

Battery Energy Storage Systems: Electrochemical Technologies and Grid-Scale Applications

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Senior Electrical Engineer | EIT Lecturer



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Introduction – Presenter

Hanane Oudli

- Senior Electrical Engineer. Founder & CEO, Hanane Global Advisory Inc. — an independent technical consulting firm based in Calgary, Alberta, Canada, specializing in Battery Energy Storage Systems (BESS), AI data center power infrastructure, DER integration, grid modernization, and power system protection
- University Technical Degree in Electrical Engineering, Moulay Ismail University, Morocco; BSEE from the Engineering Institute of Technology (EIT), Australia
- 10+ years of international engineering experience across Morocco, the USA, Canada, Southeast Asia, and Australia — including HV/MV transmission work at ONEE (Morocco) and offshore BESS projects in the USA (750 kWh / 1.8 MW system in partnership with GE Power Conversion)
- Currently completing a Master of Engineering (Electrical Systems) at EIT Australia, developing continuous grid-forming BESS control for resilient AI data center power (expected completion December 2026)
- Lecturer in Electrical Engineering at EIT Australia; Official Global Brand Ambassador & Strategic Partner for EMTP®; recognized as a LinkedIn Top Voice with 30,000+ followers



Agenda

1	Welcome and Introduction
2	Meet the Presenter
3	BESS Fundamentals and Electrochemical Technologies
4	Battery Chemistries Compared
5	Grid-Scale Applications and Use Cases
6	Grid-Forming BESS and System Integration
7	Key Takeaways, Summary, and Q&A



Webinar Overview

THE CENTRAL STORY

- **Fundamentals First:** how electrochemical batteries physically store and release energy, and the core components of a BESS
- **Chemistry Choices:** comparing Li-ion, flow, and emerging battery chemistries against duration, safety, and cost
- **Grid-Scale Value:** how BESS is deployed today — from frequency regulation to firming renewables to backing up AI data center loads
- **Grid-Forming Future:** connecting storage to grid-forming inverter control, increasingly required as natural grid inertia declines

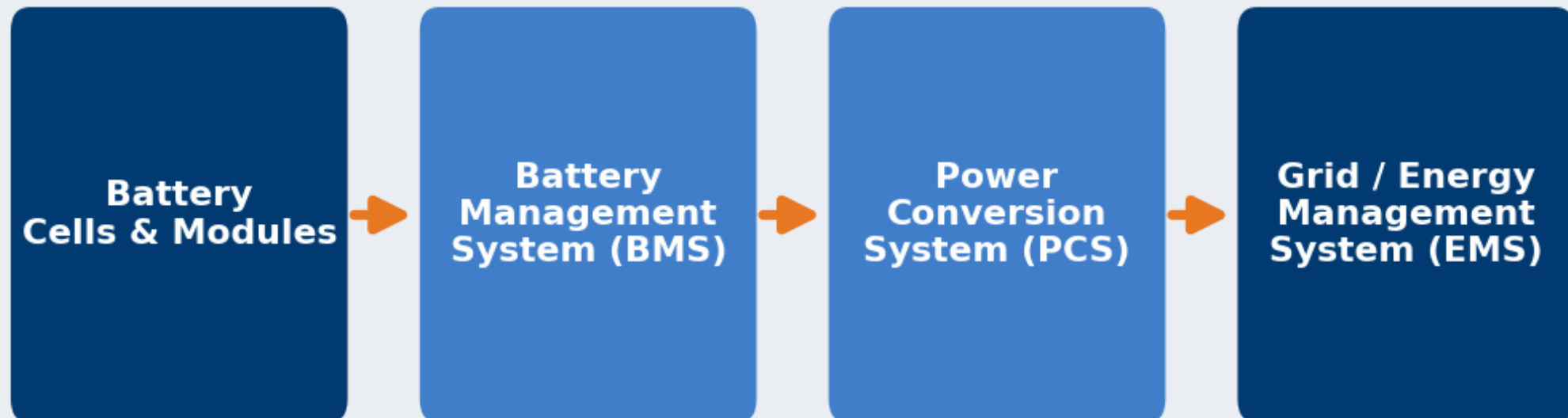
STORAGE IS WHAT TURNS A VARIABLE, LOW-INERTIA GRID INTO A CONTROLLABLE ONE.



3. BESS Fundamentals and Electrochemical Technologies

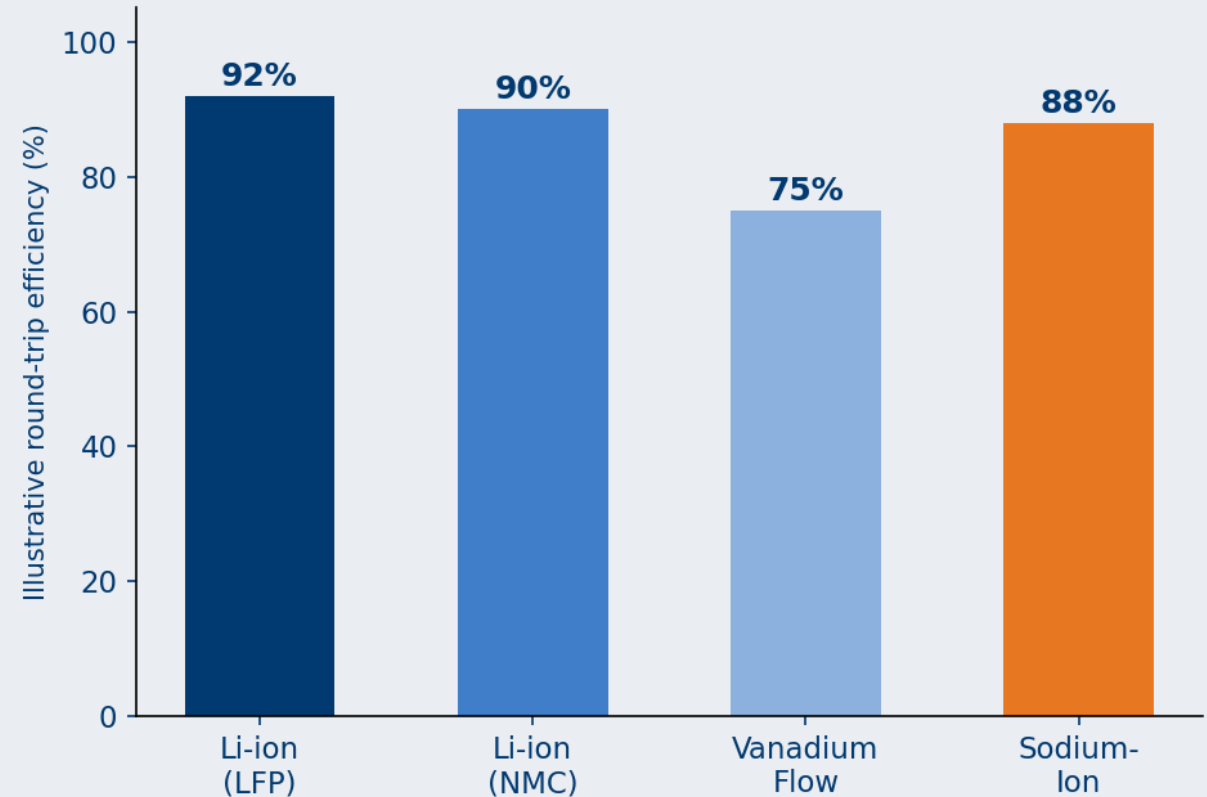
What Is a Battery Energy Storage System?

- A BESS stores electrical energy chemically and releases it on demand, acting as a fast, controllable resource for the grid
- **Core components:** battery cells and modules, a Power Conversion System (PCS), a Battery Management System (BMS), and a Grid/Energy Management System (EMS)
- Unlike synchronous generators, BESS output is fully controllable through power electronics rather than mechanical inertia



How Electrochemical Storage Works

- Charging drives ions from the cathode to the anode through an electrolyte, storing energy as chemical potential
- Discharging reverses the flow, releasing electrons through an external circuit to do electrical work
- Round-trip efficiency, degradation, and thermal behavior all depend on the specific electrochemistry used



Key BESS Design Considerations

- **Energy (kWh) vs. Power (kW):** sizing depends on whether the application needs sustained energy or a fast power boost
- **Duration:** grid-scale systems commonly range from 30 minutes to 4+ hours, with long-duration technologies pushing past 8 hours
- Safety and cycle life both vary significantly by chemistry, pack design, and operating temperature



Energy vs. Power



Duration



Safety & Thermal



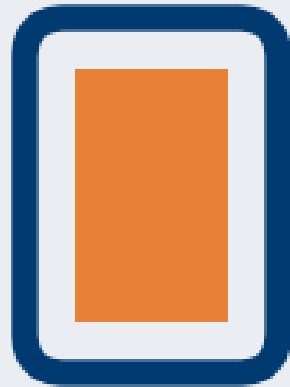
Cycle Life

4. Battery Chemistries Compared

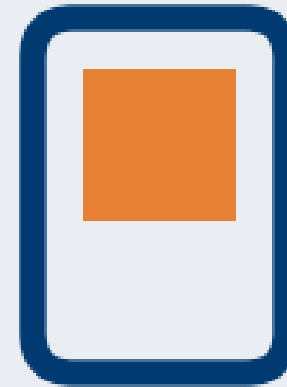


Lithium-Ion: The Dominant Grid-Scale Chemistry

- LFP (Lithium Iron Phosphate) dominates new grid-scale deployments due to thermal stability, safety, and long cycle life
- NMC (Nickel Manganese Cobalt) offers higher energy density but with more sensitive thermal behavior
- Li-ion systems typically deliver strong round-trip efficiency, well suited to short and medium duration applications



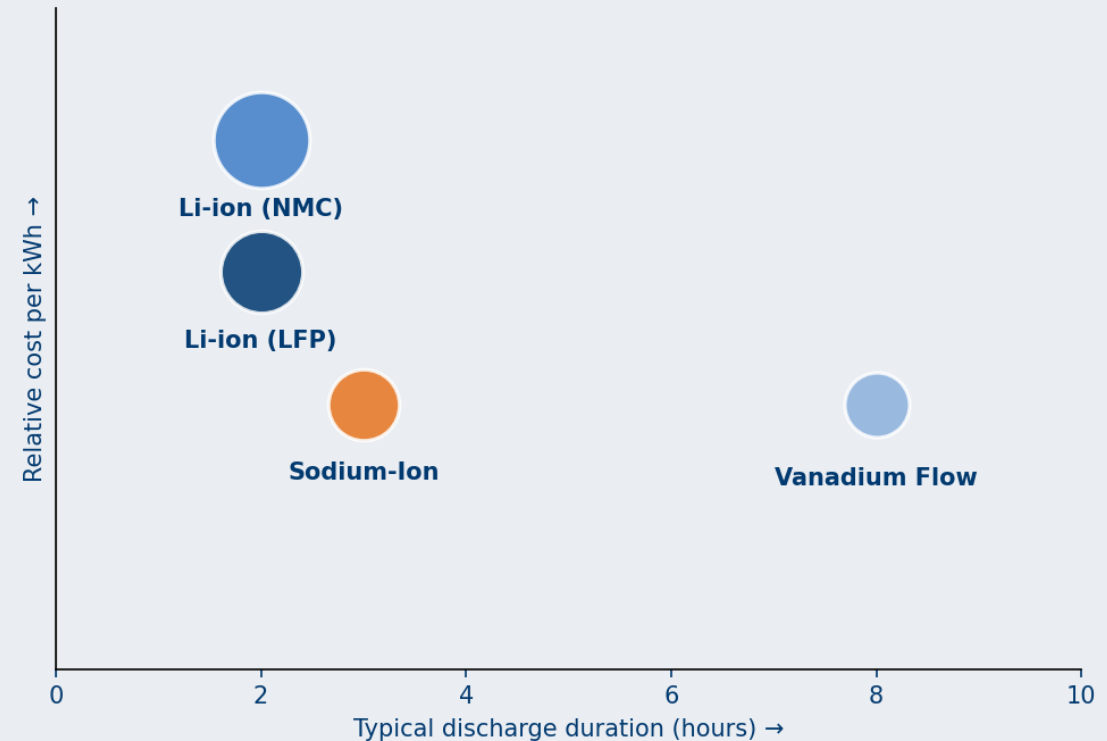
LFP



NMC

Flow Batteries and Emerging Chemistries

- Vanadium redox flow batteries store energy in liquid electrolytes, decoupling power and energy sizing — ideal for long duration
- Sodium-ion is emerging as a lower-cost, more abundant alternative to lithium for stationary storage
- Solid-state batteries promise higher energy density and improved safety but remain largely pre-commercial at grid scale



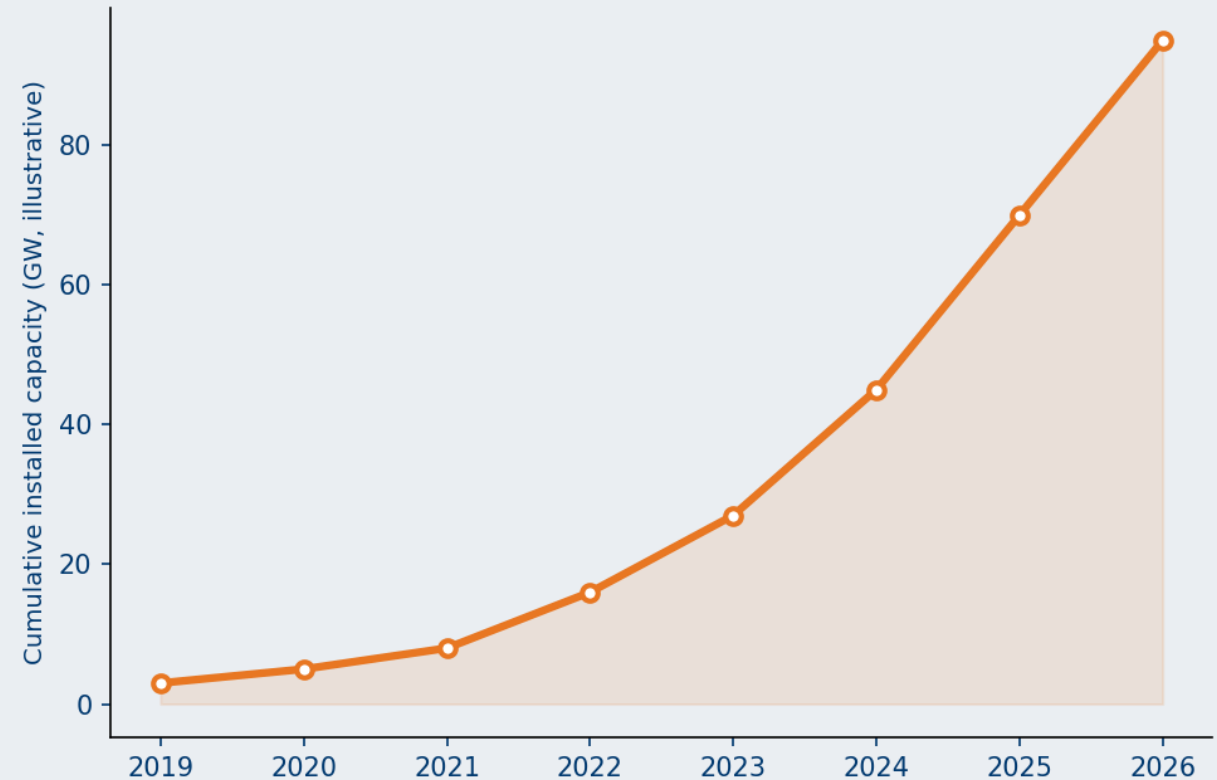
Choosing a Chemistry for a Grid-Scale Project

- Application duration and cycling frequency drive most chemistry decisions
- Site constraints — space, climate, and fire code — affect chemistry choice and enclosure design
- Total cost of ownership includes degradation, augmentation, and end-of-life recycling costs
- Grid codes increasingly call for grid-forming-capable inverters regardless of the chemistry chosen

5. Grid-Scale Applications
and Use Cases

Grid-Scale Applications Are Expanding Rapidly

- Utility-scale BESS deployment has grown sharply worldwide, driven by falling costs and rising renewable penetration
- Applications now span frequency regulation, capacity firming, transmission deferral, and resilience services
- BESS is increasingly paired directly with solar and wind projects, or sited to support large new loads such as AI data centers



Four Core Grid-Scale Use Cases

- **Frequency Regulation:** fast charge/discharge response holds grid frequency stable
- **Renewable Firming:** smooths solar and wind variability into dispatchable output
- **Black Start & Resilience:** can energize a de-energized section without external power
- **Data Center Support:** buffers sensitive, always-on AI data center loads against disturbances



Frequency Regulation



Renewable Firming

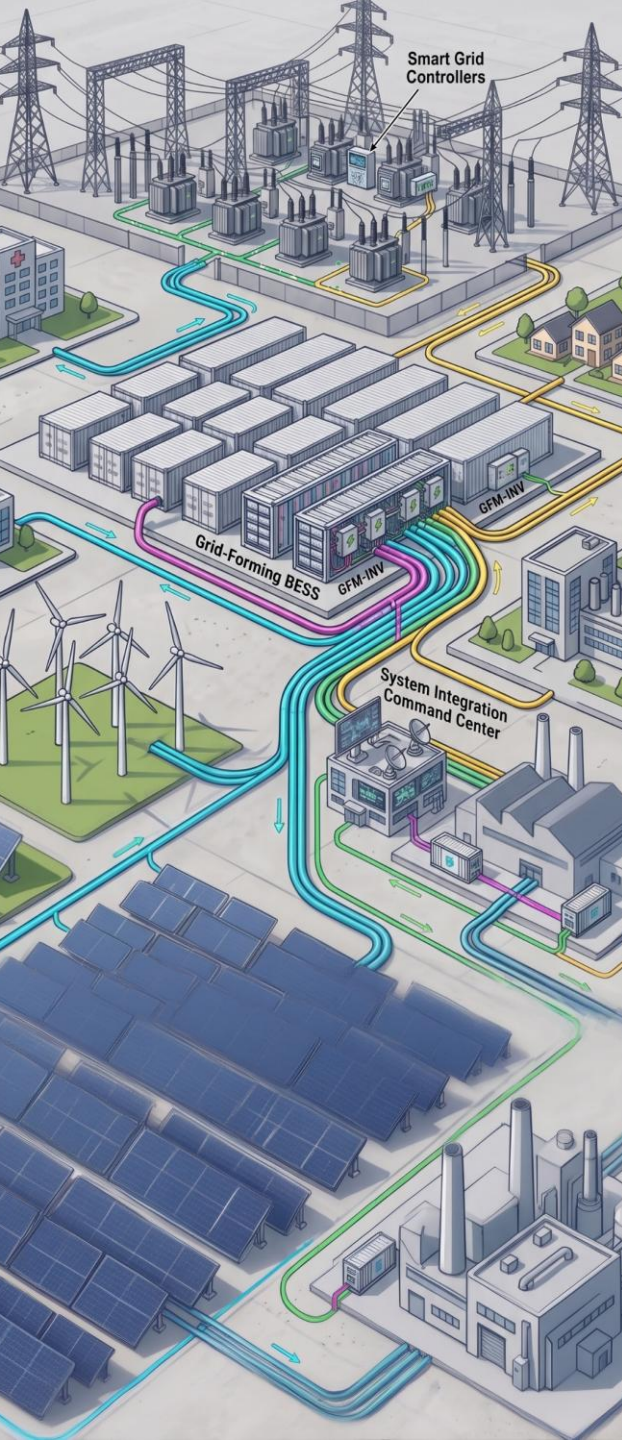


Black Start



Data Center Support

6. Grid-Forming BESS and System Integration

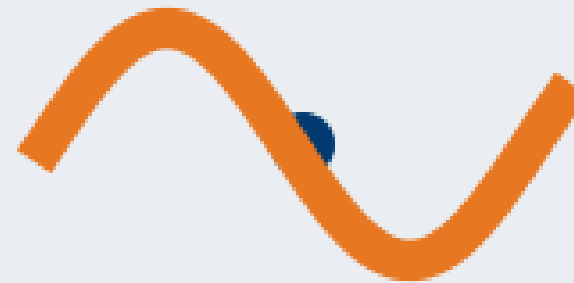


Grid-Following vs. Grid-Forming Inverters

- Grid-following inverters synchronize to an existing grid voltage and frequency reference — they need a stable grid to operate
- Grid-forming inverters actively establish voltage and frequency themselves, behaving more like a traditional synchronous generator
- As inertia falls and renewable/BESS penetration rises, grid-forming capability becomes essential for stable operation



Grid-Following

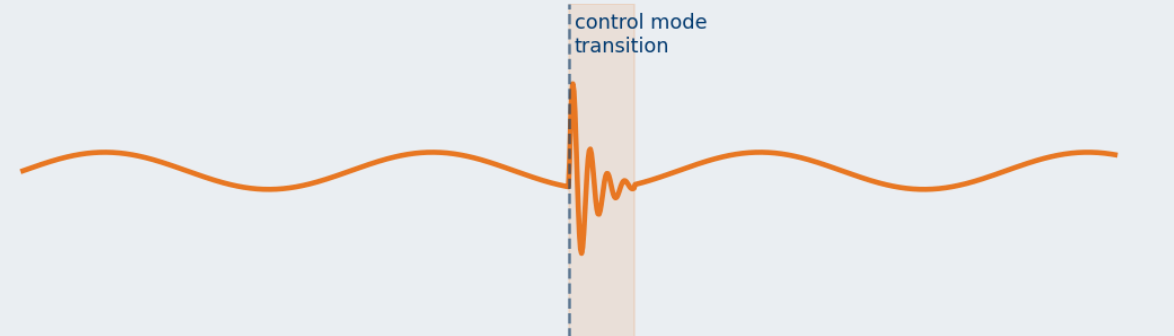


Grid-Forming

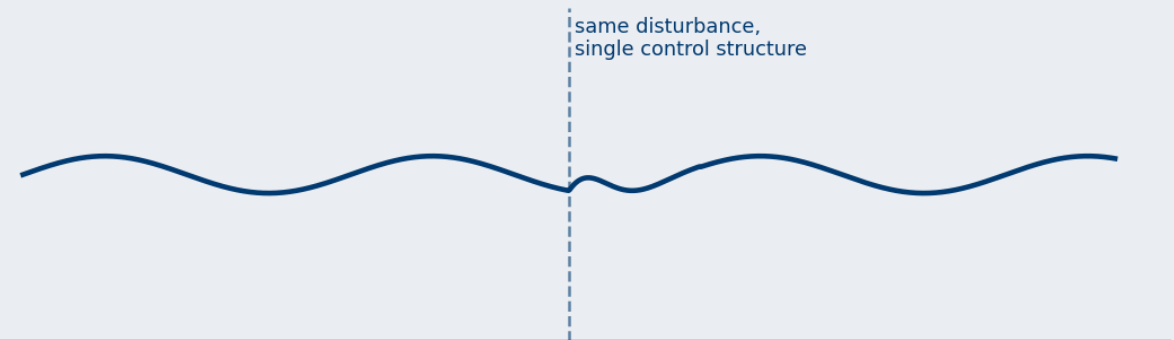
Continuous Grid-Forming Control

- Many grid-forming implementations switch between control modes depending on grid conditions, which can introduce instability during the transition
- Continuous grid-forming control avoids mode switching altogether, maintaining a single control structure across normal and disturbed conditions
- EMT (electromagnetic transient) simulation validates this behavior under fast, sub-cycle events before field deployment — essential for resilient AI data center power

Mode-Switching Grid-Forming Control



Continuous Grid-Forming Control (no mode switch)



Key Takeaways from This Webinar

- Electrochemical BESS technologies differ widely in duration, safety, and cost — the right choice depends on the application
- Grid-scale BESS applications now span frequency regulation, renewable firming, resilience, and data center support
- Grid-forming control, especially continuous designs without mode switching, is becoming essential as the grid's natural inertia declines

Summary

- Electrochemical storage converts stored chemical energy into fast, controllable electrical power for the grid
- Lithium-ion (especially LFP) leads today's deployments, while flow batteries and sodium-ion expand the long-duration and low-cost frontier
- BESS applications now extend from frequency regulation to firming renewables to backing up AI data center loads
- Grid-forming control — particularly continuous designs — is key to making these systems behave like a stable, resilient grid resource
- Looking ahead: Session 3 — 14 October 2026 — BESS Protection Engineering: Grid Stability, Fault Behavior, and EMT Simulation

STORAGE IS THE BRIDGE BETWEEN A VARIABLE GRID AND A RELIABLE ONE.

Thank You!

Upcoming Programmes

Engineering College of Technology (ECT) <i>UK-Recognised Qualifications</i>	Start Date
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Bachelor of Engineering (Honours) in Electrical Engineering	September 2026, February 2027
Master of Science (Power System Analysis and Renewable Integration)	October 2026, February 2027
Master of Science (Industrial Automation and Instrumentation Control)	October 2026, February 2027

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