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Utilities

Vaults of Power: Unleashing battery energy storage #1

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In the future, power systems are expected to increasingly rely on RE sources such as wind and solar. However, these sources present inherent challenges due to their variability and intermittency, which can pose obstacles to safe and reliable grid operations. India has been making significant strides in increasing RE into its generation mix, aiming to achieve 50% capacity from non-fossil fuel-based energy by 2030. To support this ambitious goal, the next phase of growth necessitates the integration of energy storage solutions into both RE systems and the grid. Utilities are increasingly including energy storage in their generation portfolio to complement their existing and expanding RE. We initiate a series of reports focusing on battery energy storage system (BESS), building upon our previous analysis of pumped hydro storage. These reports will delve into various aspects of BESS, explaining complex technological concepts in simplified terms to provide comprehensive insights.

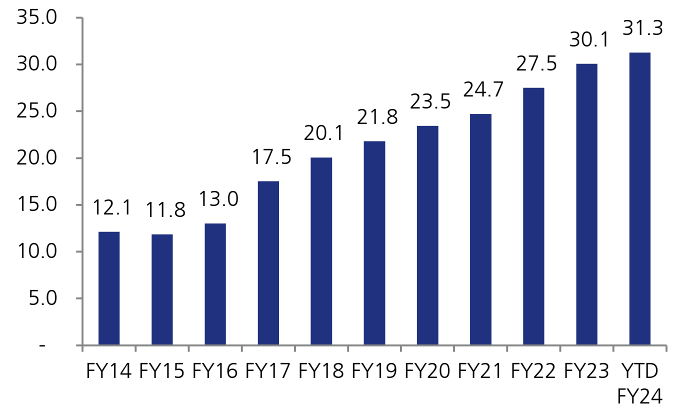
- **Storage types:** Various grid-scale energy storage systems are commercially available globally, with notable options being pumped storage plants (PSP) and battery energy storage systems (BESS). PSPs are established as long-term, technically sound, highly efficient, environmentally friendly, and flexible solutions for large-scale and long-duration energy storage needs. On the other hand, BESS operates as an electrochemical device primarily employed for real-time grid electricity balancing purposes.
- **Principal BESS characteristics**: Energy storage devices are assessed based on their output and energy density, with applications categorized by output, duration of usage, and power requirements. Moreover, energy storage devices are classified according to usage duration, power generation, and system/network operation criteria. Battery technologies for energy storage further differ in factors like energy density, charge/discharge efficiency (round trip), lifespan, and environmental sustainability.
- **Battery energy storage system (BESS):** From a basic technical perspective, BESS can be connected either in front of the meter, directly linked to the transmission grid (for utility-scale installations), or behind the meter, connected to a local distribution network. Components of energy storage systems (ESS) are typically categorized based on their function, including the battery system (comprising the battery pack, battery management system, and battery thermal management system), system control and monitoring, energy management system (EMS), system thermal management, supervisory control and data acquisition (SCADA) system, and power electronics.
- **Grid applications:** BESS can regulate frequency, stabilize voltage, and provide ancillary services, ensuring grid stability and reliability. Additionally, BESS can reduce grid congestion, optimize energy usage through arbitrage, and enable peak shaving, thereby improving grid efficiency and lowering costs. Moreover, BESS plays a critical role in black start scenarios, providing emergency power to facilitate rapid system restoration. These capabilities collectively enhance grid resilience, flexibility, and sustainability, making BESS an indispensable asset for modern power systems.
- **Business models:** Business models for energy storage services in India are evolving to meet the needs of distribution companies (Discoms). Options include storage as a generation-coupled asset (where developers supply firm renewable energy power), storage as a grid asset (offering specific storage services under contract), and storage as a merchant asset (capitalizing on price arbitrage in the wholesale energy market). These approaches are expected to offer flexibility to Discoms for effectively integrating RE in the grid.
- **JM View:** Given the focus of all Indian utilities on enhancing their RE portfolio with storage (as evident from participation in RTC, FDRE bids), we are aligned with their strategic objectives and optimistic about their earnings trajectory. We currently have a BUY rating on NTPC (TP – INR 368), Power Grid (TP – INR 312), Coal India (TP – INR 500), Tata Power (TP – INR 439), JSW Energy (TP – INR 540), NHPC (TP-91), Suzlon (TP- 54), BHEL (TP-243). We have a HOLD rating on CESC (TP – INR 130), and SELL rating on SJVN (TP-INR 72) and Torrent Power (TP- INR 800).

Vaults of Power: Unleashing battery energy storage #1

The Context

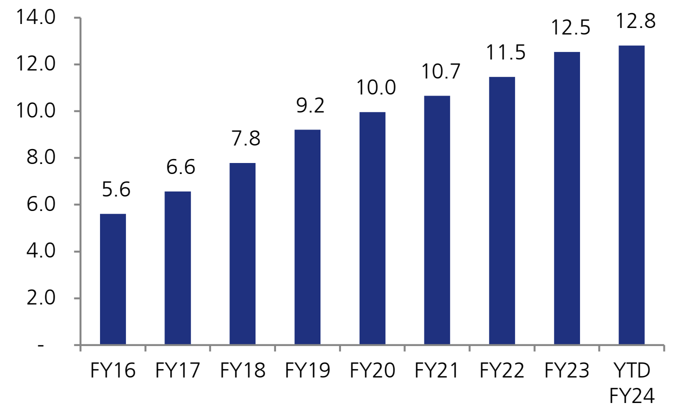
India has set an ambitious target to achieve 50% cumulative installed capacity from non-fossil fuel-based energy resources by 2030. Among these, solar and wind energy stand out as the most sustainable options for decarbonization. However, both resources face numerous challenges due to their inherent variability, influenced by factors such as time, climate, season, and location. Despite these challenges, India has made significant strides in adding renewable energy (RE), particularly solar and wind power, to its generation mix, with projections indicating further growth.

Exhibit 1. Share of RE in total installed capacity, annual (%)



Source: CEA, JM Financial

Exhibit 2. Share of RE in total generation, annual (%)



Source: CEA, JM Financial

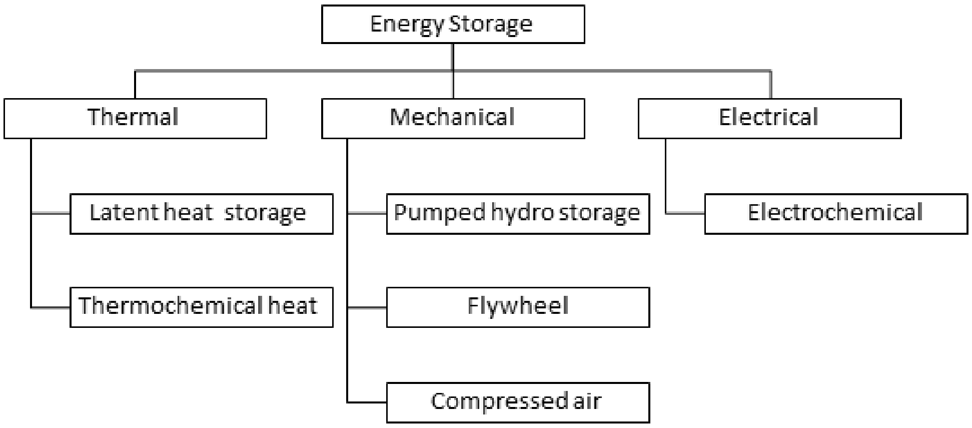
Nevertheless, the next phase of the energy transition, characterized by large-scale deployment of variable renewable energy sources (VREs), necessitates the integration of energy storage solutions. Addressing the grid integration challenges posed by intermittent generation sources requires ensuring the quality of supply on a real-time basis, which can be achieved through electricity storage systems. These systems possess the capability to store excess electricity over varying time horizons, spanning from minutes to days and even weeks.

Numerous grid-scale energy storage systems are commercially available worldwide, including pumped storage plants and battery energy storage systems. However, many other energy storage technologies, such as Green Hydrogen, are still in nascent stages of development.

Storage types

Energy storage technologies can be categorized as mechanical, electrochemical, chemical, electrical, or thermal devices, depending on the storage technology used.

Exhibit 3. Storage Types



Source: JM Financial

Pumped Hydro storage (PSP)

During periods of low electricity demand, surplus generation is harnessed to pump water from a lower-elevation reservoir to a higher-elevation one. Subsequently, when electricity demand peaks, the stored water is released from the higher elevation, passing through a turbine to generate electricity. Pumped storage resources represent a long-term, technically proven, highly efficient, environmentally friendly, and flexible method of large-scale energy storage, adept at accommodating intermittent and variable energy sources. Kindly refer to our earlier reports for comprehensive understanding:

1. Understanding PSP, along with financial model
   'Pumped storage: Back in the limelight'
2. Visit to 900MW PSP
   'Purulia Pumped Storage Plant – An engineering marvel'
3. Opportunities for industry players
   Pumped hydro - Quantifying the business opportunities
4. Projects under consideration
   Pumped storage hydropower: Revolution is Here!

However, this technology faces limitations, including the requirement for ample water resources and distinct geographic elevations. Additionally, the construction of power transmission lines to connect the storage facility with load centers is necessary. For instance, the State Grid Corporation of China (State Grid), in Feb'23 has started the construction of the 1900km Jinshang-Hubei 800-kV UHV power transmission line, with a capacity of 8GW, that will span 1,900 km between the Tibet Autonomous region and the Chinese province of Hubei. Currently, the line is the world's highest-altitude UHV direct current power transmission project and meant to evacuate power from under-construction 4x350MW pumped-storage hydropower plant in the Hubei Province.

Compressed Air

Electricity is utilized to compress ambient air, which is then stored under pressure in underground caverns or containers. During periods of high electricity demand, the pressurized air is heated and released into an expansion turbine generator to produce power.

Flywheels

Flywheels serve as a method of storing mechanical energy in the form of potential or kinetic energy. Electric motors accelerate a flywheel to high speeds, storing energy as kinetic rotational energy. When electricity demand arises, the rotational force of the flywheel is connected to a generator to generate power.

Thermal Energy

Electricity can generate thermal energy, which can be stored for later use. For instance, during periods of low demand, electricity can be utilized to produce chilled water, which can then be employed for cooling during peak electricity consumption. Given that heating demands fluctuate with the season and time of day, thermal energy storage can effectively shift loads and smooth demand on the plant, transferring heat from summer to winter as needed.

These methods of energy storage contribute to grid stability and reliability, allowing for efficient management of energy supply and demand fluctuations.

Battery energy storage system (BESS)

A battery energy storage system (BESS) functions as an electrochemical device that collects energy from the grid during charging and subsequently releases it when needed to provide electricity or other grid services. Various battery chemistries are currently available or in development for grid-scale applications, encompassing lithium-ion, lead-acid, redox flow, nickel cadmium, and Sodium-sulfur technologies.

Efforts are underway to identify the optimal battery chemistry, with multiple initiatives focused on advancing existing formulations. Below is a high-level summary of battery chemistries utilized in grid-scale BESS applications or proposed as potential alternatives.

Exhibit 4. Battery Chemistries of grid-scale BESS

Battery Chemistry	Advantages	Disadvantages and hazards
Lithium-ion Li-ion chemistries are diverse. Nickel-Manganese-Cobalt and Iron Phosphate formulations are commonly used within BESS facilities	• Energy efficiency >90% [13]. • High energy density, ranging between 100-265Watt hours per kilogram (Wh/kg). • Wide availability and cost effective. • Due to high energy density, footprint of land required for facility is comparatively lower than other low energy density formulations.	• Potential for thermal runaway (greater for Nickel Manganese Cobalt (NMC) formulation). Most electrolytes are flammable. This has been evidenced. • Limited temperature performance window (i.e., not compatible with extreme cold or hot conditions). • Compatibility issues Reactive and hazardous in off-nominal conditions. Previous incidents of failures of safety systems during electrical surges. Potential for explosion from gas accumulation of gases produced in a fire.
Lithium-ion polymer battery	• Reduction, or in some cases elimination, of thermal runaway potential. • Greater energy density than non-polymeric Li-ion chemistries. • Due to high energy density, footprint of land required for facility is comparatively lower than other low energy density formulations.	• Costly and therefore grid-scale applications may not yet be viable from a commercial perspective.
Vanadium redox flow battery	• Better safety and efficiency with long life cycle. • Easily able to scale up energy storage capacity. • Longer expected operational performance and life in comparison to Li-ion batteries. • Broad temperature operation envelope operating between -20 °C and 50 °C [14]. • Elimination of cross-contamination risks in comparison to other existing flow batteries as the same material is used in both half cells. • Lack of combustible materials used for construction.	• Low energy density in comparison to Li-ion formulations, therefore large facility footprint is required [15]. • Potential for vanadium electrolyte to be released into the environment if there is a loss of containment event.
Sodium-ion battery	• Moderate energy density, with research underway to achieve densities of up to 200 Wh/kg. • Abundant element in comparison to lithium. • Non-flammable chemistry (however, flammability is dependent on exact compositions).	• Electrolyte solvation issues.

Source: Australian Energy Council Ltd, JM Financial

Lithium-ion batteries

Lithium-ion (Li-ion) batteries offer fundamental advantages over other chemistries, positioning them as the preferred battery technology for grid-scale energy storage solutions:

- Lithium possesses the lowest reduction potential among all elements, enabling Li-based batteries to achieve the highest possible cell potential.
- As the third-lightest element with one of the smallest ionic radii among single-charged ions, lithium facilitates high gravimetric and volumetric capacity and power density.
- The monovalent charge of lithium ions contributes to reduced Li-ion mobility, enhancing battery performance.

Commonly utilized battery chemistries in grid-scale BESS facilities include Li-ion Nickel-Manganese-Cobalt (NMC) or Li-ion Iron Phosphate (LFP) formulations. For instance, LFP batteries now boast energy densities ranging between 100 and 265 Wh/kg, significantly surpassing the 90 Wh/kg density reported a decade ago.

Equipment manufacturers, such as Tesla, have transitioned from NMC batteries to LFP batteries, primarily due to the reduced propensity for thermal runaway in LFP batteries at higher operating temperatures, alongside other benefits such as increased battery lifespan.

PSP v/s BESS

In the ongoing debate between pumped storage hydropower (PSH) and battery energy storage systems (BESS), we recognize the merits and drawbacks of both technologies. We believe in a combined approach that capitalizes on the strengths of each to establish a balanced energy storage system. Specifically, PSH is ideally suited for longer duration storage needs (4 to 6 hours), while BESS excels in shorter duration storage (1 to 2 hours). Furthermore, deploying BESS near critical load centers enhances grid resilience, ensuring swift support during emergencies.

Exhibit 5. Comparison of PSP and BESS

Parameter	PSP	BESS
Technology maturity	Matured	Evolving
Intertia for grid	Mechanical	Synthetic
Reactive power control	Yes	Yes
Black start capability	Yes	Yes
Efficiency	75-80%	85-90%
Response time from standstill to full load	120-360 sec	1-4 sec
No of storage cycles	13870	2000-2500
Duration & Discharge	Longer 6-8 hours	Shorter 3-4 hours
Scale	Bulk application	Small-medium size
Project Life	40+ years	7-12 years
Supply chain	Domestic	Imported
Suitability for Distributed Generation	No	Yes
Construction time	5-7 years	1-2 years
Land Requirements	Higher	Lower, Modular in nature
Site topography	Important	Agnostic
Environment impact	Insignificant	battery disposal is a challenge

Source: Industry, JM Financial

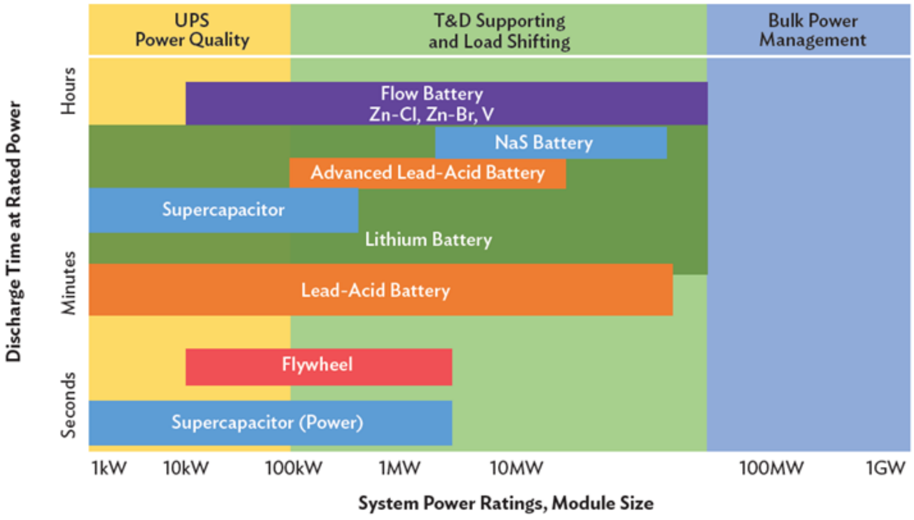
Principal BESS characteristics

The performance of energy storage devices can be evaluated based on their output and energy density. Their utilization can vary depending on the location and duration of use, determined by the adopted technology.

Applications are categorized according to output, duration of usage, and power requirements, while energy storage devices are classified based on usage duration, power generation, and system or network operation.

Battery technologies for energy storage devices can be distinguished by factors such as energy density, charge and discharge efficiency (round trip), lifespan, and eco-friendliness

Exhibit 6. Power Output and Energy Consumption for Energy Storage Technologies



GW = gigawatt, kW = kilowatt, MW = megawatt, T&D = transmission and distribution, UPS = uninterruptible power supply, V = vanadium, Zn–Br = zinc–bromine, Zn–Cl = zinc–chlorine
Source: Korea Battery Industry Association, JM Financial

Energy density refers to the amount of energy that a single system can store per unit volume or weight. For instance, lithium secondary batteries typically store 150–250 watt-hours per kilogram (kg), outperforming Na–S batteries by 1.5–2 times, redox flow batteries by 2-3 times, and lead storage batteries by about 5 times.

Charge and discharge efficiency is a performance metric used to assess battery efficiency. Lithium secondary batteries exhibit the highest charge and discharge efficiency at 95%, while lead storage batteries and redox flow batteries typically range between 60%–70% and 70%–75%, respectively.

Round-trip efficiency represents the ratio of energy charged to the battery to the energy discharged from it, usually measured as a percentage. It encompasses the total AC-AC or DC-DC efficiency of the battery system, including losses from self-discharge and other electrical losses.

Rated Power Capacity refers to the total discharge capability or maximum discharge rate that the battery energy storage system (BESS) can achieve from a fully charged state, typically expressed in megawatts (MW).

Rated Energy Storage Capacity is the total amount of stored energy in kilowatt-hours (KWh) or megawatt-hours (MWh) and can also be expressed in ampere-hours (100Ah@12V, for example).

Storage Duration signifies the duration for which the storage system can discharge at its power capacity before exhausting its energy storage capacity, measured in hours.

Depth of Discharge (DoD) indicates the total amount of capacity that has been utilized from the battery.

Cycle Life or Lifetime refers to the number of charging and discharging cycles a battery storage system can undergo before failure or significant degradation, often influenced by Depth of Discharge (DoD).

Self-discharge occurs when the battery's stored charge diminishes over time due to internal chemical reactions or without being discharged for work. It is expressed as a percentage of the lost charge over a specific period.

Discharge Rate (C) describes the current that a battery can deliver over a period, typically expressed as C5, representing the current provided over 5 hours to reach full discharge.

State of Charge represents the battery's present charge level, usually expressed as a percentage ranging from fully discharged to fully charged.

Ramp Rate denotes the rate at which the BESS can decrease or increase its power output.

Response Time indicates the time required for the BESS to transition from an idle state to full power operation.

Components of a battery energy storage system (BESS)

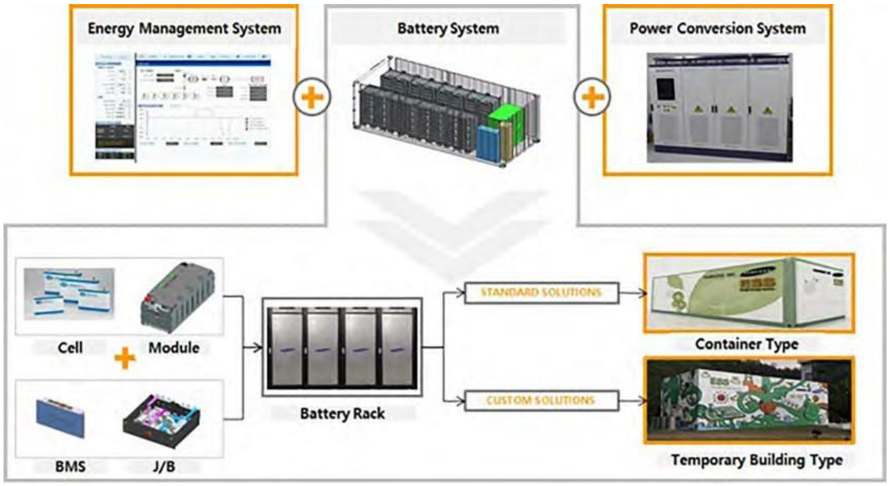
The various components of BESS are grouped according

ESS components are grouped according to function into battery components, components required for reliable system operation, and grid connection components.

- The battery system comprises several key components, including the battery pack, which connects multiple cells to appropriate voltage and capacity, the battery management system (BMS), and the battery thermal management system (B-TMS). The BMS safeguards the cells by monitoring voltage, temperature, and current, ensuring reliable and safe operation. It also balances the varying states-of-charge (SOCs) within a serial connection. The B-TMS regulates cell temperature according to their specifications, ensuring both absolute values and temperature gradients within the pack are maintained.
- For the overall system's reliable operation, certain components are indispensable. These include system control and monitoring, the energy management system (EMS), and system thermal management. System control and monitoring involve general IT monitoring, partly integrated into the supervisory control and data acquisition (SCADA) system, and may also encompass fire protection or alarm units. The EMS is responsible for controlling, managing, and distributing system power flow. Meanwhile, system thermal management oversees all functions related to heating, ventilation, and air conditioning within the containment system.
- Power electronics play a crucial role and can be categorized into the conversion unit, responsible for converting power flow between the grid and the battery, and the associated control and monitoring components. This includes voltage sensing units and thermal management systems for power electronics components, such as fan cooling, to maintain optimal operating conditions.

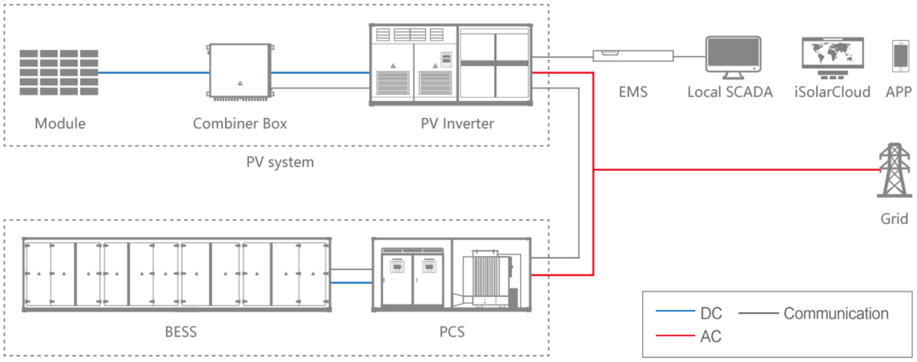
Exhibit 7. Schematic of Battery energy storage system

Figure 1.7: Schematic of A Battery Energy Storage System



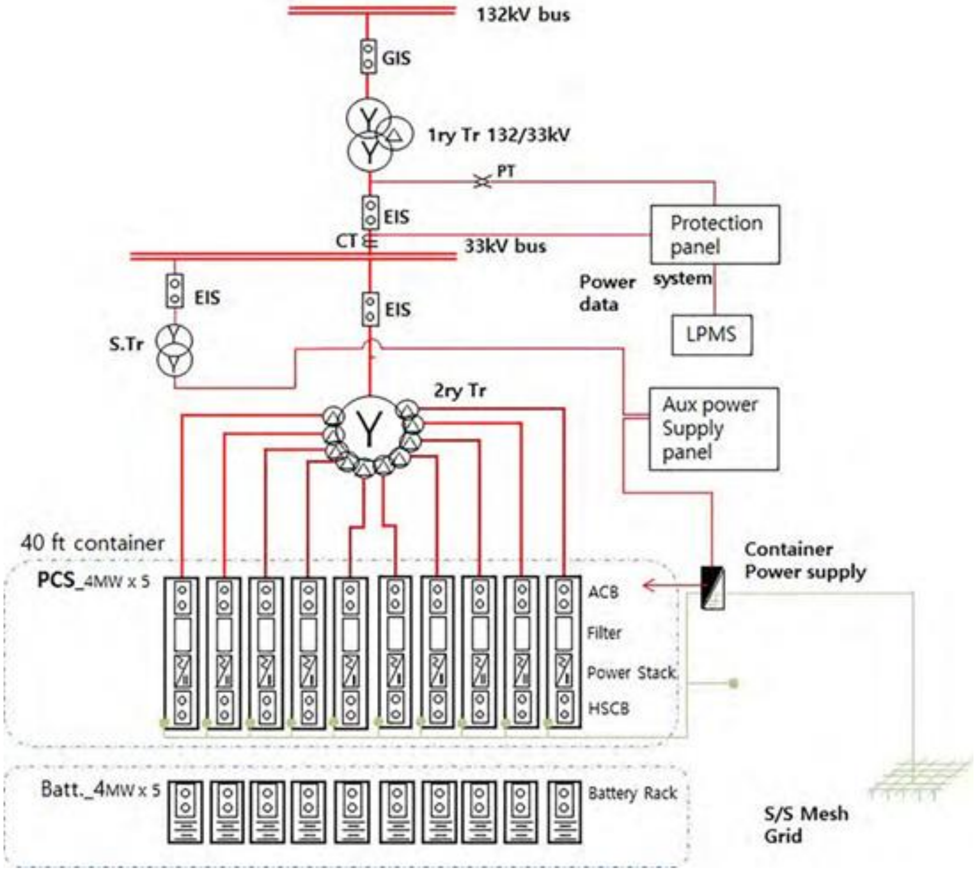
BMS = battery management system, J/B = Junction box.
Source: Korea Battery Industry Association, JM Financial

Exhibit 8. Schematic diagram of equipment



Source: Sungrow, JM Financial

Exhibit 9. Schematic of Grid-forming BESS & its devices



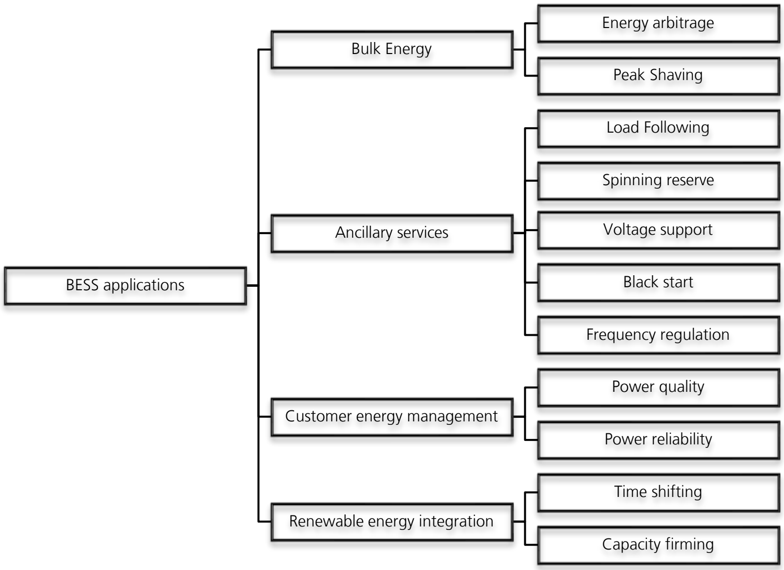
ACB = air circuit breaker, BESS = battery energy storage system, EIS = electric insulation switchgear, GIS = gas insulation switchgear, HSCB = high-speed circuit breaker, kV = kilovolt, LPMS = local power management system, MW = megawatt, PCS = power conversion system, S/S = substation system.

Source: Korea Battery Industry Association, JM Financial

Grid applications of battery energy storage systems

The services provided by batteries can be divided into groups representing the primary stakeholders.

Exhibit 10. Grid applications of BESS:



Source: JM Financial

Exhibit 11. Grid Application

Grid Application	Storage size	Discharge duration	1 hour Minimum cycles/year
Electric energy time-shift (arbitrage): Purchasing inexpensive electric energy to charge the storage system and selling at a later time when the price or costs are high	1-500MW	<1 hr	250+
Electric supply capacity	1-500MW	2-6 hrs	5-100
Regulation: One of the ancillary services for which storage is especially to maintain the grid frequency.	10-40 MW	15 min-1 hr	250-10,000
Spinning, non-spinning, and supplemental reserves: reserve capacity that can be called on when some portion of the normal electric supply resources unexpectedly become unavailable	10-100MW	15 min-1 hr	20-50
Voltage support: to generate reactive power (expressed in VAr) to offset reactance in the grid	1–10 MVAr	Not applicable	Not applicable
Black start: Storage can provide station start-up power to bring power plants on line after a failure. (check)	5–50 MW	15 min- 1 hour	10–20
Load following/Ramping up of renewables: Addressing the output variation is a response to changes in system frequency, timeline loading, or the relation of these to each other, and occurs as needed to maintain the scheduled system frequency.	1–100 MW	15 min - 1 hour	Not applicable
Transmission congestion relief: When transmission capacity additions do not keep pace with the growth in peak electric demand, the transmission systems become congested. Electricity storage can be used to avoid congestion-related costs and charges.	1–100 MW	1–4 hours	50–100
Power quality: To ensure quality of power in even of short- duration events viz. sudden variations in voltage, variations in the primary 60 Hz frequency, low power factor (voltage and current excessively out of phase with each other); harmonics (the presence of currents or voltages at frequencies other than the primary frequency)	100 kW–10 MW	10 sec- 15 min	10–200
Peak shaving: Electricity storage can be used by utility customers to reduce their overall costs by reducing their demand during peak periods.	50 kW–10 MW	1–4 hours	50–500

kW = kilowatt, MW = megawatt, MVAr = megavolt-ampere reactive, PCS = power conversion system, VAr = volt-ampere reactive
Source: Sandia National Laboratories, JM Financial

Technical Requirements

Round-Trip Efficiency

It considers energy losses from power conversions and parasitic loads associated with operating the energy storage system. It is crucial for determining the cost-effectiveness of energy storage technologies. Among various options, compressed-air energy storage (CAES) typically exhibits the lowest reported efficiency (40%–55%), while Li-ion batteries demonstrate the highest (87%–94%).

Response Time

Fast response times are particularly important for variability-damping applications, such as utility-scale photovoltaic (PV) generation, where passing clouds can cause rapid changes in power output. Solar insolation at a single point can fluctuate by more than 60% in seconds.

Lifetime and Cycling

The operational lifetime of an energy storage system (ESS) directly impacts its cost-effectiveness. Factors affecting lifetime include charge and discharge cycling, depth of discharge, and environmental conditions. Maximizing the depth of discharge minimizes the required energy storage capacity for any application.

Sizing

Frequency regulation and black start BESS grid applications are sized based on power converter capacity (in MW), while other grid applications, such as renewable energy (RE) integration, peak shaving, load leveling, and microgrids, are sized according to power storage capacity (in MWh).

Computation

BESS Capacity [MW] = Frequency gain [MW/Hz] * Governor droop [%] * System frequency [Hz]

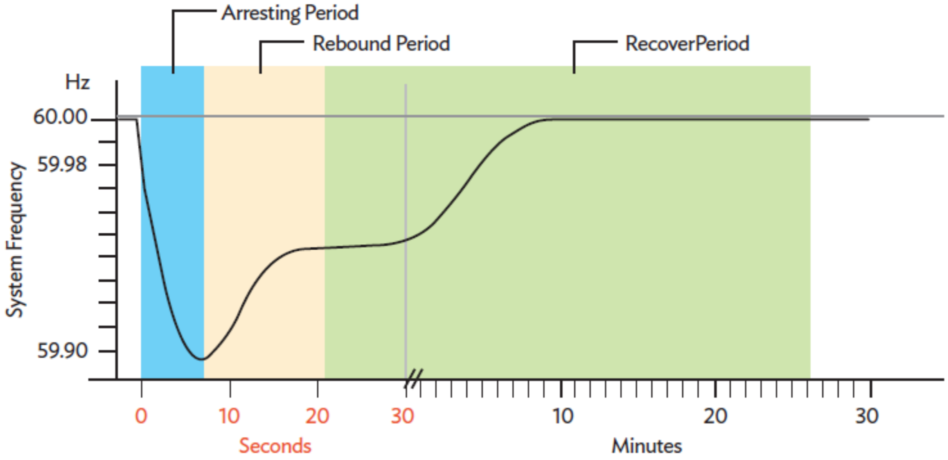
BESS Capacity [MWh] = Power required [MW] * Duration required [h] / Depth of discharge [%] * Battery efficiency [%]

Use Cases:

Frequency Regulation

Frequency regulation involves constant second-by-second adjustments of power to maintain system frequency at the nominal value (60 Hz) for grid stability. Battery energy storage with sub-second response times can provide regulating power, making it valuable for grid-balancing purposes.

Exhibit 12. Frequency Containment and Subsequent Restoration



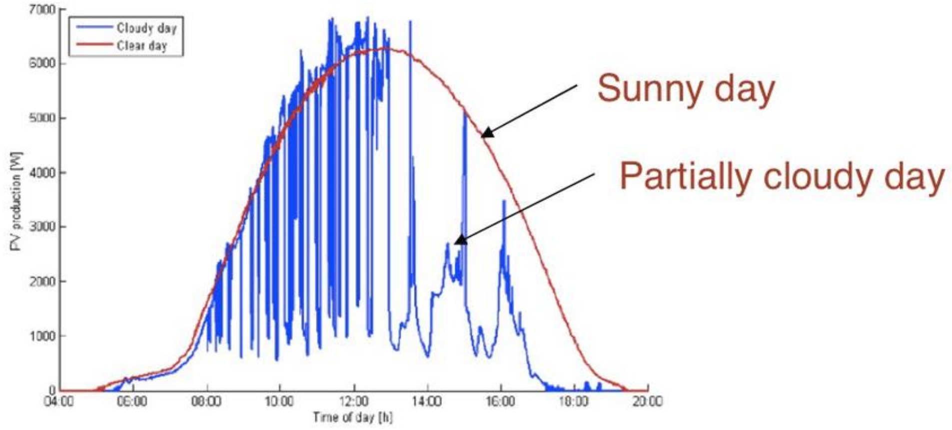
Source: Sandia National Laboratories, JM Financial

Renewable Energy Integration

Future power systems are anticipated to heavily rely on renewable energy sources (RESs) like wind and solar. However, the variability and intermittency of solar photovoltaic and wind-power generation pose challenges for safe and reliable grid integration.

Solar photovoltaic generation typically exhibits well-defined peaks in overall generation forecasts. However, volatility can occur during cloud cover, leading to minute-by-minute variations in in-feed.

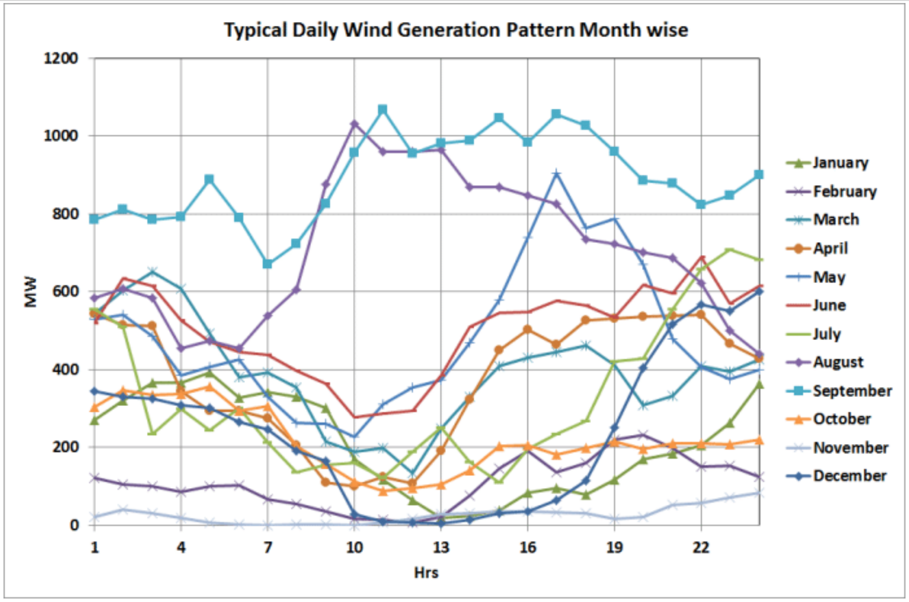
Exhibit 13. Variability in solar power generation on a sunny/cloudy day



Source: UTRECHT University, JM Financial

Wind-power generation presents even more challenging forecasting scenarios than solar photovoltaic, with large variations possible within minutes. Additionally, wind turbines are often disabled when wind speeds exceed 25 meters per second, potentially causing significant drops in power generation. The main challenges with wind-power integration include power intermittency, ramp rates, and limited wind-farm output.

Exhibit 14. Typical daily wind energy generation in Gujarat, month wise



Source: SLDC, JM Financial

Battery energy storage systems (BESS) can address these challenges by reducing forecast errors and optimizing transmission capacity utilization. Furthermore, BESS can provide ancillary services to mitigate the variability and uncertainty of RE, particularly wind power, on the grid side.

Hence, energy storage plays a crucial role in increasing the volume of renewable power that can be safely and securely integrated into the grid.

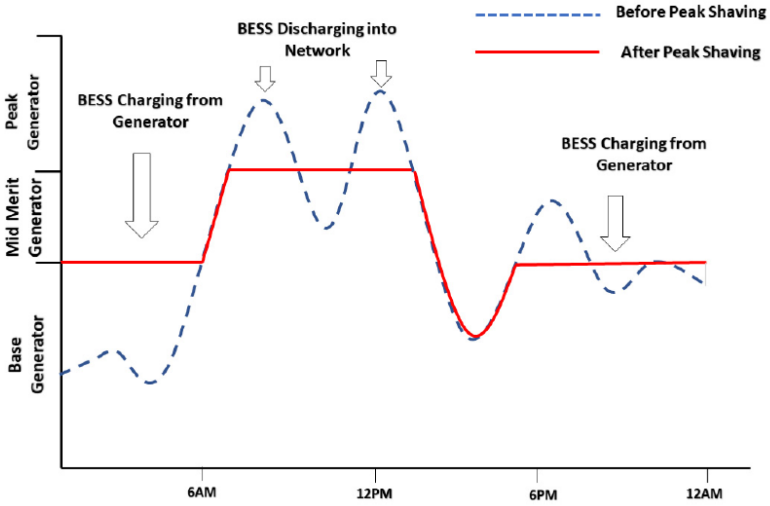
Peak Shaving

Peak shaving refers to the practice of reducing electric power demand during periods when network capacity is under stress. This strategy serves to defer investments in network expansion or reinforcement, as it helps balance demand with available capacity.

Additionally, peak shaving enables utilities to meet demand without the need to rely heavily on expensive peaking generators. By managing peak demand, utilities can optimize their existing resources and infrastructure, minimizing the need to invest in new power plants in the long run.

In essence, peak shaving not only enhances grid stability and reliability but also contributes to cost savings and efficient resource utilization for both utilities and consumers.

Exhibit 15. Use of energy storage for peak shaving (Load curve)



Source: AIMS Energy, JM Financial

Load Leveling

Load leveling involves shifting electricity consumption away from peak demand hours to off-peak periods. This can be achieved through time-of-use tariffs or behind-the-meter energy storage systems. In India, load leveling initiatives result in a notable decrease in peak-hour demand, as illustrated by the shifting load curve.

Peak shaving and load leveling are demand-side management strategies that benefit both energy consumers and generators by optimizing grid stability, reducing costs, and improving resource utilization.

Microgrids

In recent times, microgrids powered by renewable energy (RE) have gained traction for remote communities. However, inverter-based renewables lack inertia response, vital for stabilizing system frequency. Yet, community microgrids with inverter-based RE are crucial for energy security and sustainability.

Battery energy storage systems (BESS) offer key benefits for microgrids, providing essential ancillary services like frequency regulation and voltage control, and storing energy for peak demand hours.

Business models for energy storage services

Business models for energy storage services in India are evolving, offering various options tailored to the needs and preferences of distribution companies (Discoms).

Model 01: Storage as a generation-coupled asset

One prevalent model is storage as a generation-coupled asset, where tenders often require a commitment for Firm & Dispatchable RE (FDRE) power to ensure fulfillment of specified demand pattern using solar, wind, and storage hybrid plants.

Under this model, developers bear some risk as they must ensure compliance with daily demand fulfillment ratios (DFRs), with penalties for non-compliance. While not block-wise firm, developers must procure charging energy from the market if associated renewable energy (RE) sources fail to provide during solar or wind hours.

Model 02: Storage as a grid asset

In the Storage as a Grid Asset model, the storage system is owned, operated, and maintained by a developer, who provides specific storage services under a contractual arrangement similar to power purchase agreements (PPAs) signed with Discoms. These agreements typically span 10-15 years and entail the following key terms:

- The off-taker, usually the Discom, holds dispatch rights for charging and discharging the energy storage system (ESS).
- The seller, or the developer, receives a fixed capacity payment (in INR/MWh) and a variable payment for operation and maintenance (O&M) per MWh delivered (in INR/MWh).
- In exchange for the capacity payment, the seller guarantees a specified degree of plant availability along with an efficiency guarantee.

This model allows for a structured approach to energy storage deployment, providing Discoms with reliable access to storage services while offering developers a predictable revenue stream through fixed capacity payments and O&M charges.

Model 03: Storage as merchant asset

To date, the majority of storage developments have been utility-owned or supported by long-term contracts. However, as markets evolve and demand for firm renewable energy (RE) grows, merchant storage opportunities are becoming increasingly appealing. Several key merchant revenue streams are emerging, including:

- Capturing the spread between sale and purchase prices in the wholesale energy market.
- Providing capacity for peak resource adequacy, ensuring the availability of power during periods of highest demand.
- Offering ancillary services such as frequency regulation and reserves, which contribute to grid stability and reliability

These revenue streams highlight the growing potential for merchant storage projects to contribute to the energy market while providing valuable grid services.

Exhibit 16. Business Models

Storage as a…	Generation-coupled Asset	Grid Asset	Merchant Asset
Location of Battery	Generation	Transmission or Distribution grid Front-of-Meter	Anywhere
Ownership	Generators / IPPs	Independent Storage Providers, Regulated Utilities	Independent Storage Providers
Dispatch	IPPs	System operators	Independent Storage Providers
Applications	Firm-RE, Ramping for Thermal gen	All	Based on existence of market (in India – Energy Arbitrage)
Contract	PPA ($/kWh)	Tolling agreement ($/kW-year availability)	Market-based merchant revenues
Value Maximization	Medium as dispatch priority is to maximize generator value, not system benefits	Maximum as grid operator is the single dispatcher maximizing value both upstream and downstream	Low In the absence of multiple markets with deep volumes and participation
Bankability	Medium as there is volume uncertainty	High as there is a fixed capacity payment contract underlying the project	Low as the revenue stream is merchant with hourly or yearly price uncertainties
Recent use case	SECI has developed several tender designs over the years to find the ideal model for India. It includes solar + BESS, peak power supply, round-the-clock (RTC), standalone ESS, and firm and dispatchable renewable energy (FDRE). These models require storage components.	40MW/120MWh BESS with a solar PV plant & an installed capacity of 152.325 MWh at Rajnandgaon, Chhattisgarh owned by SECI	40% capacity of 500 MW/1000 MWh standalone BESS plant of JSW Energy at Fathegarh is untied

Source: Sterlite Power, JM Financial

APPENDIX I

JM Financial Institutional Securities Limited

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Rating	Meaning
Buy	Total expected returns of more than 10% for stocks with market capitalisation in excess of INR 200 billion and REITs* and more than 15% for all other stocks, over the next twelve months. Total expected return includes dividend yields.
Hold	Price expected to move in the range of 10% downside to 10% upside from the current market price for stocks with market capitalisation in excess of INR 200 billion and REITs* and in the range of 10% downside to 15% upside from the current market price for all other stocks, over the next twelve months.
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* REITs refers to Real Estate Investment Trusts.

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