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Renewable Energy generation
Energy Storage

Microgrids

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Challenges of integrating distributed renewable generations

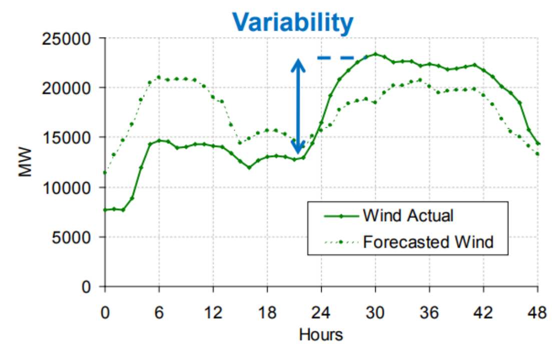
Seconds — *Renewable generation introduces **harmonics** and affects power supply quality.*

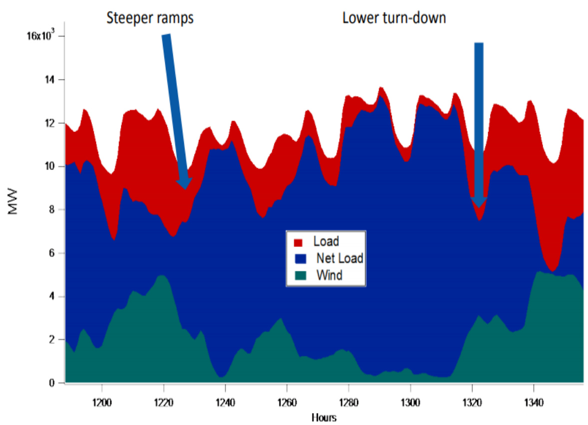
Minutes — *Rapid ramping to respond affecting power **frequency** characteristics.*

Hours — *Daily **peak** for electricity is **greater** to meet demand.*

Hours - days — *Variability of renewable energy generation needs **back-up supply or demand response**.*

Months — ***Seasonal changes** in renewable energy sources and load demands.*





Energy Storage System (ESS) is one of the efficient ways to deal with such issues

Energy Storage Systems

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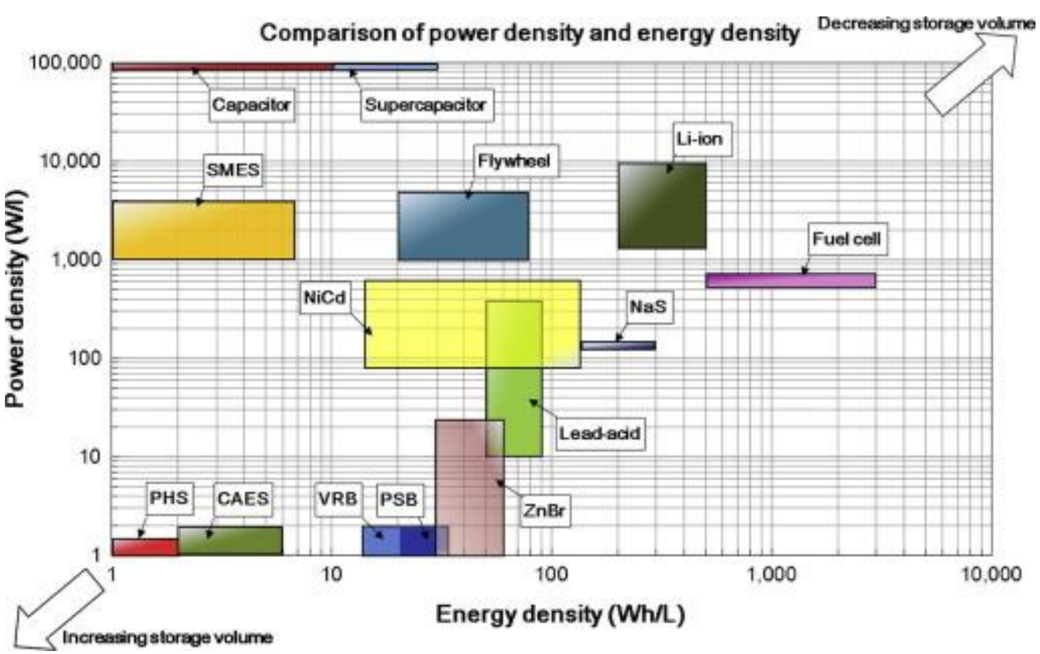
Energy Storage Systems

Mechanical	Electrical	Electrochemical	Chemical	Thermal
• Pumped hydro storage (PHS) • Compressed air energy storage (CAES) • Flywheel	• Double layer capacitor (DLC) • Superconducting magnetic energy storage (SMES)	• **Battery energy storage systems (BESS).**	• Fuel cell • Substitute nature gas	• Sensible heat storage



Energy Storage Systems

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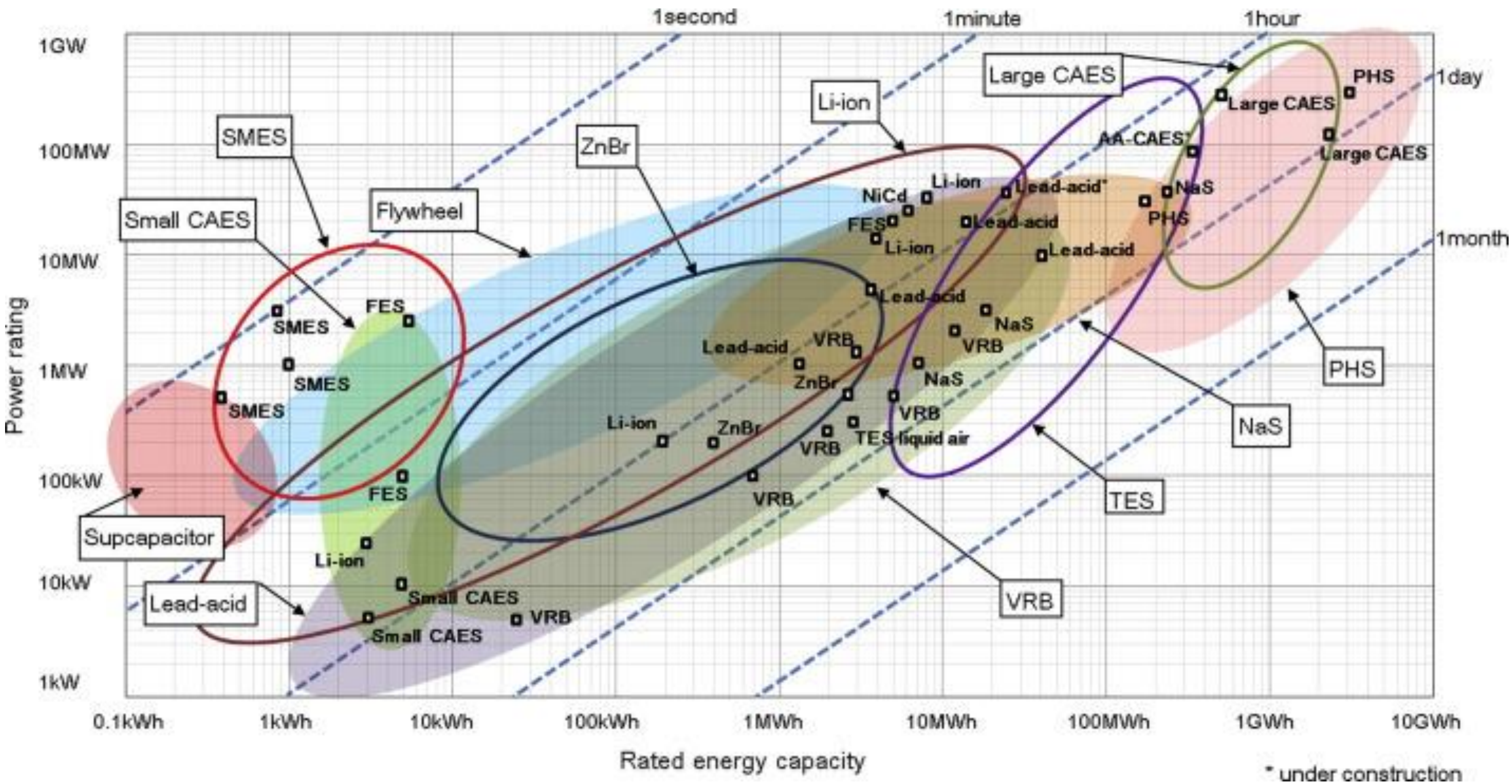
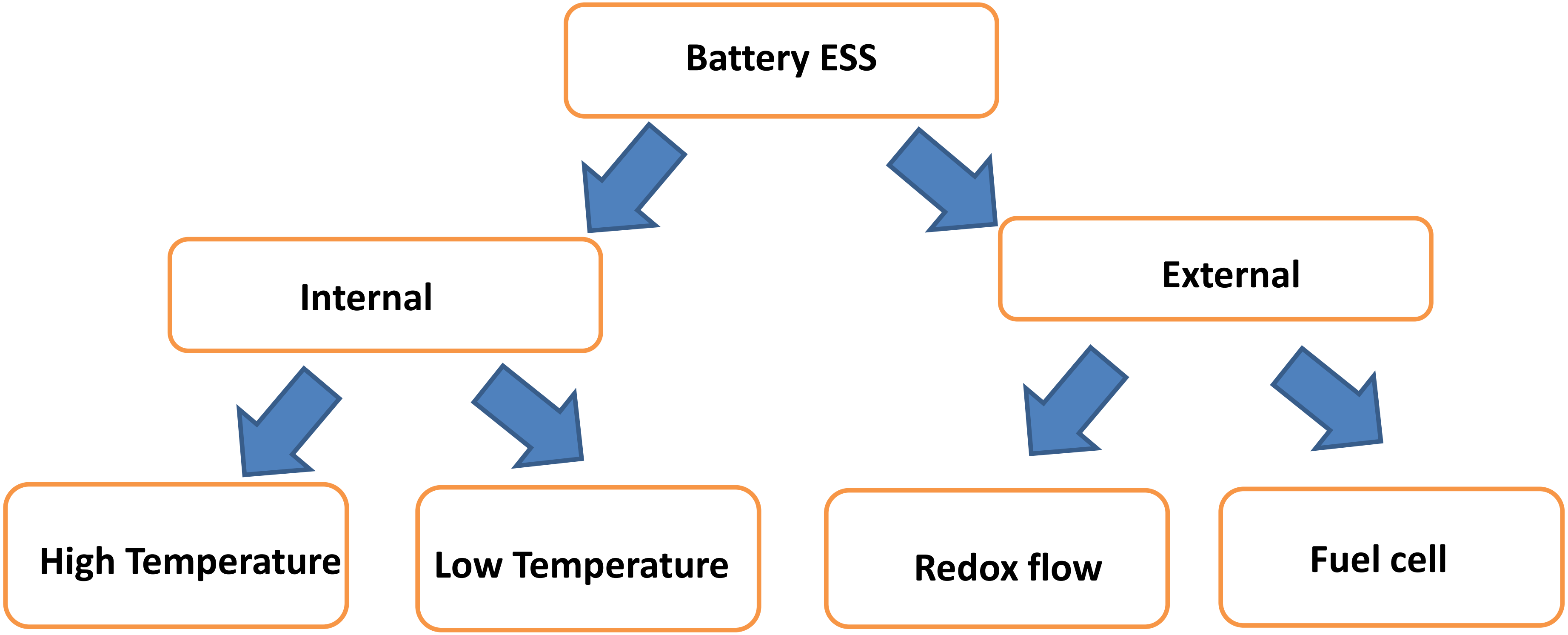


Battery Energy Storage Systems



- Lithium-Ion
- Lead-Acid
- Nickel-Cadmium

- Sodium-Nickel-Chloride ($NaNiCl_2$)
- Sodium-Sulphur (NaS)

- Vanadium
- Zinc-Bromine

- Hydrogen
- Methanation

Battery Energy Storage Systems

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Comparison of several popular battery technologies

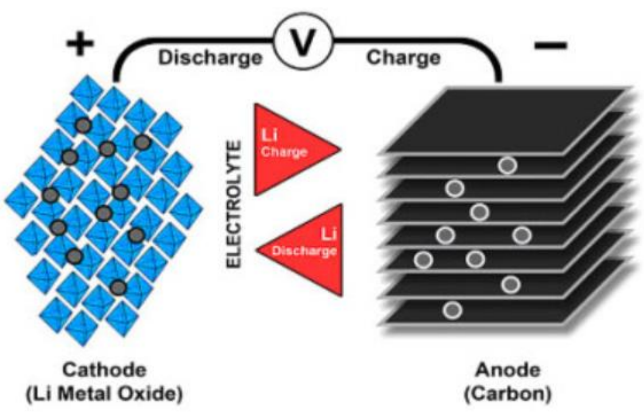
	Gravimetric energy density (Wh/kg)	Gravimetric power density (W/kg)	Volumetric energy density (Wh/L)	Volumetric power density (W/L)	Nominal cell voltage (V)	Charging Temperature (^{O}C)	Discharging Temperature (^{O}C)	Daily Self-Discharge rate (%)	Lifetime (Years)	Cycle life (Cycles)	Environment impact
Lead-acid battery	30 - 50	75 – 300	50 – 90	10 – 400	2	-20 – 50	-20 – 50	0.05 – 0.3	5 – 15	500 – 2000	Serious
Ni-Cd battery	50 – 75	150 – 300	60 – 150	75 – 700	1.2	0 – 45	-20 – 65	0.2 – 0.6	15 - 20	1500 - 3000	Serious
Ni-MH battery	54 – 120	200 – 1200	190 – 490	500 – 3000	1.2	0 – 45	-20 – 65	1 – 2	15 – 20	1500 – 3000	Medium
Zebra battery	100 – 120	150 – 200	150 – 180	220 – 300	2.58	270 – 350	270 – 350	10 – 15	10 – 20	>25000	Slight
Lithium-ion battery	**150 – 250**	**500 – 2000**	**400 – 650**	**1500 – 10,000**	**3.3 – 3.7**	**0 – 45**	**-20 – 60**	**0.1 – 0.3**	**8 – 15**	**1000 – 10,000**	**Slight**

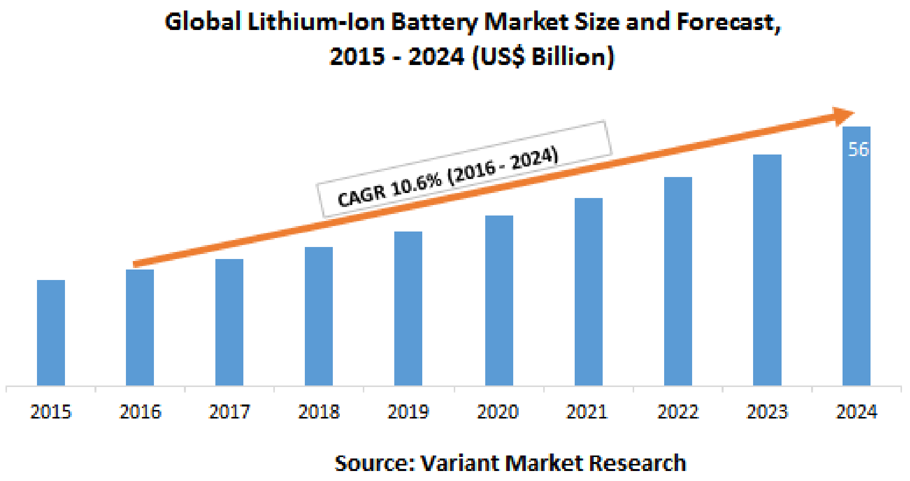
	Energy density	Efficiency (%)	Life Cycle	Cost	Safety issue
Lead-Acid	Low	85-90	500-1000	Low	Toxic/ Pollution
Lithium-ion	High	87-92	1000-	High	Potential Fire Hazard
NaS	High	75	2500	Low	Potential Fire Hazard
VRB	Low	65-75	10000+	High (Expensive Membrane Required)	V(V^{5+})is Toxic
Single flow ZNB	Low	65-85	5000-10000	Low (Abundant and cheap materials)	Ignored

Battery Energy Storage Systems

Lithium-ion battery

- The operation mechanism is based on the movement of lithium-ions.
- Cathode: layered structure of lithium cobalt oxide (LiCoO2), Nickel manganese acid, lithium ternary material (Li (Ni, Co, Mn) O2), spinel-structure lithium manganese oxides, olivine-type lithium iron phosphate and other lithium manganese oxide
- Anode: Carbonaceous materials (graphite, graphene, et), alloy/de-alloy materials such as Si, Sn, Al, Mg, etc.; and conversion reaction materials such as metal oxides (Fe3O4, Co3O4, Fe2O3 etc.)





Battery Energy Storage Systems

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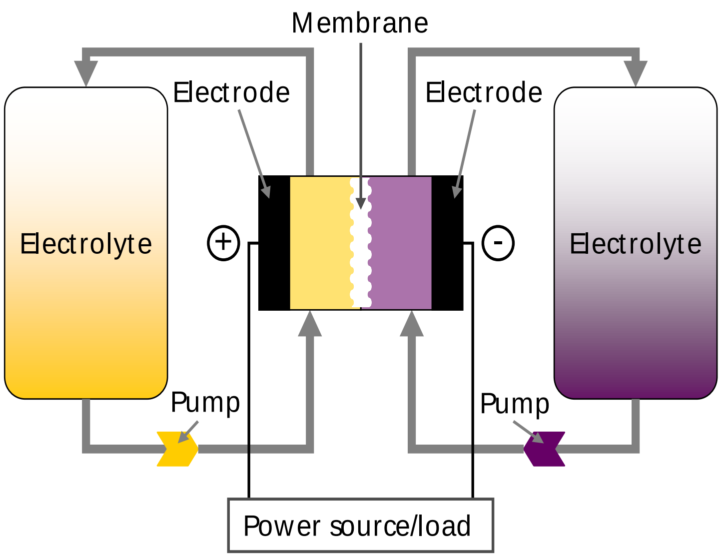
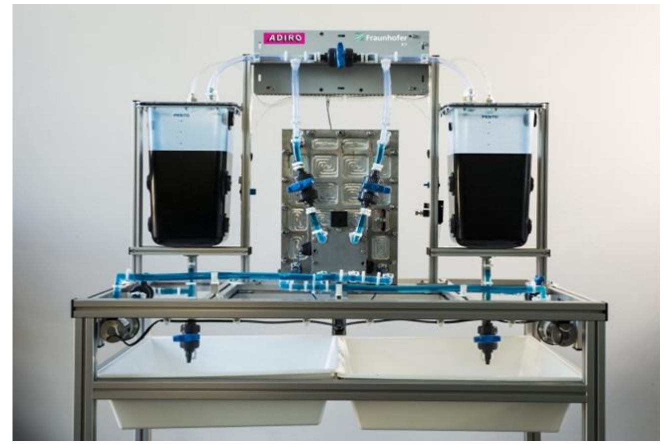
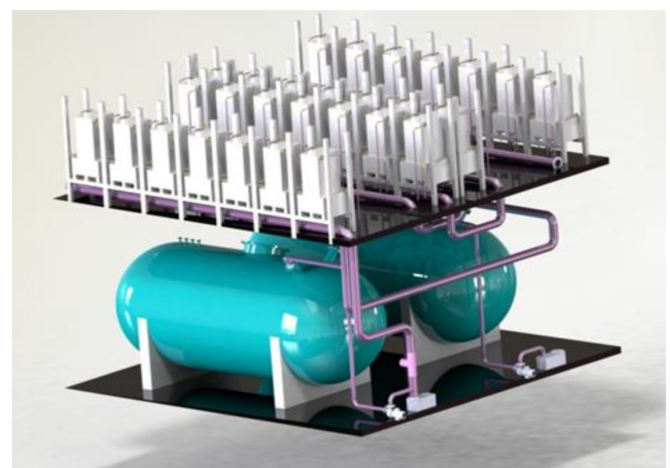
Redox flow battery



- Separated electrolyte and stacks - stored capacity and the rated power
- Easy to scale up
- Cost friendly
- Extremely safe
- Fast respond speed
- Easy to install and control



Small-size RFB



Large-scale RFB

Battery Energy Storage Systems

BESS applications in grid

Generation Level

- Renewable energy integration
- Peak shaving
- Price arbitrage
- Frequency regulation
- Spinning reserve

Transmission and Distribution Level

- Network investment deferral
- Black-start
- Voltage support
- Congestion relief

End-user Level

- Power quality and reliability
- Demand side energy management

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Generation Level

- Renewable energy integration
- Peak shaving
- Price arbitrage
- Frequency regulation
- Spinning reserve

Renewable energy integration

- Damping the variability of the renewable energy system and providing time shifting.
- *Duration of wind integration: 15 minutes (voltage support), 5 – 10 hours (off-peak storage)*
- *Duration of* PV integration: 15 minutes – 4 hours.

Peak shaving

- Avoid the installation of capacity to supply the peaks of a highly variable load
- BESS can provide fast response (**milliseconds**) and emission-free operation.
- Reducing the need for peaking units.

Price arbitrage

- Time shift: Charging the BESS during periods when the prices or system marginal costs are low, the stored energy can be used or sold at a later time when the price or cost are high.
- BESS operating cost and storage efficiency are especially important for this application.

Frequency regulation

- The BESS is charged or discharged in response to an increase or decrease of grid frequency and keeps it within pre-set limits (49.5 – 50.5Hz).
- BESS can proved fast response to meet the Primary (10 – 30s), secondary (30s – 30min) and high (10s) frequency response.

Spinning reserve

- The BESS is maintained at a specific SOC level ready to respond to a generation outage.
- Depending on the application, the BESS can response within milliseconds or minutes.

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Transmission and Distribution Level

- Network investment deferral
- Black-start
- Voltage support
- Congestion relief

Network investment deferral

- By reducing peak load growth, BESS defer the transmission upgrade investments.
- BESS discharges when the load is over the current transmission line capacity.
- BESS can be used to provide enough incremental capacity to defer the need for a large lump investment in transmission equipment.

Black-start

- BESS provides active reserve of power to energize transmission and distribution lines.
- BESS also can proved the electricity for the power plant to perform start-up operations.

Voltage support

- BESS provides reactive support to the grid with the change of its power factor to **compensate the reactive power flows** on the grid.

Congestion relief

- BESS would be installed at locations where are electrically downstream from the congested portion of the transmission system.
- Energy would be stored when there is no transmission congestion, and it would be discharged (during peak demand periods) to reduce peak transmission capacity requirements.

Battery Energy Storage Systems

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End-user Level

- Power quality and reliability
- Demand side energy management

- **BESS can effectively support customer loads when there is a total loss of power from the source utility.**
- **This support requires the storage system and customer loads to island during the utility outage and resynchronize with the utility when power is restored.**

- **BESS can be used to reduce the overall costs for electric service by reducing the demand during peak periods.**
- **Through load shifting with BESS, customer can reduce their demand charges and avoid demand charge penalties.**

Voltage Characteristics（LV&MV）

Parameter	Supply voltage characteristics (According to EN 50160)
Voltage magnitude variations	LV: ±10% of the Nominal voltage of the system MV: ±10% of the Nominal voltage of the system
Rapid voltage changes	LV: 5% (normal) and 10% (infrequently) MV: 4% (normal) and 6% (infrequently)
Supply voltage dips	Majority: duration < 1s, depth < 60% Locally limited dips caused by load switching on: LV: 10 – 50 % MV: 10 – 15%
Short interruptions of supply voltage	LV & MV: Up to 3 minutes
Supply voltage unbalance	LV & MV: Up to 2%. (3% in some locations)

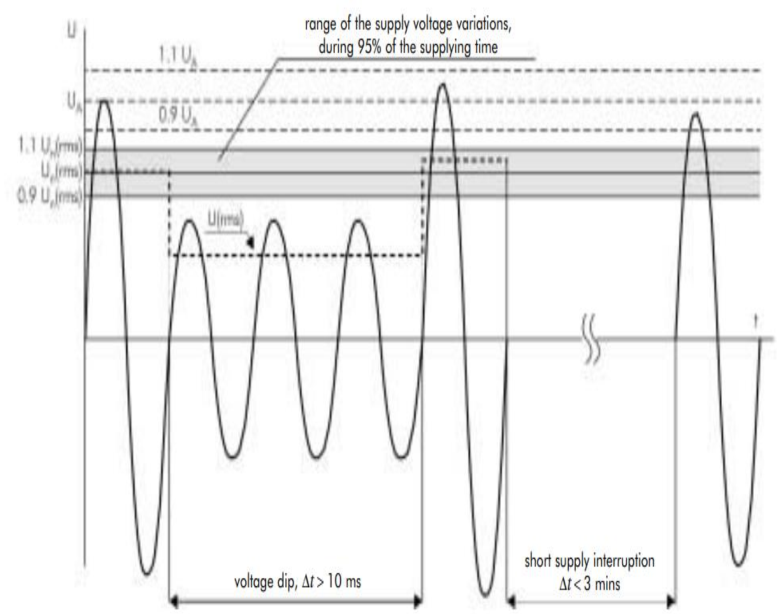

Illustration of a voltage dip and a short supply interruption

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Frequency Grid Code for BESS

- The grid-connected BESSs can be identified as **generating facilities** when they operate at the electricity generation mode.
- The BESS is required to provide a certain level of power output in the case of frequency deviations. The **nominal frequency interval is 49.5 – 50.5 Hz** and the **critical frequency interval is 47.0 – 52.0 Hz.**
- For onshore synchronous generating units (when supplying rated MW), they must be capable of continuous operation at any point **between the limits of 0.85 power factor lagging and 0.95 power factor leading** at the generating unit terminals.
- For onshore non-synchronous generating units must be capable of **maintaining zero transfer of reactive power** at the onshore grid entry point at all active power output levels under steady state voltage conditions. The steady state tolerance on reactive power transfer to and from the network should be **no greater than 5% of rated MW**.

Frequency ranges (Hz)	Operation period requirements
51.5 – 52.0	At least 15 minutes is required for each time.
51.0 – 51.5	At least 90 minutes is required for each time.
49.0 – 51.0	Continuous operation is required.
47.5 – 49.0	At least 90 minutes is required for each time.
47.0 – 47.5	At least 20 seconds is required for each time.

The requirements of generating units regarding the GB grid frequency variations [4]

[4] Transmission System Operator for UK, Grid Code, Issue 5, Revision 21, UK Nationalgrid. 2017. Available at: https://www.nationalgrideso.com/document/34091/download

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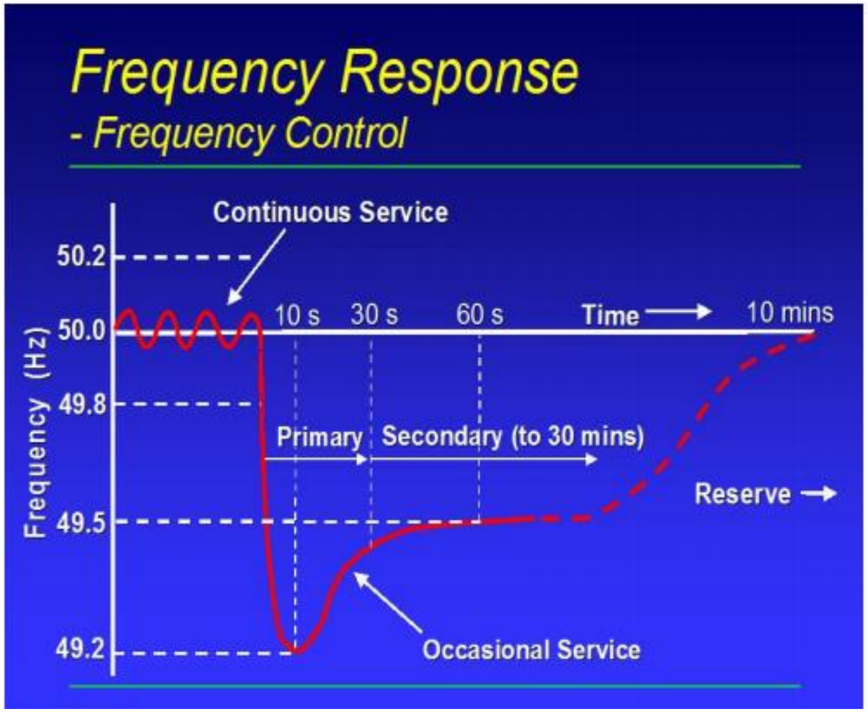
Frequency Control Strategies

- Mandatory Frequency Response: an automatic change in active power output in response to a frequency change. The service is needed to maintain the frequency within statutory (49.5 – 50.5Hz) and operational limits (49.8 – 50.2 Hz).
- **Primary Response**: Provision of additional active power within 10 seconds after an event and can be sustained for a further 20 seconds.
- **Secondary Response**: Provision of additional active power within 30 seconds after an event and can be sustained for a further 30 minutes.
- **High Frequency Response**: the reduction in active power within 10 seconds after an event and sustained indefinitely.



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Challenges

- **Safety Issues:**

  For safe and secure operations, various factors, such as life cycle, operating temperature, short-circuit problem, overcharging, over-discharging characteristics must be addressed efficiently.

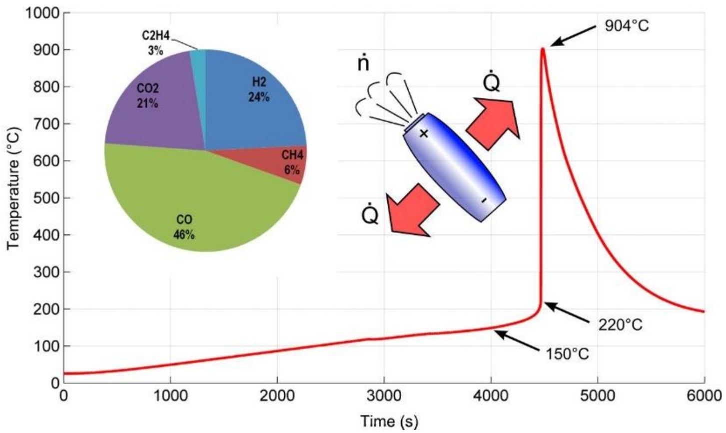
- **Energy Management System:**

  To design an efficient Energy Management System, the minimisation of the overall system loss and the control of SOC can play a vital role in optimising the efficiency and keeping the reserve for future demand.

- **Other issues and challenges:**

  Materials selection, power electronic interface, size and location, cost, environmental impact, etc.

Battery swelling caused by overcharging



Lithium-ion battery thermal runaway.

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