Electrical Energy Storage

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Module 1: Electricity Storage Services and Benefits

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the 18 primary grid services and applications for electrical energy storage across five umbrella groups.
- **Evaluate** technical performance requirements, including size, discharge duration, and cycle frequency, for specific utility and customer-side use cases.
- **Select** appropriate service "stacks" to maximize the economic viability and operational efficiency of energy storage projects.

Executive Summary: The transition from a centralized grid to a restructured, high-renewables environment has shifted the role of storage from long-duration bulk time-shifting to high-speed, multi-functional applications. To achieve commercial viability, engineers must leverage storage's unique ability to "stack" services—providing ancillary grid support while simultaneously deferring infrastructure upgrades and managing customer demand.

Energy Storage

serves as a mediator between **variable sources** and **variable loads**. In a system without storage, generation must equal consumption at every instant. Storage disrupts this constraint by allowing energy generated at one time to be utilized at another.

While this course focuses on **electricity storage**, engineers should recognize other common forms:

Chemical: Oil in the Strategic Petroleum Reserve or natural gas in underground reservoirs.

Thermal: Energy stored in ice or thermal mass (e.g., adobe).

Potential: Water in elevated reservoirs or high-pressure compressed air.

Historical Context of Storage

Electricity storage is not a modern phenomenon. Key milestones include:

1799: Volta invented the modern battery.

1836: Adoption of batteries in telegraph networks.

1880s: Lead-acid batteries managed night-time loads in NYC's direct current (DC) systems.

1929: The first large-scale U.S. system (31 MW pumped storage) was commissioned at the Rocky River Plant.

2011: Approximately 2.2% of world-wide electricity was stored, predominantly via pumped hydro.

System Architecture and Subcomponents

A complete electricity storage system, whether grid-tied or stand-alone, consists of two primary subcomponents and a suite of balance-of-plant (BOP) hardware.

The Storage Medium

This represents the source of DC energy (e.g., a battery) or mechanical energy (e.g., a flywheel).

Power Conversion System (PCS)

In battery and flywheel systems, the **PCS** is a bidirectional device. It performs two critical functions:

Inversion: Converts DC to alternating current (AC) to serve the load.

Rectification: Converts AC to DC to charge the storage medium.

Balance-of-Plant (BOP)

These components ensure the health, safety, and connectivity of the system:

Monitoring and Control: Often integrated into the PCS, these manage system states.

Physical Enclosure: Buildings or containers protecting the hardware.

Switchgear: Hardware required for grid or customer load interconnection.

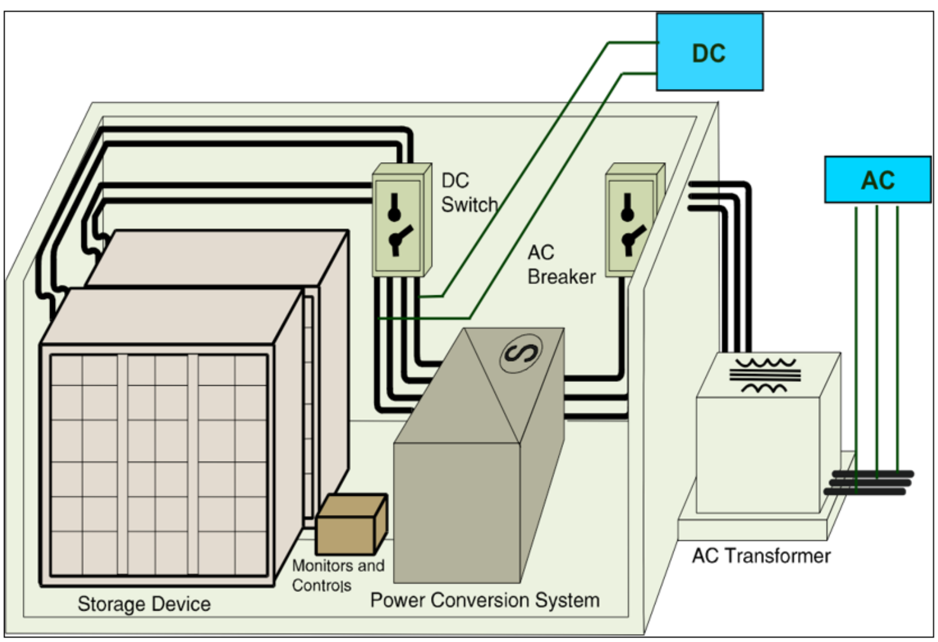

Figure 1: Schematic of a Battery Energy Storage System (Source: Sandia National Laboratories)

Bulk Storage Variations

Compressed Air Energy Storage (CAES): Energy is stored as high-pressure air in underground caverns or above-ground vessels.

Pumped Hydroelectric Energy Storage (PHES): Potential energy is captured by pumping water to an upper reservoir at a higher elevation

Electricity Storage Services and Benefits

Restructuring of the electric utility industry and advancements in technology have created a unique opportunity for storage systems to provide critical services to the evolving grid. Regulatory changes in T&D operations directly impact how storage is implemented. While storage provides services similar to other generation devices, their benefits vary significantly.

Until the mid-1980s, storage was primarily used for bulk time-shifting (coal off-peak to replace natural gas on-peak). Today, the focus has shifted toward shorter storage durations of 1 to 6 hours. This course details 18 specific services categorized into five umbrella groups.

Table 1. Electric Grid Energy Storage Services Presented in This Course

Service Group	Service
Bulk Energy Services	
	Electric Energy Time-Shift (Arbitrage)
	Electric Supply Capacity
Ancillary Services	
	Regulation
	Spinning, Non-Spinning and Supplemental Reserves
	Voltage Support
	Black Start
	Other Related Uses
Transmission Infrastructure Services	
	Transmission Upgrade Deferral
	Transmission Congestion Relief
Distribution Infrastructure Services	
	Distribution Upgrade Deferral
	Voltage Support
Customer Energy Management Services	
	Power Quality
	Power Reliability
	Retail Electric Energy Time-Shift
	Demand Charge Management

Bulk Energy Services

Electric Energy Time-shift (Arbitrage)

Arbitrage involves purchasing inexpensive energy during low-price periods to charge the system for discharge when prices are high. It also facilitates storing excess renewable energy from wind or photovoltaic (**PV**) sources that would otherwise be curtailed.

Technical Considerations

- **Storage System Size Range:** 1 – 500 MW
- **Target Discharge Duration Range:** < 1-hour to several hours
- **Minimum Cycles/Year:** 250+

💡 **Design Tip:** Round-trip efficiency and performance degradation rates are the primary drivers of economic merit. A modest decrease in efficiency can significantly reduce the number of viable arbitrage transactions.

Electric Supply Capacity

Storage can defer or reduce the need to purchase new central station generation capacity. Discharge duration is typically location-specific and dictated by how capacity is priced in the wholesale market.

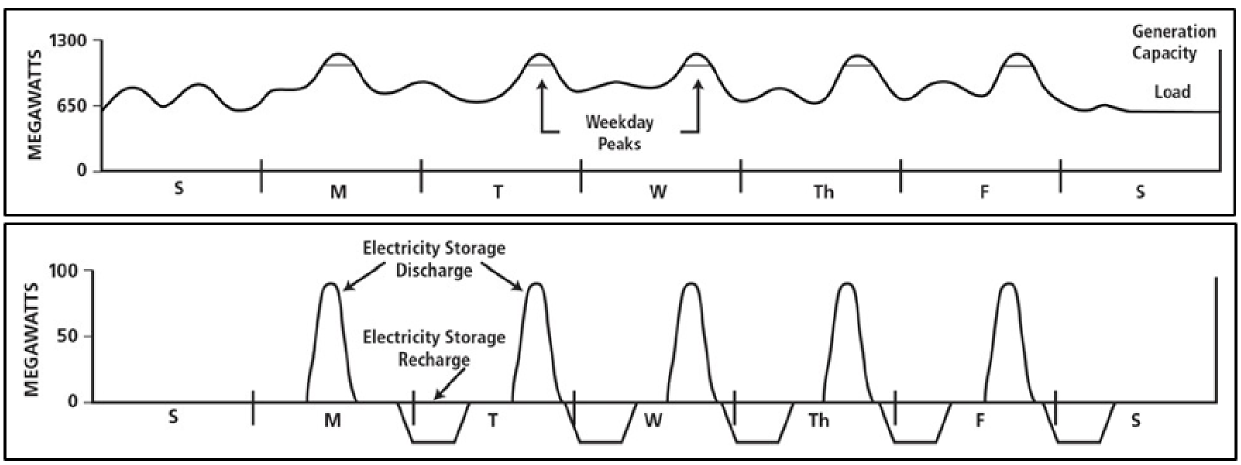

Figure 2. Storage for Electric Supply Capacity

Ancillary Services

Regulation

Regulation manages momentary fluctuations in demand to maintain grid frequency. Storage is highly valued here because its fast ramp rate can be twice as effective as conventional generation.

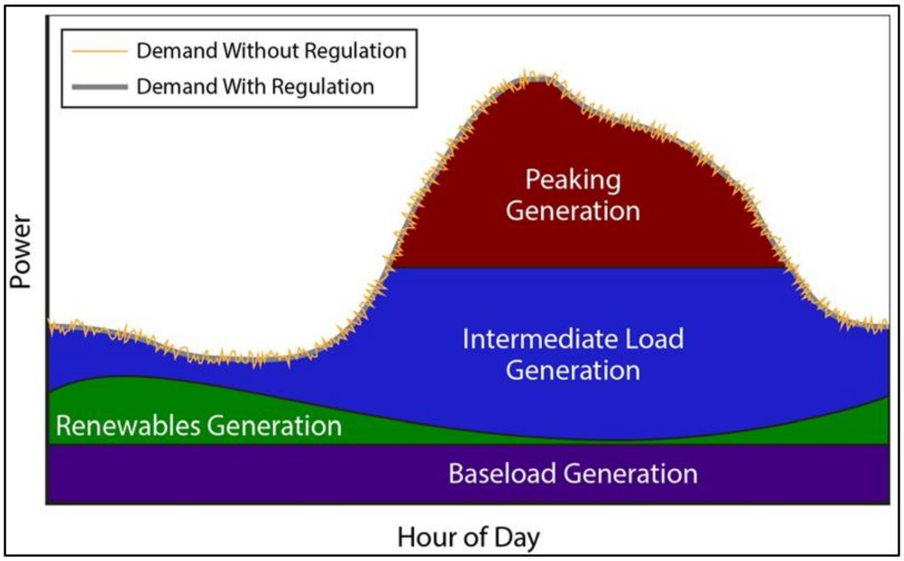

Figure 3. System Load Without and With Regulation (Source: Sandia National Laboratories)

⚠️ **Safety Constraint:** Storage for regulation must respond to the **Area Control Error (ACE)** or **Automatic Generation Control (AGC)** signal from the Balancing Authority to comply with **NERC** BAL001 and BAL002 standards.

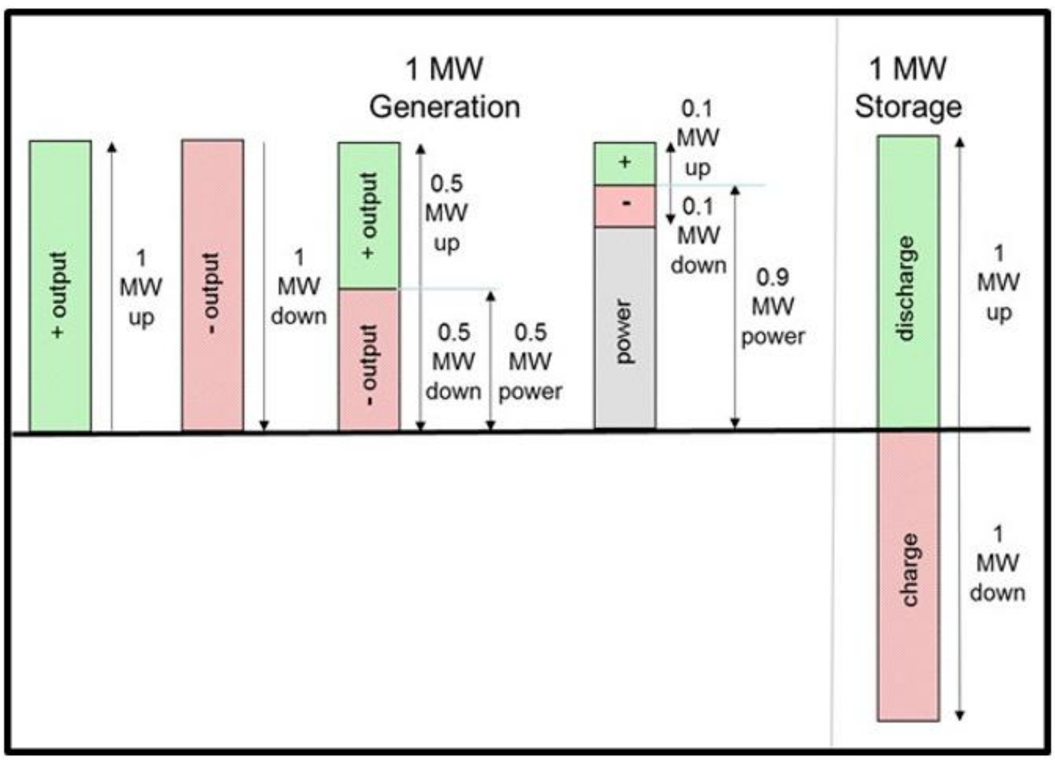

Figure 4. Storage and Generation Operation for Regulation (Source: E&I Consulting)