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An Introduction to Battery Energy Storage Systems and Their Power System Support

18 April 2024 | Technical Topic Webinar

Presenter by

Dr. Hossein Dehghani Tafti, EIT Lecturer

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Agenda

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1	Welcome and Introduction
2	High Penetration of Renewable Energy Resources - Challenges
3	Energy Storage Technologies
4	Overview of Battery Storage Technologies
5	Battery Power Converter Systems
6	Power System Support
7	Safety Standards for Battery Systems
8	Emerging Technologies and Prospects
9	Conclusion and Q&A

Introduction - Presenter

Hossein Dehghani Tafti

Lecturer/Course Coordinator at EIT

Research Fellow at The University of Western Australia – Magellan Powertronic Pty Ltd

Senior Research Associate at UNSW Sydney

Research Fellow at Nanyang Technological University

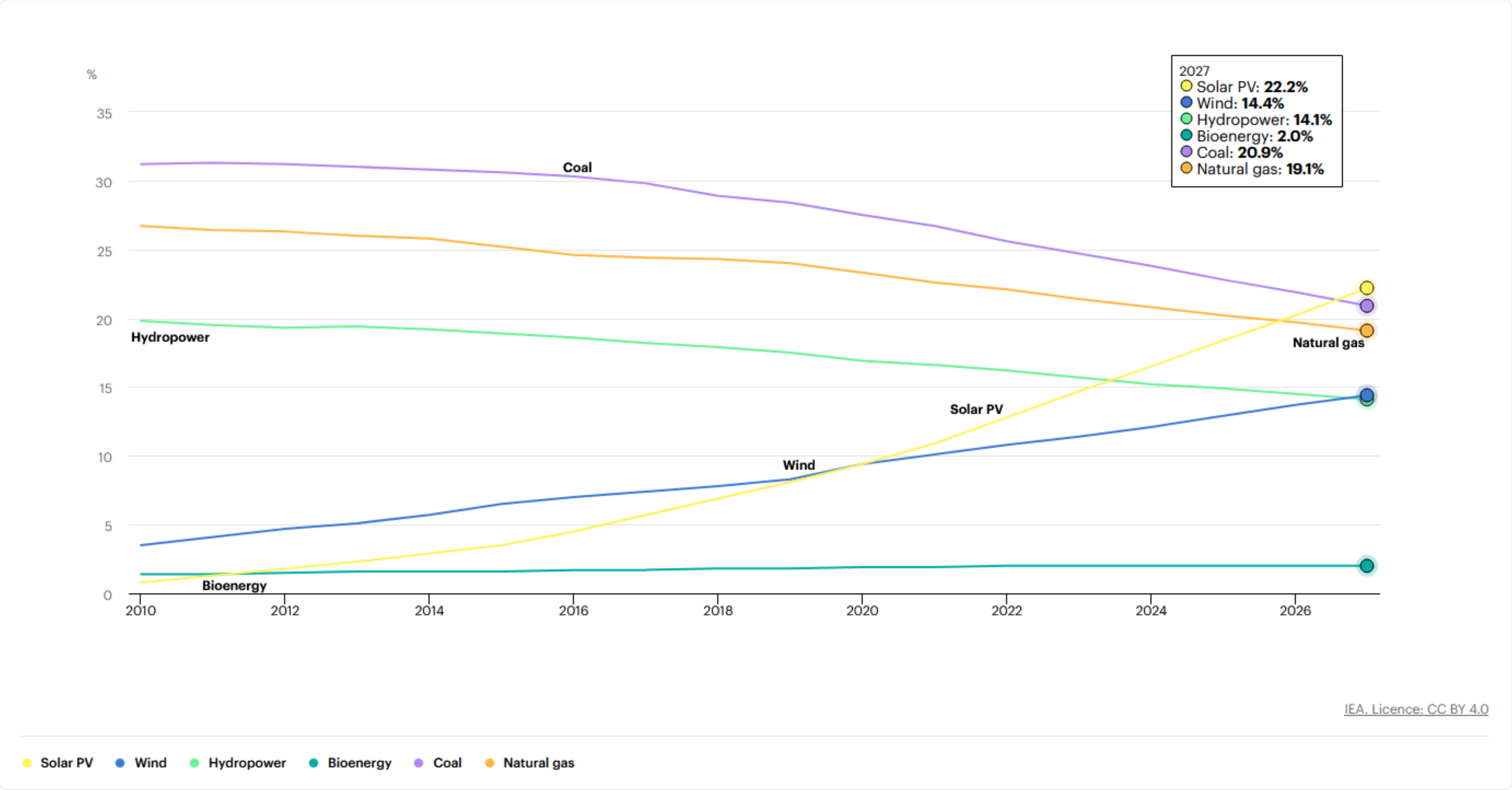
PhD in Power Electronics and Power Engineering (2018) from Nanyang Technological University, Singapore

MSc in Power Engineering from Amirkabir University of Technology, Iran (2011)

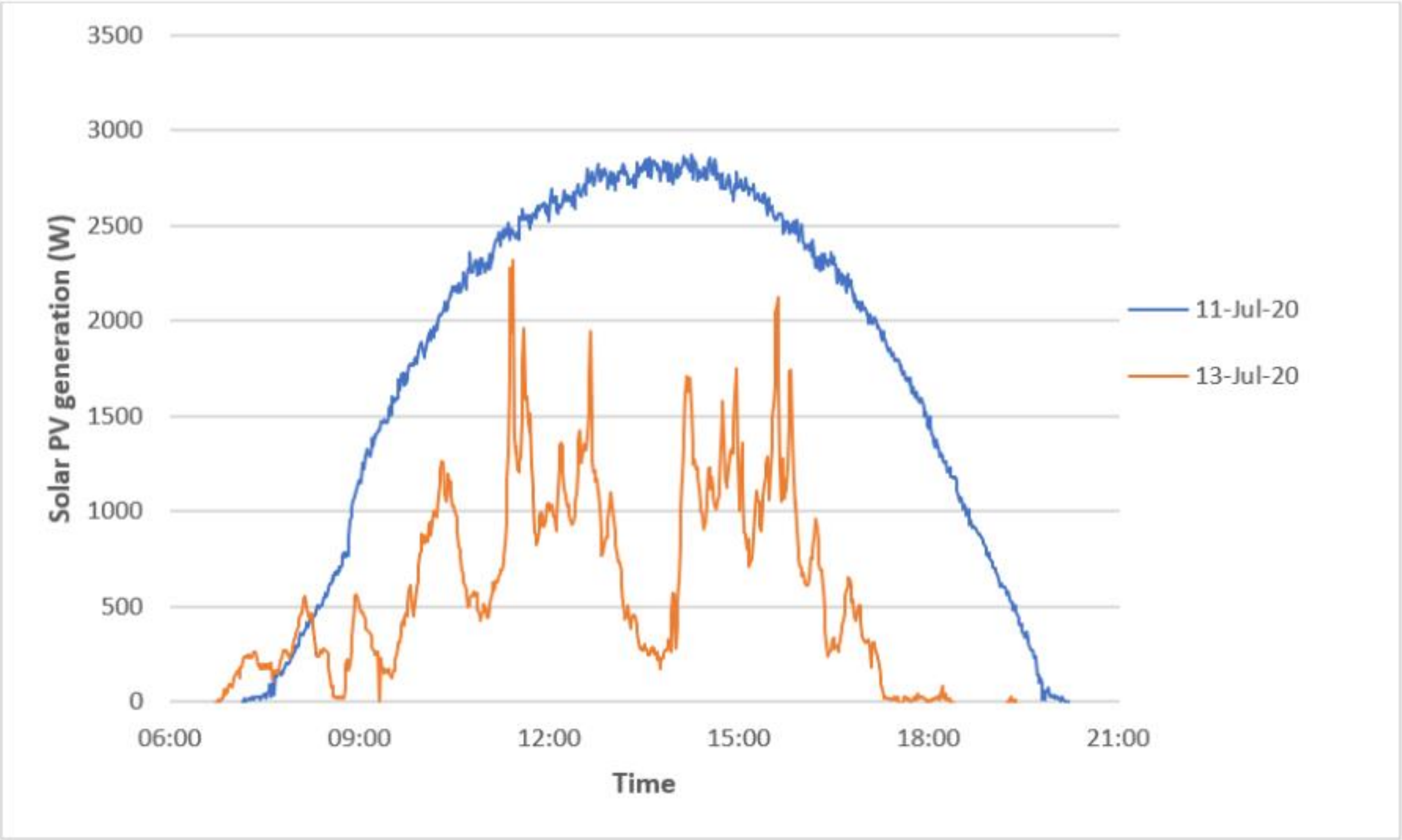
BSc in Power Engineering from Amirkabir University of Technology, Iran (2009)

2. High Penetration of Renewable Energy Resources - Challenges

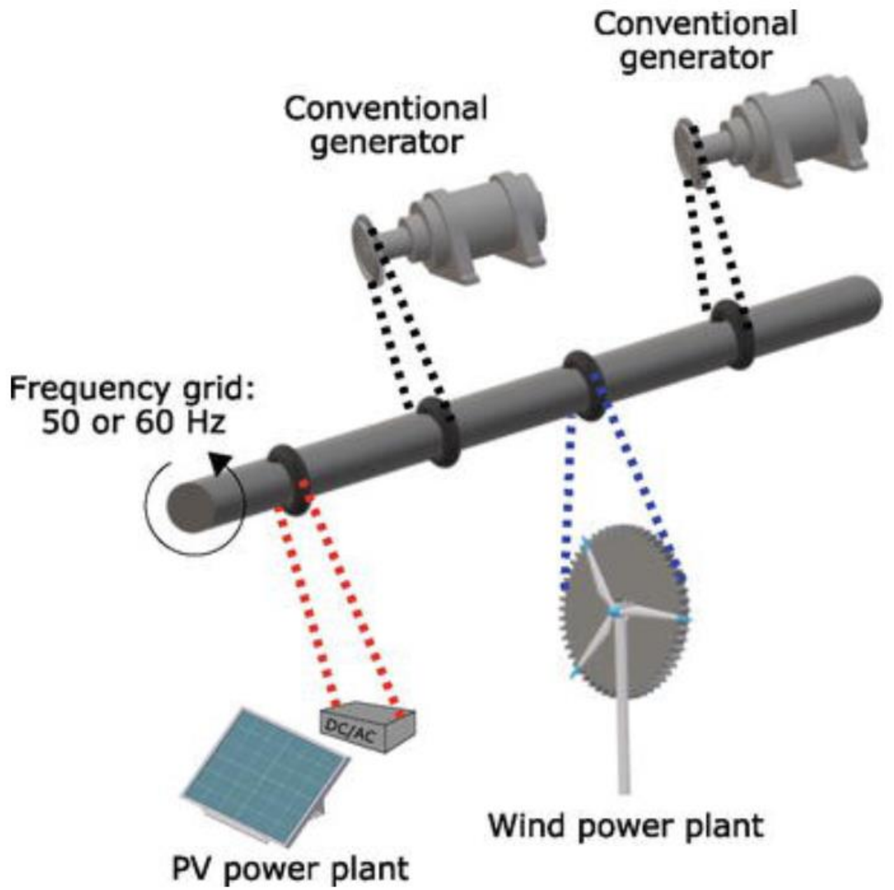
High penetration of renewable energy

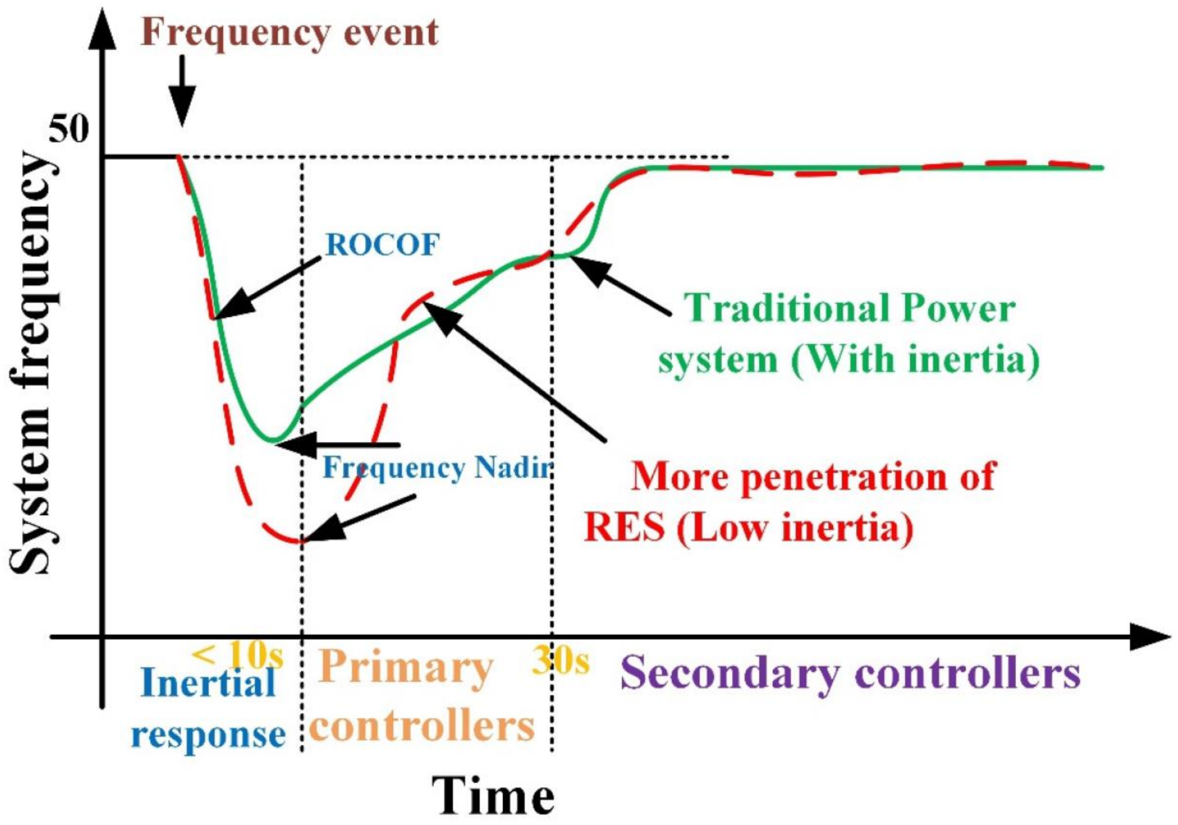


Output power fluctuation of photovoltaic



Low inertia power systems



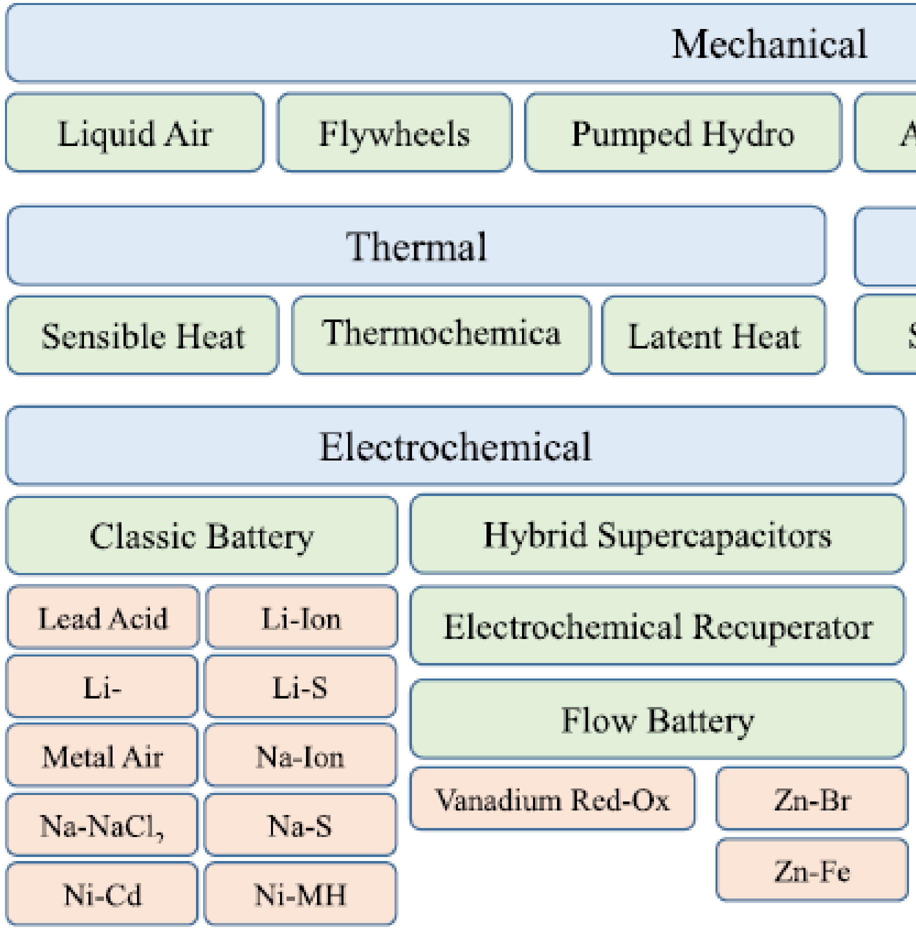


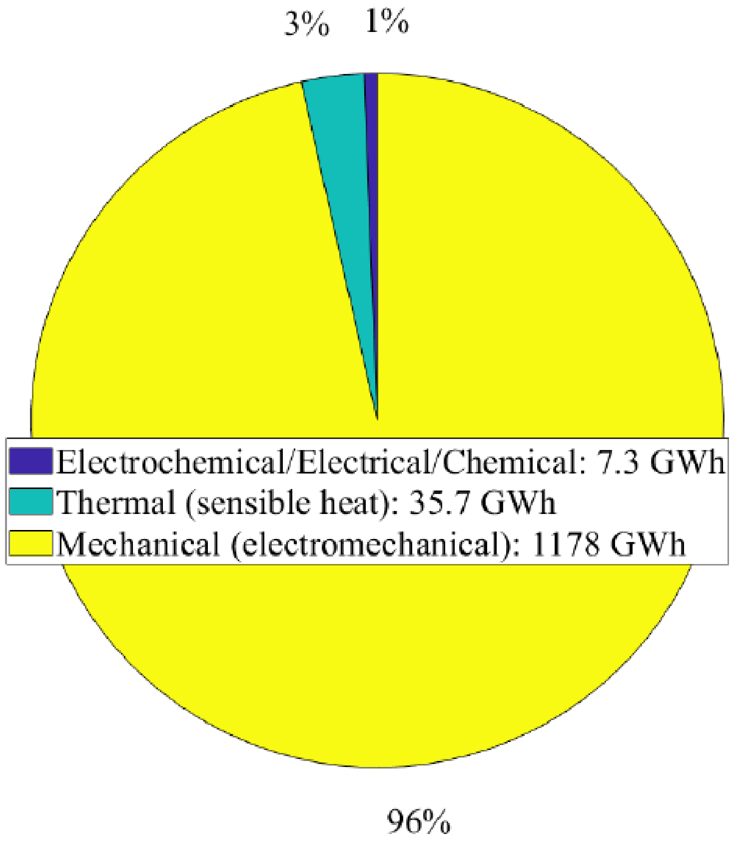
High penetration of renewable energy

- Lack of visibility of operation to power system operators
- Lack of central control
- …

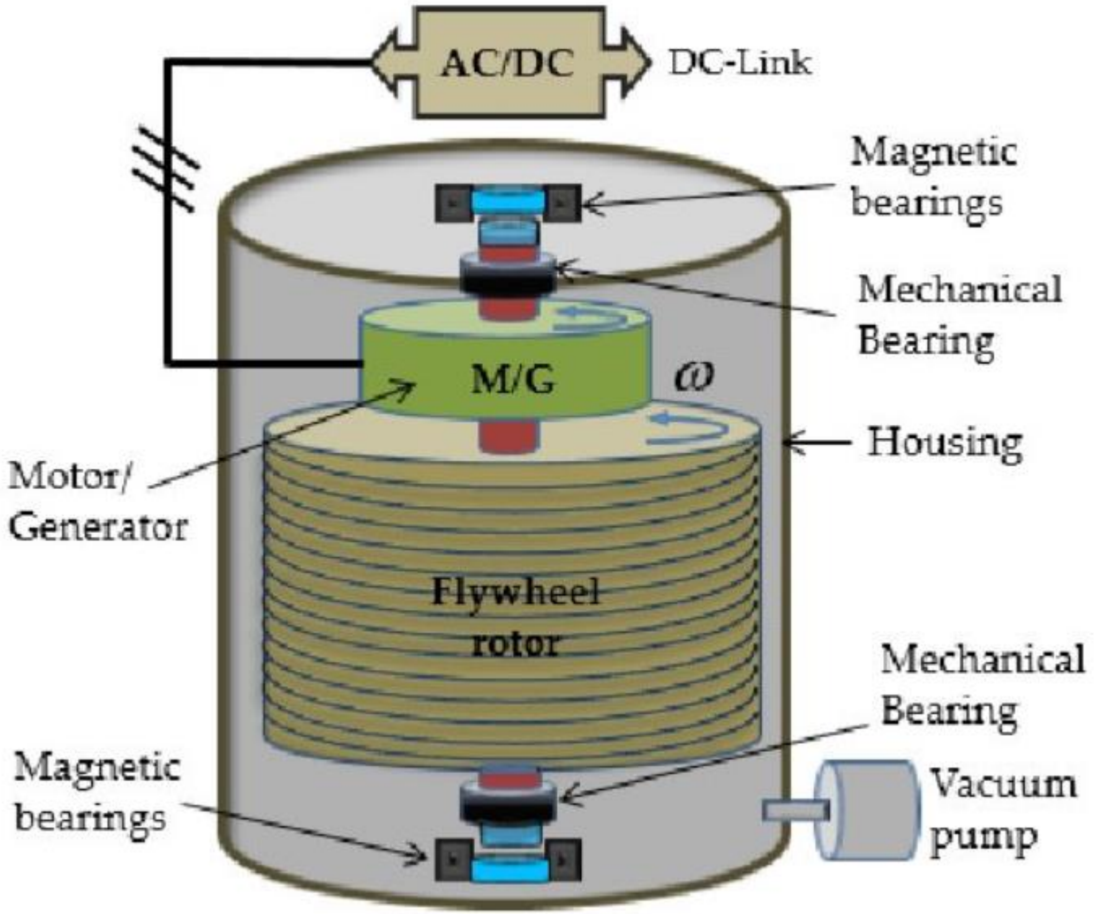
3. Energy Storage Technologies

Energy storage technologies

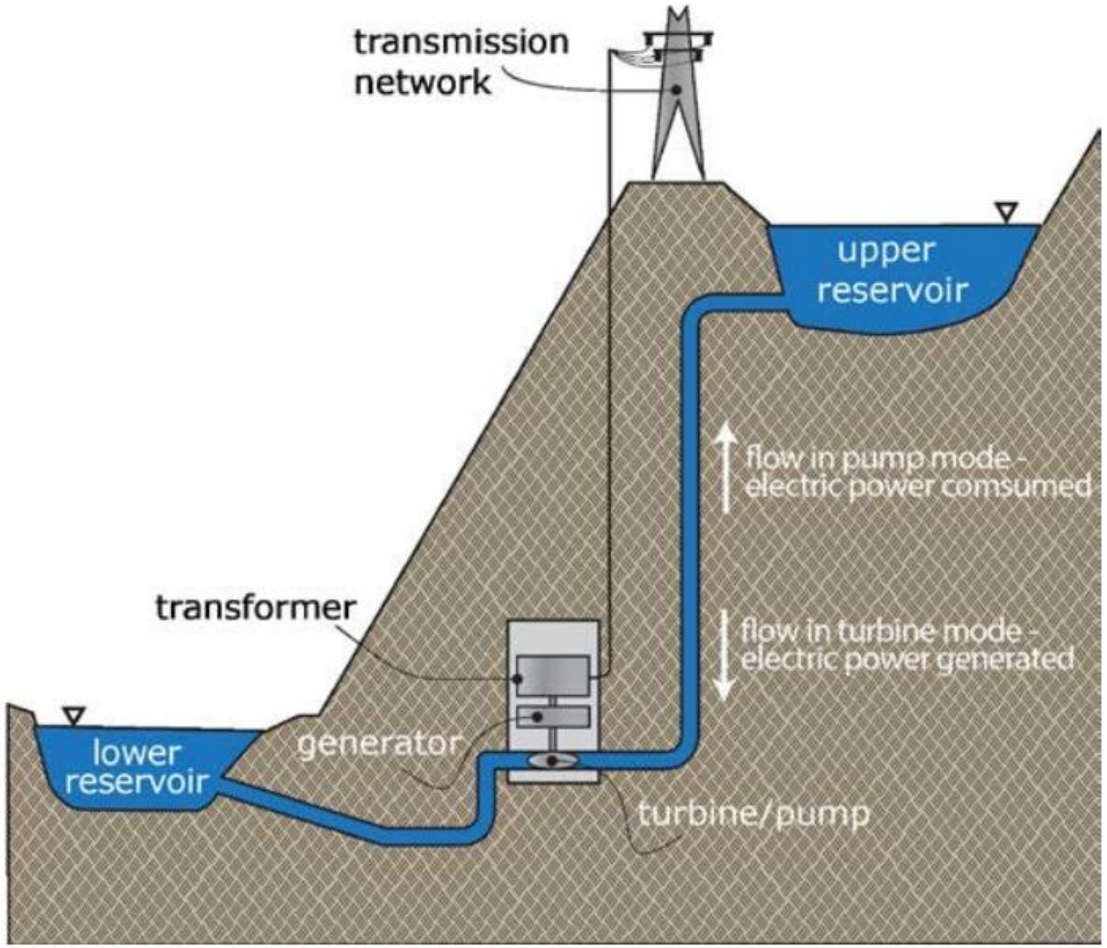




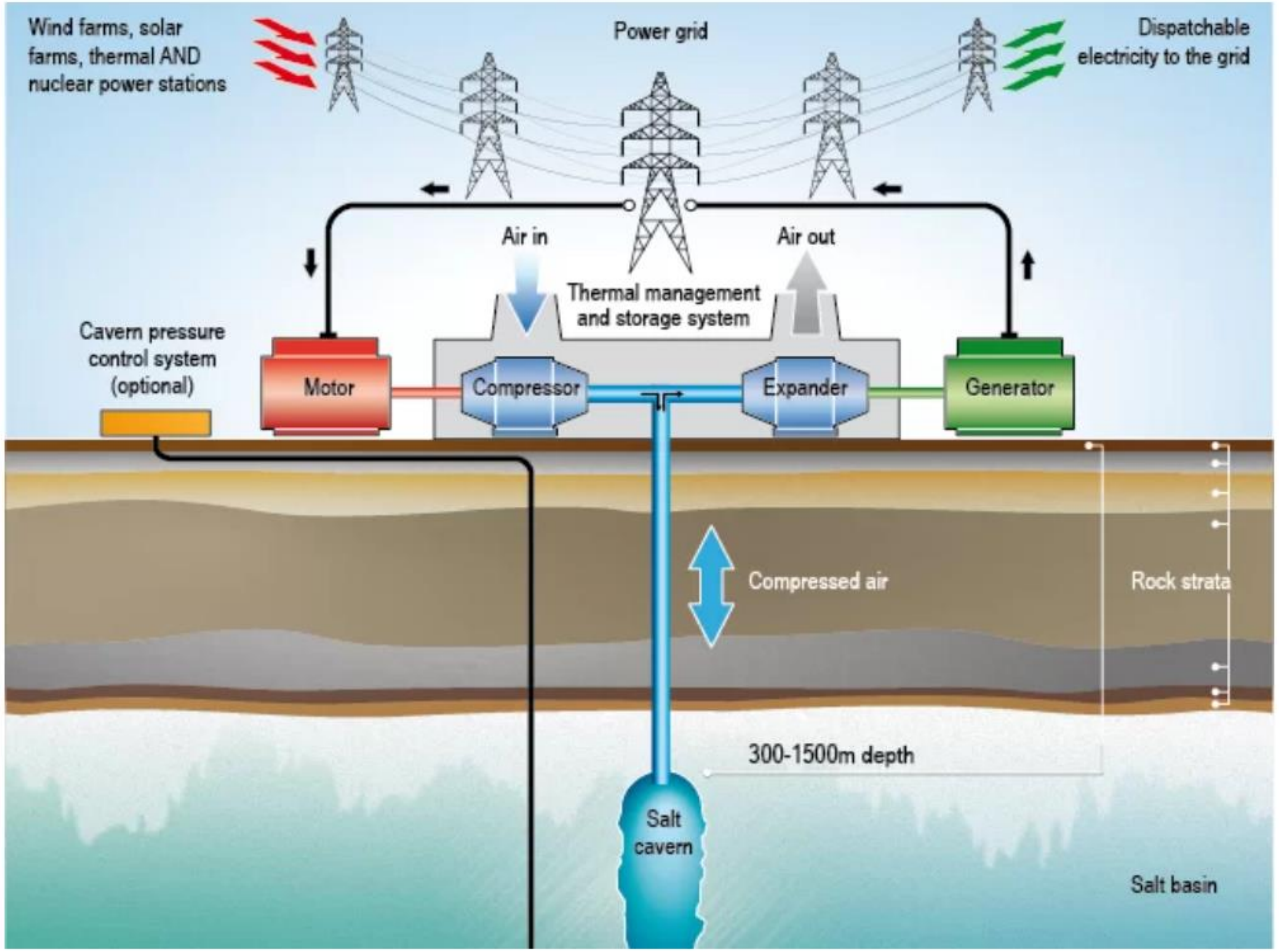
Flywheel energy storage



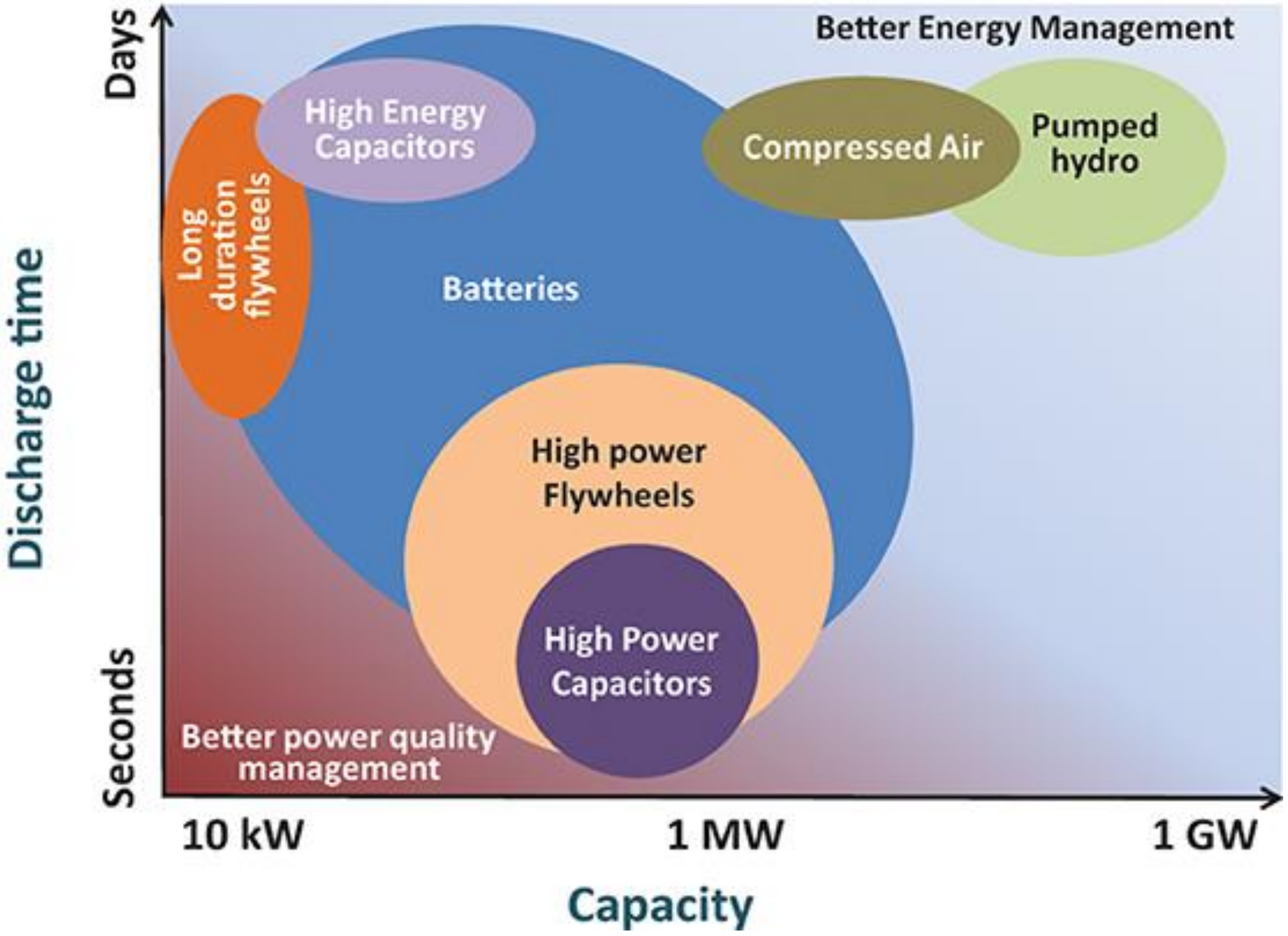
Pumped Hydro Energy storage



Compressed air energy storage

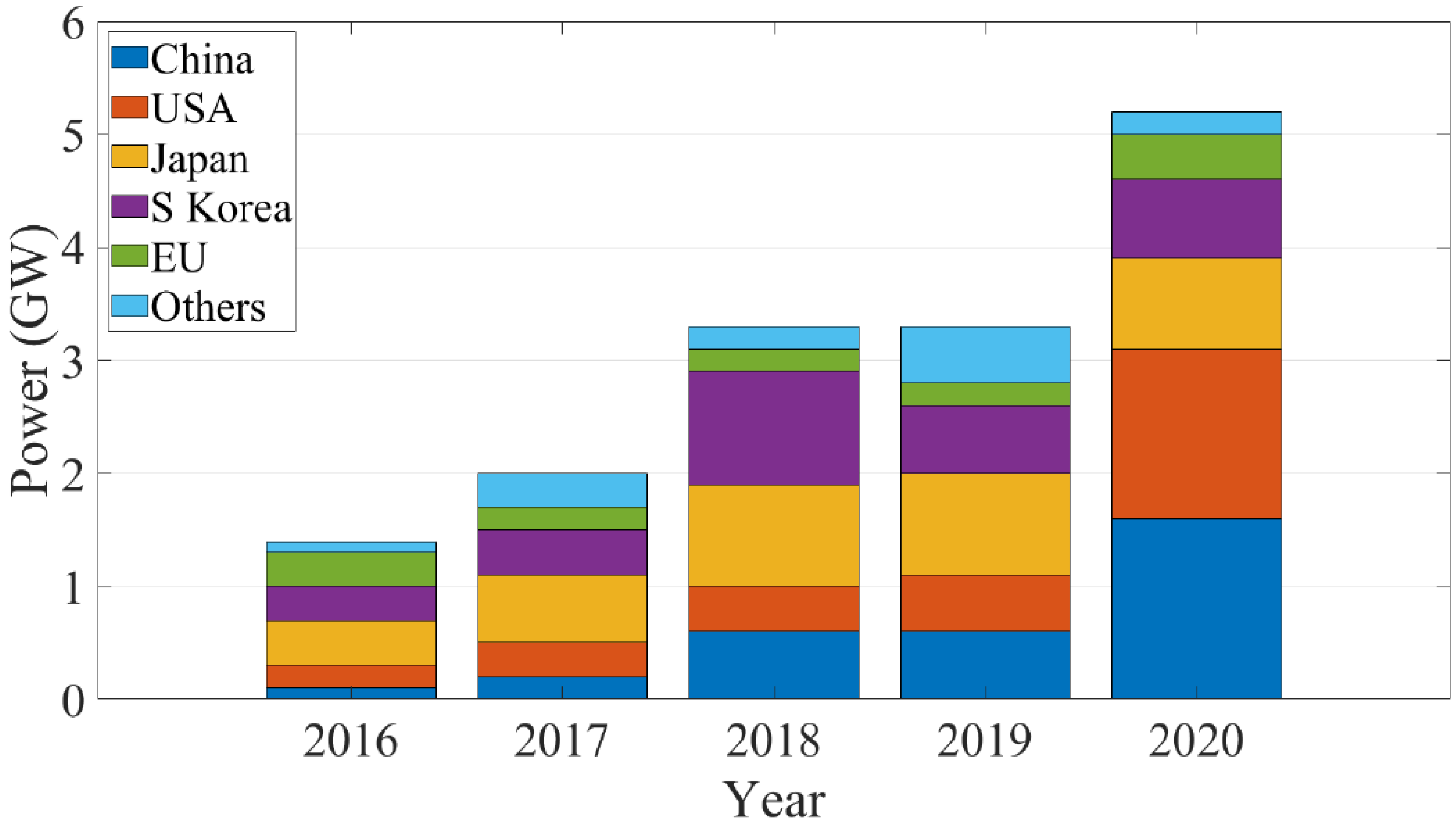


Comparison of energy storage technologies

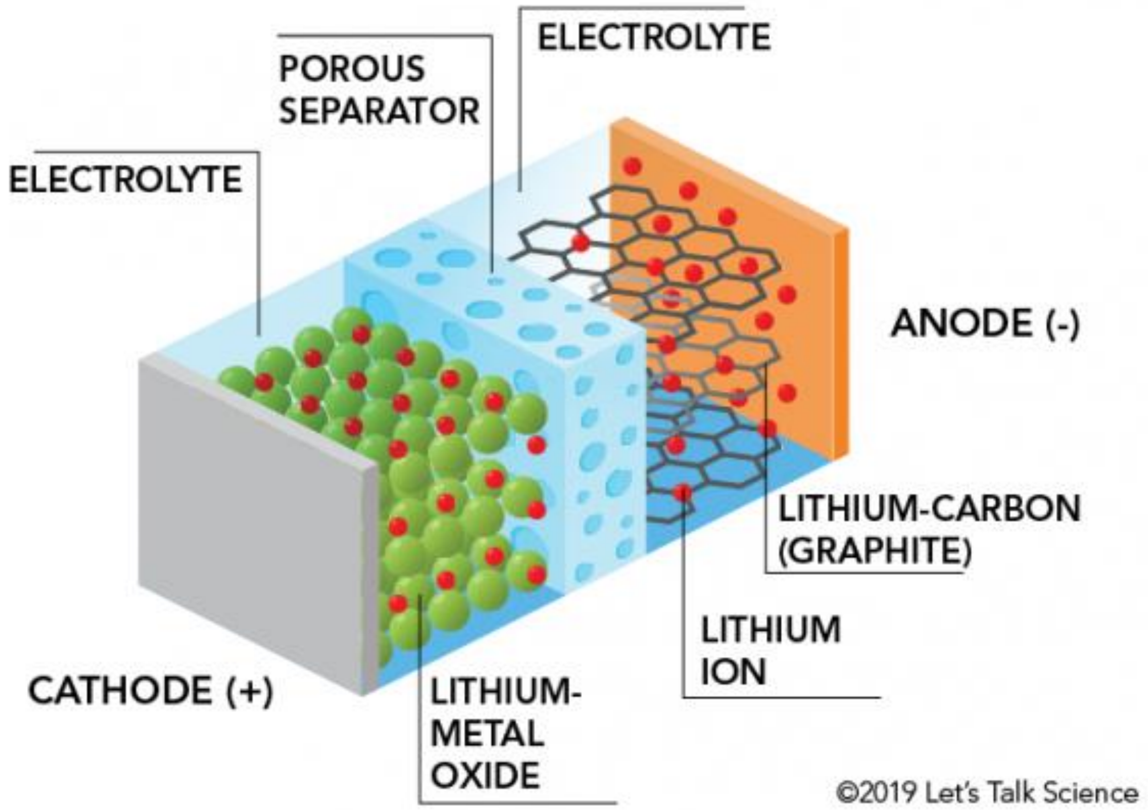


4. Overview of Battery Storage Technologies

Quick Comparison of different battery technologies



Lithium-ion (Li-ion) Battery



- ❖ **Anode (negative electrode):**

$$C_n + xLi^+ + xe^- \underset{discharge}{\overset{charge}{\rightleftarrows}} Li_xC_n$$

- ❖ **Cathode (positive electrode):**

$$LiXO_2 \underset{discharge}{\overset{charge}{\rightleftarrows}} Li_{1-x}XO_2 + xLi^+ + xe^-$$

- ❖ **Overall:**

$$LiXO_2 + C_n \underset{discharge}{\overset{charge}{\rightleftarrows}} Li_xC_n + Li_{1-x}XO_2$$

➢ (300) Lithium-ion battery, How does it work? – YouTube

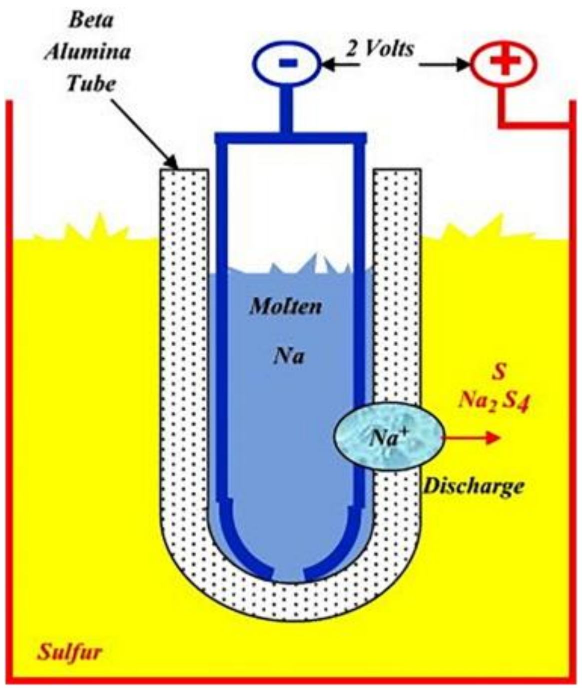
Sodium Sulfur Battery

Engineering Institute of Technology.

- Liquid Electrodes & Solid Electrolyte (Separator)

Negative Electrode: Liquid Sodium (Molten), Surrounded by Tube Shape Electrolyte (Beta Alumina Tube)

Positive Electrode: Liquid Sulfur (Embedded in Carbon Felt)



Note: Electrodes are Melted to Liquid States under High Temperature ($300^oC \sim 350^oC$). At this temperature, Solid Electrolyte is Good Conductor of Ions in Reactions.

Anode: $2Na \Leftrightarrow 2Na^+ + 2e^-$

Cathode: $xS + 2e^- \Leftrightarrow S_x^{2-}$

Overall: $2Na + xS \Leftrightarrow Na_2S_x$

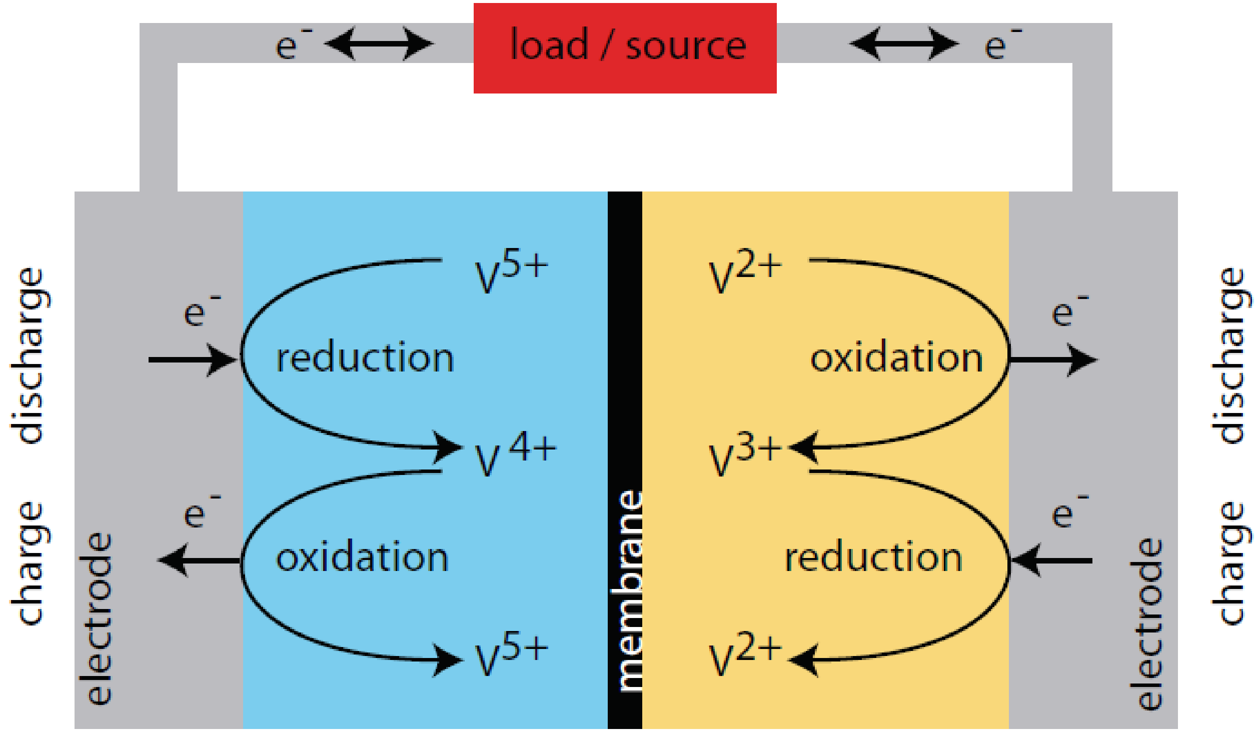
Discharge: Sodium in Negative Electrode is Oxidized into Sodium Ions, Flowing through Electrolyte to Positive Electrode & Combine with Sulfur → Sodium Polysulfides

Charge: Sodium Polysulfides Decompose

Sodium Ions go back through Electrolyte

Vanadium Redox Flow Battery

- Electrochemical Reactions in VRB: exploiting vanadium's ability to exist in 4 different oxidation states, i.e. V^{2+}, V^{3+}, V^{4+} and V^{5+}.

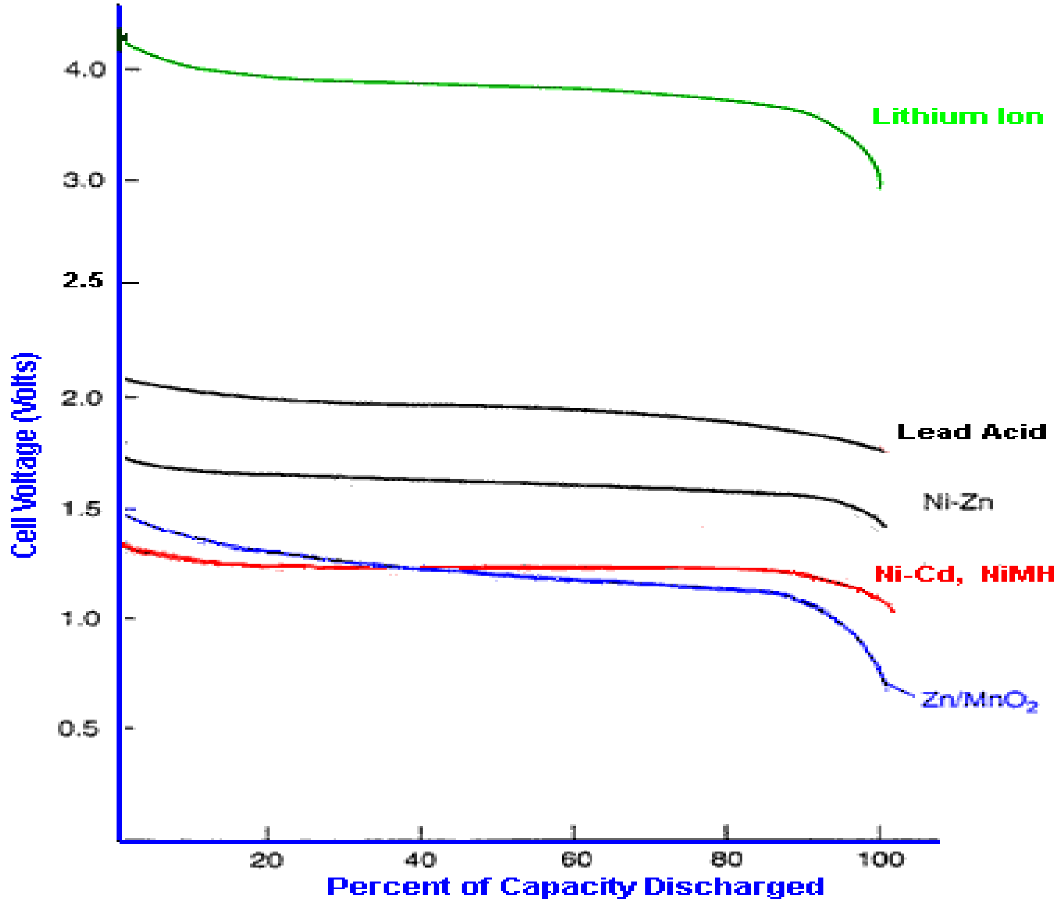


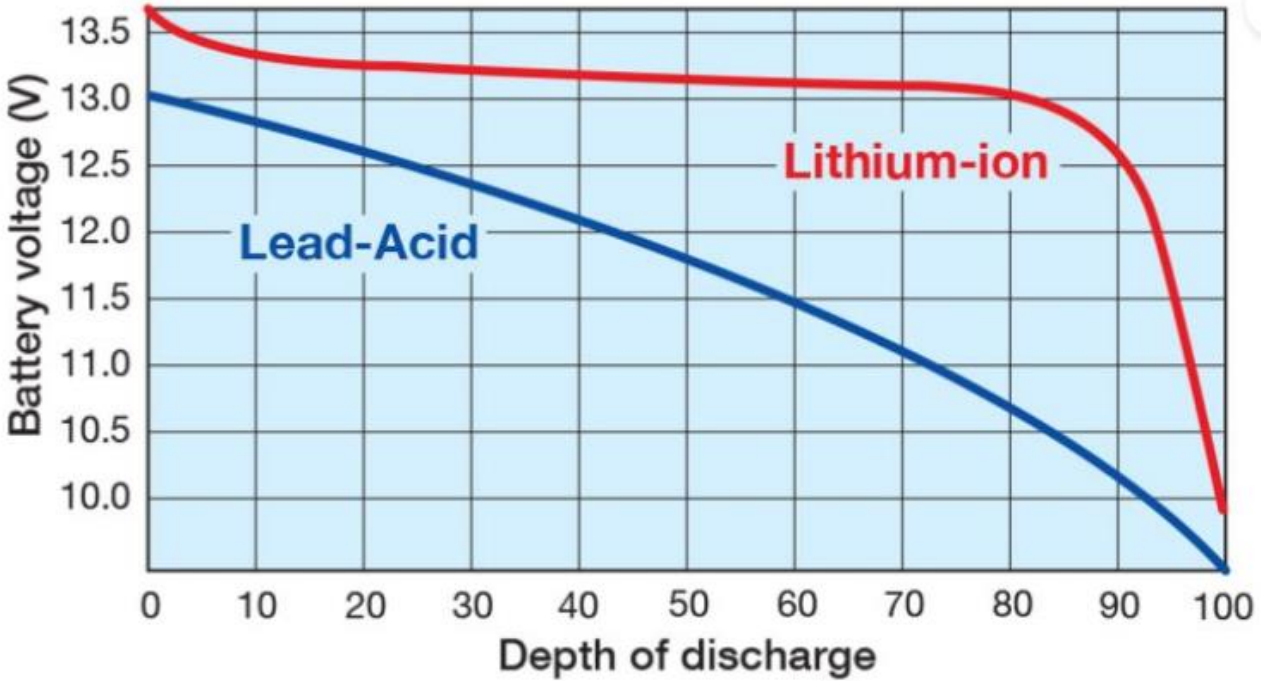
Positive Electrode: $VO_2^+ + 2H^+ + e^- \rightleftarrows VO^{2+} + H_2O$

Negative Electrode: $V^{2+} \rightleftarrows V^{3+} + e^-$

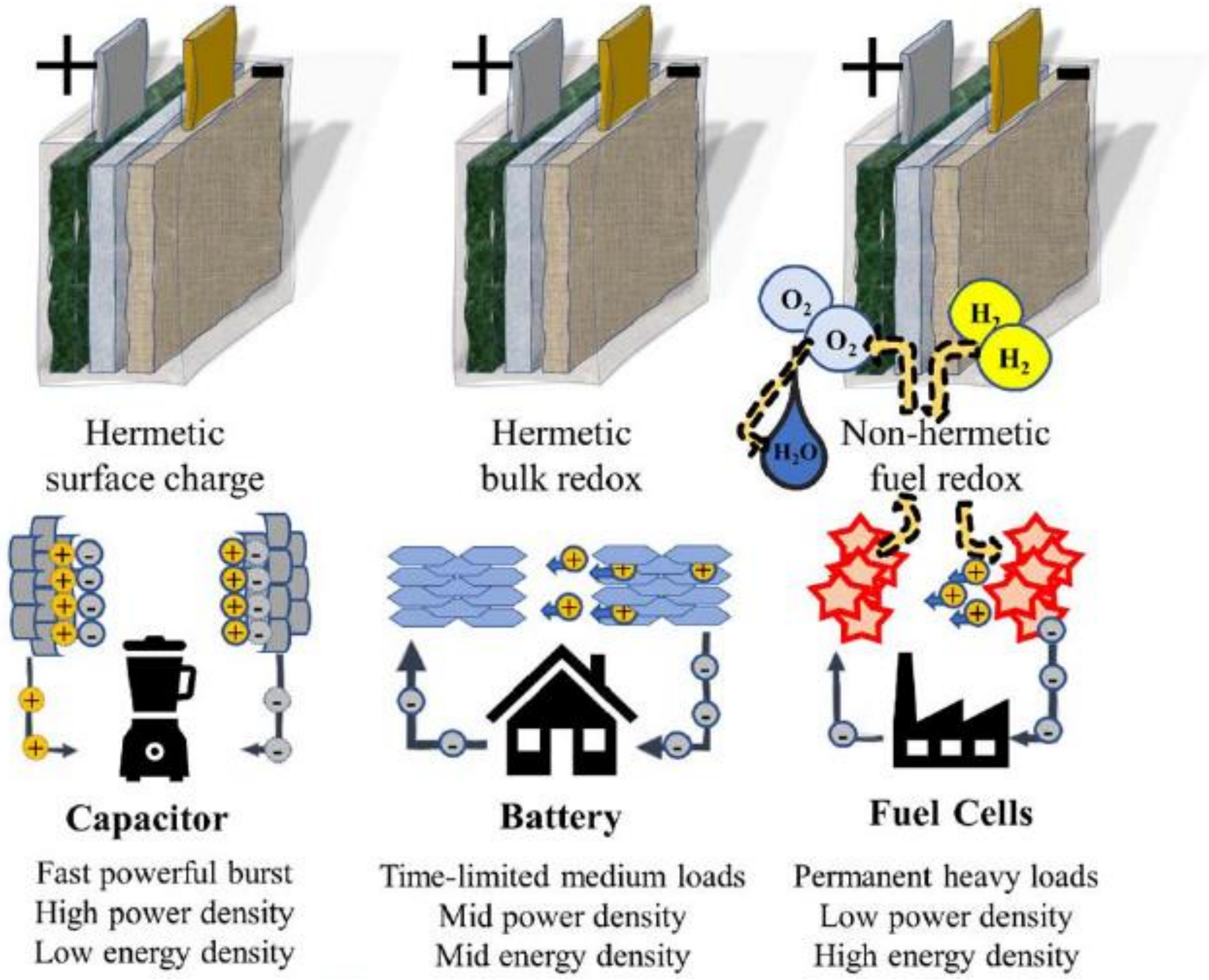
Overall: $V^{2+} + VO_2^+ + 2H^+ \rightleftarrows VO^{2+} + V^{3+} + H_2O$

Voltage Performance Comparison



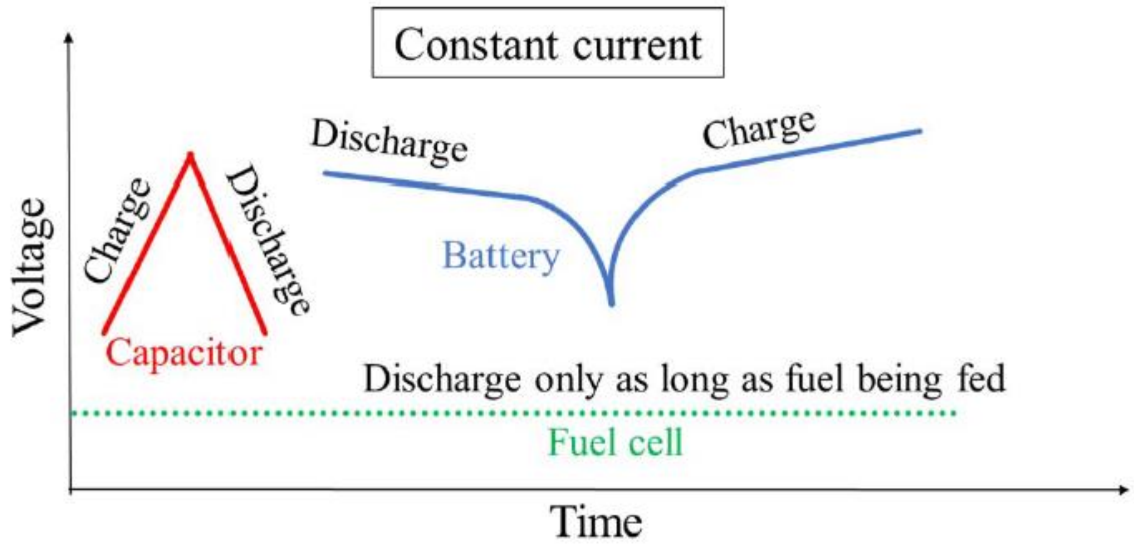


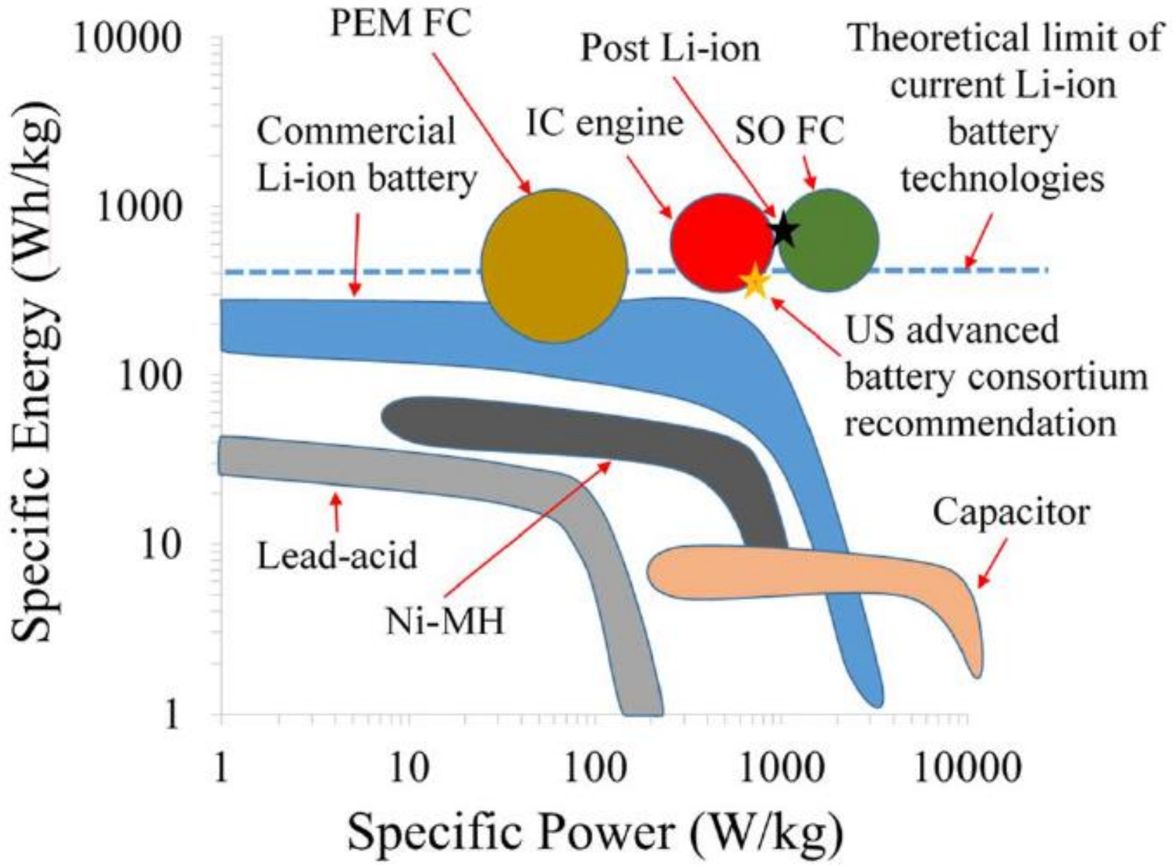
Quick Comparison of different battery technologies



G. G. Farivar *et al.*, "Grid-Connected Energy Storage Systems: State-of-the-Art and Emerging Technologies," in *Proceedings of the IEEE*, vol. 111, no. 4, pp. 397-420, April 2023

Quick Comparison of different battery technologies





Quick Comparison of different battery technologies

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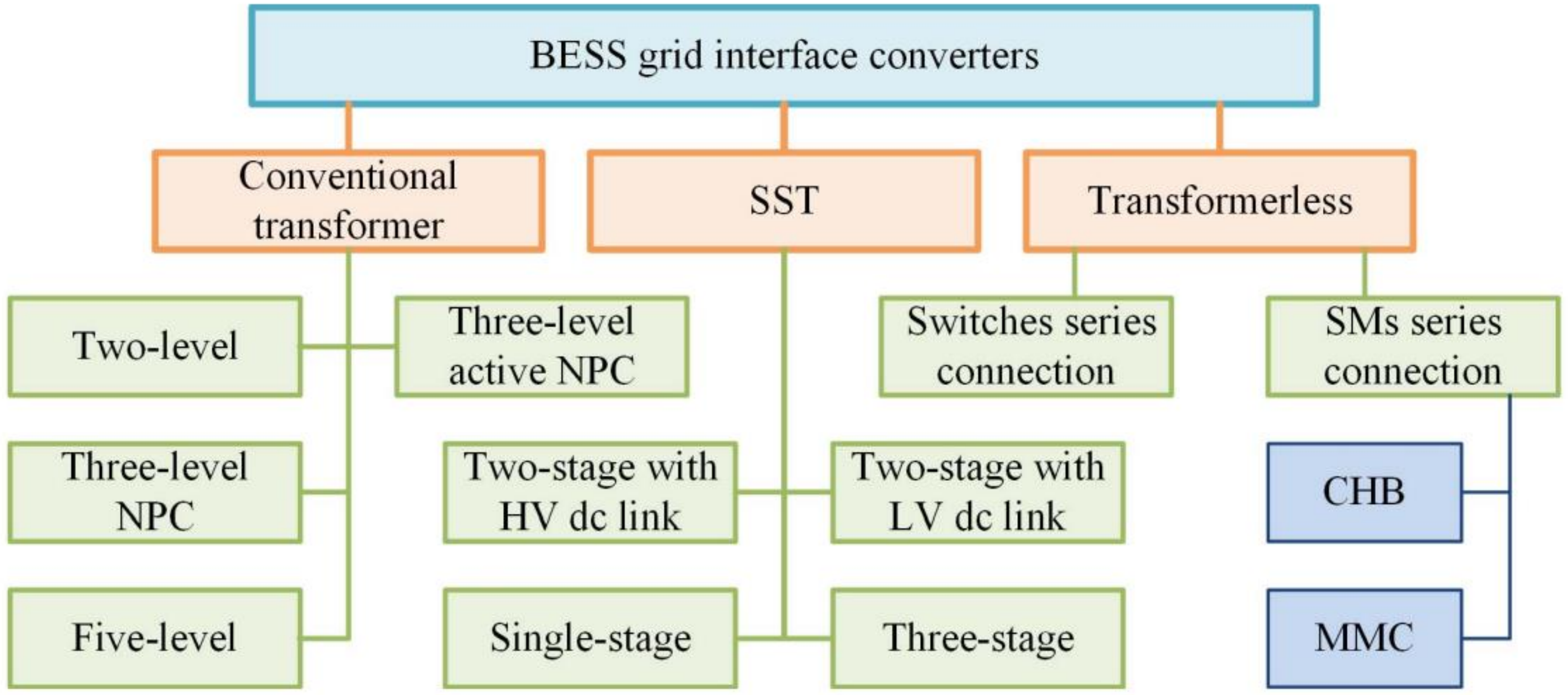
Energy storage system	Advantages	Disadvantages	Application
Conventional Li-ion battery [52]	High energy density High power density Short response time (minutes to hours)	High cost Aging	Peak-shaving/load-levelling solutions for the grid, accounts for majority of worldwide deployment (>90%)
Lead-Acid battery [52]	Low cost Technological maturity	Low energy/power density Toxic components Short calendar life Short response time	Minimal worldwide deployment for the grid (<2%) due to limited performance, used as standby-power mostly
Vanadium redox battery [52]	High energy storage capacity (ease of scalability)	Low energy/power density Complex construction (need pumps)	Load-levelling at substations. transformer upgrade deferral, and support for grid integration of solar and wind
Supercapacitors [52]	High power density	Low energy density	Buffer spike pulses (60s) in transmission or distribution lines to improve power factor and overall system efficiency
PEM fuel cells	Room-temperature operation possible	Can only use H_2 as fuel	Continuous stable power output (as long as there is a scaled H_2 fuel tank)
Solid oxide fuel cell [53]	Can use various hydrocarbons as fuels	High-temperature operation necessary (>350°C)	Can operate both as fuel cell and electrolyzer, can be deployed with heat cogeneration and eco-friendly steel production

G. G. Farivar *et al*., "Grid-Connected Energy Storage Systems: State-of-the-Art and Emerging Technologies," in *Proceedings of the IEEE*, vol. 111, no. 4, pp. 397-420, April 2023

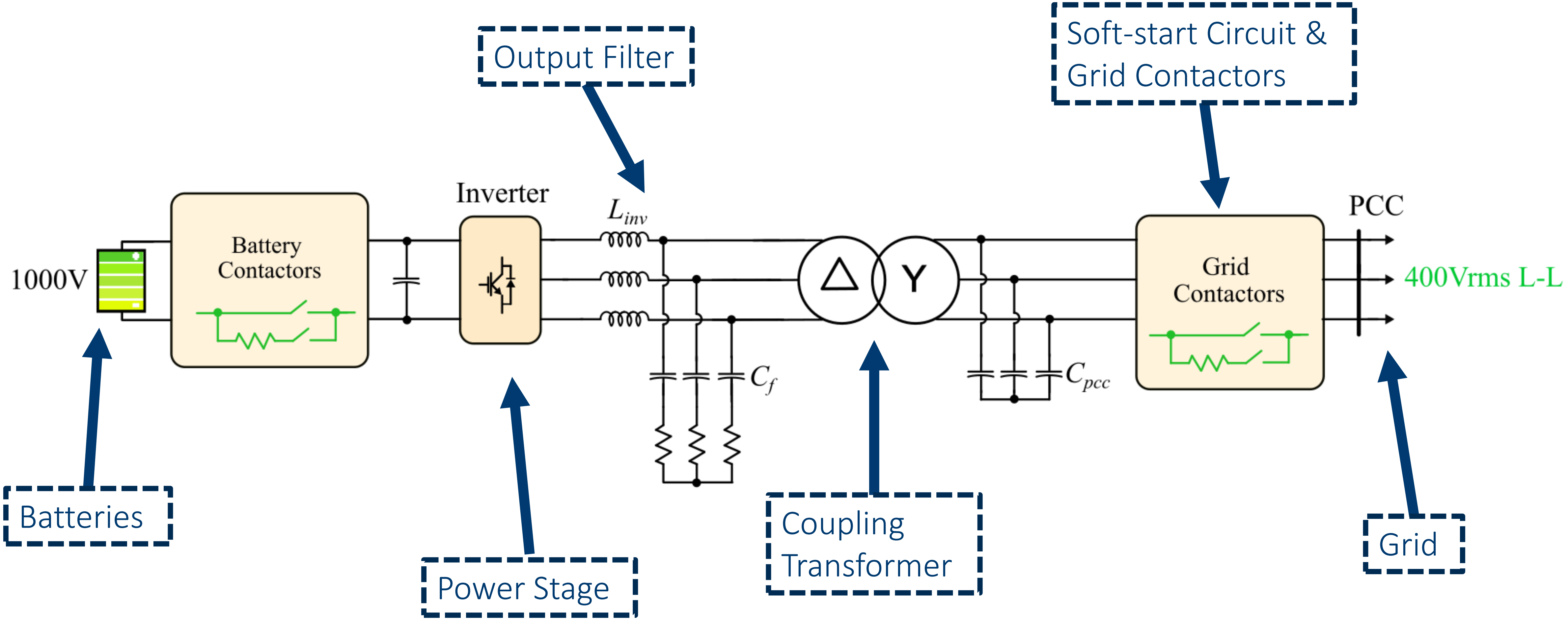
5. Battery Power Converter Systems

Battery Power Converter Systems

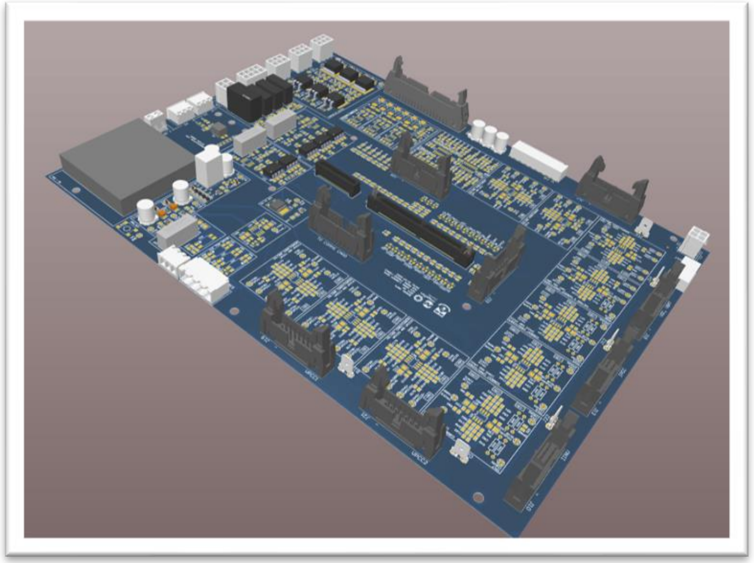


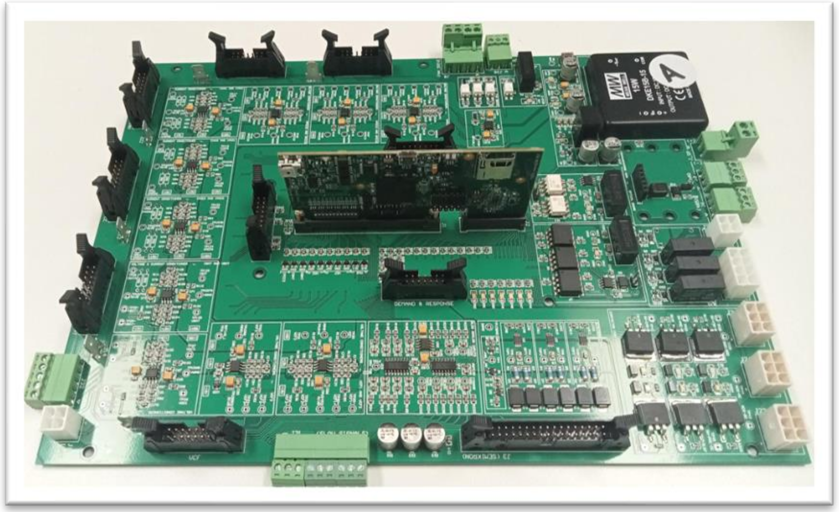
G. G. Farivar *et al.*, "Grid-Connected Energy Storage Systems: State-of-the-Art and Emerging Technologies," in *Proceedings of the IEEE*, vol. 111, no. 4, pp. 397-420, April 2023

Battery power converter system with transformer



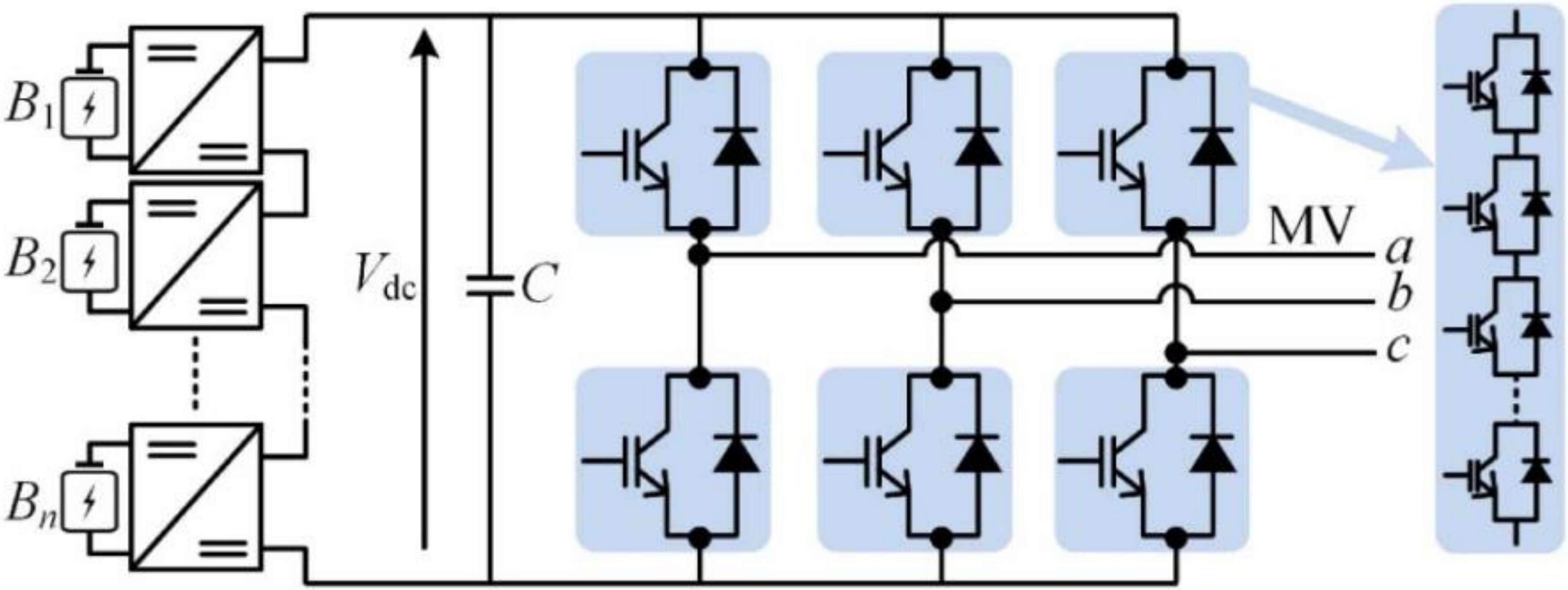
Battery power converter system with transformer



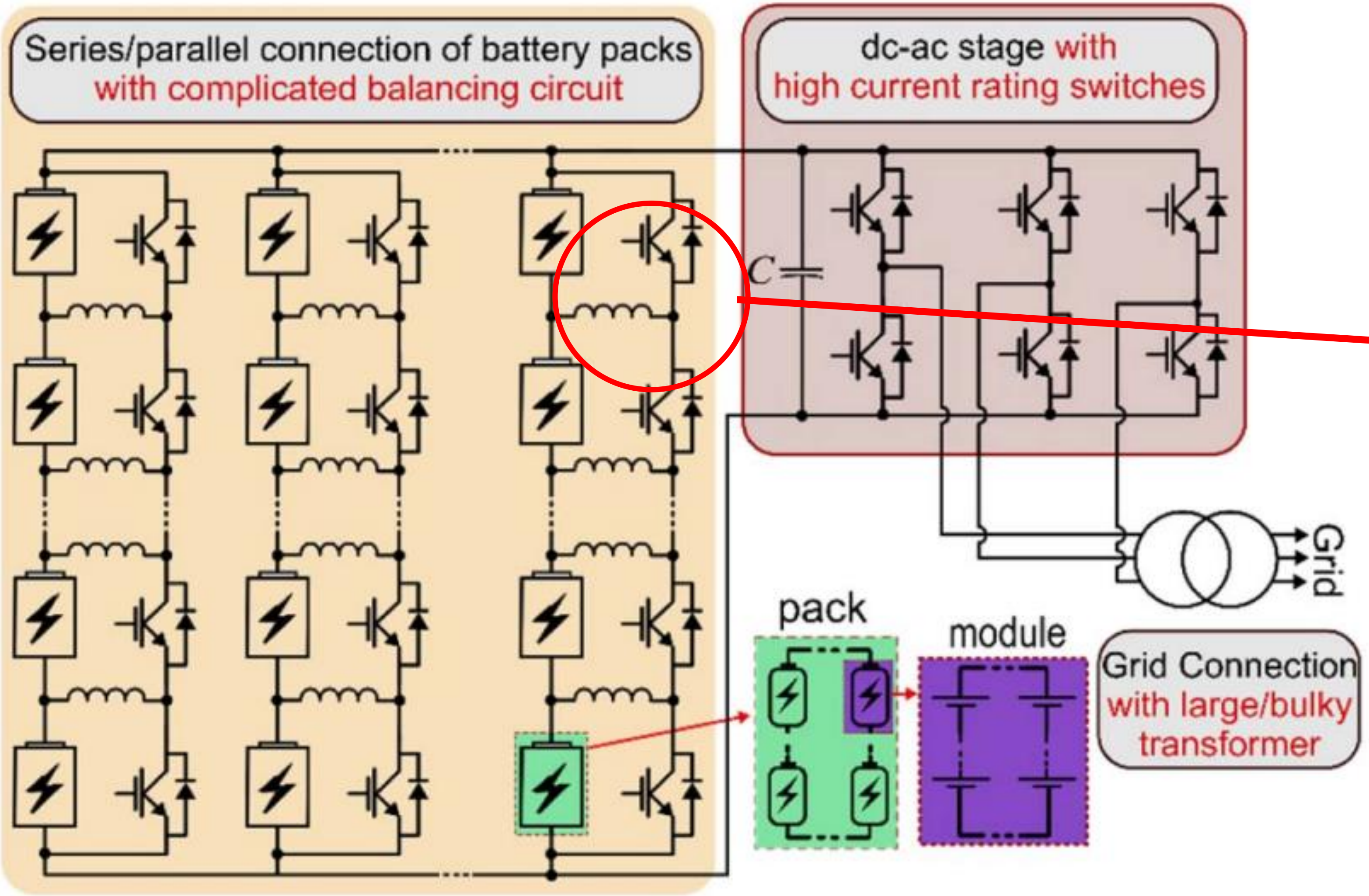


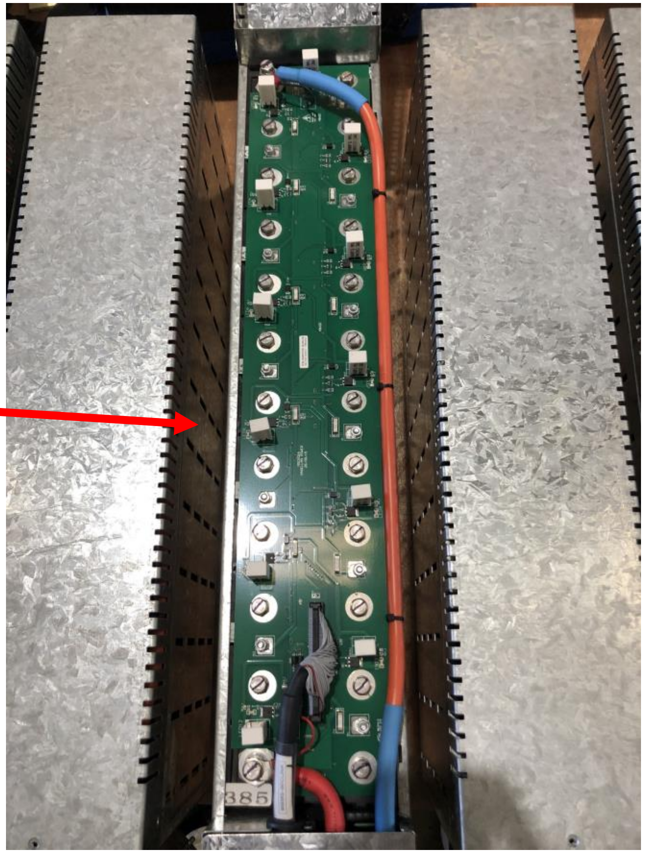
Battery power converter system with transformer

Series connection of semiconductor switches



Multilevel Converter

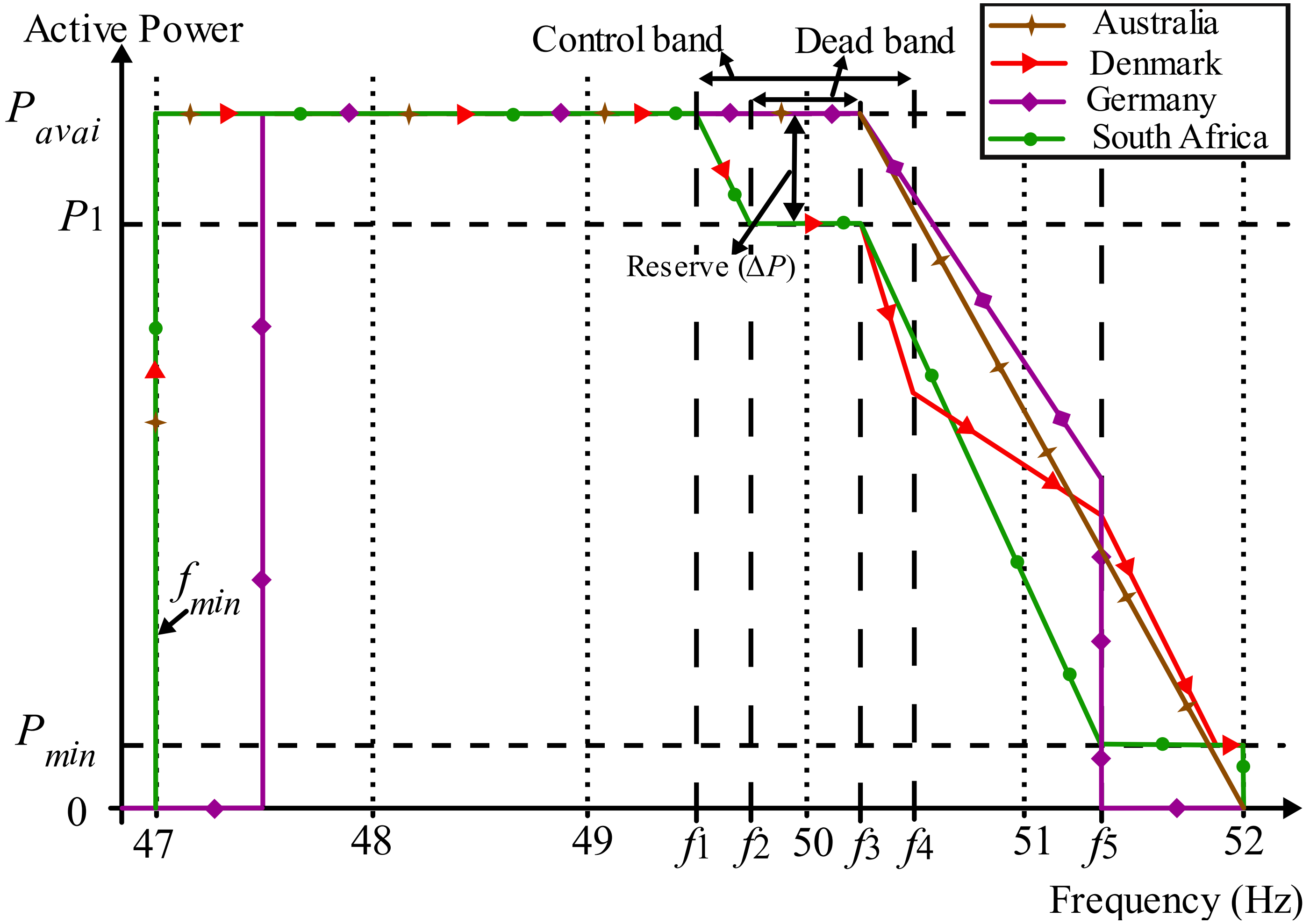




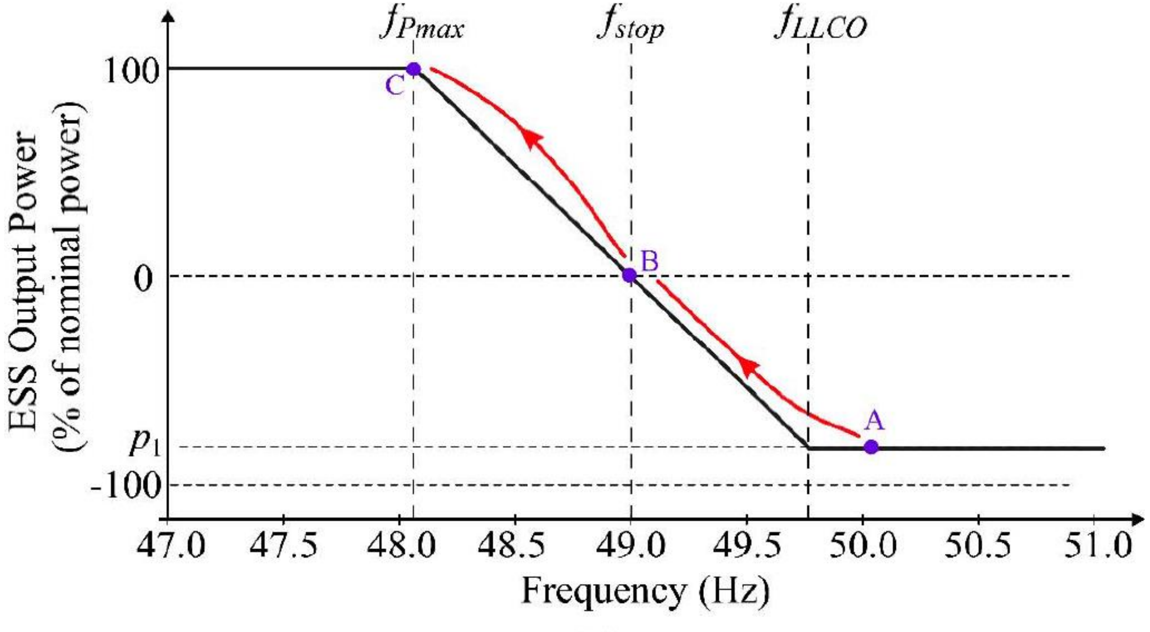
Battery management system

6. Power System Support

Frequency Support



Frequency Support



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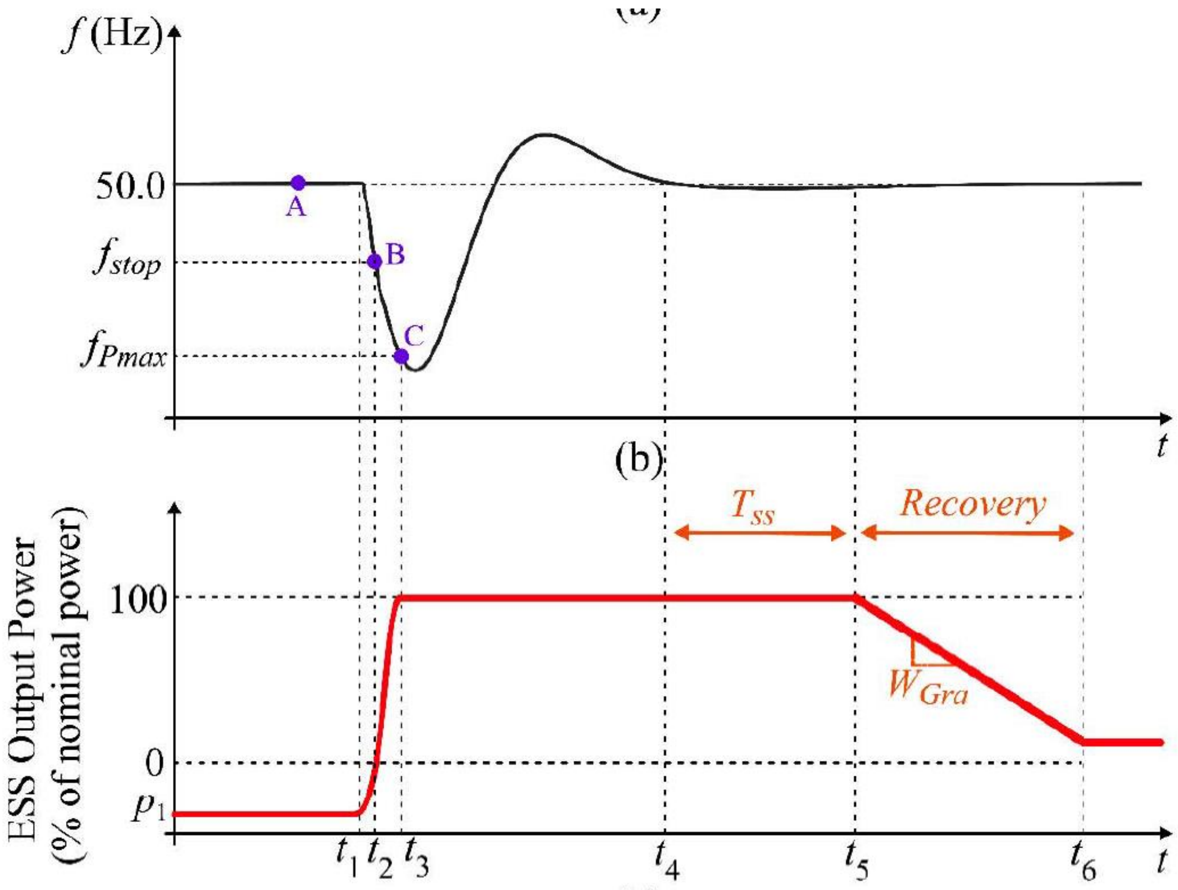
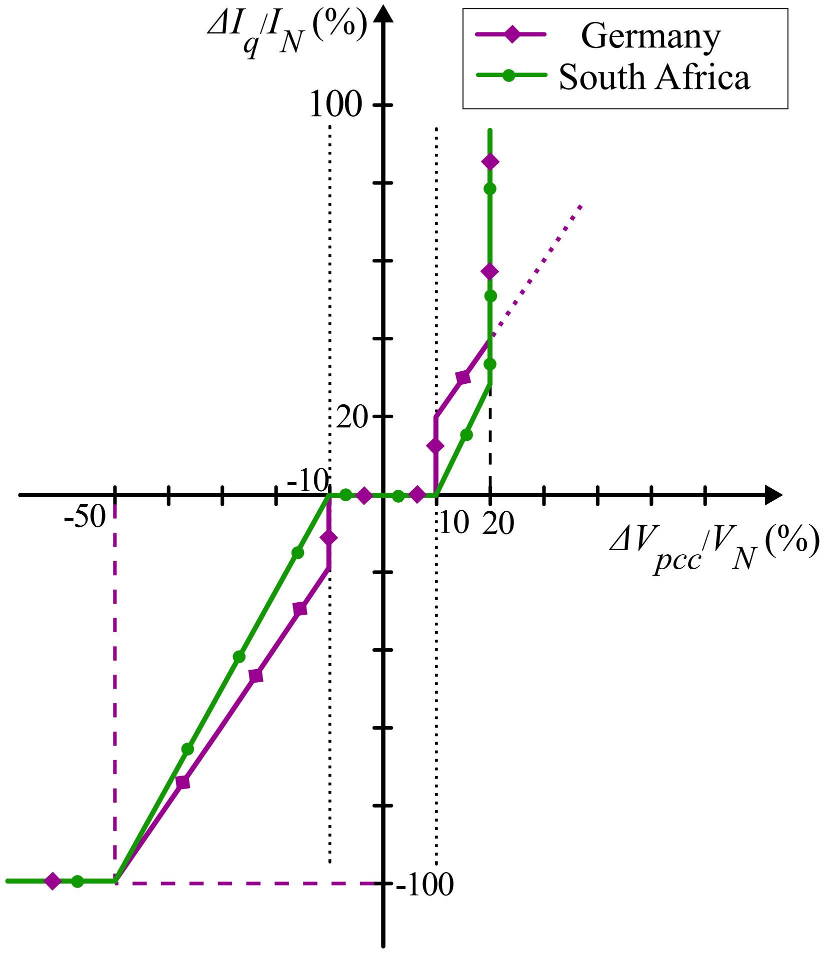


(c)

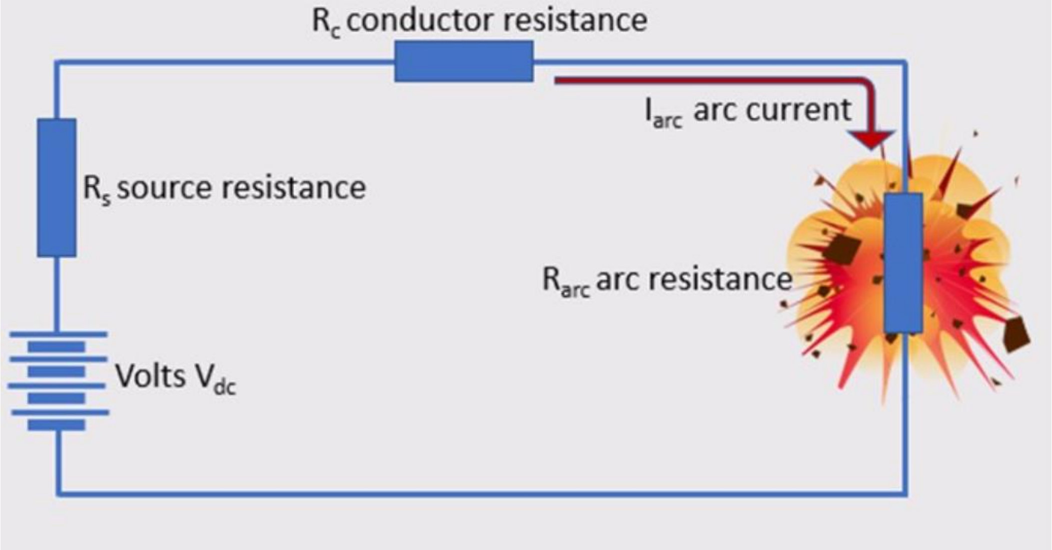
Voltage Support



7. Safety Standards for Battery Systems

Arc flash principle

$$IE_{\text{max power}} = 0.239 * (V_{\text{sys}}/2)^2 / R_{\text{sys}} * T_{\text{arc}} / (4 * 3.14 * D^2)$$



$IE_{\text{max power}}$	estimated incident energy at the maximum power point (in calories/cm^2);
V_{sys}	system voltage (in volts);
R_{sys}	system resistance (in ohms);
T_{arc}	arcing time (in seconds);
D	worker's distance from the arc (in centimeters).

Arc flash safety requirements

WARNING

Arc-Flash and Shock Hazard
Appropriate PPE Required

Number Of Batteries Per String	20	System Float Voltage	272.40
Number Of unprotected batteries per string	10	Float Voltage (Unprotected section)	136.20
Incident Energy at 45.5cm(Cal/cm)	2.69	Fault Current (KA)	1.36
Hazard Risk Category	CAT 1	Flash Protection Boundary (cm)	68

ACTIVITY	PPE CATEGORY
SWITCHING	CAT 1
ELECTRICAL WORK	CAT 1
COVER REMOVAL (OPENING DOOR)	CAT 1
VISUAL INSPECTION WITH CLOSED DOOR	CAT 1
SHOCK LIMITED APPROACH BOUNDARY	1 METER
SHOCK RESTRICTED APPROACH BOUNDARY	0.3 METER

Date:	28/04/2022
Job Number:	1289
Assessed as per:	NFPA 70E D.5.1

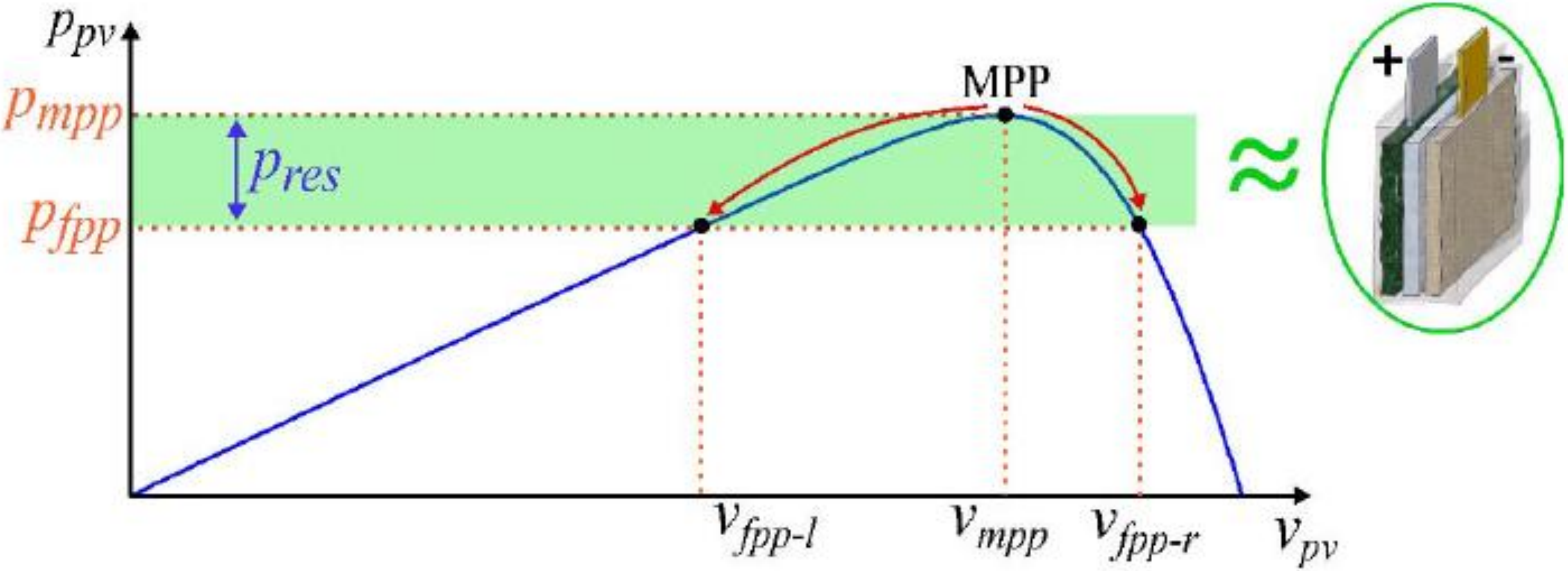
magellan power

AUSTRALIAN MADE AND OWNED

8. Emerging Technologies and Prospects

1) Flexible Power Point Tracking in Photovoltaic Systems

Flexible power point tracking in photovoltaic systems



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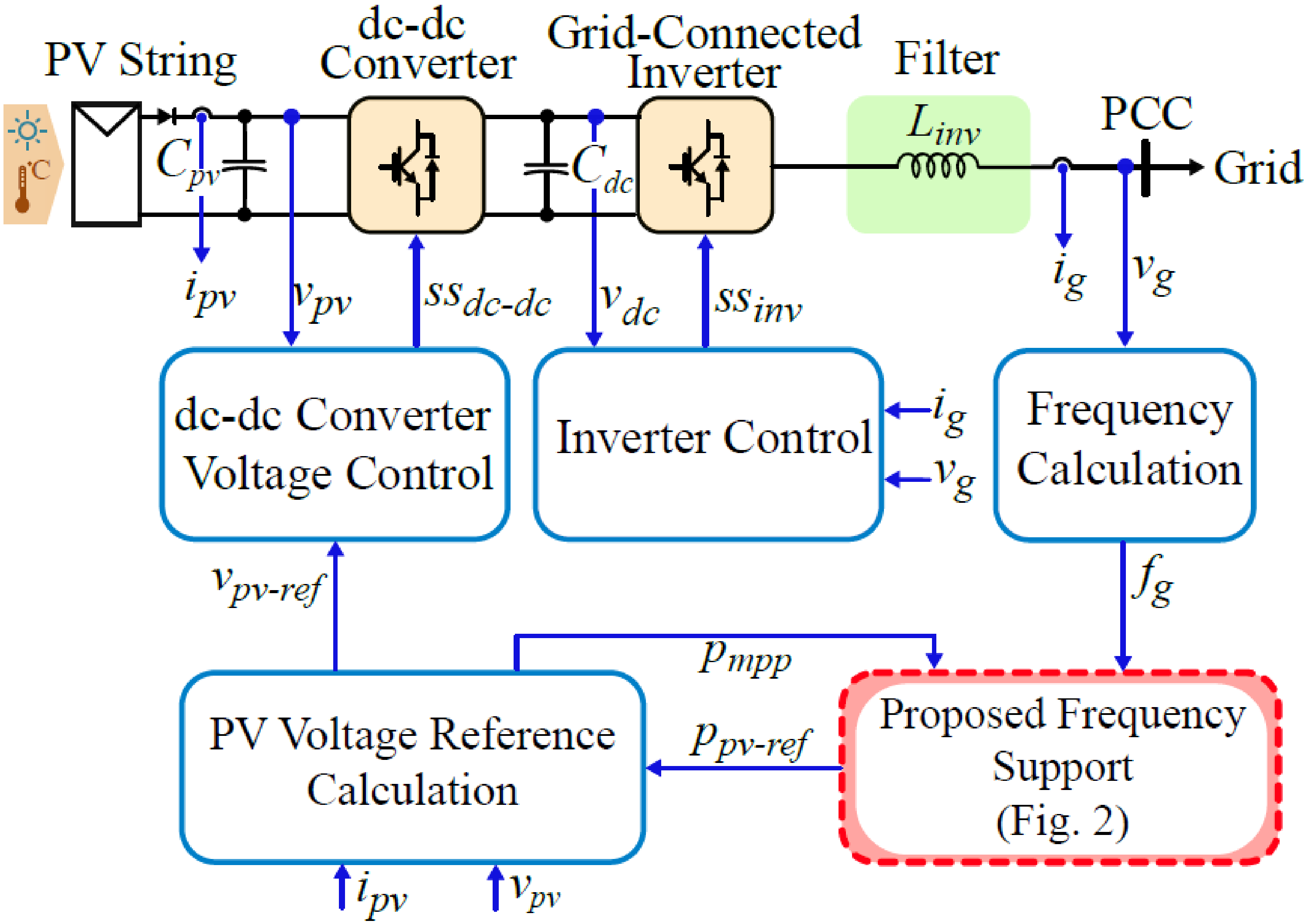
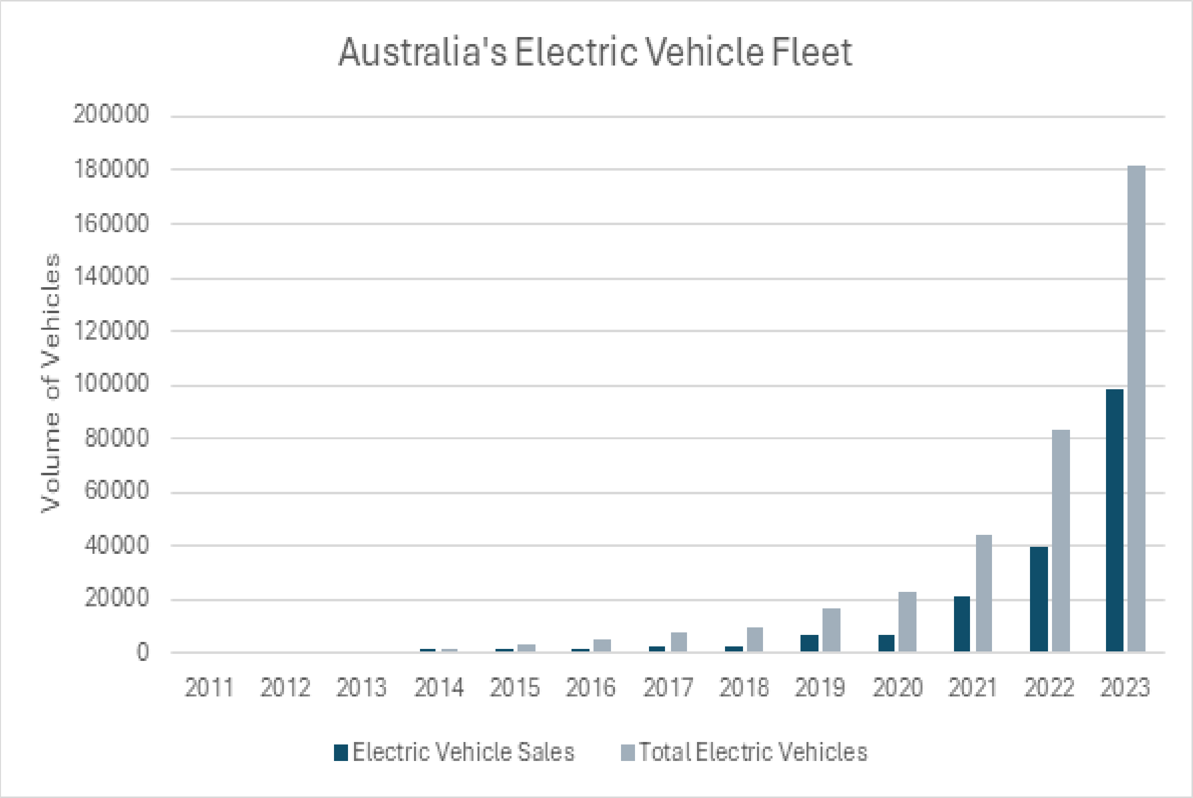
Frequency support with PV systems



8. Emerging Technologies and Prospects

2) Electric Vehicle Battery Systems

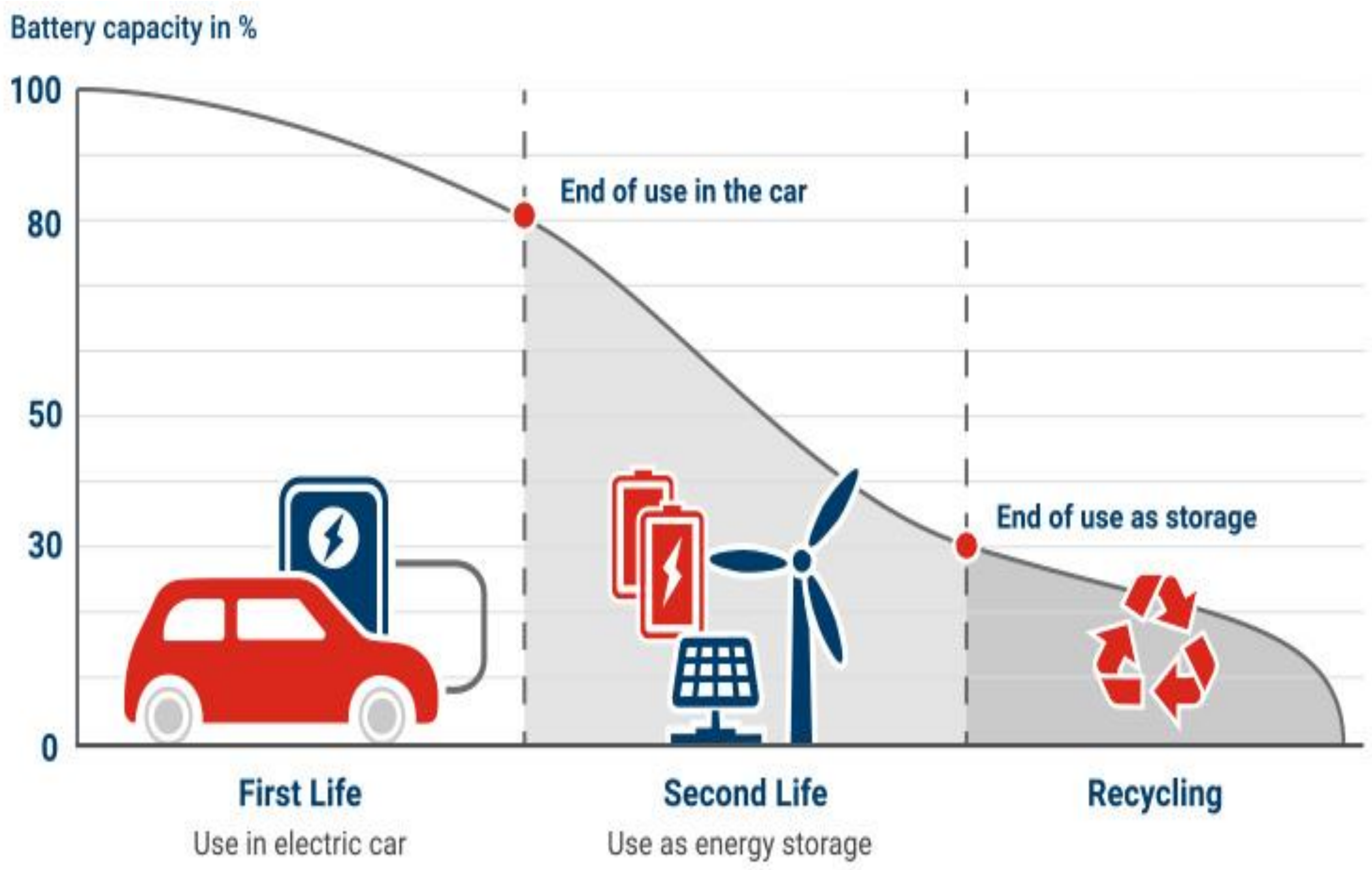
EV battery systems



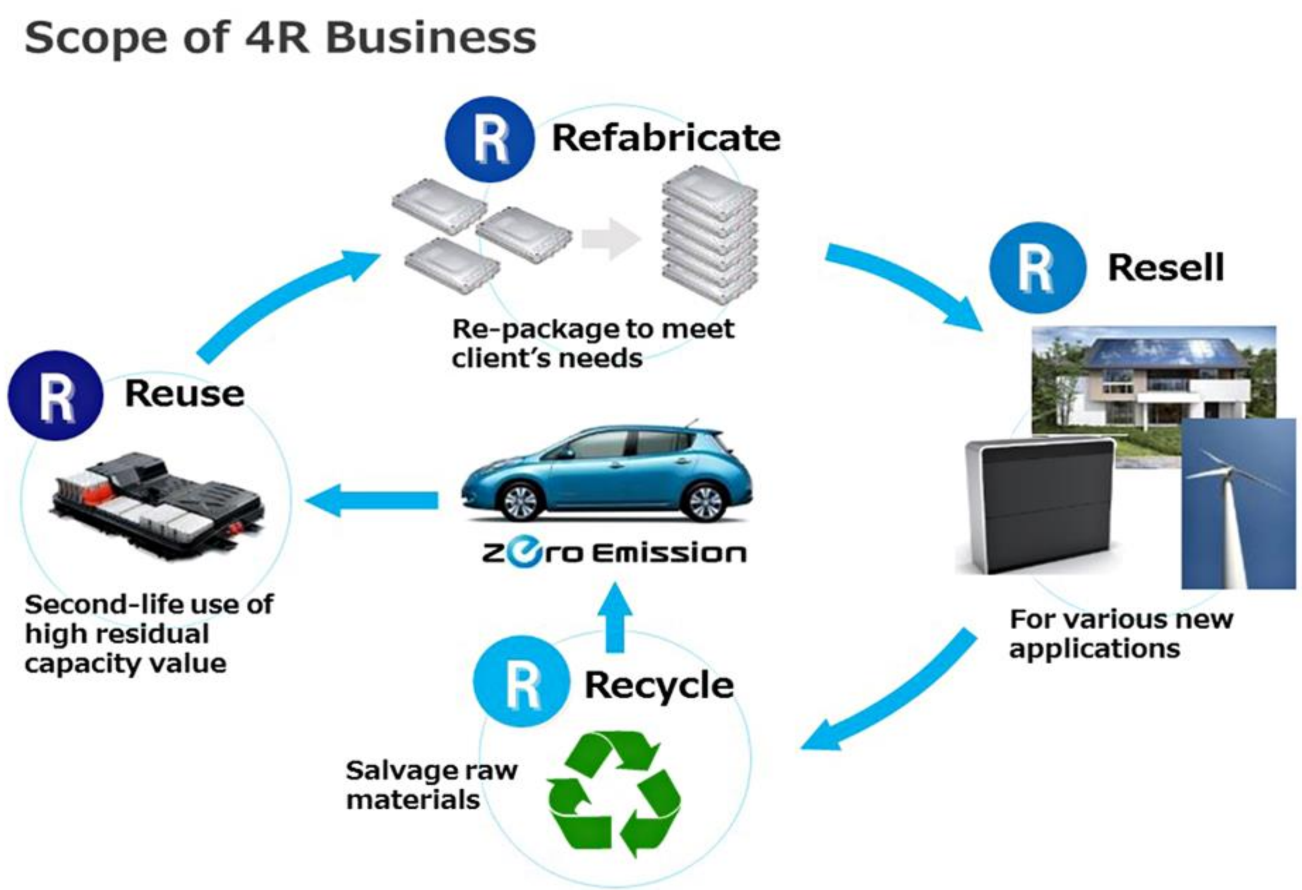
Overview of Australia's Electric Vehicle Fleet (BEV and PHEV), by Sales, Source: FCAI

Nissan EV Battery Pack, with Modules Displayed, Source: Nissan

EV battery life cycle



EV battery - 4R



Summary

- New challenges for power system operators under high penetration of PV systems
- Overview of different energy storage technologies, especially battery systems and their comparison
- Power system support
- Safety standards
- New technologies/trends for solar systems and EVs

Thank You!

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We have a range of courses in Renewable Energy Engineering.

Courses	Start Date
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52859WA Graduate Certificate in Renewable Energy Technologies	4 June 2024
Online – Master of Engineering (Electrical Systems)	24 June 2024
52894WA Advanced Diploma of Applied Electrical Engineering (Renewable Energy)	2 July 2024
Professional Certificate of Competency in Hydrogen Energy – Production, Delivery, Storage, and Use	9 July 2024
Online – Bachelor of Science (Electrical Engineering)	22 July 2024
Professional Certificate of Competency in Hydrogen Powered Vehicles	6 August 2024
Professional Certificate of Competency in Battery Energy Storage and Applications	10 September 2024
Professional Certificate of Competency in Renewable Energy Systems	10 September 2024
Professional Certificate of Competency in Smart Grids	1 October 2024

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Q&A

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