstrated in a utility application across the globe.

Compressed air energy storage (CAES), technically considered hybrid storage/power production systems, use off-peak electricity to power a motor or generator that drives compressors forcing air into an underground storage reservoir, such as an aquifer, a salt cavern or an abandoned hard rock mine. When the demand for electric power peaks, the process is reversed. The compressed air is returned to the surface, heated by natural gas in combustors and run through high-pressure and low-pressure expanders to power the motor or generator to produce electricity.

In traditional gas turbines, the air that drives the turbine is compressed and heated using natural gas. CAES technology needs less gas to produce power because it uses air that has already been compressed. These peaking power plants use less than 40% of the gas used in a conventional gas turbine to produce the same amount of electric power output. A 290 MW facility operates in Huntorf, Germany and a 110 MW plant in the United States. Both plants have been in operation for almost 30 years.

Conventionally designed, **pumped hydro storage** has two large reservoirs located at significantly different elevations. Using off-peak power, water is pumped from the lower reservoir to the higher, where it is stored. When needed, the water released from the upper reservoir turns hydraulic turbines which generate electricity. The most mature and largest-size source of energy storage, these facilities require optimal geographic features, large pieces of land, and suffer high construction costs and long construction schedules.

Pumped hydro offers greater flexibility for plant startups and shutdowns without significant detrimental effect on the service life of the equipment, has zero fuel costs, no operational emission of greenhouse gases and can operate at a low minimum load – often less than 10% of rated capacity. These plants also have a high load variation speed, which means the power output can vary by as much as 100% per minute.[6] Worldwide the list of pumped storage plants is long, with over 50 plants in China alone, in operation or under construction over the next 10 years.

Flywheels store energy by accelerating a rotor to a high rate of speed and storing the energy in the system as inertial energy. The energy is released from storage by reversing the process and using the motor as a generator. As the flywheel releases its energy, the rotor slows until the energy is fully discharged.

Rotors for flywheels can be manufactured from advanced composite materials, lowering the weight of the rotor and allowing for extremely high speeds. The majority of flywheel technology has been developed for auto and aerospace applications. These systems are compact and have lower maintenance costs than battery systems. Power delivery capacities fall in the range of 150 kW to 1 MW. Technology development is focused on markets requiring better power quality and reliability.

Ultracapacitors are electrochemical storage devices that work like large versions of common electrical capacitors. Also known as supercapacitors, they store energy in an electrostatic field rather than in chemical form. Ultracaps can deliver quick bursts of intense power and withstand hundreds of thousands of charge and discharge cycles, where batteries last for just a few hundred or thousand cycles. On the down side, they carry a higher price tag than batteries and use a less established technology. In power systems, they are most likely to be used as bridging power sources in uninterruptible power supplies, much like flywheels.

Batteries store energy in a chemical form using a closed energy system. All batteries are electrochemical cells. They can be recharged and reused for a finite number of cycles. Currently, the only way to store solar energy is by using batteries.

Opportunity lies in using ultracaps and batteries together, calling on the strengths of both technologies. The ultracap serves as the power component and the battery as the energy component, collectively offering more efficient energy storage, and alleviating concerns about warranty issues when replacing large, expensive batteries.

Lead-acid batteries are the most common type of battery. Utilities and electricity consumers use this type of battery as a backup energy source for critical electricity needs. Commonly, the lead-acid battery is made up of plates, lead, and lead oxide immersed in a solution consisting of 35% sulfuric acid and 65% water. This solution is called "electrolyte," and causes a chemical reaction that produces electrons. Various other elements are also used to change the density, hardness, and porosity of the plates.

More recently, two new types of lead-acid batteries have emerged. Valve-regulated lead-acid (VRLA) batteries are sealed, need no topping off with water and require less maintenance than regular lead-acid batteries. Gel-type lead-acid batteries are filled with a gel instead of liquid, making them much less likely to spill.

Flow batteries work the same way as lead-acid batteries, but the electrolyte is stored in external containers and circulated through the battery cell stack as required. This external reservoir of rechargeable electrolyte can be as large as needed, and located where convenient. Some flow batteries use two different kinds of electrolyte that are stored separately.

The electrical storage capacity of flow batteries is limited only by the capacity of the electrolyte storage reservoirs. They provide very high power and very high capacity batteries for load-leveling applications on the electricity grid. Zinc-bromine (ZnBr) flow batteries are commonly used in the United States. Both sodium sulfur and lithium ion batteries are considered advanced battery technologies and are currently too expensive for large-scale utility applications but are used for power quality and backup purposes at manufacturing plants.

Sodium sulfur (NaS) batteries can operate at high temperatures, and have proven safe under extreme conditions. In wide use by utilities in Japan,[7] this technology is used in more than 190 sites, totaling over 270 MW. The largest installation is a 34 MW, 245 MWh unit in northern Japan, used for wind power stabilization.[8]

Lithium ion (Li ion) batteries, which are used in over 50% of the small portable electronic market, provide twice as much operating time as conventional batteries. Extremely high costs, estimated at over $600/kWh, currently limit large-scale usage of these batteries, but several companies are working to reduce manufacturing costs.

Regenerative fuel cells, also called redox (oxidation-reduction) flow cell batteries, store and release energy through a reversible electrochemical reaction between two salt solutions (electrolytes). Both zinc bromide (ZnBr) and sodium bromide (NaBr) are used as the electrolytes. An example is using molten salt as a thermal storage medium from concentrating solar power sources. Molten salt, which remains liquid at atmospheric pressure, is an efficient, low-cost solution.

The 4 Primary Benefits of Energy Storage Technologies

Storage technologies as a whole differ widely in capability and application. Described as a “shock absorber” for the electrical power market, energy storage appears negligible for many utilities, but can provide incremental and beneficial impacts when incorporated into the system. There are four primary benefits when implementing advanced energy storage technologies:

1. Improved power quality

   Currently, grid operators are more concerned with preventing power outages than with power quality considerations. Power quality refers to a set of boundaries that allow electrical appliances and systems to function in their intended manner without significant loss of performance.[9] The move toward twenty-first century power quality means delivering power that is free of sags, spikes, disturbances and interruptions.

   Lack of power quality can cause malfunctions, premature failure or devices that won’t operate at all. Critical applications such as hospitals and emergency services require a high factor of safety. Some experts even foresee that consumers will be offered different levels of power quality based on variable pricing schemes.

2. Increased stability and reliability

   A stable electrical grid protects sensitive manufacturing and computer equipment from unpredictable changes in voltage and frequency. Often measured in just milliseconds, these changes can damage fragile equipment. Blackouts and brownouts cause an estimated $150 billion annual reduction in the gross domestic product (GDP) of the United States because of increased equipment downtime and decreased worker productivity. [10]

   Storage applications can also provide “bridging” power, via an uninterruptible power supply (UPS). This allows consumers to ride out a short duration power disruption with no negative effects.

3. Higher utilization of assets

   In most industries, supply and demand play almost equal parts. Yet in the electric industry, demand is still king. Utilities must be able to forecast a demand that is revealed only just before the power must be supplied. Without knowing when the “peak” will occur and exactly how high it will go, utilities must keep “peaker” plants online and ready to go, knowing they may be utilized less than 5% of the time.

   Storage technologies provide both an economic cushion and a factor of safety in meeting demand. Because the price of wholesale electricity varies throughout the day, when electricity is sold is just as important as how much electricity is sold. The cost of storing power produced during off-peak hours will be easily offset by the value of this energy during peak hours. And the capital investment in new facilities can potentially be reduced.

4. Enhanced renewable energy resources

   Renewable energy resources such as wind and solar can be volatile and difficult to forecast. Energy storage helps solve the problem of intermittency associated with renewable energy and will help these technologies scale faster and reach a wider market penetration.[11]

   By gaining the resources to store power generated from renewables, they are transformed from low-value, unscheduled power sources into high-value, reliable products. Storing renewable energy and discharging it on a contract basis, makes the electricity much more valuable. Off-grid electrical systems, a small part of global capacity, can be drawn from a larger pool of generation sources, and become more valuable.

Energy Storage Policy Considerations

Looking at the policy landscape today, most incentive, cost recovery, market regulation and tariff decisions classify electrical industry assets into four basic categories: generation, transmission, distribution, or consumer usage. These classifications make explicit and implicit assumptions about the technical and functional capabilities of the assets based on the paradigm that energy cannot be stored. But as energy storage becomes more widespread, a proposed storage asset description (and a new asset class) could be based on the following definition.

An Electricity Storage Device would be defined as a depreciable capital asset with the following characteristics[12]:

- Ability to store (receive and supply back) a definable amount of energy to an electrical network or electrical grid.
- Maintains a definable rate of both storing and providing the stored energy.
- Definite maintenance criteria and schedule.
- Maintains a definable calendar life (years) under specified conditions.
- Measurable round trip efficiency (including parasitic losses) to be used for economic analysis.
- Maintains a definable cycle life (total kWh transferred) under specified conditions.
- Can be designed for use in one or more specific applications to optimize grid operation and energy economics.

This definition would encourage investment in storage technologies by creating a figurative box in which to place them. Giving policy makers specific direction in describing this asset class increases the chance that costs could be recovered through incentives and other funding.

Global Trends

As documented in the 2009 Update to the Renewables Global Status Report, global renewable power capacity climbed to 280 MW at the end of 2008, growing 75% over the past four years. Annual renewable energy investment worldwide reached $120 billion. In 2008 alone, wind power grew by 29% and grid-tied solar PV showed a 70% increase.[13]

Nanomarkets, an industry analyst firm, predicts that the global market for battery and supercapacitor storage systems for smart grid applications will grow from $1.5 billion in 2012 to $8.3 billion in 2016.[14]

According to a new report from GTM Research, the global grid storage market is set to grow from $365 million in 2009 to almost $2.5 billion in 2015.[15]

And what about investment trends? In the first quarter of 2009, energy storage technologies received over $121 million in venture capital, making it the second most funded sector of cleantech behind solar technologies.

Asian Market Trends

Asian countries, specifically China, India, Indonesia, Singapore, South Korea and Vietnam are dominated by state-owned or controlled electric utilities. Japan's electricity industry has 10 privately owned power companies that act as regional monopolies. All of these countries except China and India lack significant domestic energy reserves. Most have just begun to explore the benefits of renewables and energy storage technologies.

China

As of 2009, China is the world's leading producer of renewable energy based on absolute numbers. Renewables make up 152 GW of 800 GW of total installed capacity. Hydropower provides over 95% of renewable energy, followed by wind power. China's installed wind capacity, almost 13 GW at the end of 2008, makes it the third fastest growing wind power market, behind the United States and Spain.[16]

China boasts abundant energy reserves, but great distances separate resources from fast growing industrial load centers. To alleviate some of these issues, a governmental stimulus package totaling 4 trillion yuan ($586 billion), launched in November 2008, targeted all sectors of the economy, including the electrical power infrastructure.[17] Vehicles such as tax breaks and advantageous lending rates are just two of the ways the stimulus package seeks to affect the industry. Further long-term goals include development of the transmission network, integration of regional networks and addition of planned new generation capacity.

Reform of the State Power Corporation (SPC) in 2002 by the Chinese government created an electricity generation sector dominated by five state-owned holding companies that generate half of the country's electricity. The remaining electricity comes from independent power producers (IPP) in partnership with private arms of the state owned companies. Deregulation and other reforms have opened this industry to foreign investment, although that investment has been limited so far.

In 2006, China established a Renewable Energy Law designed to boost the use of renewable energy technology at least 10% by 2020.[18] The law sets grid connection priorities and requires power grid operators to purchase resources from registered renewable energy producers. There are financial incentives including discounted lending and tax preferences for renewable energy projects, and the creation of a national fund to foster development of renewable energy resources.

Based on the current market landscape, many experts believe that China has several natural advantages in adopting energy storage and renewable resources.

- There are fewer longstanding "legacy" issues related to existing infrastructure and embedded interests.
- The government maintains a top down policy control allowing accelerated changes in infrastructure.
- Chinese leaders see cleantech (including the energy storage component) as a growth industry.
- China's sheer industrial size and strength has the power to change the direction of electric storage companies across the globe.

India

India suffers from a severe shortage of electrical capacity and major cities throughout the country see regularly occurring blackouts. Most power is generated via conventional thermal sources while renewables account for less than 1% of total generation. India's goal is to diversify its sources of electrical power generation while adding capacity.

Indonesia

With the fourth largest population in the world (behind China, India and the United States), Indonesia's electricity sector lacks generation capacity, causing officials to set a goal of adding 10,000 MW by 2010. Also, the government sets the price at which electricity is sold. In the past few years, financial crises have forced the sale of electricity at less than the cost of production. Financial problems coupled with the inability to raise prices, have prevented investment in new infrastructure projects.

Japan

Japan, with virtually no domestic energy resources, pursues energy efficiency measures, seeking to increase energy security and reduce carbon emissions. Renewable energy sources are actively pursued yet make up just

2% of electrical generation. The Japanese government seeks gradual deregulation of the electric power sector.

Singapore

Three companies represent 90% of Singapore's electricity generation capacity. Despite abundant reserves, Singapore has also been prone to reliability problems, seeing five blackouts within the past two years. Efforts are underway to restructure and privatize this sector.

South Korea

Another country with limited domestic energy resources, South Korea has plans to privatize the power sector. Less than 1% of generated electricity comes from renewables and hydropower.

Vietnam

With one of the lowest levels of per capita energy consumption in Asia, Vietnam maintains no renewable power capacity. The state-owned organization dominates generation, transmission, distribution and sales of electricity.

What do all these trends mean? Many countries face increasing demand for electricity without a corresponding increase in capacity. Renewables coupled with energy storage technologies can help to close the gap. Together renewable energy sources and energy storage technologies will see massive investment and growth over a relatively short period of time. And these trends are happening in countries all across the globe.

Strategies for Maintaining Electric Reliability

Electric reliability remains paramount when implementing new technologies and resources. By following the seven strategies below, utilities can integrate new sources of clean energy (including storage) and maintain electric reliability for the end-user.

- Deploy different types of variable resources to take advantage of complementary generation patterns and locate resources across a larger area.
- Create and implement policies to make transmission development, siting and permitting easier and faster.
- Develop other flexible resources – such as plug-in electric vehicles – to help grid operators quickly respond to output changes without excessive strain on the system.
- Invest in research and development for better forecasting and measurement output and incorporate forecasting techniques into real-time operating practices.
- Treat distributed variable generation sources the same as transmission-connected power plants for planning purposes.

- Create larger balancing areas – perhaps by consolidating current base-load areas – to allow for larger pools and more flexibility in matching generation to demand.
- Invest in and promote two-way communication between utilities and end-users via smart grid technology. Tell users when demand is approaching available supply and give them the option of altering electrical usage.

These strategies dovetail with energy storage applications and give utilities more flexibility in designing systems that match local demands and conditions.

The Real Future of Energy Storage

The real future of energy storage is not clear to anyone in the utility industry today. New storage technologies will appear and others will fall off the radar screen because of real-world needs and constraints. Geography, economics, climate, regulatory and political environments. All will play a role.

The goal is to approach this debate by considering all that energy storage applications offer, looking at their drawbacks and understanding how they fit. By taking these steps consistently, reasoned evaluation can and will overcome a variety of challenges.

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