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Driving the Performance of Modern Electric Grid Using Battery Energy Storage Systems - AEP Transmission Experience

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SUMMARY

This paper provides a comprehensive overview of the energy storage systems (ESS) for electric power transmission and distribution networks. It summarizes the strategic drivers behind the energy storage initiatives; its value propositions and business cases; grid services and storage business opportunities; and energy storage technologies, deployment and integration into the electric power systems. It also provides the energy storage experience, challenges and lessons learned by American Electric Power (AEP) company in its transmission network.

KEYWORDS

Energy Storage; Power; Energy; Grid Services; Lithium Ion; Lifetime Project Net Present Value (NPV); Frequency Regulation.

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1. Introduction

Energy Storage systems (ESS) are important components of an increasingly secure, reliable, low carbon, and cost-effective electricity in the future. They have the potential to help integrate deeper penetrations of renewable energy into the electric power grids; accelerate the adoption of other distributed energy resources by enabling customer independence; and, most importantly, deliver efficient, low-cost, fundamental electric grid services to society at large [1]-[3].

Utilities, regulators, and private industry have begun exploring how battery-based energy storage can provide value to the U.S. electric power grid at scale. However, the location of energy storage deployment in the power system can have an immense impact on the value created by the technology [2], [4]-[7].

1.1 Drivers for Energy Storage [1], [2], [7]-[14]

A) Increasing Renewable Generation

- ✓ Renewable generation is driving new flexibility needs
- ✓ Trends in Solar + Storage is changing the game every year

B) Decrease in Costs

- ✓ Lithium ion has become the primary technology deployed since 2013, as shown in Figure 1.
- ✓ Driven by massive investment in the research and development (R&D) for portable electronics and Electric Vehicles (EVs).
- ✓ The sales growth of Electric Vehicles (EVs) has led to a decrease in battery costs as shown in Figure 2.
- ✓ Suppliers and publicly available studies indicate a continuous trend of cost decline for battery- based storage technologies, particularly lithium-ion.
- ✓ Prices of battery-based energy storage resources have reached a very promising level.

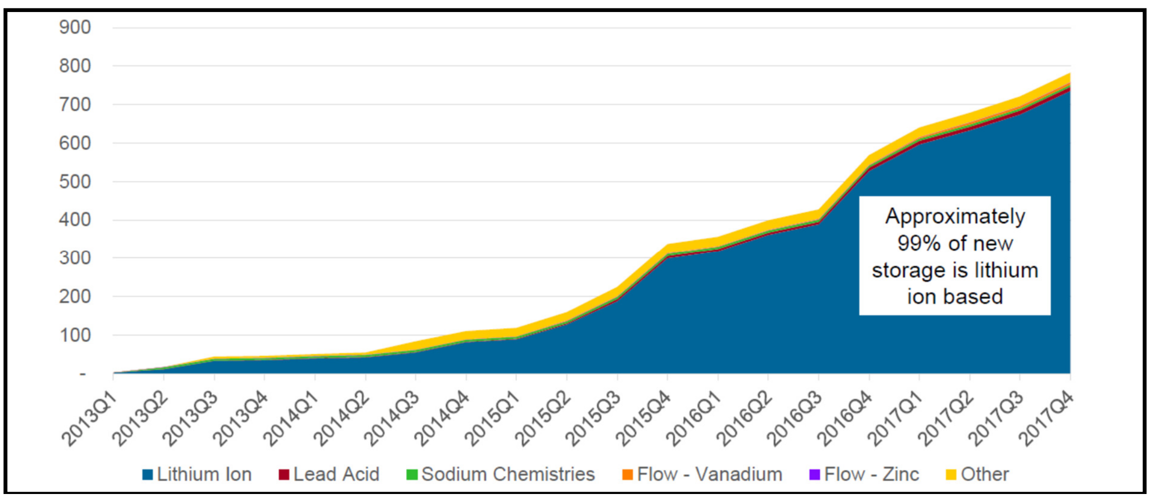


Figure 1. Cumulative Battery Deployments by Technology (MW) Since 2013 [6].

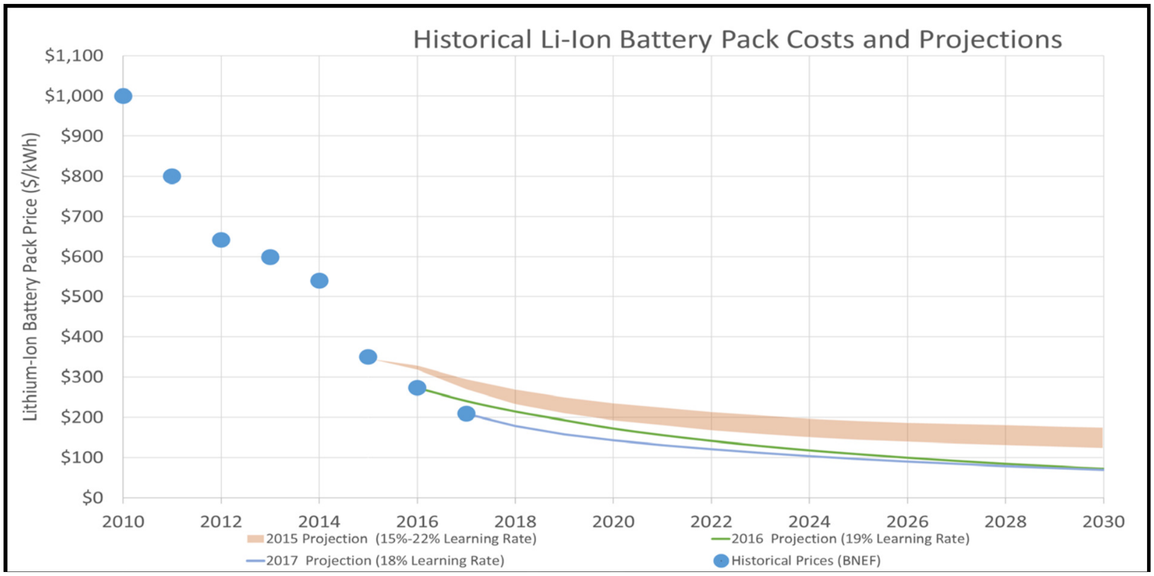


Figure 2. Lituim-Ion Battery Actual Costs and Cost Projections-EPRI Estimes [4], [8], [9]. Data Source : BllombergNEF (BNEF)

C) Utility Needs

- ✓ Aging utility infrastructure
- ✓ Grid infrastructure is sized for infrequent peak needs
- ✓ Utility focus is on "Life Extension"

D) Policy Changes

- ✓ The Federal Energy Regulatory Commission (FERC) has issued Order 841 that removes barriers that currently limits the participation of energy storage resources in the capacity, energy and ancillary services markets operated by Regional Transmission Organizations (RTOs) and Independent System Operators (ISOs). This order will enable much broader energy storage participation in the wholesale markets, and will help support the efficiency and resiliency of the bulk power system [5], [10], [15], [16].
- ✓ Recent several state policies are considering energy storage as shown in Figure 2.

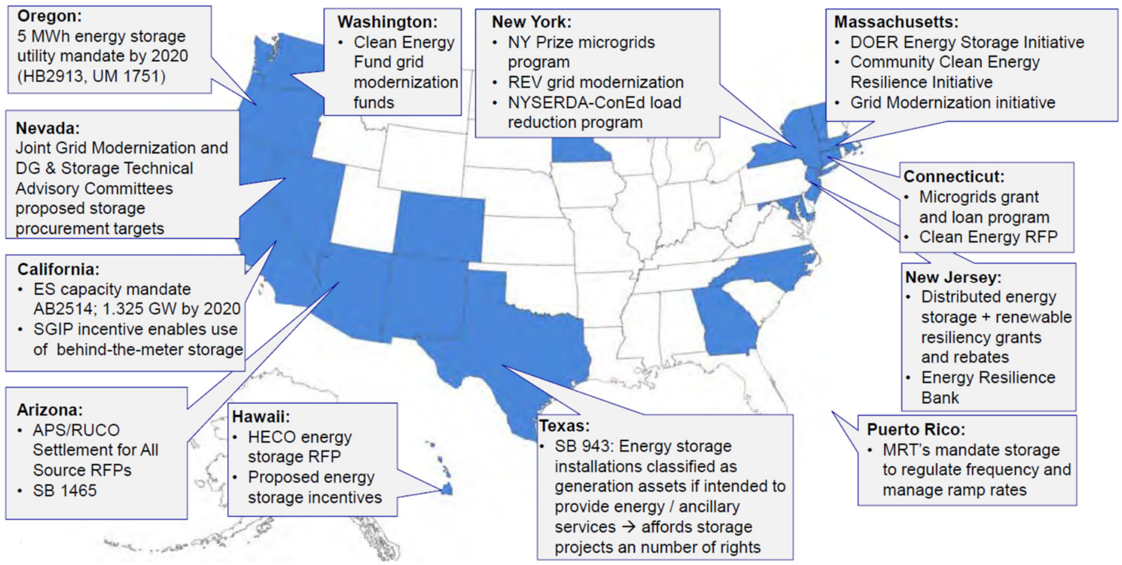


Figure 2. Several State Policies in the US are Considering Energy Storage [3], [4], [14], [17]-[20].

1.2 Energy Storage Functions in the Bulk Power System

Energy Storage can be seen as [18], [20]-[22]:

A) Capacity Resource: Non-wires alternative or Peak replacement
B) Flexibility Resource: System ramping, renewable variability and uncertainty
C) Voltage / Power Quality Resource: Power conditioning system capabilities
D) Resiliency/ Reliability Resource: Electricity inventory for reserves

2. Energy Storage Technology

2.1 Available Energy Storage Technology in the Market

Energy Storage has several potential roles in the growing power system. Unlimited arrangements of energy storage and other resources are possible as shown in Figure 3. Several energy storage technologies are also available in the market as shown in Figure 4, with their pros and cons listed in Table 1. The overall picture of the energy storage industry can be summaries as [1], [8], [9], [11], [13], [14]:

A) Lithium ion companies are dominating current market share;

- ✓ The supply chain exists for Lithium-ion batteries
- ✓ Suppliers have secured long-term commitments from automakers
- ✓ Lithium-ion has the biggest market share at 97% since 2016
- ✓ Surplus product now available at low prices

B) Other technologies face difficult near-term path in the market

- ✓ Many companies insist they can match lithium ion prices, but cost structure is uncertain and the technology is not robust.
- ✓ Several prominent companies have shut down, exited, or realigned their businesses

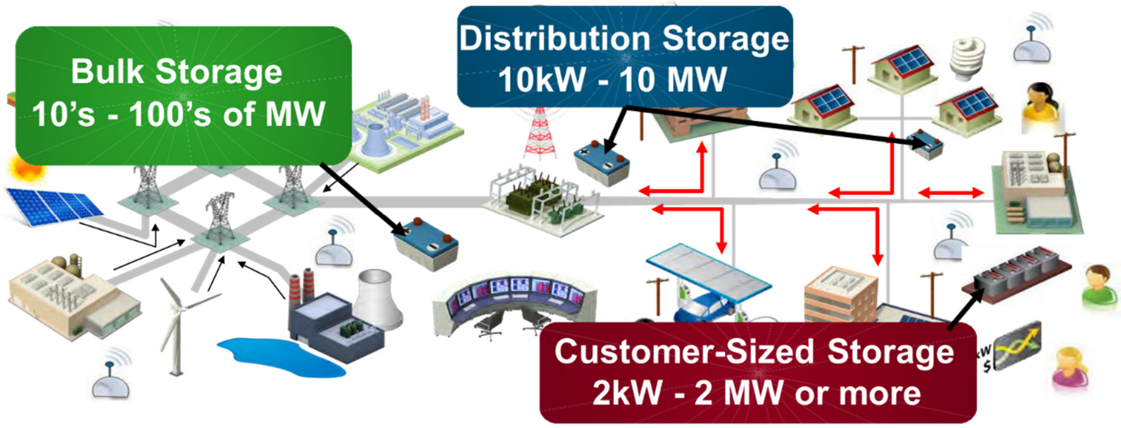


Figure 3. Potential Roles of Energy Storage in the Bulk Power System [4], [8], [20]-[22], [24].

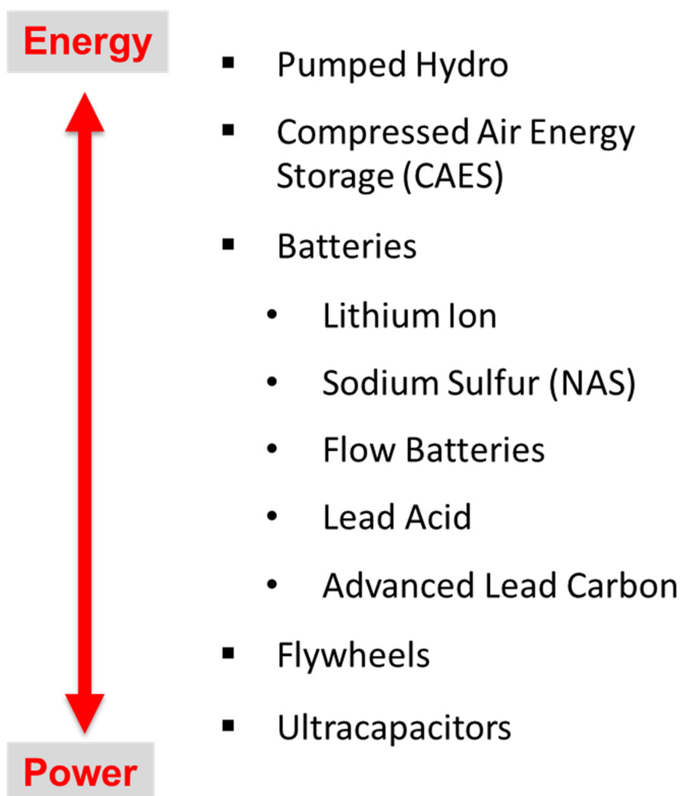


Figure 4. Available Energy Storage Technologies [13], [20]-[22], [24].

Table 1. Selected Comparative Advantages and Disadvantages of the Available Energy Storage Technologies [4], [8], [13], [20]-[25].

Technology	Advantages	Disadvantages
Compressed Air	Low cost, flexible sizing, relatively large-scale	Requires suitable geology
	Mature technology and well-developed design	Relatively difficult to modularize for smaller installations
	Leverages existing gas turbine technologies	Exposure to natural gas price changes
Flow Batteries	Power and energy profiles highly and independently scalable (for technologies other than zinc-bromine)	Power and energy rating scaled in a fixed manner for zinc-bromine technology
	Designed in fixed modular blocks for system design	Relatively high balance of system costs
	Low degradation in "energy storage capacity"	low efficiency due to rapid charge/discharge
Flywheel	High power density and scalability for short duration technology; low power, higher energy for long-duration technology	Relatively low energy capacity
	High depth of discharge capability	High heat generation
	Compact design with integrated AC motor	Sensitive to vibrations
Lead-Acid	Mature technology with established recycling infrastructure	Poor ability to operate in a partially charged state
	Advanced lead-acid technologies leverage existing technologies	Relatively poor depth of discharge and short lifespan, Environmental impacts
Lithium-Ion	Multiple chemistries available	Some safety issues. Manufacturers provided robust solutions for these issues.
	Rapidly expanding manufacturing base leading to cost reductions	Requires advanced manufacturing capabilities to achieve high performance
	Efficient power and energy densities	
	Robust and mature technology	
	Low cost	
Pumped Hydro	Mature technology (commercially available; leverages existing hydropower technology)	Relatively low energy density
	High power capacity solution	Limited available sites (i.e., water availability required)
Sodium Sulfure (NAS)	High temperature technology: Relatively mature technology (commercially available); high energy capacity and long duration	Although mature, inherently higher costs—low temperature batteries currently have a higher cost with lower efficiency

	Low temperature technology: Smaller scale design; emerging technology and low cost potential; safer	Potential flammability issues for high-temperature batteries
		Limited power capabilities
Zinc	Currently claimed to be the lowest cost	Currently unproven commercially
	Claimed to have deep discharge capability	Low efficiency
		Cost structure is uncertain

2.2 Energy Storage Technical Characteristics

Several technical characteristics are considered in selecting a specific energy storage technology. Some of these characteristics are summarized in Figure 5 [18], [20]-[25].

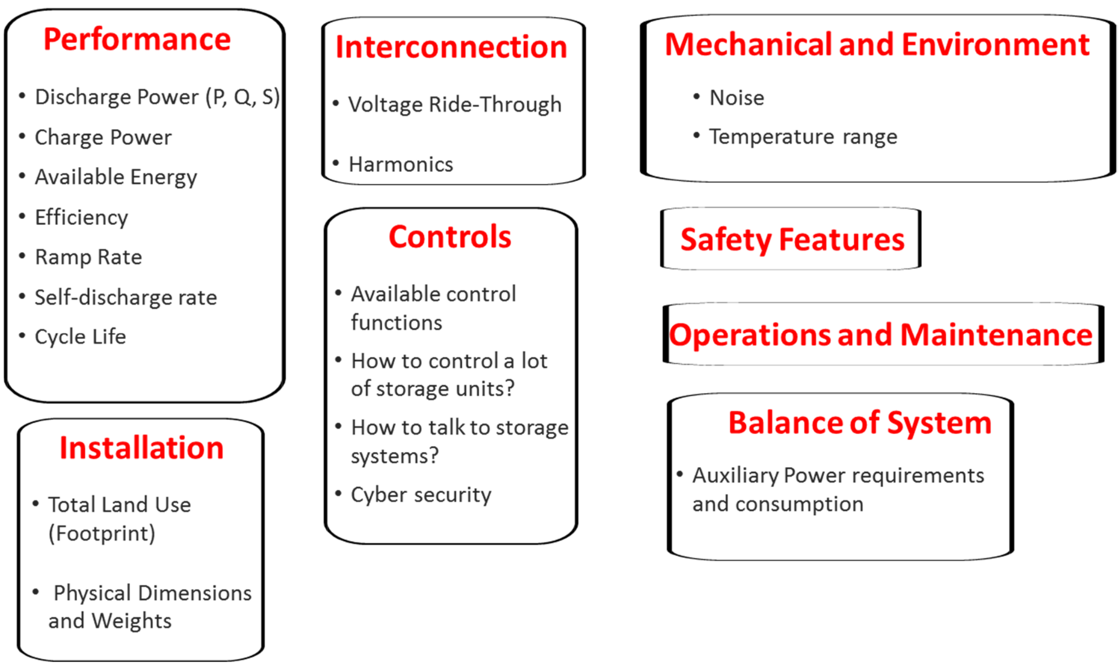


Figure 5. Energy Storage Technical Characteristics

3. Grid Services and Energy Storage Applications

Many studies have been conducted on the different values and services that energy storage can provide to the electric power grid over the past decade. The number of services that energy storage can provide and the definitions of those services vary across reports [3], [6], [18], [20]-[25].

The Energy Storage Services (ESSs) can be divided into Transmission-level Services or Bulk Storage (10’s –100 of MW), and Distribution level Services (10kW – 10 MW) as shown in Table 2. They can also be divided according to the stakeholder group that receives the largest share of the benefit from the delivery of each service as shown in Table 3. The stakeholder groups are: Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs); Utilities; and Customers. Although some services benefit more than one group, segmenting services by which group receives or monetizes the majority of value helps to better define the services themselves [5], [6], [15], [16], [20]-[25].

Table 2. Utility Grid Services [4], [15], [16], [20]-[25].

Transmission-Level Grid Services	Distribution-Level Grid Services
Long-term planning / resource adequacy	Distribution upgrade deferral
Transmission upgrade deferral	PQ/ voltage control
Day-ahead/real-time energy shifting	Phase balancing
Frequency regulation	Backup/ Microgrid
Contingency reserve (spin/non-spin)	
Ramping reserve	

Table 3. Energy storage services according to the stakeholder group that receives the biggest share of the benefit from the delivery of each service [4], [15], [16], [20]-[25].

ISO/RTO Services	Energy Arbitrage
	Frequency Regulation
	Spin/Non-spin Reserves
	Voltage Support
	Black Start
Utility Services	Resource Adequacy
	Distribution Deferral
	Transmission Congestion Relief
	Transmission Deferral
Customer Services	Time-of-Use Bill Management
	Increased PV Self Consumption
	Demand Charge Reduction
	Backup Power

3.1 ISO Grid Services

Energy storage devices are capable of providing a suite of ancillary services that largely benefit ISOs/RTOs and, in states where the electricity markets have not been restructured, vertically integrated utilities. These services, outlined in Table. 3 are largely differentiated from each other by the time horizon for which they are needed [6], [15], [16], [20]-[25].

In restructured areas of the U.S., generation, capacity, and ancillary services are traded on wholesale electricity markets. In regulated areas where organizations operate as vertically integrated utilities, a system operator/scheduling coordinator conducts a merit order dispatch of generation assets to provide both energy and a suite of ancillary services to minimize total production costs [15], [16], [23]-[25].

3.1.1 Utility Services

Utility services generally fall into two categories. First, transmission and distribution system upgrade deferral, which focuses on using investments in energy efficiency and distributed energy resources to defer large investments in transmission and distribution infrastructure. Typically, distribution infrastructure upgrades are driven by peak demand events that occur on only a few, fairly predictable occasions each year. Transmission upgrades, on the other hand, are driven by large new interconnection requests or transmission congestion. On the distribution side, using incremental amounts of energy storage to deal with limited time duration events can defer large investments and free up capital to be deployed elsewhere. This can also avoid “over-sizing” the distribution system in the face of uncertain demand growth. Energy storage can also be used to reallocate this demand to a period when the system is not capacity constrained, thus shaving off the peak of the projected system load and not exceeding the capacity of the system.

Table 3. Utility Grid Services [4], [5], [6], [8], [20]-[25].

Service Name	Definition
Resource Adequacy	Instead of investing in new natural gas combustion turbines to meet generation requirements during peak electricity-consumption hours, grid operators and utilities can pay for other assets, including energy storage, to incrementally defer or reduce the need for new generation capacity and minimize the risk of overinvestment in that area.
Distribution Deferral	Delaying, reducing the size of, or entirely avoiding utility investments in distribution system upgrades necessary to meet projected load growth on specific regions of the grid.
Transmission Congestion Relief	ISOs charge utilities to use congested transmission corridors during certain times of the day. Assets including energy storage can be deployed downstream of congested transmission corridors to discharge during congested periods and minimize congestion in the transmission system.
Transmission Deferral	Delaying, reducing the size of, or entirely avoiding utility investments in transmission system upgrades necessary to meet projected load growth on specific regions of the grid.

3.1.2 Customer Services

Customer services like bill management provide direct benefits to end users. Accordingly, the value created by these services can only be captured when storage is deployed behind the meter. Table 3 defines these customer-facing services.

The monetary value of these services flows directly to behind-the-meter customers. However, the provision of these services creates benefits for ISOs/RTOs and utilities, as well. When energy storage either maximizes on-site consumption of distributed solar photovoltaics (PV), generates savings by optimizing load against a time-of-use rate, or reduces a building’s peak demand charge, it is effectively smoothing the load profile of the building where it is deployed. A smoother, less peaky load profile is much easier and less costly to match up with the output of centralized generating assets. This is why price signals such as peak demand charges and time-of-use pricing exist: to incent end users to alter their metered load profile in a way that lowers overall system production costs [5], [6], [15], [16], [20]-[25].

Table 4. Customer Services [4], [5], [6], [15], [16], [18]-[25].

Service Name	Definition
Time-of-Use Bill Management	By minimizing electricity purchases during peak electricity-consumption hours when time-of-use (TOU) rates are highest and shifting these purchase to periods of lower rates, behind-the-meter customers can use energy storage systems to reduce their bill.
Increased PV Self-Consumption	Minimizing export of electricity generated by behind-the-meter photovoltaic (PV) systems to maximize the financial benefit of solar PV in areas with utility rate structures that are unfavorable to distributed PV (e.g., non-export tariffs).
Demand Charge Reduction	In the event of grid failure, energy storage paired with a local generator can provide backup power at multiple scales, ranging from second-to-second power quality maintenance for industrial operations to daily backup for residential customers.
Backup Power	In the event of grid failure, energy storage paired with a local generator can provide backup power at multiple scales, ranging from second-to-second power quality maintenance for industrial operations to daily backup for residential customers.

4. Energy Storage Competitiveness and Evaluation

The following points must be considered in developing the energy storage business cases [4], [5], [8], [11], [18], [20]-[25]:

- ✓ Energy storage is more than just a battery.
- ✓ Standard cost metrics for generation are not suitable for energy storage.
- ✓ Storage doesn't produce energy, so Levelized Cost of Energy (LCOE) is not an appropriate unit of measurement.
- ✓ Lifetime project net present value (NPV) is more straightforward for energy storage projects.
- ✓ Understanding energy storage value requires understanding of utility planning and operations.
- ✓ Safety, Reliability and Affordability are the top three priorities that must be considered in developing the energy storage business business cases, as shown in Figure 6.

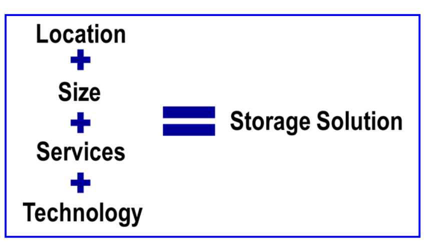
Figure 6. Top three priorities that must be considered in developing the energy storage business cases.

The major steps in the development process of energy storage business business cases can be summarized as:

A. Finding Storage Business Opportunities:

- ✓ Defer Transmission investments
- ✓ Integrate renewables
- ✓ Ancillary services market
- ✓ Comparison vs conventional solutions?

B. Customizing and Comparing Storage Projects:



C. Storage Optimization and Operation

- ✓ Address technology characteristics
- ✓ Prioritize compatible service combinations
- ✓ Meet the interconnection constraints

5. AEP Energy Storage Experience

AEP Transmission is always looking to find the right tool or solution to improve the system performance or solve any problem. Technology solutions are considered based on the following criteria:

- ✓ Excellent operational performance
- ✓ Best value to customers
- ✓ Safety/quality/Cost effective
- ✓ Reliability and regulatory standards
- ✓ Long term availability and maintainability

Furthermore, AEP Transmission is continuously evaluating the asset renewal needs of its infrastructure. This is done by considering three major factors:

- ✓ The condition of the asset: vintage, deterioration, maintenance needs, availability of spare parts, etc.
- ✓ The performance of the asset : hours of operation vs downtime, number of unanticipated outages, etc.
- ✓ The risk of the asset: what happens to the system if it is not available when needed, how much load is exposed, etc.

As a result, AEP is one of the major leading utility companies that have deployed multiple ESS in its transmission and distribution networks, as summarized in Table 5. The AEP Transmission road map for deploying ESS is shown in Figure 7.

Table 5. AEP Transmission Energy Storage Projects.

Project	Location	Business Need	Solution	Date

ETT / AEP Transmission Support	Presidio, TX	• Presidio was served by a single 60-mile, 69 kV transmission ("T") line. • "T" line 50 years old, runs to border with Mexico at the end of US grid. • Presidio was subject to frequent lightning storms and power outages.	• 4 MW NAS installed to supply power during outages. • Due to prompt response, NAS addresses voltage fluctuations. NAS allowed maintenance of the "T" line without service interruption.	2010
AEP Remote Feeder Support	Milton, WV Bluffton, OH Churubusco, IN	• Perennially a poor performing feeder. • 35 mile, 34.5 kV radial with 2 MVA load at the end of the line. • Most faults upstream of 2 MVA load. • Nearest transmission is 8 miles distant.	• 2 MW NAS installations with "islanding" capability to protect critical loads • Benefits included quick deployment and upgrade deferral	2008
AEP Substation Upgrade Deferral – 1st US Demo	Charleston, WV	• Aging Distribution substation, overload reaching criticality • 2-year delay to add a second transformer	• 1 MW NAS installation deployed to "heat shave" transformers • Benefits included quick deployment, capital deferral • Demonstrated combined upgrade deferral (grid service) and energy arbitrage (market service).	2006

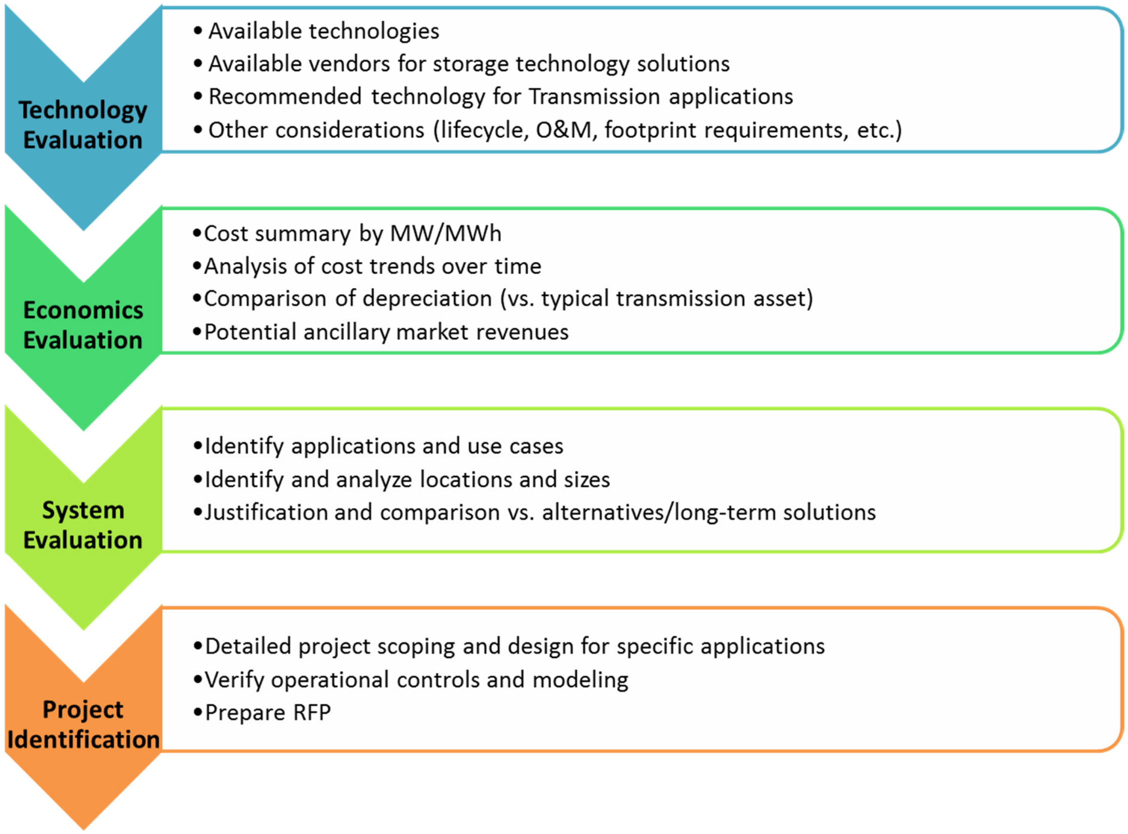


Figure 7. AEP Transmission Road Map for Energy Storage.

6. Energy Storage Challenges and Lessons Learned [4] , [5], [8]-[11], [20]-[25]

A. Analysis and Evaluation

- ✓ Energy storage has unique attributes
  - ✓ Flexible and Dispatchable
  - ✓ Storage as a resource can be seen through different lenses.
  - ✓ Time-series modeling capabilities are need
- ✓ Standard analysis tools for generation are not suitable for storage
- ✓ Energy Storage is more than just a battery
- ✓ Regulations and rules are changing
  - ✓ Value Stacking is promising but not clear and challenging
  - ✓ Technical requirement must change

B. Performance and Reliability

- ✓ Existing tools do not properly model all storage capabilities and benefits
  - ✓ Utilities and ISOs have the same challenge
- ✓ New Simulation models for energy storage are required
  - ✓ Customizable
  - ✓ Transparent

    - ✓ Validated
    - ✓ Follow the technology development
- ✓ Evaluating technology characteristics is a challenge
    - ✓ Cycle Life vs. Degradation
    - ✓ Efficiency
- ✓ Reliability is still a challenge

C. Grid Integration

- ✓ Several parties need to be involved:
    - ✓ Regulators
    - ✓ Utilities
    - ✓ Vendors and Integrators
    - ✓ Customers
- ✓ Requires parties with experience in communications, protection, controls and metering
- ✓ Control integration is one of the biggest challenges
- ✓ Cyber security is a challenge
    - ✓ Vendor remote access
- ✓ Overlap between referenced codes and standards
- ✓ Specific standards for safety, testing and commissioning need to be developed and mature

7. Conclusion

Energy Storage is a powerful asset that is capable of providing a collection of several services to the power grid at a very competitive cost compared to other traditional solutions. New federal regulations and policy changes have enabled much broader energy storage participation in the wholesale markets. This will help to support the efficiency and resiliency of the bulk power system. As a result, regulators; utilities; vendors and Integrators; and customers must collaborate to develop a complete portfolio that defines energy storage as a major asset option and clarifies all related technical issues. AEP is one of the major leading utilities that have deployed multiple ESS in its transmission and distribution networks to provide multiple grid services. AEP has also developed a detailed road map that will enable much broader energy storage integration in its network.

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