Energy Storage Systems (ESS) – Is India Ready?

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***Abstract*— Energy storage systems will become increasingly relevant for the Indian power system as more and more variable renewable energy (VRE) based power generation capacity gets connected to the grid. ICF's analysis shows that for a typical day in 2022 with 175 GW installed Renewable Energy (RE) generation capacity, solar power may meet up to 44% of the total demand during the peak solar generation hour. Similarly, power feed-in from wind power plants may vary as much as about 8 GW in as little as 5 hours.**

There are several options to meet this variability in the residual demand (total demand less the generation from VRE), with storage being one of them. In this paper, we present an overview of the various commercially-prevalent storage technologies and the various business models (use-cases) and policies/regulations that would be required to promote adoption of storage technologies at the grid-connected level in India.

I. WHY IS STORAGE IMPORTANT FOR INDIA?

The Indian electricity grid is in the midst of a paradigm shift as the country strives to achieve its target of 175 GW of installed RE capacity by 2022. With such large and variable RE capacity, a key challenge will be to manage the significant variability in net demand that will be introduced into the system.

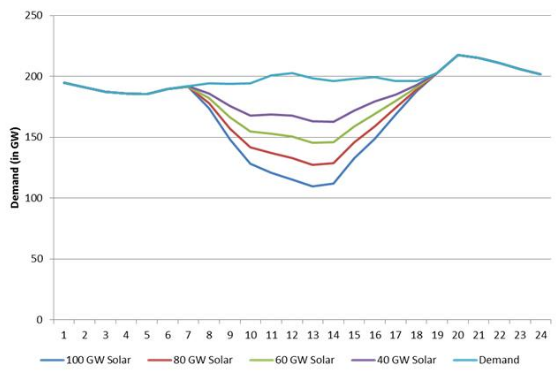

Figure 1: Net demand curve for Indian power system in 2022

The net demand "duck curve" (Figure 1) for India means that significant balancing capacity will be required to balance the renewables. If the Indian ecosystem indeed meets the stated targets of RE capacity addition, then **during a typical day in 2022, solar power may meet up to 44% of the total demand during the solar peak generation hour**. In addition, wind capacity of 60 GW will bring about **a variation of up to 8 GW in as little as 5 hours**.

Such vast amounts of renewable energy will need to be backed up by a mix of fast response and high capacity energy storage to support sudden drops in output and the morning and evening ramping requirements. In addition, if there is a drop in demand, there would be a need to absorb the excess generation for later use and prevent curtailments.

II. OPTIONS TO MEET THE REQUIRED FLEXIBILITY

Fundamentally, there are a number of sources that can be used to support the variable generation. However, each source has a specific purpose and can support only a certain type of use case with the right market structure. Some of the common flexible power generation options are listed in Table 1 below.

Table 1: Options to meet the required flexibility

Spinning Reserves	• Cycling coal plants • Operating CCGT
Peakers	• Open cycle GT • Pumped hydro / hydro with pondage
Virtual Power Plants (VPPs)	• Combining wind, solar, biomass, loads through a software solution to run as a virtual power plant – dispatch as single unit
Demand Response	• Peak load management by utilities • Load shifting
Energy Storage System	• Fastest emerging technologies supported by global R&D efforts and rapidly reducing costs

Of all these options, Energy Storage Systems (ESS) are the fastest emerging alternatives supported by very strong global R&D efforts and are likely to come of age much quicker than anticipated with prices reducing rapidly over next few years.

III. WHAT ALL STORAGE TECHNOLOGIES ARE THERE?

There are many different types of energy storage options ranging from flywheels and pumped hydro systems to batteries, double layer capacitors, and superconducting magnetic coils. Some of the prevalent technologies are enlisted in Table 2 below.

Table 2: Different storage technologies

Mechanical	**Electro-chemical**	**Chemical**	**Electrical**	**Thermal**
Pumped Hydro (PHS)	Secondary Batteries (Lead Acid /NiCd /NiMh /Li-	Hydrogen (Electrolyser / Fuel Cell/ SNG)	Double Layer Capacitor (DLC)	Sensible Heat Storage (Molten Salt/ A-

	Ion /NaS)			CAES)
Compressed Air (CAES)	Flow Batteries (Redox Flow (RFB) / Hybrid Flow)		Superconducting Magnetic Coil (SMES)	
Flywheel (FES)	Electric Vehicles – Vehicle to Grid (BEV)			

As shown in Figure 2 and Figure 3, these different technologies vary significantly in terms of their rated power as well as the timescale of their discharge.

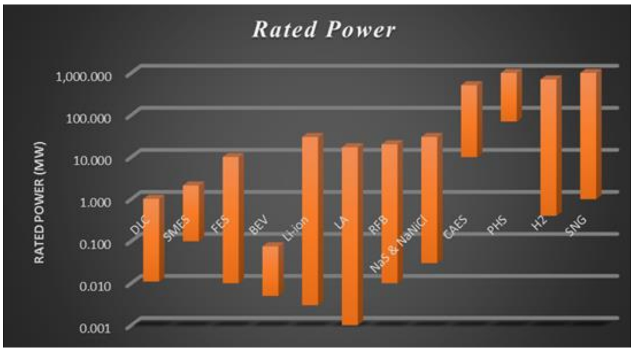

Figure 2: Rated power of different storage technologies

For example, batteries may be able to provide backup ranging from minutes to a few hours, whereas synthetic natural gas or hydrogen storage systems could provide backup for up to a day.

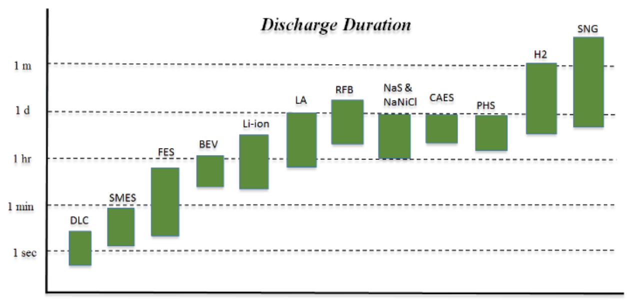

Figure 3: Discharge duration of different types of storage technologies

Thus the **choice of storage technology must be based on the desired use case and the performance characteristics of the storage**, which make it optimally suited for certain grid services and less so for others.

IV. Spectrum of Services Possible with ESS

Energy storage systems can serve various functions, from ancillary services to energy services, depending on where they are placed in the electricity value chain. Some of the common services provided by ESS are:

- 'Ancillary Services' such as frequency regulation and spinning reserves, are fast gaining industry attention
- 'Energy Services' such as peak shaving and firming of variable renewable generation are widely recognized in North American markets and now becoming relevant for Indian market too with the increasing share of renewables
- Capacity and reliability services from storage technologies are beginning to be provided but still require deployed at large scales

However, in order for storage to provide these services, the regulations and markets structures needs to be supportive. Currently India market does not have the mechanism that supports storage providers to benefit from and obtain revenue for any of these services. The question being asked in India is where the ownership of storage is suited. In our view this is probably a pre-mature question and perhaps need not even be the right question.

Ultimately what is important is that whoever the owner, the storage facility should be able to satisfy more than one need and thus be compensated for more than one service it can provide. Ultimately the ownership will be determined by the nature of services required and the market structure, and whichever stakeholder (generator, transmission company, distribution company, etc.) is best placed to maximize the value out of the storage system must retain its ownership.

V. Balancing Costs with Stacked Value Streams

Any discussion on storage today is incomplete without referring to costs. Capital costs of batteries have declined steadily in recent years largely due to significant R&D efforts. It is expected that costs will drop rapidly over the next few years especially as Electric Vehicles become mainstream and 'Vehicle to Grid' becomes a reality.

Based on cost estimates published by Lazard [1], ICF has computed the lifecycle cost of sample grid scale 20 MWh Lithium-Ion battery in an Indian context. Based on today's technology, this calculates to a lifecycle cost in the range of ₹18-20 /kWh (Figure 4) ($350-400/ kWh capex; 7,000 cycles; 80% DoD; and 92% round trip efficiency).

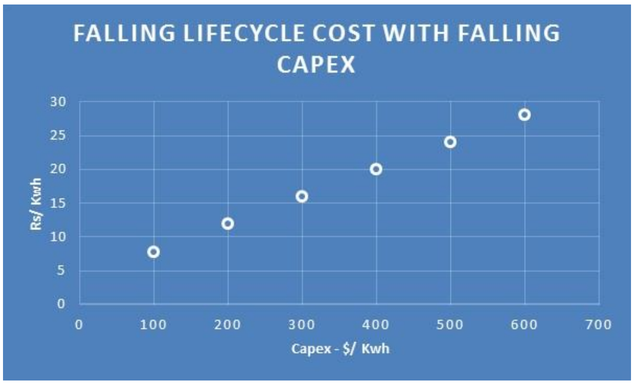

Figure 4: Reducing lifecycle costs with reducing capex

While the lifecycle cost of grid scale battery storage is expected to reduce over the next few years, to justify these costs, it is important to look beyond the primary service provided by an ESS and create the enabling policy/regulatory environment that allows storage operators to provide multiple services (Figure 5).

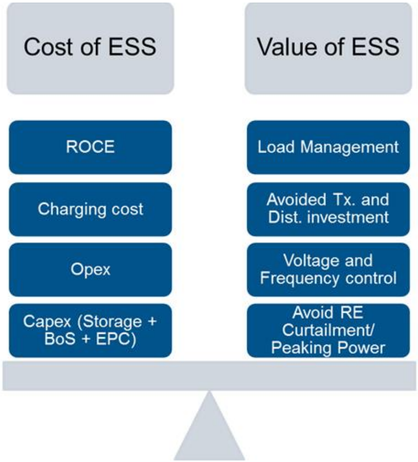

Figure 5: Costs and benefits of ESS

For example, analysis of an ESS in San Francisco by the Rocky Mountain Institute suggests that its primary service of commercial demand-side management was insufficient to cover its cost. However, additional services such as frequency regulation, resource adequacy, and energy arbitrage, when coupled with the primary service allowed it to generate sufficient additional revenue to cover its cost.

VI. What is Happening in Energy Storage Globally?

Despite rapidly falling costs, the development of advanced ESS has been highly concentrated in select markets, primarily in regions with highly developed electrical systems. However, at the same time, ESS applications are gaining a lot of traction even in developing markets such as Mexico, Singapore, and India. In this section we analyze the key drivers that triggered development of ESS in three regions – California, UK, and Germany – that have emerged as the global leaders in deploying ESS.

A. California

California traditionally has been the frontrunner in incubating and mainstreaming emerging technologies. A growing familiarity with energy storage technology and procurement led to the passage of a legislation in 2013 known as AB 2514. The state law set an aggressive goal for California' three regulated utilities, Pacific Gas & Electric, Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E) to procure energy storage capable of delivering a total of 1,300 MW by 2020 and have it online by 2024. Although this law was enacted in 2013, development of ESS in California was kick-started in 2015 after a gas leak in well SS25 of the Aliso Canyon natural gas storage facility threatened the reliability of power supply in the region.

As part of a multi-part response to the crisis, the California Public Utilities Commission in May 2016 fast-tracked approval of 104.5 MW of battery-based energy storage systems within the service areas of SCE and SDG&E. By the end of February 2017, seven of eight fast-tracked Aliso Canyon–related energy storage projects were online, helping the region's energy grid regain stability [2].

B. UK

The UK's energy storage sector has risen to international prominence over the past year due in part to the success of advanced energy storage projects in auctions for the capacity market as well as to provide enhanced frequency response to the grid. A key aspect of these auctions was that they were technology agnostic, thereby encouraging participation from sources

Battery storage projects dominated the outcome of the UK's National Grid 200 MW Enhanced Frequency Response (EFR) tender in August 2016, with 61 of the 64 awarded projects based on this technology. Later that year, energy storage projects took just over 6 percent of a total 52.43 GW of capacity awarded in the U.K.'s 2016 T-4 auction. Of the 3.2 gigawatts of storage, around 500 megawatts of capacity went to new-build battery projects [3].

C. Germany

Energy storage systems are an integral part of Germany's *Energiewende* ("Energy Transition") project. While the demand for energy storage is growing across Europe, Germany remains the European lead target market and the first choice for companies seeking to enter this fast-developing industry.

At the end of 2015, Germany was home to 67 MW of energy storage (128 MWh) with a value of $169 million. A large portion of this capacity is installed in the residential segment, largely driven by factors such as declining feed-in tariffs, high retail electricity prices and an incentive known as the KfW 275 program. Under this program homeowners are offered subsidy on the upfront capex for energy storage systems paired with a new or existing solar installation; the incentive covered up to 30 percent of the system costs between 2013 and 2015, currently covers 22 percent, and steps down by 3 percent every half-year [4].

It is expected that in the near term, there will be opportunities for ESS to participate in Germany's primary and secondary reserve markets.

VII. Conclusions: What India Needs to Do to Mainstream ESS?

Historically, the most prevalent storage technology in India has been pumped-hydro with about 6.8 GW of capacity in operation and under construction. It was not until last year that SECI invited bids for grid connected battery storage projects in Andhra Pradesh and Karnataka. Storage now seems to be garnering the attention of policymakers with the Central Electricity Regulatory Commission (CERC) coming out with a staff paper on electricity storage in India in January, 2017 [5]. Although, these are great initiatives, a lot needs to be done to bring ESS into the mainstream:

1. **Pilots**: Pilots of different grid-scale ESS technologies in India to understand operating parameters in Indian conditions (temperature impact on battery operation is very significant)

2. **Services and benefits to stakeholder**: The services that can be provided to different stakeholders (generation, transmission, DISCOMs, consumers, off-grid, etc.) in the Indian context need to be assessed and incentivized
3. **Enabling regulatory framework**: Assessing how existing regulations like DSM, Time of Day (TOD) tariffs, ancillary services, etc., will impact ESS development
4. **Cost curve of ESS solutions**: It is important to understand the cost curves (supply side) of the different ESS technologies today in Indian conditions
5. **Stacking of services**: Creating the necessary regulatory/policy framework that enables ESS to provide multiple services (stacking) thereby reducing per unit usage cost of ESS

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BIOGRAPHICAL INFORMATION

Gurpreet Chugh is currently Consulting Director, Energy at ICF Consulting. He has close to 15 years of experience in the global Energy sector with a mix of consulting, M&A, business development and operations. He has structured private M&A deals in West Africa, Russia, Indonesia and India. In his professional career as a consultant, he has worked on consulting engagements for International energy majors and provided advisory services on issues across the gas value chain. He has worked in India, UK, Russia and West Africa. Gurpreet is a Chartered Financial Analyst (CFA®), has received an MBA in finance from Management Development Institute, Gurgaon and has a Bachelor's degree in Engineering from NSIT (formerly DIT), University of Delhi.

Mr. Sagun Tripathi is currently working as a Senior Associate in the Energy Practice of ICF's New Delhi office. Sagun has a cumulative experience of about 5 years in industry and academia. At ICF, Sagun has been involved in a wide variety of projects covering areas of data analytics, capacity building and institutional strengthening, demand and market size estimation, regulatory/policy research and market analysis for investment decision making support, business model development, pilot project feasibility analysis and implementation support, policy advocacy amongst others. Sagun coordinated ICF's activities in the space of renewable energy grid integration as part of the Clean Energy Grid Integration Network (CEGIN), a joint initiative of NREL, Low Emission Development Strategies (LEDS) Partnership and the Clean Energy Ministerial. Sagun has also co-authored several knowledge papers and white papers on the RE sector in India highlighting the key challenges and way forward.

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