Stability deep dive

28th March 2023

We will start at 10:02

Agenda

Agenda item		
Introduction and housekeeping	Kelly	
System Operability Framework (SOF) process	Kelly	5 mins
What are the future operability challenges?	Kelly	5 mins
What have we achieved so far?	Kelly	10 mins
How are we continuing to meet these challenges?		
• Inertia monitoring	Anna	10 mins
• Future of GB Grid Forming	Dechao	10 mins
• System strength development	Xiaoyao	15 mins
• Stability Market	Ed	15 mins
Q&A	All	25 mins

Introductions and housekeeping

Name	Role
Kelly Larkin	Senior Operability Analyst
Anna Blackwell	Product Manager – Inertia Monitoring tools
Xiaoyao Zhou	Operability Policy Manager
Dechao Kong	Power System Engineer
Ed Farley	Senior Market Development Lead

https://www.nationalgrideso.com/research-publications/system-operability-framework-sof

We want your input!

Throughout today's webinar, please let us know whether there are topics you would like to see future SOF reports published.

sof@nationalgrideso.com

System Operability Framework publication plan

The System Operability Framework (SOF) takes a holistic view of the changing energy landscape to assess the future operation of Great Britain's electricity networks.

The SOF combines insight from the Future Energy Scenarios with a programme of technical assessments to identify medium-term and long-term requirements for operability. The table below details the publications planned over the next few months.

Please visit the SOF webpage for details of past and present publications.

Reports	Overview	When to expect
Power Quality in Electrical Transmission Network	Power quality is critical to the performance of equipment connected to the electricity network. There is direct correlation between power quality and system strength. The stronger the system strength, the easier it is to manage the power quality to the relevant standards. As more asynchronous generation connects to the system, the system strength continues to decline. This report will provide an outlook of the changes in the power quality of the electricity network.	Mar 2023
System Strength	How to effectively manage system strength of the GB system with a future high penetration of inverter-based resources (IBR) is important for stable operation of the system. This report shares our thinking about how system strength should be defined and managed in an IBR dominated system.	May 2023
Management and Mitigation of Oscillations on the GB Transmission System	Since oscillations were observed on the SSEN-T transmission system in August 2021, detailed investigations have been taking place reviewing: • Network analysis to understand the drivers of the oscillations. • Assessment of indicators to be used as a screening technique to determine areas at greater risk of oscillatory events; and • Application of system monitoring tools to give greater visibility of events This report will share findings and insights from our investigations.	Aug 2023
GB Grid Forming Development	Grid Forming is widely recognised as a promising technology for global net zero energy transitions. This report introduces the GB Grid Forming strategic developments that will help address existing or potential operability challenges on the GB system. In particular it will look at the interaction with the decline of system inertia and the reduction in system fault levels.	Nov 2023

Comms & engagements are ongoing within 2021 Oscillation Incident Investigation Working Group including ESO, GB TOs.

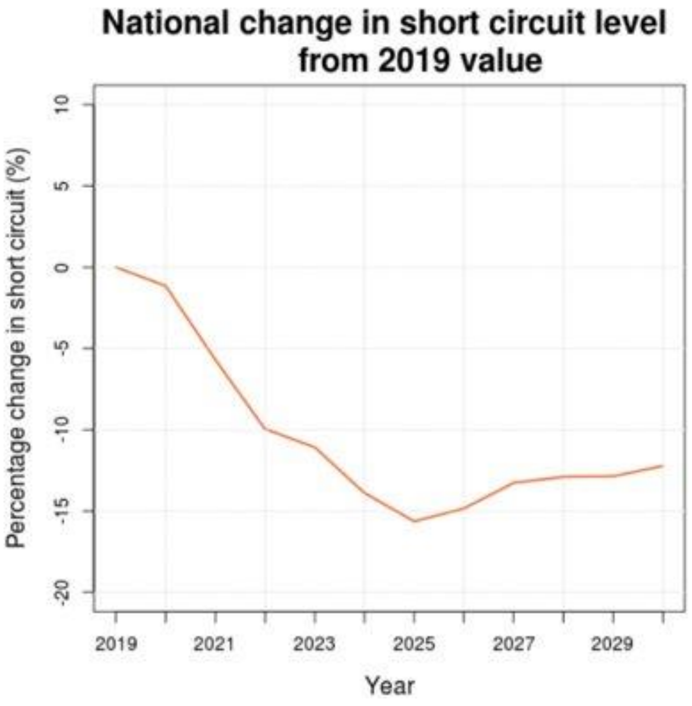
Comms & engagements are completed within ESO's GBGF Best Practice Group, Grid Code Dev Forum (GCDF) as well as wider industry forums e.g. CIGRE, G-PST and ENTSO-E.

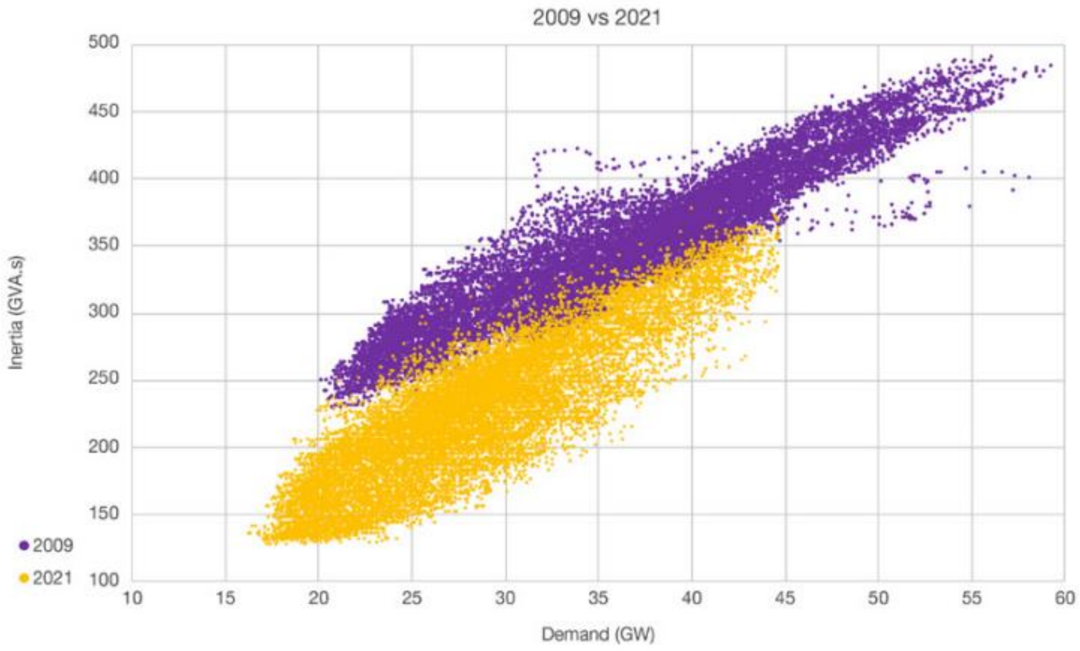
What are the future operability challenges?

What are the future operability challenges?

We use 'Stability' to describe a broad range of operational challenges, some of which are:

- Inertia
- Short circuit level
- Dynamic reactive power
- Loss of mains protection
- Fault ride through





What have we achieved to date?

Successes

Stability Pathfinders

- To date, we have held three separate tender rounds for stability pathfinders.
- These have all concluded and we have procured a total of 36GVA.s of inertia, and sufficient SCL to resolve local constraint issues across GB.
- Solutions are from new technology types, including synch comps and Grid Forming batteries
- These solutions are directly facilitating our ability to operate a zero carbon system

Accelerated Loss of Mains Change Programme (ALoMCP)

- Since the programme launched in September 2019:
- A total of 8430 applications have completed protection changes with funding from the programme (equating to 13.2GW of capacity)
- In addition, 6059 sites (11.0GW) have reported to the programme their compliance with the G59/3-7 Loss of Mains protection requirements
- Together this means 94% (24.2GW of the generation capacity in scope of G59/3-7) has confirmed compliance

Frequency Risk and Control Report (FRCR)

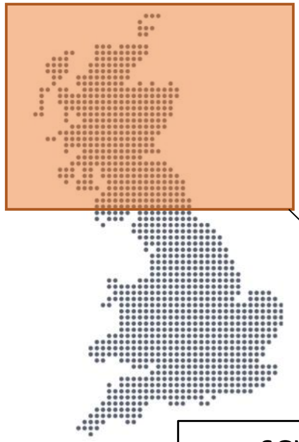
- The progress with the ALoMCP has enabled us to review our policy for how we manage frequency deviations on the system
- FRCR was established in 2021 and has fundamentally changed how we manage system frequency risks
- The 2023 FRCR has recommended a reduction of minimum inertia from 140GVA.s to 120GVA.s.

Stability Pathfinders

Phase 1

- 12.5GWs inertia procured across GB
- Paid for availability
- 90% availability is mandatory
- All are Sync Comps
- All units are now live and providing inertia to the system

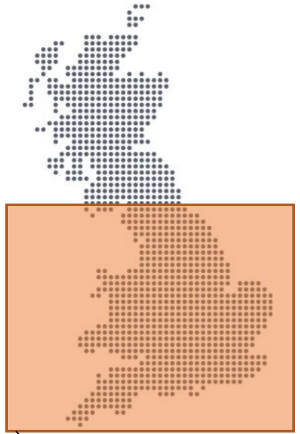
Connection	Inertia (MWs)	Go live date
CRUA2	533.33	July 2020
RASS1	750	Feb 2022
CONQ4	1533	Jun 2021
CONQ4	1533	Jun 2021
KILL4	1430	April 2022
KILL4	1430	April 2022
KEIT1	450	Dec 2021
KEIT1	450	Jan 2022
GRAI4	1729	March 2023
GRAI4	1729	March 2023
LISD2	450	Feb 2023
LISD2	450	Feb 2023



Phase 2

- 6GWs inertia procured across Scotland
- SCL need is met
- Paid for availability
- 90% availability is mandatory
- 5 Sync comps and 5 GFC
- Will be in service between 2024-2026

Connection	Technology
COYL2	GFC
NEIL1	GFC
BEAT4	Sync Comp
GRNA4	Sync Comp
ROTI4	Sync Comp
THUS2	Sync Comp
NEIL4	Sync Comp
BLHI2	GFC
KILS4	GFC
ECCL4	GFC



Phase 3

- 17.1GWs inertia procured across E&W
- SCL need is met
- Paid for availability
- 90% availability is mandatory
- 29 Sync comps
- Will be in service between 2025-2026

How are we meeting future operability challenges?

Inertia Monitoring

Anna Blackwell

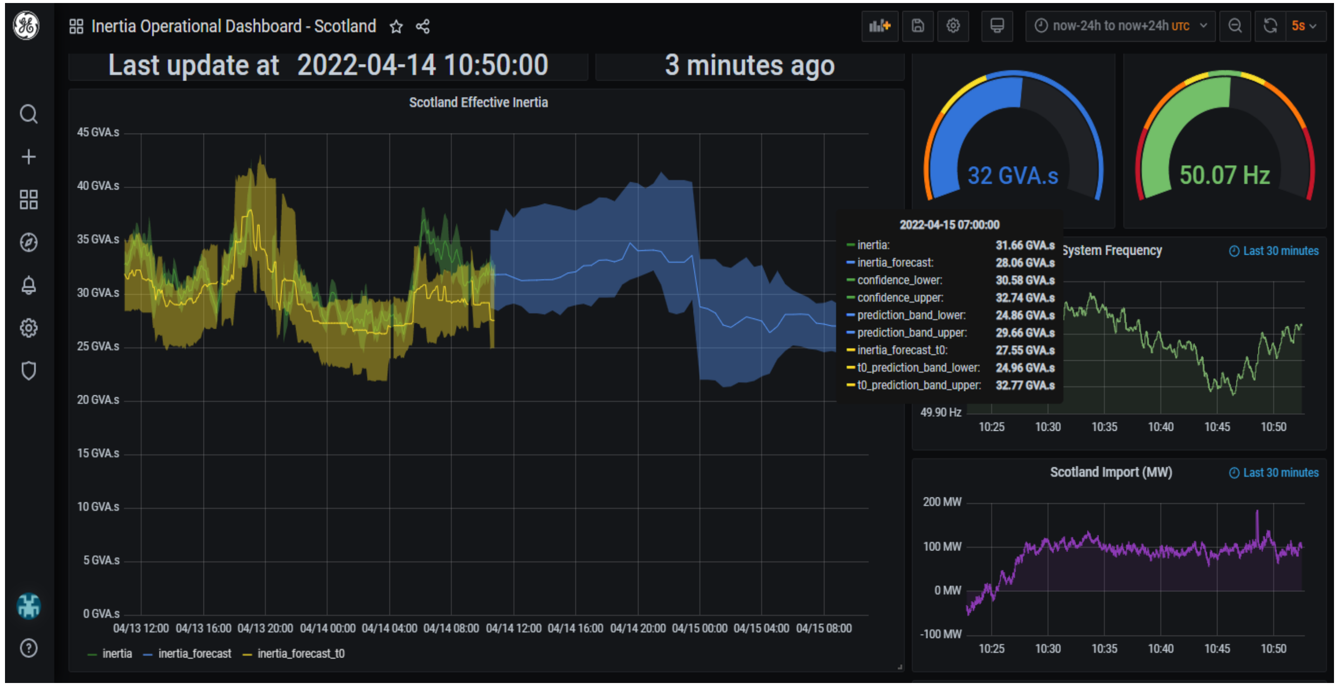
ESO

Inertia Monitoring

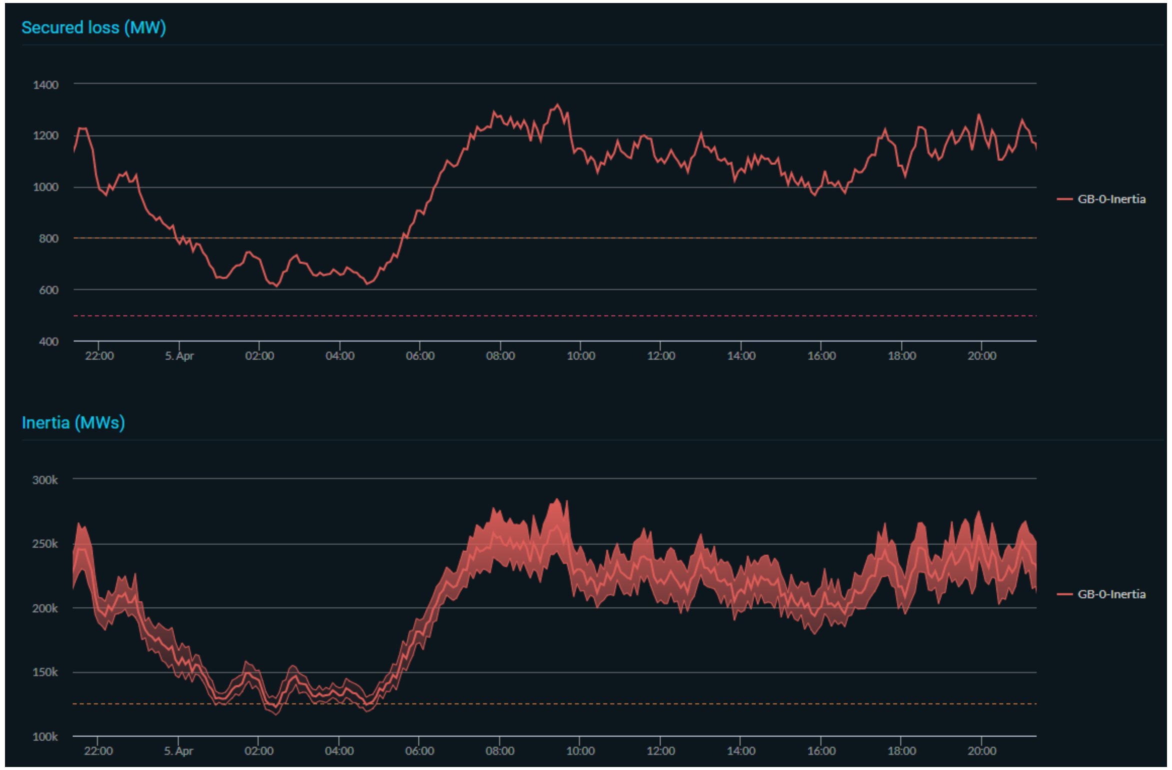
Implemented two new “first-of their-kind” inertia monitoring tools

- GE Digital solution providing:
  - Regional based
  - Real-time monitoring based on Phasor Measurement Units (PMUs)
  - Day ahead forecasting per settlement period using operating data (demand, wind, solar & synchronous inertia)
  - Verified against loss of load events
  - Operating since late 2021, currently Scotland only based on PMU availability
  - Full GB availability limited by NGET PMU rollout

- Reactive Technologies solution:
  - GB wide 5 minute real-time monitoring
  - Uses ultra capacitor to provide “controlled” signal onto frequency
  - Measured across GB in distribution network
  - Operating since July 2022, mainly over periods of high renewables



Inertia Operational Dashboard - Scotland
now-24h to now+24h UTC
5s
Last update at 2022-04-14 10:50:00
3 minutes ago
Scotland Effective Inertia
32 GVA.s
50.07 Hz
2022-04-15 07:00:00
inertia: 31.66 GVA.s
inertia_forecast: 28.06 GVA.s
confidence_lower: 30.58 GVA.s
confidence_upper: 32.74 GVA.s
prediction_band_lower: 24.86 GVA.s
prediction_band_upper: 29.66 GVA.s
inertia_forecast_t0: 27.55 GVA.s
t0_prediction_band_lower: 24.96 GVA.s
t0_prediction_band_upper: 32.77 GVA.s
System Frequency
Last 30 minutes
Scotland Import (MW)
Last 30 minutes
inertia
inertia_forecast
inertia_forecast_t0



Secured loss (MW)
GB-0-Inertia
Inertia (MWs)
GB-0-Inertia

ESO

Data Verification

- Internal review of data
- Data Analysis being undertaken independently by National Physical Laboratory (NPL*) to:
  - Assess both products alongside internal evaluation.
  - Establish regional representation
  - Establish standardisation for measurements
- Comparison of 6 months data
  - Strong correlation with synchronous inertia (>0.85)
  - Confidence values within 10% for 95% of measurements
  - Initial indication of regional variations
  - Detailed analysis of periods of high renewables ongoing
- Incorporate into ENCC situational awareness summer 2023
- Potential data publication (depending on commercial agreements)

* NPL is an institute developing and maintaining the national primary measurement standards. It is a Public Corporation owned by the Department of Business, Energy and Industrial Strategy (BEIS)

Future of GB Grid Forming

Dechao Kong

ESO

Strategic Roadmap for GB Grid Forming Development

Business Case

- ESO Operability Strategy Report
- System Operability Framework (SOF) Article on GFM/VSM

Collaboration with External Stakeholders

- VSM Expert Group (Completed).
- GC0137 GB Grid Forming Working Group (Completed).
- GB Grid Forming Best Practice Group (Completed).

SOF "The Potential Operability Benefits of Virtual Synchronous Machines and Related Technologies" Apr, 2020

Share insight

Feasibility Studies

Tech Spec & Best Practice

GC0137: Minimum Specification Required for Provision of GB Grid Forming (GBGF) Capability (formerly Virtual Synchronous Machine/VSM Capability), implemented in Feb, 2022

Innovation Projects:

- Virtual Synchronous Machine (VSM) Demonstrator (Completed)
- Hybrid Grid Forming Converter (Completed)
- Demonstration of Virtual Synchronous Machine Control of a Battery System (Completed)

Future of GB Grid Forming

The penetration and proportion of Grid Following (GFL) based IBRs on the GB energy system will increase hugely into the foreseeable future.

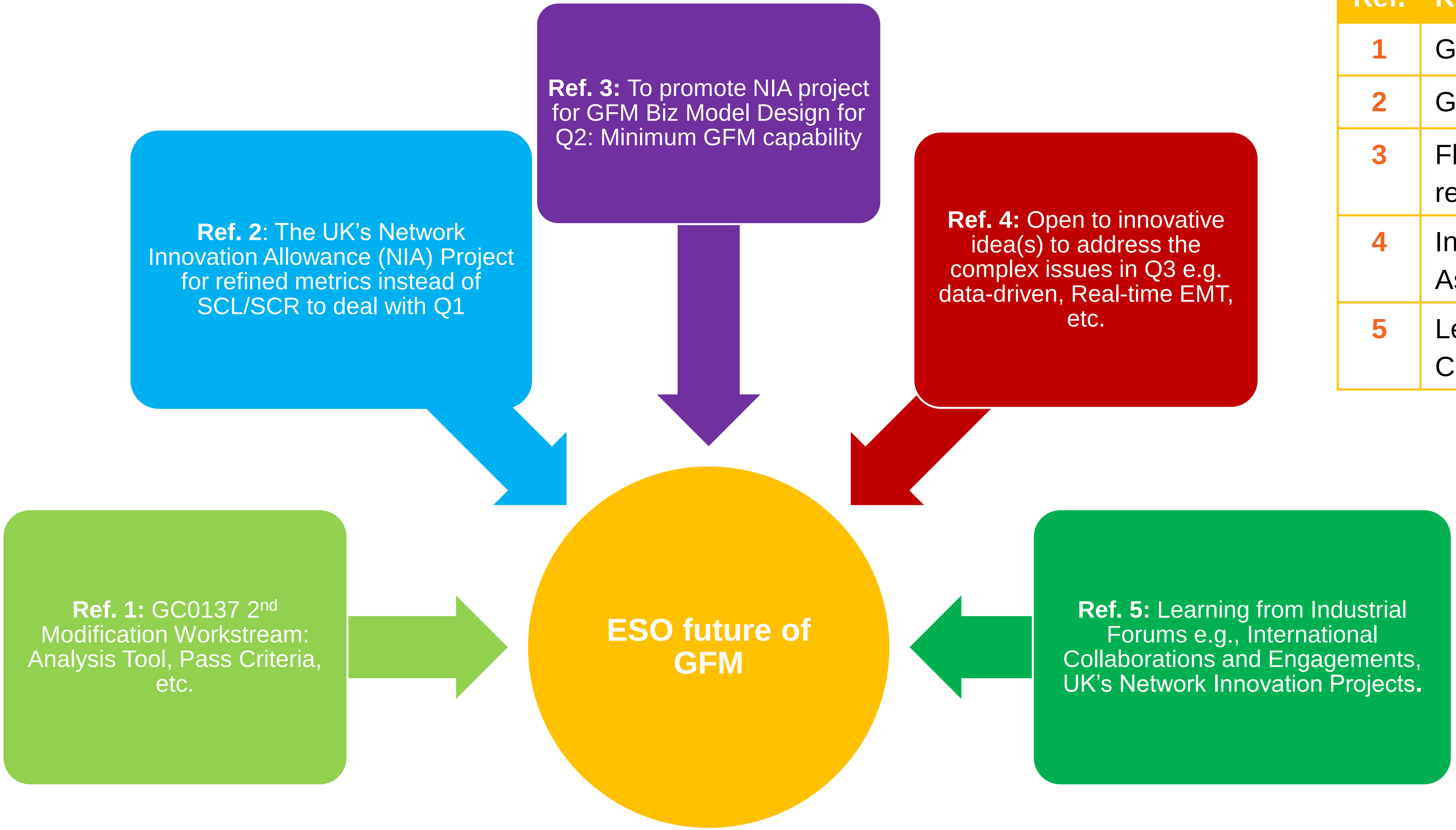
A number of challenges are foreseen below. How best can we address these issues?

- Q1: How much Grid Forming (GFM) capability will be required on the system to manage operability issues?
- Q2: Should GFM capability be mandated?
- Q3: How can we assess interoperability issues between GFL/GFM-based IBRs and Synchronous Machines?

Future Roadmap for GB GFM Development

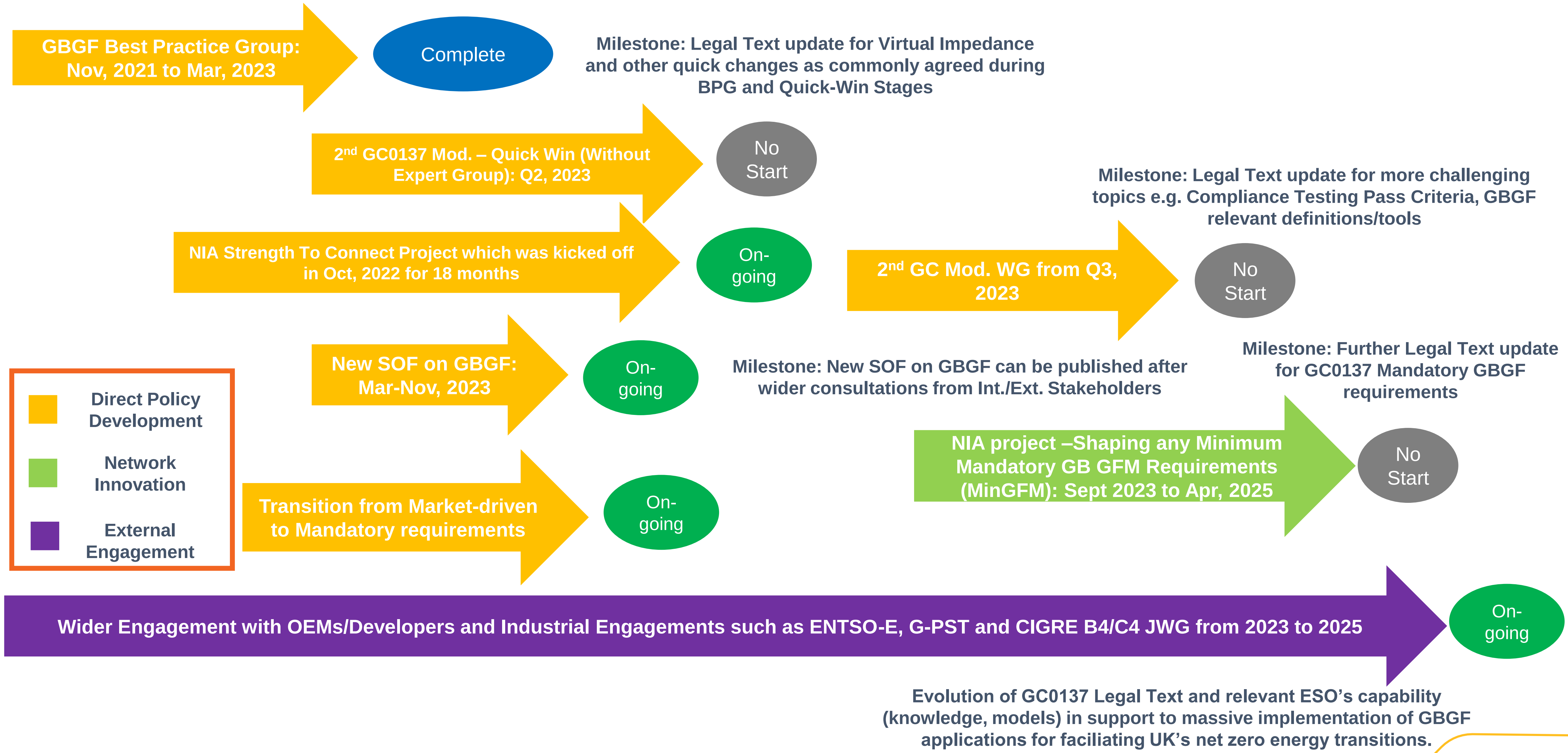
Ref.	Key Activities	Term
1	To **further update GC0137** in line with key findings/suggestions of **GBGF Best Practice Group**.	Short
2	To understand how to **quantify the GFM capability** as required on the system to manage operability issues (in line with Q1).	Middle
3	To **set flexible entry requirements** for potential players in the GB Grid Forming markets (in line with Q2).	Middle
4	To **understand how to assess interoperability issues** among GFL-based IBRs, GBGF-Inverter/Synchronous and conventional Synchronous Gens (in line with Q3)	Middle
5	To **learn from industrial forums**, **facilitate international collaborations** and **implement network innovation projects** for further technical/market developments of GB GFM.	Middle/Long

Ongoing and future activities



Ref.	Key Activities
1	GC0137 2nd Modification
2	GFM capability quantification
3	Flexible market entry requirements
4	Interoperability Issue Assessment
5	Learning from Others, Collaboration and Innovation

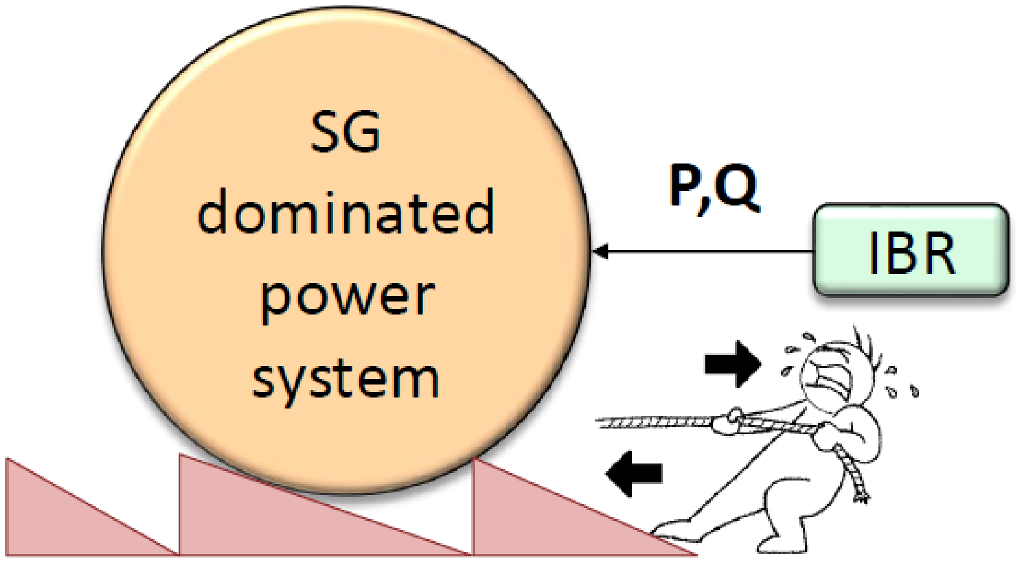
ESO's Future Strategic Roadmap for GB Grid Forming Development



System strength management

Xiaoyao Zhou

What is a strong system

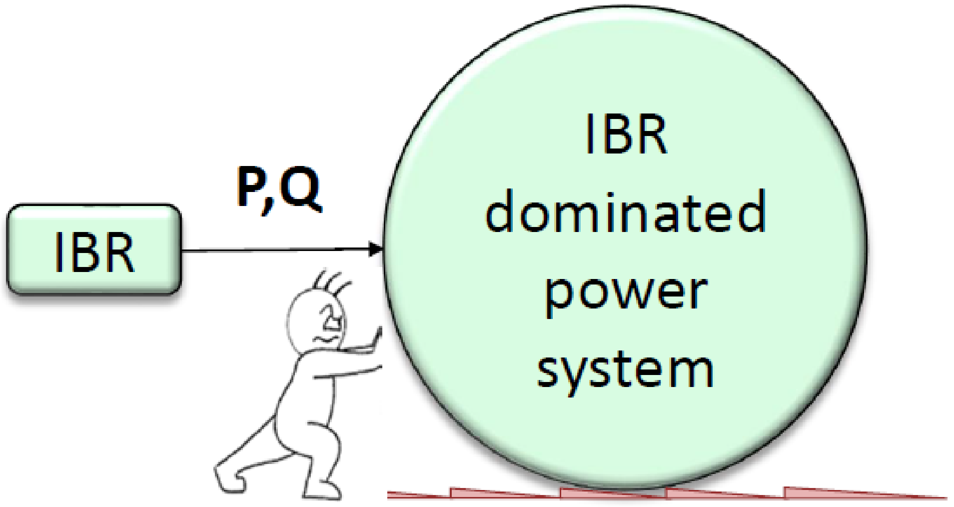


- Majority of today's IBR control is designed to work in a stiff system
  - Changes in IBR injected current do not 'move' the stiff system
  - Changes in system cause IBR to 'move' in tandem
- This behavior has recently been labeled as grid following (GFL)

[EPRI Tutorial Grid Forming]

IBR: Inverter Based Resource

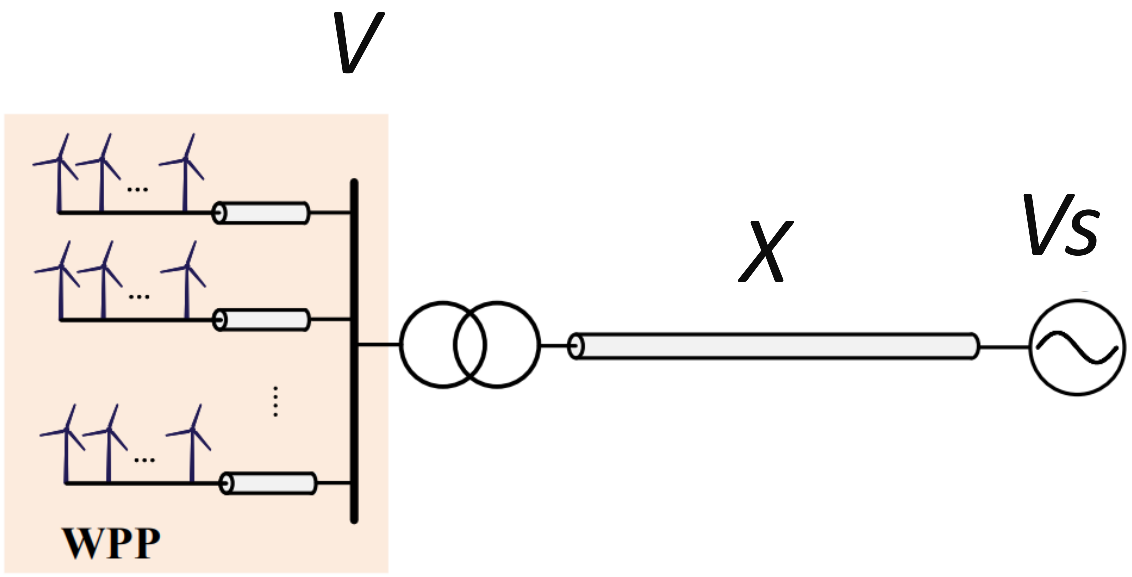
What is a weak system



- In IBR dominated power system:
  - Increased elasticity in the grid
  - Changes in IBR injected current will 'move' the system
  - This movement in system will itself cause IBR to 'move' in tandem
- This increased interaction is to be stabilized for IBR to deliver expected needs

EPRI Tutorial Grid Forming

Typical system representation



$V = Vs - jX*I$

Weak System: Large *X*

Small *I* change, Large *V* change

Short Circuit Level (SCL) Vs System Strength (SS)

- **Short Circuit Level:** is the amount of current that flows on the system during a fault.
- **System Strength:** is power system's ability to maintain the stable voltage. It can be measured by the amount of current that flows on the system from the plants with voltage source behaviours during a fault.
- The same system at the same operating condition may exhibit different level of strength for different phenomena (e.g. transient stability vs dynamic stability vs voltage control). Focus here is on transient stability and fault ride through.
- For a synchronous machine dominated system, SCL is very close to SS; for a IBR dominated system, SS could be much lower than SCL.

	SCL	SS
Rotating Machine	Y	Y
Grid Following Converter	Y	N
Grid Forming Converter	Y	Y

	SCL	SS
Protection	Y	N
Equipment Rating	Y	N
System Stability	N	Y

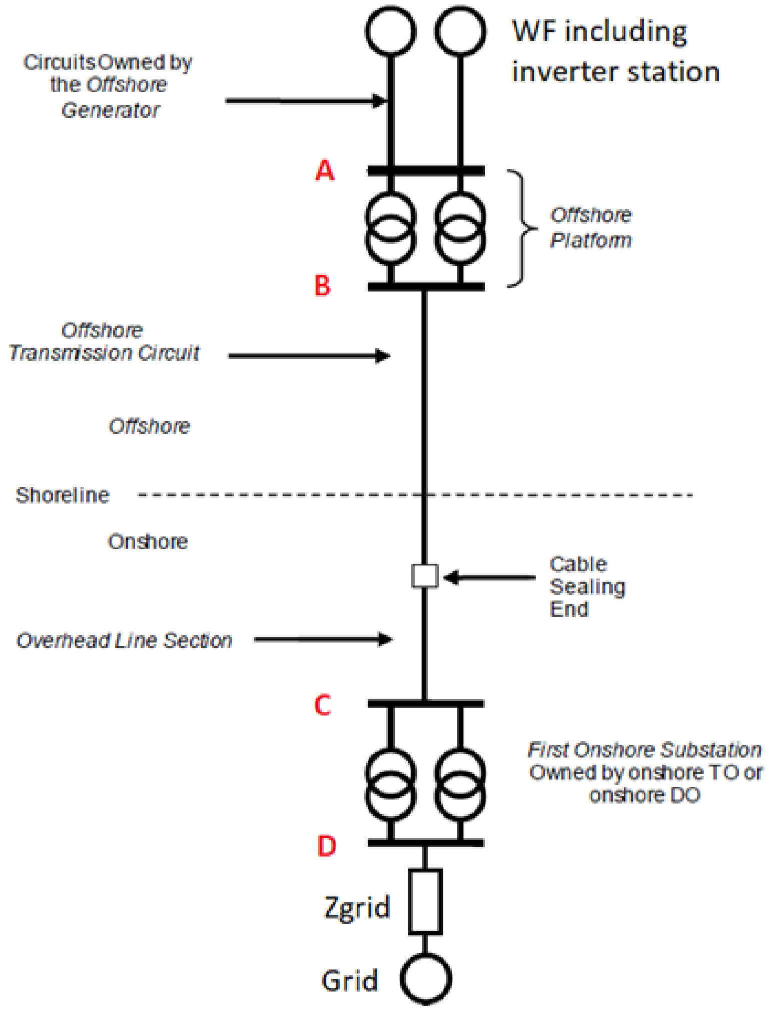
Short Circuit Ratio (SCR)

- **Short Circuit Ratio is more relevant to a particular user connection**
  SCR= SCL/Rating of the Machine

- **It is more appropriate to use system strength rather than SCL when calculating SCR.**
  SCR= SS/Rating of the Machine

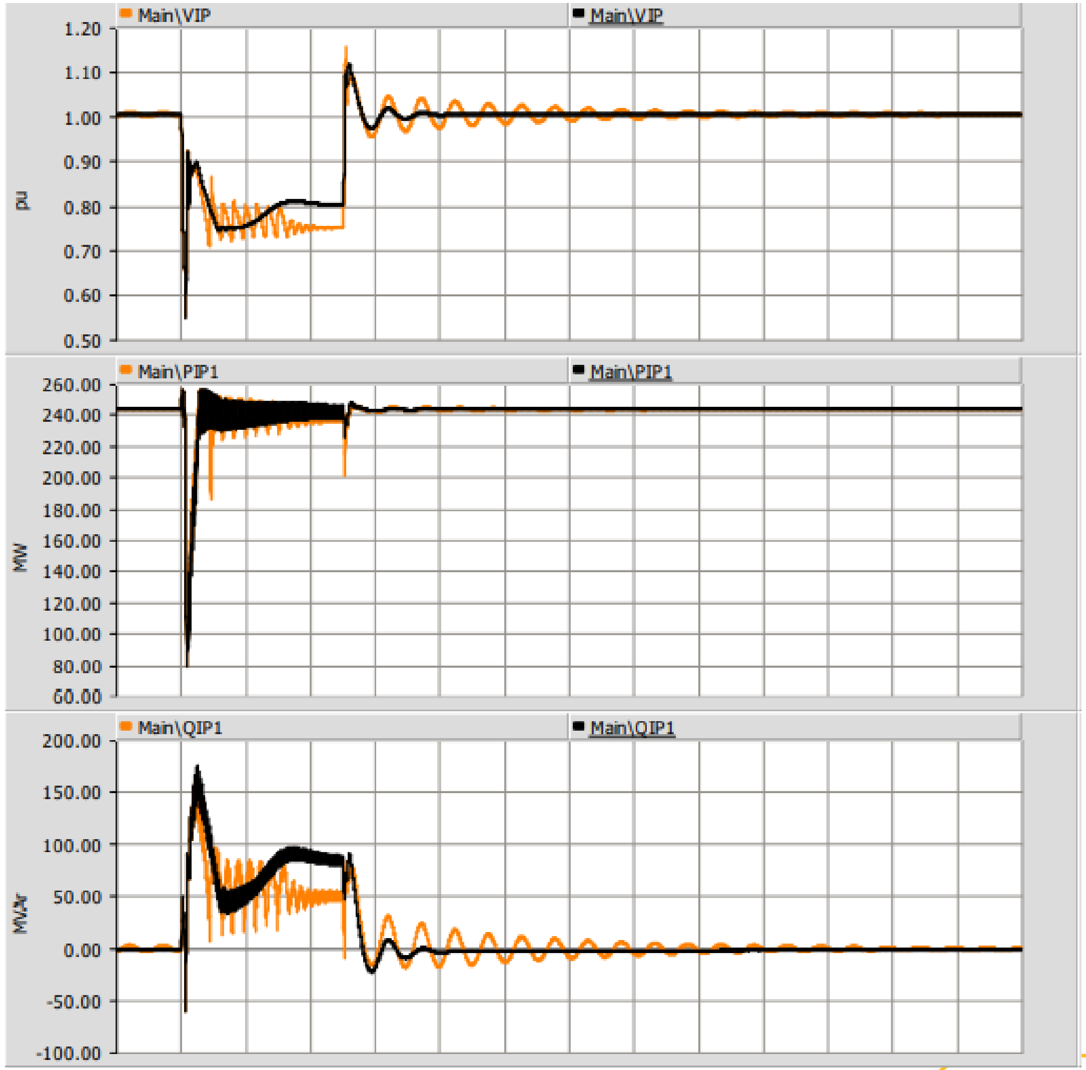
- **SCR for a specific connection can be estimated at different points. For example, the SCR for an offshore windfarm would be higher if estimated at the TIP than if estimated at the inverter terminal (point A) due to high impedance between D-A**

	SCR
A (66kv)	1.26
B (132kv)	1.64
C (132kv)	1.96
D (400kV/275kv)	3



Minimal SCR for single IBR stable operation

- With reduction of SCL, it becomes challenging for generator to meet the grid code requirements
- There is a risk that existing generator might not remain compliant with reduced SCL
- Tuning parameters may improve the performance under low SCR, however it is case by case and hard to determine the limit.



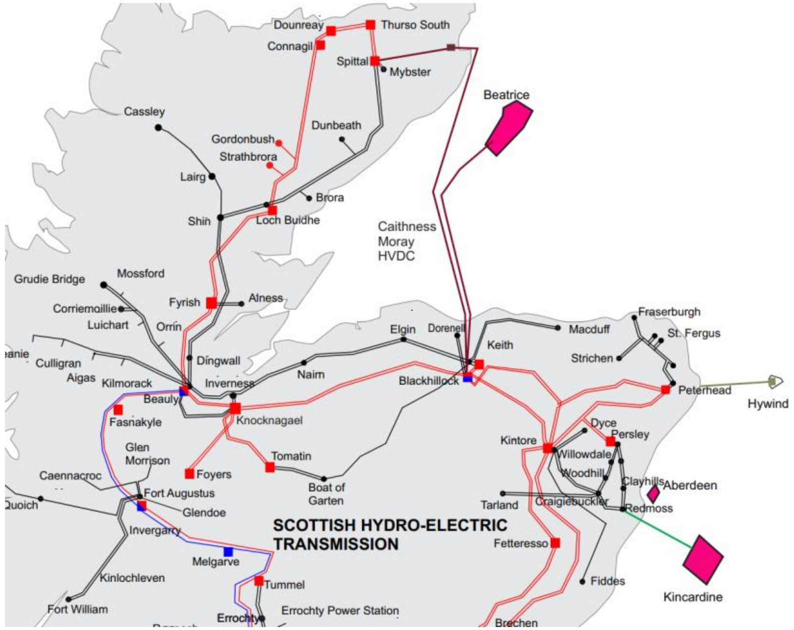
Minimum SCR for single IBR stable operation

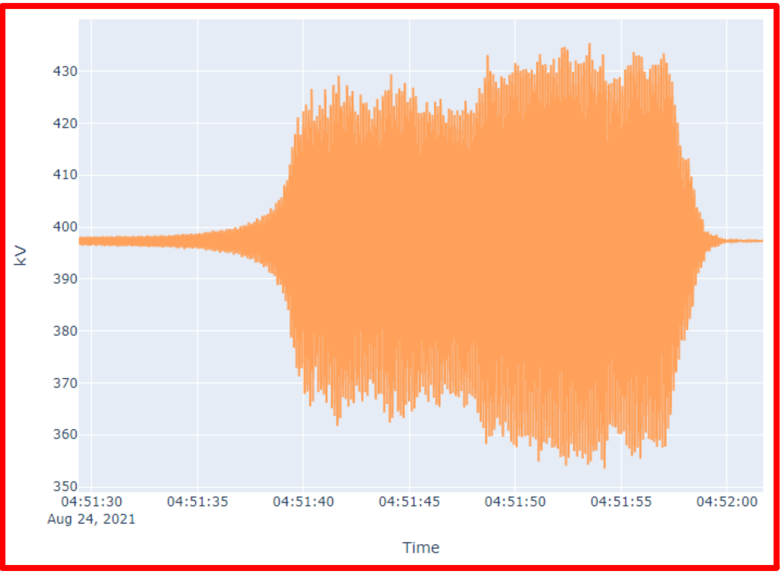
- Minimal SCR (MSCR) is the minimum SCR required for IBR to maintain stable operation.
- Many TSOs have attempted to apply a consistent assumption for MSCR across their network. Examples are shown in the table.
- If the SCR is above these levels, the likelihood of instability is low. However, there is no clear cut without a detailed EMT study.
- Generally, controllers could be retuned to reduce the minimum SCR for an IBR. However, there are cases when this was not successful.

	MSCR at TIP	Connection type
AEMO	3	AC
EirGrid	2	HVDC
VDE	2	HVDC
GB experience	3	AC

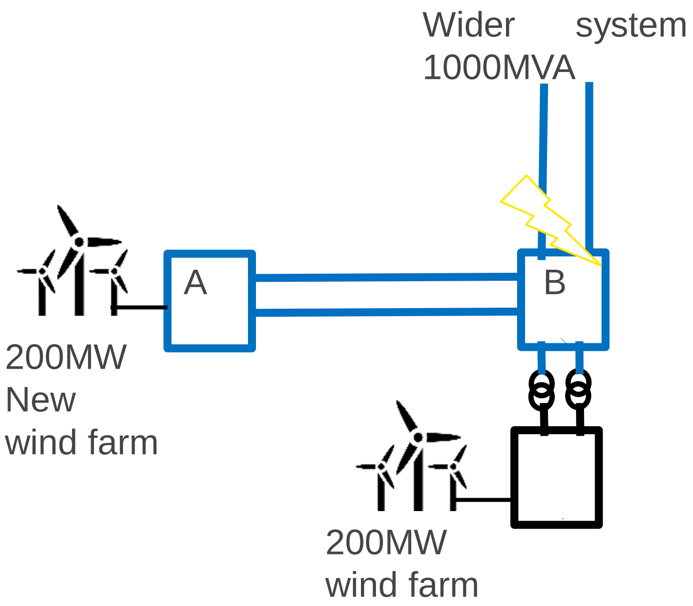
Minimal SCR for multi-IBRs connection

- Additional challenge of control interaction under low SCR
- Potential solution: increase SCL or tunning controller, much more difficult to determine the effectiveness
- Different SCR method will give different result
- The issue/oscillation might not be strictly correlated to SCL





Minimum SCR for multi- IBRs connection



Option	SCL(MVA)	SCR
1	1200	6
2	1000	5
3	400	2
4	1200 or 500	2.5 (ESCR)

Define SCR for a group of IBRs

New 200MW windfarm connection at A, what is the appropriate SCL information for the connection?

Options

1. Existing windfarm contribution based on inverter rating

SCL=1000+200=1200MVA ; SCR=6

2. No SCL contribution from inverter (only consider voltage source behind an impedance)

SCL=1000MVA; SCR=5

3. Grid following inverter consumers SCL/system strength; CIGRE WB4.62

Available SCL=1000-200*3=400MVA (assume min SCR=3 for existing windfarm); SCR= 2

4. Considering MIIF, ESCR; (CIGRE WB4.62)

ESCR=1000/400=2.5; SCL=1200MVA or 500MVA

Summary

- System Strength is not the same as SCL
- For stability assessment, System Strength is more relevant
- Current SCR method can be modified using system strength rather than SCL
- SCR method works better for single IBR connection, when rest of system can be represented as an equivalent voltage source
- More work needs to be done for multiple IBRs connection

Ongoing Innovation Project - Strength to Connect with Imperial College London

- 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
- 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
- Scope for each area
  - Properly defined grid strength metric
  - Properly defined and declared compatibility levels for grid strength
  - Tool creation for locational compatibility levels metric, and heat maps to visually describe compatibility of the whole system
  - Assessment guidance of IBR capability to add strength and evaluation on their ability to work in low grid strength

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

Meeting our Stability Needs and the Stability Market Innovation Project

Ed Farley

How we currently meet our stability needs

Stability as a by-product of energy

- As a result of synchronous units (and demand) scheduling themselves in energy markets (e.g., wholesale, reserve), a proportion of inertia and SCL is provided as a by-product.
- This contributes significantly to a stable system and means that we often meet our 140GVA.s inertia threshold without further intervention.
- As the contribution from invertor-based generation increases, ESO have to take additional actions to ensure compliant system operation.

Stability Pathfinders

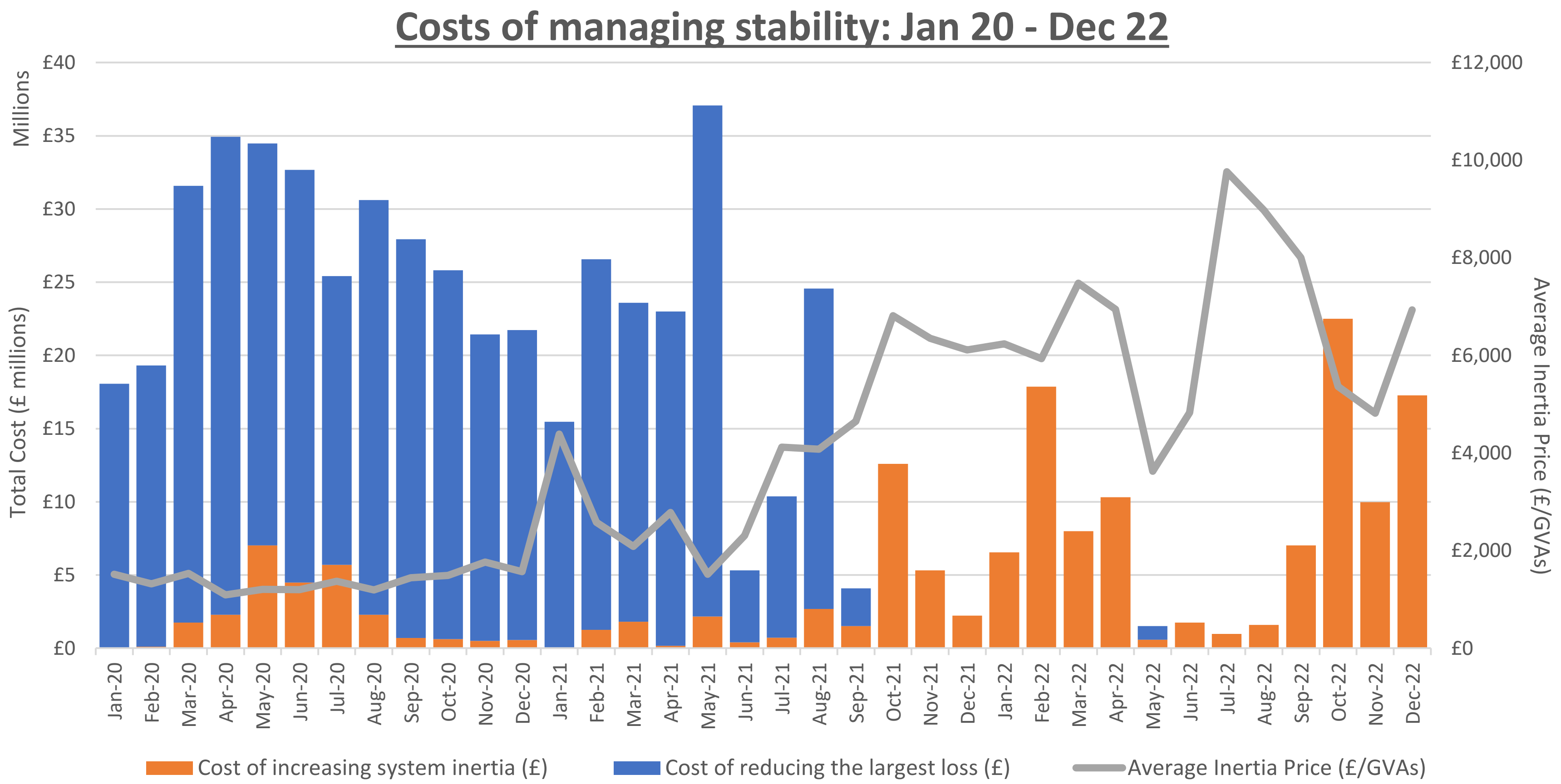
- All 12 units from Stability Phase 1 are now operational for dispatch by ESO control room. They contribute 12.5GVA.s inertia and are available for at least 90% of the year.
- These synchronous condensers, plus grid-forming battery energy storage from Stability Pathfinder Phase 2, are contracted on 6-10 year terms and help to facilitate our zero carbon operation commitments at low cost.

Balancing Mechanism

- Where there remains a requirement for stability in real-time with pathfinder units running, ESO use the Balancing Mechanism to instruct additional synchronous machines.
- Our stability requirements are typically greatest during low demand, high renewable periods where non-synchronous generation is the dominant energy source.
- Therefore, instructing synchronous machines for stability often coincides with bidding off cheaper generation to ensure supply and demand remain balanced.

Managing stability in 2022

- Costs of actions taken to reduce the size of the largest loss decreased very significantly in 2022, but the costs to increase system inertia increased to £104m.
- The average cost per unit to increase system inertia was £6,575/GVA.s in 2022 versus £3,981 in 2021.



Stability Market Design Overview

- To maintain compliance and reduce costs associated with managing stability, we are conducting an innovation project with AFRY to explore designing new markets to procure stability services.
- Phase 1 concluded in 2022 and recommended that a blend of long and short-term competitive procurement is the optimal approach.
- Phase 2 is building on this through more detailed evaluation of eligibility rules, contract structure and procurement strategy.

		Long Term (Y-4)	Mid Term (Y-1)	Short Term (D-1)
Purpose		– Procure capacity in advance (LT), to signal the need for new assets – Allow financing of new build capacity (and enhanced capability, TBD) through LT contracts	– Procure capacity in advance (MT), to adjust LT procurement in case necessary – Allow MT financing of new, incremental and existing capability able to provide stability	– Procure capacity to fulfil residual of total requirements for Stability closer to real time (ST) – Allow remuneration of marginal costs for providing Stability.
Timeline	*Procurement lead time*	– Y-4	– Y-1	– D-1
	Contract duration	– 10+ y	– 1 y	– Service windows
Product	*Contract type*	– Baseload availability	– Baseload availability	– 4 h (EFA blocks)
	Contract obligations	– e.g. 90% availability	– e.g. 90% availability	– 100% availability

Stability Market Design – Next Steps

- There are several themes which are the core focus for the remainder of the project:
  - To confirm eligibility rules for mid-term and short-term markets
  - To determine the appropriate structure of availability and/or delivery payments
  - To finalise stacking rules between stability and other ancillary services

- We have been engaging with stakeholders via a Stability Market Expert Group and will be following up with further whole industry engagement to summarise the key conclusions of the innovation project.

More information will be shared in the stability chapter of Markets Roadmap – to be published this Friday

Link to Markets Roadmap webpage

Link to Markets Roadmap webinar

Q&A