+ Zenobē –

Grid-forming Project Development

March 25th, 2024

ZENOBĒ

Contents

Our unique platform covers both power and transport

Network infrastructure

Grid-scale battery storage can maximise the use of renewables and drive down consumer bills. Zenobē builds and operates battery storage to make clean power accessible:

- 735MW battery storage live/in construction
- Goal of >3.5GWh by 2026
- First directly connected battery systems on UK transmission network
- Planned investment of >$1.25b into advanced battery solutions

Second life batteries

We are experts in repurposing electric vehicle batteries.

- Largest second-life battery business in Europe
- World-leading knowledge in residual value

Analytics & software

Proprietary software and advanced analytics power our results.

- Team of 52 dedicated specialists
- Managing and optimising power across 75+ sites

Fleet electrification

Low risk, zero emission fleets are possible now. Zenobē provides everything needed to switch to EVs - with a track record that's hard to beat:

- The #1 e-bus platform in the UK, Australia and New Zealand
- c.28% market share in the UK and c.30% in ANZ
- >1,500 electric buses, coaches and trucks supported globally
- Electrified over 75 depots to date

Power ← → Transport

Network Infrastructure

- Network Infrastructure is a global team, headquartered in London and with offices in New York City and Austin
- The Network Infrastructure team targets projects with the following characteristics:
  - >100MW
  - Transmission connected
  - Full, firm access to all markets
  - Additional value from location-specific grid services contracts (e.g. voltage, fault-current, inertia)
- NI collaborates with grid operators and top-tier suppliers to maximize the capability of grid-forming technology and navigating challenging regulatory / interconnection processes
- Strong internal engineering focus and team size, due to complexity and scale of projects

A successful project for Zenobe is one where we add value through coordinating a complex set of counterparties and technical requirements

Core team members and +50 additional employees

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NI Global Director

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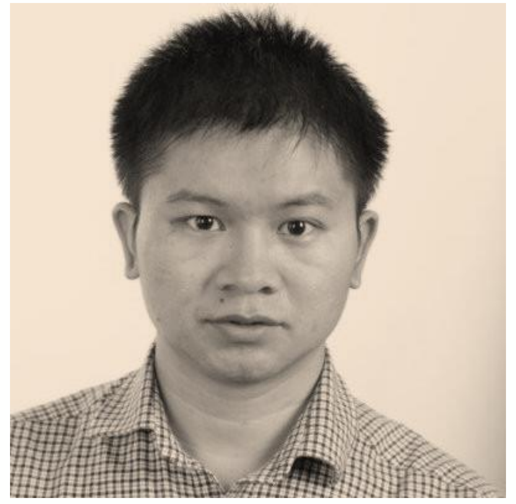

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US BD – Markets & Policy

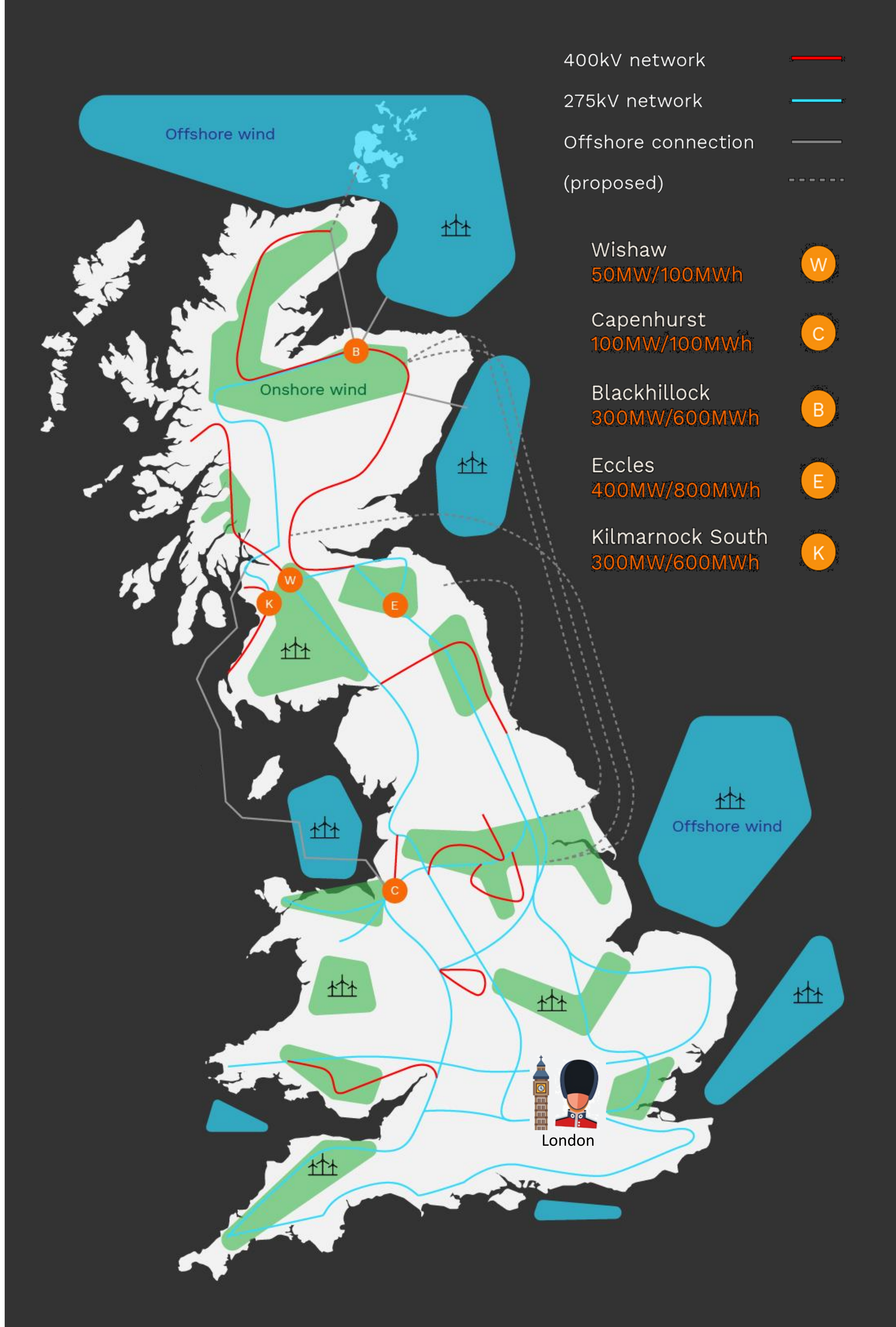
Storage As a Transmission Asset (SATA) in the UK

UK Power Grid needs and inclusion of SATA

- Increased need for additional transmission grid services: inertia, fault-current, dynamic voltage control, thermal constraint mgmt.
- Electricity System Operator (ESO) opened a competitive process (“Pathfinder” tenders) to procure these transmission services
- Battery storage was embraced by the System Operator to compete against traditional transmission equipment (synchronous condensers, shunt reactors)
- $100m Pathfinder revenue awarded to battery storage, delivering c.$1bn of grid savings of which Zenobē won c.$70m of Pathfinder contracts across all categories (voltage, stability, constraint)

Success factors

- Transparency on locational requirements and technical data allowed battery storage players to optimize siting and engineering design
- Allowed storage to stack SATA alongside normal energy market participation (balancing, arbitrage etc.)
- Technology-neutral tenders to procure lowest cost combination of projects
- **Additional contracted revenue provided the incentive to build at these locations**



Note: Savings calculated by ESO. Comparing the cost of pathfinder contracts versus accessing grid services from stand-by thermal generators in GB Balancing Mechanism
https://www.nationalgrideso.com/industry-information/balancing-services/pathfinders/noa-stability-pathfinder

Zenobe UK SATA projects

- Zenobe secured ESO Stability contracts (inertia, SCL) for 3x battery storage projects, 900MW in total, in Scotland
- These projects will be the first grid-forming battery projects on the UK grid

				SATA contract requirement			
				Fault-current		Inertia	
Project	kV	Rated Power (MW)	COD	Max SCL (MVA)	p.u.	Min inertia (MVA.s)	p.u.
Blackhillock	275	200	24Q4	120	0.6	380	1.3
Kilmarnock South	400	300	25Q4	480	1.6	1500	5.0
Eccles	400	400	26Q3	960	2.4	3000	7.5

- o **Fully stackable** with other services (balancing, arbitrage), as the SCL and inertia are minimum guaranteed levels across all operational profiles.
- o $250-300m[1] savings to grid = 4x savings vs contract cost ($70m over 8-10yr)
- o Different p.u. factors are due to procurement needs in the specific areas as determined by ESO. Zenobe offered a range of capabilities for each site.
- o SCL and inertia are not required as minimum grid code standards for battery storage. These contracts are providing 100% additional capability.

B Blackhillock
300MW/600MWh

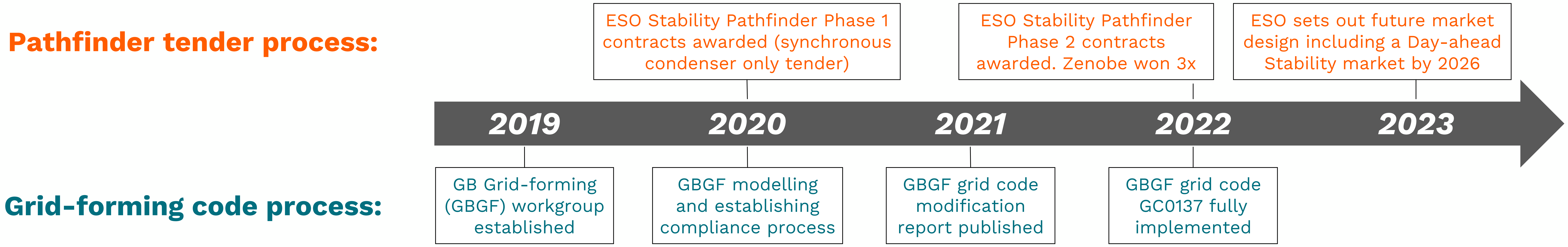
- Fully financed and under construction. Operational Q3 2024
- Located in Northeast Scotland (Aberdeenshire)
- Will provide inertia and fault-current via Pathfinder contract

Relevant learnings from this project:

- With the rise of intermittent generation, ESO procured fault-current to manage local grid stability, as well as more system-wide inertia
- **ESO created a market signal and provided transparency on SCL requirements and effectiveness** inc. retained voltage at all substations
- Zenobe's three projects won alongside five synchronous condenser projects

* Fault-current is referred to at Short-circuit level (SCL)
Source: National Grid ESO Stability tender results https://www.nationalgrideso.com/industry-information/balancing-services/pathfinders/noa-stability-pathfinder#Phase-2-(concluded).
1. Savings calculated by ESO, comparing the cost of pathfinder contracts versus accessing grid services from stand-by thermal generators in GB Balancing Mechanism https://www.nationalgrideso.com/industry-information/balancing-services/pathfinders/noa-stability-pathfinder

Zenobe UK SATA projects – timeline, compliance, challenges



- As a key player in the GBGF workgroup, **Zenobe worked with the ESO from 2019-21** on the grid code studies and compliance process
- For the 3x Stability Pathfinder projects, Zenobe is required to meet GC0137 and demonstrate the stability services through:
  - Dynamic simulations (Electromagnetic Transient (EMT) studies), Factory Acceptance Testing and On-site testing*

Key Challenges

- Significant volume and complexity of study work required to provide simulations demonstrating plant performance
  - Engineering team worked alongside consultants, ensuring they understood requirements and carried out studies to ESO's satisfaction
- Coordinating with suppliers on the submission of plant-level models (i.e. issues around supplier IP), as part of GC0137
- Complex stability services such as inertia and SCL cannot be tested on site at the power station level
  - Upon energisation, ESO will test certain aspects of the stability performance by injecting test signals into our plant
  - Our plant will be recorded by Dynamic System Monitors, installed on site, and assessed post-event to confirm we met the contracted requirements
- Presents complexities with commercial contracts (i.e. performance validation) in the event of our plant not responding as required to a system event and agreeing how it can be proved that the issue has been resolved before another system event occurs

SATA opportunity for the West Texas grid

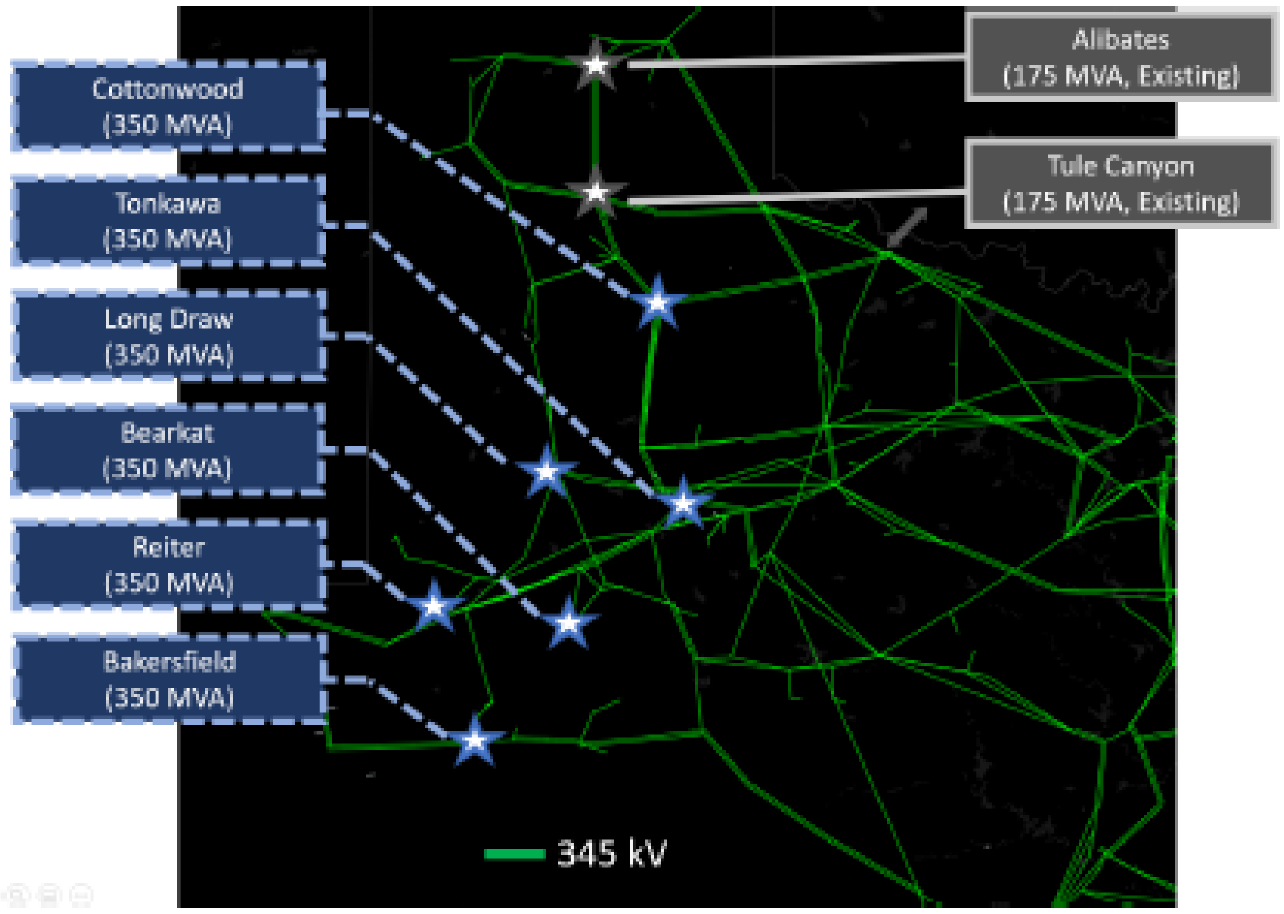
- **Problem** = Growth of grid-following inverter-based resources (solar, wind, battery storage) is decreasing grid stability
- **Technical issue** = Need for increased inertia, voltage control and fault-current support
- **Proposed solution (see right)**:
  - 6x 350MVA synchronous condensers
  - Each providing 350MVAr of reactive power and 2,150[1] MVA of short-circuit level of fault current
  - Inertia (exact amount TBC)
  - Capex of $60m-$80m per synchronous condenser ($360-$480m for 6x)

- **Zenobe recommends grid-forming battery storage to be considered in this procurement, alongside synchronous condensers**
  - ✓ Effective at providing inertia, fault-current & dynamic reactive power
  - ✓ <2 years build time
  - ✓ Highly cost competitive, especially if stackable with energy services, vs ONLY procuring synchronous condensers

Proposed 6x 350MVA synchronous condensers in West Texas

ERCOT recommends the following locations and engineering specifications for the new synchronous condensers:

- Six locations: Cottonwood, Bearkat, Tonkawa, Long Draw, Reiter, and Bakersfield 345-kV substations
- Approximately 350 MVAr capacity at each location
- Around 3,600 Ampere (A) of three-phase fault current contribution to the 345-kV point of interconnection (POI)[2]
- A combined total inertia of 2,000 MW-seconds (MW-s) or above at each location, incorporating synchronous condenser with flywheel
- Effective damping control to meet the ERCOT damping criteria in the Planning Guide Section 4.1.1.6.



Recommended Locations for Synchronous Condensers in West Texas

Source: *ERCOT Assessment of Synchronous Condensers to Strengthen the West Texas System version 1.0*

1. SCL = Sqrt(3)*3.6kA*345kV = 2151 MVA

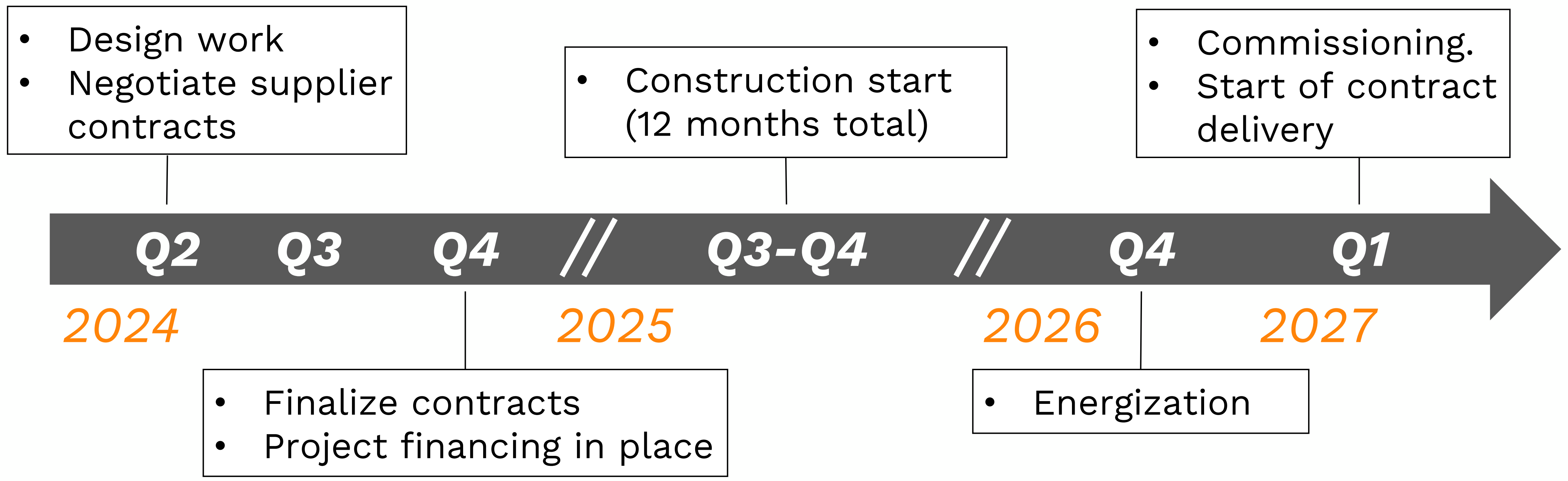
Zenobe proposed SATA solution for West Texas grid

- Zenobe is proposing a grid-forming battery storage solution to help address the Stability issues identified by ERCOT in West Texas
- The solution will provide fault-current, inertia and dynamic reactive, but will require further technical analysis with ERCOT team to optimal inform solution design and sizing
- Zenobe works with world-leading battery integrators and grid-forming inverter suppliers to maximise the SATA capability and bring a cost competitive solution

Indicative SATA project and contract cost

	300MW grid-forming BESS
BESS contract cost (10yr)	• $5m p.a. (for 10 years) • $10m-$30m cheaper per synchronous condenser (350MVA)
Services provided **(100% availability across full MW range)**	• 450-750MVA* of fault-current (1.5-2.5 p.u.) • >2GVA.s of inertia • 160-220MVAr reactive power range

Project timeline – Pre & construction timeline



- *SCL amount dependent retained voltage / fault impedance, measurement timing (e.g. 100ms), assumed MVAr initial dispatch
- Inertia capability can substantially higher if coordinated with lower active power output requirement e.g. 0MW output = 9GVA.s

Source: Submitted Zenobe modelling for Pathfinder stability contracts

Conclusion and recommendations

Grid-forming battery storage to provide Stability:

- Can be deployed much faster than poles & wires or significant DG system redesigns
- Zenobe is deploying grid-forming battery storage in the UK to solve the stability issues that will be present in every grid
- Grid operators can save money by procuring grid-forming battery storage (stacking alongside other revenues) vs only procuring single-use transmission asset, as shown from the UK experience
- This requires grid operators to be transparent on technical and locational requirements, and allow battery storage developers to optimize siting and engineering design to compete with existing solutions
- However, very little grid-forming technology is being deployed on US grids as there is no incentive and it adds significant upfront design & engineering cost and project complexity

Reasons to avoid minimum standard route for stability services from battery storage:

- From a process, compliance and timeline perspective, delivering stability services with grid-forming technology is relatively new to the sector and technically complicated, as shown with the UK compliance process
- Enforcing a minimum standard for stability services will add complexity to all battery storage projects. This will increase project costs and impact timelines, increasing overall system cost
- Stability services like fault-current and reactive power and highly location specific. It is not cost effective to enforce system-wide minimum standards for these services compared to targeted, location-specific tenders
- Even if minimum standards for stability services are set, the capabilities might not be built in the locations needed

Zenobe suggestions

- Engagement with grid operators is needed to fully understand the technical issues
- Open procurements (e.g. synchronous condensers) to include grid-forming battery storage to provide a market signal, as per the UK experience
- Pilot solutions could be deployed very quickly across US grids to prove the technology use case and potential savings from SATA

Appendix – Modelled SCL contribution from BESS vs Synchronous Condenser solutions

1) Modelled fault current from BESS and synchronous condenser, depending on measurement time and retained voltage

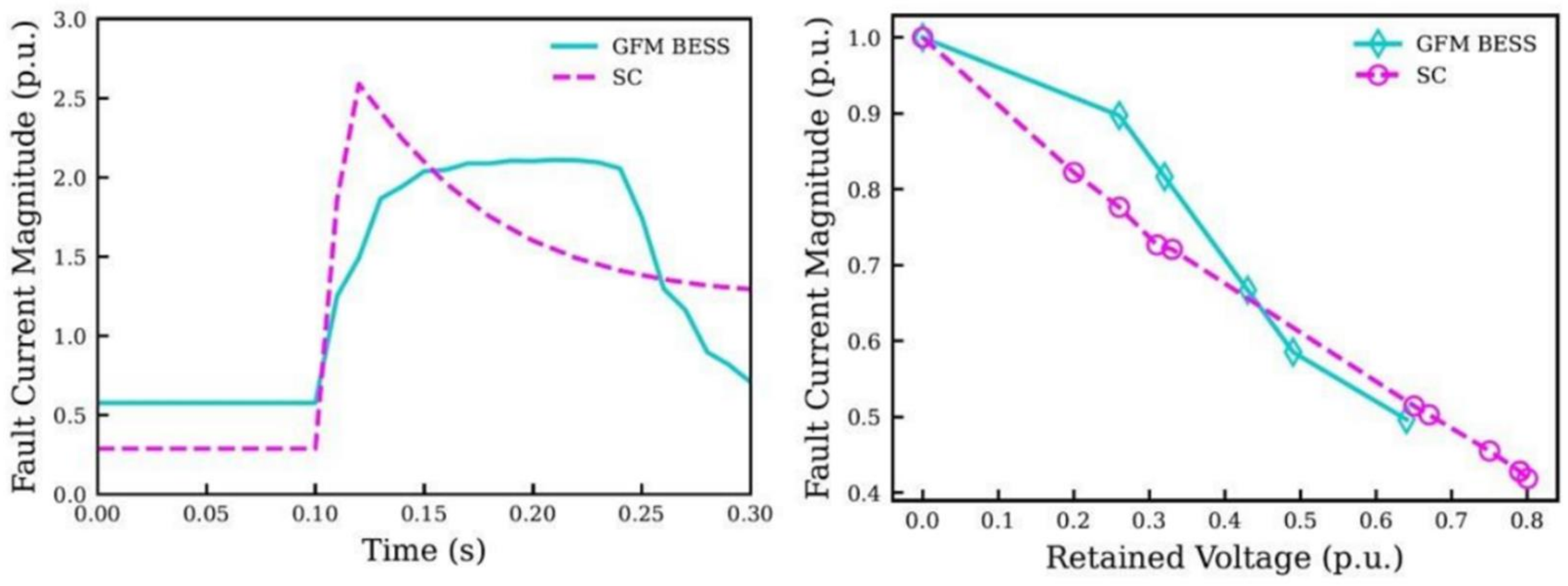
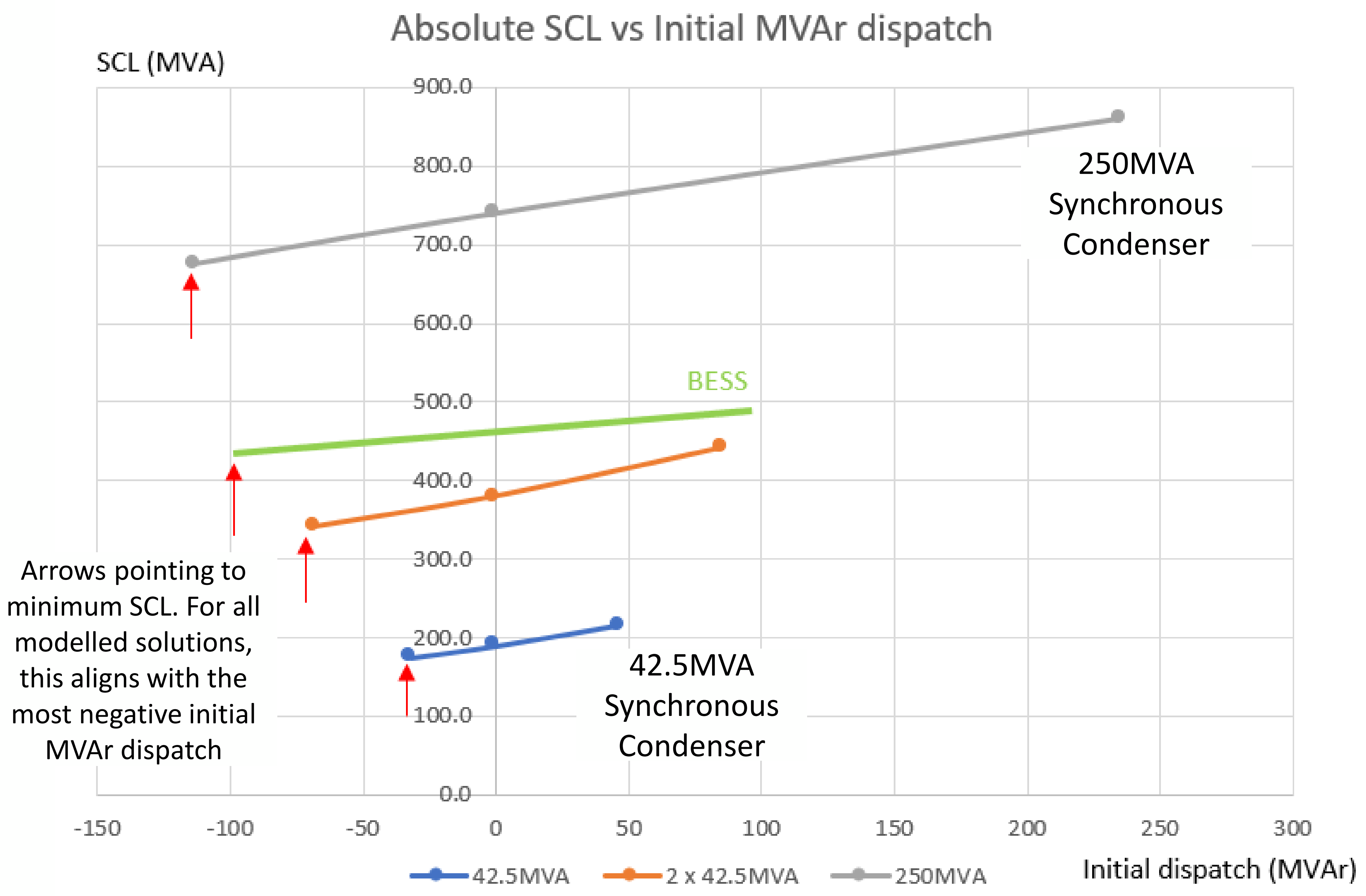


Figure 8: Fault current contribution of GFM BESS and SynCon

2) Modelled absolute SCL from 300MW BESS (green) and 3x synchronous condenser configurations, across MVAr range



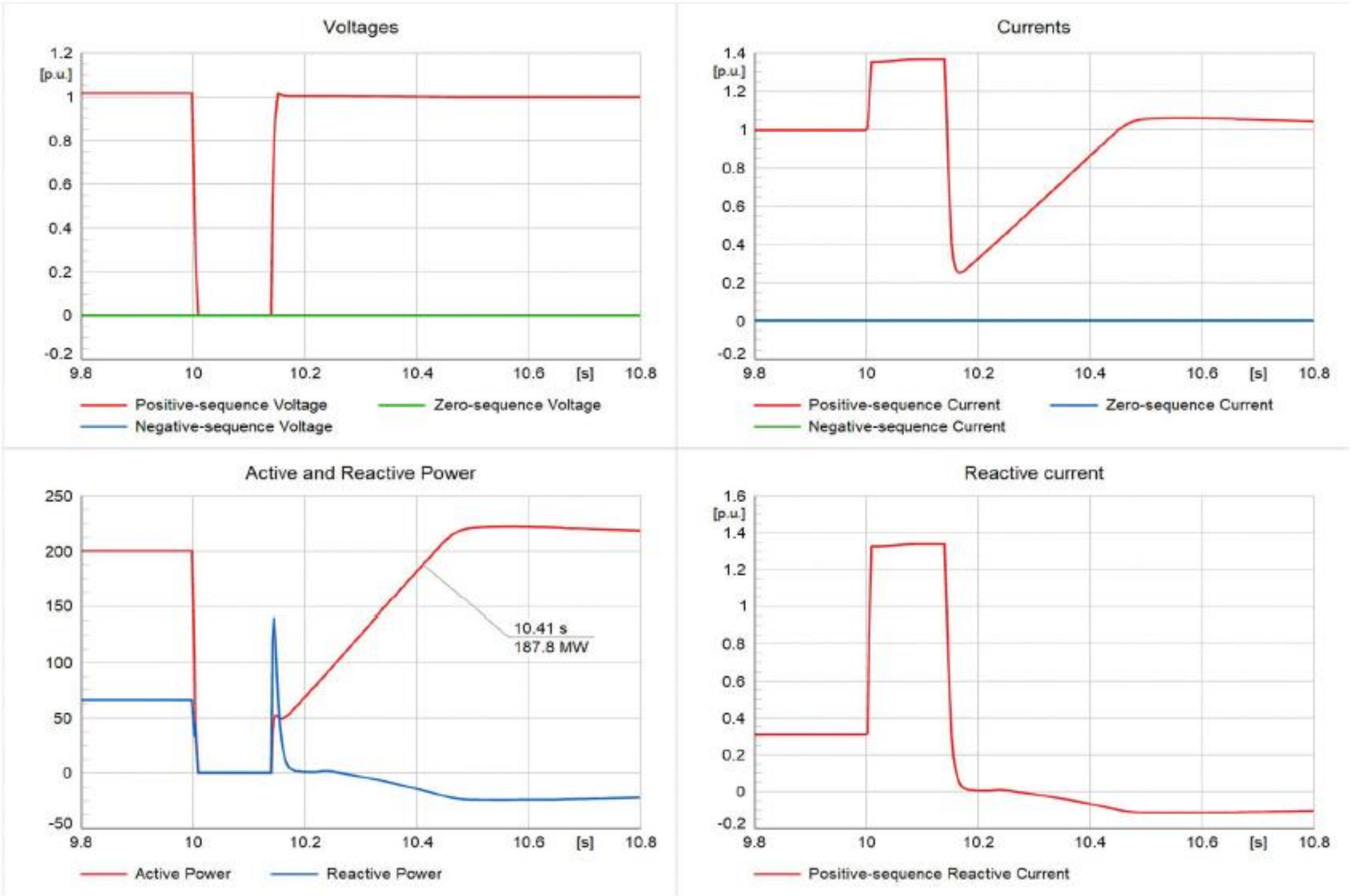
Appendix – Fault Ride Through studies

Fault Ride Through study tests that were completed:

- 3 phase fault at the PCC with 0% retained voltage for 140ms (see example shown on the right)

- Solid phase-phase fault at the PCC for 140ms
- Phase-phase-earth fault at the PCC with 0% retained voltage for 140ms
- Earth fault at the PCC with 0% retained voltage for 140ms
- Balanced Fault with retained super-grid voltage of 30% for 384ms
- Balanced Fault with retained super-grid voltage of 50% for 710ms
- Balanced Fault with retained super-grid voltage of 80% for 2.5s
- Balanced Fault with retained super-grid voltage of 85% for 180s

Figure D-1 - 3-phase-fault -140ms – generation case



- As per the Grid Code ECP.A.3.5 requirements the first fault considered was a 3-phase fault, applied at the connection point busbar. The fault was applied for a duration of 140ms. Figure D-1 shows the sequence voltages at the connection point as well as the sequence currents of the PPM fault contribution. The real power recovers to 90% of the pre-fault value in under 300ms following the fault clearance, less than the 0.5s minimum requirement.
- As the retained voltage is less than 50%, full reactive current injection is required. The pre-fault reactive current is 0.308p.u., while during the fault the reactive current is maintained at 1.338p.u. Therefore, the PPM exceeds the minimum FFCI requirements.

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