1.3 The Power Storage for Viksit Bharat: Moving Energy Through Time

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Abstract

This paper examines the paradigm shift in Bharat's energy landscape from fossil fuels to renewable energy sources of energy generation to attain a net-zero carbon emission world by 2070. Because renewable generation is spatio-temporally discrete, it creates grid imbalances that cost the Indian economy ₹12,000 crore annually (DC&T Global, 2026), warranting robust energy storage. While pumped hydro storage is utilized, Battery Energy Storage Systems (BESS) offer geographical flexibility and rapid deployment, making them essential for meeting Bharat's 2030 target of 500 Gigawatt (GW) non-fossil capacity. The study evaluates the current prominence of lithium-ion batteries while highlighting promising, safer alternatives like sodium-ion to overcome critical mineral supply chain risks and thermal runaway issues. Crucially, an economic analysis reveals that a deflation in the Levelized Cost of Storage allows dispatchable solar-plus-storage (₹6.61/kWh) to definitively outcompete new fossil fuel assets like coal (₹10.18 to ₹10.27/kWh) (Ember, 2025). Finally, the text assesses policy interventions such as the ₹18,100 crore Advanced Chemistry Cell Production Linked Incentive (PLI) scheme (Cabinet, 2021), noting severe structural headwinds, and concludes that future energy stability requires battery recycling, strengthened international supply chains, and supplementary technologies like hydrogen and thermal energy storage.

Keywords

Renewable Energy Integration; BESS; Pumped Hydro Storage; Levelized Cost of Storage; Green Hydrogen; Grid Imbalances; Advanced Chemistry Cell

Introduction

Bharat's Energy Basket

The evolving landscape of energy generation has seen a paradigm shift in this century. The erstwhile generation from coal and gas has now de-metamorphosed to renewable energy systems viz., solar energy at the pinnacle of energy mix, wind energy, and the evolving forms, viz., geothermal energy and tidal energy. This change has also brought in certain other changes. Some positives include a way forward for a net zero world, which Bharat, the largest democracy has aimed to deliver by 2070. Renewable energy transforms the sun's energy. Unlike fossil fuels, it does not rely on ancient, stored carbon, and is therefore, carbon neutral.

Batteries: A Saviour

The negative aspects, however, regarding these sources are the spatio-temporal discreteness in their generation. This has led to an increasing interest of scholars, startups, and countries alike in the field of batteries and energy storage. Solar output drops to absolute zero post-sunset, rendering the region without energy until the next morning. In case of wind turbines, the wind generation fluctuates with extreme seasonal and regional variations (DC&T Global, 2026a). This forces the grid operators to rely on the inefficient cycling of coal plants to meet severe evening ramp up. In Bharat, there is an over reliance on coal plants than the gas-fired plants (NITI Aayog, 2026). Gas-fired plants are easy to ramp up when compared to coal fired ones. The west is relying on gas-fired plants to ramp up their electricity, however, Bharat does not have gas in abundance and is heavily dependent on imports (India Energy & Climate Centre, 2024). This warrants the need for storing the electricity generation in the battery so that the excess electricity generated during the period when there is excess energy can be transported through time in the deficient days. Moreover, the solar energy falling on the solar panels is not constant throughout the day due to the sun's changing angle and other meteorological challenges like clouds, rains, and changing seasons. At the same time, the electricity demand is also constantly changing. Hence, to prevent the demand supply mismatch there must be a storage unit, this storage unit is battery, which optimises the flow of electricity. The Central Electricity Authority (CEA) estimates grid imbalances cost the Indian economy ₹12,000 crore annually in excess operations (CEA, nd). So, to optimize grid utilization, stationary energy storage has transitioned from an aspirational technological novelty to a bankable, critical infrastructure asset. Moreover, this has also become a critical infrastructure due to fragility of the supply chain. There have been constraints in all the points of the supply chain. There is constraint in mining the lithium, the raw material behind the batteries. There is also constraint in refining the lithium, which is concentrated in a few countries. COVID has rightly depicted the fragility in the supply chain. Bharat is dependent on fossil fuels for more than 80 percent of its requirement (International Energy Agency, 2021). To become *atmanirbhar*, it must chalk a new trajectory for itself. Electric vehicles show the path to *atmanirbharta*. This has led to a paradigm shift in the current mobility landscape which has changed with the increasing adoption of electric vehicles at both passenger and commercial levels. This too requires batteries, particularly the lithium-ion ones.

Multiverse of Powerhouse

Energy storage can happen in the following forms: pumped hydro storage, BESS capacitors, flywheels, fuel cells, and molten salts. In Bharat, it is primarily driven by battery energy storage and pumped hydro storage. Battery energy storage stores electrical energy to chemical energy and then delivers this in electrical energy when demanded by the user. During charging, an electrical current forces ions to travel from the cathode to the anode. During discharge, the ions travel from anode to cathode, releasing electrons to power the grid. Many types of batteries are available in the market. Li-ion batteries are the prominent ones in the market, due to its high energy density, high longevity, and fast charging speeds. However, it is mired by the scarce presence of lithium and higher costs involved. Moreover, there exists the issue of thermal runaway, a chain reaction of exothermic chemical reactions leading to uncontrollable rise in battery's temperature. To overcome these challenges, sodium ion batteries are an active area of research for scholars around the world. Like lithium, it is monovalent, has low ionisation potential, and falls in the same group of elements. However, it has some additional benefits too. Sodium is relatively more abundant and widely available, preventing the supply chain risks. It is much safer and at the same time, the issue of thermal runaway is not that pronounced. It also has faster charging rates. Advancements in chemical engineering and material sciences show a promising future for the sodium ion batteries. Another mode of storage is pumped hydro storage which converts the electrical energy into potential energy of water and then this potential energy is released again to electrical energy when demanded by the user. When electricity demand and prices drop, excess grid power is used to pump water to an upper reservoir. During peak demand, this water flows back down through a turbine, generating electricity as it returns to the lower basin. The difference between the two also lies in the fact that the BESS are man-made, whilst the pumped hydro storage systems rely on natural reservoir, where water is pushed up. In addition, the BESS can be located with geographical flexibility while the pumped hydro storage systems are fixed to certain topography. This restricts the usability of pumped hydro storage. The pumped hydro storage systems last much longer than BESS owing to the chemical degradation of the batteries, Moreover, the batteries can

can be built in a year or two while it takes nearly a decade to build pump hydro storage (DC&T Global, 2026b). Hence, due to rapid buildup and shorter release time, energy BESS provide a promising future for the Indian landscape.

The Landscape

Bharat has crossed 250 Gigawatt (GW) of installed non-fossil fuel energy by 2025 and is galloping to achieve its stated target of 500 GW of non-fossil energy by 2030. The Central Electricity Authority forecasts that realizing Bharat's strategic ambitions will necessitate an energy storage capacity of 60.63 GW, equivalent to 336 GWh, by the year 2030 (CEA, n.d.). This total goal is split between pumped hydro, aiming for roughly 18.9 GW, and battery systems, aiming for about 41.65 GW. However, right now, there is a lot of building to do-as of 2024, only 4.7 GW of pumped hydro and a fraction of a Gigawatt (111.7 MW) of battery storage are actually online. Global Pumped Hydro Storage (PHS) capacity is over 180 GW. Potential available in India for PHS, assessed by CEA is more than 96.5 GW. However, at present, total installed capacity of pumped hydro storage is about 4.7 GW that consists of nine plants. Driven by these requirements, India's BESS market is on a steep upward trajectory. Valued at $2.05 billion in 2026, it is projected to hit $8.59 billion by 2031, expanding at an impressive compound annual growth rate (CAGR) of 33.2 percent.

Cost analysis

Due to global supply chain scaling and improvement in battery sciences not limited to improved cell energy densities alone, there has been a dramatic deflation in the Levelized Cost of Storage (LCOS) (Ember, 2025a). Total BESS Capital Expenditure (CapEx) has stabilized at roughly ₹10,875/ kilowatt-hour (kWh) globally for 4+ hour utility-scale systems (Ember, 2025b). For a 1,000-kWh system, the initial capital cost (C0) is ₹1,08,75,000. Core battery equipment accounts for roughly ₹6,525/kWh, and the balance-of-plant, installation, and grid interconnection accounts for roughly ₹4,350/kWh. The Levelized Cost of Storage (LCOS) measures the lifetime costs of the battery system against the total amount of usable energy it will deliver over its life, adjusted for the time value of money. It divides the net present value of all costs by the net present value of all electricity discharged.

Mathematically,

$$LCOS = \frac{\sum_{t=0}^{t=n}[Ct / (1 + r)^t]}{\sum_{t=1}^{t=n}[Et / (1 + r)^t]}$$

Where,
Ct: Total costs in year t
Et: Total electrical energy discharged in year
r: Discount rate (7% or 0.07)
t: Year index (from 0 to n)
n: Lifetime of the system (20 years)

Calculating the Total Discounted Costs (Net Present Value [*NPV*]$_{\text{Costs}}$)

To determine the financial outlay to build and maintain the 1 Megawatt-hour (MWh) system.

Year 0 (Capital Expenditure)

The initial cost is ₹10,875/kWh, which translates to ₹1,08,75,000 for the 1 MWh system

$$C_0 = ₹1{,}08{,}75{,}000$$

Years 1 to 20 (Operational Expenditure)

The annual maintenance cost is assumed to be 2% of capital costs.

$$OpEx_t = 0.02 * C_0$$

$$OpEx_t = 0.02 * ₹1{,}08{,}75{,}000$$

$$OpEx_t = ₹2{,}17{,}500$$

Discounting the Operational Expenditure

Each year's operating cost i.e., ₹2,17,500, is discounted by the 7% discount rate to adjust for money's depreciation over time.

Equation for Total Discounted Costs

$$NPV_{\text{costs}} = C_0 + \sum_{t=1}^{t=20} [\, OpEx_t / (1+r)^t \,]$$

$$NPV_{\text{costs}} = ₹1{,}08{,}75{,}000 + \sum_{t=1}^{t=20} [₹2{,}17{,}500 / (1+0.07)^t \,]$$

$$NPV_{\text{costs}} = ₹1{,}31{,}80{,}500$$

Calculating Total Discounted Energy NPV_{Energy}

Annual Cycles

At an 80% utilisation rate, the battery completes the equivalent of 0.8 full cycles per day. This translates to 292 cycles per year over 365 days.

$$0.8 * 265 = 292$$

Energy Delivered (Efficiency)

The newest batteries have round-trip AC to AC efficiencies of 90%. This means 10% of the energy is lost. Thus, a 1 MWh capacity yields about 0.9 MWh of usable output per cycle.

$$\textit{Year 1 Total Output } (E_1)\text{:} 292 \; cycles \times 0.9\, MWh = 262.8\, MWh.$$

Annual Degradation

The battery loses 2% (d = 0.02) of its capacity annually.

$$E_t = E_1 * (1-d)^{t-1}$$

Discounting the Energy

Future energy generation is mathematically discounted by the 7% rate to match the financial metric.

Equation for Total Discounted Energy

$$NPV_{\text{Energy}} = \sum_{t=1}^{t=20} [\, E_t / (1+r)^t \,]$$

$$NPV_{\text{Energy}} = \sum_{t=1}^{t=20} [262.8 * (1-0.02)^{t-1} / (1+0.07)^t \,]$$

$$NPV_{\text{Eenergy}} = 2{,}330 MWh$$

Result

Calculating the decaying energy output over 20 years and applying the 7% discount rate yields an NPV of all energy discharged of approximately 2,330 MWh.

$$LCOS = NPV_{\text{Costs}} / NPV_{\text{Energy}}$$
$$LCOS = ₹1{,}31{,}80{,}500 \; / \; 2{,}330 \; MWh \approx ₹5.66 \text{ / kWh}$$

Now the storage costs on the solar energy comes out only for the energy one actually stores. Assuming one stores 50 percent of the daily power for later use, one only adds ₹2.87/kWh (0.5*₹5.66/kWh) to the total costs. Add that to a base generation cost of ₹3.74/kWh, one gets fully dispatchable, on-demand solar for just ₹6.61/kWh.

In stark contrast, recent industry analyses place the cost of new-build coal generation without subsidy at a global weighted average of ₹10.18 to ₹10.27/kWh (Lazard, 2024). Dispatchable solar-plus-storage therefore definitively outcompetes new fossil fuel assets.

To catalyse a sovereign battery supply chain and reduce import dependency, the Ministry of Heavy Industries launched the National Programme on Advanced Chemistry Cell (ACC) Battery Storage under the Production Linked Incentive (PLI) scheme in late 2021 (Ministry of Heavy Industries, 2021). Featuring a massive total financial outlay of ₹18,100 crore ($2.08 billion), the scheme aims to establish 50 Gigawatt-hour (GWh) of domestic cell manufacturing capacity. However, the execution of the ACC PLI scheme has encountered severe structural headwinds. By early 2026, no beneficiary firm has successfully claimed incentive disbursements. First-time battery manufacturers face acute supply chain bottlenecks, difficulties in sourcing and refining critical minerals, and geopolitical friction regarding visa approvals for the Chinese technical specialists required to install complex extrusion, mixing, and cell-coating machinery (International Institute for Sustainable Development [IISD], 2023).

The Future

Lithium in li-ion battery is hardly 3 percent, so recycling efforts needs to be ramped up. Alternate batteries are coming up, like sodium ion, so industrial-academia linkage needs to be strengthened. There is also a need to develop ties with countries on defence, trade, strategic front with Latin American countries and then critical minerals supply will be assured. In order to fully harness renewable energy, the time has come to develop state-of-the-art forecasting techniques which let the operators predict with much greater accuracy exactly how wind and solar power generation will fluctuate throughout any given day. This helps the grid operators to better plan on the front of adjusting power from other sources which ensures a steady and reliable supply of electricity for the end users.

The hydroelectric power now comes to rescue as unlike other sources; hydro facilities can rapidly ramp their output up or down in order of some seconds. A paragon of this flexibility was displayed during the lights-off campaign amidst the pandemic, where hydro power was utilized for grid stabilization and preventing blackouts (Power System Operation Corporation Limited [POSOCO], 2020). Gas turbines come after hydropower as far as ramp up and ramp down rates are concerned. The coal and nuclear power plants require hours of advance notice just to begin ramping up their supply, making them suitable for baseload supply (International Energy Agency [IEA], 2019).

Hydrogen is the future for energy storage. To produce hydrogen, excess renewable electricity is used to split water into hydrogen and oxygen through electrolysis. The hydrogen generated is called green hydrogen because it is generated by renewable electricity. The new hydrogen gets saved in big tanks above ground or in caverns below. Then, when there's a spike in electricity demand, it can be quickly turned back into grid power. This has effectively transferred the energy through time, moving from excess electricity supply to excess consumer demand. Right now, Bharat mainly uses hydrogen for industries like steel and ammonia production. The green hydrogen mission aims to develop hydrogen storage systems and electrolysers to scale this up (Ministry of New and Renewable Energy [MNRE], 2023).

Bharat could also get into Thermal Energy Storage (TES), which stores energy by heating materials like molten salts. They can warm these up when there's extra energy and use the heat later. While Bharat hasn't fully jumped into large-scale TES, combining it with their growing solar industry could open up some huge possibilities.

The Energy Storage-as-a-Service (ESaaS) model is on the rise. This means energy users can tap into storage without paying big upfront costs. They only shell out for what storage they use, similar to how cloud computing works (Market Research Future, 2025).

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Author's Profile

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