Network resilience supported by inverter-based resources

Grid Edge Solutions

Marija Vujacic – Global Product Management, GES

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Power quality – A growing challenge

Power Quality is a major concern for anyone involved in the generation, transmission and distribution of power, as well as for many industrial and commercial consumers.
The changing grid landscape including growth of renewable integration and non-conventional loads will draw more attention to power quality issues.

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A Day Without Power

For large companies, the cost of an outage can escalate into the millions of dollars per hour of downtime. In fact, the DoE recently estimated that outages are costing the U.S. economy $150 billion annually.

Studies have shown that the cost of data center outage has grown to more than $8,000 per minute.

For large manufacturing enterprises, a single hour of downtime tops the $5 million mark.

For large retailers, that cost is even higher, reaching upwards of $5 million.

0.1% down of availability can lead to 90% up of outage-related costs.

The reality of power reliability

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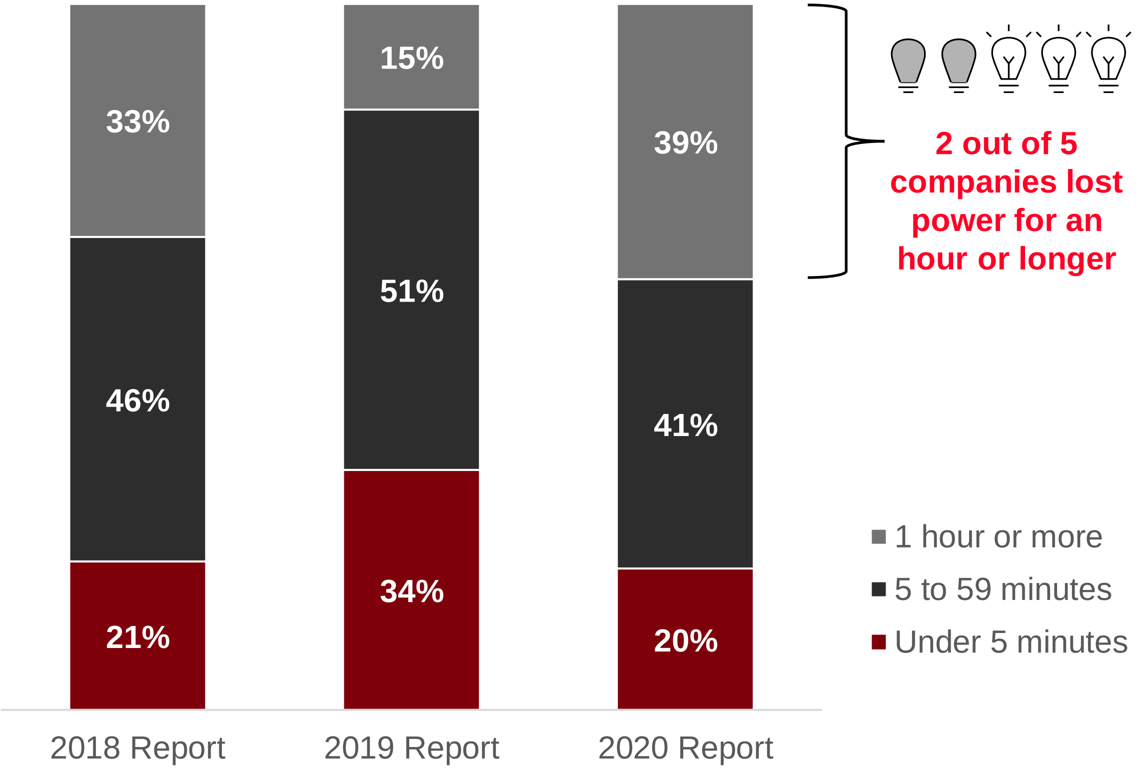
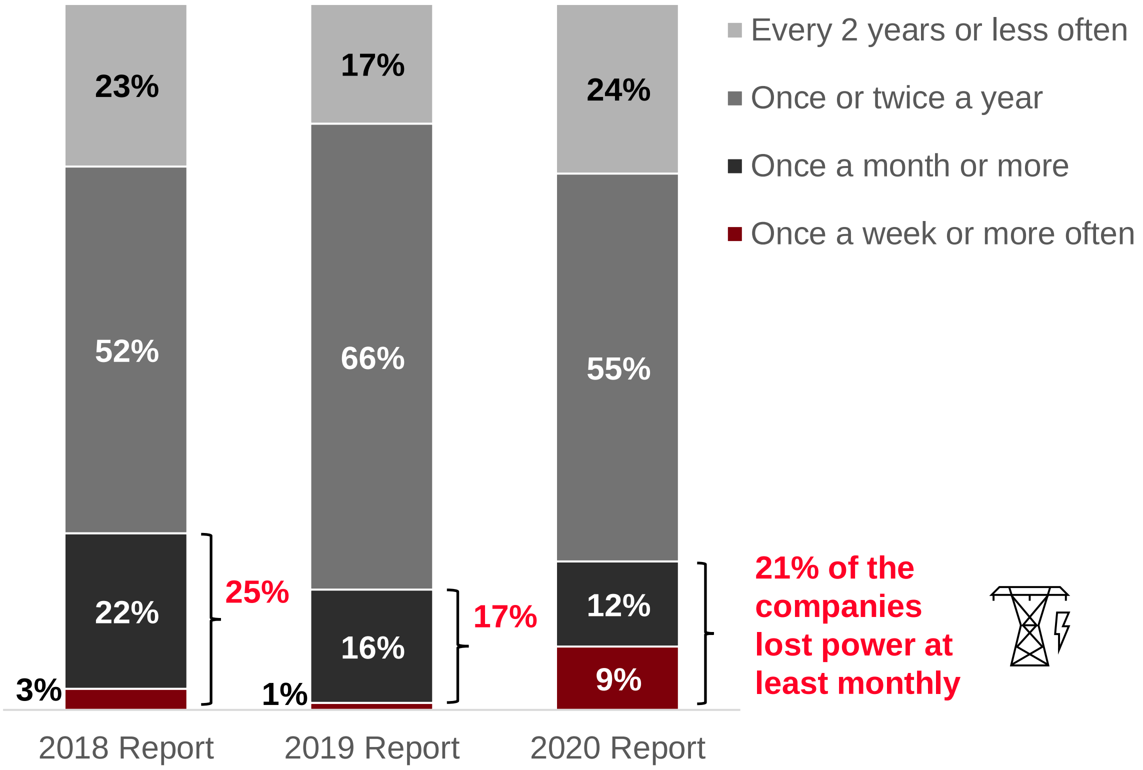
Typical outage duration



Power loss frequency



Power reliability continues to be a major issue for manufacturing facilities
As battery costs continue to decrease, the (technical and commercial) viability of projects continues to increase

Source: Frost & Sullivan. **Base:** Comparable groups for the yearly reports (same industry and company size representation)

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The changing power landscape: growing importance of resilience

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Generation

- Increasing energy production
- Integration of renewables
- Deal with distributed generation

Need for good power quality

Consumers

- Increasing power consumption
- New grids in emerging markets
- Faster and stronger transportation systems

Transmission and Distribution

- Aging infrastructure
- Changing regulations grid code compliance
- Energy trading between regions
- Reversible power flow

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Resilience and reliability – discussion topics

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CIGRE WG C4.47 “Power system Resilience is the ability to limit the extent, severity and duration of system degradation following an extreme event.”

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DER management in GES

New energy ecosystem

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Grid

- Generation
- Transmission
- Wholesale markets
- Retail
- Advanced distribution network management
- Transactive energy

Digital solutions

- Aggregation
- Energy Management Solution
- Blockchain
- Comms, Cyber Security & Asset Health

Physical Assets

- Generation
- Flexible Demand
- Energy Storage

Consumers / prosumers

- Residential
- Commercial
- Industrial
- Community

Digital solutions enable:

- Maximized customer value
- System performance optimization
- Grid reliability
- Energy services
- New business opportunities for energy providers

Evolving ecosystem due to growth in distributed capabilities

Distributed energy resources (DER)

Enabling digital solutions & services

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e-mesh portfolio focused on enhancing value stacking benefits

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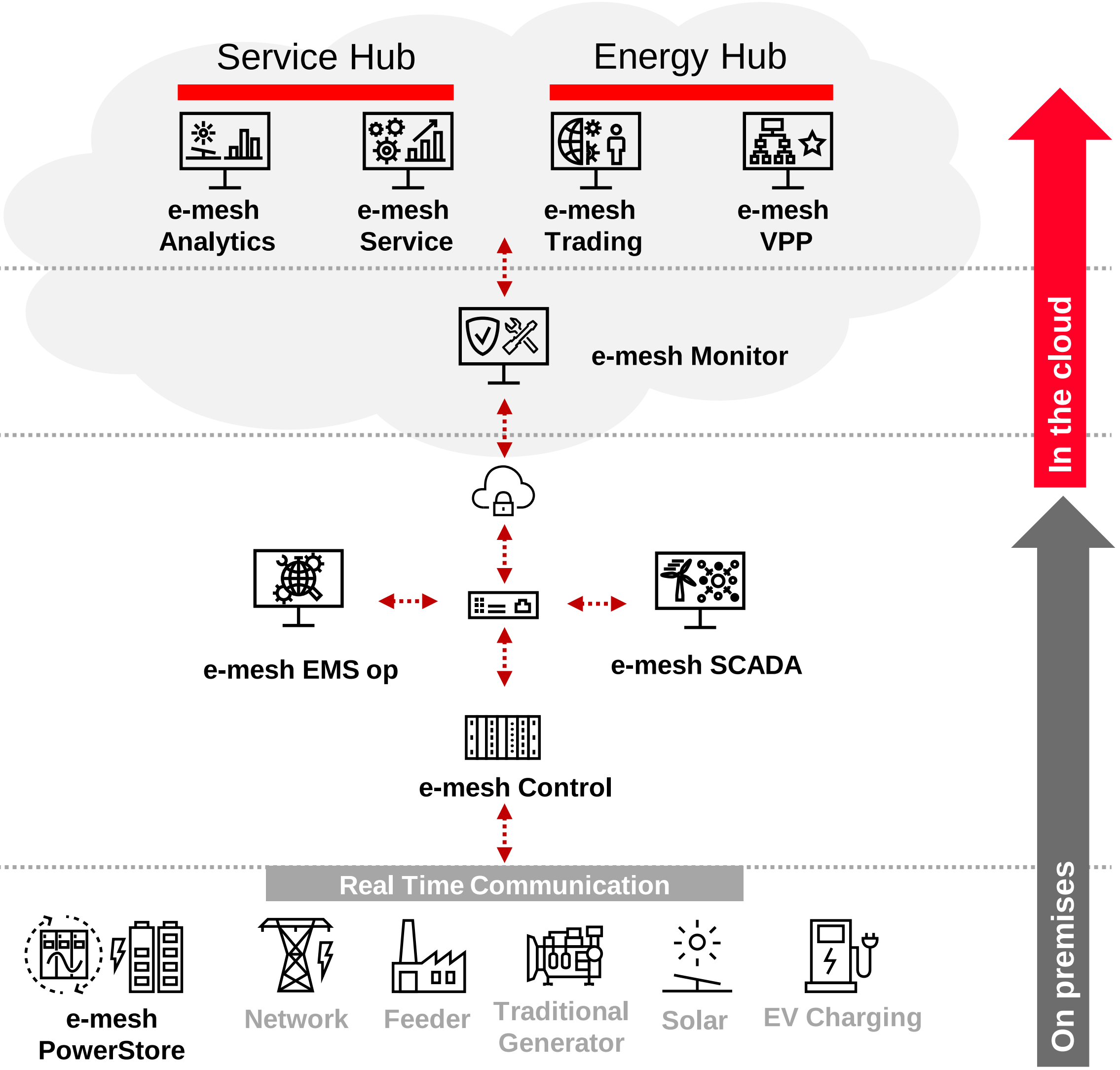
e-mesh value stack

Digital
additional value streams for optimized business cases

Automation
integration of RE, system optimization for max RE penetration: Energy management is the optimization of a full depot or site energy profile incl smart charging

Power
Site flexibility element for peak lopping, grid stabilization, islanding & resiliency



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Differentiating “smart” BESS with Grid Edge Digital and Automation solutions

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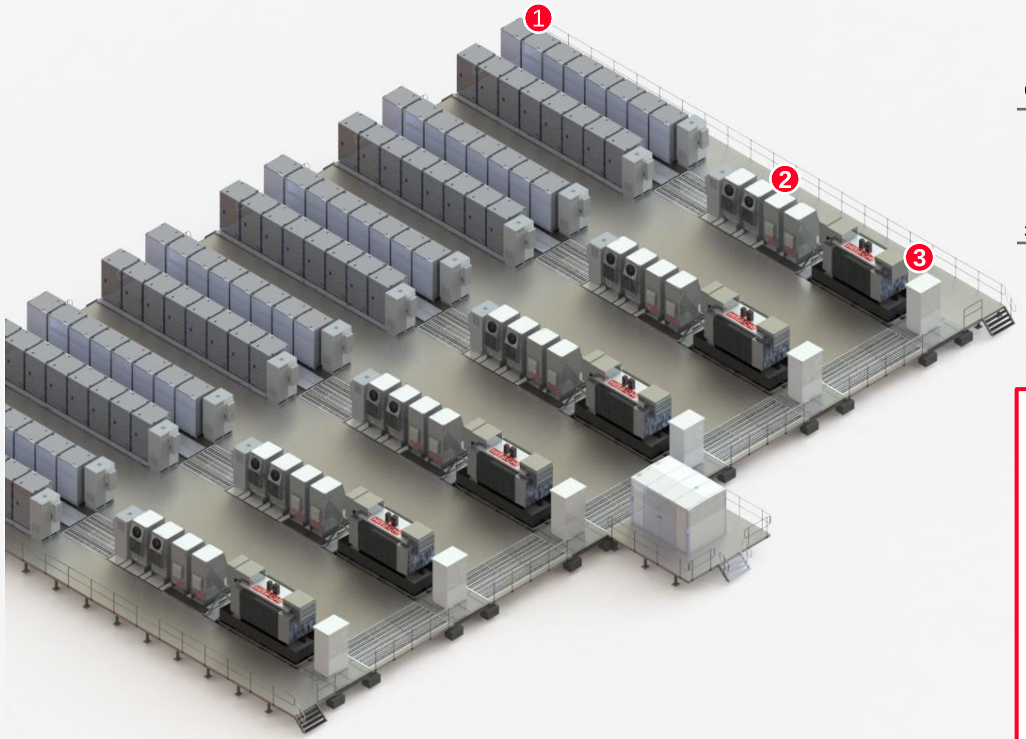

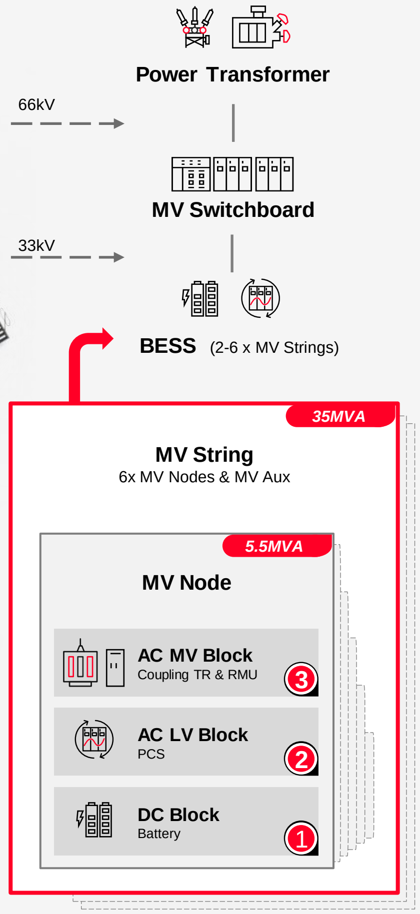

External
Network operator, markets

Secondary or plant control

10-100ms cycle time

Primary control
~1ms cycle time

Unit control
~100µs cycle time

System level
Battery energy mgmt.
Frequency regulation
Voltage stabilization
Base load levelling
Peak shaving
Spinning reserve
Renewable integration
Blackstart
Islanding

Power Conversion level
Virtual Synchronous Machine emulation

Grid code compliance (LVRT, protection)
Voltage source / Current source operation

Hardware | Automation | Services

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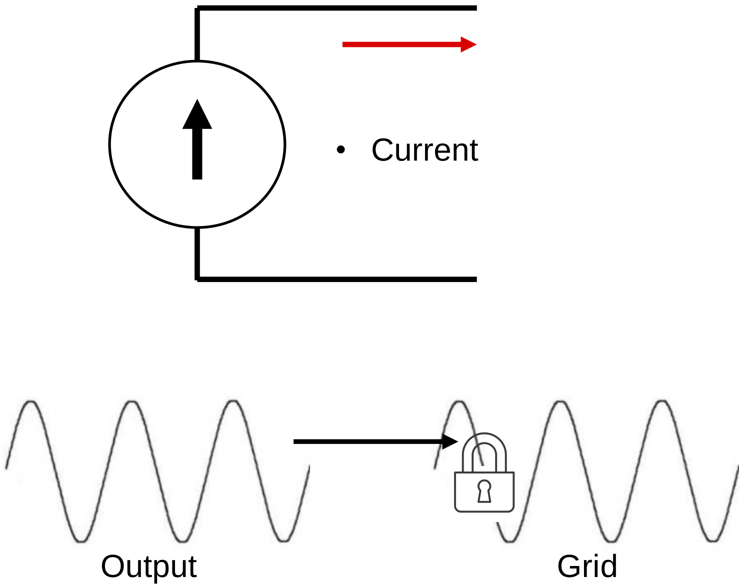
How PowerStore digitally stabilizes grids

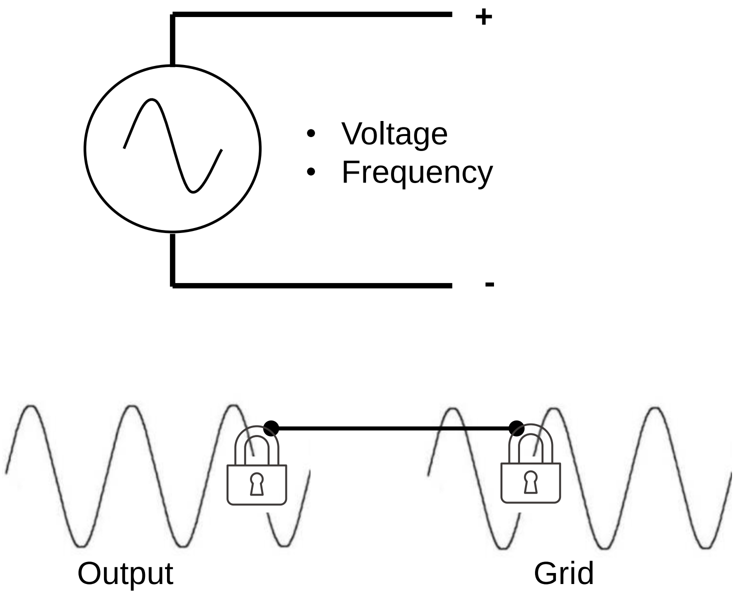
Grid following (GFL)

Current Source Inverter (CSI)



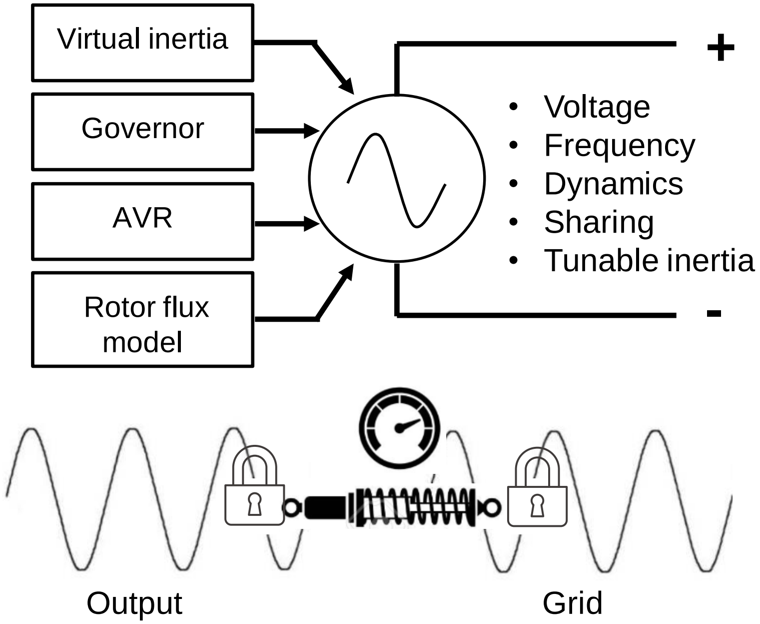
Grid forming (GFM)

Voltage Source Inverter (VSI)



Virtual Synchronous Machine (VSM)

PowerStore GFM BESS in VGM



The key to stabilizing grids and unlocking new revenue streams is digital automation and smart controls intelligently applied to grid forming (GFM) converters

e-mesh PowerStore ensures network stability through grid services

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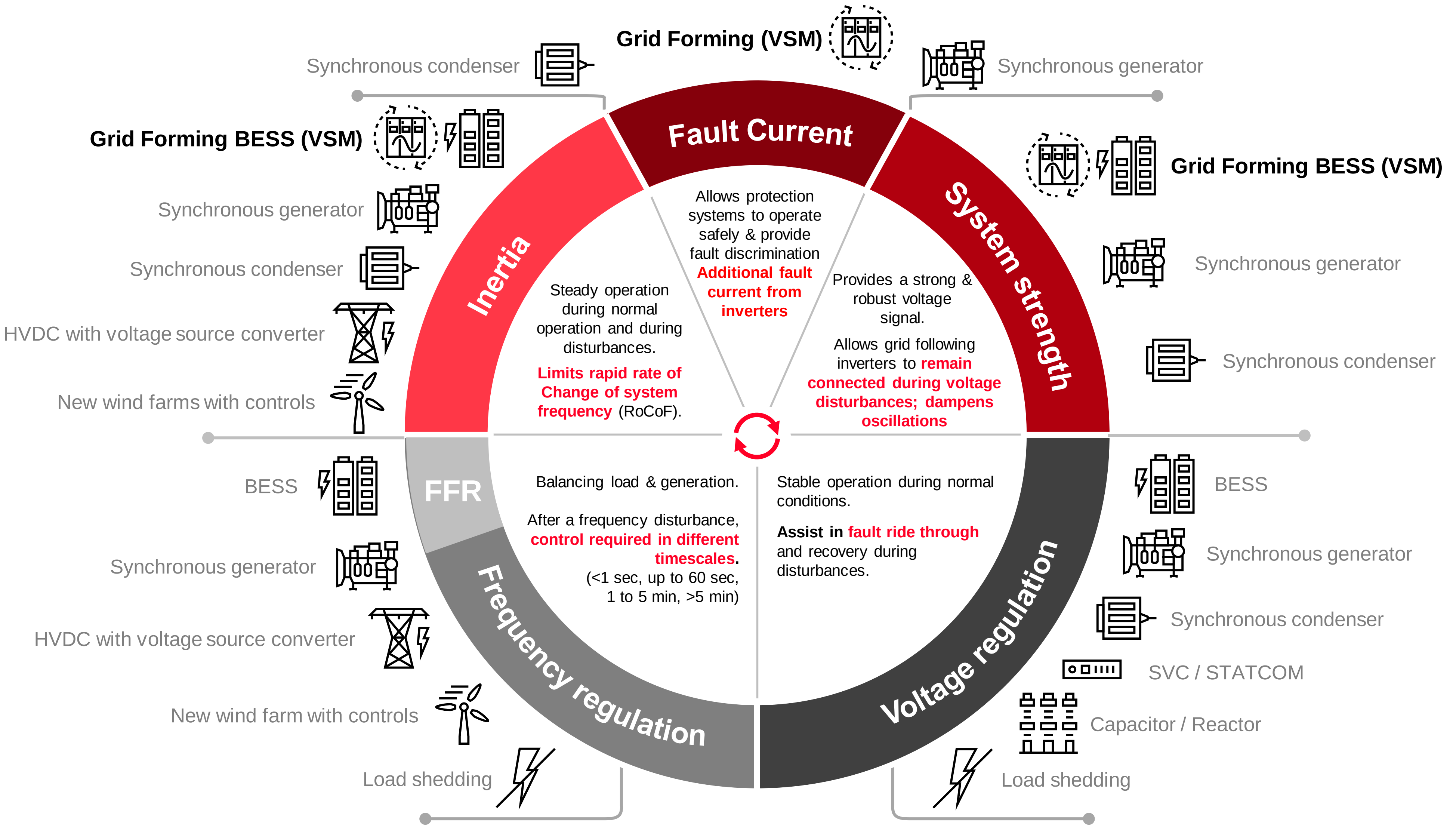

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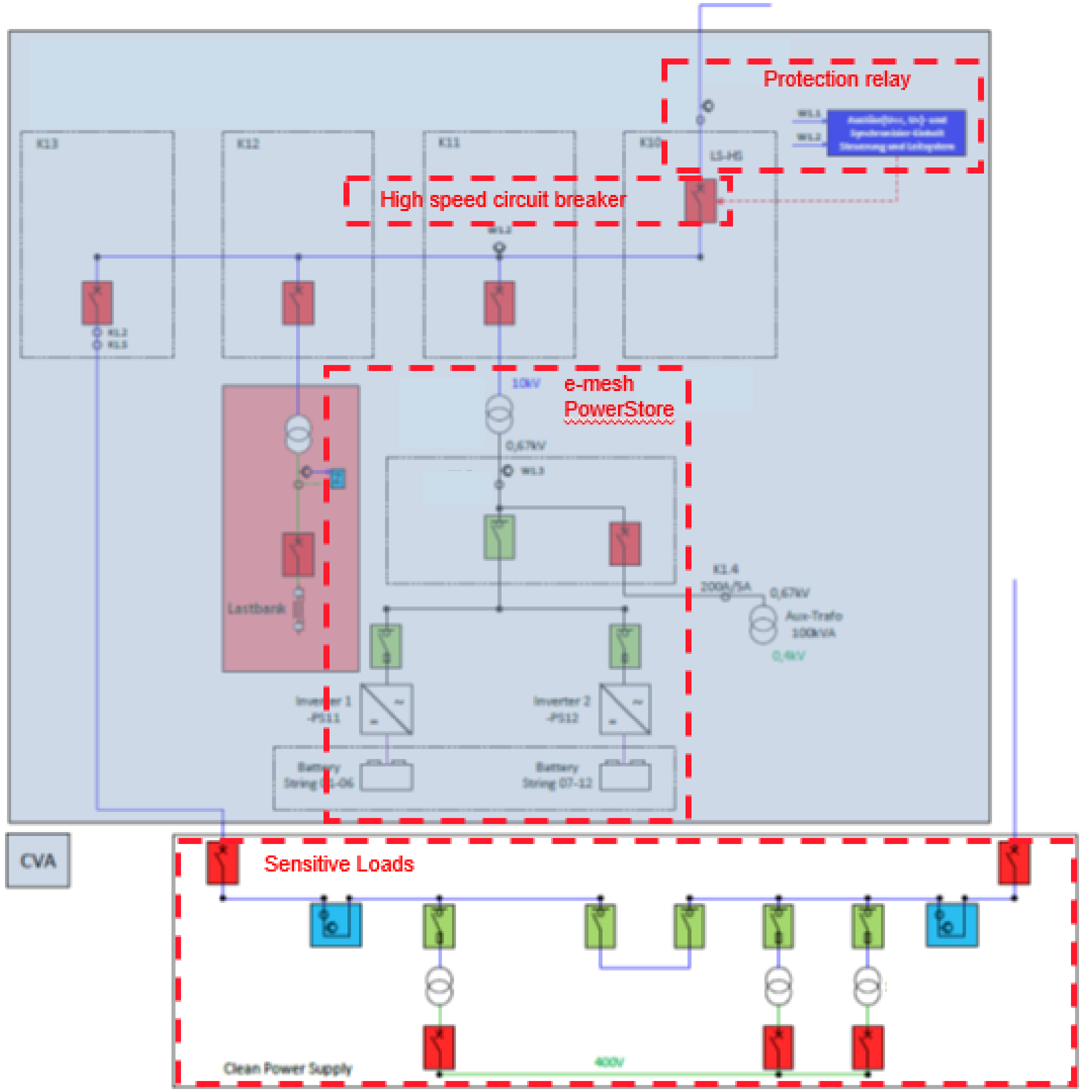
Project example: BESS as Emergency Power Supply System

EPSS e-mesh PowerStore – What does it refer to?

Key Services and Functionalities

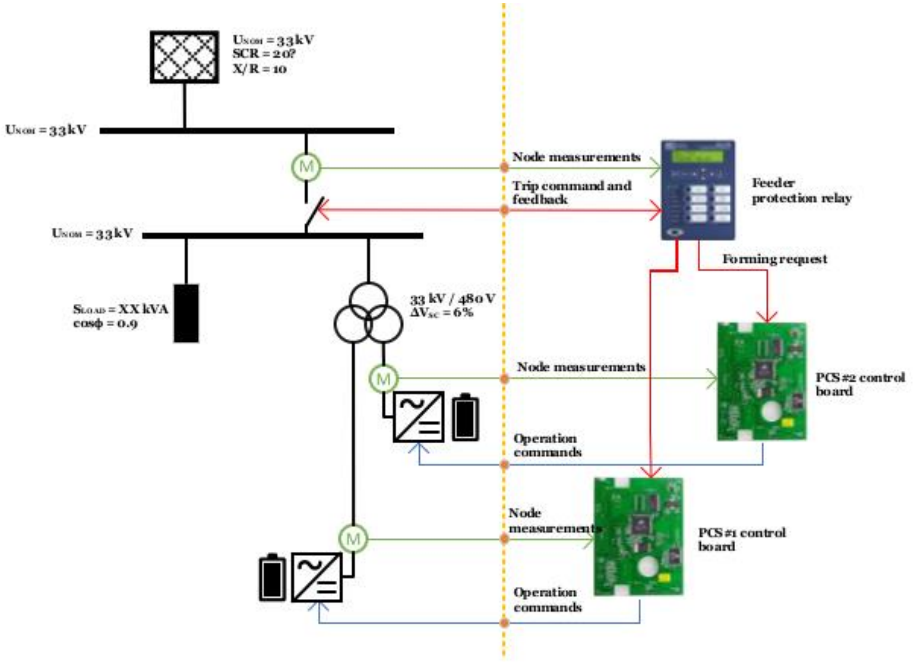
- Ensuring grid stability: by regulating voltage and frequency in compliance with grid code requirements, made possible by the converters' grid support functions during grid support mode.
- Enhancing grid resilience: by riding through certain grid faults in grid-connected grid support mode
- Reinforcing system strength by providing fault current and inertia, facilitated by the voltage source converter's grid forming capability.
- Enabling secure and synchronized operation with other voltage sources, including bulk power systems, by mimicking the behavior of a virtual synchronous generator through the VSG algorithm integrated into grid forming control.
- Facilitation the transition into islanded operation and subsequent resynchronization to the power grid



GFL: Grid Following, GFM: Grid Forming

EPSS PowerStore: HiL validation

Key elements



T0: event initial time, when the lowest of the 3 phases falls below 90% of the Vnom,
T1: when the lowest of the 3 phases is restored above 70% of the nominal voltage,
T2: when the lowest of the 3 phases is restored above 80% of the nominal voltage,
T3: when the lowest of the 3 phases is restored above 90% of the nominal voltage.

Performance validation

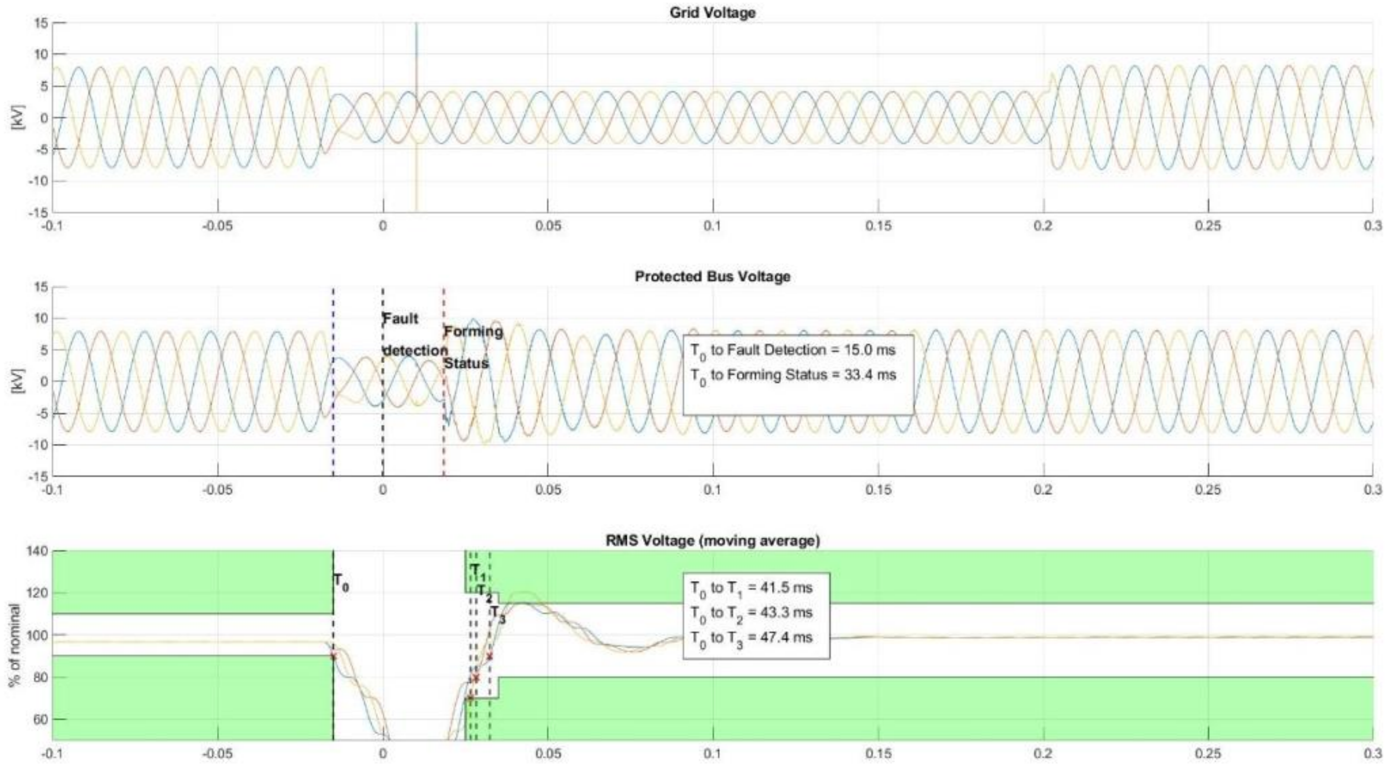


Figure 8: HiL measured voltages during symmetrical fault.

BESS equipped with fast fault detection device and high-speed circuit breaker ensures load protection with rapid response times and greater efficiency compared to a standard double-conversion UPS

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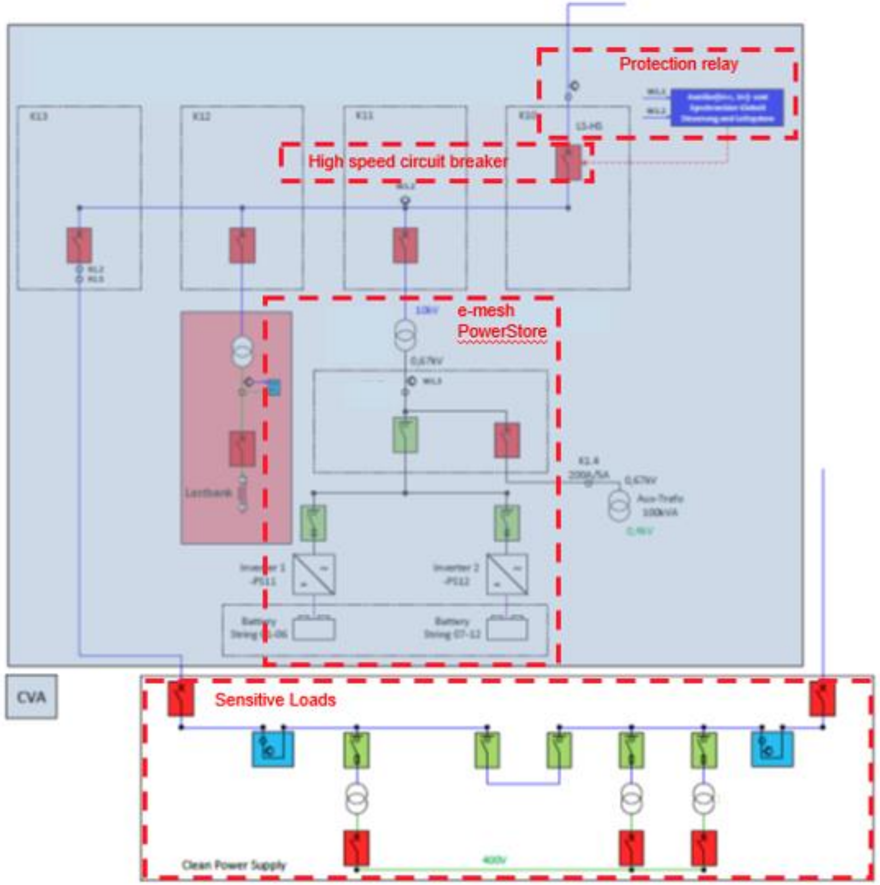
EPSS PowerStore: Field testing

Key elements



Performance validation

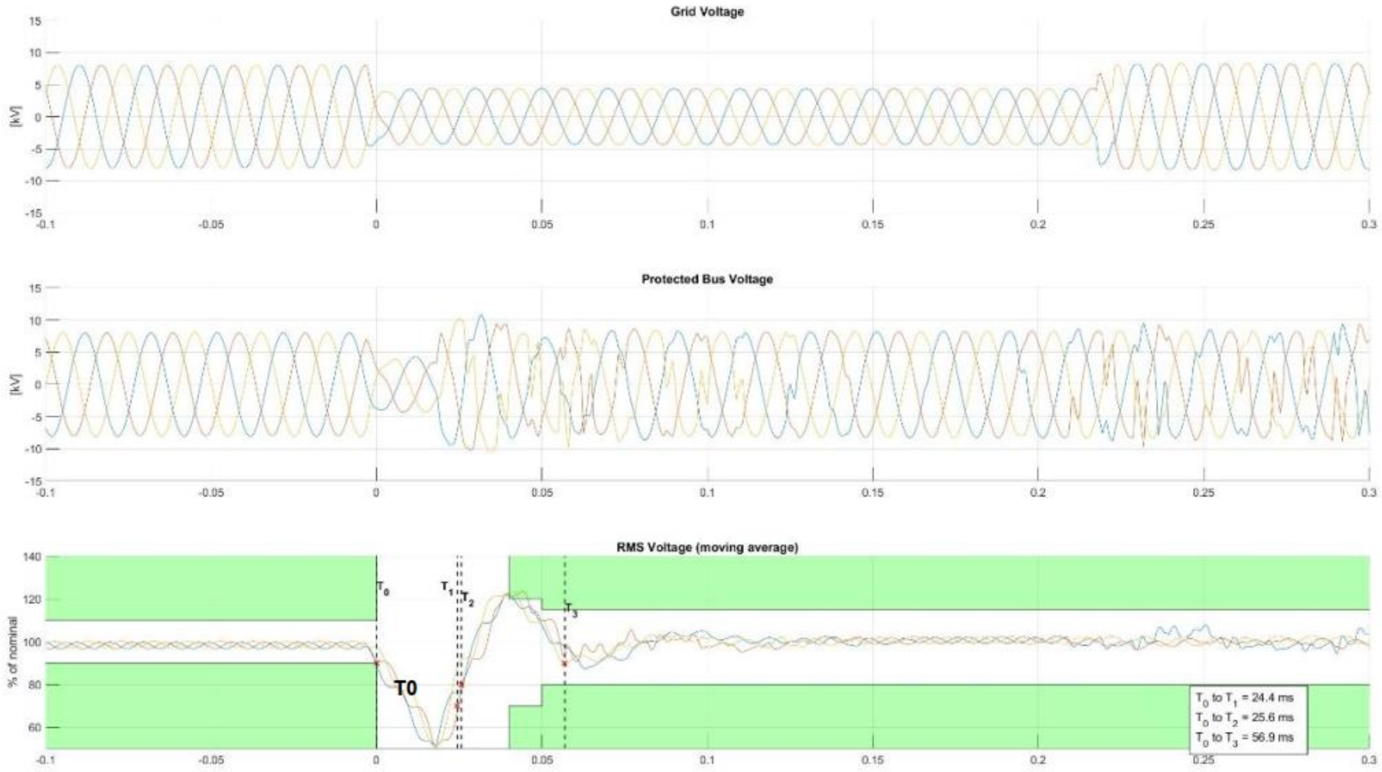


Figure 10: On-field measured voltages during symmetrical fault.

BESS equipped with fast fault detection device and high-speed circuit breaker ensures load protection with rapid response times and greater efficiency compared to a standard double-conversion UPS

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Project example: Grid strength with BESS (ESCRI)

Dalrymple ESCRI: The world's largest autonomous microgrid

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> If the wind is blowing and the sun is shining the battery can support supply to the local community indefinitely, which is a great outcome for customers.
>
> **Rainer Korte**
> Group Executive,
> Asset Management, ElectraNet

Challenge

To improve the reliability of supply in the lower Yorke Peninsula, which is prone to lightning strikes, while supporting the integration of renewables

Solution

Developed a Virtual Synchronous Machine with energy storage to stabilize the state’s electricity grid and seamlessly island the region to enhance reliability and utilize local wind power

Impact

Reduced outages from 8 hours to 30 mins in the first six months of operation. All external funding repaid within 3 years

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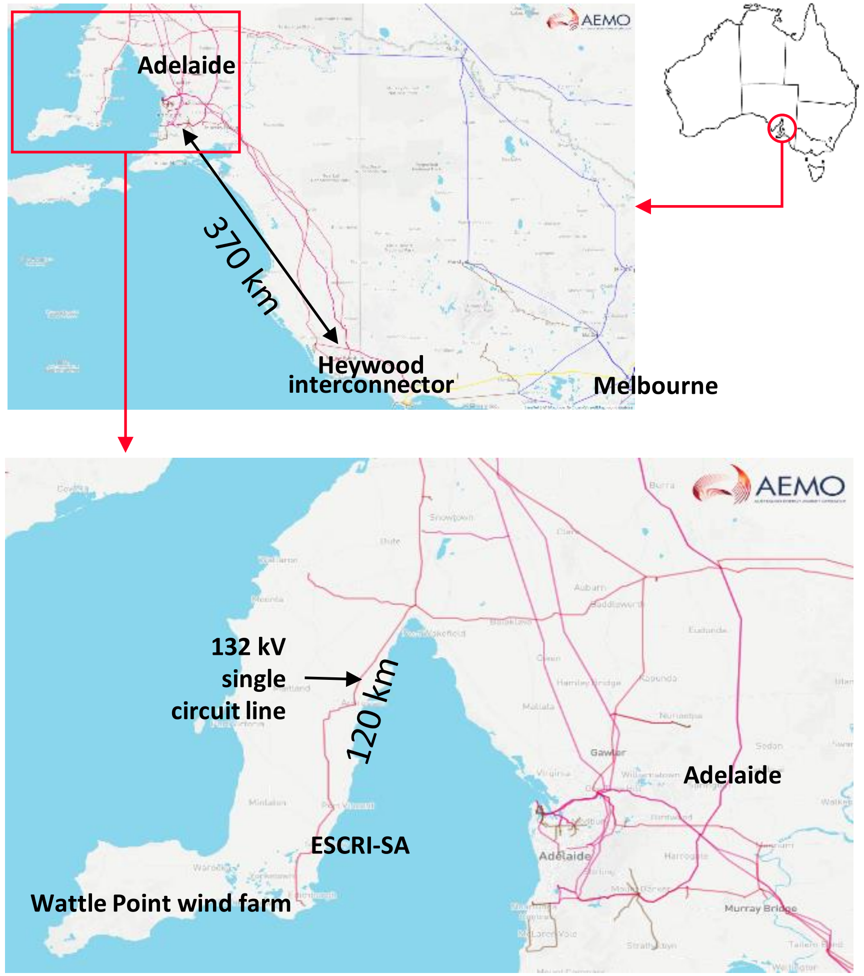
ESCRI BESS: location at the edge of NEM

Utility scale 30MW/8MWh BESS near the end of a long radial line in proximity to a wind farm

- Connection at 33 kV at Dalrymple substation on Yorke Peninsula – land available
- Opportunity to reduce expected unserved energy under islanding conditions (max demand is about 8 MW but on average need about 3 MW for 2 hours)
- Site is close to the 91 MW Wattle Point Wind Farm – provides opportunity for battery to support islanded operation with the wind farm and 2 MW of local rooftop solar, following network outages
- BESS is also traded in the FCAS and Energy markets. During a network event where the BESS is required to respond, the system has been configured to automatically switch to one of the higher priority services.



In 2018, ESCRI became the first registered VGM on the NEM playing a pivotal role in assisting NEM in overcoming challenges related to the transition

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South Australia Islanding Event: Inertia Response

Grid forming inverter responds to frequency change in the network – 8-second view

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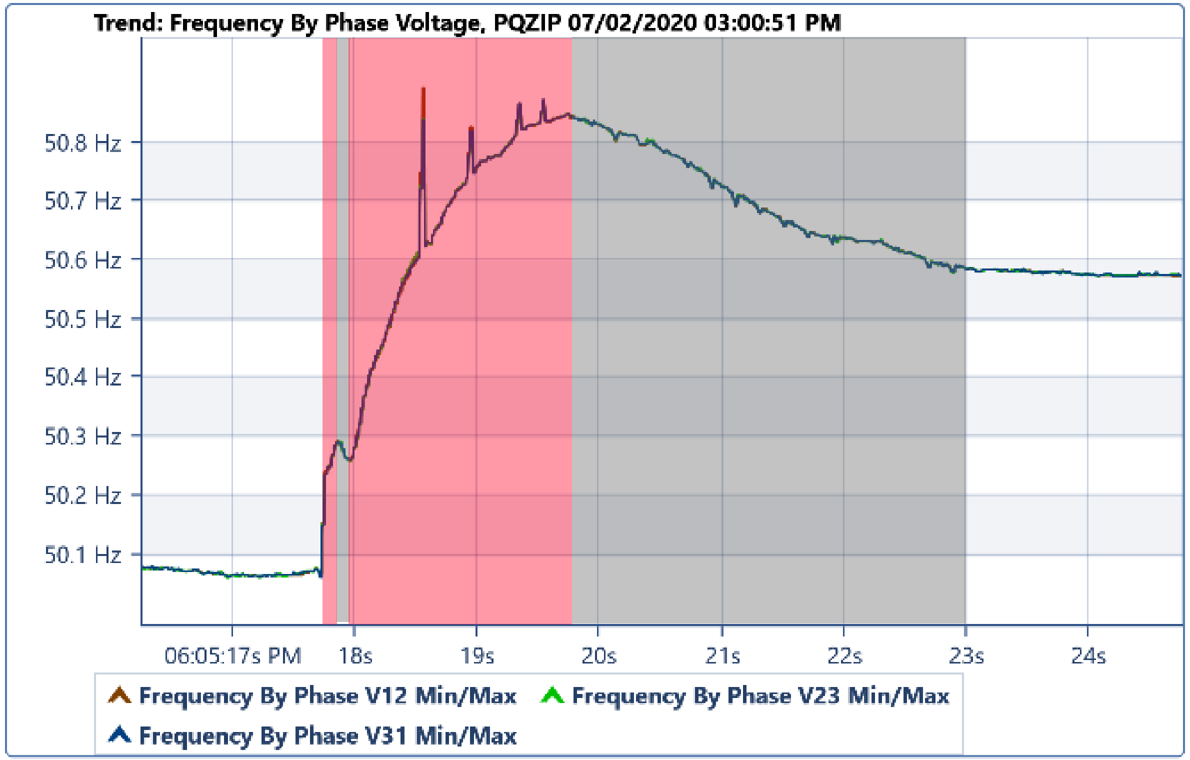
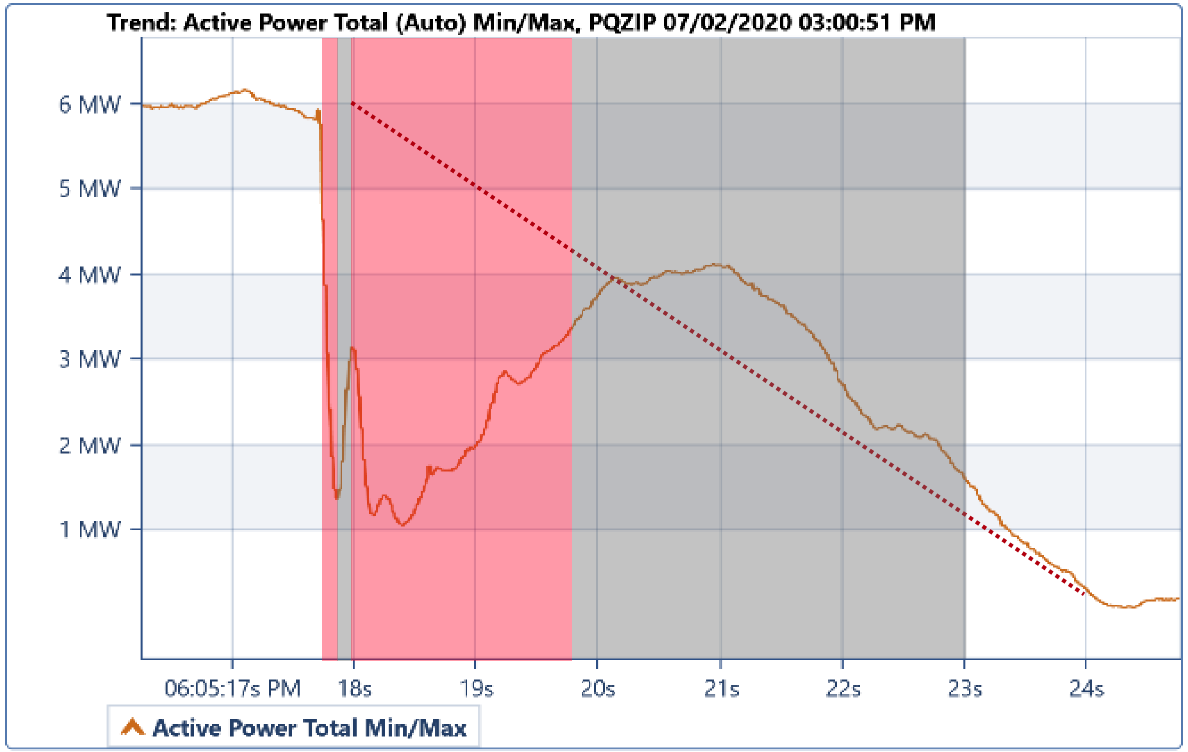
RoCoF event in South Australia over 8s (red positive RoCoF, grey negative RoCoF)



Active Power response over 8s – Inertial response initially to grid frequency (left) prior to FCAS setpoint (red dotted line) on secondary controller driving 6 second FCAS market response as per bid 6MW bid



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South Australia Islanding Event: Inertia Response

VSM responds to frequency change prior to high-speed data recorder

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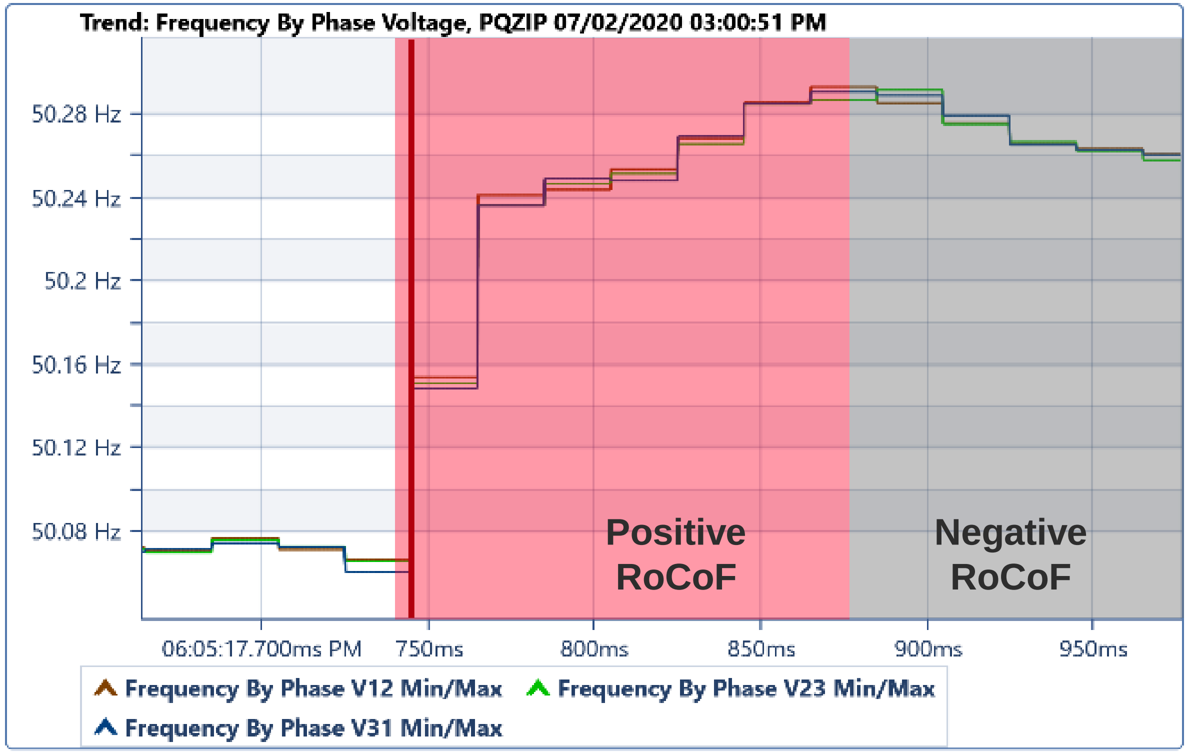
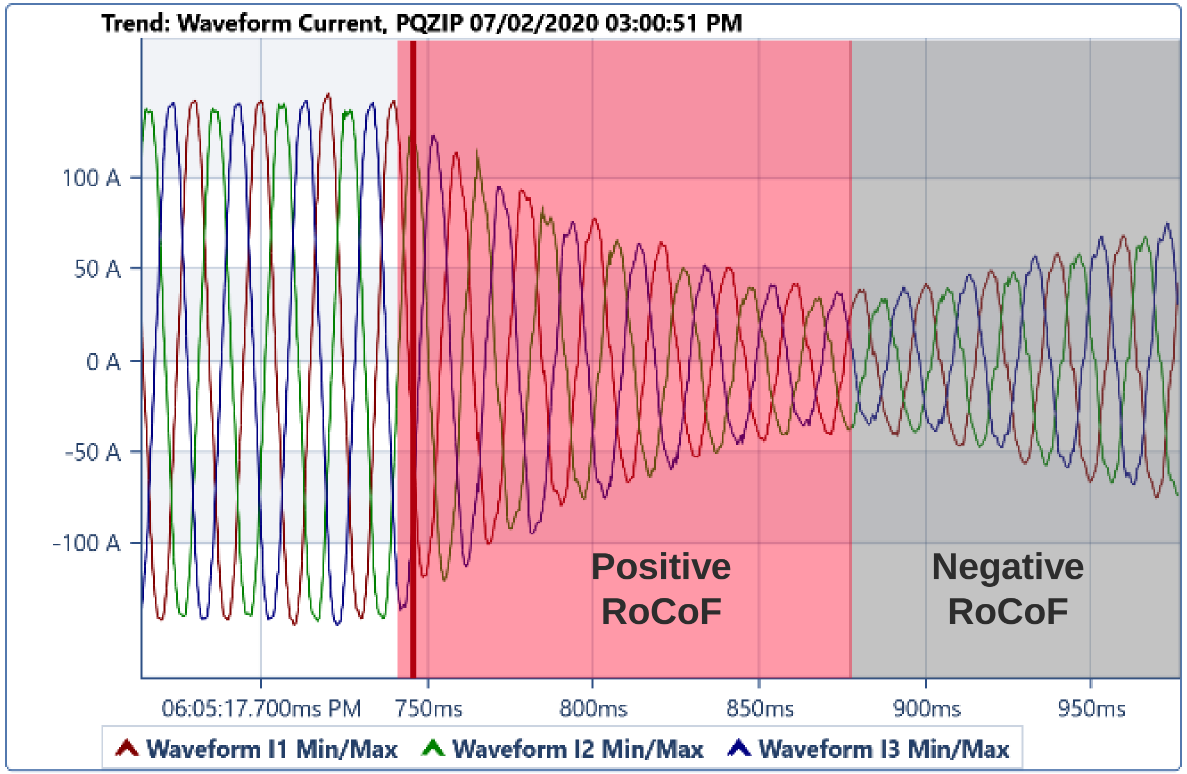
Frequency Measurement by high-speed data recorder over 300ms



VSM Response – Current responds prior to frequency measurement (red vertical line) and the output (below) mirrors the grid frequency (left) as it resists the change in frequency



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Application of AGSI in the NEM, AEMO White Paper

Advanced inverter applications investigated

The Dalrymple BESS project has shown that grid-forming BESS can provide a range of advanced technical capabilities to support the operation of power systems with high penetration of IBR (as outlined in Section 3).

In the first six months of operation, the Dalrymple BESS reduced the loss of supply in the area from approximately 8 hours to 30 minutes.

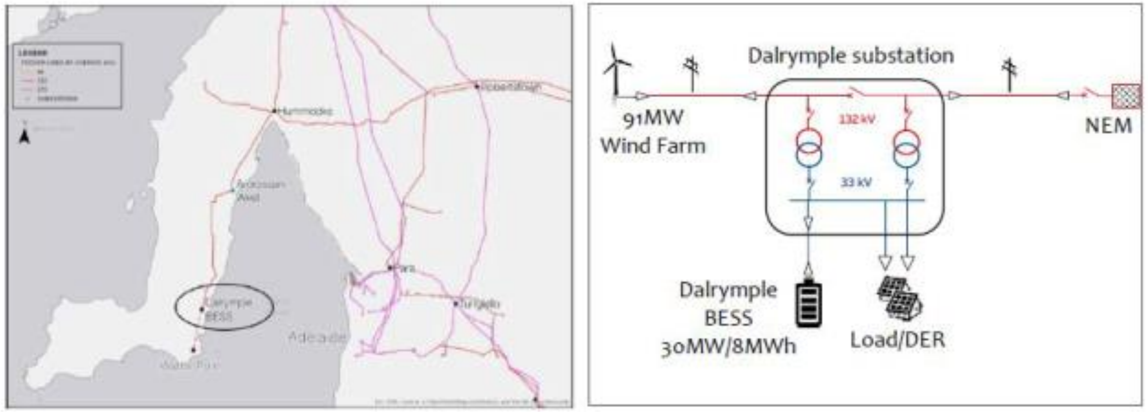
The capabilities provided by the project include:

- **Island operation** – the system can operate in islanded configuration and transition to and from an islanded state. When the upstream connection to the transmission system is lost and the system is islanded, it regulates frequency in the microgrid using synthetic inertia, a frequency governor operating in droop mode on the primary control level, and a frequency controller with a small dead-band on the secondary level. Additionally, under islanded conditions, Dalrymple can adjust the system frequency to invoke curtailment of behind-the-meter DER to avoid over-generation conditions.
- **System restart** – the grid-forming BESS can black start the local 33 kV distribution network. This is achieved through a soft energisation of the system (where voltage is ramped up slowly to prevent inrush current and harmonics). However, system restart capability was unproven beyond the small section of local distribution network.
- **Connecting IBR in weak grid areas** – the system can operate at very low Short Circuit Ratios (<1.5), significantly beyond what traditional IBR generation can perform. It is also able to provide system strength support capability via short-term fault current overload.
- **Supporting system security (provision of inertia)** – the BESS can provide adjustable synthetic inertia, rapidly arresting frequency deviations on the grid.

A1.3 Case study 3: ESCRI battery in grid-forming mode

This case study is adapted from a CIGRE paper by ABB[36] and outlines the capabilities provided by the Dalrymple Energy Storage for Commercial Renewable Integration (ESCRI) BESS in SA. It is currently the largest grid-forming BESS in the world, at 30 MVA and 8 megawatt hours (MWh). It is the first large-scale, grid-forming BESS connected to the NEM. It was installed on the lower Yorke Peninsula in South Australia in 2018, near the end of a long 132 kilovolt (kV) single-circuit radial feeder, as shown in Figure 15.

Figure 15 ESCRI battery network location – a simple network diagram



ESCRI BESS has demonstrated a range of valuable capabilities in the NEM

https://aemo.com.au/-/media/files/initiatives/engineering-framework/2021/application-of-advanced-grid-scale-inverters-in-the-nem.pdf

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Project example: Empowering RE Transition through BESS (Faroe Islands)

Faroe Islands: Enabling 100% renewable generation by 2030

> One important step toward a 100% RE electricity sector is to translate current research in inverter dominated power systems into real hands-on project.
>
> **H.M. Trondheim, T. Nielsen**
> R&D, Power Company SEV, DK
> CIGRE CSE 030, 2023

Challenge

To support the integration of renewables without compromising the stability and security of the power system on the island.

Solution

Integration of innovative solutions such as the VGM BESS with synchronous condenser to enable 100% wind penetration on the island.

Impact

The islanded power system of Suðuroy runs frequently with 100% instantaneous WP generation. The contribution of BS-SC has resulted in a narrower frequency distribution and less voltage fluctuations.

Faroe Islands SEV-1: Suðuroy Island

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Generation Mix

e-mesh PowerStore battery system (BS) of 6.3MW/7.5 MWh and a synchronous condenser (SC) of 8 MVA were installed in 2022 to enable the IWP.

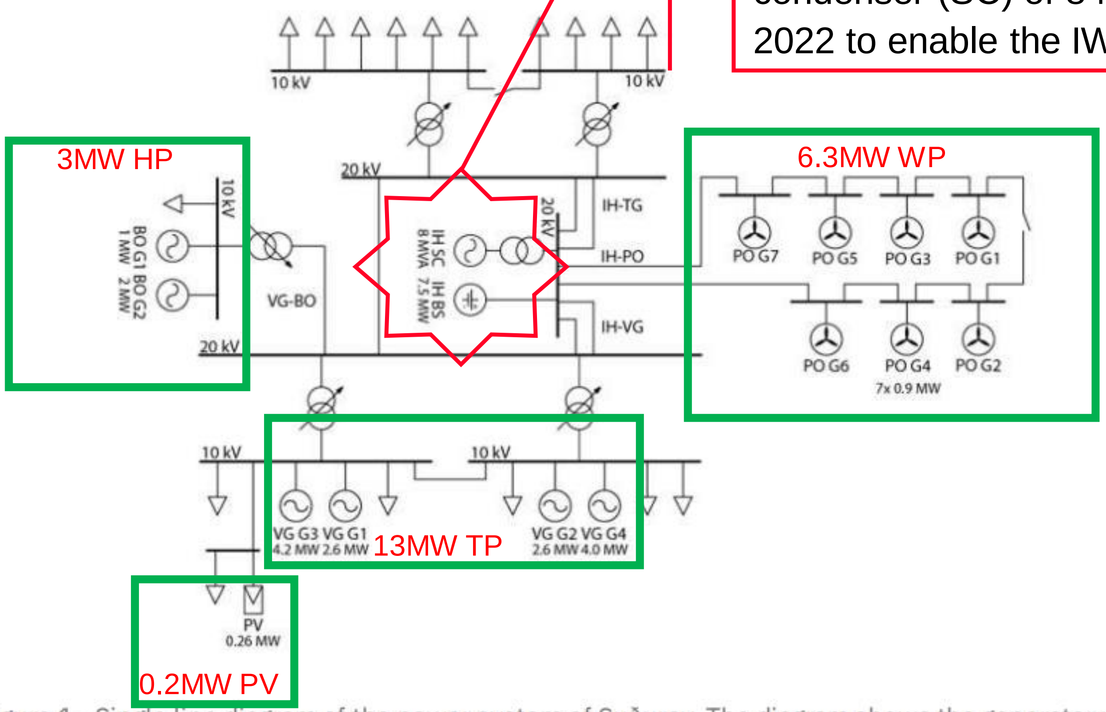
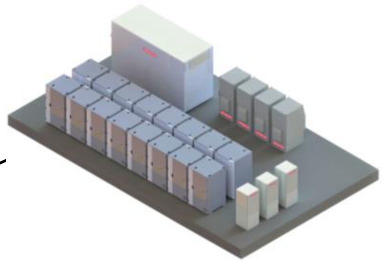
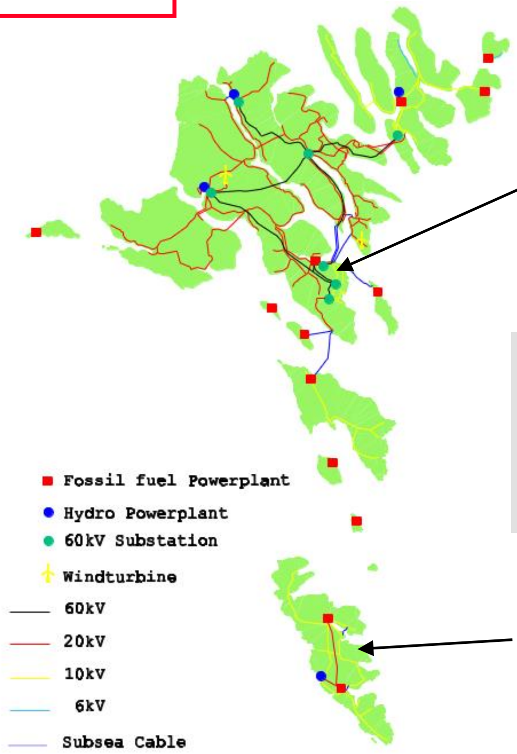


Figure 1 - Single line diagram of the power system of Suðuroy. The diagram shows the generator units, i.e. hydro (BO G1-BO G2), thermal (VG G1-VG G4), wind turbines (PO G1-PO G7), the battery system (IH BS) and the synchronous condenser (IH SC) together with the loads, lines, transformers and busbars [3]

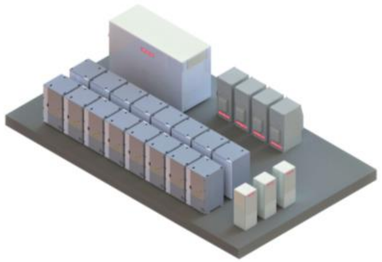
*The AVG load in 2020 was 4 MW (8 MWpeak and 2 MWmin).

SEV-2
12,5MW BESS location – Sund Power Plant
In operation: Dec-2023





SEV-1
6,25MW BESS location – Suðuroy
In operation: Sep-2022



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IWP: Increased Wind Penetration, HFO: Heavy Fuel Oil

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Faroe Islands SEV-1: Inertia Response

Hydro Turbine Outage

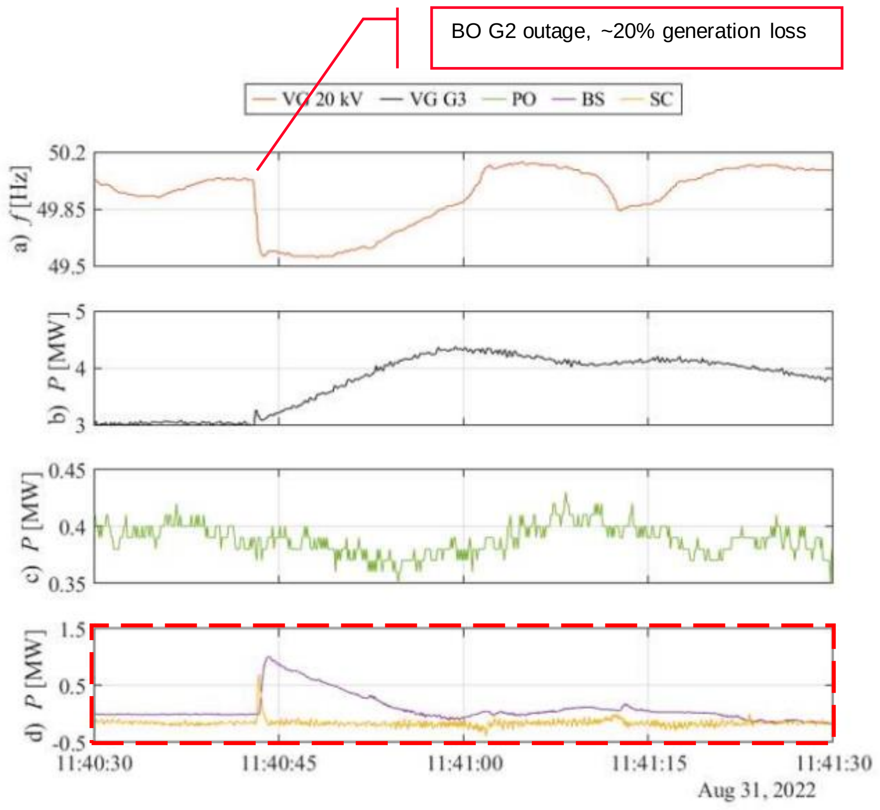

Figure 3 - a) Frequency at VG 20 kV, b) active power of VG G3, c) active WP, d) active power of BS and SC during the outage of BO G2

Full Production Drop in 15 seconds

- WP was the only generation unit at this specific moment
- The response of the SC is not included as it is not significant (the production drop happens over 15sec only).

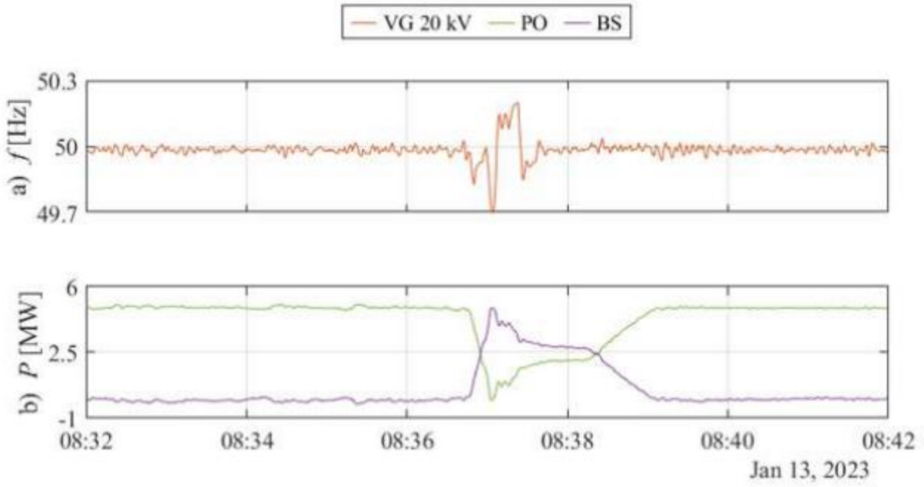

Figure 4 - a) Frequency at VG 20 kV and b) WP and BS active power during a loss of full production within 15 seconds

CSE_30-experiences-with-100-wind-power-generation-in-an-isolated-power-system-suduroy-faroe-islands.pdf

Faroe Islands SEV-1: Ensuring reliable operations

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Unstable wind conditions

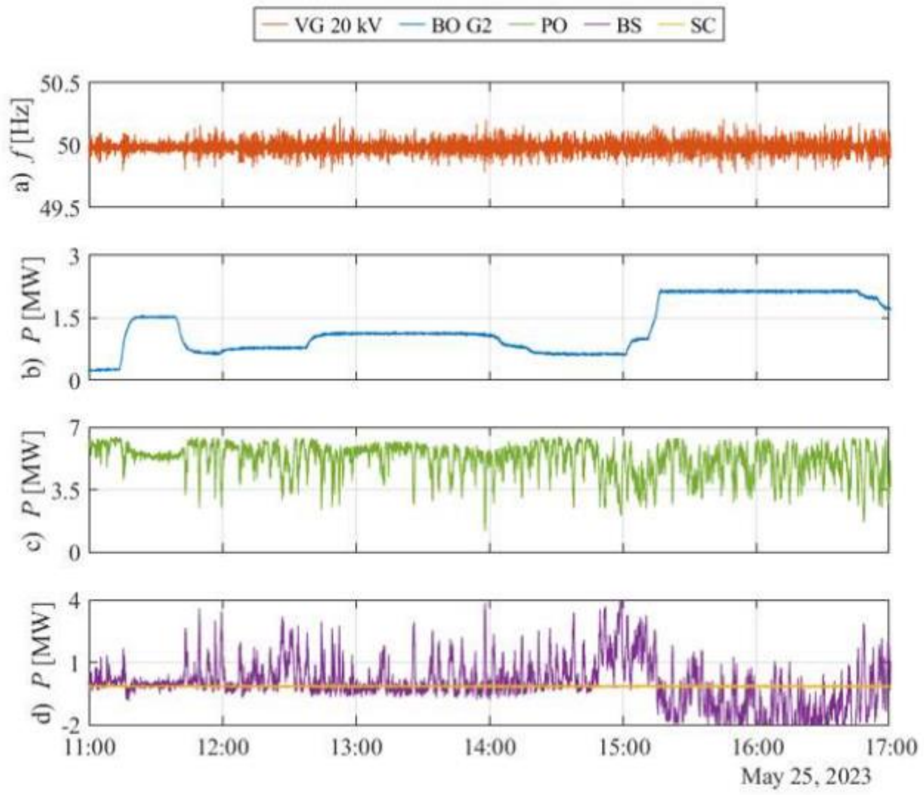
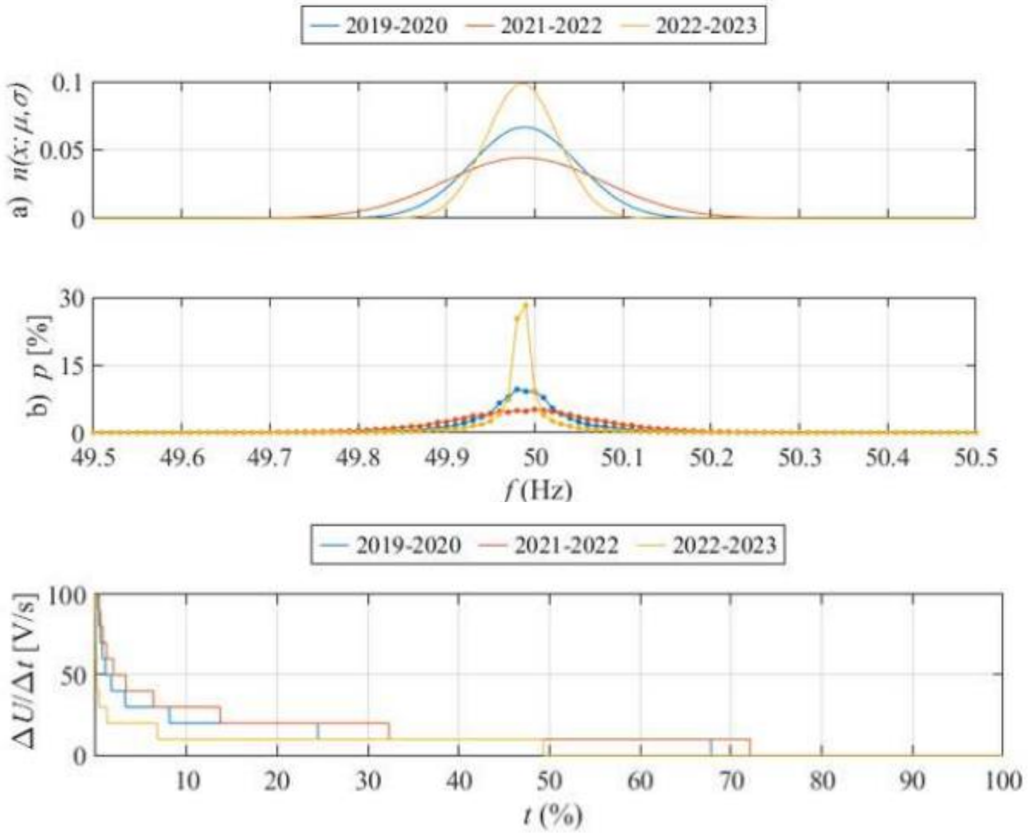


Figure 5 - a) Frequency at VG 20 kV, b) active power of BO G2, c) active WP and d) BS and SC active power

Improved Voltage and Frequency



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Resilience and reliability – Outlook

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Network resilience supported by VSM BESS: continue the energy transition to RE even in weak grid environments

- Business case for value stacking vs alternative technology choices
- Markets grid strength services
- VSM BESS as part of advanced network control

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