G-PST Webinar “Operating the system towards zero carbon”

30 August, 2022

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GB Grid Forming

Antony Johnson, National Grid ESO

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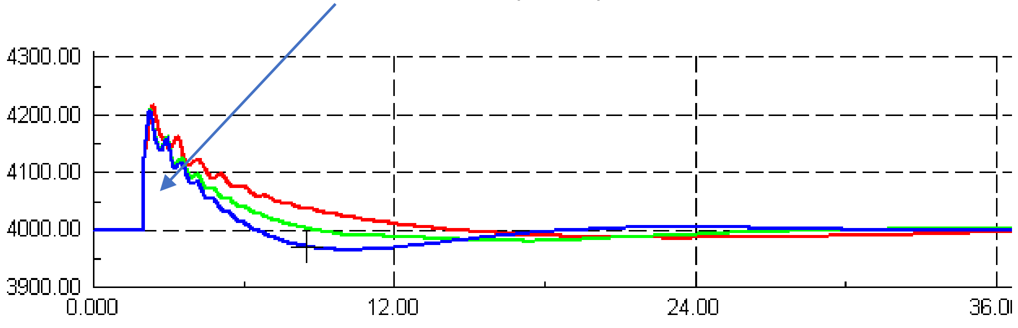
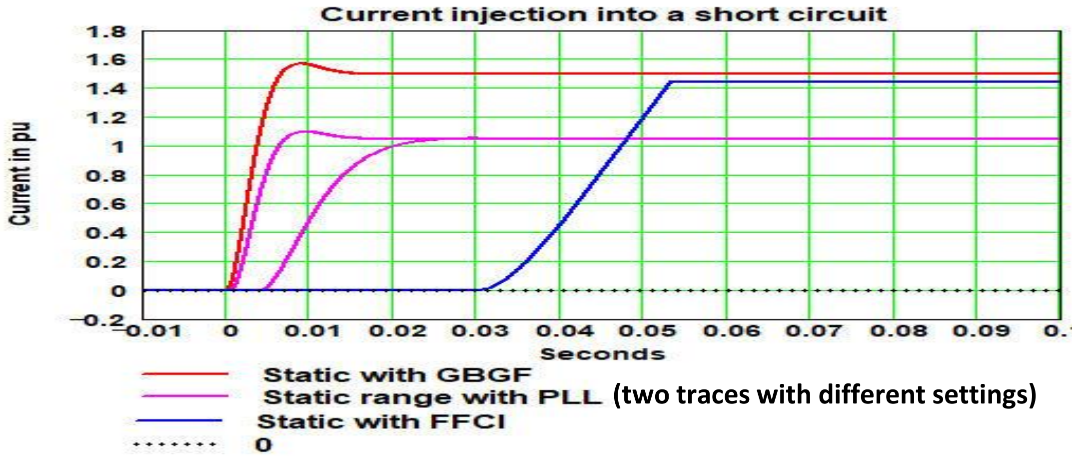
Characteristics of Synchronous Plant compared with Power Electronic Converters

- Key Features
  - Synchronous Generators are frequency and phase sensitive and respond instantaneously to system phase changes.
  - Synchronous Plant will supply significant fault current (2 – 4pu at the connection point) upon fault inception – Traditional Converter based plant will supply little more fault current than its plant rating
  - Synchronous plant contributes to inertia, short circuit level and synchronising torque whereas these features are not inherently provided by PLL converter based plant
  - Whilst Traditional Converter control strategies can provide fast fault current injection, they are based upon measurement and calculation resulting in a delayed response.

Active Power injection of Synchronous Plant during a fault/frequency fall





Deficit of rapid injection of Power (as per a synchronous machines) results in significant issues for post fault frequency, post fault voltage profile , high risk of generator tripping and increased vector shift

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Short Circuit decline and impact – Drivers for change

Figure 2: Regional short circuit level over the next 10 years

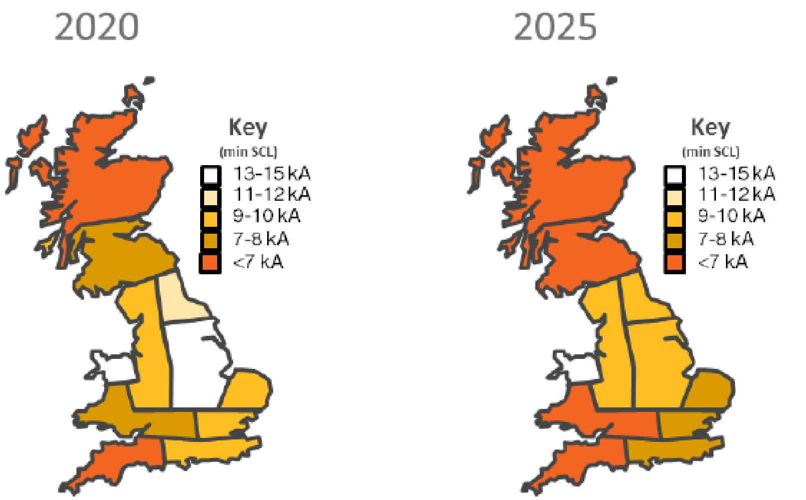
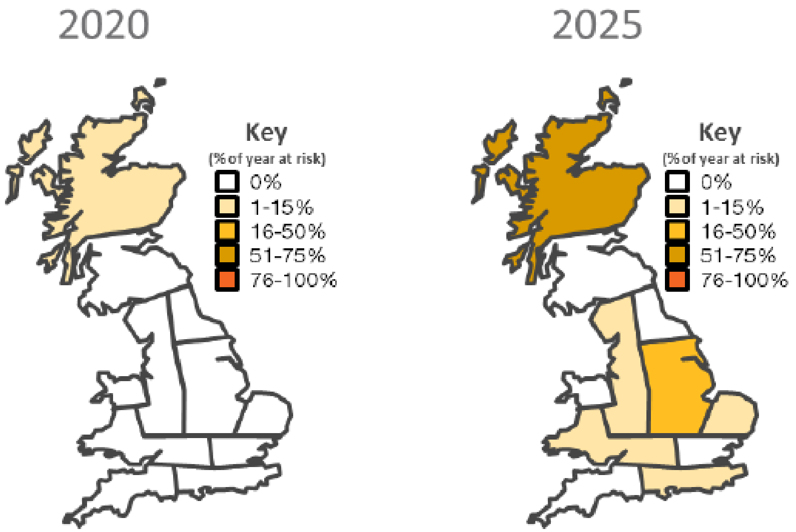


Figure 3: Regional Phased Locked Loop risk over the next 10 years



National Grid has published a series of publications identifying a general decline in short circuit current contribution during a fault:-

1. Our 2018 SOF report on ‘Impact of declining short circuit levels’. Summarised protection and control impacts across GB, Identifying areas of focus.
2. Our 2018 SOF report on ‘Whole system short circuit level’ describes trends and modelling considerations at Transmission and Distribution levels.
3. Our 2018 SOF report on ‘Frequency and Voltage Dependency’ highlight other factors to be borne in mind
4. Our 2018 ‘Regional Trends and Insights’ document highlighted variation of synchronous generation across future years and its effect on SCL.
5. Our 2017 SOF report on ‘Performance of Phase Locked Loop based convertors’ identified potential vulnerabilities relating to the magnitude and extent of the variation of SCL.
6. Our ‘2014-2018 SOF documents‘ illustrate the trends and distribution of SCL decline.

Short circuit level is a function of the availability of contributing sources to fault current. SCL is primarily provided by synchronous generation at present. Accordingly these levels are a function of the demand and generation balance achieved and will vary across a year, and in future years.

Against SCL change, acceptable performance of HVDC, and other converter based plant, continues to be required, this is one of the main reasons for developing the GB Grid Forming “GBGF” technology.

Grid Forming in GB – An ESO Perspective

- Limits to the maximum volume of non-synchronous generation connected to the Transmission System first identified in circa 2012/2013
- Papers of GB Grid Forming / Virtual Synchronous Machines (VSM) published in 2016
- VSM was considered as an option for fast fault current injection during implementation of GC0100 (RfG Implementation – Circa 2017)
  - https://www.nationalgrideso.com/industry-information/codes/grid-code/modifications/gc0100-eu-connection-codes-gb-implementation-mod
- VSM Expert Group Established in 2018 that largely had a focus on Active Inertia power.
  - https://www.nationalgrid.com/uk/electricity/codes/grid-code/meetings/vsm-expert-workshop
- Grid Code Modification GC0137 - GB Grid Forming Work Group Established late 2019.

  This change was made as studies showed that Active Phase Jump power was more important than Active Inertia power. The term GB Grid Forming was added to separate the work from VSM and Grid Forming.
  - https://www.nationalgrideso.com/industry-information/codes/grid-code-old/modifications/gc0137-minimum-specification-required
- A number of Developers are demonstrating Grid Forming Capabilities at a Commercial level which is an essential tool required to contribute to Net Zero and Zero Carbon Operation by 2025

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Aims of the GC0137 Workgroup

- Provide a high level overview of Grid Forming and the Transmission System Need
- Develop a high level flexible specification which would be Non-Mandatory and provide the necessary framework so the specification can be used in a future market
  - Technical Specification of Plant Requirements
  - Submission of data and models
  - Compliance Simulation and Tests
- Ensure consistency with the Stability Pathfinder Work
- Put measures in place so more detailed work can take place outside of the GC0137 Workgroup
  - Establish a separate Expert Group to develop a GB Grid Forming Best Practice Guide (Ongoing)
    - Eg Basic operation, worked examples, simulations, testing, monitoring techniques, performance, analysis, performance, interaction techniques etc
  - Develop Stability Markets (Ongoing)
- The GC0137 Minimum Specification is NOT as detailed Technical Specification

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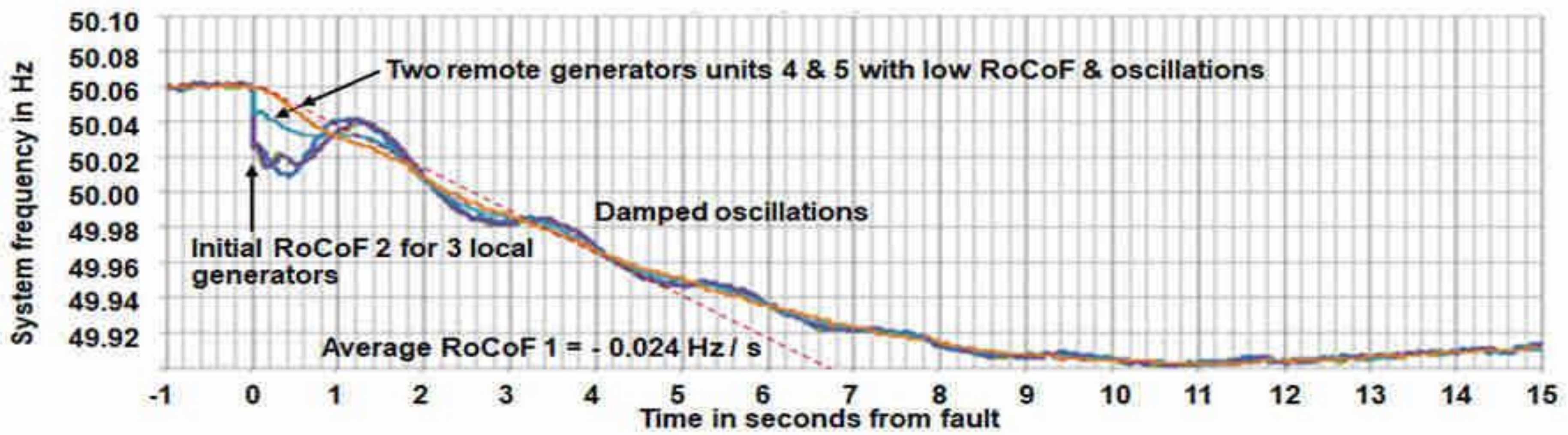
Grid Forming - Key Technical Features of a GBGF Converter

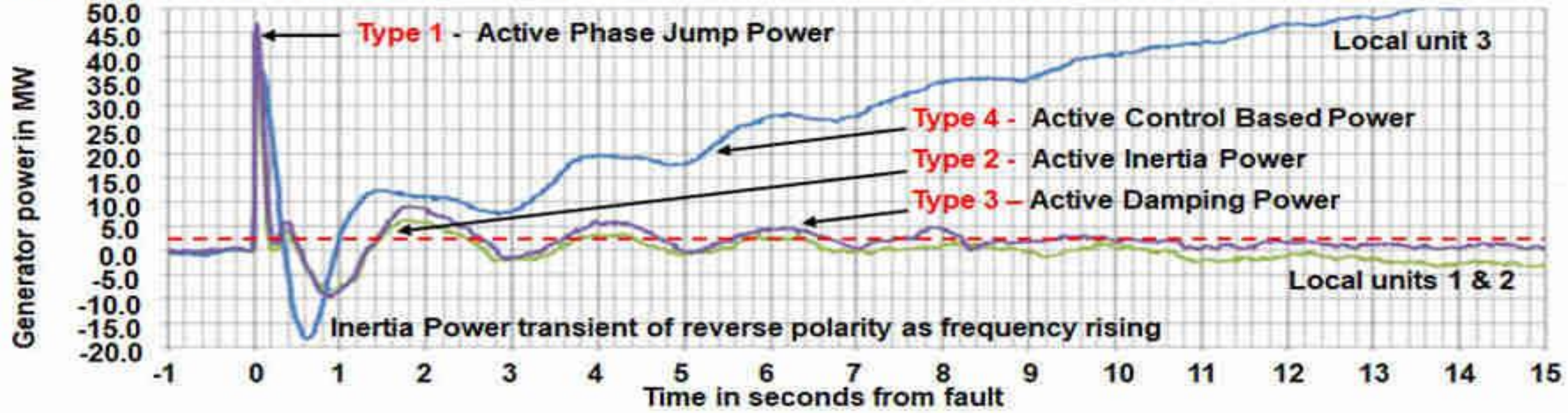
- Comprises a synchronous internal voltage Source behind an impedance (similar to a Synchronous Generator) operating over the range DC to 1KHz
- Capable of contributing to:-
  - Transient Impedance of the AC Grid that is not provided by PLL based Traditional Converters.
  - Phase Jump Power (Instantaneous contribution to System Disturbances – eg synchronising torque)
  - Inertia Power (ie Contribution to System Inertia)
  - Damping Power (Contribution to Damping)
- Capable of control of Active and Reactive Power through independent control
- Directly responds in milliseconds to changes in the phase of the AC grid without any actions being required in the associated control system.
- Ability to change the Voltage or Phase of the Grid Forming Plant's Internal Voltage Source but only at bandwidths below 5Hz so as to prevent undue interactions to the System or other Users Plant and Apparatus
- Capable of riding through Grid Faults and supplying fast fault current injection
- Option for a Black Start Capability
- These features were traditionally provided for free by synchronous generation as a by product of their technical characteristics. They have a fundamental behaviour on the characteristics of the Transmission System which is essential for its retained robustness and stability
- Going forward these features will now have to be paid for

Grid Forming Characteristics - Key Features

Site data recordings of AC Grid frequency for 3 local and 2 remote GBGF-S generators



Site data recordings of AC Grid power of 3 local GBGF-S generators



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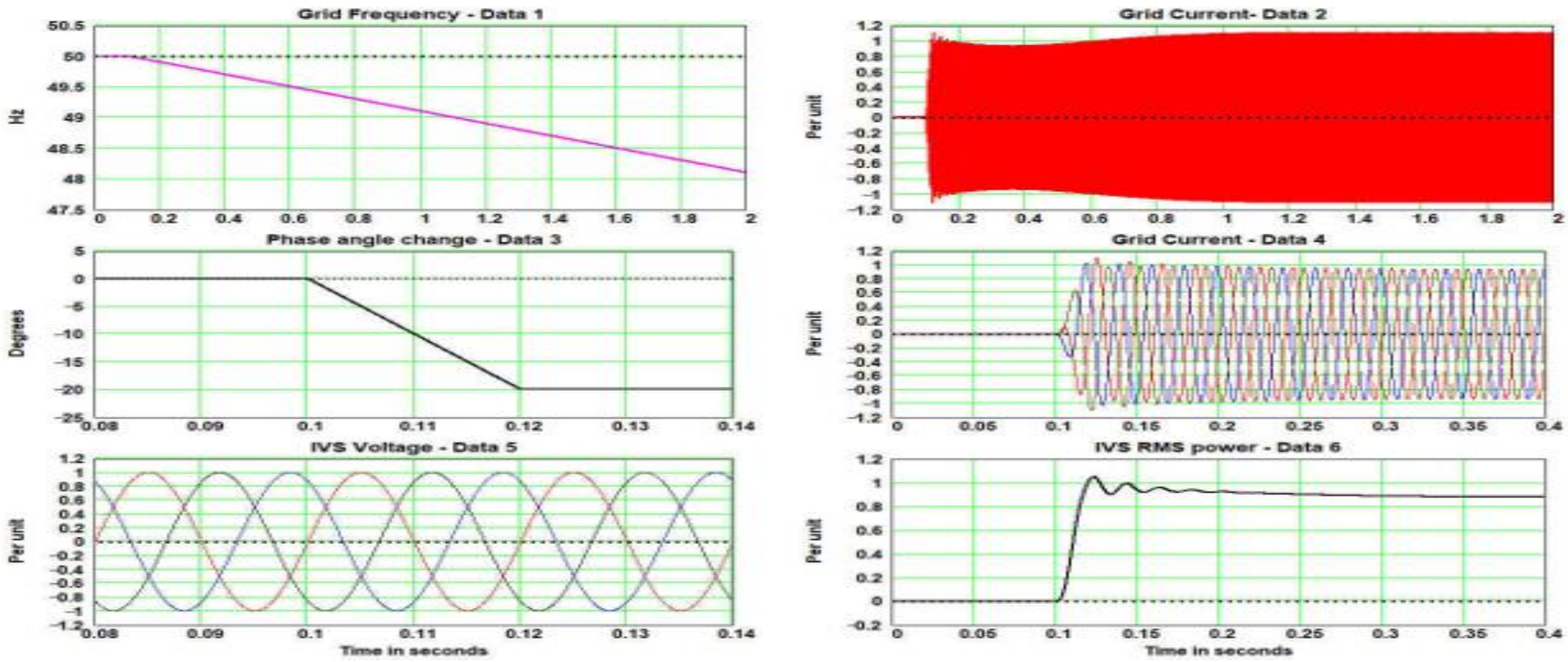
Simulation Results – 20 Degree Phase Jump followed by a Frequency Change of -1Hz/s



Note: Simulation results kindly supplied by ENSTORE

Compliance – Testing and Simulation - Overview

Grid Forming Plant

Tests and Simulations applicable under Grid Code Irrespective of Grid Forming (ECP.A.3 – ECP.A.7)

- Reactive Capability (including HV operation across voltage range)
- Voltage Control
- Active Power Control
- Power output with falling frequency
- Frequency Response (LFSM/FSM)
- Voltage and frequency control verification
- Control System Tests
- PSS Tuning / Damping control
- Quality of Supply Assessment
- Fault Ride Through and fast fault current injection

+

Grid Forming Plant additional Tests and Simulations

- Phase Based Real Inertia Power
- Phase Based Real Phase Jump Power
- Phase Based Real Damping Power

→

Total suite of Tests and Simulations To be performed on Grid Forming Plant

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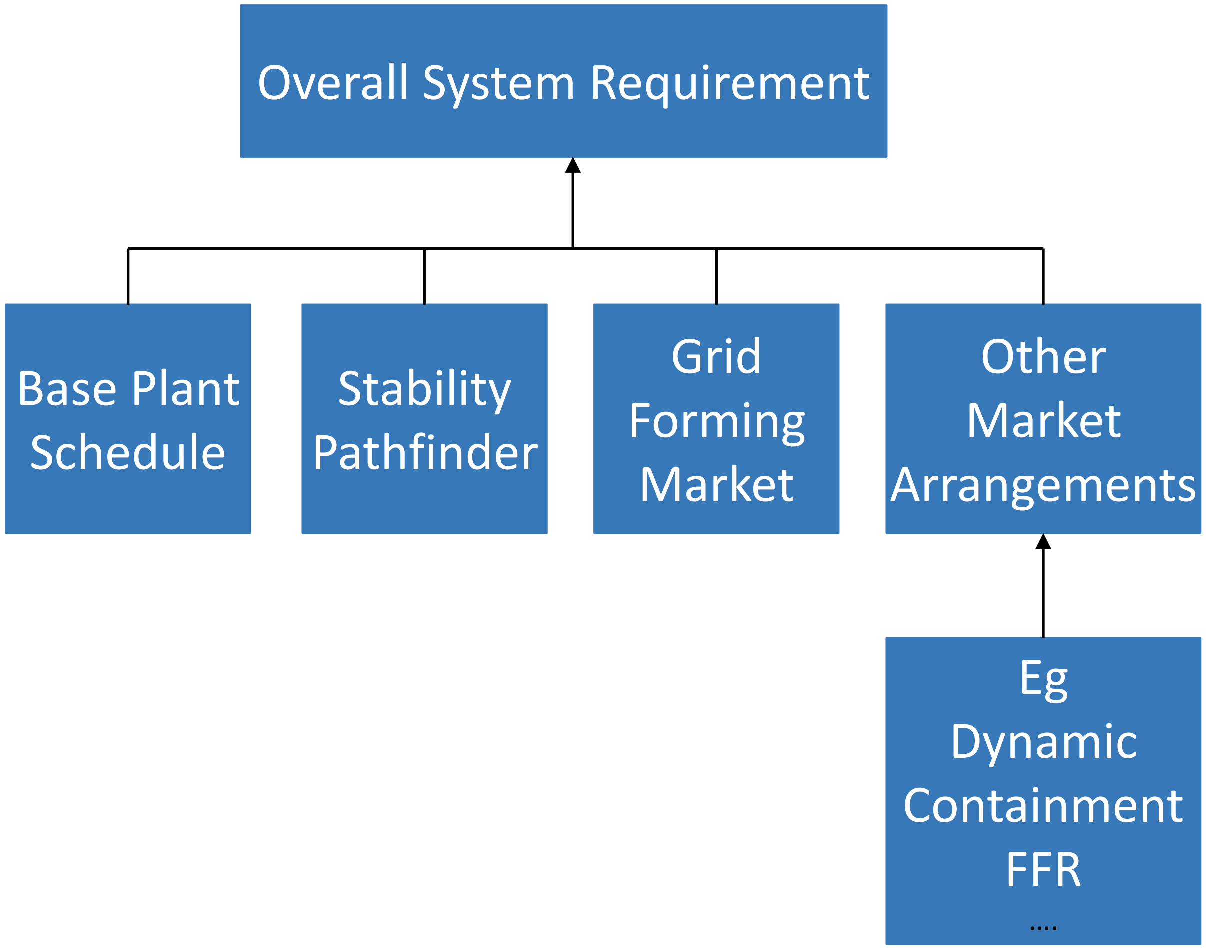
Interaction with other Initiatives / Markets



Summary

- The GC0137 Specification was approved by our Regulator (Ofgem) in late January 2022 and implemented into the Grid Code in February 2022
- The GC0137 Work is consistent with the National Grid ESO Stability Pathfinder Work
- The final GC0137 Work Group Report is available from:-
  - https://www.nationalgrideso.com/industry-information/codes/grid-code-old/modifications/gc0137-minimum-specification-required (Draft / Final Modification Reports Tab)
- The Expert Group is proceeding on the GB Grid Forming Best Practice Guide and good progress is being made.
- The ESO has been working with partner organisations as part of a Network Innovation Allowance project to explore a potential enduring market design for the procurement of stability services. The primary objective of the stability market is to ensure cost-efficient provision of services needed to maintain system stability and security in the interests of consumers.
  - https://www.nationalgrideso.com/future-energy/projects/stability-market-design --> for detailed project reports, recorded versions of external engagements and slides, and also a 'thought piece' indicating future steps.
- National Grid ESO wishes to acknowledge the help of all those organisations who have been involved in this extensive work in particular Enstore, Siemens Gamesa Renewable Energy and GE

Update of NGESO GB Grid Forming Best Practice Group

Dr. Dechao Kong, National Grid ESO

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Overview:

A GB Grid Forming Best Practice Guide is being produced by NGESO in collaboration with comprehensive external stakeholders in the GB and wider to ensure a workable standard for all parties can be created to facilitate grid forming applications within GB energy markets.

Drivers:

- To provide necessary guidance on existing GC0137 Legal Texts as much as possible
- To capture any good practices in GB and wider as well as comprehensive valuable thoughts, suggestions for future development of GB Grid Forming where appropriate.
- To identify any future Grid Code changes that may be required in order to facilitate grid forming applications within GB energy markets.

Structure of GBGF BPG Subgroups:

To establish an Expert Group (50+ people) with a good mix of Subject-Matter Experts from GB and wider for their contributions into the following four subgroups:

- Subgroup 1: Definition of GB Grid Forming Plant and its functionality
- Subgroup 2: Analysis Methodology
- Subgroup 3: Modelling requirement
- Subgroup 4: Compliance Testing

Subgroup 1 – GB Grid Forming Definition

Key Points of ToR

To provide guidance on definitions of GB Grid Forming Plant (including GBGF-S & GBGF-I), IVS, and their GF capabilities in line with GC0137 Legal Texts.

Key Topics for Discussion around Definition of Internal Voltage Source

- The Pros & Cons of virtual impedance when introduced for GB Grid Forming
- When virtual impedance can be introduced – normal mode or withstand mode e.g. during disturbance.
- If virtual impedance can be introduced together with real impedance – Does ESO need to give clear definitions and requirements of virtual/real impedance (Whitebox) or focus on functionality/performance as whole and inputs/outputs (Blackbox)

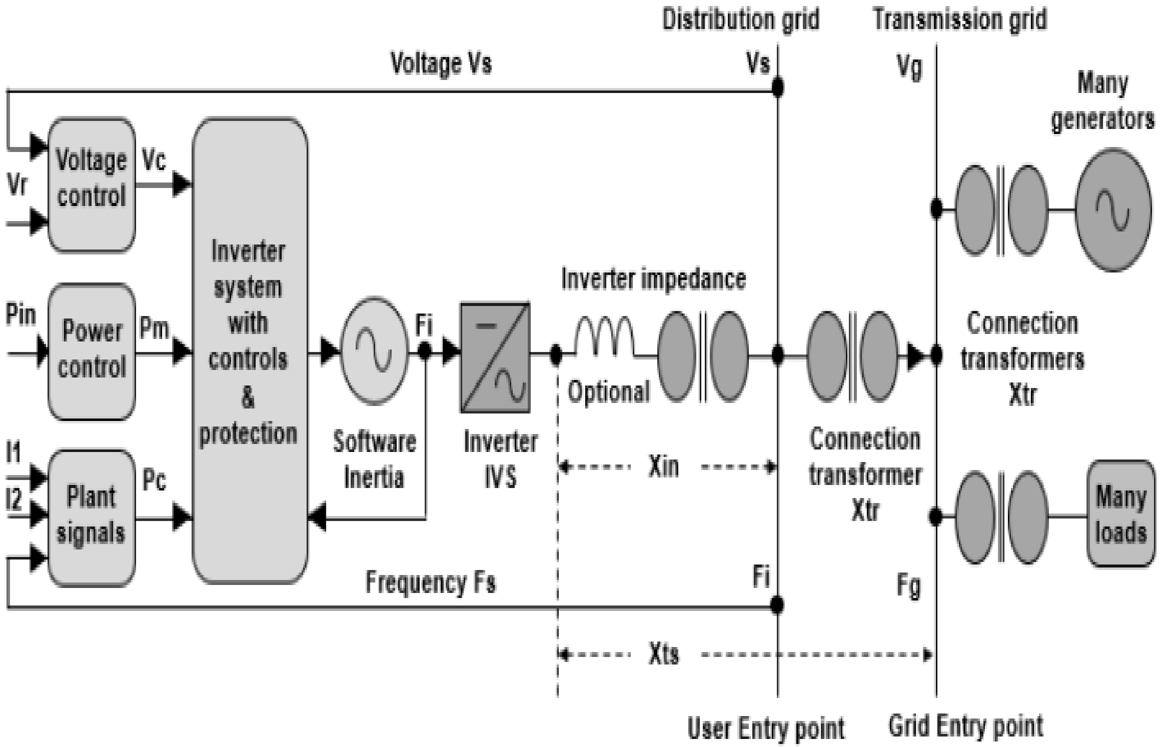

Figure PC.A.5.8.1: a high level equivalent architecture diagram of GBGF-I

Key Suggestions

- Virtual impedance can be introduced with strong evidences from external stakeholders e.g. manufacturers, developers and academia.
- For the position of ESO, the equivalent IVS should be defined as a black box rather than a white box, where its functionality/performance and inputs/outputs should be clearly defined.

Subgroup 2 – Analysis Tools

Key Points of ToR

- To provide guidance on **when** time-domain (e.g. RMS and EMT) and frequency-domain analysis tools (e.g. NFP and Impedance scan) are required and **what** are the most appropriate time-domain and frequency-domain tools to be adopted;
- To develop **Network Frequency Perturbation** (NFP) Plot(s) (or equivalents/alternatives e.g. impedance-based scan/measurement).

Subgroup 2 – Analysis Tools

Ref. No	Task	Clause in GC0137	Time-Domain Analysis (Nonlinear)			Time-Domain (Linear)	Frequency-Domain Analysis (Linear)	
			EMT – Offline	EMT – Real Time	RMS	Eigen Value Based	Impedance Based	NFP
1	Active ROCOF Response Power under Extreme System Frequencies	ECP.A.9.1.9.3	✓	✓			✓	
2	Active ROCOF Response Power over full System Frequency range	ECP.A.9.1.9.4	✓	✓			✓	✓
3	Phase Jump Active Power under normal operation	ECP.A.9.1.9.5	✓	✓	✓			✓
4	Phase Jump Active Power under Extreme Condition	ECP.A.9.1.9.6	✓	✓	✓			
5	Phase Jump Active Power during a faulted condition for GBGF-I	ECP.A.9.1.9.7	✓	✓	✓			
6	Fault Ride Through during a faulted condition for GBGF-I	ECP.A.9.1.9.7	✓	✓				
7	Fast Fault Current Injection during a faulted condition for GBGF-I	ECP.A.9.1.9.7	✓	✓				
8	Active Damping Power for GBGF-I	ECP.A.9.1.9.7	✓	✓		✓	✓	✓

Subgroup 3 – Modelling Requirement

Key Points of ToR

- To provide further guidance on GC0137 Clauses as relevant to Model Requirement.
- To capture any good practices from Subgroup 3 Contributors (report, testing system if possible and allowed, etc.)
- To identify any unique modelling requirements for GBGF-I plants in comparison with GC0141.

Note: GC0141 "Compliance Processes and Modelling amendments following 9th August Power Disruption"

Key Questions:

- **Question 1:** When the voltage is below 0.9 p.u. yet the current limiter of GFM inverter is not triggered, shall we force the inverter to fast inject the current (or equivalent active and reactive power)?
- **Question 2:** When the current limiter is triggered, i.e., the fault current of GFM inverter is clamped, shall we force the inverter to inject fully reactive current?
- **Question 3:** The "linear mode" is defined based on the voltage level, rather than the current limit level. Instead of "linear" and "nonlinear" mode, any more appropriate alternative definition of operational modes e.g. "Normal Operation" and "Current-Limiting Operation"?

Key Suggestions:

- The PE-based converters with pre-defined Grid Forming mode should provide nature response as long as possible rather than transfer to Grid Following mode for fast injection of currents. The relevant ECC clauses should be reviewed and updated, if necessary, during 2nd round of GC0137 modification.
- To avoid confusion – Normal/withstand Modes instead of "Linear/Non-Linear" modes to reflect the operational conditions. The definition and relevant claues should be modified during 2nd round of GC0137 modification.

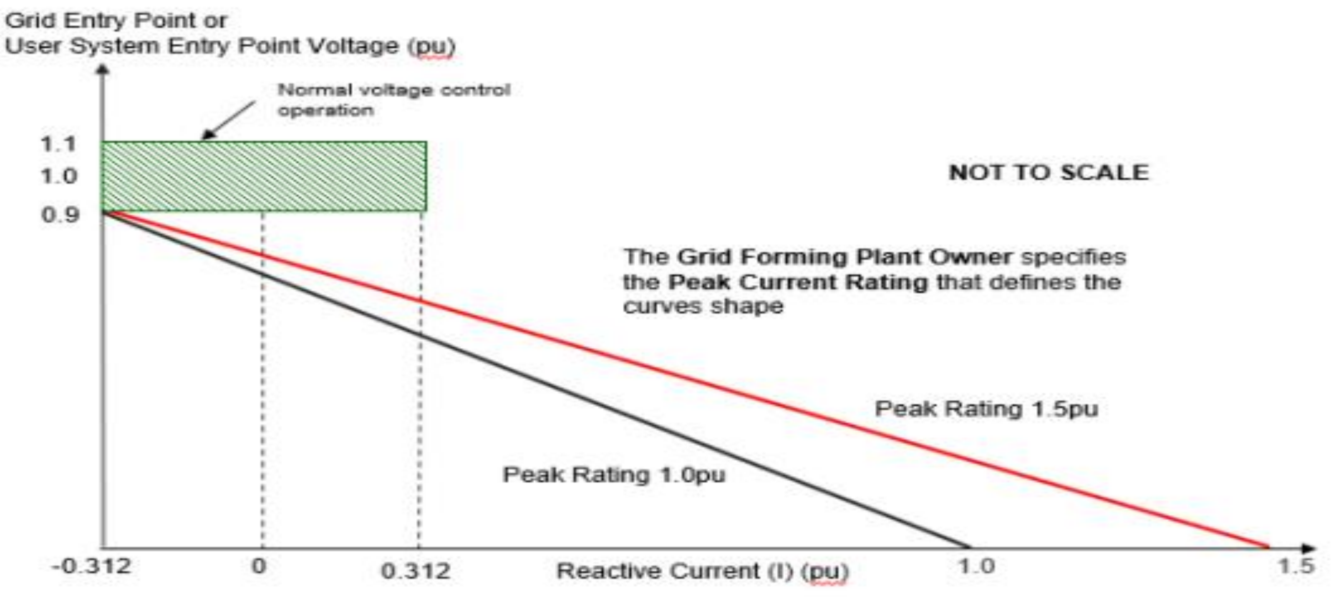

Figure ECC.6.3.19.5(a)

Subgroup 4 – Compliance Testing

Key Points of ToR

- To provide further guidance on GC0137 Clauses as relevant to Compliance Testing.
- To capture any good practices from Subgroup 4 Contributors (report, testing system if possible and allowed, etc.)
- To further evaluation compliance requirements for GBGF-I plants e.g. Phase Jump Angle Withstand.

Key Questions:

- **Question 1:** What kind of scenarios can potentially trigger phase angle change up to 60 degrees when considering compliance tests for active phase jump power under extreme conditions (ECP.A.3.9.4 - vi)?
- **Question 2**: If a fault event e.g. 3Ph-to-ground phase can be regarded as the worst scenario or sufficient, can we just consider existing LVRT to cover the phase-jump ride through.
- **Question 3**: Is it challenging for GBGF-I to ride through a Phase Jump event with phase angle change up to 60 degrees?

Key Suggestions:

- Some scenario was suggested from group discussion but a very rare condition in a very small part of an AC Grid.
- For three-phase symmetrical fault, LVRT can cover as Output Power is independent from phase angle. For asymmetrical faults, more detailed requirements for Phase-Jump ride through could be further evaluated during 2nd round of GC0137 modification.
- Phase Jump Withstand requirement up to 60 degrees will be further reviewed and updated if necessary during 2nd round of GC0137 modification stage for massive rolling-out of GBGF-I applications .

Future Plan

- Multiple-stage Best Practice Guide draft review between mid Aug to mid Oct, 2022.
- Some comments with intensive interests will be discussed in group meeting around end Sept, 2022.
- The Best Practice Guide will be further updated and finally issued by end Oct, 2022 after official approval of Grid Code Panel.

Stability Pathfinder

Shurooque Baloch, National Grid ESO

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Stability Pathfinder

- Traditionally synchronous generation has provided stability characteristics
  - Inertia
  - Short Circuit Level (SCL)
  - Dynamic reactive power
- As more non-synchronous generation enters the system, we need to find alternative sources of stability.
- Stability Pathfinders
  - Finding the most cost-effective way to address stability issues
  - Comparing commercial market-based solutions as well as transmission owner-based solutions
  - Providing long term commercial contracts
  - 'Learning by doing' approach

Stability Pathfinder – system requirements

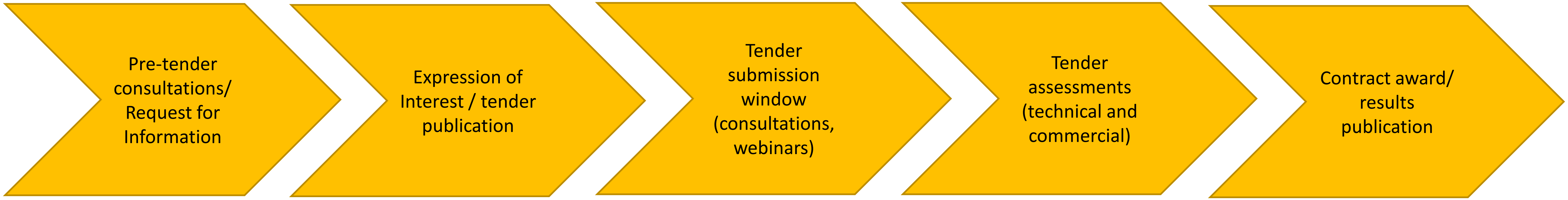
Key drivers for stability requirements

- Inertia
  - National and regional considerations
- Voltage performance during and immediately after faults
  - Retained voltage
  - Temporary over voltage
  - Voltage recovery
  - Voltage angle changes
- Short circuit ratios
  - Impact on converter based plant

Stability Pathfinder – key technical capabilities

- Alignment with GC0137
- Inertia
- Instantaneous Fault current
- Instantaneous Active Power caused by a phase angle change
- Synchronising Torque
- Damping Power
- Vector Shift Limitation
- Fault ride through
- Temporary over voltage withstand
- RoCoF withstand
- Compliance requirements
- Model requirements

Stability Pathfinder – tender process



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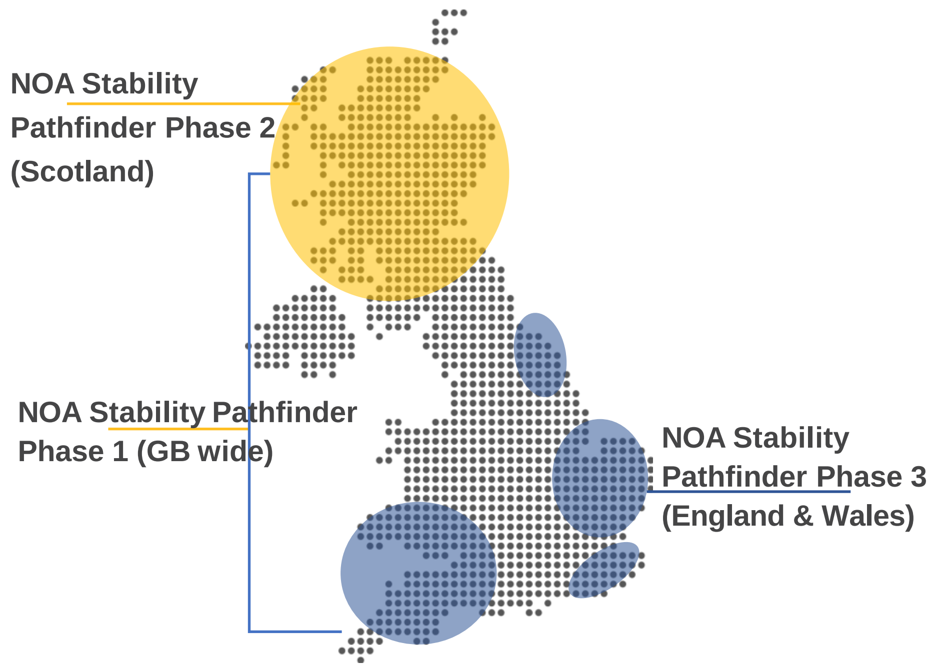
Stability Pathfinder

	Stability Pathfinder Phase 1	Stability Pathfinder Phase 2	Stability Pathfinder Phase 3
Requirement	Inertia and dynamic voltage GB wide	Inertia, SCL and dynamic voltage	Inertia, SCL and dynamic voltage
Status	Tender concluded in Jan 20 with most units now live	Tender concluded in Apr 22. Go-live from Apr 24	Tender period - Commercial window now closed. Go-live expected from 2025
Participating technology	0MW Synchronous Compensators only	Synchronous and Grid Forming Converter based	Synchronous and Grid Forming Converter based
Procurement regions	GB wide	Scotland	England and Wales
Procurement volume	12.5 GW.s of inertia	8.4 GVA of SCL 6 GW.s of inertia	7.5 GVA of SCL 15 GW.s of inertia
Contract duration	Up to 6 years	End of Mar 2034	End of Mar 2035
Contract payments	Availability payments for SCL& Inertia Utilisation payments for reactive power		

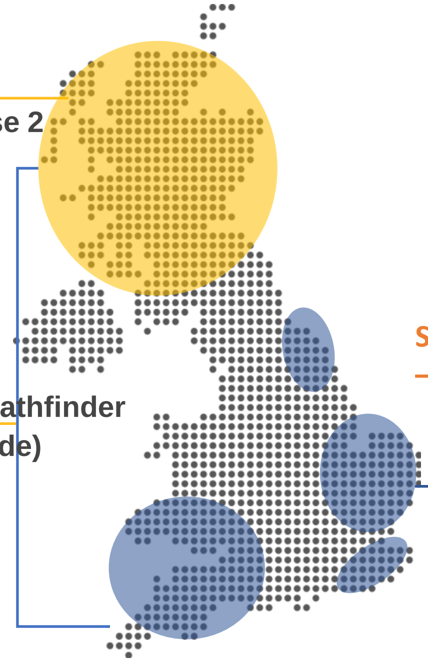


https://www.nationalgrideso.com/future-energy/projects/pathfinders/stability

Stability Pathfinder

Stability Pathfinder Phase 1 results

Company Name	Connection Substation	Technology	Inertia (MW.s)	Date
Drax Generation Enterprise Limited	Cruachan 275kV	Synchronous compensator mode	533	Live
Rassau Grid Services Limited	Rassau 132kV	Synchronous compensator	750	Live
Deeside Power (UK) Ltd	Connah's Quay 400kV	Synchronous compensator	1533	Live
Deeside Power (UK) Ltd	Connah's Quay 400kV	Synchronous compensator	1533	Live
Uniper UK	Killingholme 400kV	Synchronous compensator	1430	Live
Uniper UK	Killingholme 400kV	Synchronous compensator	1430	Live
Uniper UK	Grain 400kV	Synchronous compensator	1729	Next few months
Uniper UK	Grain 400kV	Synchronous compensator	1729	Next few months
Statkraft UK Ltd	Keith 132kV	Synchronous compensator	450	Live
Statkraft UK Ltd	Keith 132kV	Synchronous compensator	450	Live
Statkraft UK Ltd	Lister Drive 275kV	Synchronous compensator	450	Next few months
Statkraft UK Ltd	Lister Drive 275kV	Synchronous compensator	450	Next few months



Stability Pathfinder Phase 2 results

Company Name	Connection Substation	Technology Type	Inertia (MW.s)	Date
Statkraft UK Ltd	Colton 275kV	Grid Forming Battery Storage	0	30/04/2025
Statkraft UK Ltd	Neilston 132kV	Grid Forming Battery Storage	0	29/04/2024
TINZ Programme 1 ProjectCo 3 Limited	Beatrice 400kV	Synchronous Condenser	549	01/04/2024
WP Grid Services 3 Limited	Gretna 400kV	Synchronous Condenser	470	31/10/2024
WP Grid Services 8 Limited	Rothienorman 400kV	Synchronous Condenser	470	31/05/2024
WP Grid Services 1 Limited	Thurso 275kV	Synchronous Condenser	454	31/05/2024
WP Grid Services 9 Limited	Neilston 275kV	Synchronous Condenser	454	31/08/2024
Zenobe Energy Limited	Blackhillock 275kV	Grid Forming Battery Storage	333	31/03/2024
Zenobe Energy Limited	Kilmarnock South 400kV	Grid Forming Battery Storage	1341	25/10/2024
Zenobe Energy Limited	Eccles 400kV	Grid Forming Battery Storage	2686	30/04/2026

Stability Pathfinder – challenges

- Continuous learnings through various stages of the pathfinder process
- Demonstration of technical capabilities of grid forming converter based technologies
  - Desktop based simulations for tender participation
- Connections
  - Substation bay reservations for tenderers in Stability Pathfinder Phase 3
- Tender assessment
  - comparison of commercial solutions with TO regulated asset solutions

Stability Market Design

- Stability pathfinders allow us to test procurement approaches for long term stability requirements, but the ESO still rely on the dispatch of synchronous generation in the Balancing Mechanism to ensure stability.
- Stability market could offer the ESO a route to access stability services through an open, transparent, and competitive market.
- Stability Market Design Project
    - Development of long term and short term stability markets
    - https://www.nationalgrideso.com/electricity-transmission/future-energy/projects/stability-market-design

Strength to Connect

Dr Xiaoyao Zhou, National Grid ESO

Acknowledge for Great Support from Project Partner: Prof. Tim Green, Imperial College London

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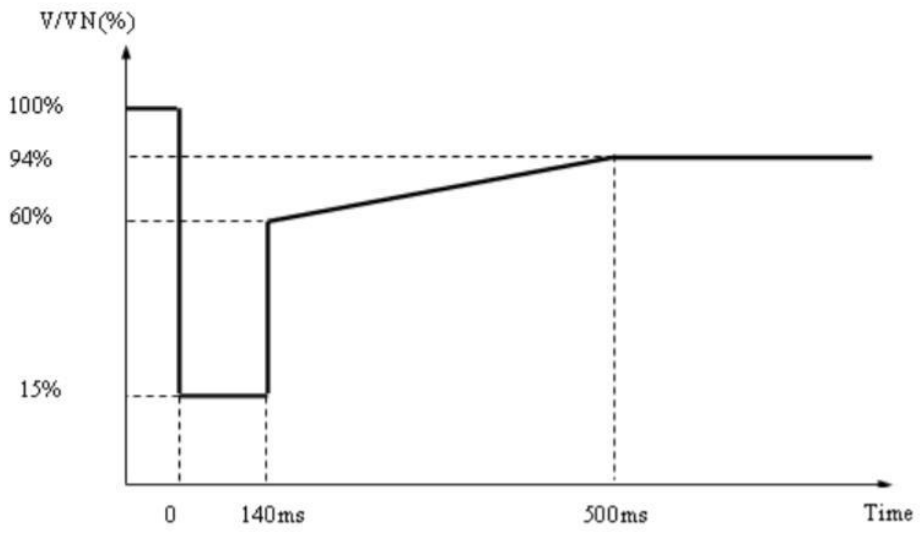
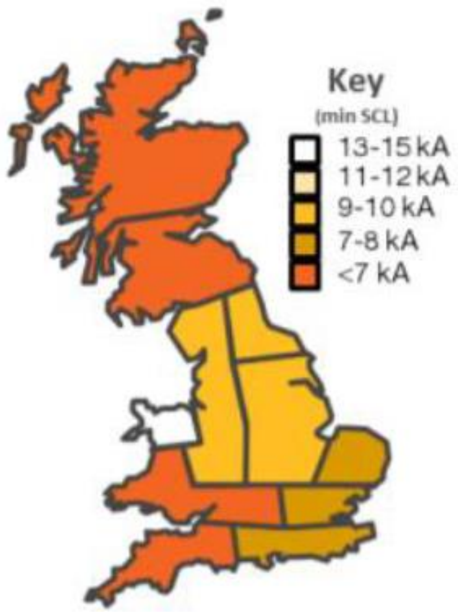
Status-Quo of Short-Circuit Level

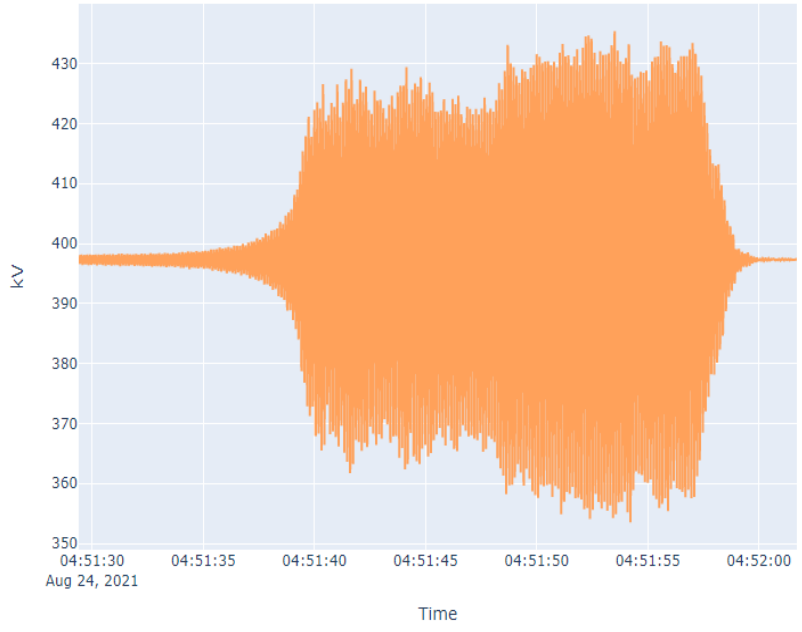
- Short Circuit Level (**SCL**) is a **Standard Measure of Grid Strength** to indicate how stable is the electricity system.
- Various interests in Grid Strength from Key Players across GB Electricity Market but all have **Different perspective** and **Different requirements**.



For Generation-side e.g. Wind Farm
Recovery after Low-Voltage Ride-Through Event

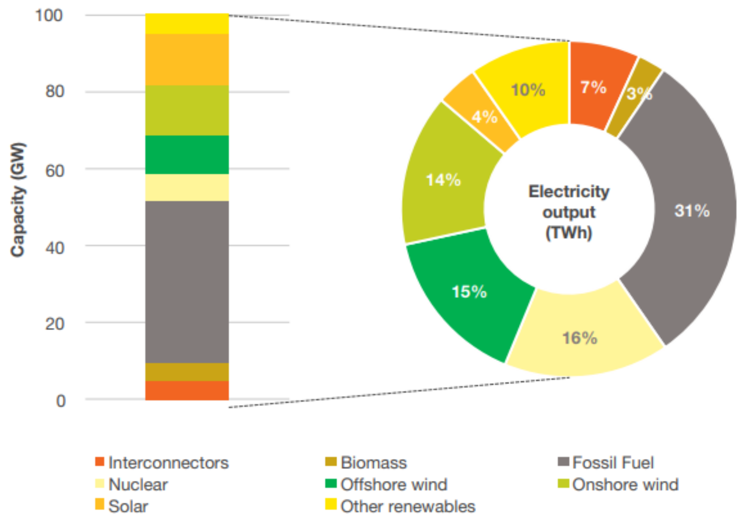


For TOs/DNOs
Appropriate Protection Configuration based on Fault Current



For GBESO
System Stability

Challenge for Future Inverter-based Resources (IBR) Dominated GB Electricity System



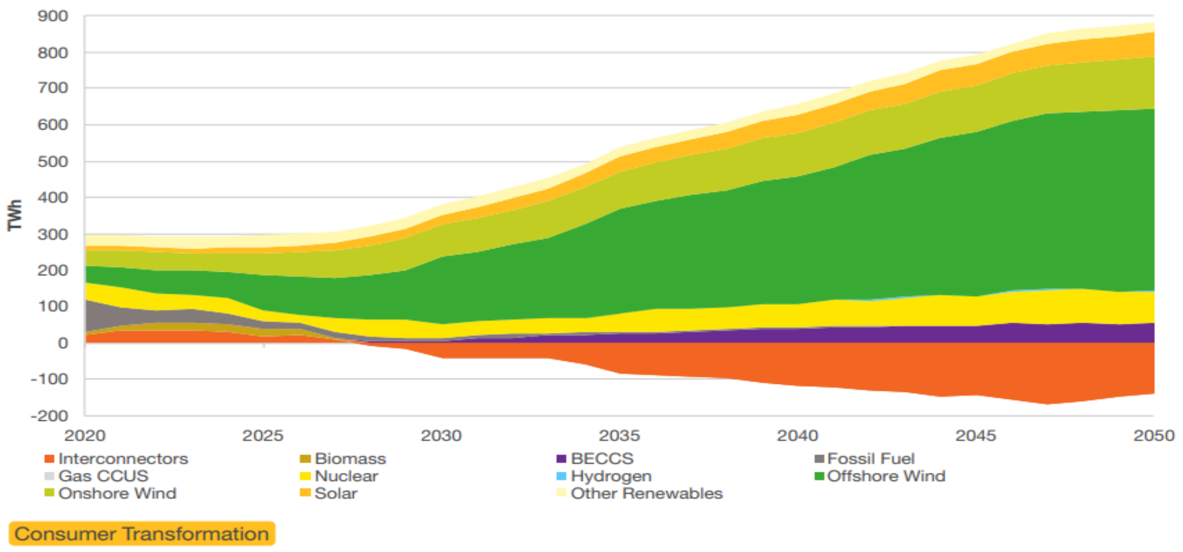
Generation Mix - 2020

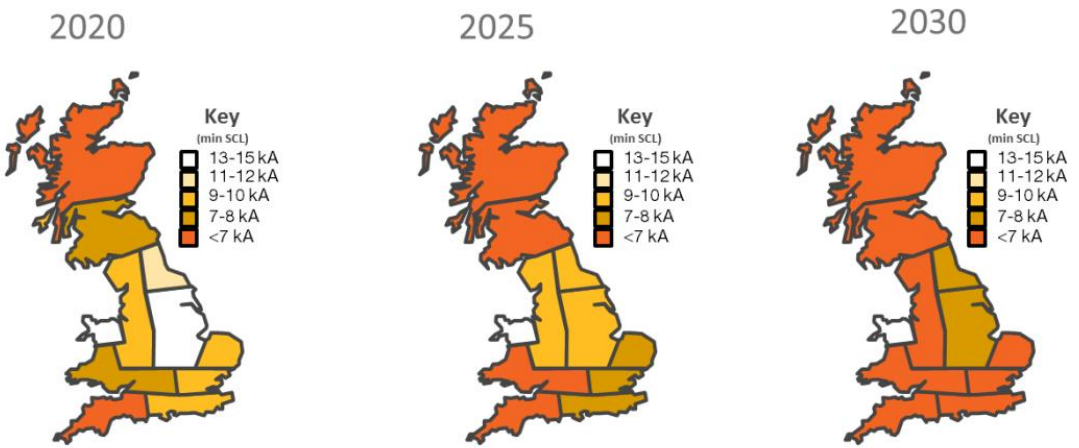
Customer Transformation (CT)

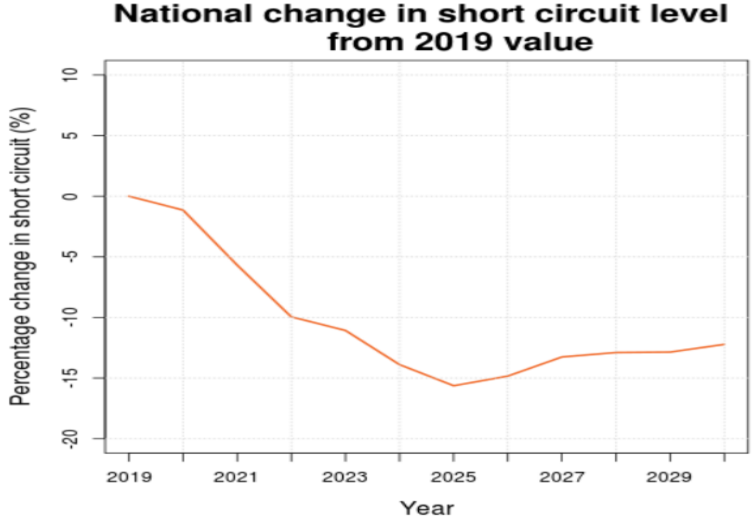
System Transformation (ST)

Leading the Way (LW)

Steady Progression (SP)







SCL is still a **good all-purpose indicator?**

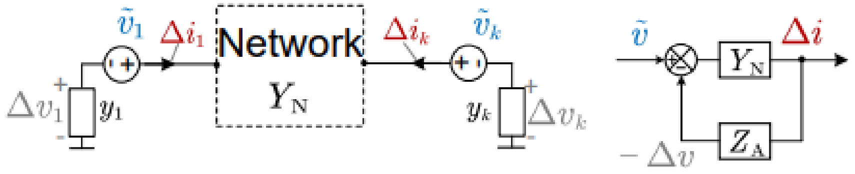
SOF Document “Impact of Declining Short Circuit Levels”

Strength to Connect

- Issues
  - Short Circuit Level (SCL) is a Standard Measure of Grid Strength to indicate the electricity system's stability.
  - Grid "strength" is decreasing
  - IBR have different disturbance behaviours; short-circuit level is no longer a good all-purpose indicator
- Four emergent areas need separate Grid Strength measure
  - Substandard voltage regulation,
  - Increased recovery times from voltage dips
  - Potential instability of grid-following inverters
  - Mal operation of protection.
- For each areas
  - Properly defined levels of grid strength metric for each area.
  - Properly defined levels to declare compatibility levels for grid strength.
  - A fit-for-purpose tool for locational compatibility levels metrics, and heat maps to describe compatibility of the whole system.
  - Guidance on the assessment of IBR capability to add strength and evaluation on their ability to work in low grid strength.

Impedance Models for Whole-system Stability Analysis

Whole-system impedance/admittance models representing the whole network



$$\Delta i = Y^{\text{sys}} \cdot \tilde{v}$$

Whole-system admittance model defined based on virtual voltage injections and feed-back loop.

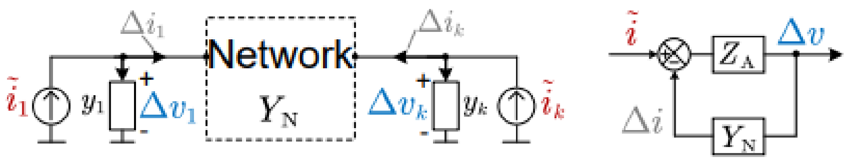
$$Y^{\text{sys}} = \begin{bmatrix} Y_{11}^{\text{sys}}(s) & Y_{12}^{\text{sys}}(s) & \cdots & Y_{1N}^{\text{sys}}(s) \\ Y_{21}^{\text{sys}}(s) & Y_{22}^{\text{sys}}(s) & \cdots & Y_{2N}^{\text{sys}}(s) \\ \vdots & \vdots & \vdots & \vdots \\ Y_{N1}^{\text{sys}}(s) & Y_{N2}^{\text{sys}}(s) & \cdots & Y_{NN}^{\text{sys}}(s) \end{bmatrix}$$

An admittance matrix

$$\begin{bmatrix} Y_{11,dd}^{\text{sys}}(s) & Y_{11,dq}^{\text{sys}}(s) \\ Y_{11,qd}^{\text{sys}}(s) & Y_{11,qq}^{\text{sys}}(s) \end{bmatrix}$$

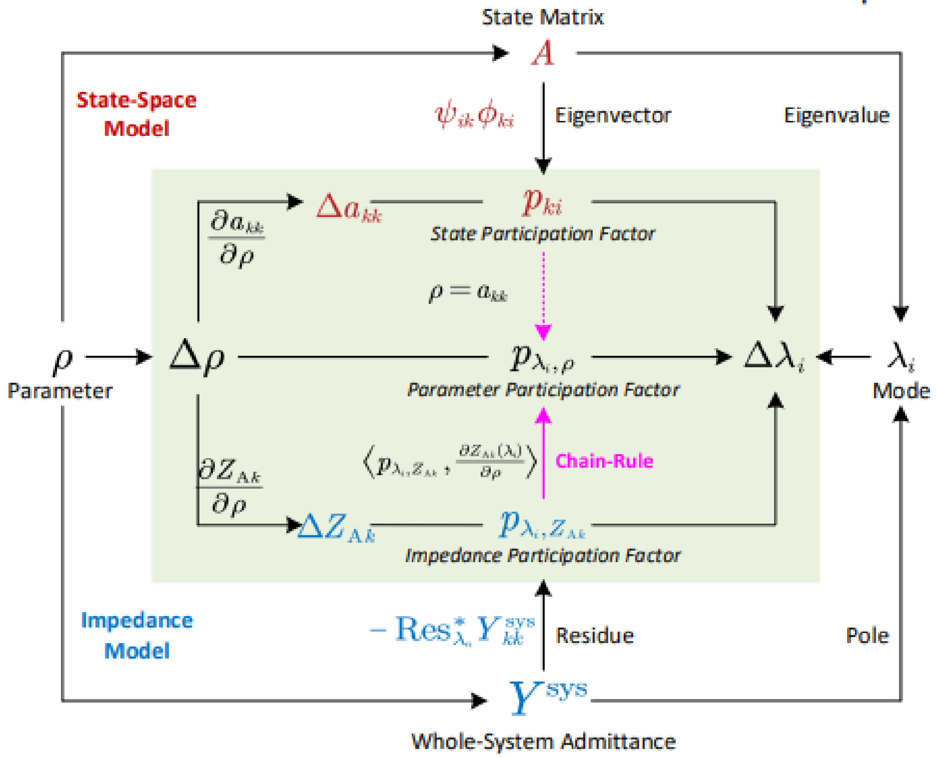
$$\hat{Y}_{11}^{dd}(s) = \frac{r_{11,1}^{dd}}{s-\lambda_1} + \frac{r_{11,2}^{dd}}{s-\lambda_2} + \cdots + \frac{r_{11,N}^{dd}}{s-\lambda_N}$$

Poles: eigenvalue of the state-space (oscillatory mode)
Residues: impedance participation factor.



$$\Delta v = Z^{\text{sys}} \cdot \tilde{i}$$

Whole-system impedance model defined based on virtual current injections and feed-back loop.



The relationship with state-space and the chain-rule linking impedance model and state-space model.

Y. Zhu, Y. Gu, Y. Li, T. C. Green, "Participation Analysis in Impedance Models: TheGrey-Box Approach for Power System Stability" in IEEE Transactions on Power Systems, vol. 37, no. 1, pp. 343-353, Jan. 2022, doi: 10.1109/TPWRS.2021.3088345.

Strength to Connect benefits

- A Deeper understanding of the intricacies of grid strength means that strength levels can be tailored to operational circumstances
- Moving beyond a one-size-fits-all approach would mean that we would only need to procure the adequate amount of services to maintain secure and reliable operation, thereby reducing costs
- Ability to achieve lower whole-system costs by requiring IBR’s, in some circumstances, to operate at lower grid strength.
- Reduce constraints on connections and boundary flows with refined definitions of limits to help the net-zero transition
- Prepare the market for a trial deployment in a pathfinder project by raising awareness of services likely to be needed

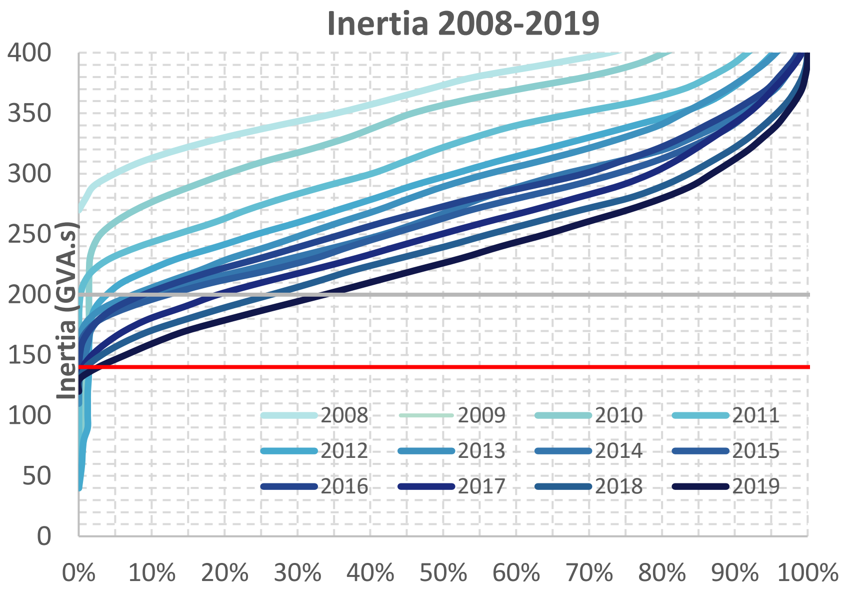
System Inertia Monitoring

Anna Blackwell, National Grid ESO

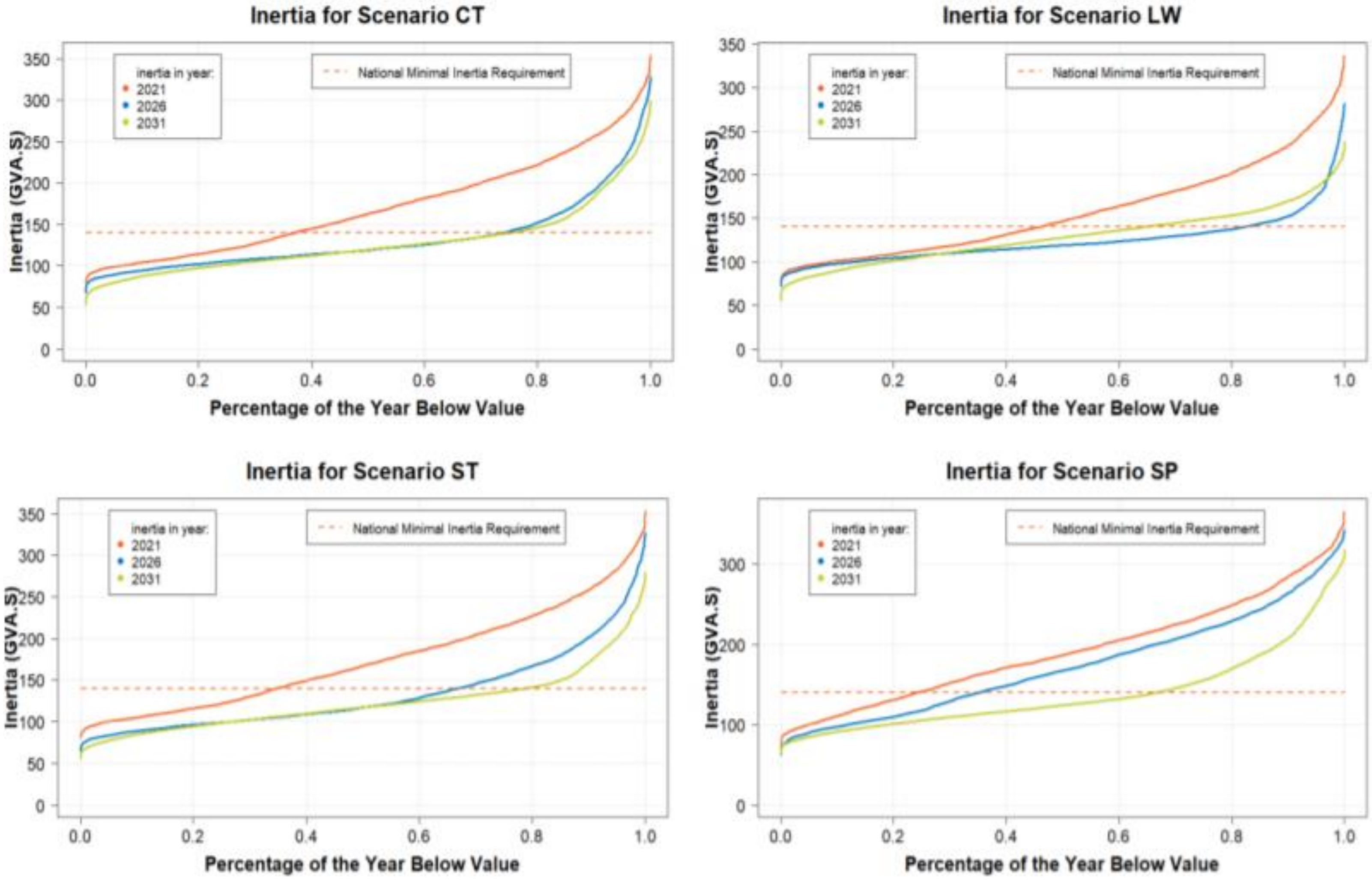
nationalgridESO

Declining inertia

- The rate at which frequency changes following a loss of generation or demand depends on the total system inertia.
- The declining trend of the inertia is across all scenarios.



Annual distribution of inertia for four future energy scenarios



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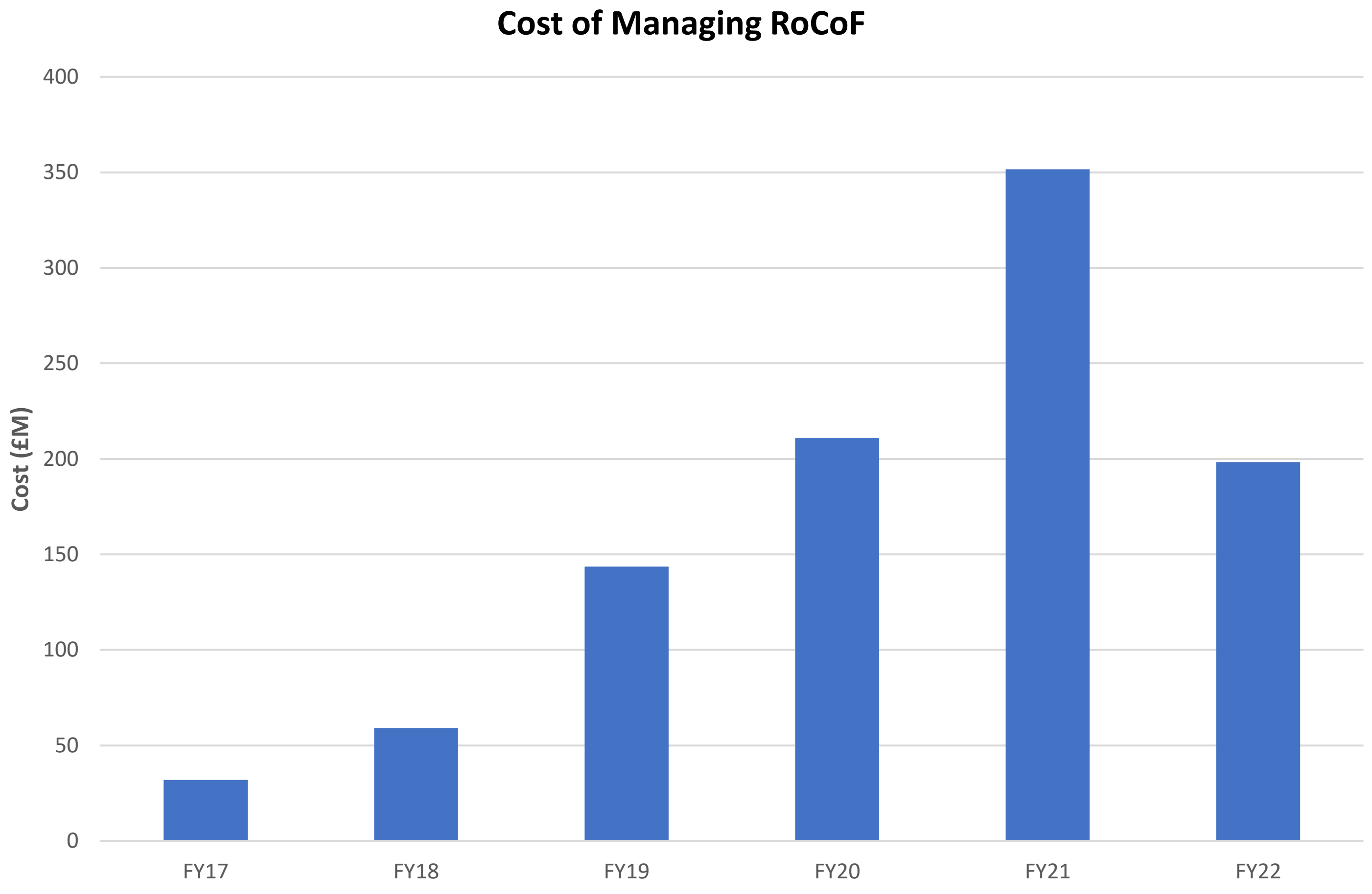
GB Inertia Costs

- Increased costs of managing Rate of Change of Frequency (RoCoF)
    - Increasing renewables
    - Increasing Interconnectors
- Increasing requirement for Response products (eg Dynamic Containment, Fast Frequency Response)



Inertia – where it comes from

Bulk Generation & Plant
Steam/Hydro/Gas generation
Flywheels

Load
Rotating machines
Other passive/active behaviour

Inverter-Based Resources
Solar/Wind Generation
HVDC Links
Energy Storage

Rotating Inertia
Easy to know

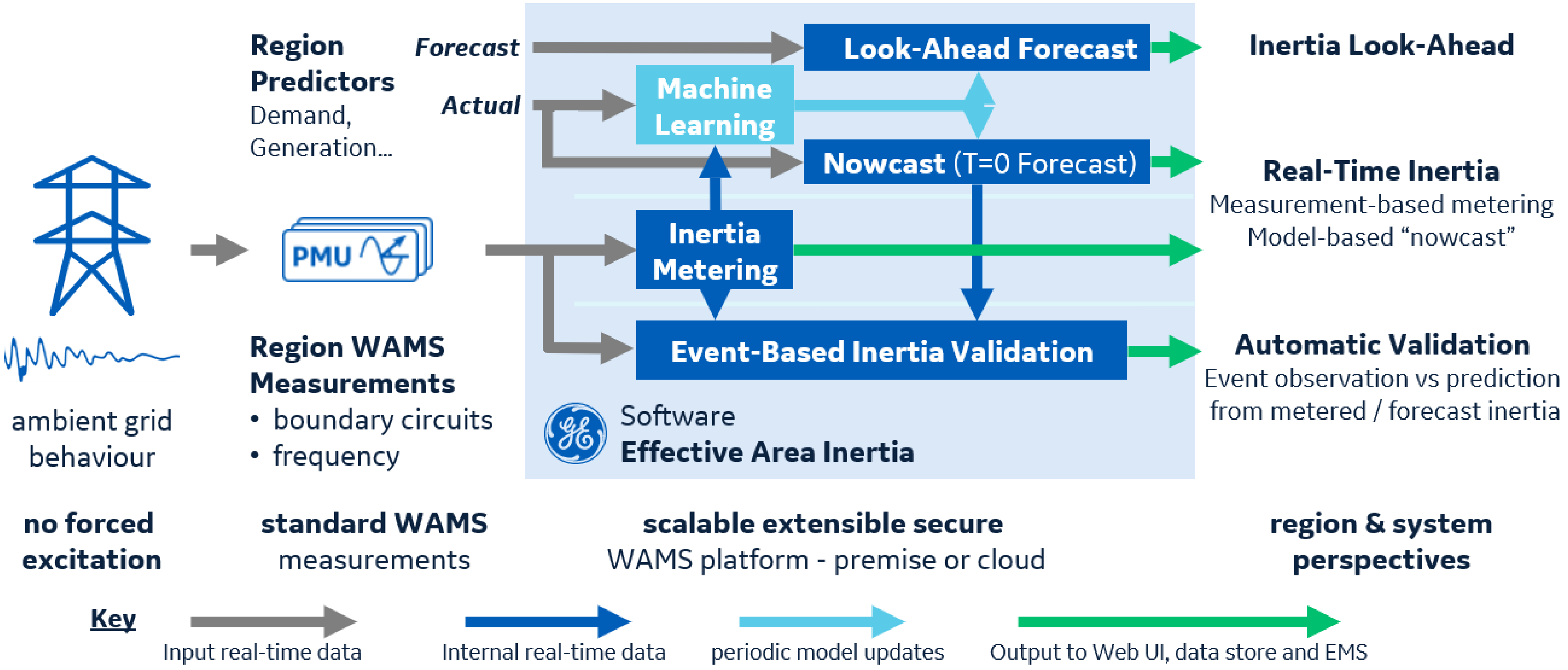
Effective Inertia
Includes “hidden” contributors

Then / Now
High inertia
Easy to estimate

Now / Future
Low inertia
Harder to estimate

Measurement & Forecasting of Effective Inertia is becoming **critical** to operation

GE Digital Effective Inertia Forecasting & Metering



RTL GridMetrix Inertia Measurement

Modulator

eXtensible Measurement Units (XMU)

Grid Metrix Cloud

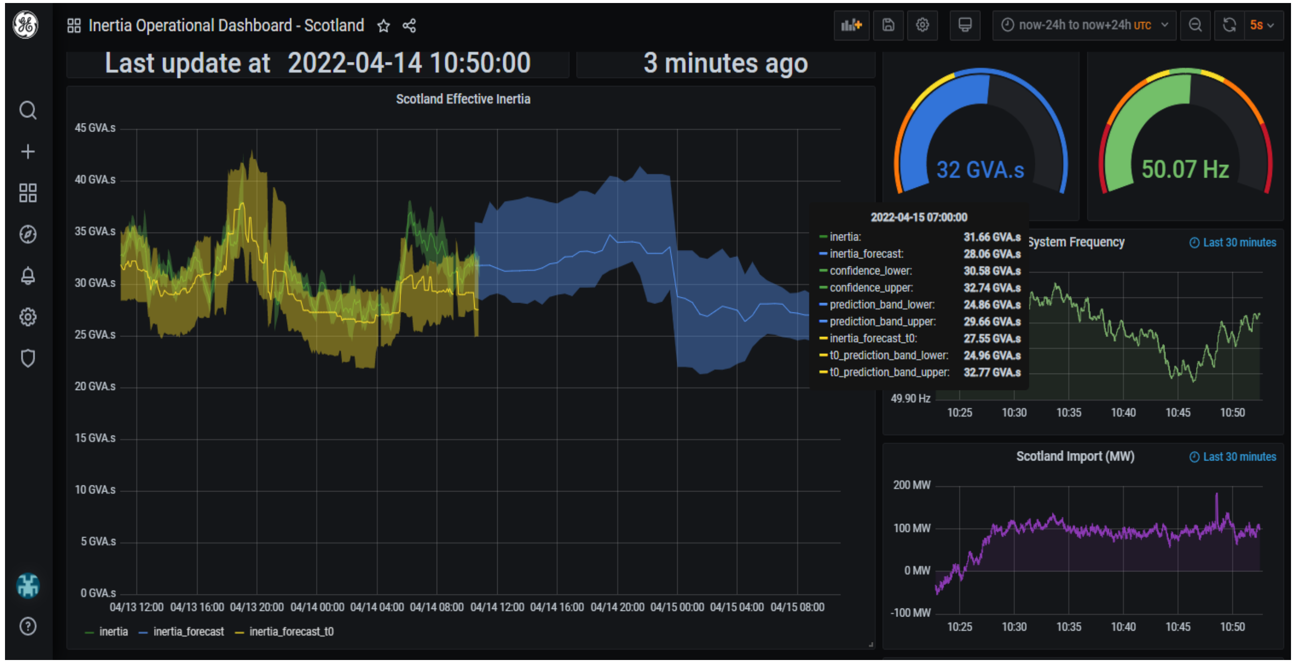
Customer's control centre

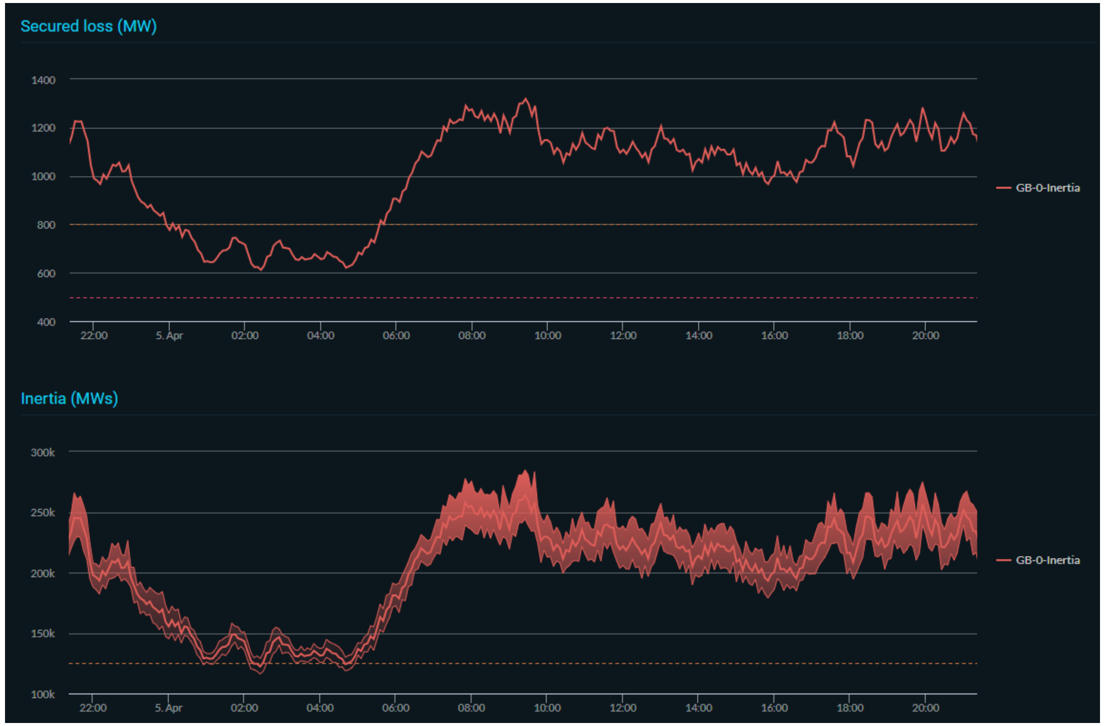
Send small signals through the Grid and extrapolate meaning gives unique insight

Wide area monitoring, improved measurement and visibility

Software/infrastructure as a service:

- Analytics to translate measurements into valuable datapoints for Grid operation improvements
- Cloud platform allows for scalability and additional applications to be built from same infrastructure





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Q&A

Thanks for your attention!

Any Question?