AN ANALYSIS OF BATTERY ENERGY STORAGE SYSTEMS FOR RENEWABLE ENERGY

Pathik Kapadiya, Miloni Parikh

ABSTRACT: The world energy is dependent on conventional sources of energy for the base load[1] despite the increasing popularity and implementation of renewable energy sources as the latter are not steady state energy sources. Storage systems aid in maximizing utility of renewable energy sources. To accommodate the projected high penetration of intermittent nature of renewable sources like solar and wind energy in future grids, storage facilities are needed to deliver the right amount of power at right quality with lower grid rejection loss.

The below analysis focuses on the cost impact of the implementation of Battery Energy Storage Systems (BESS).

I. INTRODUCTION

Grid energy storage is a collection of methods used to energy storage on a large scale within an electrical power grid. Traditionally, energy storage in the power sector has been dominated by a technology called pumped hydropower storage[2] and it is being changed in recent years. However 21st century has been dominated by renewables. Consequently, with modern renewable energy generation technologies and changing consumption pattern, storage has drawn a huge attention. Any technology can only survive and grow if it is cost effective and provides more value than it expends.

Energy Storage systems and specifically Battery Energy Storage Systems have been studied for many different reasons. Regardless of the application, a typical BESS includes an interconnection with the grid, a power conversion system and battery cells. The power conversion systems, converts electricity bi-directionally, i.e. from the power source to the batteries (AC to DC) and from the batteries to the load (DC[3] to AC[4]) with high efficiency up to 95%. Moreover, a power conversion system can support the system by controlling, besides the real power, its reactive power[5] too.

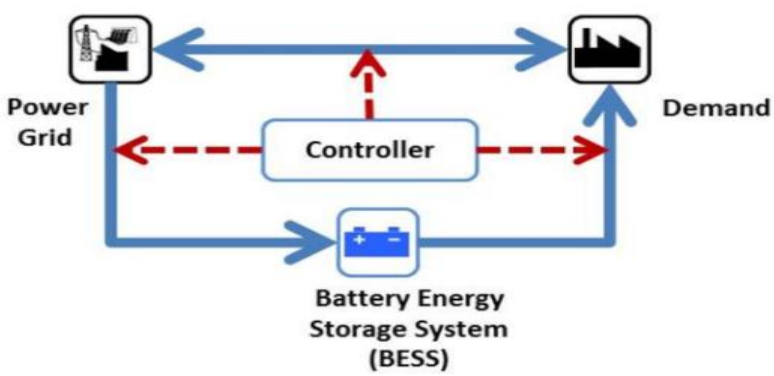


Figure 1: BESS representation

[1] Base Load: *The baseload (also base load) on a grid is the minimum level of demand on an electrical grid over a span of time.*

[2] Pumped hydropower storage: *a method of using power at a period of low demand to pump water back up to a high storage reservoir so that it can be released to generate electricity at a period of peak demand.*

[3] DC: *Direct Current*

[4] AC: *Alternating Current*

[5] Reactive Power: *Reactive Power is when the Current flow, caused by AC Voltage applied across a device, results in the Current flow being either ahead or behind the applied AC Voltage.*

II. GRID CONNECTED BESS

A Grid Connected BESS compensates the intermittent nature of generation, reduces output variability and improves quality of power to be injected from Renewable Energy plants to the transmission grid.

It reduces curtailment of Renewable Energy power due to transmission constraints. In simple words, electricity can be stored in battery whenever excess generation (e.g. during midday hours in case of solar plant) and stored electricity can be injected into the grid when demand is higher (during night times).

From the figure 1, the grid connected BESS market trend can be understood. In 2014, the major share (60%) of installed BESS capacity is Li-Ion batteries. The global installed capacity of BESS is expected to increase upto 2600 MW[6] by 2020.

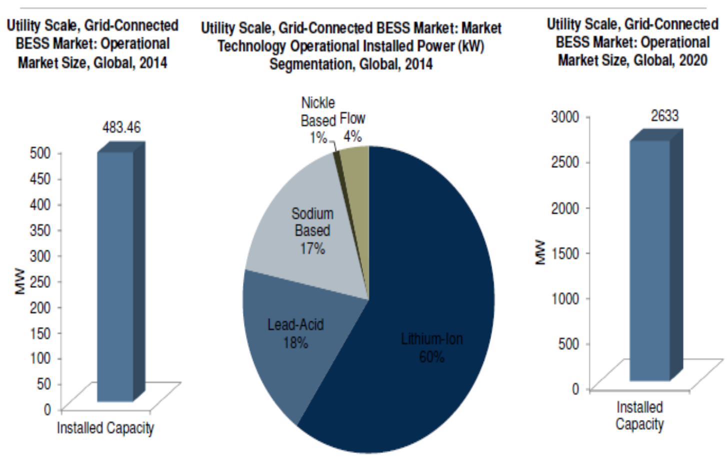


Figure 2: Utility scale BESS market trends

III. GLOBAL SCENARIO:

Large scale grid connected BESS facilities along with Renewable Energy projects are already operational in various countries like Japan, Germany & USA. Some of such pioneer projects are listed below.

Country	Project Name	COD	BESS Capacity	Installer
USA	Laurel Mountain Wind Project	Oct., 2011	32 MW	AES
California, USA	SD&G	Feb,2017	30MW 120MWh	AES
Kogoshima, Japan	Kogoshima PV Integration	April,2016	500Kw 1.2 MWh	NEC Energy Solutions
Denmark	Ringkobing Wind	Oct, 2010	400kw	NEC Energy Solutions
Hawaii, USA	Auwahi Wind Project	Dec,2012	11MW 4.3MWh	NEC

(Source: Deployment Disclosures of NEC & AES)

Table 1: World Scenario - Grid connected BESS for Renewable Energy projects

[6] MW: *MegaWatt*

Figure 3: Actual Site Images of BESS Japan & USA

IV. INDIAN SCENARIO:

Currently in India, the Renewable Energy rich states use coal based thermal power plants to counter balance the variability of the renewable generation(wind & solar). However, with increasing share of Renewable Energy in grid, regulating generation output of coal based TPP, to address the variability of renewable generation is not recommended based on number of considerations including economical & performance factors.

CERC had published a discussion paper on "Electricity Storage Services" in January, 2017. Also, the tender for India's first such storage project is out for Kadappah Solar park in Tamil Nadu. The Project specifications disclosed in the RfS[7] document for 100 MW Grid Connected Solar PV Projects Along with BESS in Kadapa Solar Park are as follows:

Objective: To improve the quality of power injected into the grid by Solar PV plants
PV Installation Capacity: 50MW
Battery Storage Capacity: 5MW, 2.5MWh
Discharging response: Provide energy for up to 30 min at the rated power of BESS
Cycle life of battery: Minimum cycle life of 5000 cycles at 80% Depth of Discharge @ 250 C.
Battery End of life: as 80% of its initial Energy capacity rating
Ramp rate: Smooth injection of power by positive and negative ramp rate of up to 5MW per minute.
Battery Charging from grid: Charging from the grid is allowed as a part of auxiliary power.

V. BEHIND THE METER (ROOFTOP) BESS

BESS can also be installed along with rooftop solar and micro-grid Renewable Energy plants. Thus, the commercial cost of Renewable Energy generators can be reduced by Storing electricity at off-pick time and using it during peak time to reduce the peak demand.

To identify the battery requirement for rooftop solar, we need to know the power and energy requirement of the building.

Following table indicates per day usage of electricity and connected load to the meter for an average 2BHK house of 4 members.

[7] Rfs: *Request for proposal*

Appliances	Nos.	Power Rating(watt)	Total connected load(watt)	Operating Time (hours)	watt-hour	Kwh[8] (unit)
Lights	6	40	240	10	2400	2.4
Fan	4	85	340	8	2720	2.72
AC	2	1600	3200	6	19200	19.2
Microwave	1	1000	1000	1	1000	1
Fridge	1	200	200	24	4800	4.8
Washing Machine	1	500	500	1	500	0.5
Others	1	400	400	2	800	0.8
Total			**5880**			**31.42**

Table 2: Example - daily energy requirement of a household

Daily power requirement is around 30KWh (units) and power requirement do not exceed than 6000 watt.

We can assume that out of 30 units, around 20 units are consumed during non-sunny hours i.e. between 6:00PM to 9:00AM next day. So, to meet the full demand only via solar power, we need a battery which is able supply power upto 6 kW at a time and also capable of meeting the energy need of 20 kWh in 15 odd hours.

Battery Selection:

- Power Rating: 6KW
- Energy Rating: 20KWh
- Voltage Level: 48V (Advisable as our power requirement is higher)

VI. TECHNOLOGY AND COST ANALYSIS

Battery Technology

Battery Energy Storage System (BESS) contains several primary components like battery, monitoring and control systems, and a power conversion system. In recent times, several types of batteries are available including Lead-Acid battery, Li-Ion battery, Flow battery, Sulfur battery etc.

Basically battery is a chemical device which converts electrical energy into chemical energy while charging and converts it again into electrical energy while discharging.

Since batteries are composed of chemicals, their performance, cost and life time are affected by the manner and conditions under which they are used.

[8] Kwh: *Kilowatt/hour*

Following table contains major battery technologies suitable for Renewable Energy storage:

	Lead Acid	*Advance Lead Acid*	*Li-Ion*	*Flow Batteries*	*Sodium Sulphur*
Efficiency (%)	80-85 %	90 – 94%	85- 95%	60 – 70%	70 – 90%
Power Storage Capacity (MW)	<=50	<=50	<100	<100	5 - 100
Storage Duration	2 – 4h	1 min to 8h	Upto 8h	Upto 6h	Upto 8h
Charging-discharging cycles	1000 – 5000	4500 – 10000	1000 – 10000+	>10,000	2,500 – 4,500
Life (Years)	3-15	5-15	10-20	20	5 – 15
Commercial Status	Mature	New in market	Mature		New in market
Major companies	Hitachi, Exide, Enersys	ACME, Exide	Samsung, LG, Panasonic, TESLA, ACME	VRB, ZBB, Plurion, RedFlow	NGK, GE

Table 3: Comparative Analysis of globally available battery technologies for RE

VII. COST TRENDS

The historical and future trends of cell level cost of various technologies is presented in the graphs here.

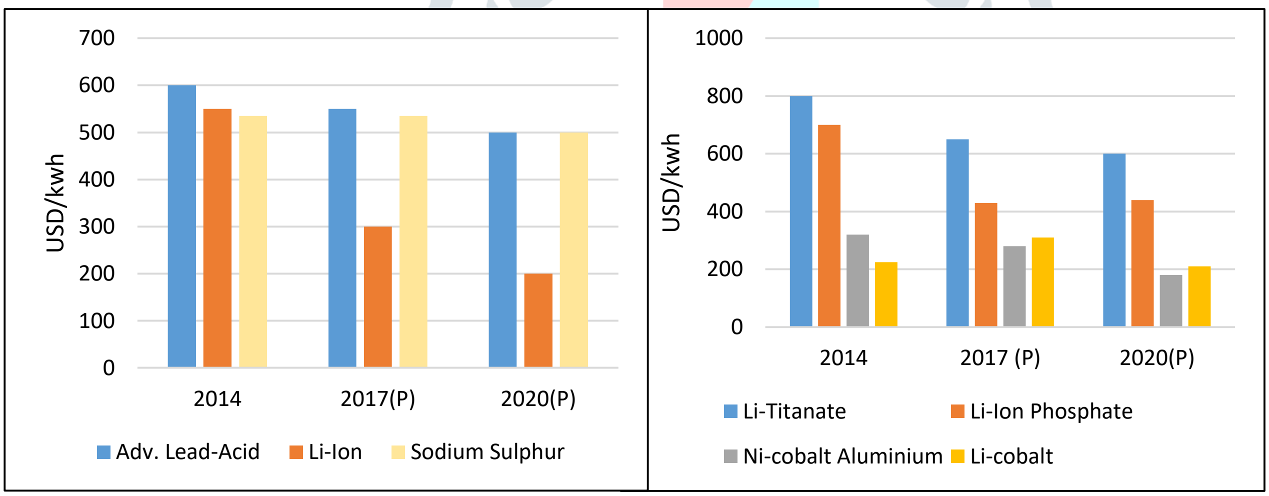


Figure 3: Cell level cost comparison of battery technologies (IRENA 2015)

The prices are representative ones. However, the battery modules and containers, power components, thermal management systems and other components add to the overall cost. The total is also dependent on the size and complexity of a project. The accurate costs are hard to collate due to the current lack of defined standards and approaches by which companies provide cost and performance data. So, multiple assumptions must be made to calculate cost like temperature, Depth of Discharge, cycle life etc.

There are number of ways to calculate the project cost of any battery storage facility like cost per KWh (energy), cost per KW (power), Levelized Cost of Storage (LCOS). More frequently used methods are cost per KWh and LCOS.

Cost per KWh (per unit cost):

The following table indicates the data for three 5MW batteries having different technical specifications. Each can be seen as individual case and the prices can be compared depending upon the specifications. This is very simplified aspect to address the cost of a battery.

	Battery Technology	Lead Acid	Li-Ion	Li-Ion
1	Power Capacity (kW)	5	5	5
2	Energy Capacity (KWh)	14.4	8	10
3	Usable Energy Capacity(KWh)	7.2	6.4	10
4	Cycle Life (Nos.)	2800	3000	5000
5	Price (USD)*	4500	5000	8000
6	USD/KW (5÷1)	900	1000	1600
7	USD/KWh (5÷2)	**310**	**625**	**800**
8	USD/usable KWh (5÷3)	625	780	800
9	USD/usable KWh/Cycle (8÷4)	**0.22**	**0.26**	**0.16**

(Source: IRENA, Various articles on battery cost, www.alibaba.com)

Table 4: Cost Calculation (Per Unit Cost)

VIII. LEVELIZED COST OF STORAGE (LCOS):

The cost of any storage technology is equally dependent on its initial material & installation cost and how it is being used & maintained during its service life. LCOS can be used to represent the complete cost of a storage system as it is determined by adding all relevant initial, variable and end-of-life costs for an installation. This is then divided by the life time output of electricity and measured in kWh or MWh. The time value of money with an appropriate discount rate over the life is also considered here.

"Thus, LCOS is a method to benchmark the actual costs of energy storage taking into account all known costs and limitations of the asset from its COD to its termination of service."

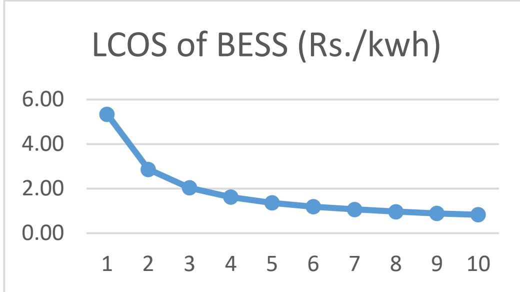
The calculation of LCOS can be explained by the following hypothetical example.

Assumptions:

Battery Type: Li-Ion
Initial cost: 600 USD/KWh.
Operating Life: 10 years (irrespective of its cycle life)
O&M cost: 50 USD/year
Discounting Factor (DF): 13%

		Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
1	**Initial cost ($/kwh)**	$600										
2	**O&M ($/kwh)**		50	50	50	50	50	50	50	50	50	50
3	**Total cost realization**	$600	$644	$683	$718	$749	$776	$800	$821	$840	$857	$871
5	**Capacity**	100%	100%	98%	96%	94%	92%	90%	88%	86%	84%	82%
6	**Efficiency**	88%	88.00%	87.90%	86%	85.40%	84.65%	84%	83.15%	82.40%	82%	80.90%
7	**Lifetime Utilization factor**		0.880	1.741	2.567	3.370	4.149	4.904	5.635	6.344	7.030	7.693
9	**LCOS ($\kwh\year)**		$732.10	$392.44	$279.72	$222.19	$187.02	$163.12	$145.71	$132.40	$121.85	$113.26
10	**LCOS ($\kwh)**		0.08	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01
11	**LCOS (Rs.\kwh)**		5.35	2.87	2.04	1.62	1.37	1.19	1.06	0.97	0.89	0.83

Table 5: Cost Calculation (LCOS)



Notes:

1. Initial cost consists material & installation cost.
2. O&M cost consists maintenance, warranty, monitoring, management cost etc.
3. Total cost realization is calculated at 13% discounting factor and it represents the NPV of future cost.
4. Capacity is degraded every year. General industrial practice is to terminate battery usage at 80% storage capacity.
5. Efficiency indicates how efficient the battery is working in %.
6. Lifetime Utilization factor (LUF) indicates the accumulated usable energy storage each year.

LUF (year n) = LUF (year n – 1) + capacity% (year n) x efficiency% (year n) x 1 (yr)

7. LCOS is calculated as dividing the "total cost realization" by "LUF". LCOS is the cost of owning and operating BESS per usable energy storage per year.
8. In the 9th row, LCOS per usable storage per year is calculated in USD for 10 years of battery life. We can convert it into INR as shown in 10th row (Taking 1 USD = 70 INR)

IX. CONCLUSION

- Based on the global scenario it is observed that major Energy Storage Projects across the world are installed as pilot projects and not observed as commercially viable due to non-competitiveness of the cost of storage facility in terms of LCOS.
- As on date, the electricity from renewable energy costs around 3-3.5 Rs/kwh. On the other hand, the BESS adds up to Rs. 5-5.50 Rs/Kwh (above analysis) resulting effective electricity cost of Rs. 8-9 Rs/Kwh.
- The case study of Kadapa Rfs for competitive BESS in Indian Market, referred in this analysis, was unable to attract the players for the reverse bidding. Few of the reasons for the same are as below:
  - Higher cost of storage facility makes it commercially unviable as analyzed above. This results into higher effective LCOE
  - Lack of established track record for large scale (MW scale) BESS
- Though India is aggressively leading on Renewable Energy Installation front, It is lacking on innovative solutions for make the Renewable Installations and sustainable for a longer run. It has not yet seen any successful grid integration of BESS for RE projects

REFERENCES

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ii. Energy Storage World Markets Report – 2014-2020