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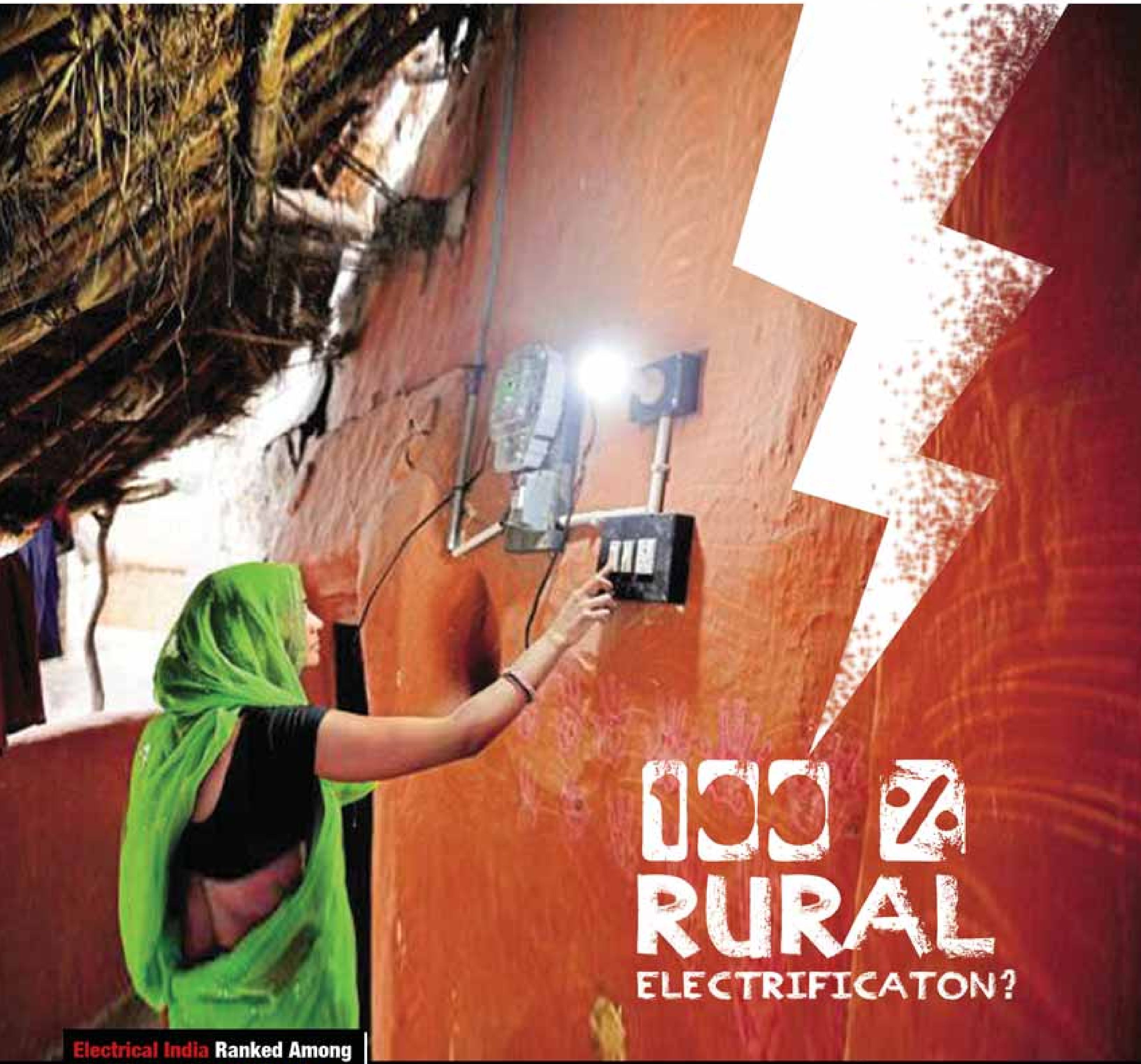

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BATTERY ENERGY STORAGE SYSTEM FOR RENEWABLE ENERGY INTEGRATION

This article presents an overview on the battery energy storage technologies and its integration with renewable energy, selection criteria and its key design considerations.

In India generation of electricity from renewable energy sources is growing at a very high rate. The total installed capacity of renewable energy in India as on December 2018 was around 21 per cent (72 GW) of total energy. Indian government has set an ambitious target of 227 GW of renewable power generation by 2022. This increase is largely due to combination of various factors such as falling price of renewable generation, deficit in the availability of fossil fuels and strict environmental norms. This increasing dependency on renewable generation in turn is posing challenges to utilities and system operators. One of the key issues with renewable generation like PV solar, wind is that their generation is of intermittent in nature. Energy Storage System (ESS) can provide support in balancing the variable generation of renewable energy. When ESS is properly deployed it can help to improve the grid reliability and asset utilisation.

ESS is classified on the basis of the form of energy stored such as Pumped storage, Batteries, Fly wheel, Compressed air, Super capacitors etc. Battery Energy

Storage System (BESS) is a type of ESS where energy is stored electrochemically. This paper discusses various application aspects of BESS that enables large scale renewable energy integration.

BESS Definition

A BESS comprises of series and parallel combination of electrochemical cells which converts electrical energy into chemical energy and utilises this stored chemical energy by converting back into electrical energy as per the application demand. Each cell consists of an anode and a cathode separated by an electrolyte which can be solid, liquid or viscous states. Other major components of battery energy storage system include:

- Power Converter/ Inverter with controller
- Battery management system (BMS)
- SCADA
- Transformer and switchgear.

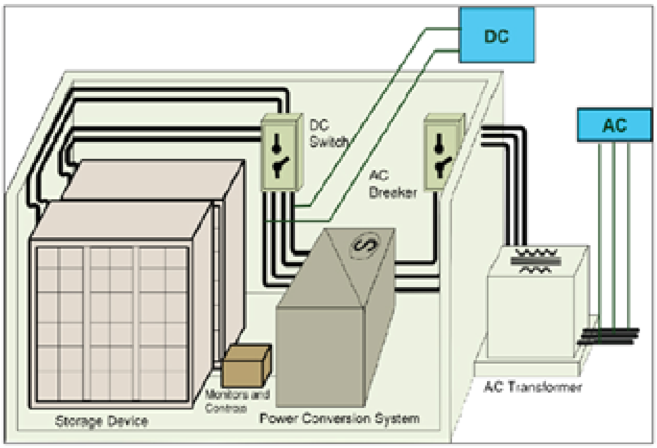

Figure 1: Schematic of Battery Energy Storage System

Battery Technologies

There are several types of battery technologies. Battery technologies which are popular are depicted in Figure 2. One significant observation can be made on the physical state of electrolyte. Electrolytes present in the secondary batteries are either in solid or viscous state. However, in flow batteries, it is in liquid state due to which it flows between anode to cathode or vice-versa during charge-discharge cycle.

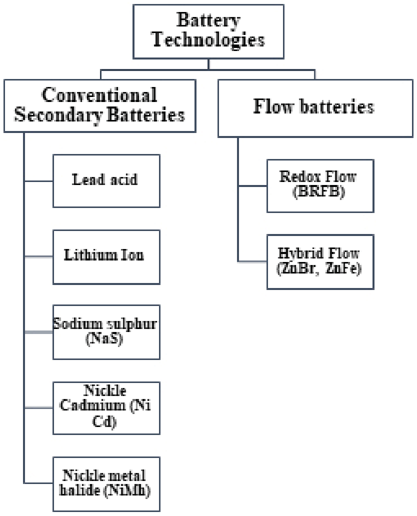

Figure 2: Classification of battery technologies

Lithium-Ion (Li-Ion) batteries have gained the popularity in the last few years due to their high energy density, high voltage, better cycle life and higher efficiency. Thus Li-Ion leads the battery energy storage market with significantly large number of demonstrated grid applications, particularly in conjunction with renewables across globe. Li-Ion includes many sub types based on the chemistries. Some common available sub types are:

- Lithium Nickel Manganese Cobalt Oxide (LiNiMnCoO2) - NMC
- Lithium Nickel Cobalt Aluminium Oxide (LiNiCoAlO2) - NCA
- Lithium Titanate (Li4Ti5O12) - LTO
- Lithium Iron Phosphate (LiFePO4) - LFP
- Lithium Manganese Oxide (LiMn2O4) - LMO
- Lithium Cobalt Oxide (LiCoO2) - LCO.

Lithium Nickel Manganese Cobalt Oxide (NMC) is the most widely used in grid-scale energy systems for its balanced performance characteristics in terms of energy, power, cycle life, and cost.

Sodium Sulphur: Sodium Sulphur (NaS) is a molten salt battery which is termed as high temperature battery as the operating temperatures of these batteries are in the range of 300-degree to 360-degree C. It has higher energy density, negligible self-discharge, easily recyclable and higher depth of discharge. However, high operating temperature and requirement of auxiliary system to maintain its operating temperature poses safety threat. Sodium Sulphur batteries have been proved in many grid and renewable applications, majority in Japan.

Flow Batteries: Flow batteries are unique in their design when compared to both Li-Ion and high temperature batteries because of the cell construction. In this battery, the electrolyte is stored in tanks external to the battery cell. During discharge and charge cycles, electrolyte is pumped from the tank into the cell stack to interact with the electrodes. Highest cycle time and calendar life, suitability for long duration, and negligible self-discharge are some of its merits. However, low energy density, low efficiency, large space requirement and complicated control system have put the technology a step backward.

Advanced Lead Acid Battery: It is a hybrid energy storage device that combines the characteristics of a super capacitor and conventional lead acid battery at the material level within the cell. Due to its low energy density, low depth of discharge and short cycle life, this technology has not gained its popularity and market share.

Nickle based batteries are not suitable for large grid-based applications.

Renewable Energy Applications

Renewable energy is intermittent in nature. They are affected by the geographical location, time duration, climatic condition, hence output power generated by these energy sources are unpredictable. This unpredictability causes fluctuation in frequency and voltage which could cause instability of grid. One of the main objectives to be addressed in renewable energy connected grid is to improve the reliability and provide stability to the grid, thus making it energy efficient. Battery energy storage helps in smoothening renewable generation output thereby improving power quality. Thus, reducing the need for grid regulation services, and making better use of network infrastructure. Renewable energy applications of BESS are ramp support, energy time shift and capacity firming.

RAMP Support: RAMP Support reduces large fluctuation in renewable energy. Its main purpose is for improving the economy of operation rather than peak demand. When there is a sudden change in wind speed or passing cloud, it causes a rapid change in the output of a PV array or wind generation leading to significant drop in MW output (by 70 to 80 per cent) in about a minute's time. Battery can discharge quickly to ensure that the net facility output is smoothened with respect to demand (see figure 3).

Figure 3: Ramp rate control

Energy Time Shift: Energy time shift involves storing energy during periods of low tariff and discharging during high tariff periods. This is customarily accomplished by storing energy during off-peak period (during night) and then using it during peak demand.

Energy time shift is predominantly best suited for wind energy as the energy from wind generation can be stored at night and during early morning. Stored energy can be discharged during high demand i.e. during weekday afternoons.

Figure 4 depicts an example for wind energy time shift for a storage capacity of 1 MW. Batteries are charged during off peak hours (0-5 hrs) i.e. when the demand is low and energy tariff is also low. Stored

Continued on page 58

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energy is discharged during peak demand hours (13-18 hrs). From the graph it is apparent that with integration of battery energy storage the generation output gets doubled during times when both demand and the tariff of electric supply are highest.

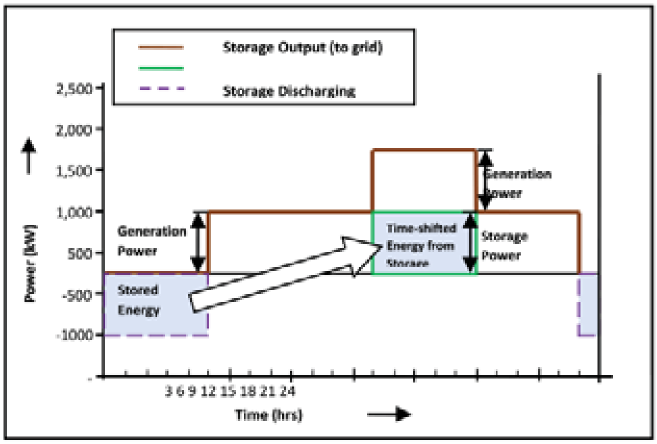

Figure 4: Renewable energy time shift

Renewable Capacity Firming: Capacity firming refers to the 'Firm' generation capacity in which constant power generation is guaranteed. This defers the need to upgrade existing generation or transmission infrastructure. Storage not only helps in fulfilling the loss of generation but also keep the output generation stable.

From the point of capacity firming, renewable energy intermittency can be of 'short-duration' or for a 'diurnal'.

Short-duration occurs randomly over time scales ranging from seconds to minutes. It is caused by location specific terrestrial obstructions such as trees and tall buildings. However, the most undeniable and uncontrollable cause of short-duration intermittency is due to clouds in case of solar generation and variations of wind speed in case of wind generation.

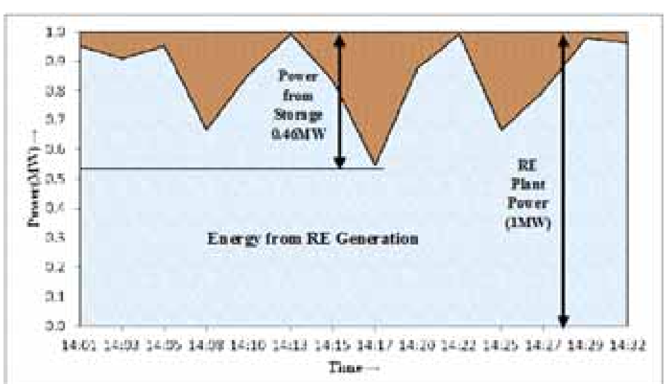

Figure 5: Renewable-fuelled generation, short-duration intermittency

Diurnal intermittency occurs in a regular or predictable way over a 24-hr period. Diurnal intermittency of solar generation depends on the solar insolation (solar radiation received on the earth surface/ sqm in a day (Watts/m2/day)) which varies throughout the day based on the position& angle of the sun, altitude, atmospheric conditions and the geographical location. In case of wind generation, wind speed tends to vary over a day, sometimes it is higher in evening while relatively lower in the morning (refer Figure 6).

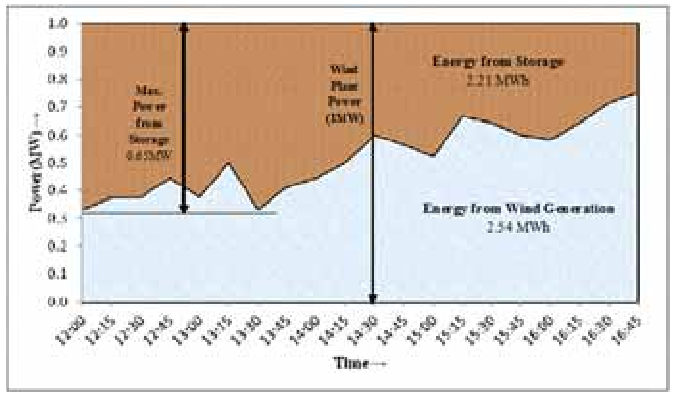

Figure 6: PV generation output variability during peak demand hours

Battery Selection

Selection of battery energy storage for the renewable energy grid application depends upon the specific application need and the way it competes the strength of different battery technology options. Hence, no single battery technology solution is the best in many cases.

The key factors which govern the selection of battery technology for a particular application are:

- Performance parameter of the battery
- Duration of the application and capability of the battery to meet the discharge duration.
- Cost economics.

Performance Parameter

The key technical performance parameters which are important in selection analysis are:

- Energy density.
- Depth of discharge (DOD) or State of Charge
- Response time.
- Round Trip Efficiency
- Life cycle.

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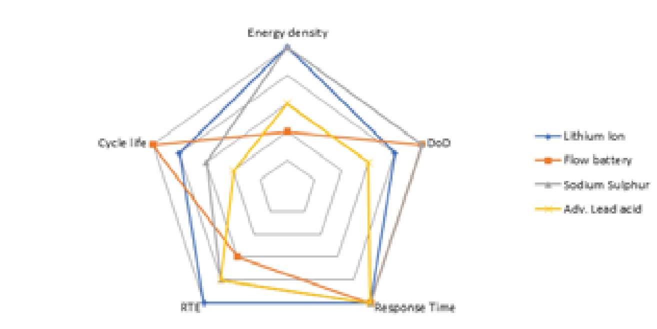


Figure 7 depicts the comparison of the performance parameters of four technologies

Discharge Duration

Discharge duration measures how long a storage device maintains its output before reaching its cut-off voltage. Discharge duration may range from few minutes to few hours. Long duration applications demand large storage capacity in order to provide prolonged discharges (which may last for one or more hours). Contrary to long duration application, short duration applications require a fast and short charge and discharge capability (generally ranging between few minutes up to 1 hour).

Design Considerations

Based on discharge duration criteria, the design considerations for various renewable energy applications are:

Ramp Support: Renewable resource variability is fast and occurs frequently and thus battery storage with ramping capability is one of the key factors. Ramping support falls under frequent short duration application. So, storage systems with response time in a minute, high power output and long-life cycle are best suited for this application. The discharge duration for this application is few minutes to 1 hour.

Energy Time Shift: Discharge duration depends mostly on the duration of the region's off-peak and on-peak periods and the on- peak versus off-peak energy tariffs. This application falls under frequent and long duration discharge application. Storage system with long discharge capability, high efficiency for economical operation, long life cycle will be best suited for this application. The discharge duration for this application is around 3 to 5 hrs.

Renewable Capacity Firming: As its primary use is to provide constant power, the storage used for capacity firming should be more dependable with long discharge capability as this falls under long duration discharge application. Discharge duration varies from 2 to 4 hrs.

Cost Considerations

The cost economics of battery energy storage plays a vital role in selection of battery technology as the cost of batteries is significantly high at present. The capital cost of energy storage system comprises of following components:

- Energy Storage Equipment
- Power Conversion Equipment
- Power Control System
- Balance of System
- Installation.

At present Li-Ion technology has high market share and competitive cost when compared with other technologies.

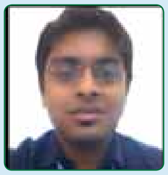
Conclusion

There is a persistent need to integrate more renewable energy sources into future grid. Renewable energy sources, when coupled with energy storage, can immensely benefit the grid by smoothing renewable generation output, improving power quality and making the renewable grid more reliable.

Some major challenges in the deployment of battery energy storage systems such as cost competitiveness of battery technology, limited engineering standards, availability of evaluation tools, and mitigation of safety risks associated with fire and explosion needs attention while planning BESS. However, with increase in demand and usage, battery prices are expected to fall. All these aspects will make battery storage more viable for wide deployment of BESS across globe. EI

D. Geethalakshmi

Deputy General Manager, Electrical
Tata Consulting Engineers Pvt Ltd, Chennai



Bhaskar Shriman

Senior Engineer, Electrical
Tata Consulting Engineers Pvt Ltd, Noida