ระบบกักเก็บพลังงานแบบปฐมภูมิ

(Primary Energy Storage System: PESS)

- Superconducting Magnetic Energy Storage (SMES)
- Supercapacitor

Outline

- Why PESS?
- PESS Characteristics
- Superconducting Magnetic Energy Storage (SMES)
- Supercapacitors

Why PESS?

- Renewable energy distributed generation (DG) penetration

- Power Quality & Reliability
  - Low Voltage Ride Through
  - Load Frequency Control
  - Spinning Reserve
  - Load Fluctuation Compensation
  - Generation Fluctuation Compensation

- Instantaneous (Pulse) Electrical Power & Energy capable storages

- **Superconducting Magnetic Energy Storage**
- **Supercapacitor**

Storage Techniques

SMES

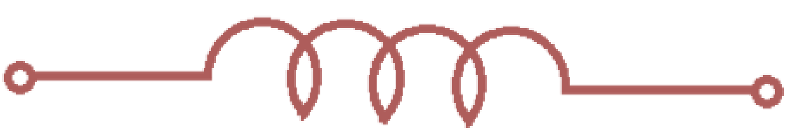
by

"Magnetic Field"

Supercapacitor

by

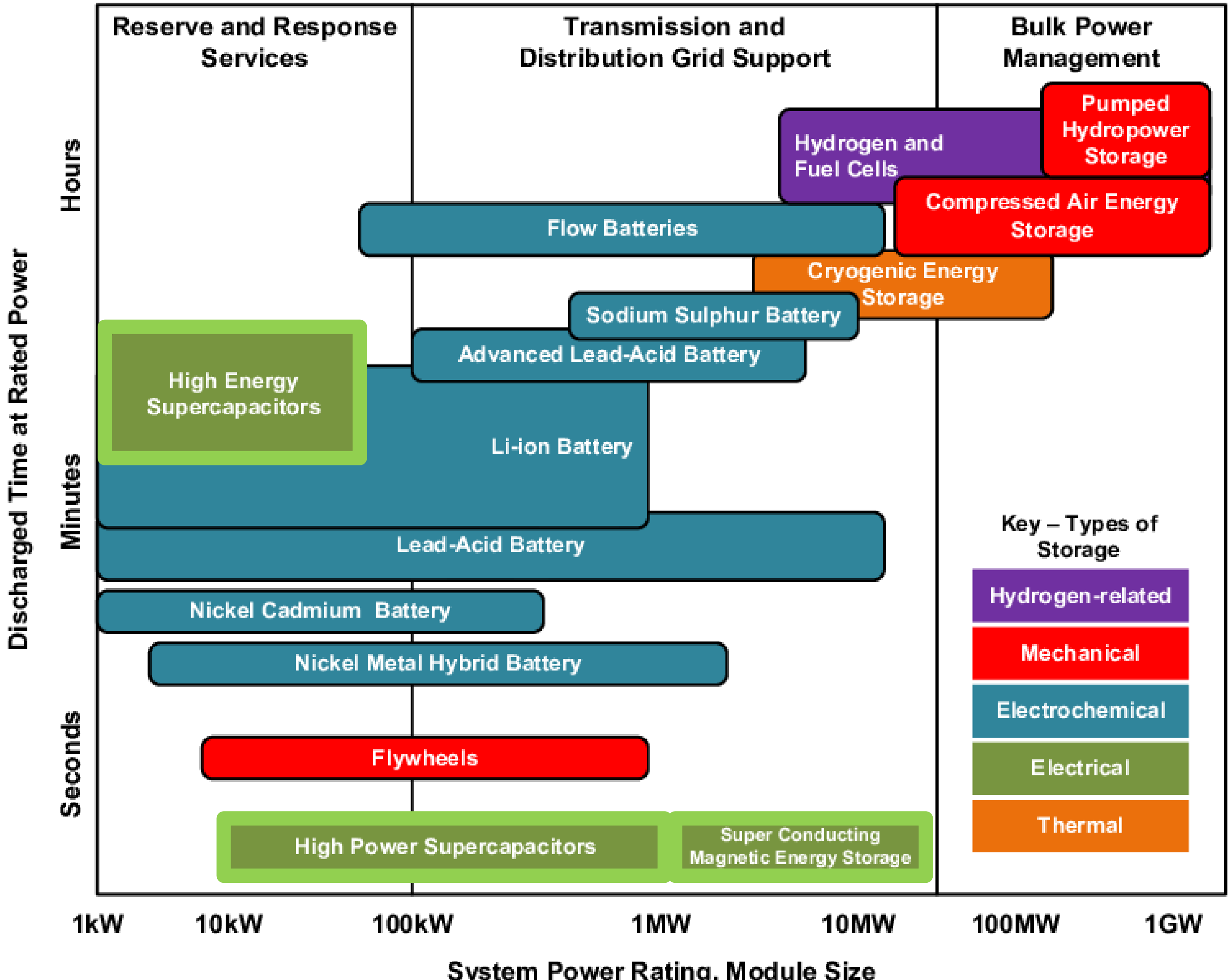
"Electric Field"



Inductor

Capacitor

PESS Characteristics



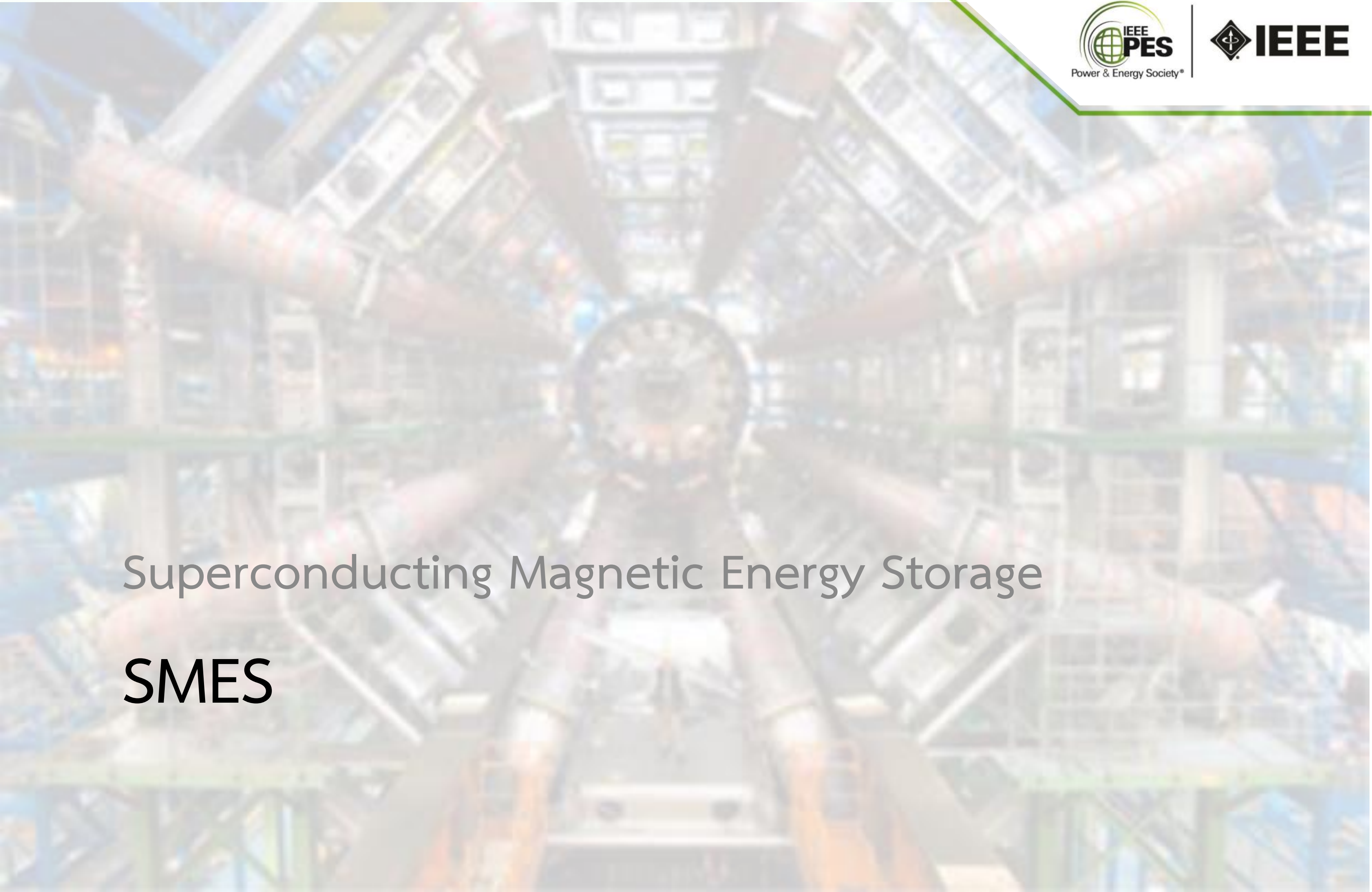
Source: DOI:10.1109/ITECHA.2017.8101925

PESS Characteristics

POWER, ENERGY, AND COST COMPARISON OF THE HIGH-POWER STORAGES TECHNOLOGIES

Storage technology	Energy density (Wh/kg)	Energy density (kWh/m^3)	Power density (W/kg)	Power density (MW/m^3)	Energy capital cost [$/kWh]	Power capital costs [$/kW]
Supercapacitor	0.5–5	4–10	1000–10 000	0.4–10	500–15 000	100–400
SMES	1–10	0.2–2.5	500–2000	1–4	1000–10 000	200–500
Flywheel	10–50	20–100	500–4000	1–2.5	2000–5000	150–400
Li-ion	70–200	200–600	150–500	0.4–2	600–2500	1200–4000

Source: Mustafa Farhadi et.al., “Energy Storage Technologies for High-Power Applications”



Superconducting Magnetic Energy Storage

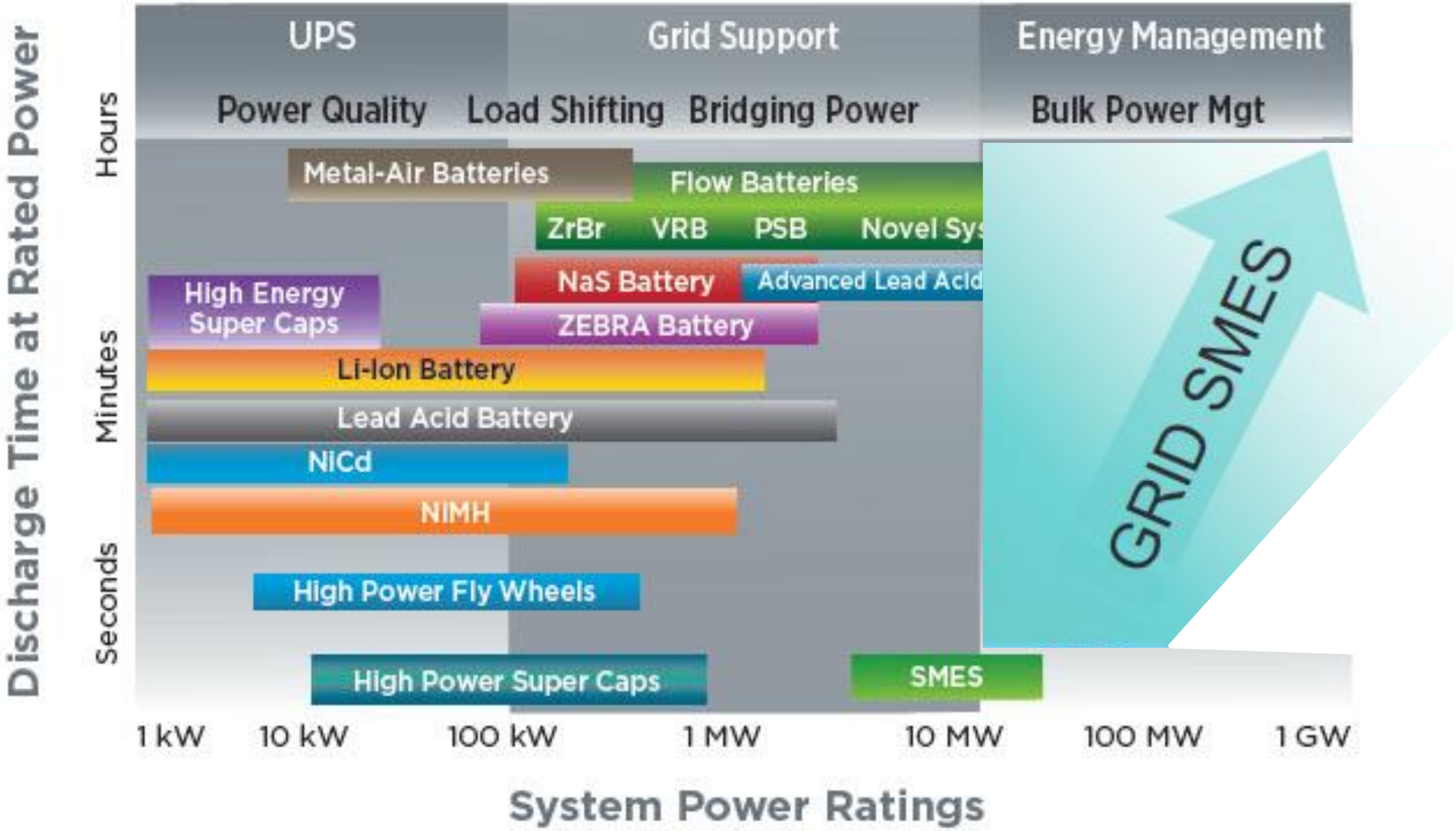
SMES

Superconducting Magnetic Energy Storage (SMES)

- A SMES system can:
  - Store or discharge large amounts of electric energy in a very short time.
- Compared other ESSs, SMES has:
  - A high cyclic efficiency (> 90%),
  - Large power density,
  - Quick response time and
  - Unlimited charging and discharging cycles

Note: Superconductivity is a phenomenon of zero electrical resistance that occurs when the three conditions of temperature, magnetic field and current density are satisfied.

Trend of Development



Source: DOI:10.1109/ITECHA.2017.8101925

SMES Operation Concept

Materials conducting current with no resistive losses.

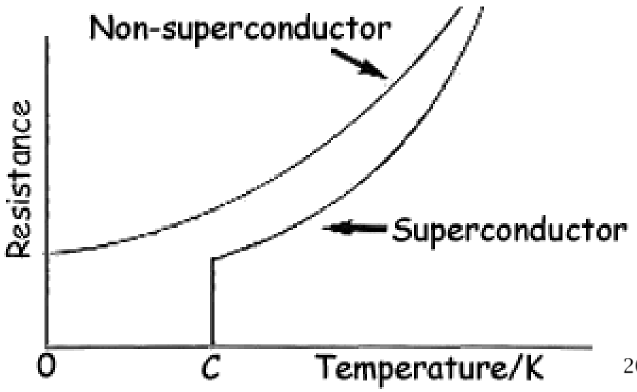
Electric currents produce magnetic fields.

Magnetic fields are a form of pure energy which can be stored.

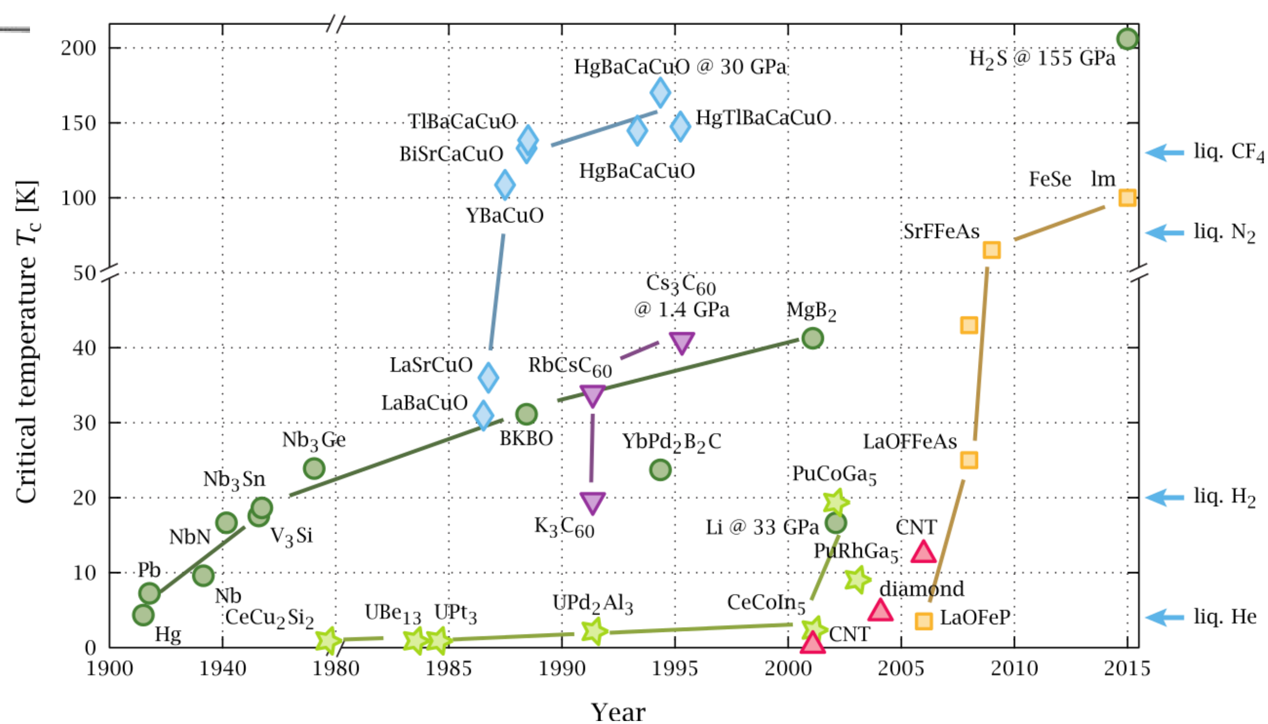
Properties of Superconductors:

- Zero resistivity
- Critical Temperature, T_c
- Critical Current, J_c
- Critical Magnetic Field, B_c

Superconductor – Zero Resistivity

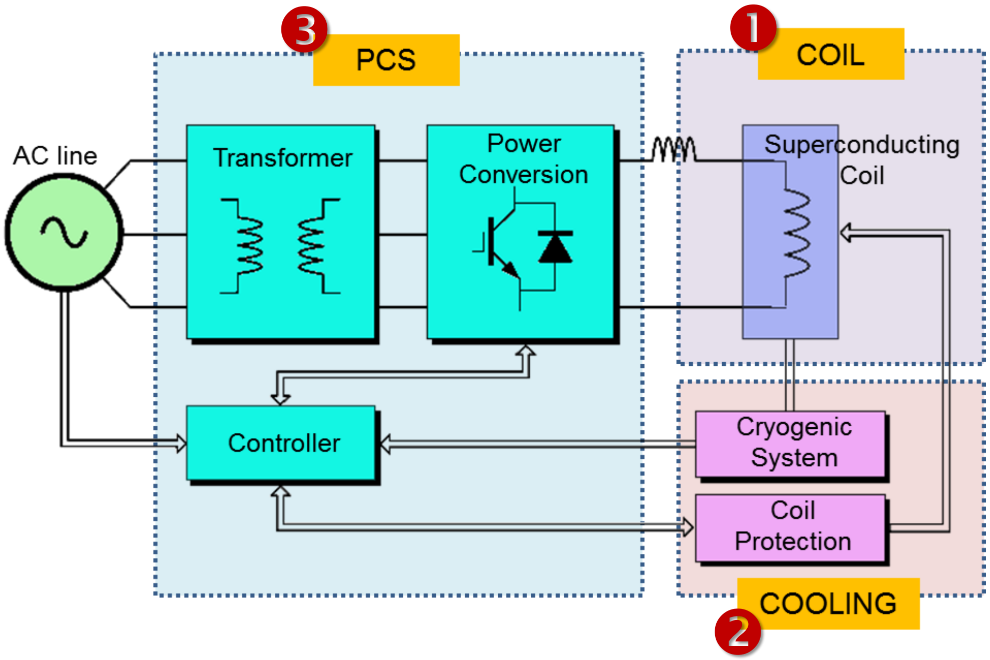


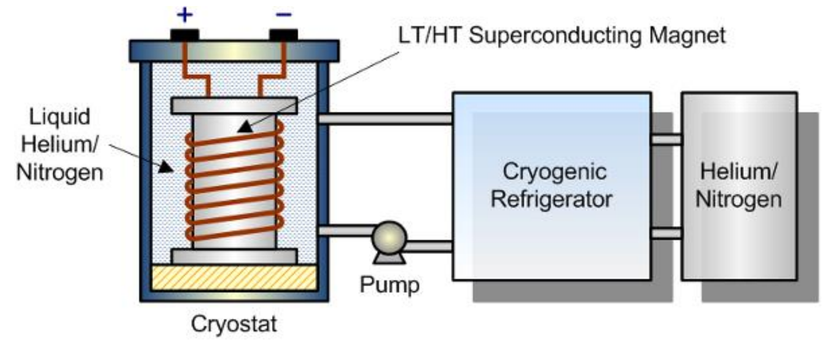
C = critical temperature



Source: Wikipedia, https://www.globalspec.com/learnmore/materials_chemicals_adhesives/electrical_optical_specialty_materials/superconductors_superconducting_materials

SMES System Components





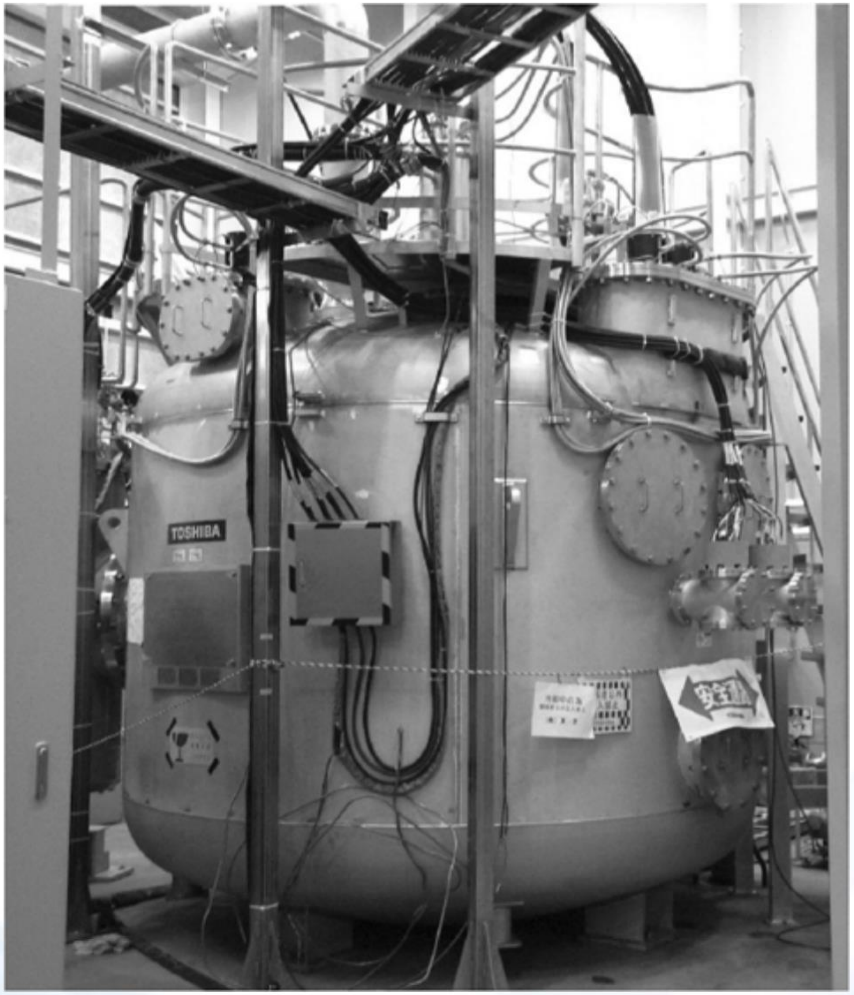
Cryogenic System & Superconducting coil

Features:

- Superconducting alloy of Niobium and Titanium (Nb-Ti)
- Operation at temperatures near the boiling point of liquid helium, about 4.2 K (-269°C or -452°F)

Source: Andy Kyung-Yong Yoon, et. Al., Edward Barbour

SMES Component: Cryostat

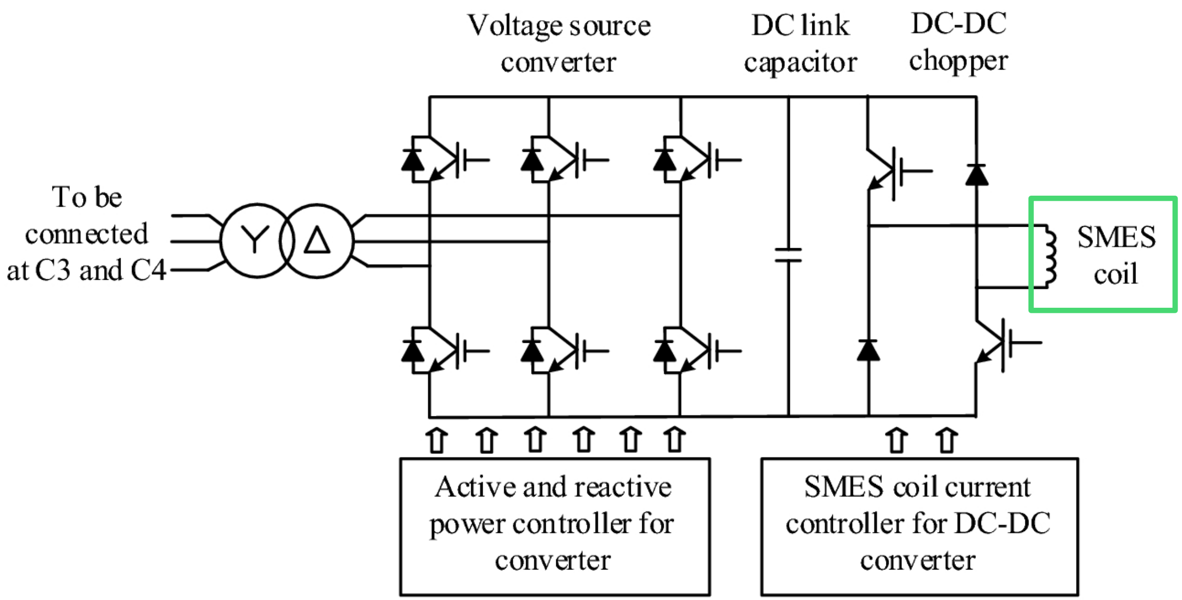


The cryostat for the 10 MVA/20 MJ SMES prototype, tested at an actual power system including hydro power generators in order to compensate the fluctuating power load from a metal rolling factory

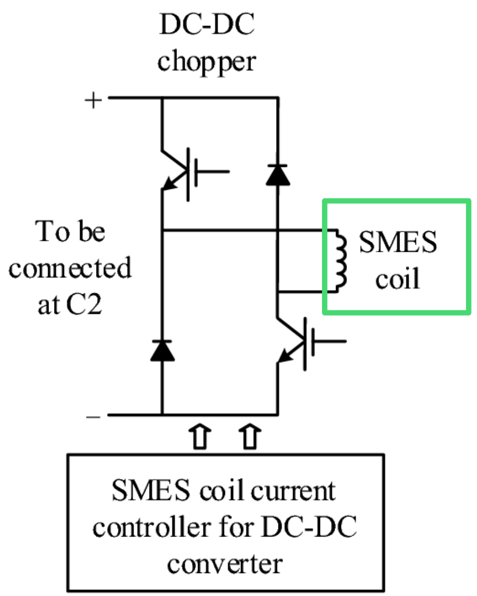
T. Katagiri *et al., IEEE Trans. Appl. Supercond., 19,* 1993–1998, (2009).
Nomura, et al, *IEEE Trans. Appl. Supercond., vol 20 (2010)*

SMES Component:
Power Conditioning System (PCS)

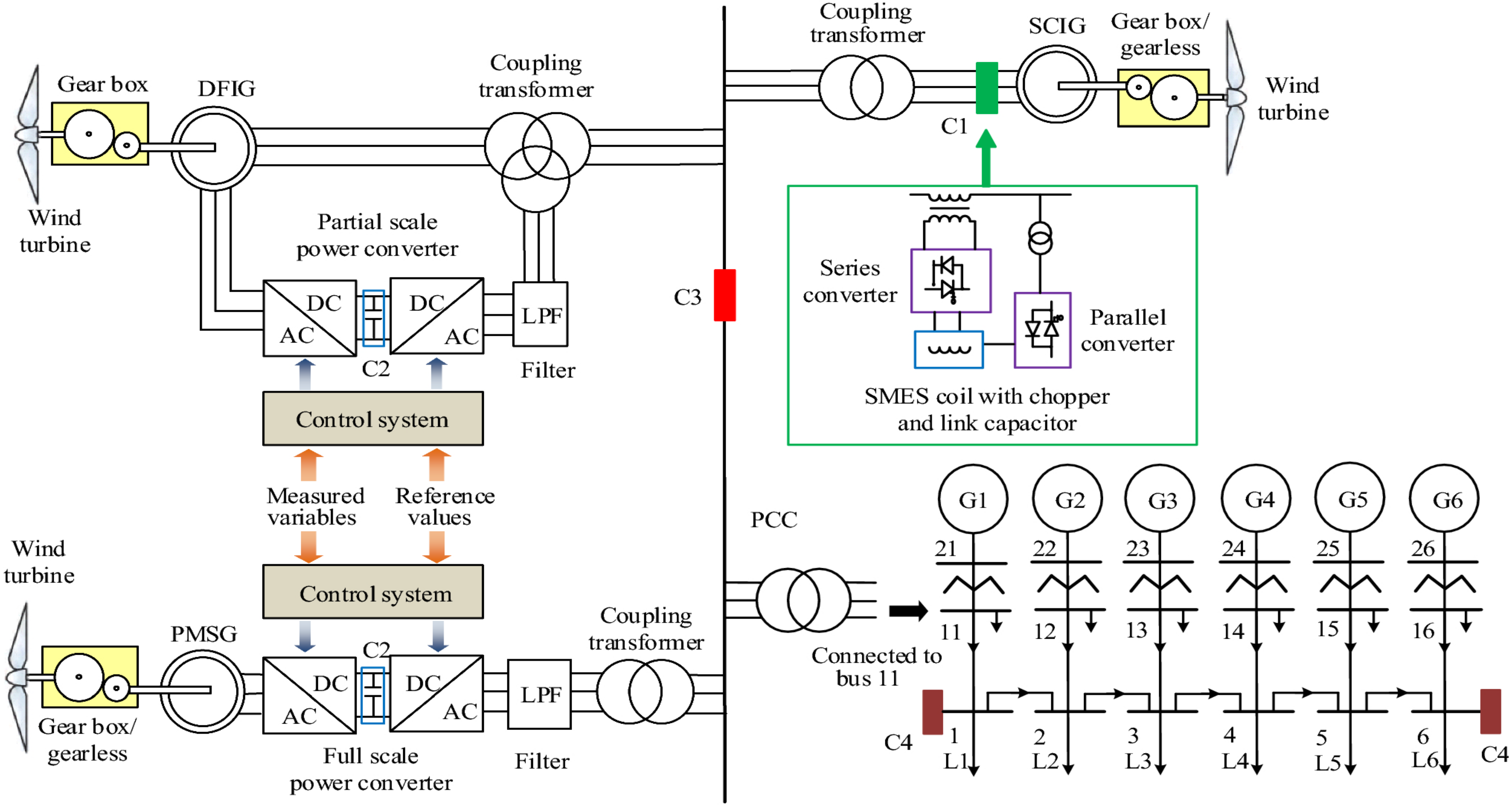
❶ AC Interface



❷ DC Interface



SMES Interfaces



Source: Poulomi MUKHERJEE, “Superconducting magnetic energy storage for stabilizing grid integrated with wind power generation systems

Stored Energy

- The magnetic energy stored by a coil carrying a current is given by:

$$E = \frac{1}{2}Li^2 \quad \Rightarrow \quad E_{discharge} = \frac{1}{2}L({i_{max}}^2 - {i_{min}}^2)$$

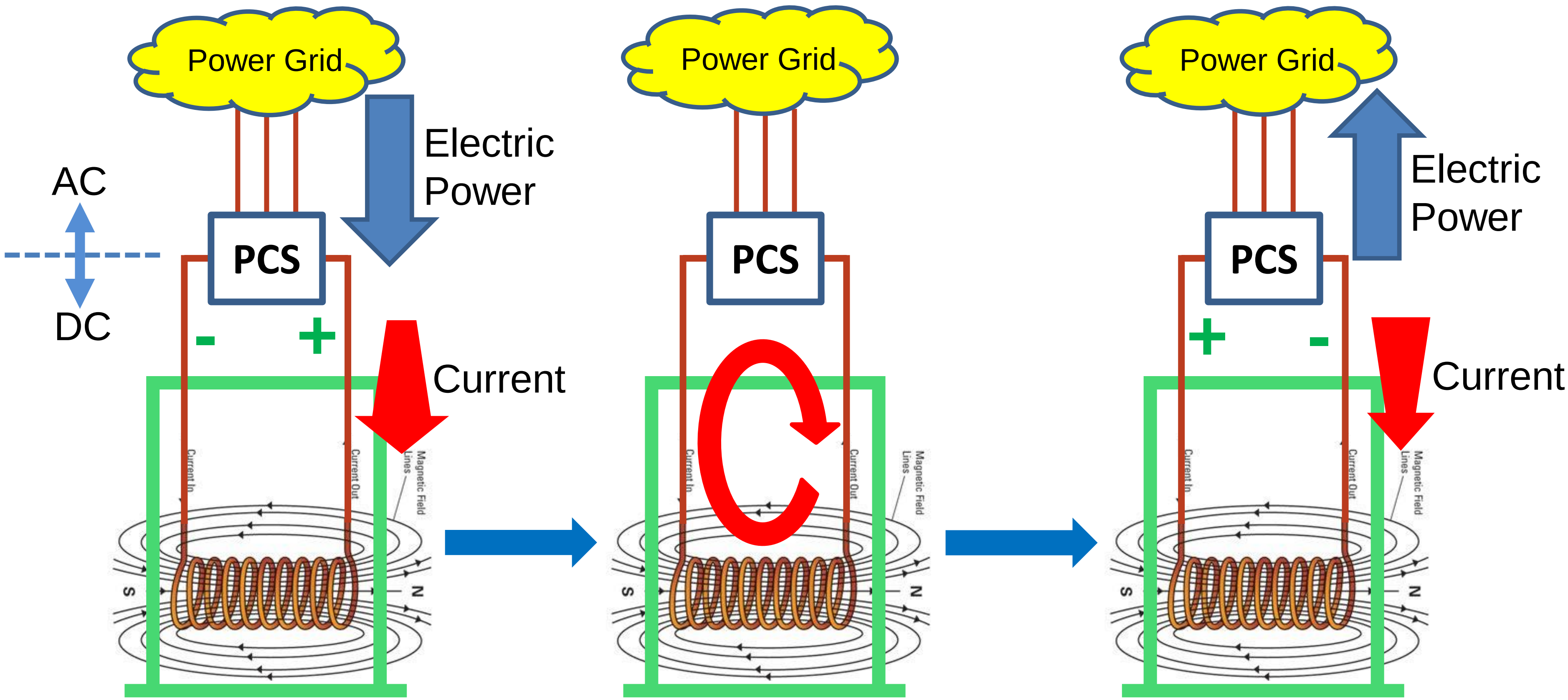
where,

E = energy measured in Joules

L = inductance measured in Henries

i = current measured in Amperes

SMES Operation Principle



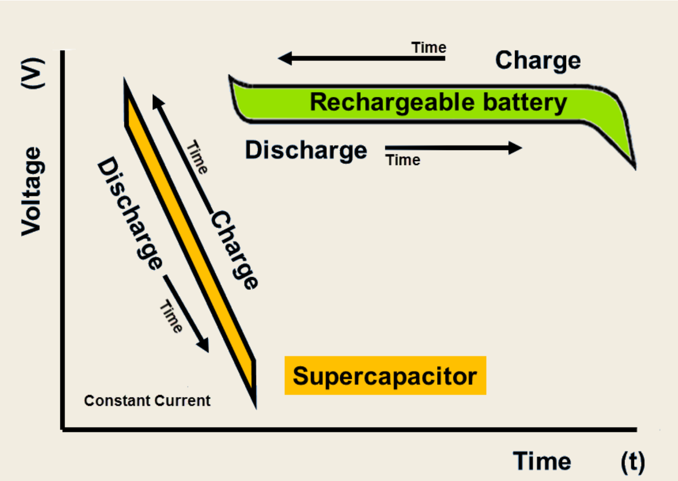
SMES Mode:	**Charge**	**Storage**	**Discharge**
PCS Mode:	**Rectifier** **AC -> DC**	**Zero Voltage**	**Inverter** **DC -> AC**

Supercapacitors, Ultracapacitors, Double-layer Capacitors

SUPERCAPACITORS

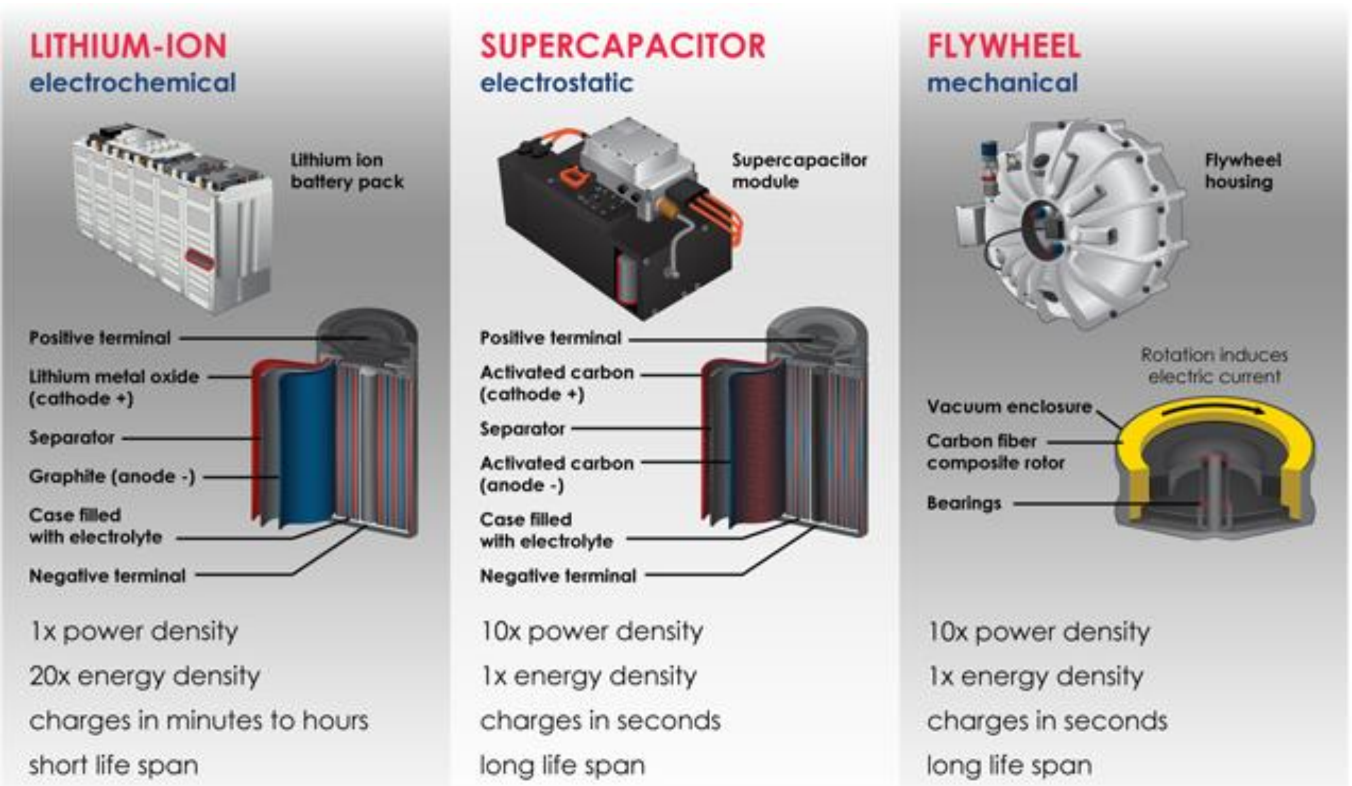
Supercapacitors (Ultracapacitors)

- A supercapacitors is a capacitor
  that can be defined as an energy storage device storing energy electrostatically by polarizing an electrolytic solution.
- Characteristics:
  - Store 10-100 times more energy per unit → Electrolytic caps
  - Charge/discharge time much faster → Battery



Source: MAXWELL TECHNOLOGIES, INC.

Supercapacitors Position



Source: WTWH Media, LLC.

Supercapacitors Position

Advantages	• Virtually unlimited cycle life; can be cycled millions of time • High specific power; low resistance enables high load currents • Charges in seconds; no end-of-charge termination required • Simple charging; draws only what it needs; not subject to overcharge • Safe; forgiving if abused • Excellent low-temperature charge and discharge performance
Limitations	• Low specific energy; holds a fraction of a regular battery • Linear discharge voltage prevents using the full energy spectrum • High self-discharge; higher than most batteries • Low cell voltage; requires series connections with voltage balancing • High cost per Wh

Source: https://batteryuniversity.com/learn/article/whats_the_role_of_the_supercapacitor

Supercapacitor Applications

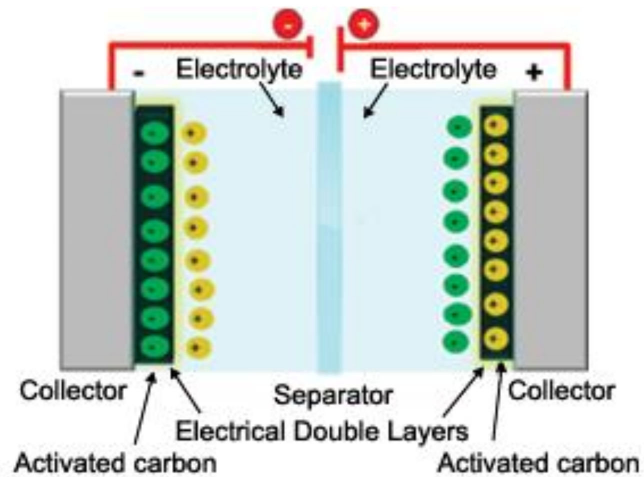
- **Solar and Wind Power Firming:**
  - To mitigate ms-s timeframe power fluctuations to ensure local power quality
- **Microgrids:**
  - Stand-alone asset or integrated with batteries to provide near real time frequency, voltage and power firming and smoothing in island mode.
- **Voltage Sag Mitigation and UPS:**
  - To provide voltage, frequency and power stabilization in near real time.

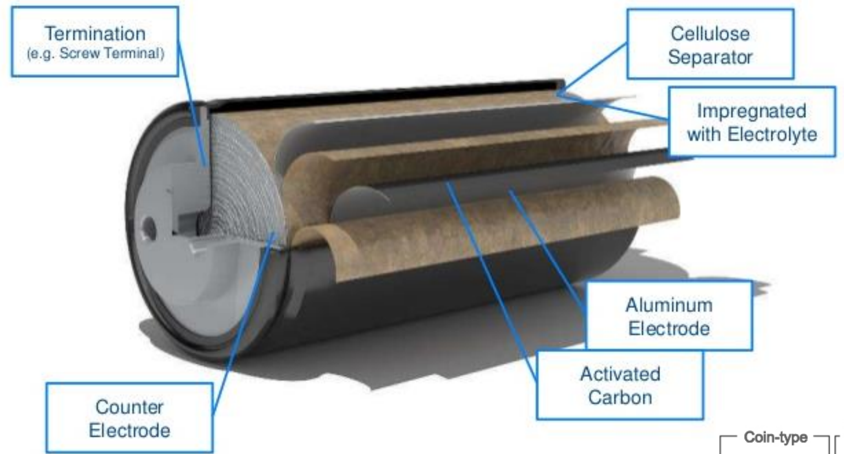
Source: https://www.maxwell.com/products/ultracapacitors/grid-energy-storage-system

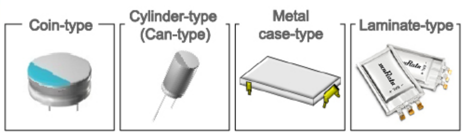
Supercapacitor Applications

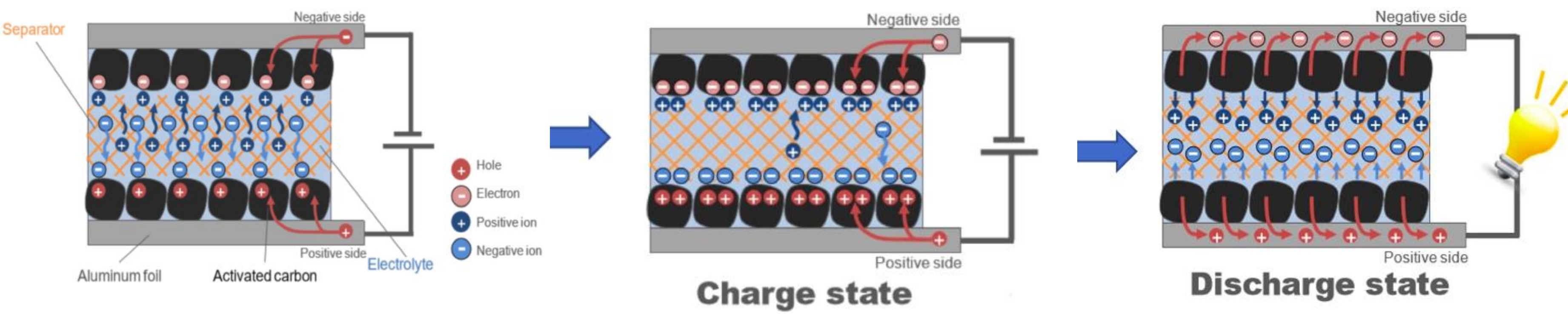
- **Primary Frequency Response:**
  - Fast response to mitigate, in near real time, a decrease in generation, generation-load imbalance and unpredictable variations in demand.
- **Generator Bridging, Ramping, and Regulation:**
  - provide controlled ramp rates from cycles-to-seconds-to-minutes until generator ramp is complete.
- **Hybrid Storage:**
  - Integrating battery with ultracapacitors to manage capacity, peak load and energy arbitrage.

Supercapacitor Structure & Operation Principle









Source: Murata Manufacturing Co., Ltd, KEMET

Stored Energy

- The electrostatic energy stored by a supercapacitor withstand a voltage is given by:

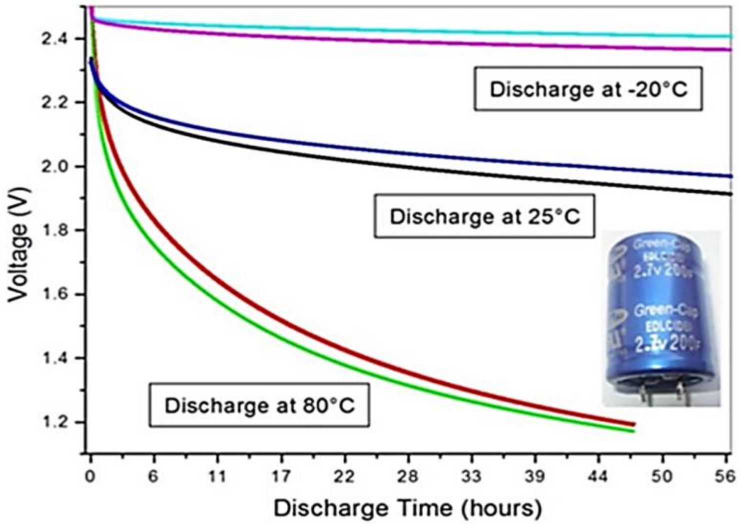
$$E = \frac{1}{2}Cv^2 \Rightarrow E_{discharge} = \frac{1}{2}C({v_{max}}^2 - {v_{min}}^2)$$

where,

E = Energy measured in Joules

C = Capacitance measured in Farads

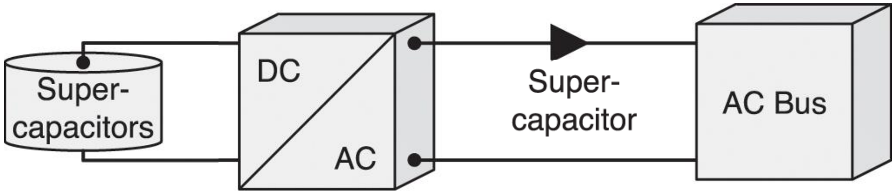
v = Voltage measured in Voltages



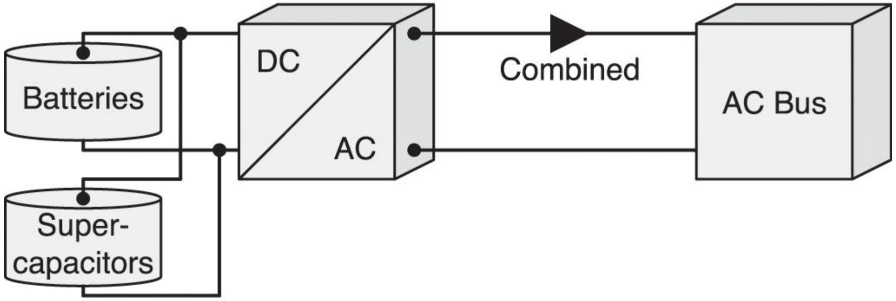
Source: P. Svasta et.al., "Supercapacitors - an Alternative Electrical Energy Storage device"

Supercapacitor ESS

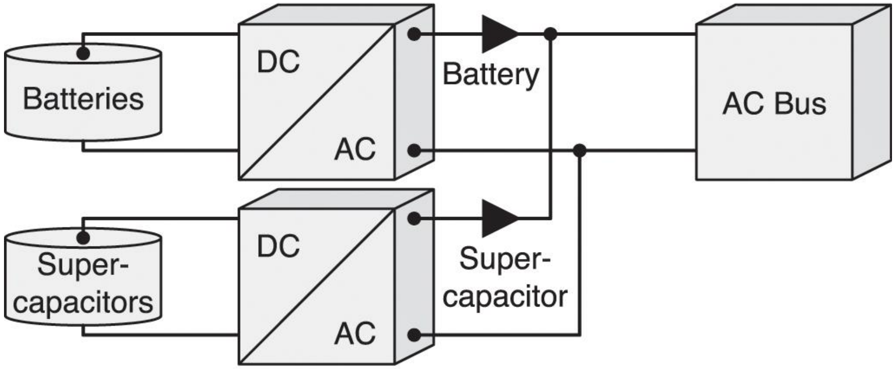
❶ Homogeneous



❷ Passive Hybrid

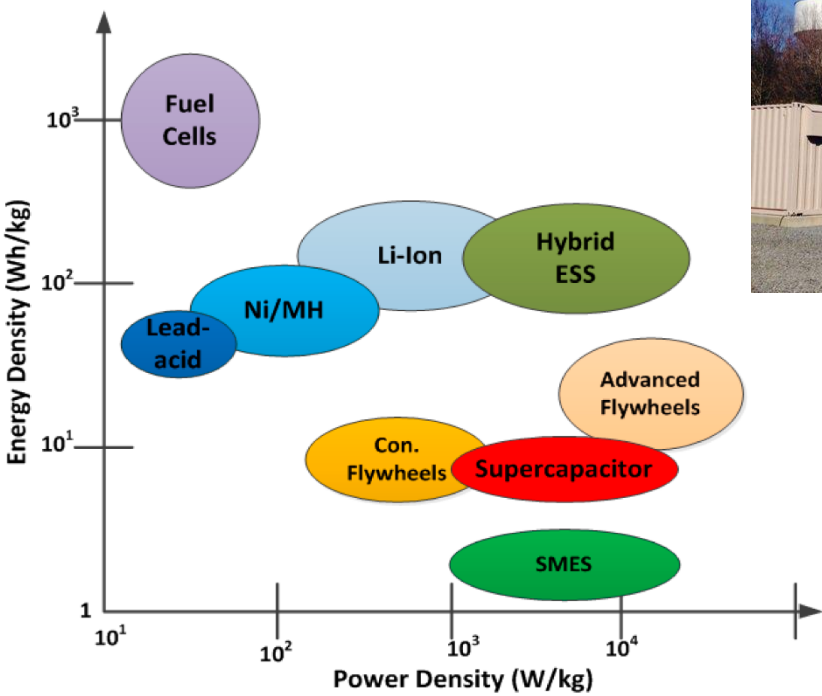


❸ Active Hybrid



Source: Younghyun Kim, “Design and Management of Battery-Supercapacitor Hybrid Electrical Energy Storage Systems for Regulation Services

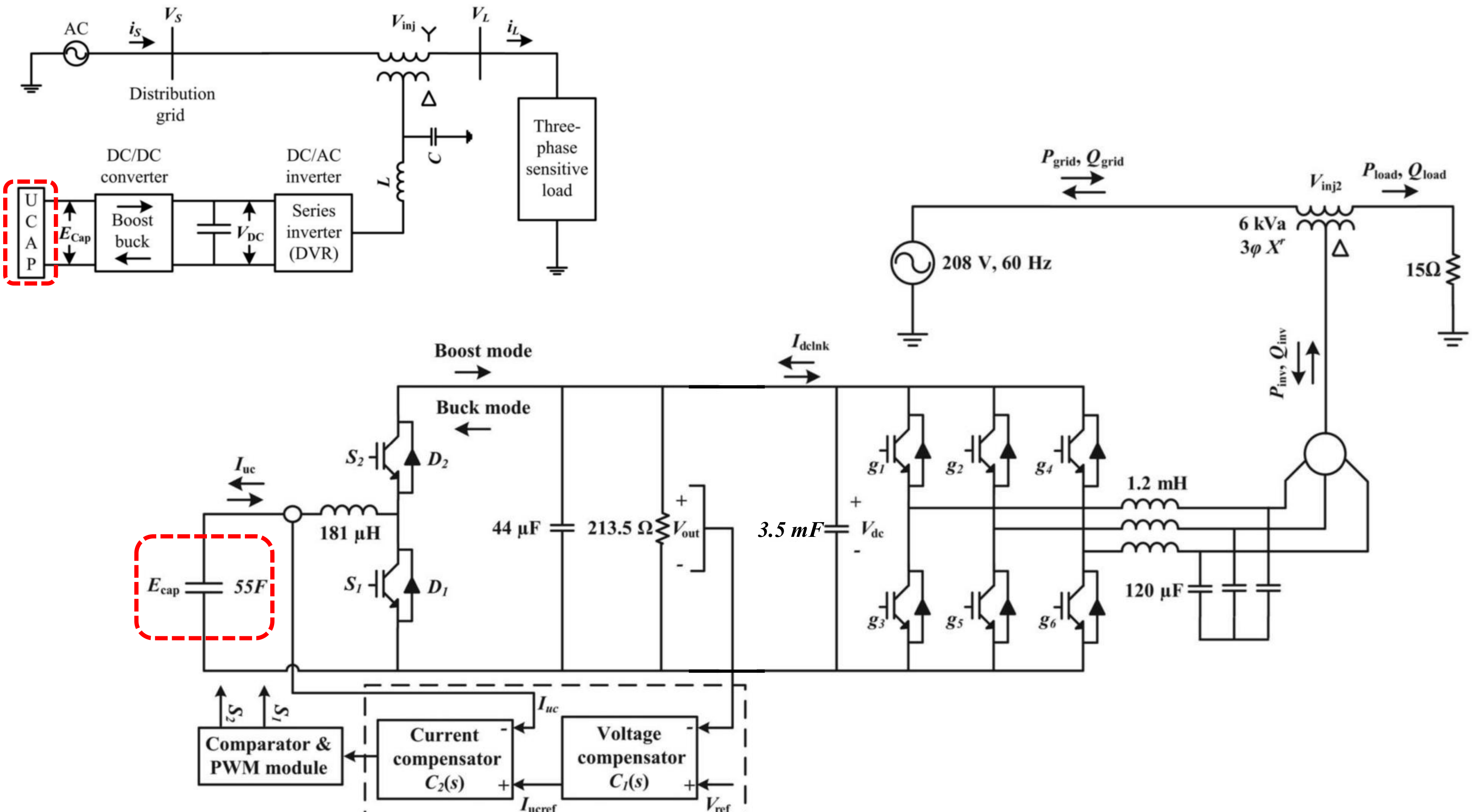
Hybrid Energy Storage System



Source: Google, Shantha Gamini Jayasinghe et.al, “Review of Ship Microgrids: System Architectures, Storage Technologies and Power Quality Aspects

Example of Supercapacitor Applications:

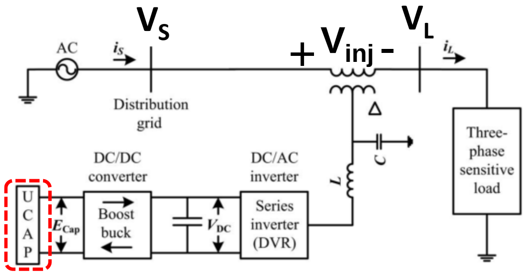
Dynamic Voltage Restorer (DVR)



Source: Deepak Somayajula and Mariesa L. Crow, "An Integrated Dynamic Voltage Restorer-Ultracapacitor Design for Improving Power Quality of the Distribution Grid

Example of Supercapacitor Applications:

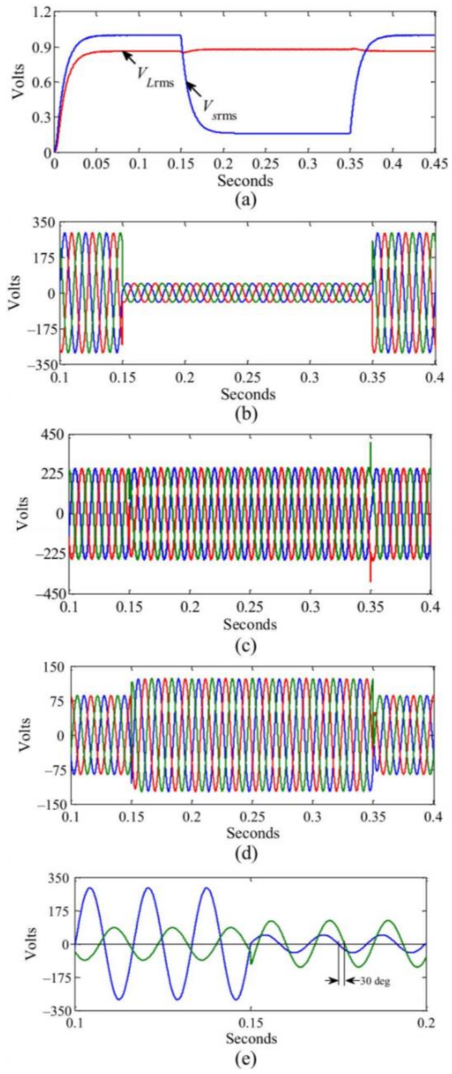
Dynamic Voltage Restorer (DVR)

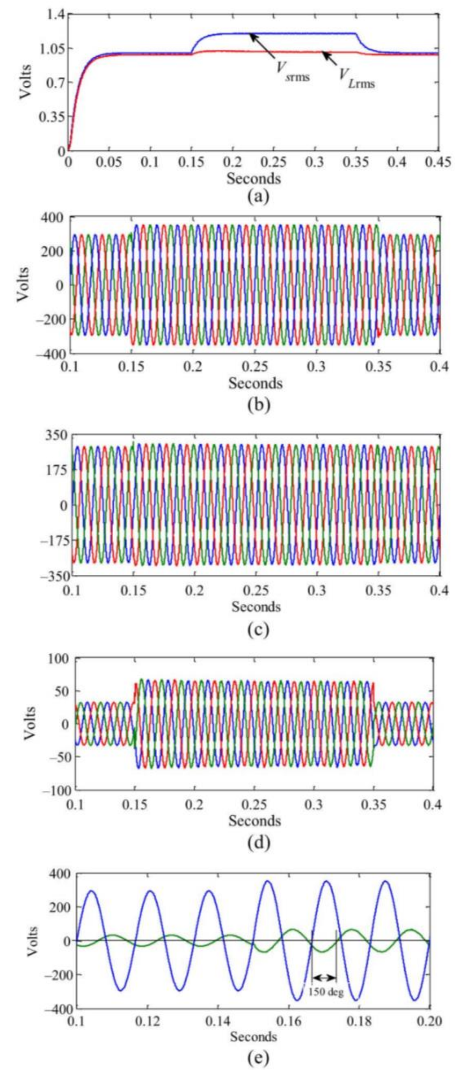


Source Voltage, $\mathbf{V_S}$

Load Voltage, $\mathbf{V_L}$

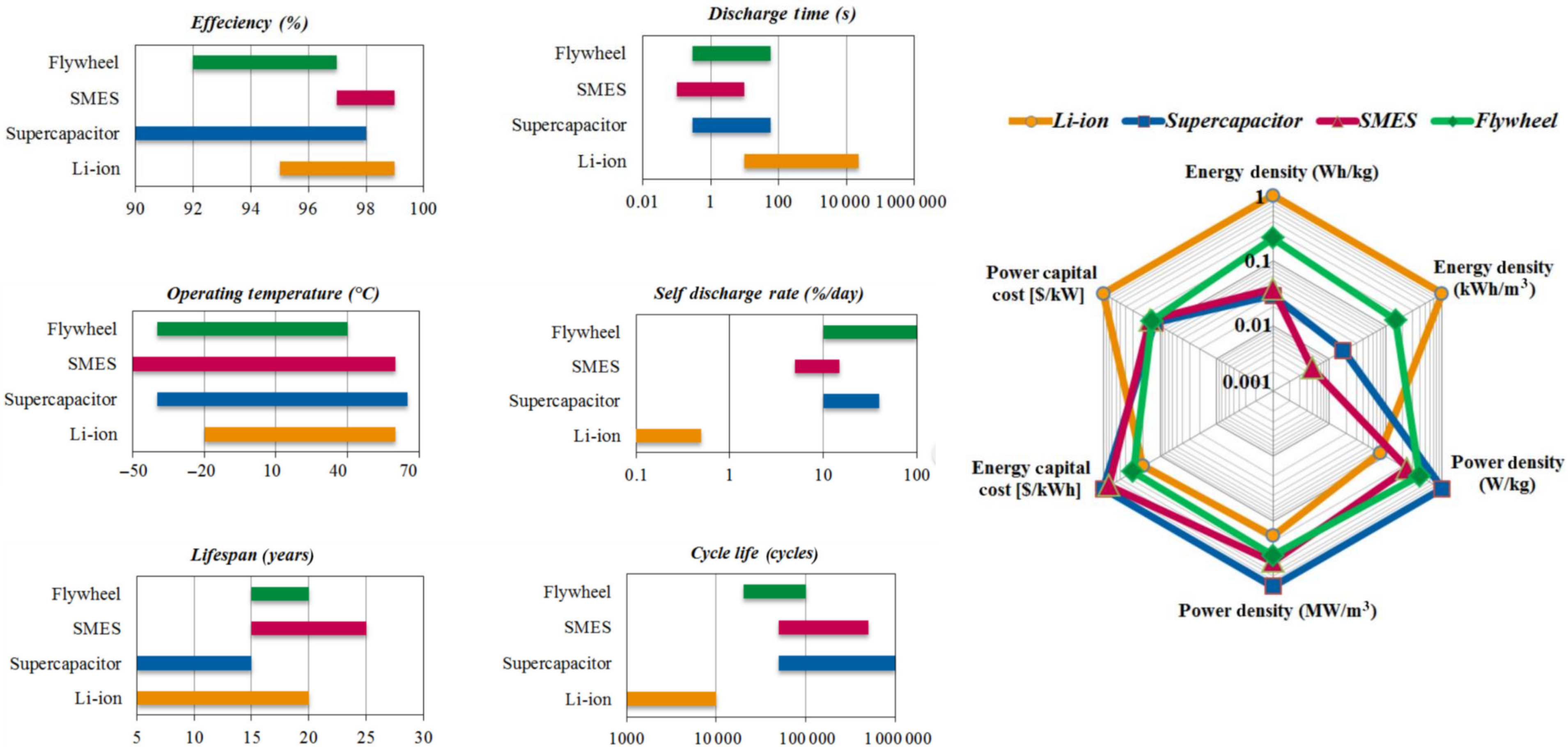
Injected Voltage, $\mathbf{V_{inj}}$





Source: Deepak Somayajula and Mariesa L. Crow, "An Integrated Dynamic Voltage Restorer-Ultracapacitor Design for Improving Power Quality of the Distribution Grid

Recent Trend of SMES and Supercapacitors



Source: Mustafa Farhadi et.al., "Energy Storage Technologies for High-Power Applications"