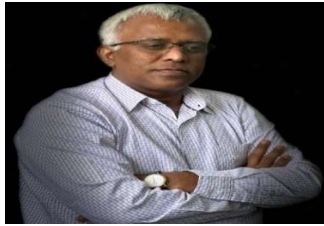


Evolutionary Energy Storage 'Responding Cusp to Sustenance'



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“Bridge between intermittent and stable source of energy from renewables is the optimised levelized capital cost among contemporaries of storage system”

Evolution is the driver of ecological's continual in responding "LIFE" as live in for experiencing. Each of us traverses to be in travesty to be far away from purpose in unfolding basic of living, 'Energy'. This being harnessed from fossils, definitely unconventional means that cumulatively we termed as conventional, reflecting our parenting in seeding essence of pivotal, Energy, to move on in living and experiencing the life. Thereby, brought journey of new again that shudders to adopt the path of course, renewable as source of intake energy in coexistence and forever growth with nature. Noble way of energy intake from nature demands ride over intermittency by threading energy storage to be in new regime of evolution in everlasting green path to human and nature.

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Imperatives of energy storage are:

- to store energy in off-peak hours when electricity price is low and to supply loads in peak hours when electricity price is high (energy time shift), hence enabling energy arbitrage and resulting in economic benefits for the owners.
- storage deploys to support renewable generation in which highly volatile and intermittent generation of these resources can be efficiently captured by coordinated charging/discharging of the energy storage.
- high importance and applicability in microgrids as viable means to support islanded operations when supply of power from utility grid is interrupted.
- reactive power supports that can be used to correct power factor and/or adjust voltage levels.

enhances grid resilience in either extreme weather or backup on emergency / critical events.

Exponential power adds in India to meet its growth journey as well energy transition in adhering NDC's obligations necessitates immediate response to Energy Storage. The massive addition of renewables exceeding 500GW which are intermittent and distributed in power system pose serious challenges to grid operation. Capacity integration (GWh) constituents are as:

Year	Grid		Stationary	e-mobility	Total
	EHV	MV/LV			
2022	7	10	121	40	178
2027	45	34	381	247	707
2032	142	67	793	1414	2416

Storage models can be roughly grouped in increasing complexity, into atemporal, perfect information, imperfect information and strategic operation.

Benefits of storage come at expense of high capital cost of energy storage. The most encompassing metric in arriving efficient of storage technology is levelized cost of electricity (LCOE). Therefore, extremely important to determine its LCOE and efficient comparison with other technologies from an economic viability perspective. The levelized cost of energy is defined as the net present value of entire cost of electricity generated over lifetime of a generation asset divided by the total generated energy. This metric includes cost of fuel and electricity purchased to meet all of the system demand and to charge storage devices and thus, LCOE is highly variable in response to local electricity or fuel prices. Thereby, some analysts prefer to use the levelized cost of storage (LCOS) which explicitly focuses on the costs associated with electricity stored. LCOE is a life-cycle cost concept that includes all physical assets, resources required to deliver one kWh of electricity. It reflects the break-even price that must be achieved as average revenue to yield a zero-net-present value for equity investors.



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Energy storage system (ESS) classification is:

1. Mechanical - Pumped Hydro Energy Storage (PHS), Compressed Air Energy Storage (CAES), Flywheel Energy Storage (FES)
2. Electrochemical – (a) Battery Energy Storage - Lead Acid Batteries, Lithium Batteries, Sodium Batteries, Zinc Batteries
(b) Flow Battery Energy Storage (battery systems for grid-scale energy provision) - vanadium redox, zinc-iron, zinc-bromine
(c') Fuel cells – solid oxide fuel cells (SOFC), proton exchange membrane (PEM), phosphoric acid fuel cells (PAFC)
3. Thermal – Thermal Energy Storage, Electrochemical Storage, Industrial Heat Recovery System, Heat to Power Conversion, Heat Pump, Thermal Storage in Solid Material
4. Electrical – Super Capacitors, Superconducting Magnetic Energy Storage (SMES)
5. Chemical – hydrogen storage with fuel cell /electrolyser, synthetic natural gas (SNG), reversible chemical reactions

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All energy storage technologies have losses as storage will never be able to deliver the same amount of energy that was used to charge it since it governs by 2nd law of thermodynamics, "Not all heat can be converted into work in a cyclic process". These losses are usually described using a round-trip efficiency for the technology which may be set as a constant for modelling purposes or vary as a function of other parameters in more sophisticated analyses. Round trip efficiencies of technologies are as: PHS 70-85%, CAES with natural gas <55%, thermal storage 33%, FES 90-95%, lithium ion 80-85%, sodium ion 90-95%, vanadium flow battery 75-95%, iron flow battery <70%, zinc bromine flow battery 65-75%, lead acid 81%, capacitors 75-95%.

Batteries of various types and sizes are used as one of the most suitable systems to store energy; however, environmental impacts of large-scale battery

use remain a major challenge. It also confirms that battery shelf life and use life are limited; a large amount and wide range of raw materials, including metals and non-metals, are used to produce batteries; and, the battery industry can generate considerable amounts of hazardous waste, greenhouse gas emissions and toxic gases during different processes such as mining, manufacturing, use, transportation, collection, storage, treatment, disposal and recycling. Battery use at a large scale or grid-scale (>50 MW), which is widely anticipated, will have significant social and environmental impacts; hence, it must be compared carefully with alternatives in terms of sustainability. Lithium-ion batteries owing to its versatile usage, fast declining cost attracts better manufacturing ecosystem to match race with India's momentum on radical economic, industrial transformation and fast-growing global market (prominent with 55% market share). Batteries are the most common and efficient storage method for all small-scale power needs, and vast numbers of batteries of different types and sizes are manufactured annually; this will grow as population and demand for portable electronic devices. Higher energy density batteries are more suitable for transportation applications due to their compactness and lower weight. Flow batteries differ from conventional batteries as energy is stored in the electrolyte instead of the electrodes. BESS can provide transmission congestion relief by reducing load in transmission and distribution system and in same way, can help defer expensive upgrades of the transmission and distribution network. For the moment, Lithium-Ion offers the highest degree of versatility at a reasonable cost.

Factors contributing selection a type of storage system are power density, energy density, stability, response time, self-discharge rates, low overall magnitude, safety, grid-scale potential, flexibility, long life, operation and maintenance costs, efficiency, space requirement, maturity of technology. ESS deployment expects to grow multifold with new long-duration energy storage technology gaining maturity. Energy storage systems for stationary grid applications must evolve



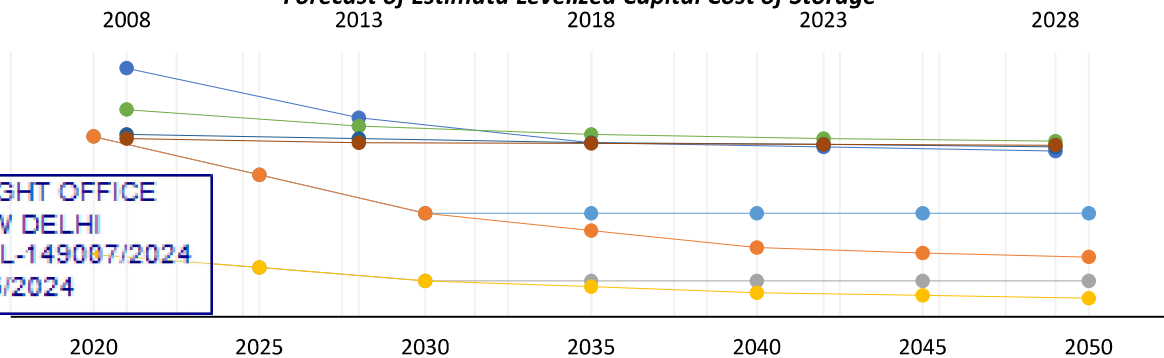
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beyond lithium-ion technologies to achieve affordable Long-duration energy storages (LDES) as four-, six-, and eight-hour storage on sodium ion technology, GH2-based storage solutions for seasonal storages that would be critical to have a RE transition in the grid.

Nature has developed a comprehensive and complex system for converting solar energy into fuel which is a biochemical mechanism process that known as photosynthesis. That allows plants, algae, certain bacteria to capture

may lead to major breakthrough in cooling and energy storage from industrial heat energy dissipation. A long-term trajectory for Energy Storage Obligations (ESO) has also been notified by the Ministry of Power to ensure that sufficient storage capacity is available with obligated entities. ESO shall gradually increase from 1% in FY 2023-24 to 4% by FY 2029-30. This obligation shall be treated as fulfilled only when at least 85% of the total energy stored is procured from Renewable Energy sources on an annual basis.

Forecast of Estimated Levelized Capital Cost of Storage



Cost Trend of Installed Battery System and Storage Capacity

- Min (INR Cr/MWh)
- High (INR Cr/MWh)
- Min (INR Cr/MWh)
- High (INR Cr/MWh)
- Lead Acid
- NaS
- Li-Ion
- VRB

solar energy and store it in the form of carbohydrates, serving as fuels for their growth and maintenance. Conversely, artificial photosynthesis involves capturing sunlight and utilizing stored energy to chemically transform water and carbon dioxide into fuels, resulting in production of solar fuels. Amalgamation of couple of types storage system are being done to arrive advantageous attributes for specific project requirement. This hybrid solution is being made by integrating two storage systems such as one with high energy density and other with high power density in serving deeper & wider spectrum. Since high-power storage systems, characterized by rapid energy delivery at higher rates for shorter durations whereas high-energy density storage systems offer slower response times but can sustain power delivery for extended periods.

Thermal energy system relies on the absorption and release of heat energy during and association of molecular which process harnesses enthalpy of store heat energy. This technology

The stress strain phenomenon with distortion along aggravating surrounding environment is evident in each aspect where human traverses each day. Continual deformation may be guarded by strong threading with insertion of cusp of retainment that breaks the flow as pause only symbolises embracement of internal energy to move on for a distance in reaching the objective destination. This transition point yields the sustenance which nowadays is key gradient on any facet of technology. Overall efficiency to dominance of this vital aspect of energy storage being governed by discharging timeline from intermittent to temporal storage, current density and levelized cost of energy in "Responding Cusp to Sustenance". Cycles of processes being intrigued from inception to readiness of storage system conforming to sustainability is paramount that it becomes parent with no further pause in co-existence, co-living, co-growth with complementing and supplementing to each other by human and nature.



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