ISGF
India Smart Grid Forum

ISGF White Paper

DIESEL GENERATOR REPLACEMENT WITH LITHIUM-ION BATTERIES IN LARGE BUILDINGS AND CAMPUSES

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Diesel Generator Replacement with Lithium-ion Batteries in Large Buildings and Campuses

Abstract

Delivering reliable 24x7 services is the primary objective of every large building for which uninterrupted power supply is essential. Diesel generating (DG) sets are commonly used for power backup for all critical infrastructure. Owing to increasing pollution levels, most cities are banning the use of DG sets. This paper examines the business models for the replacement of a DG sets with lithium-ion battery energy storage systems in large buildings and campuses.

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About India Smart Grid Forum (ISGF)

ISGF is a public private partnership initiative of the Government of India with the mandate to assist government, utilities and regulators on electric grid modernization and electric mobility. ISGF was set up in 2011 by Ministry of Power, Government of India to provide a mechanism through which academia, industry, utilities and other stakeholders could participate in the development of Indian smart grid systems and provide relevant inputs to the government programs and policies.

Table of Contents

List of Figures

List of Tables

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EXECUTIVE SUMMARY

Cities are concentrations of economic, social, and technical assets, which are fundamental to addressing the climate challenges. With the unplanned growth of urban areas in most developing countries, electric utilities often struggle to provide reliable and uninterrupted power supply to all their customers. This situation necessitates provision of large size diesel generating (DG) sets for power backup in commercial buildings, government and private office buildings, industrial areas, IT parks, shopping malls, hotels, hospitals, educational campuses and residential complexes. In most cases, the DG sets automatically start once grid power is unavailable. Mega-watt (MW) scale DG sets are deployed in large buildings in India. By some estimates there are over 70,000 MW of large DG sets in India. DG sets emit heat, particulate matters, carbon dioxide, carbon monoxide, nitrogen oxides and hydrocarbons besides causing the noise pollution.

In 2018, the National Green Tribunal (NGT) banned the usage of DG sets between October and March in the National Capital Region (NCR) in India. Many other Indian cities where the pollution levels are dangerously high are also likely to ban the usage of DG sets soon. Commercial buildings, hotels, hospitals, data centres etc., cannot afford to run without power for more than few seconds, hence the replacementhas to be highly efficient, cost-effective, pollution-free, and instantaneous sources of backup power. Thereare many alternatives to DG sets such as gas turbines and hydrogen fuel cells but due to technological maturity, reliability, safety, and efficiency the best option presently is lithium-ion batteries (LiB) as described in this paper.

A battery backup system can be charged either from the grid or from solar rooftop photovoltaic (RTPV) systems. While a typical DG set operates during the power outgaes which is few hours in a month, the battery energy storage system (BESS) connected to the grid can support the grid 24x7 by providing frequency and voltage support and can be a great resource for renewable energy (RE) and electric vehicle (EV) integration with the electricity distribution grid.

In this study, ISGF has surveyed few large hotels in different cities and analyzed the data regarding the DG set usage and diesel consumption. The cost-benefit analysis indicates that ***the cost of generation of power with a DG set is presently INR 29.07 per kWh whereas it is INR 15.17 with LiB.*** On comparative analysis the LiB not only save costs but also eliminate emission of carbon and other pollutants.

The paper also describe three business models through which BESS can replace DG sets: (i) owned by the electric utilities, (ii) owned by the building and leased to the electric utility for grid support; and (iii) ownedby third parties or Independent Power Producers (IPP).

According to latest IEA projections, Indian power system is set to grow from the present capacity of 395 GW to 823 GW by 2030 and 1584 GW by 2040. Out of 1584 GW, 869 GW is expected to be renewable energy (RE) resources. Considering the larger share of RE in the generation portfolio, IEA estimates ±85% flexibility for the Indian power system by 2040 which will be a huge challenge to manage. Therefore, building flexibility in the power system assumes top priority and BESS is one of the most reliable resource to increase the flexibility of the grid. During periods of surplus generation, electricity can be stored in the batteries and discharge the batteries during peak-hours. Replacement of DG sets distributed across the country with BESS is the fastest and cheapest route to build flexibility for the Indian grid. The reduction in emissions from DG sets will help meet the NDC targets as well.

1 INTRODUCTION

1.1 Backup Power Supply Options in Large Buildings and Campuses

1.1.1 Diesel Generator (DG) Sets

Commercial buildings and hotels are large consumers of electricity and fossil fuel-based energy systems to provide high-quality services to their customers. For providing uninterrupted power supply, DG sets are widely adopted as the power backup solution in most of the commercial buildings and campuses. A DG set is the combination of a diesel engine with an electric generator to produce electricity. The diesel consumption is directly proportional to the size of the DG and the number of hours it operates.

Each building decides the size/capacity and number of DG sets according to the critical loads to be served during power outages and the duration of average power outages in the area. The DG sets are used as a backup at the time of power outages; and some buildings have now adopted solar PV integrated with DG sets in their premises.

1.1.2 Uninterrupted Power Supply Systems

The traditional uninterrupted power supply (UPS) systems comprise of lead-acid batteries and inverters. The electricity from the grid is stored in the batteries and supplied to the equipment/appliances during interruption of regular power due to load shedding, power failure, power fluctuations, etc. The UPS provides reliable and stable power to the equipment/systems sensitive to power variations and interruptions from the batteries. It functions as a voltage stabilizer and also isolates the sensitive equipment from the grid. UPS are available in the range of 250 Watt to 5 MW. UPS provides emergency lighting and power to critical loads such as lifts, communication equipment, intercoms, computers etc. In most buildings, more than 50% of the electricity demand is for air conditioning which is not usually serviced by UPS.

1.1.3 Gas Turbines

A gas turbine connected with turbo generator can start quickly and supply electricity. Figure - 1 depicts how a gas turbine provides backup to a buildings in case of power outages.

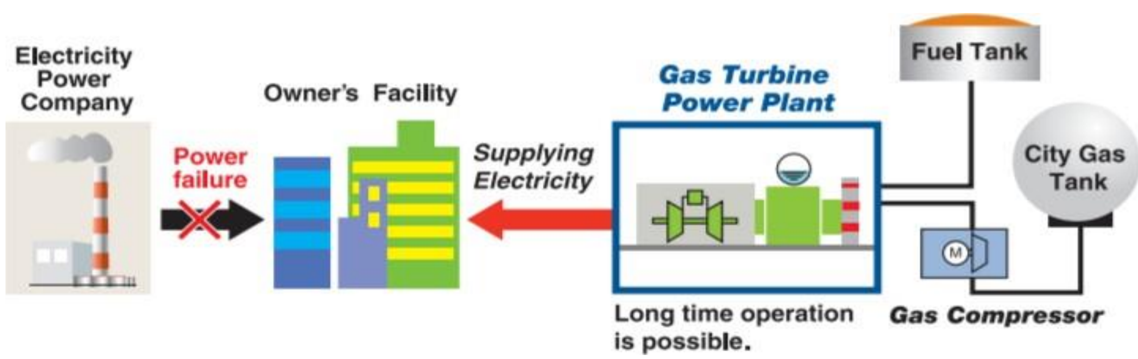

Figure 1: Gas Turbine Model

1.2 Issues with DG Sets

1.2.1 Pollution

DG sets burn diesel and emit carbon dioxide, carbon monoxide, nitrogen oxides (NOx), and particulate matter (PM 2.5 and PM 10)) besides causing noise pollution. DG sets release harmful particles into the atmosphere and substantially reduce air quality in the neighborhood. Every litre of fuel burned in a DG set crates 0.73 kg of pure carbon and 2.6 kg of carbon dioxide. Imagine a DG set of 500 kVA capacity which requires approximately 100 litres of diesel per hour and if it is run for 5 hours each day for a month, the amount of carbon dioxide released would be 39,000 kg.

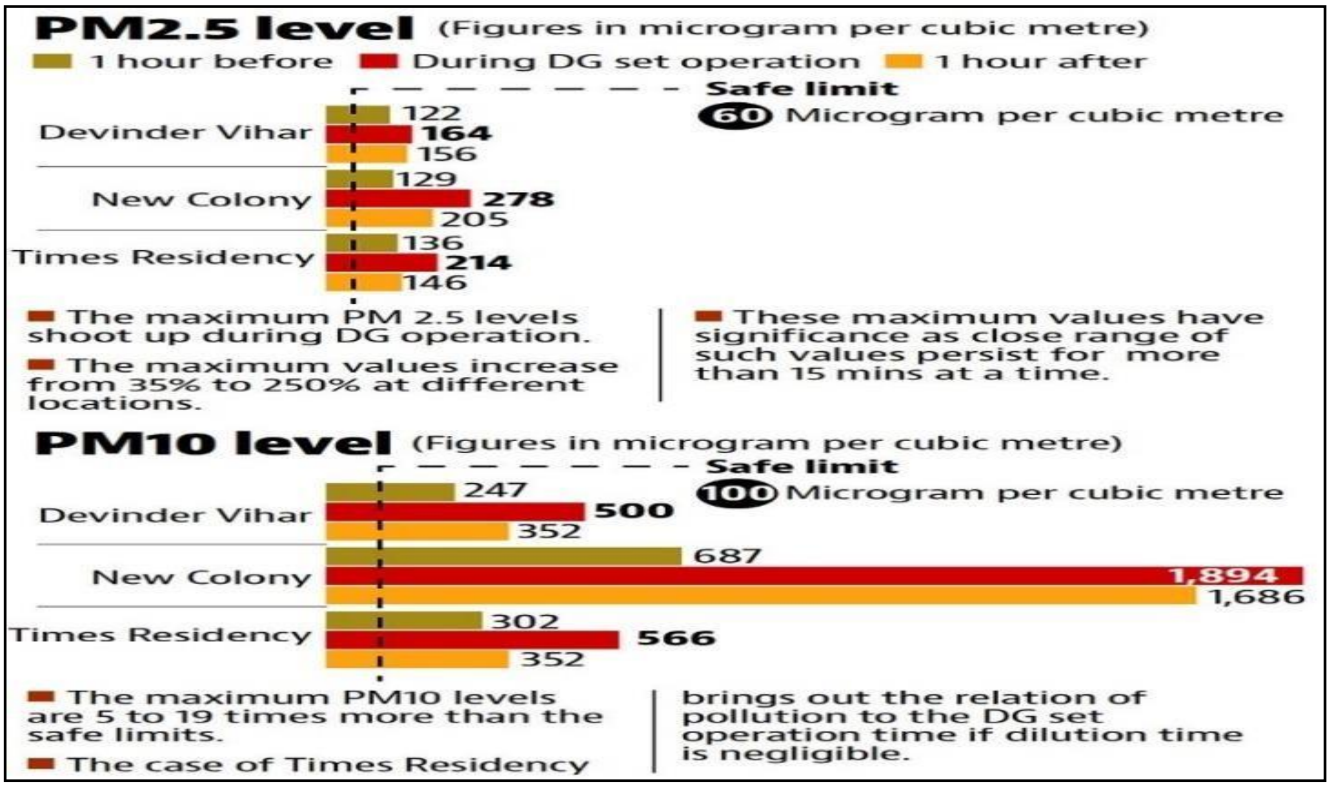

Figure 2: Pollution Levels in Some Localities of Delhi-NCR

1.2.2 Licenses and Statutory Compliances

The Central Pollution Control Board (CPCB) has issued certain emission and noise limits for DG set operations:

- The maximum permissible sound pressure level for new DG sets with a rated capacity up to 1000 kVA, manufactured on or after the 1st January 2005 shall be 75 dB(A) at 1 meter from the enclosure surface
- The DG sets should be provided with an integral acoustic enclosure at the manufacturing stage itself
- The implementation of noise limit for these diesel generator sets shall be regulated

- Emission limits for new DG sets (upto 800 kW) should follows the limits as per Table - 1

Table 1: Emission Limits for DG Sets

Power Category	Emission Limits			Smoke Limit (Light absorption coefficient)
	NOx + HC	CO	PM	
Up to 19KW	≤7.5	≤3.5	≤0.3	≤0.71 2
19KW to 75 KW	≤4.7	≤3.5	≤0.3	≤0.7
75KW to 800 KW	≤4.0	≤3.5	≤0.2	≤0.7

1.2.3 National Green Tribunal Guidelines for DG Sets

Installation of DG Sets

- DG sets must be installed with a stand-alone foundation with proper anti-vibration packing/pad, etc.
- The smoke of a DG set should be channelized/evacuated properly to avoid any nuisance in the neighborhood
- DG set should be installed in the basement, rooftop, ground floor, front/back offset of the premises/building appropriately to avoid any nuisance in the neighborhood
- The developer for new market/malls, high rise building, or a gated green field colony shall necessarily install a standby power back-up; and installation of the DG set by individuals should be prohibited. Developer shall install a system to harvest solar or wind energy, as a source of electricity apart from solar geysers

Phasing out old DG sets

Phasing out of old DG sets should be enforced by concerned SPCB/PCC, area SDM, and police as per the following schedule:

- Any DG set having engines not engraved with the manufacturer's name and date of manufacturing is not to be allowed to operate on or after 01.06.2015
- Any DG set without certified acoustic enclosure as per GSR 371(E), dated 17th May 2002 should not to be allowed to operate on or after 01.06.2015
- DG sets must be scrapped and dismantled after its useful life of 15 years from the date of manufacturing or 50,000 hours of operation, whichever earlier

[1] http://cpcb.nic.in/generator-set/

2 OPTIONS FOR REPLACEMENT OF DG SETS

2.1 Gas Turbines

The advantages of using a gas turbine instead of a DG set are:

- It enables the choice of diesel and gas as the fuel. This dual-fuel capability ensures reliable power supply and long-term operation compared with the simple DG sets
- Comparatively cleaner exhaust with gas as fuel
- Gas turbines have better efficiency - up to 40% whereas DG sets operate typically at 30% thermal efficiency

Despite these advantages, it is not feasible to use a gas turbine as a replacement for a DG set in most places due to the following limitations:

- **Fuel handling:** Storing gas is difficult and expensive than storing diesel
- **Start-up time:** DG set starts faster and get online within minutes, whereas a gas turbine needs to be purged, gas supply established and then started
- **Reliability/Availability of the machine:** Gas turbines have 95-98% availability with multiple peripheral systems which need monitoring from the safety perspectives. The diesel engines can have as high as 99-100% availability and it doesn't need continuous monitoring

2.2 Fuel Cells

A fuel cell is a device that converts the chemical energy from hydrogen into electricity through chemical reaction with oxygen or an oxidizing agent. A fuel cell will produce electricity as long as it has fuel (hydrogen) and air. Fuel cells offer longer continuous runtime and greater durability in harsh outdoor environments under a wide range of temperature conditions. With fewer moving parts, they require less maintenance than both DG sets and gas turbines. They can also be monitored remotely and have less maintenance time. Compared to DG sets, fuel cells are quieter and have no emissions.

Few concerns limits the viability of replacing DG sets with fuel cells in buildings:

- Hydrogen is colorless, odorless, tasteless, and non-toxic; but highly inflammable. Therefore, it is necessary to utilize gas detection systems while handling hydrogen gas which adds to the operational cost and complexity
- Hydrogen must be delivered to a fuel cell site if not produced on-site. Most buildings like hotels, hospitals and office complexes cannot produce hydrogen. Transportation of hydrogen is risky andcostly

2.3 Battery Energy Storage System (BESS)

Rechargeable batteries have been traditionally used for backup power supply. However, owing to high cost and limitations in the performance characteristics of different types of batteries, its usage was limited to certain application in few domains. Lead-acid batteries are in use for over a century for variety of applications and it is a matured industry globally. Through lithium-ion battery was invented in 1980s, its initial usage was limited to electronic gadgets only. Commercial application of lithium batteries for electric

Vehicles and energy storage applications have taken-off only after 2010; and during the past ten years theprice of lithium-ion batteries have fallen by 90%. Table - 2 below gives a comparison between lead-acid batteries and lithium-ion batteries.

Table 2: Comparison between Lead Acid Batteries and Lithium-ion Batteries

Type of Battery	Image	Description	Specifications
Lead –Acid Batteries (LAB)		• Lead-acid batteries are a low-cost reliable power workhorse used in heavy-duty applications for over a century • They are usually large and heavy; and have low cycle life • Have better thermal stability and capable of working continuously between -20 and +60 Deg C • Used for applications such as vehicle ignition, inverters, emergency lights, backup power for data centre etc.	• **Specific energy:** 35-40 Wh/kg • **Energy density:** 80-90 Wh/L • **Specific power:** 180 W/kg • **Charge/discharge percentage:** 50-95% • **Cycle durability:** <350 cycles; certain industrial designs can go up to 1600 cycles • **Nominal cell voltage:** 2.1V • **Recharge rate:** 0.15 C to 0.25 C[2]
Lithium-ion Batteries (LiB)		• Lithium-ion batteries are rechargeable; lithium ions from the negative electrode migrate to the positive electrode during discharge and migrate back to the negative electrode when the battery is being charged • Lithium-ion batteries generally possess high energy density, little or no memory effect, and low self-discharge compared to other battery types	• **Specific energy:** 100-265Wh/kg • **Energy density:** 250-693 Wh/L • **Specific power:** 250-340 W/kg • **Charge/discharge percentage:** 80-90% • **Cycle durability:** 2000 to 4000 cycles • **Nominal cell voltage** (NCM)**:** 3.6/3.85V • **Recharge rate:** 0.3 C to 10 C

As can be seen from the table above, lithium-ion battery (LiB) is the viable option for replacing the DG sets. Different LiB chemistries that can be considered are presented in Table-3.

[2] C-rate is used to indicate the speed at which a battery can be charged and discharged. If a battery can be fully charged in one-hour, it is a 1C battery. If it can be charged in 20 minutes, it is a 2C battery; and if it takes 2 hours to fully charge, then it is a 0.5C battery.

Table 3: Types of Lithium-Ion Batteries

LiB Types	LCO	NCA	NCM	LM	LFP	LTO	Si/C
Cathode	**Lithium Cobalt Oxide**	**Lithium Nickel Cobalt Aluminum Oxide**	**Lithium Nickel Cobalt Manganese Oxide**	**Lithium Manganese Spinel**	**Lithium Iron Phosphate**	**Lithium Titanate Oxide**	**Silicon Carbon Composite**
Cell Voltage	4.2V	4V	4.2V	4.2V	3.6V	2.8V	4.2V
Energy	++	+++	+++	+	++	-	+++
Power	++	+++	++	+++	++	+	++
Calendar Life	+	+++	+	-	++	-	-
Cycle Life	+	++	++	++	++	+++	--
Safety	+	+	+	++	+++	+++	+
Cost	-	+	++	++	+	++++	++

Lithium-ion Iron Phosphate (LFP) batteries are best suited for replacing DG sets due to the following reasons:

- Lowest in cost – costly metals such as nickel and cobalt are not used in LFP batteries
- Better thermal properties – does not need active cooling in most parts of India
- Reasonably good cycle life and charging – discharging efficiencies

3 DETAILED ANALYSIS OF DG SET USAGE SCENARIO IN COMMERCIAL BUILDINGS IN INDIA

3.1 Usage Profile

A report in 2018 by public policy consultancy Chase-India estimated the installed capacity of DG sets at 2042 MW in NCR cities – Gurugram (1623 MW), Faridabad (74 MW), Noida (294 MW), Ghaziabad (51 MW). All of the new sectors in Gurugram (58 to 115) runs on DG sets since the power lines have not been built into the societies as of 2018. Less than 15% of the demand for DG sets is for prime power and 85-90% of the DG market is for backup power owing to unreliable power supply from the grid.

ISGF conducted a survey amongst few select hotels in different cities to understand the DG set usage in hotels across the country which is presented in Table-4.

Table 4: Survey Result on DG Set Usage

Hotel Survey	Connected Load (kW)	Contract Demand (kVA)	Hours of DG set Operation in the Year		Highest Usage Month (Hours of DG set Operation)	
			2017-18	2018-19	2017-18	2018-19
Hotel A Gurgaon	1200	660	901	506.9	July (212)	July (172)
Hotel B Pune	520	550	394	441	August (58)	October (55)
Hotel C Ahmedabad	115	200	NA	0.4	NA	March (10 min)
Hotel D Nashik	199	209	29.7	179.2	November (11.5)	June (24.1)
Hotel E Coimbatore	660	650	37.85	265.4	October (13.5)	June (24.1)
Hotel F Chennai OMR	336	400	211	136.2	September (70.2)	May (29.3)

3.2 Diesel Consumption

The survey captured the monthly fuel consumption pattern during FY 2018 and FY 2019.

Table 5: Survey Result on Diesel Consumption

Hotel Survey	Connected Load (kW)	Contract Demand (kVA)	Hours of DG set Operation in the Year		Longest Power Outage (hrs.)	Average Monthly Fuel Consumption (Liters)	Average Monthly O&M Cost (INR)
			2017-18	2018-19			
Hotel A Gurgaon	1200	660	901	506.9	36	2000	20,000
Hotel B Pune	520	550	394	441	6	1300	90,000
Hotel C Ahmedabad	115	200	NA	0.4	10 min	500	NA
Hotel D Nashik	199	209	29.7	179.2	NA	80	3,333
Hotel E Coimbatore	660	650	37.85	265.4	10	2,000	1,56,500
Hotel F Chennai OMR	336	400	211	136.2	10	100	5,000

3.3 Cost of Electricity from DG Sets

A basic cost model was built considering the following assumptions:

- Two DG sets, each of 625 kVA with daily usage of 2 hours was considered
- The cost of diesel is considered at a constant rate of INR 95 per litre (present cost in 2021)
- The projections have been given for the 1st to 10th year respectively
- The total O&M cost for the two DG sets were taken at actuals as provided by the property owners
- ***The cost of power from a 625 kVA DG set is INR 29.07 per kWh*** as presented in Table-6.

Table 6: Energy and Cost Calculation for DG set (625 kVA *2) ~ 1 MW

Sl No	Description	Value
General Information		
1	DG capacity in kVA	625
2	Power Factor	0.8
3	DG capacity in kW	500
4	Load Factor (%)	80
5	DG capacity @ 80% load factor (in kW)	400
6	Average daily hours of operation	2
7	Total units generated per day (kWh)	800
A. Capital Cost - DG set		
1	Cost of DG set	₹ 39,00,000.00
B. Operation and Maintenance Costs		
1	Total cost of general Inspection-A	₹ --
2	Total cost of Inspection-B (10 nos)	₹ 8,00,000.00
3	Total cost of Inspection-C (5 nos)	₹ 7,50,000.00
4	Total cost of Inspection-D (5 nos)	₹ 16,50,000.00
5	Total Maintenance Cost	₹ 32,00,000.00
C. Installation Costs (Per DG set)		
1	Installation and other Operational Costs	₹ 15,00,000.00
2	Total Costs (A+B+C)	₹ 86,00,000.00
Unit Cost Calculation (INR/kWh)		
1	Diesel required per hour (Litre)*	110
2	Cost of Diesel per litre in INR	₹ 95.00
3	Cost of electricity per unit [3]	₹ 26.13
4	Cost of Maintenance per unit[4]	₹ 2.95
	Cost per kWh of electricity	**₹ 29.07**

**Diesel consumption for 625 kVA genset @100% load is 140 litre/hour; at 80% load it is about 110 litre (not proportional)*

[3] Cost of electricity per unit (110X95)/400 = 26.13

[4] Cost of Maintenance per unit (86,00,000/(500X0.8X2X365X10)) = 2.95

4 BATTERY ENERGY STORAGE SYSTEM FOR STAND BY POWER IN BUILDINGS

4.1 Battery Energy Storage System (BESS)

Battery Energy Storage System (BESS) is a rechargeable battery system that stores energy from the electric grid or any renewable energy sources and provides that energy back to the building when needed. The primary component of a BESS is Lithium-ion Battery (LiB). An LiB typically comprises of a cathode (positive electrode) which is a metal oxide, an anode (negative electrode) which is porous carbon, and an electrolyte.

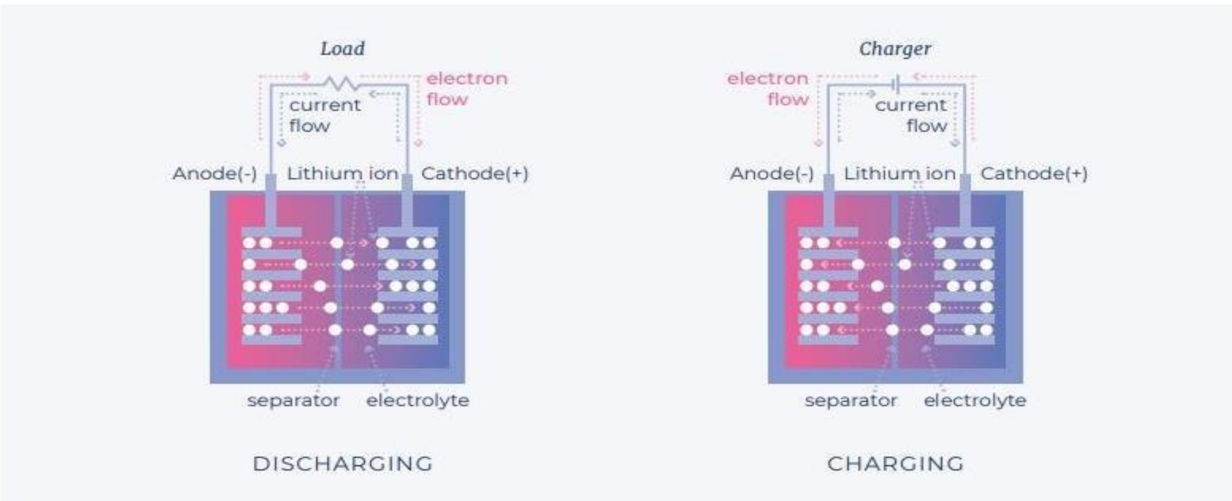

Figure 3: Lithium-Ion Battery Charging and Discharging

When the circuit is closed, the ions flow from the anode to the cathode during discharge, generating electricity. Charging reverses the direction of the ion flow.

The BESS unit contains following components:

- **Battery modules:** Multiple, swappable battery modules prevent an entire energy storage unit from going down if one battery module fails. The module can be swapped without any downtime
- **Sensors:** Sensors ensure safe operation and allow remote monitoring to help maintain operating temperature within limits, watch for battery module failure, and report usage data to the owner/operator
- **Control components:** Control components enables storage systems to perform their intended job without any user intervention. For example, batteries can be configured to charge automatically when energy is cheapest and discharge automatically when it’s most expensive
- **Inverter:** An inverter converts the AC electricity from the grid to DC for charging the battery and also converts the DC electricity from batteries to AC electricity while discharging
- **Battery management system (BMS):** It is the software that controls the charging and discharging operations based on the state of the battery and other conditions specified

4.2 Safety Issues with Lithium-ion Batteries

Lithium-ion batteries (LiB) have inherent fire risks if not managed correctly. Previously, these systems were used by agencies that had in-depth understanding of the battery characteristics and potential dangers. Today, a buyer of a BESS could be a property developer, malls or hospitals with limited understanding of the battery chemistry. Following are the risk involved with LiBs:

- **Thermal runaway:** The battery charging cycle creates heat and excessive heat is a major risk for LiBs. It can be caused by a battery having internal cell defects, mechanical failures/damage, or over voltage. It leads to high temperature and potential explosive rupture of the battery cell, resulting in fire and/or explosion.
- **Difficulty of fighting battery fires:** Battery fires are often very intense and difficult to control. They can take days or even weeks to extinguish properly, and may seem fully extinguished when they are not. They can also be very dangerous to fire fighters and other first responders because, in addition to the immediate fire and electricity risks, it involves toxic fumes and exposure to hazardous materials. Different types of batteries also react differently to fire, so firefighters must be knowledgeable about how they react and how to respond. When the fire cannot be contained, often it is left to burn itself out leading to the loss of the entire facility.
- **Failure of control systems:** Another issue can be a failure of protection and control systems. For example, a BMS failure can lead to overcharging and inability to monitor the operating environment, such as temperature or cell voltage.
- **Sensitivity of LiB to mechanical damage and electrical transients:** Contrary to lead-acid battery technology, LiBs are very sensitive to mechanical damage and electrical surges. This type of damage can result in internal battery short circuits which lead to internal battery heating, battery explosion, and fire. The loss of an individual cell can rapidly cascade to surrounding cells resulting in a larger scale fire.

Despite the above mentioned risks, LiBs are becoming very popular and affordable for a variety of applications. The price of LiBs have declined by over 90% in the last ten years while their performance and cycle life has increased considerably. For certain applications LiBs are provided active cooling.

4.3 Battery Sizing Criteria

BESS capacity for a typical application is based on the critical loads to be served during power outages and the average duration of power outages in the locality. For example a building with 3 MW connected load has classified 1 MW as the critical load and the average power outgaes in the area is 4 hours, then the BESS may be designed as per the formula below:

$$\text{Battery Energy Storage System Capacity [MWh]} = \frac{(\text{Power required [MW]} * \text{Duration required (h)})}{(\text{Depth of discharge [\%]} * \text{Battery Efficiency [\%]})}$$

$$\text{E.g.: } \frac{(1\text{ MW} * 4\text{ h})}{(90\% * 93\%)} = 4.77\text{ MWh}$$

Backup power being stationery operation, the depth of discharge (DoD) of the battery is considered up to 90% where as in mobility applications like electric vehicles DoD is limited to 80% only. Battery efficiency considered at 93%, though latest batteries gives above 95%.

4.4 Cost of Electricity from BESS

A basic cost model is formed considering the following assumptions:

- An LFP battery of 500 kW*2 = 1 MW was considered in this scenario
- Daily usage of 2 hours was considered
- Cost of electricity from the grid for charging the battery is considered @ Rs 7.25/kWh
- The projections have been given for the 1st, 2-4 years, 5th, and a 5-10th year respectively
- **The cost of power from the BESS is INR 15.17/kWh**

Table 7: Energy and Cost Calculation for Battery Energy Storage System (for 500 kW*2 = 1 MW)

Sl No	Description	Value
General Information		
1	Exchange rate of USD vs INR	74.66
2	Power Required (KW)	500
3	Daily Operations (Hours)	2
4	Depth of discharge - DOD (%)	90
5	Round-trip efficiency (%)	93
6	Units generated (kWh)	930
7	Total Battery Capacity (KWh)	1194.74
A. Battery and Other Component Cost		
1	Battery Pack ($ / KWh)	164
2	PCS ($ / KWh)	18
3	Balance of System ($ / KWh)	25
4	Battery management system ($ / KWh)	20
5	Engineering, Procurement and Construction (EPC) ($/KWh)	25
6	Total Installation cost ($/ KWh)	252
7	Total Cost (Rs / KWh)	₹ 18,814.32
8	Total cost (Rs)	₹ 2,24,78,279.57
B. Operation & Maintenance Cost		
1	For 1 Year	₹--
2	For 2-4 years	₹ 1,32,500.00
3	For 5th year	₹ 61,22,120.00
4	For 5-10 year	₹ 1,65,625.00
5	Total Maintenance cost	₹ 4,20,245.00
6	Total Cost (A+B)	₹ 2,88,98,524.57
Cost Calculations (INR/kWh)		
1	Battery Replacement cost (5th yr)	₹ 61,22,120
2	BESS Power (kW)	500
3	Daily battery cycling (cycles)	1

4	Daily energy use (KWh)	578.10
5	Cost of Electricity from Grid (Rs/KWh)	₹ 7.25
6	Cost of Energy storage (Rs/KWh)	₹ 7.92
	Cost per kWh	**₹ 15.17**

4.5 Applications for BESS for Grid Support

Other than providing power backup for the buildings, following are the other applications of a BESS:

- **Electric energy time shift:** Batteries can be charged with inexpensive electricity when the power price is low and discharged when electricity price is high. BESS can provide a similar time-shift duty by storing excess energy production from renewable energy sources which might otherwise be curtailed. The stored energy can be sold at a higher price during peak hours which is often referred to as price arbitrage.
- **Peak shaving:** Peak shaving is a form of energy time-shift application which help the user to reduce his maximum demand from the grid during peak hours by using the stored energy from the BESS. An energy storage system used for energy time-shift could be located at user building, or near the energy generation site or in other parts of the grid. Important parameters for the BESS operating in peak shaving application are the variable operating costs, the round-trip efficiency, and the storage performance decline over time.
- **Deferral of grid upgrades:** BESS could be used to defer or reduce the need to build new generation capacity and consequent transmission and distribution grid capacity enhancements. In this application, the BESS supplies part of the peak capacity when the demand is high, thus reducing the demand from the grid. The BESS is recharged when the demand is lower.
- **System regulation:** Power system regulation or balancing can be done efficiently by a BESS by adjusting the momentary differences between demand and generation inside a control area or momentary deviations in interchange flows between control areas, caused by constant fluctuations in generation and loads. Conventional power plants are less suited for this application as rapid changes in power output could incur significant wear and tear. BESS with rapid-response characteristic are suitable for operation in such balancing application.
- **Voltage support**: Grid operators are required to maintain the grid voltage within specified limits. This usually requires the management of reactive power and active power which is referred as Volt/VAR support. Voltage support is especially valuable during peak load hours when distribution lines and transformers are generally over loaded. BESS placed at strategic locations could serve as a source or sink of the reactive power. The distributed placement of BESS allows for voltage support near large loads within the grid.
- **Load following/ramping support for renewables:** Load following is one of the ancillary services required to balance the electric grid with large share of RE resources. BESS can supply (discharge) or absorb (charge) power to compensate for variations in RE generation as well as variations in loads. In general, the load variations should stay within certain limits for the rate of change, or ramp rate in generation; and this application is a form of ramp rate control. The advantages of BESS over conventional power generation are:
    - BESS can operate at partial load with minor performance issues

- BESS can respond quickly to a varying loads
    - BESS are suitable for both load following down (as the load decreases) and load following up (as the load increases) by either charging or discharging
    - BESS can smooth-out grid variability of RE generation
    - BESS can maintain a set power factor and prevent voltage fluctuations that might affect sensitive equipment
- **Frequency response:** Typically the power system stability is maintained by the physical inertia provided by conventional power plants with synchronous generators. If the total amount of physical inertia decreases in a power system, the amount of synthetic inertia should be increased to maintain the minimum amount of total inertia. BESS can add synthetic inertia to the system and can thereby compensate for fluctuations in the grid frequency.
- **Time of Use (ToU) bill management:** When electricity prices are variable depending on the time of day, storing energy for use during peak hours can reduce power costs. Energy is drawn from the grid to be stored when demand and prices are low (typically at night) and then consumed during peak times when prices are higher would help reduce the overall power bills.
- **Transmission and distribution congestion relief**: Transmission and distribution network capacities are utilized maximum during peak hours during the peak season (summer months). The maximum peak load is experienced for few hours in a year; but the cost of grid strengthening to meet that additional load for few hours in a year is prohibitive. In such scenarios, BESS can defer system upgrades by few years by giving load relief during congestion in the network. BESS located strategically can service such loads that causes the network congestion.

5 COMPARATIVE ANALYSIS OF DIESEL GENERATOR V/S BESS

The following is a comparison between a 1250 kVA DG set and a 1 MWh Lithium-ion Iron Phosphate (LFP) battery on various parameters.

Table 8: Comparative Analysis between a 1250 kVA DG Set and 1 MW LFP Battery

Parameter	Diesel Generator (1250 kVA)	1 MWh Lithium-ion Iron Phosphate Battery (LFP)
Noise Emission	50-74 db	Nil
Pollutant Emission	2.6 Kg of CO_2 per litre of diesel	Nil
Activation Time following Outage	10-30 seconds	Nearly Instantaneous
Cycle Life	12000 Hours	2400-4000 cycles
Lifetime	10-15 years	15-20 years
Cost (INR/kWh)	INR 29.07	INR 15.17
Applications	Power Backup	Power Backup Peak Shaving RE Integration EV Charging Voltage Regulation Option of Selling Power Back to Grid

6 TESTING STANDARDS AND CERTIFICATIONS FOR LITHIUM-ION BATTERIES

Different battery chemistries present unique challenges for ensuring safety and reliability. The conformity with standards ensures safety. Globally, there has already been a lot of work done on this subject which can be of immense help in this regard. International Electro-technical Commission (IEC) and Underwriters Laboratories (UL) have published relevant standards as presented below:

Table 9: Relevant Storage Standards

Series of Standard	Categories Included
UL 9540	Energy Storage Systems (ESS)
IEC 62933	Electrical Energy Storage (EES) Systems
UL 1989	Standby Batteries
UL 2743	Portable Power Packs
IEC 61427	Secondary Cells and Batteries for Renewable Energy Storage
IEC 62485	Secondary Batteries and Battery Installations
UL 1642	Lithium Batteries
IEC 62619	Large Format Li-B Secondary Cells and Batteries for Industrial Application
IEC 62897	Stationary Energy Storage Systems with Lithium Batteries: Safety requirements
UL 991 and UL 1998	Tests for Safety-Related Controls Employing Solid-State Devices; and Standard for Software in Programmable Components
UL 2271	Light Electric Vehicles (LEV)
UL 2580	Electric Vehicles (EV)
UL 1973	Batteries for use in Light Electric Rail (LER) and Stationary Applications

ISGF recommends that rapid adoption and application of these standards with necessary deviations depending on regional specific requirements would be a realistic approach for the industry. This practice is also being regularly followed by BIS for all the IEC, IEEE and ISO standards.

7 CASE STUDY: INDIA'S FIRST MW-SCALE HYBRID ENERGY STORAGE PROJECT

To overcome the inconvenience of frequent power cuts at Om Shanti Retreat Centre in Maneswar, Haryana, M/s Vision Mechatronics has designed and installed a Zero Blackout Solution. It is a solar based unique combination of MW-scale by battery energy storage system (BESS): lithium-ion and lead-acid hybrid battery system which utilized the existing lead-acid batteries with the new LFP batteries to have a long duration backup solution to ensure that there is a smooth power transition when the grid fails. It also helps to achieve the cost of energy at grid parity. This solution has been developed and manufactured in India by Vision Mechatronics.

The entire system effectively performs as the backup, frequency regulation, grid feed, voltage regulation, smooth power transition and DG set replacement. The system also prevents and predicts the faults in advance to ensure smooth and reliable functioning. The power is used to run heavy-duty studios, electric irons, induction cooktops, computers, and washing machines, community kitchen appliances, baking ovens, air-conditioners, submersible water pumps, lights and fans. It provides clean and green energy to the campus.

Figure 4: Mega Watt Scale Hybrid Energy Storage with Lithium-Ion Battery

This hybrid BESS has a combination of 614.4 kWh of new LFP batteries and 480 kWh of lead-acid batteries (tubular gel type) to achieve economic long duration backup. The batteries are DC coupled; and Victron and Fronius inverters are deployed. The system transitions from grid power to BESS and vice-versa in a flicker-free mode. The hybrid energy storage model can help commercial entities reduce their initial capex investment by 35% to 40% for a long duration energy storage systems.

The campus has over 800 kW of solar PV panels of which 200 kW PV panels are connected to the BESS; and the batteries are charged only from the solar energy. The cost of electricity from this BESS is Rs 7-8/kWh which is at par with the power from the grid in Haryana. This BESS replaced 400 kVA DG sets (320 kVA x 1 + 80 kVA x 1) and a 7000 litre diesel storage tank.

8 BUSINESS MODELS FOR DG SET REPLACEMENT WITH BATTERIES

8.1 Utility Owned

The utility can own BESS and sell services to commercial or industrial users. The hotels or the building owner may pay the annual fixed charge to utility at a notified tariff derived by the regulatory commission. Long-term energy services agreements can be entered between the user and the utility. The BESS may be operated by the load dispatcher based on system requirements.

Advantages:

- Utilities can co-optimize their operations with BESS to meet the reserve requirements as well as provide frequency response

- BESS can be utilized for multiple applications, such as balancing, synchronous reserve, and peak capacity
- Utility can defer distribution network capacity enhancement by several years
- Competitive bidding may drive down prices

8.2 Building Owned and Leased to Utility for Grid Support

Building owner set up the BESS and lease that system to the utility for a mutually agreed fee. The utility will have the rights to charge or discharge the storage system as per the grid conditions and the terms to serve the BESS owner's loads as per the service agreement between them. Under this model, the utility uses the batteries primarily to provide power capacity to the grid and maintain power system reliability in an area where it has difficulty meeting peak demand. So, BESS are essentially used as an alternative to infrastructure augmentation.

8.3 Investor (Third Party) Owned

In this model a third party or independent power producer (IPP) will own the BESS and have a three- party agreement between the property owner and the utility. The IPP will assure emergency power to the property owner for which he will receive a monthly fixed fee and energy charges for the energy supplied to the building during power outages. IPP will also be paid by the utility for using the BESS for grid support.

9 CONCLUSION

According to latest IEA projections, Indian power system is set to grow from the present capacity of 395 GW to 823 GW by 2030 and 1584 GW by 2040. Out of 1584 GW, 869 GW is expected to be renewable energy (RE) resources. Considering the larger share of RE in the generation portfolio, IEA estimates ±85% flexibility for the Indian power system by 2040 which will be a huge challenge to manage. Therefore, building flexibility in the power system assumes top priority and BESS is one of the most reliable resource to increase the flexibility of the grid. During periods of surplus generation, electricity can be stored in the batteries and discharge the batteries during peak-hours. Replacement of DG sets distributed across the country with BESS is the fastest and cheapest route to build flexibility for the Indian grid. The reduction in emissions from DG sets will help meet the NDC targets as well.

NOTES

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