



Energy Storage Systems

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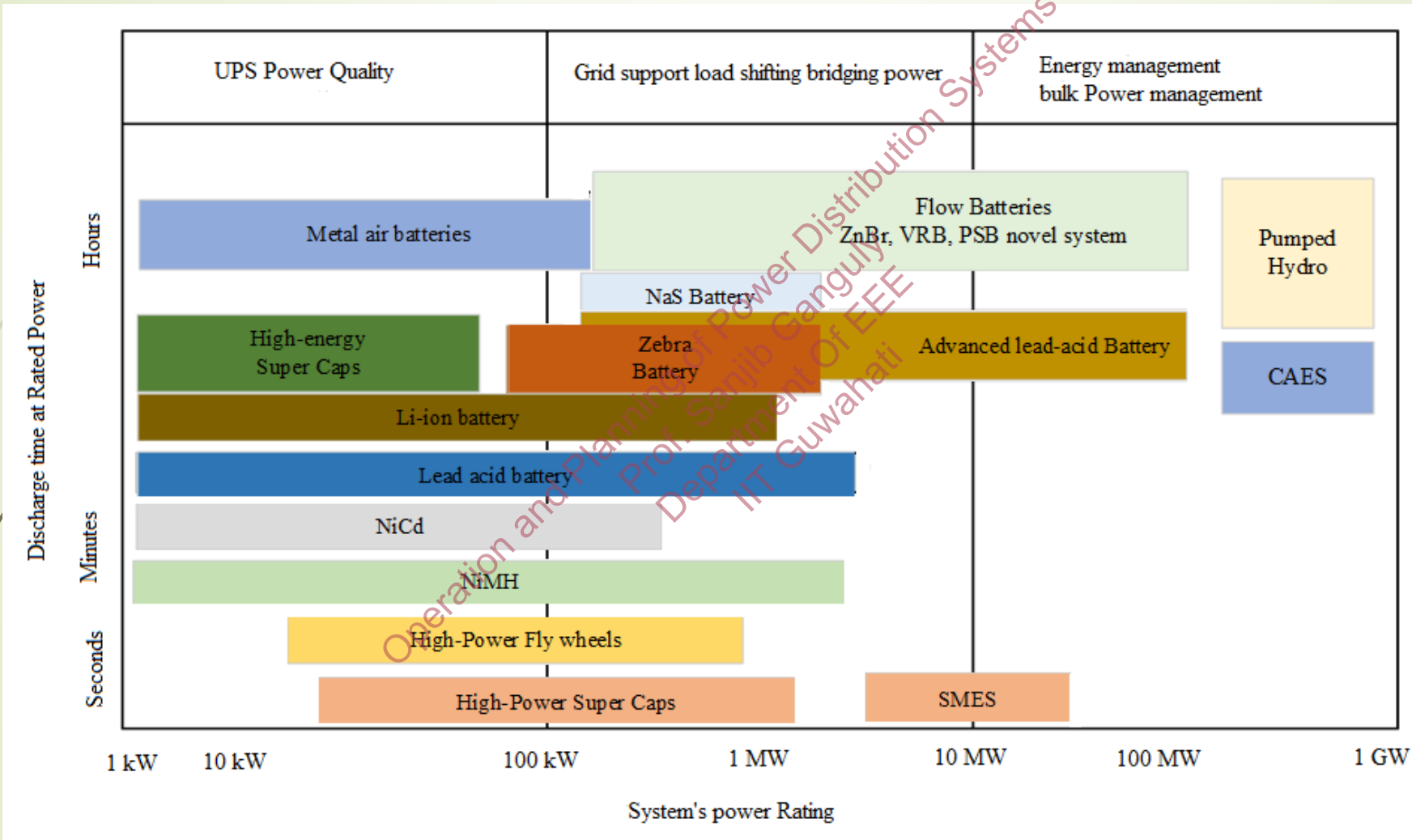
Storage systems: Importance

- Previously, storage systems were only used to provide power to the switchgear during cold start-up of generating stations.
- Now-a-days, they are used to store energy available from renewable sources, in which there is no control of generation.
- By storing energy from variable resources, such as wind and solar power, the energy could be used more efficiently, whenever required.
- Storage applications can be used to mitigate the congestion patterns and during peak demand time.

Types of storage units

- Compressed air energy storage (CAES)
- Pumped storage units (hydro)
- Superconducting magnetic energy storage
- Super-capacitor
- Hydrogen
- Flywheel
- Batteries

Types of storage units



CAES for compressed air energy storage, SMES for superconducting magnetic energy storage,

Ref. T. Gonen. *Electric Power Distribution System Engineering*

Superconductive magnetic energy storage (SMES)

- SMES units to store energy and/or damp power system oscillations has increased.
- It stores energy within a magnetic field created by the flow of direct current in a coil of superconducting material.
- Typically, the coil is maintained in its superconducting state through immersion in liquid helium at 4.2 K within a vacuum-insulated cryostat.
- SMES can be seen as a controllable current source whose magnitude and phase can be changed within one cycle.
- A power electronic converter interfaces the SMES to the grid and controls the energy flow bidirectionally.

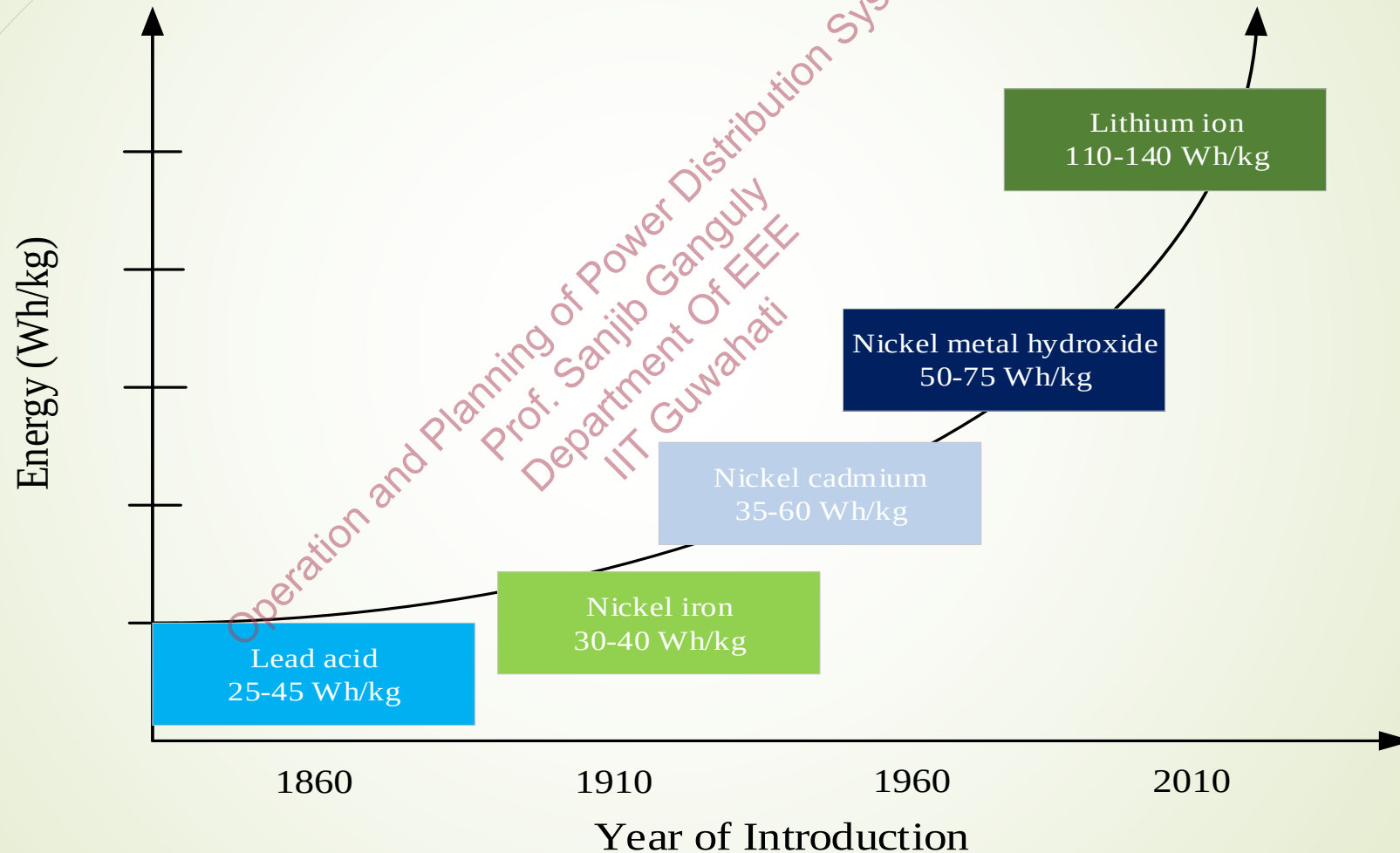
Batteries

- Battery systems are quiet and nonpolluting. They can be installed near load centers and existing suburban substations.
- Their efficiencies are in the range of 85% and can respond to load changes within 20 ms.
- Lead-acid batteries as large as 10 MW with 4 h of storage.
- Although the input and output energies of a battery are electrical, the storage is in chemical form.
- Chemical batteries are individual cells filled with a conducting medium—electrolyte that, when connected together, form a *battery*.
- Essentially, there are two basic types of batteries: *primary battery* (nonrechargeable) and *secondary batteries* (rechargeable).

Secondary Batteries

- Secondary batteries are rechargeable batteries.
- They are further divided into two categories based on the operating temperature of the electrolytes.
- *Ambient operating temperature batteries* have either *aqueous* (flooded) or *nonaqueous* electrolytes.
- *High operating temperature batteries* (molten electrodes) have either solid or molten electrolytes.
- Rechargeable lead–acid and nickel–cadmium batteries have been used widely by utilities for small-scale backup, load leveling, etc.

Improvement in battery performance



Battery: Some definitions

- *Specific energy* : The amount of usable energy, measured in watt-hours per kilogram
- *Energy density*: Amount of energy stored per unit volume
- *Specific power*: It is defined as the potential for acceleration and the ability to work in extreme heat or cold.

Different types of Batteries

➤ Sodium-sulfur batteries:

- This battery is a high-performance battery,
- The electrolyte operates at temperatures of 572°F (300°C).
- Consists of a liquid (molten) sulfur positive electrode and a molten sodium negative electrode separated by a solid beta alumina ceramic electrode.

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Different types of Batteries

➤ Flow battery technology:

- Use electrolyte liquids flowing through a microporous membrane to generate an electrical charge.
- They store and release electrical energy through a reversible electrochemical reaction between two liquid electrolytes.
- Advantage: the ability to scale systems independently in terms of power and energy. For example, more cell stacks permit for an increase in power rating, and a greater volume of electrolytes provides for more runtime.

Different types of Batteries

➤ **Zinc–bromine Flow battery:**

- This battery operates with a solution of zinc bromide salt dissolved in water and stored in tow tanks.
- The battery is charged or discharged by pumping the electrolytes through a reactor cell.

➤ **Vanadium redox Flow battery:**

- During its charge and discharge cycles, positive hydrogen ions are exchanged between the two electrolyte tanks through a hydrogen-ion permeable polymer membrane.

Different types of Batteries

➤ **Lithium-ion batteries:**

- Among the available battery technologies today, the lithium-ion battery has the greatest applications.
- It can be applicable in a large variety of shapes and sizes, permitting the battery to efficiently fill the available space, such as a cell phone or a laptop computer.
- They are also lighter in weight in comparison to other aqueous battery technologies, such as lead-acid batteries.
- They have the highest power density (110–140 Wh/kg) of all batteries on the commercial market on a per-unit-of volume basis.
- The leading lithium-ion cell design is a combination of lithiated nickel, cobalt, and aluminum oxides, referred to as an NCA cell.
- There are two lithium-ion designs that are starting to be employed in higher-power utility grid applications: lithium titanate and lithium iron phosphate.

Different types of Batteries

► **Lead–acid batteries:**

- They are the oldest and most mature among all the battery technologies.
- Because of their large applications, lead–acid batteries have the lowest cost of all battery technologies.
- This battery operates at an ambient temperature and has an aqueous electrolyte.
- Even though the lead–acid battery is relatively inexpensive, it is very heavy, with a limited usable energy by weight (specific energy).

Different types of Batteries

➤ **Nickel–cadmium batteries:**

- Nickel–iron (Edison cells) and nickel–cadmium (Ni–Cad) pocket and sintered plate batteries have been in use for many years.
- Both of these batteries have a specific energy of approximately 25 Wh/lb (55 Wh/kg), which is higher than advanced lead–acid batteries.
- Both are nontoxic, while Ni–cads are toxic. They can be discharged to 100% of depth of discharge without damage.
- The biggest obstacle to the utilization of these batteries is their cost.

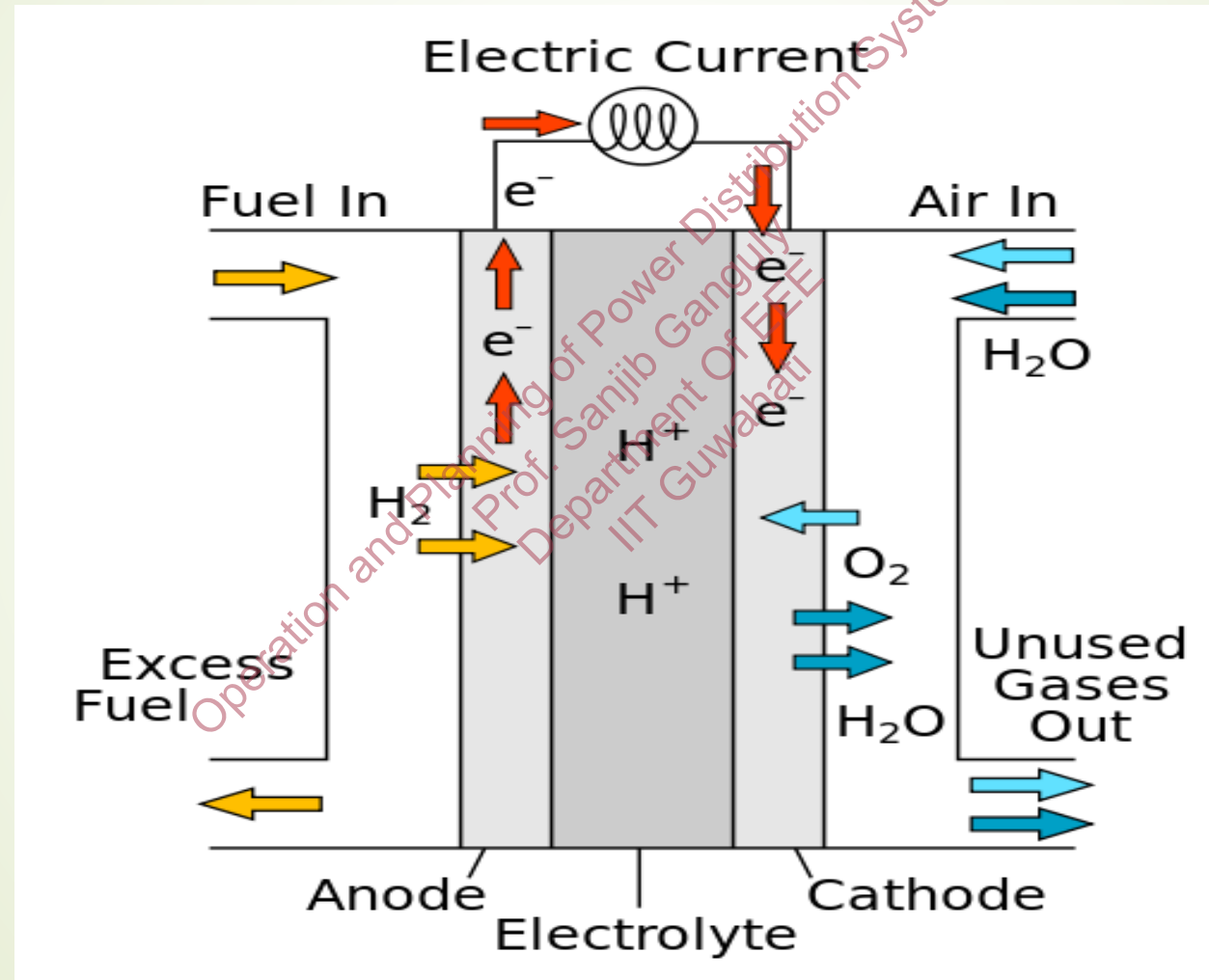
Operational problems of battery usage

- The storage battery must be at a discharge state in the morning to prepare for charging around noon.
- If the lead-acid battery is left in a discharge state, it may deteriorate and shorten the life time.
- The frequency of use of the storage batteries may be varied by the impedance of the distribution line and by a power flow condition.
- There are round-trip energy losses of the storage battery and power conditioning system increases when charging and discharging larger amounts of energy.

Fuel Cell

- Fuel cells are firstly used in the 1960s by NASA to generate fuel for electricity needed by the space-crafts Apollo and Gemini.
- Fuel cells are quiet, clean, and highly efficient on-site generators of electricity that use the electrochemical process to convert fuel into electricity.
- This is the reverse electrolysis. It has few moving parts and produces very little waste heat or gas.
- Fuel cells can also serve as a thermal energy source for water and space heating or for cooling absorption

Working principle of fuel cell



Fuel cell

- Fuel cells are classified according to the nature of the electrolyte used and the operating temperature, with each type requiring particular materials and fuels.
- The electrochemical efficiency tends to increase with fuel cell temperature.
- It is often the nature of the membrane that dictates the operating temperature, and expensive catalysts, such as platinum, may be required to step up the rate of electrochemical reactions. Fuel cells can run using hydrogen, natural gas, methanol, coal, or gasoline.
- More environmentally friendly fuels, such as biogas, and biomass, may be used.
- For most fuel cells, such fuels must be transformed into hydrogen using a reformer or coal gasifier.

Types of fuel cells

- 1. Polymer electrolyte membrane (PEM)
- 2. Alkaline fuel cell (AFC)
- 3. Phosphoric acid fuel cell (PAFC)
- 4. Molten carbonate fuel cell (MCFC)
- 5. Solid oxide fuel cell (SOFC)

Comparison among different fuel cells

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Type	Electrolyte	Operating Temperature (°C)	Applications	Advantages
PEM	Solid Organic Polymer	60-90	Electric utility, transportation, portable power	H ₂
	Metal Oxide (Y ₂ O ₃ /ZrO ₂)	700-1000		H ₂ , CH ₄ , biogas, etc. Efficiency is 35%-55%
Direct Alcohol	Polymer membrane/liquid alkaline	60-120	Transportation, portable power	H ₂ , CH ₄ , biogas, coal gas, etc. Its efficiency is 35%-40%
Alkaline (AFC)	Aqueous solution of potassium hydroxide soaked in a matrix	50-90	Military, space	Cathode reaction faster in alkaline electrolyte; thus high performance. It uses H ₂ as fuel. Efficiency is 50%-60%.

Comparison among different fuel cells

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Type	Electrolyte	Operating Temperature (°C)	Applications	Advantages
Phosphoric Acid (PAFC)	Liquid phosphoric acid soaked in a matrix	150-220	Electric utility, transportation, and heat	Its efficiency is 45%-55%. Upto 85% efficiency in regeneration of electricity
Molten Carbonate (MCFC)	Liquid solution of lithium sodium, and/or potassium carbonates soaked in a matrix	600-750	Electric utility	Higher efficiency, fuel flexibility, inexpensive catalysts. It uses H ₂ , CH ₄ , biogas, coal gas, etc.
Solid Oxide (SOFC)	Solid zirconium oxide to which a small amount of yttria is added	600-1000	Electric utility	Higher efficiency, fuel flexibility, inexpensive catalysts. Solid electrolyte advantage like PEM

Reference

- T. Gonen. *Electric Power Distribution System Engineering*; CRC Press, 3rd Edition, 2014.

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Thank You...

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