SHOW AND TELL

INCENTIVE Beta Phase

TRANSMISSION

Background innovation concept

CARBON TRUST

- Seeking to demonstrate how offshore wind can stabilise the GB onshore networks
- Focussing on bringing innovative solutions that are **high TRL, but low CRL / IRL** to market ASAP

INCENTIVE SOLUTIONS

Business as usual offshore wind farm

(No inertia provision from the turbines; standard “grid following” turbines)

Onshore substation of offshore wind farm with the following providing inertia:

- Battery (“grid forming”)
- STATCOM (“grid forming”)
- Synchronous condenser
- HVDC terminal (“grid forming”)

GB onshore network

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INCENTIVE – overarching story

Discovery Phase

BESS w/ grid forming converter

STATCOM w/ energy storage and grid forming converter

Syncon

HVDC terminal

Flow battery
Hydrogen turbine
Wind turbine

Alpha Phase

BESS
- w/ grid forming converter
- w/ uprated grid forming converter
- w/ grid forming converter that replaces STATCOM functionality

STATCOM
- w/ energy storage and grid forming converter
- w/ inherent energy and grid forming converter

Syncon
- w/ flywheel
- w/o flywheel

HVDC terminal

w/ energy storage and grid forming converter
w/ inherent energy and grid forming converter

Beta Phase

BESS
- w/ grid forming converter
- w/ uprated grid forming converter

STATCOM
- w/ energy storage and grid forming converter

Syncon
- w/ flywheel

INCENTIVE Consortium

Funding

Project Partners

Delivery Team

Advisory panel

Project Champions

OWA Partners

11
OSW Developers

5
OEMs

2
Regulated License Holders

INCENTIVE Project

WP2b
Commercial Assessment (Business model development)

WP2a
Regulatory Assessment (Business model development)

WP3
Technical Assessment

INCENTIVE
Beta Phase

WP1
Project Management

WP6
Project Dissemination

WP4 & WP5
Site Assessment & Future Work Scoping

INCENTIVE BETA

WP2a. Regulatory Assessment

WP2 Objectives

- Devise site-specific business models for range of INCENTIVE solutions.
    - Commercial case to feed into FID (CBA, led by Frazer Nash).
    - Understanding required regulatory changes to facilitate business model implementation.
- Generalise business models into broadly applicable recommendations for stakeholders looking to procure stability services from offshore wind farms.

Key Research Questions

Can a developer retain ownership of a STATCOM after the OFTO divestment period?

1. Will Ofgem allow a STATCOM to be omitted from the OFTO tender specification and transfer?

2. Can the INCENTIVE STATCOM be owned and operated under a generation licence?

How can an INCENTIVE asset earn revenue in different ownership scenarios?

3. Will a bespoke agreement with NGESO be needed for stage 2, or can INCENTIVE get a R1/2 Stability Market Contract?

4. What contractual mechanism would allow for INCENTIVE asset owners to share in OFTO reactive power revenues?

5. What is the nature (direct vs indirect) of TO involvement in Stability Markets? What are Ofgem's plans for TOs post 2025?

How will OFTO grid compliance and risk management change because of INCENTIVE?

6. How will Ofgem address the *perception* of risk to the OFTO of a substation asset they cannot control?

7. Does the real time variable performance of the whole system need to be understood to adhere to grid code requirements?

8. How will INCENTIVE assets be metered considering their location in relation to current metering infrastructure?

What impact does an INCENTIVE asset have on OFTO tender prices and resulting TNUoS?

9. To what extent would the removal or addition of an INCENTIVE asset from the OFTO tender specification impact bid prices?

10. How would the removal or addition of an INCENTIVE asset from the OFTO tender specification impact local TNUoS charges?

11. Could increasing developer revenues from stability services increase the competitiveness of developer CfD tenders?

What impact will INCENTIVE assets have on the substation's physical constraints?

12. Given unchangeable substation dimensions, is there enough space for enhanced INCENTIVE assets?

13. Are there any additional resulting costs of asset integration, e.g., increased size of asset housing?

Stakeholder Engagement & Requirements

CARBON TRUST

Windfarm Developers	Ofgem	NESO
Commercial rationale and viability of INCENTIVE solutions	Value to GB billpayers	System operability, Stability Market integrity and value to GB billpayers

DESNZ	OFTOs	OEMs
Long term policy (OFTO Regime Review) Energy Security Offshore wind targets	Meeting compliance with low technical/financial risk	Route to market for innovative gird forming technologies

The Problem(s) with STATCOM ownership models

CARBON TRUST

INCENTIVE Alpha CBA indicated that augmenting STATCOMs with supercapacitor energy storage could provide **low-cost inertia to GB billpayers.**

STATCOM is divested to the OFTO

No (current) access to stability market

NGESO has recently launched its Y-1 Stability Market tenders, with D-1 procurement set to launch in 2026. TOs and OFTOs are unable to participate in these markets due to their regulatory/licencing conditions prohibiting participation. This may change for longer term (Y-4) auctions in the future.

OFTO regime cost minimisation approach

Developers must design and build the OFTO network in the most efficient way to transmit power from the windfarm to onshore system. The OFTO regime has no incentives for developers to design and commission INCENTIVE STATCOMs – moreover, it directly prohibits them from doing so.

Low OFTO capabilities/resources

OFTOs are often financial holding companies that may not have the technical capabilities or desire to optimise assets in a live market environment (e.g. NESOs stability market).

Developer retains ownership

OFTO tender specification

While developers have owned STATCOM devices in the past, they are typically considered essential transmission equipment that is transferred over to the OFTO after the 18-month divestment period.

OFTO STC reactive requirements

OFTOs currently use STATCOMs to meet their STC requirements in relation to reactive compensation at the transmission interface point.

WP2 started with 7 regulatory models, down selected to 3 through stakeholder engagement

CARBON TRUST

- ✗ (1) ROI pre-divestment — Unpalatable merchant risk + increased stability prices
- ✓ (2a) Developer ownership (STC assist)
- ✓ (2b) Developer ownership (Grid Code) — **Prioritised option after stakeholder workshop**

Developer Ownership

OFTO Ownership

- ✗ (3) OFTO licence derogation — Significant change that could impact market integrity
- ✗ (4) Developer bid, OFTO ownership — Complex commercial relationship
- ✗ (5a) Socialised cost model (local/offshore TNUoS) — Disincentivises developers to build
- ✓ (5b) Socialised cost model (wider/onshore TNUoS)

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Transfer of responsibilities

For statutory dynamic reactive compensation at the transmission interface point

Removal of the OFTOs STC obligations through Condition E13

Transmission Licence Condition E13:
"The Authority may (following consultation with all affected STC parties) issue directions relieving the licensee of its obligations to implement or comply with the STC in respect of such parts of the licensee's transmission system or the national electricity transmission system or to such extent as may be specified in the direction."

Precedent: Used in NESO pathfinder project to relieve NGET from the obligation to comply with section D part 2 of the STC.

Addition of generator responsibility via alterations to the windfarms TOCA documents

The Transmission Owner Connection Agreement (TOCA) documents (Service capability (SCS), Transmission interface site (TISS) and Connection site specifications (CSS)) form part of the windfarms legally binding bi-lateral connection agreement.

Precedent: Have been previously used to define generator contribution to OFTO STC requirements through grid forming

Ofgem: process for those looking to install INCENTIVE assets

CARBON TRUST

1 Application

- Developer contacts Ofgem ahead of FID to discuss their plans.
- Developer submits a request for derogation from the relevant parts of the STC (section K) to Ofgem on behalf of a future OFTO, drawing on transmission license condition E13.

2 Assessment

- Ofgem assesses the application in line with their sandbox guidance conditions
- Ofgem runs a consultation with affected STC parties, in line with condition E13 (this may take several months).

3 Minded-to decision

- If the application was successful, Ofgem would take a minded-to decision to grant the derogation to the future OFTO
- The decision would be published on Ofgem's website

4 OFTO tendering

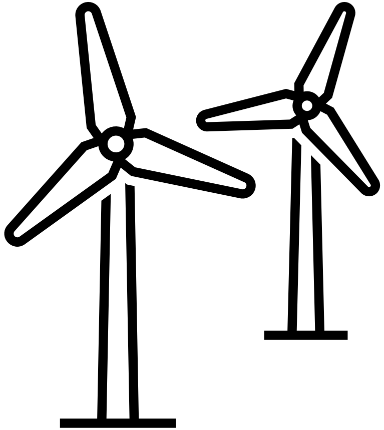
- The Ofgem-led tendering process would inform potential OFTO bidders on what assets would be divested to the OFTO, what would be retained by the generator and what responsibilities would fall on the OFTO versus the generator.
- This would ensure any bidder could make an informed decision, based on the information made available to all bidders at the start of the process.

Summary statement from Ofgem

VICTORIA PELKA: PRINCIPAL POLICY EXPERT

"We welcome this detailed report that forms part of the findings of INCENTIVE Beta Stage 1. INCENTIVE has the potential to unlock new sources of inertia, contributing to greater system resilience as well as reducing electricity consumer bills.

The INCENTIVE team has made significant headway in understanding how existing regulation applies, and whether and how it would need to change to accommodate this innovative project. We note that any specific development will be subject to regulatory approval and will be evaluated on a case-by-case basis. Ofgem's Innovation Hub is available to support any company looking to explore the INCENTIVE business models further."



INCENTIVE BETA

WP2b. Commercial Assessment

INCENTIVE CBA

Assumes we *can* build an INCENTIVE device – but *should we*?

Perspective	Question	
Whole system/economic perspective	Is the incremental investment in an INCENTIVE device a more cost-effective way to deliver stability services than other options?	Whole system = Developer + System operator + Consumer
Owner (Operator) perspective	Can the owner of an INCENTIVE device make a suitable return on their investment?	Analysis needs to consider the component parts of the whole system. Regulation and ownership becomes important – it determines how the economic benefits are distributed.
Consumer Perspective	Do consumers benefit if INCENTIVE is implemented such that networks/developers make a return?	

Changes from Alpha

Incorporating the outcomes of the ownership question allowed the Beta CBA to examine the developer/system operator/customer perspectives.

Engagement with OEMs and wind farm developers has given a fuller picture of the costs and performance of the supercapacitor STATCOM and BESS options.

Increasing clarity on the stability markets and analysis on prices.

Whole system economic perspective

Is the incremental investment in an INCENTIVE device is a cost-effective way to deliver INERTIA?

STATCOM

- Both cost of adding supercapacitors and the resulting inertia capability were underestimated in Alpha.
- Largely balance one another out, though this option no longer represents an incremental cost.
- Analysis of inertia prices from Pathfinder suggests that inertia from a STATCOM with supercapacitor energy storage could deliver inertia at a cost in the range of **£230 – £270/GWs/hr**. This is lower than over 50% of the tenders in Pathfinder.
- First of a kind technology – would expect prices to come down in business-as-usual case

BATTERY

- Looks at the cost of adding grid forming capability to an over-rated converter for the battery
- We have not considered battery operational strategies (e.g. which markets, attitudes to risk) or the impact of inertia provision on the operational lifetime of the battery
- Analysis of inertia prices from Pathfinder suggests that inertia from an INCENTIVE BESS would cost less than almost all Pathfinder tenders: **£110 - £200/GWs/hr.**

The developer perspective

Is the incremental investment in an INCENTIVE device is a cost-effective way to deliver INERTIA?

STATCOM

- Assumes a business model where the wind farm developer retains ownership of the INCENTIVE STATCOM rather than divesting it to the OFTO.
- Developer benefits: inertia revenues (if they are awarded a contract), reactive power payments (currently via ORPS) and lower TNUoS payments
- Developer liabilities: the full cost of the STATCOM – not just the additional costs of supercapacitors – as this is not recovered at OFTO divestment and the operational and maintenance costs
- This is a tough ask, especially over 10 years (a timescale that ties in with likely inertia contract lengths), and depends not only on inertia prices but also on reactive power payments received.
- Analysis suggests that an inertia contract price of **£680 - £770/GWs/hr** would allow a hurdle rate of 8% to be achieved on the investment. This is **a lower price than around 25%** of the Pathfinder tenders awarded and indicates that this is feasible.

BATTERY

- Yes – there are no ownership complications.
- Target prices to achieve 8% hurdle rate are around £140 - £230/GWs/hr depending on the extent of the over rating

The consumer perspective

Do consumers benefit if INCENTIVE is implemented (and developers make a return)?

STATCOM

- Assumes a business model where the wind farm developer retains ownership of the INCENTIVE STATCOM rather than divesting it to the OFTO.
- Depends on combination of reactive power and inertia payments. Tendering for inertia will set price for ~10 years. Reactive power revenues are variable – prices vary month by month and so will the volumes procured. Likely that the benefits from an INCENTIVE STATCOM could mainly go to the developer.
- This outcome is driven by the ownership/business model.

BATTERY

- Yes – consumers are likely to see lower bills as the system operator's inertia costs should fall.

Additional Sources of Benefit – system strength and capacity factors

If system strength alone is considered, then a synchronous condenser provides the most cost-effective option for increasing SCL (noting high running costs). However, if inertia payments are included, the INCENTIVE STATCOM provides the highest return on investment (better than both synchronous condenser and BESS).

It is difficult to see a route by which earnings from sales of inertia could cut CfD strike prices for developers, at least until there is greater certainty in the likely revenues. The timeframes in which the CfD auctions and inertia tenders operate would not allow a developer to factor inertia revenues into the CfD pricing.

INCENTIVE CBA – Summary Conclusions

FRAZER-NASH CONSULTANCY
A KBR COMPANY

Perspective	Question	STATCOM	BESS
Whole system/economic perspective	Is the incremental investment in an INCENTIVE device a more cost-effective way to deliver stability services than other options?	✓	✓
Owner (Operator) perspective	Can the owner of an INCENTIVE device make a suitable return on their investment?	✓ Beats higher-cost alternatives	✓
Consumer Perspective	Do consumers benefit if INCENTIVE is implemented such that networks/developers make a return?	✓ Reactive power uncertainties	✓
System Strength	Does the INCENTIVE option provide a more effective route to delivering system strength and inertia?	✓	✓

Future Considerations

Technical requirements

Storage duration

- The cost, and hence CBA, for the STATCOM with energy storage is sensitive to storage duration.
- Reduction to storage requirements will make supercapacitor options more competitive.

Contribution to system strength

- Sync condensers are preferred for providing system strength based on current ways of measuring system strength (SCL), but they come with substantial operating losses.
- If grid forming devices can be shown to provide similar benefits to system strength, then they will likely offer capability with lower whole life costs.

Future stability markets

- The analysis uses the stability pathfinders as a reference – which was first of its kind and dominated by synchronous condensers
- Future tenders will give a better view on other technology options and enduring market price for stability services

Technology maturity

- The existing STATCOM with energy storage solutions are first-of-a-kind. We expect costs will decrease over time and our report demonstrates how future cost reductions could impact competitiveness.

INCENTIVE BETA

WP3.Technical

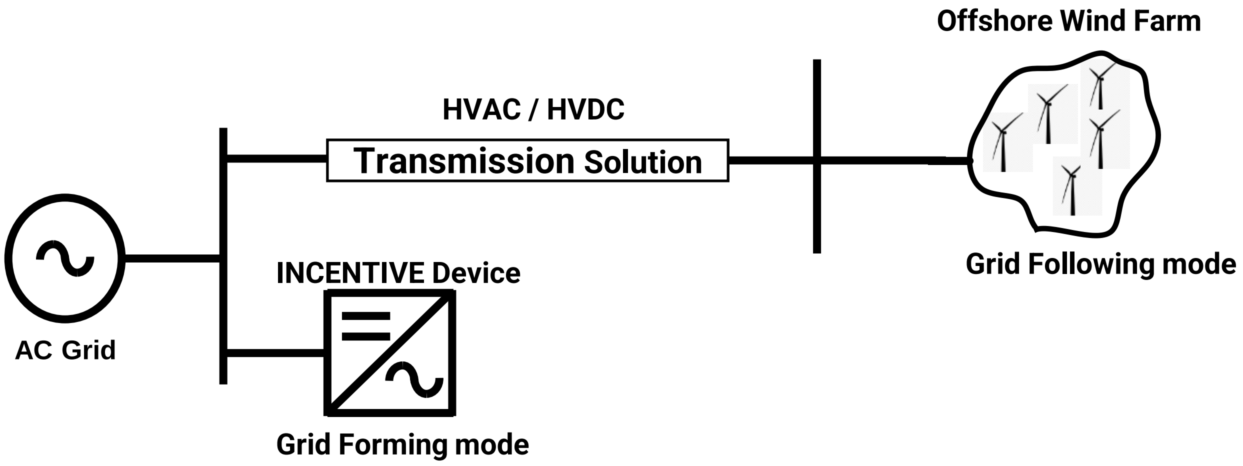
Scope

OBJECTIVE

- Understand if INCENTIVE devices can meet the grid code requirement or whether grid code requirements need to change
- Understand the interactions of INCENTIVE devices with the offshore wind farm
- To create a testing environment for assessing the performance of vendor-provided INCENTIVE device models with the site-specific offshore wind farm.

Task 3.1	Task 3.2	Task 3.3	
INCENTIVE Testing Setup	**INCENTIVE Device standalone Testing**	**INCENTIVE Device & Offshore Windfarm Testing**	**Engagement and Dissemination**

INCENTIVE Testing Setup



❑ Simulation Environment

- The testing is running **on an offline PSCAD environment**

❑ Offshore wind farm

- Generic offshore HVAC wind farm
- Generic offshore HVDC wind farm

❑ INCENTIVE Device

- Vendor type BESS
- Vendor type STATCOM with energy storage

❑ AC Grid

- Controllable ideal AC Source

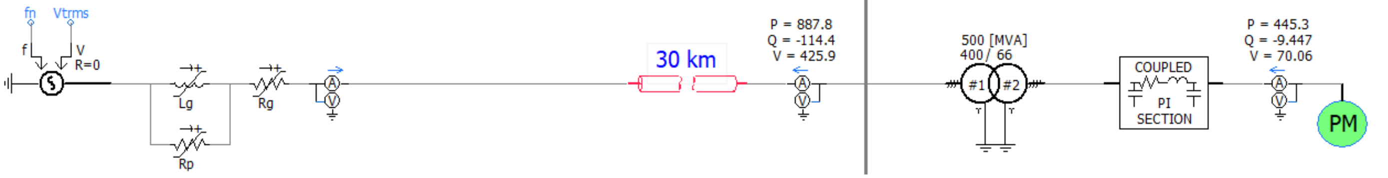
❑ Testing Events:

- Frequency Events
- Fault Events
- Angle Events
- Frequency scans

Offshore Wind Farm Model

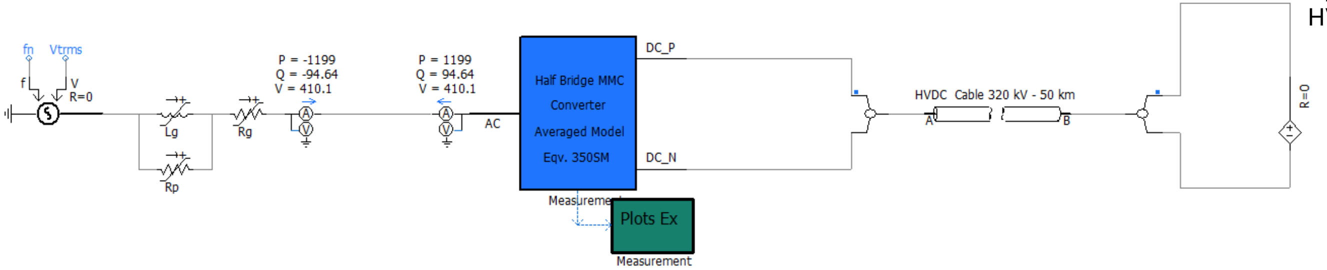
Type 4 Wind Turbine connected with Controllable AC source

Generic Model from the PSCAD library [1]



HVDC MMC converter with Ideal DC source connected with Controllable AC Source

Open-Source PSCAD Model from HVDC Centre [2]



The generic wind farm model and open-source MMC converter model are upgraded by the WP3 team with project champion's input

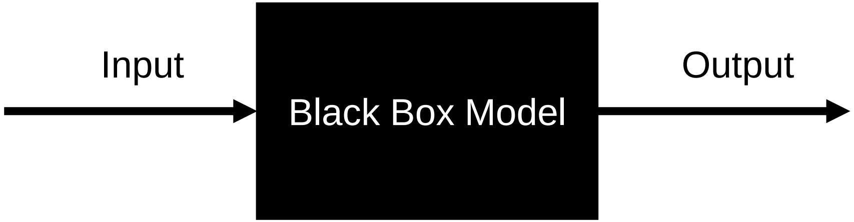
- Type 4 wind turbine with Scaling transformer represents the wind farm using an HVAC transmission system.
- MMC onshore converter is used as an HVDC onshore converter station to represent the offshore wind farm using HVDC transmission system
- The 4% *P-f* droop control with + 0.4 Hz deadband is used to simulate the limited frequency sensitive mode.

[1] HVDC VSC transmission linking an (offshore) islanded wind farm with (onshore) AC grid Link: https://www.pscad.com/knowledge-base/article/223
[2] Developing Open-Source Converter Models Link: https://www.hvdccentre.com/innovation-projects/open-source-converters/

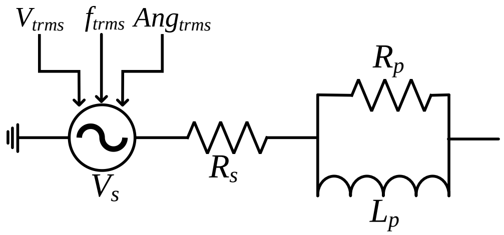
INCENTIVE Devices

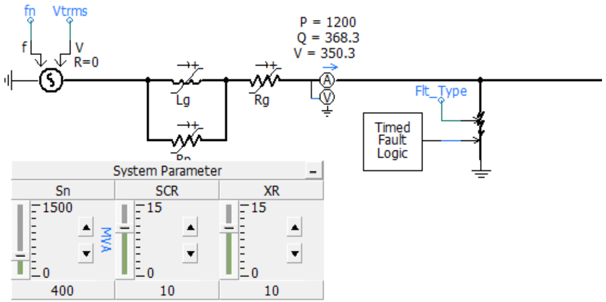
Four black box models of different grid-forming devices were provided by the advisory panel members:

- 2 Grid Forming STATCOM models
- 2 Grid Forming BESS models



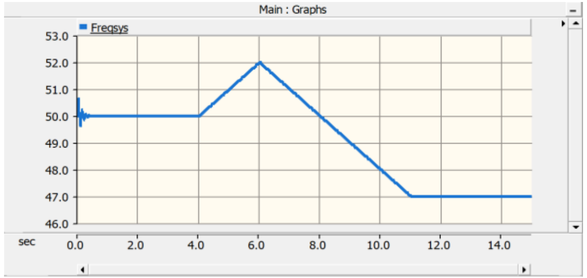
Test Rig Grid (PSCAD)



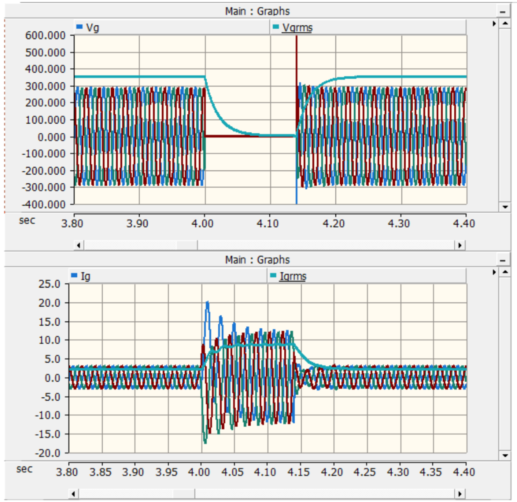


Grid Conditions		
SCR = 1.5	SCR = 3	SCR = 5
Weak Grid	Normal Grid	Strong Grid

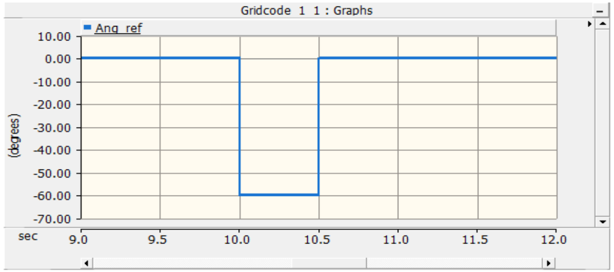
FREQUENCY TEST



FAULT TEST



ANGLE TEST



INCENTIVE Testing Plan

Test plan for INCENTIVE Stage 1 is based on Great Britain Grid Forming (GBGF) Best Practice Guide published in April 2023

GRID CODE COMPLIANCE TESTING

- Frequency Events
- Fault Events
- Angle Jump Events

SMALL SIGNAL SCAN

- Network Frequency Perturbations Scan
- Impedance Scan

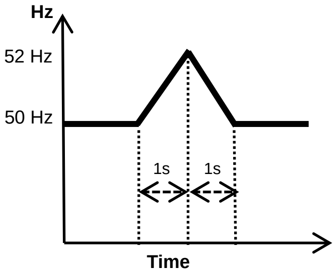
Reference to Grid Code modification GC0163 and Great Britain Grid Forming Best Practice Guide:
How Grid Forming Technology is changing, NGESO, Link**:** How Grid Forming Technology is changing | ESO (nationalgrideso.com)

Frequency Events

The National HVDC Centre

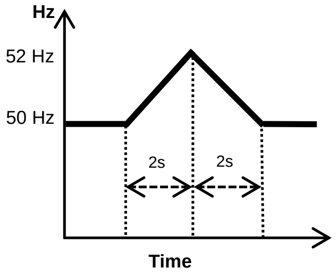
University of Strathclyde Glasgow

Frequency Event 1



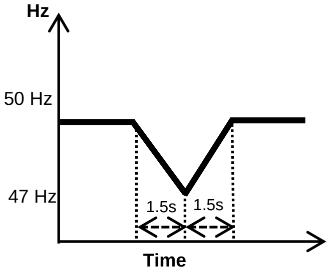
RoCoF= ±2 Hz/s

Frequency Event 2



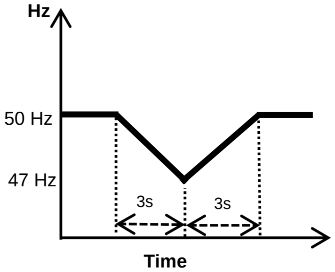
RoCoF= ±1 Hz/s

Frequency Event 3



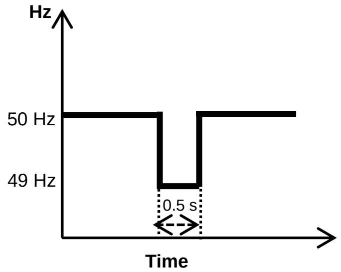
RoCoF= ±2 Hz/s

Frequency Event 4



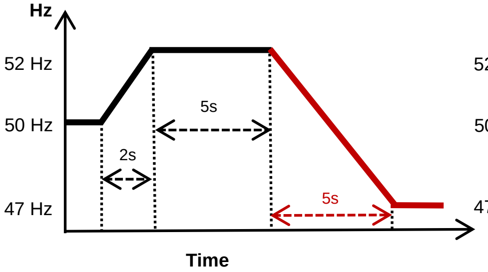
RoCoF= ±1 Hz/s

Frequency Event 5



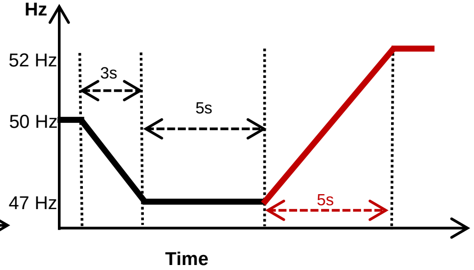
Frequency Step = -1 Hz

Frequency Event 6



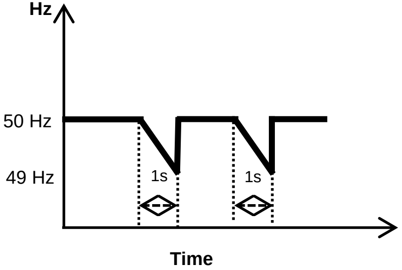
RoCoF= ±1 Hz/s

Frequency Event 7



RoCoF= ±1 Hz/s

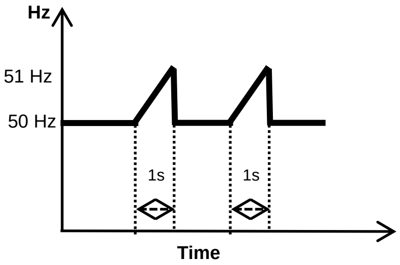
Frequency Event 8*



Consecutive Event

Decrease from 50 – 49 Hz with RoCoF = 1 Hz/s
Step back to 50 Hz

Frequency Event 9*



Consecutive Event

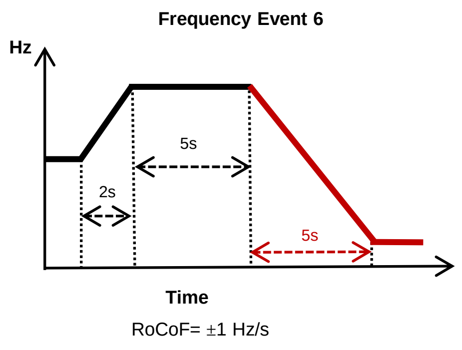
Increase from 50 – 49 Hz with RoCoF = 1 Hz/s
Step back to 50 Hz

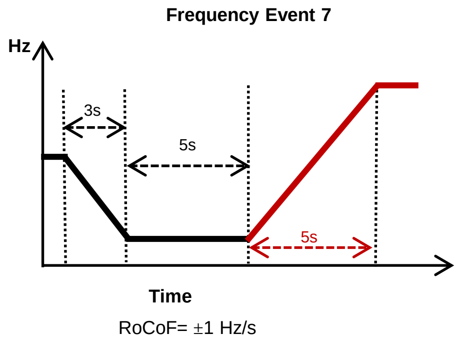
*Event 8 and 9:Mid-Term (Y-1) Stability Market, Round 1 2025/2026, Published Dec 2023

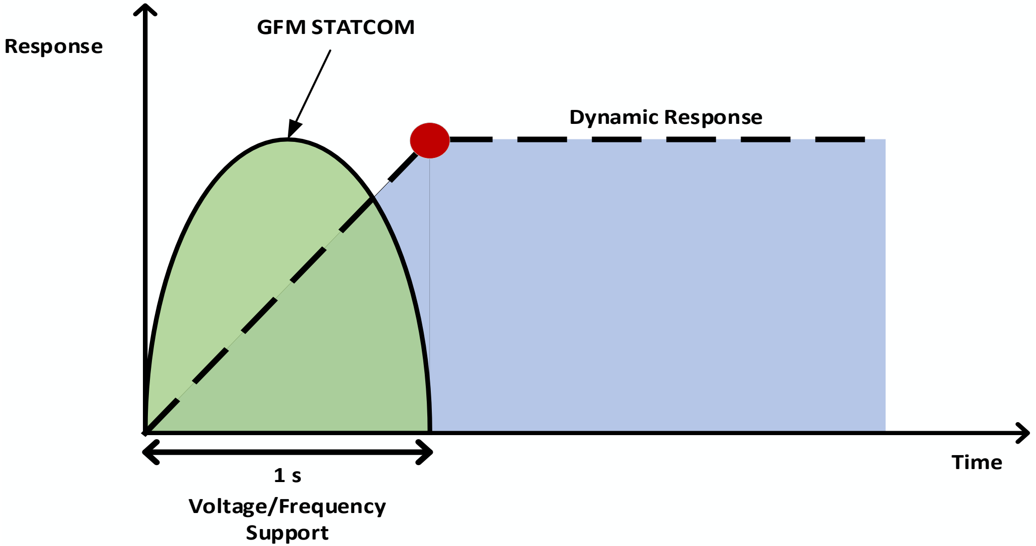
Frequency Events

The National HVDC Centre

University of Strathclyde Glasgow

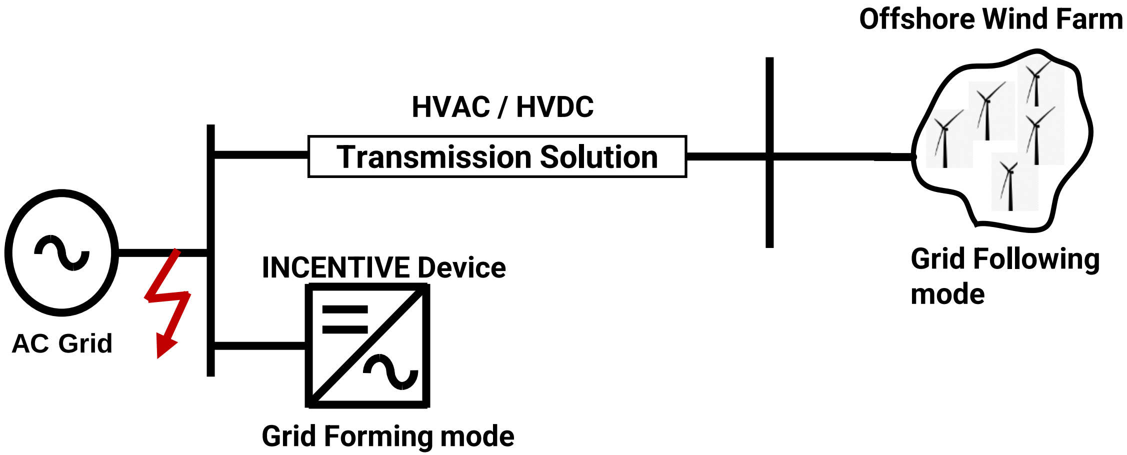






Removing or relaxing the requirement for the 5-second ramp event test can help to minimise unnecessary hardware requirements, particularly for Grid-Forming (GFM) STATCOM.

Fault and Angle Events



Fault events

1. A solid 1-phase-to-earth fault at the Grid Entry Point that is cleared after 140ms.
2. A solid 2-phase-to-earth fault at the Grid Entry Point that is cleared after 140ms.
3. A solid 3-phase-to-earth fault at the Grid Entry Point that is cleared after 140ms.
4. A solid phase-to-phase fault at the Grid Entry Point that is cleared after 140ms.
5. Simulate a 3-phase-to-earth fault at the Grid Entry Point that results in a 30% retained voltage and is cleared after 140ms.
6. Simulate a 3-phase-to-earth fault at the Grid Entry Point that results in a 60% retained voltage and is cleared after 140ms.
7. Simulate a 3-phase-to-earth fault at the Grid Entry Point that results in a 90% retained voltage and is cleared after 140ms.

Angle events

1. 5 degrees jump at the Grid Entry Point lasting for 0.5s.
2. 60 degrees jump at the Grid Entry Point lasting for 0.5s.

Small-signal Frequency Scan
Network Frequency Perturbations Scan

The National HVDC Centre

University of Strathclyde Glasgow

- Used to characterise a device's response to small-signal system frequency deviations
- Apply system frequency perturbations $f = f_0 + \Delta f \cos(2\pi f_{NFP_{mod}})$ where $0.02 \text{ Hz} < f_{NFP_{mod}} < 20 \text{ Hz}$
- Measure resultant active power response
- For each perturbation utilise FFTs to calculate the ratio at independent frequency components
- Inertia and damping can be estimated using a curve fitting method

$$\Delta P(f_{NFP_{mod}}) = \left| \frac{-2H\omega_g i \Delta\omega(f_{NFP_{mod}})}{\left(-\frac{2H\omega_g}{kx}\left(\Delta\omega(f_{NFP_{mod}})\right)^2 + \frac{D_d\omega_g i}{Kx}\Delta\omega(f_{NFP_{mod}}) + \omega_g^2\right)} \right|$$

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Impedance Frequency Scanning Tool

- Frequency scanning tool developed by the HVDC Centre in PSCAD
- Used to calculate 2x2 MIMO modified sequence domain impedance
- DQ calculation is also possible
- Injects voltage perturbations across the frequency range
- Both positive and negative injections are applied
- Measurement of current response from devices
- Components extracted at each frequency using FFTs

Webinar Recording:
HVDC Centre Small Signal Analysis Webinar, the record can be found:
https://www.hvdccentre.com/films-list/small-signal-analysis-studies-webinar/

Conclusion

- WP3 has completed testing the INCENTIVE Solution, including standalone device models, and device models connected to an offshore windfarm.
  - 4 GFM devices were provided the advisory panel – 2 GFM STATCOM with Energy storage system and 2 GFM BESS
  - Some GFM device models were being tested by third parties for the first time.
  - 3 offshore wind farms were modelled with data inputs from project champions
- Two test reports have been produced with key findings:
  - INCENTIVE STATCOM and INCENTIVE BESS provide stability support to the system
  - From grid code compliance testing, identified several potential changes to stability market requirements that could reduce the burden on developers and OEMs without affecting the provision of stability
  - From small-signal scan analysis, there is evidence showing that grid-forming devices improve system strength at weak connection points, enhancing wind farm stability. However, this needs further examination.
- Hosted one webinar[1] and submitted one academic paper abstract to IET ACDC 2025 (abstract accepted)
- Participating in the GB Grid Forming Expert Group to share our findings from INCENTIVE, thus making those involved aware of the hardware requirements that need further discussion.

[1] INCENTIVE Webinar – A Pathway to testing Grid Forming Device, the record can be found: https://www.hvdccentre.com/films-list/incentive-sif-project-a-pathway-to-testing-grid-forming-devices-webinar-5th-september-2024/

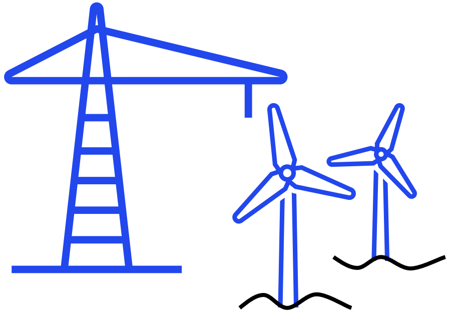
INCENTIVE BETA

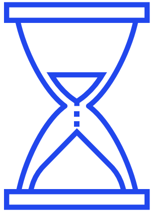
Conclusions and Next Steps

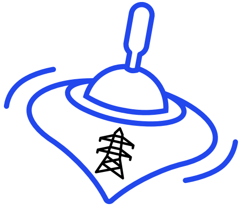
Conclusions

CARBON TRUST

The UK's 60GW-by-2030 offshore wind target means lots of **new-build assets** (generation, storage and transmission) are under development.







If the huge pipeline of new-build assets are built without the capability to provide stability, this opportunity will be lost. The assets being built today will be in operation until ~2050-2070. We are working in **a closing window of opportunity** to "build better".

Follow on Offshore Wind Accelerator Project

Leverage German TSO progress

Learn from German TSOs who will be installing E-STATCOMs in 2025 and, as such, are ahead of the OSW industry

- Methods for E-STATCOM specification and location selection
- Technical test results

Share with German TSOs

- Share INCENTIVE testing results, CBA results, and development guidance with German TSOs

Inertia provision from complimentary resources

Determine if stability asset at onshore substation + OSW windfarm" can provide **more inertia response** than standalone stability assets elsewhere on the system

- If the INCENTIVE solution provides true "inertia" for short time before OSW windfarm takes over with dynamic "fast frequency response"
- This could greatly **decrease the cost of providing inertia**

Strengthening weak grid connections for OSW

System strength provision

- Examine how GFM STATCOMs and E-STATCOMs can strengthen the grid connection of OSW windfarms vs using (more expensive) synchronous condensers
- This question was discussed but not examined in previous phases
- This can **increase power exports** (and therefore revenues) at **lower costs** than using a synchronous condenser

Produce a **development and design guideline for OSW developers**

Thank you for listening