

INSIGHT: 'End of Phase'

22nd June 2023

INSIGHT - Innovative Network Status Intelligence Gathered by
Holistic use of Telemetry and Simulation



nationalgridESO



Scottish & Southern
Electricity Networks

"This project is funded by network users and consumers under the Strategic Innovation Fund, an Ofgem programme managed in partnership with UKRI."

TRANSMISSION

Contents

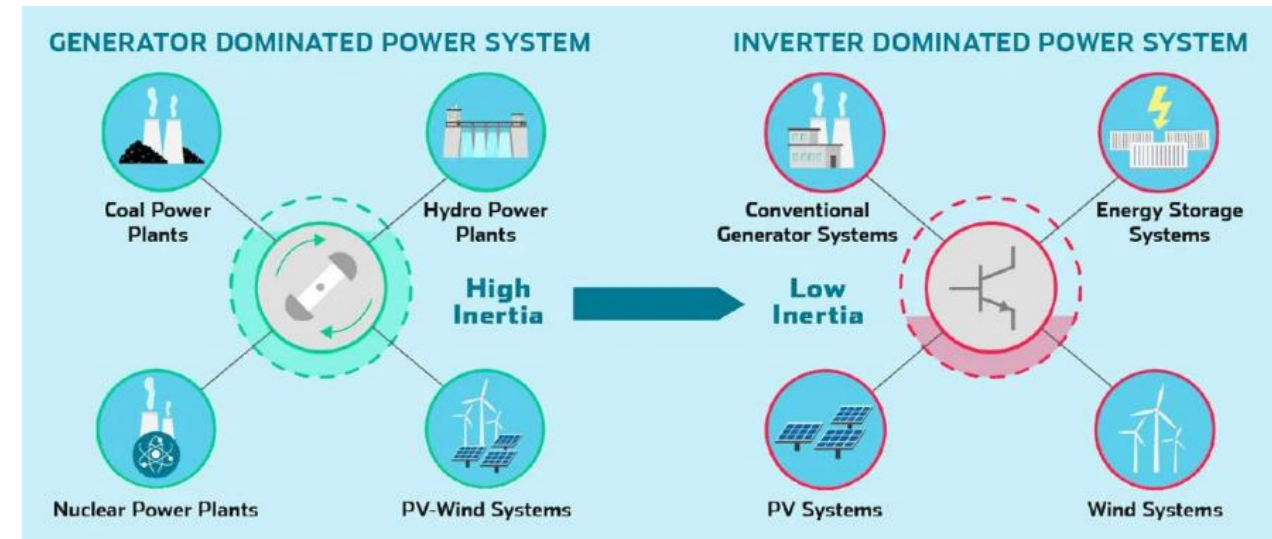
- Project Outputs and Lessons Learnt
- Final update on the project plan
- A summary of each work package
- Barriers, risks, issues that you identified and overcame
- Project specific conditions from project direction
- Comms and engagement plans going forward
- Plans for Alpha

The Problem

The **Net Zero** energy system transition is causing new types of oscillations on the electricity transmission network

Why?

- The UK grid is a complex dynamic system made up of numerous different elements that must be able to operate together in a stable way.
- Historically, dynamic behaviour was dominated by high-inertia turbine generators, but new technologies are needed for renewable energy sources.
- Renewable energy sources such as wind and solar are inverter-based, unlike traditional coal and gas-fired power stations.
- These new technologies exhibit very different dynamic behaviour and can interact with one another in ways that are difficult to predict and understand.
- New approaches are needed to tackle these challenges.



[Wind turbine inertia - supporting the grid with active power \(skeletontech.com\)](https://www.skeletontech.com/)

Key Project Outputs

- **Enhanced understanding of system oscillations and monitoring:**
 - Frequency range
 - Global events
 - Modelling requirements
 - Views of a range of Stakeholders
 - Gaps in current technologies
- **Milestones:**
 - Achieved according to the agreed plan
- **Cost Benefit Analysis:**
 - Initial calculations demonstrate an annual saving of ~£29M due to improvements in system operability
- **Plan for the Alpha Phase**

Lessons Learnt

- Technical solutions are available but are limited mainly to post-oscillation detection and they cannot pick up the entire frequency range of the disturbances.
- Modelling of oscillations in a simulated environment is essential to understand measurement techniques and the response of potential technology solutions.
- Stakeholder engagement has clearly shown there is a definite need for the INSIGHT technology

Project Plan - Update

INSIGHT Gantt Chart

Start of Discovery

WP0 - Project management

- 0.1 Maintain and track the project schedule, project actions, and project deliverables and expenditure forecast
- 0.2 Monitor and manage the risk register
- 0.3 Begin planning the Alpha phase and secure internal agreement to proceed
- 0.4 Prepare for Show and Tell webinars
- 0.5 Prepare conclusion document for monitoring officer

WP1 - Literature review

- 1.1 A review of the fundamentals of system oscillation
- 1.2 A review of existing and emerging techniques for analysing oscillation events
- 1.3 A survey of internationally observed oscillation events, and the learnings from the events
- 1.4 A survey of technical activities in professional organisation in the area of system oscillation
- 1.5 Produce technical literature review report

WP2 - Learning from experience

- 2.1 Conduct a review of previous INSIGHT related system oscillations and gather data from these events
- 2.2 Engage with National Grid ESO to incorporate experience and knowledge from system operator perspective.
- 2.3 Create a data repository and organise the data from previous system events
- 2.4 Prepare a summary report of findings and recommendations

WP3 - Modelling and simulation requirements

- 3.1 Investigation of the scale, level of details and methods for appropriate modelling of oscillation events (based on learnings from WP1 and 2)
- 3.2 Survey of available device (CIG, SG STATCOM) models and assess their suitability in simulating different oscillation mechanisms
- 3.3 Investigate methods/practices for representing proprietary converter models
- 3.4 Develop a list of key data required for modelling
- 3.5 Develop the Alpha phase modelling plan

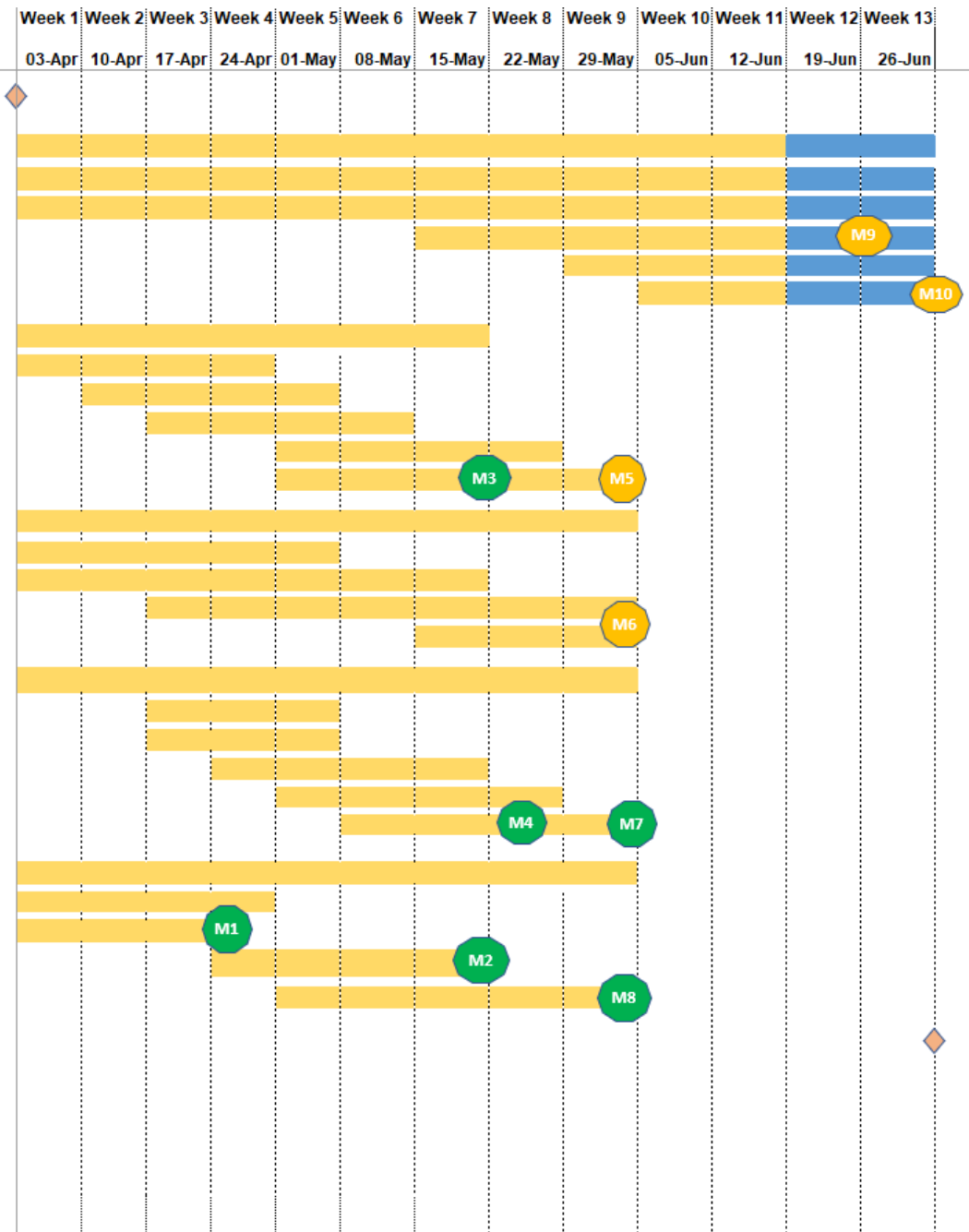
WP4 - Stakeholder engagement

- 4.1 Identification of key internal and external stakeholders
- 4.2 Preparation and issuing of questionnaire to a variety of external stakeholders
- 4.3 Stakeholder workshops
- 4.4 Prepare a summary of the outputs of the stakeholder engagement questionnaire and workshops

End of Discovery

Key: Responsible organisation

- SSE Transmission
- University of Strathclyde
- NGESO
- Progress



WP1: Literature Review

Led by University of Strathclyde

Goals

- Understand system oscillation mechanisms and how they manifest in real world power systems
- Determine suitability of existing measurement techniques
- Review of system oscillation solutions

Delivery

- Survey of real-world inverter-based resource (IBR) oscillation events
- Literature review of techniques for monitoring and analysing oscillations
- Literature review of professional organisation activities


Outputs


- IBR driven oscillation event list
- Literature review summary report

WP1 Literature Review

Comparison: Electro-mechanical (EMO) and IBR driven oscillations

	EMO	IBR Driven Oscillations
Mechanisms	<ul style="list-style-type: none">Mainly driven by Synchronous Generation (SG) dynamics (Swing Equation).Potential interactions among (groups of) SGsControl interactions possibleDamping properties are important	<ul style="list-style-type: none">Interaction between DFIG and series compensated networkControl interaction with weak network or other IBR controlsHarmonic Resonance (power electronic switching)
Frequency Ranges	<ul style="list-style-type: none">Low frequency oscillations (LFO)~0.1 – ~2Hz	<ul style="list-style-type: none">$0 < f_{SSO} < \sim 2f_n$ Sub/Super Synchronous Oscillations (SSO) for control interactionsUp to switching frequency for Harmonic Resonance
Modelling Requirements	<ul style="list-style-type: none">N (usually 6th) order SG model – minimum requirement is the swing equationStandard exciter, governor, PSS modelsRMS domain suitable	<ul style="list-style-type: none">Representation of converter controllerEMT modelling required
Measurement Requirements	<ul style="list-style-type: none">PMUs demonstrated accurate monitoring of real-world events	<ul style="list-style-type: none">PMUs subject to aliasingInstantaneous waveform measurements have shown multiple (sideband + fundamental) oscillation components in real-world events

- 
- Underlying mechanisms well understood
 - Frequency ranges predictable
 - Modelling, measurement and mitigation fairly mature

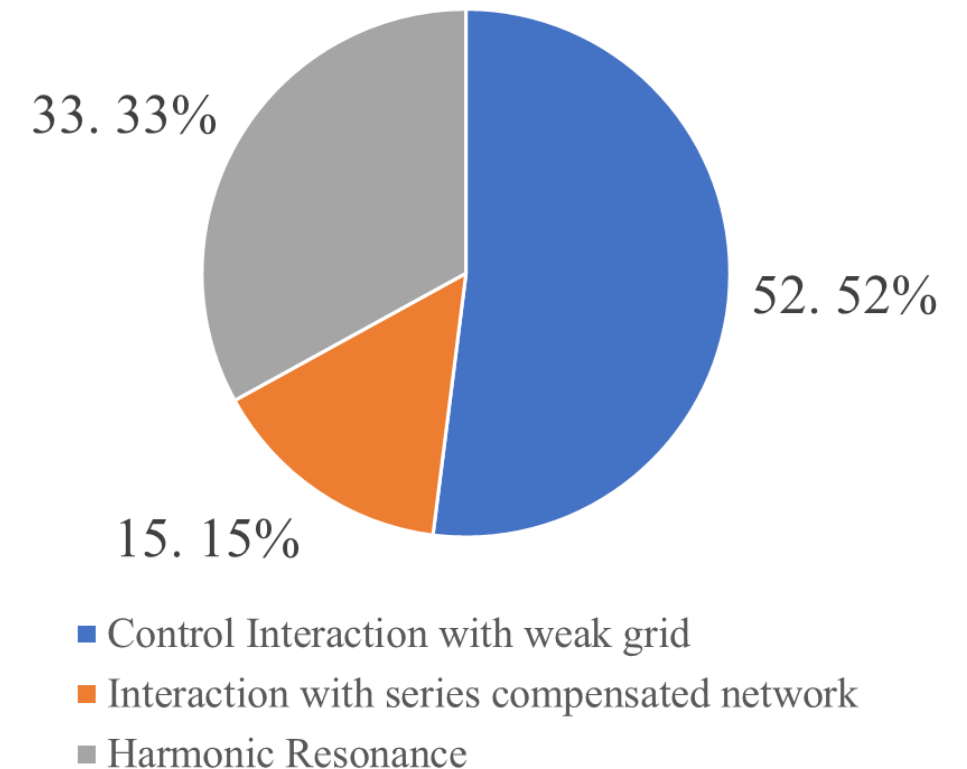
- 
- Influenced by proprietary controller design
 - Wide possible frequency ranges
 - Modelling, measurement and mitigation still under investigation

WP 1 Literature Review

Review of real-world IBR driven oscillation events

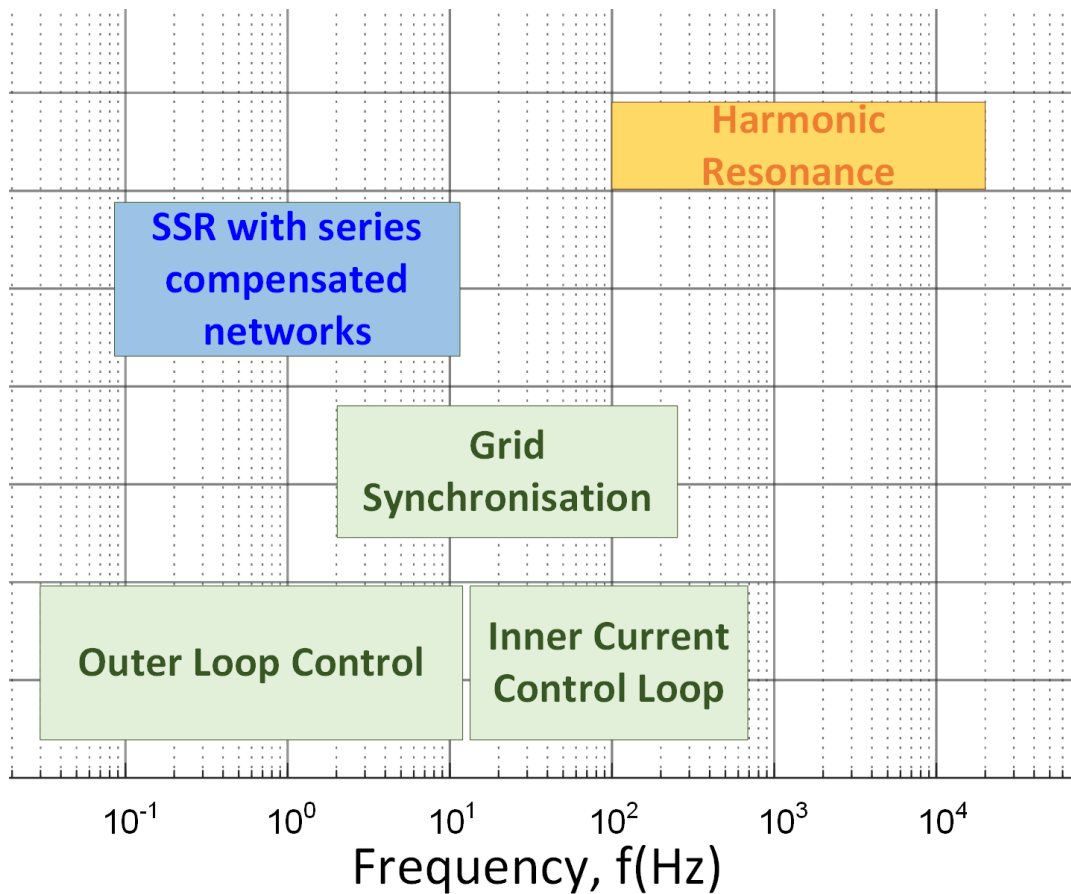
- 28 events (with some events having multiple occurrences) identified between 2007 to 2021
- Events observed in Australia, North American, UK, Europe, China.
- Events occur in areas of the network with high penetration of IBRs
 - Texas Panhandle (61% penetration of wind during an event)
 - Western Murray Zone, Australia (defined as “Low system strength zone” by AEMO)

Distribution of IBR driven oscillation mechanisms of real-world events



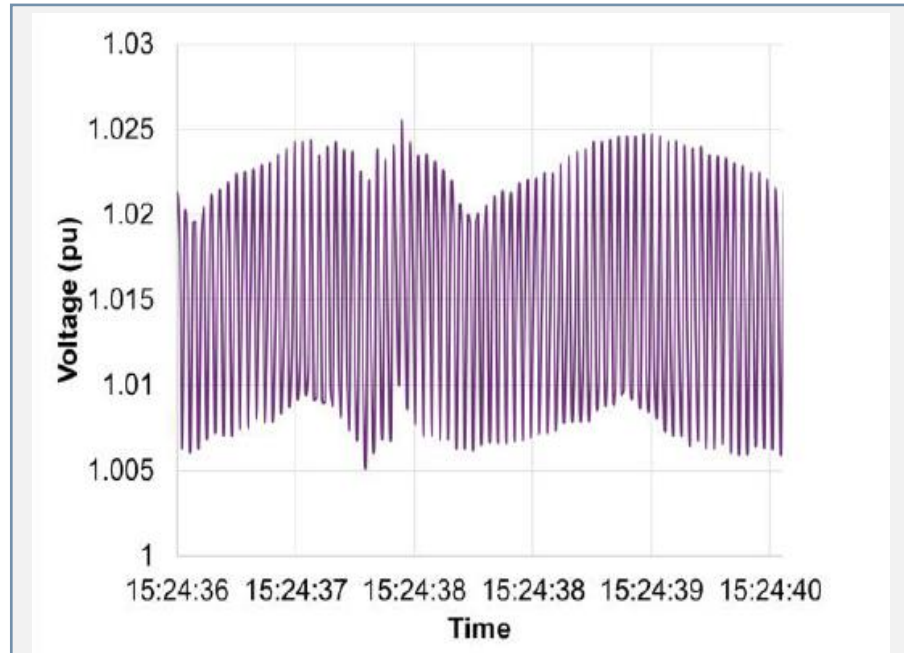
WP 1 Literature Review

Learning from past events

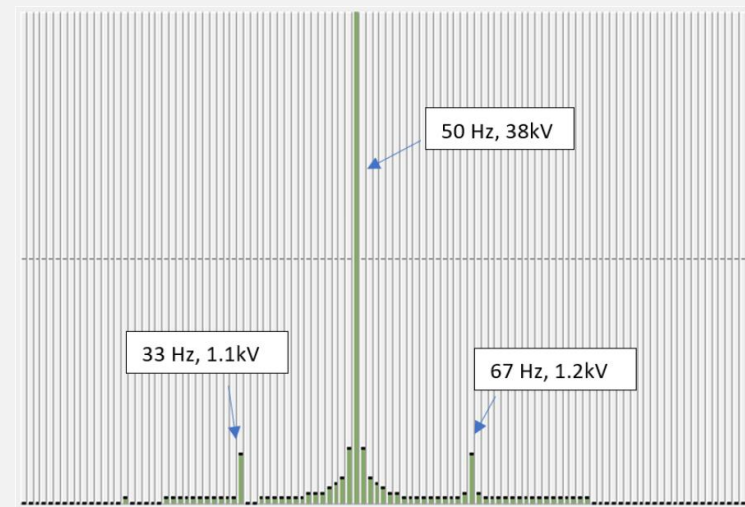


← f_n → $\sim f_{PWM}$
Sub-synchronous Super-synchronous

Wide frequency range: challenge for existing monitoring tools (e.g. PMUs)



PMU – ~17-19 Hz oscillation in rms voltage



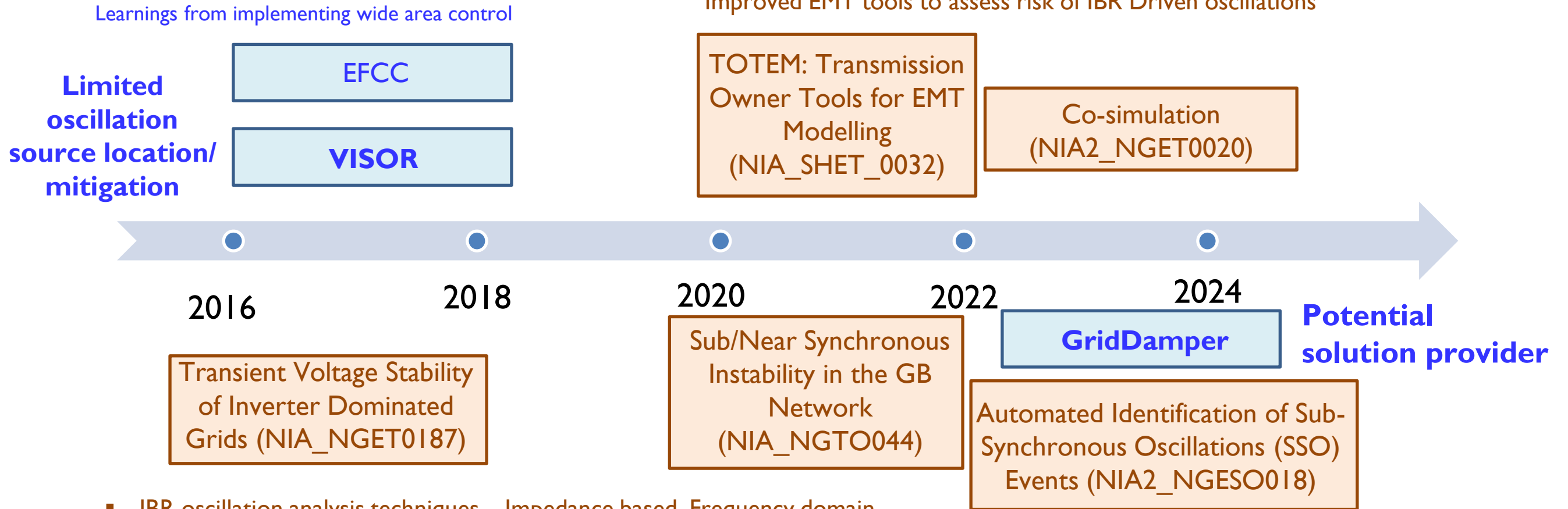
FFT of PoW voltage – 50 +/- ~17 Hz

- PMUs subject to aliasing
- Higher resolution data used in post event analysis

- **Real-time, automatic mitigation actions?**
 - Better utilisation of high resolution measurements

WP 1 Literature Review

Related Projects



- IBR oscillation analysis techniques – Impedance based, Frequency domain
- Identify network locations/ conditions which may lead to IBR oscillations
- Facilitate **system planning approach** to mitigate oscillations

- Potential for online implementation of data driven SSO event detection.
- Potential for data driven online IBR stability analysis?



INSIGHT

- Improved IBR driven oscillation monitoring compared to VISOR
- Implement **real time** IBR oscillation mitigation/ stability prediction? (beyond what VISOR is currently capable of)

WP1 Literature Review

Key outcomes

Gaps with business-as-usual approaches

- Improved monitoring tools needed to supplement PMUs
- System planning approach difficult to achieve due to complexity of IBR control interaction
- Real-time monitoring/control solutions available not readily suitable for IBR driven oscillations
 - **Post-event analysis** typically done for understanding IBR driven oscillations
 - **Offline EMT modelling** used to investigate past events/assess risk of future events
 - Optimal (real-time) monitoring and control capability are not commonly available

WP2: Learning from Experience

Led by SSEN Transmission

- Goals

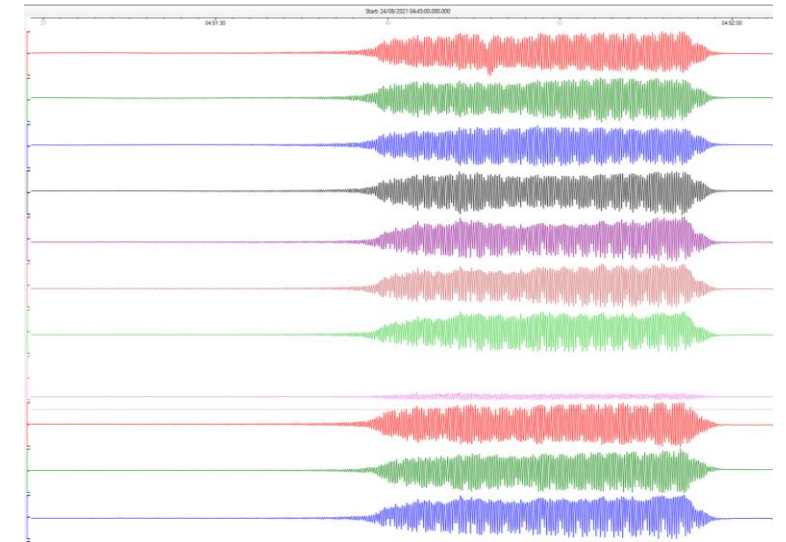
- Review data from real system oscillation events
- Create a data repository for the project
- Reflect real-life experience

- Delivery

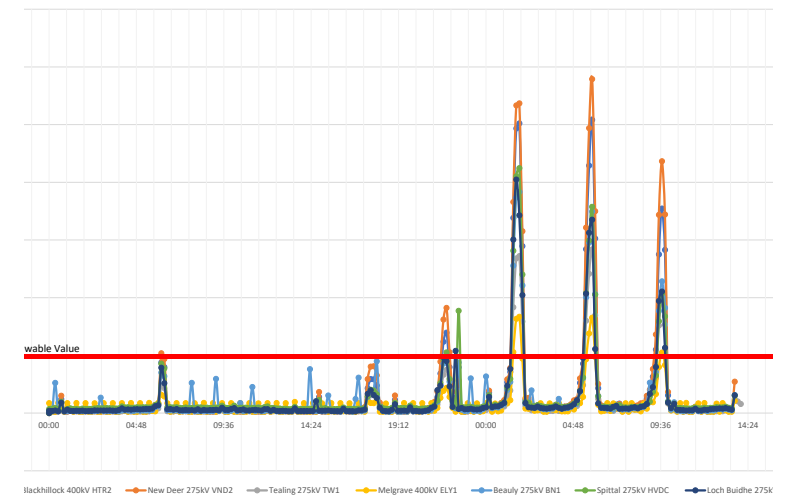
- Expert knowledge and experience fed into literature review and stakeholder engagement
- Measurement data from past events collated and shared
- Workshop discussions informing future work

- Outputs

- Data repository (1.4 GB)



Flicker Values – Excel Graph



WP3: Modelling Requirements

Led by University of Strathclyde

Goals

- Determine appropriate modelling techniques for IBR driven oscillations
- Identify modelling/simulation requirements of IBR driven oscillations
- Develop an Alpha phase modelling plan

Delivery

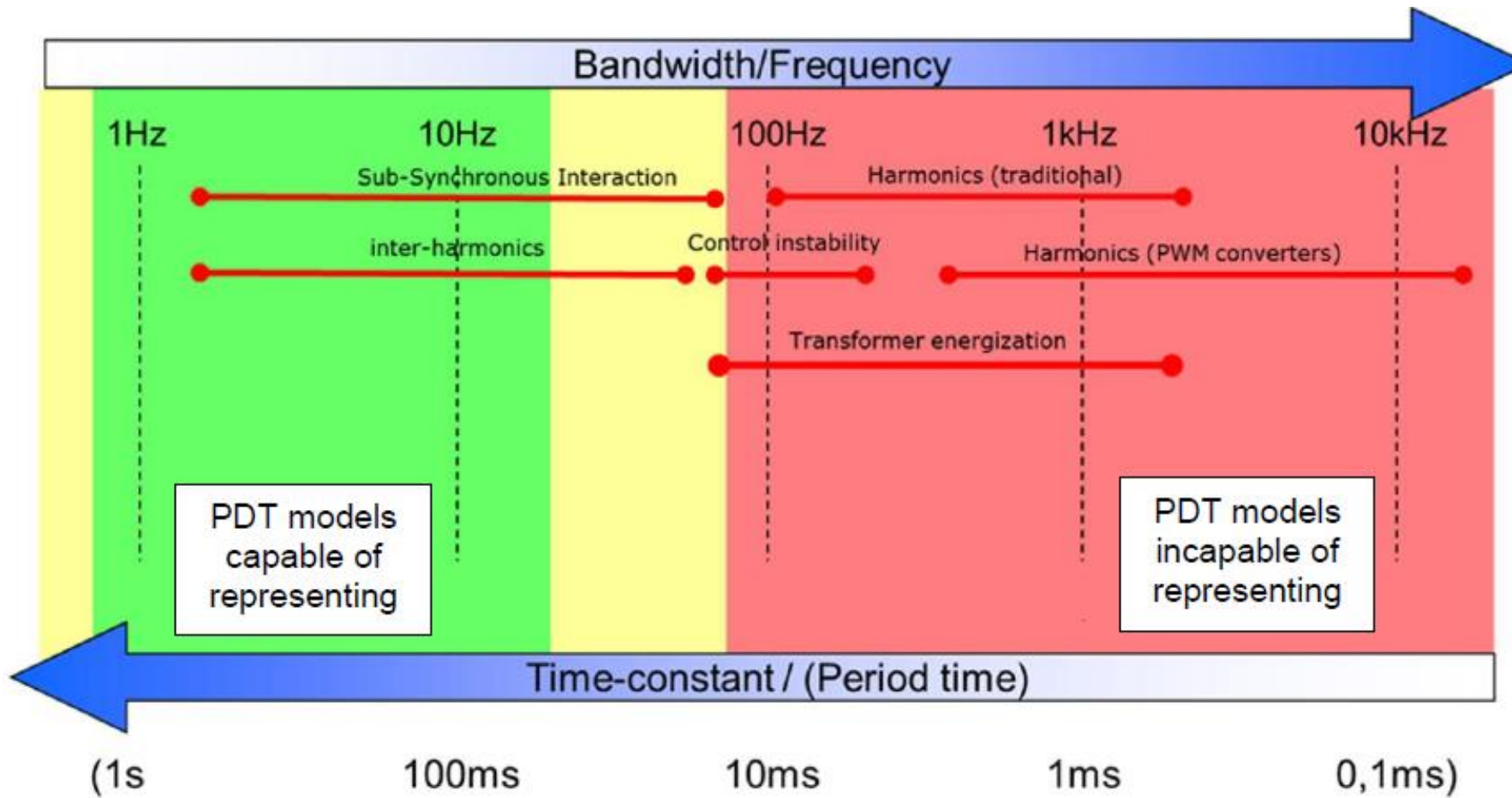
- Review of Electromagnetic Transient vs Phasor Domain modelling
- Review of EMT modelling of real-world IBR driven oscillation events
- Review of proposed benchmark IBR driven oscillation models

Outputs

- High level Alpha phase modelling plan
- Summary Report

WP3 Modelling Requirements

Phasor Domain (PD) vs Electromagnetic Transient Model (EMT)



EMT models represent dynamics associated with :

- PLL
- Fast acting control loops
- Non-linear dynamics
- Harmonics

- Phasor domain models incorporate simplified modelling of IBR control systems
- Phasor domain simulation may fail to predict/ accurately represent IBR control interactions

WP3 Modelling Requirements

Adequate representation of IBR components for studies of interest [1]

	Transient stability	Sub-synchronous interactions	High-frequency transient	Harmonics [#]
Dynamic braking resistor / chopper	PDT, EMT	EMT	-	EMT
DC link	PDT, EMT	EMT	EMT*	EMT
IGBT switches and PWM switching	-	-	EMT	EMT
Unit transformer ^B	PDT, EMT	EMT	EMT	EMT
Internal filters	PDT, EMT	EMT	EMT	EMT
Inner loop converter control	EMT	EMT	EMT*	EMT
Outer loop converter control	PDT, EMT	EMT	EMT*	EMT
Phase locked loop ^C	EMT	EMT	EMT*	EMT
Frequency control ^D	PDT, EMT	EMT	-	EMT
High voltage ride-through	PDT, EMT	EMT	EMT	-
Low voltage ride-through	PDT, EMT	EMT	-	-
Multiple fault ride-through limitations	PDT, EMT	EMT	-	-
Protection	PDT, EMT	EMT	EMT	-

Harmonic Resonance

- Representation of power electronic switching

Control Interactions

- EMT representation of IBR control loops
- Simplified representation of power electronic switching
- IBR transient response also an important consideration

WP3 Modelling Requirements

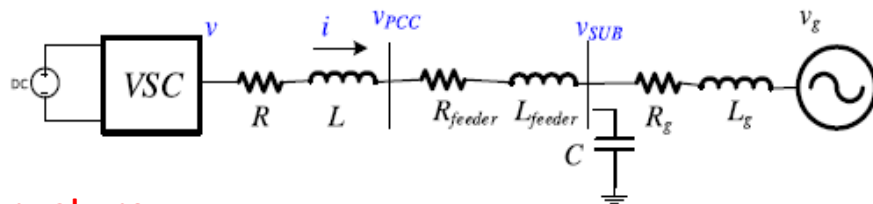
EMT Models of IBR: Generic vs Detailed

Generic Models

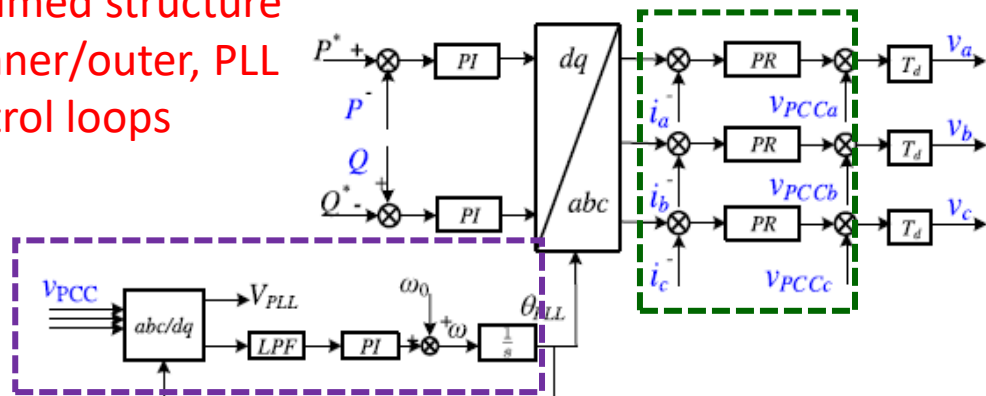
- Represent a control strategy or selected control loops (as opposed to specific control structure)
- Not tailored for a particular IBR design / site settings
- Possible to parametrize model to get a reasonable match to actual device response

Detailed Model

- OEM specific models with actual control logics incorporated
- Can also be site-specific
 - Site specific inverter settings
 - Important in understanding / assessing real world control interaction risks
- OEM can provide “blackbox” models to protect IP of proprietary controller designs
- Challenges
 - Model complexity
 - Cross-platform conversion / conformity
 - Validating OEM blackbox models

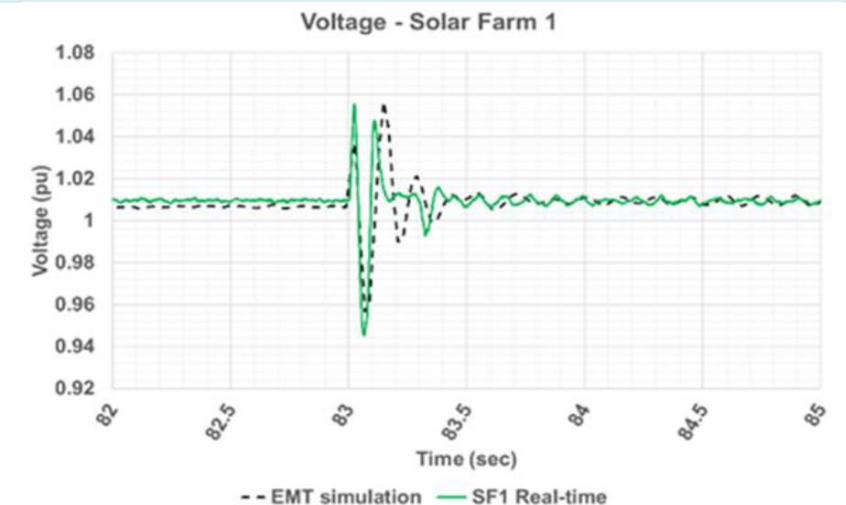


Assumed structure of inner/outer, PLL control loops



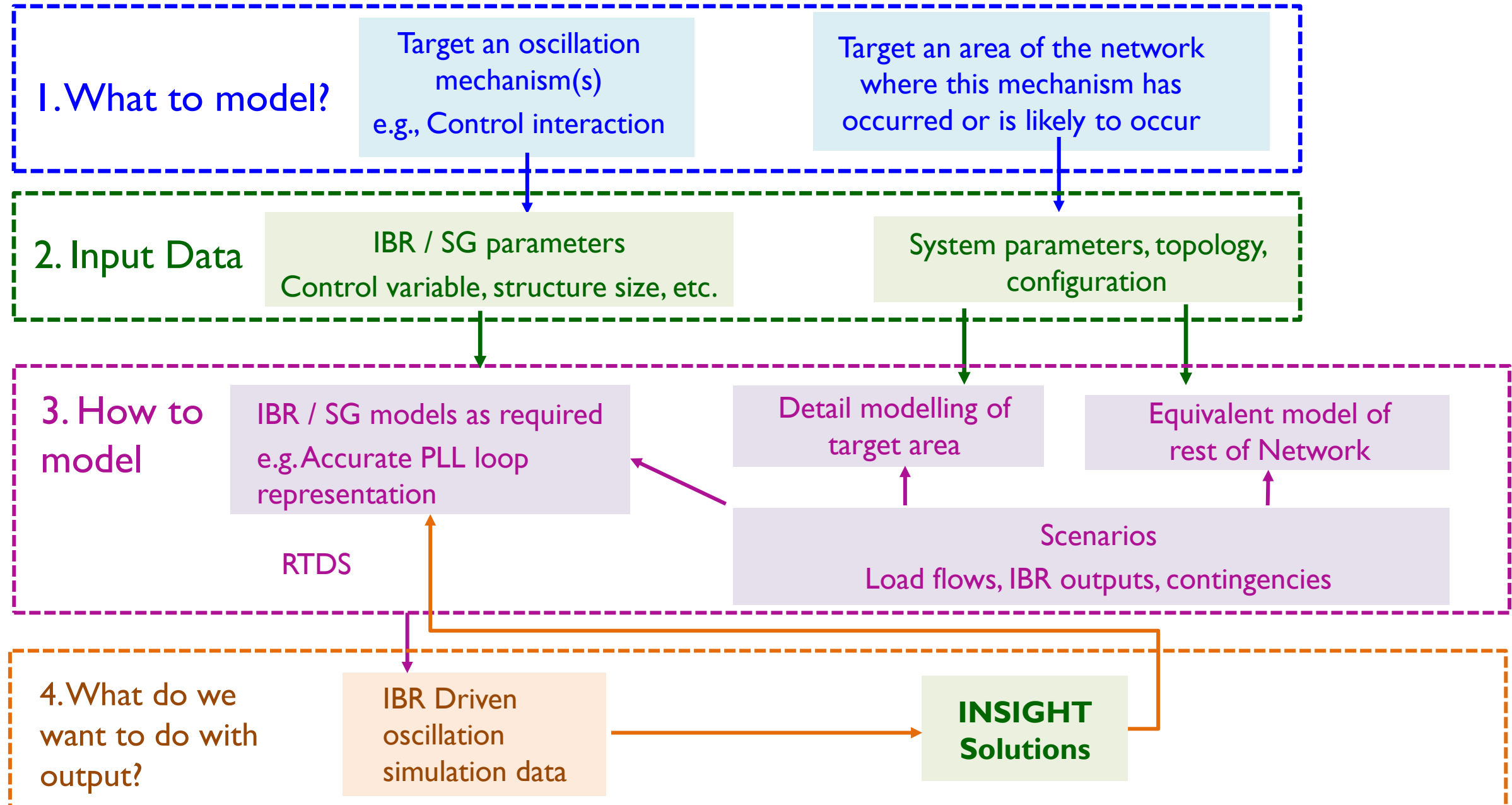
EMT model with updated site-specific inverter settings

- Accurate representation of real-world event (Australia)



WP3 Modelling Requirements

Alpha Phase Modelling Consideration



WP4: Stakeholder Engagement

Led by The National HVDC Centre

• Goals

- Better understand the complexities of real-time oscillation mitigation and the requirements for new solutions
- Gather input from external stakeholders through questionnaire
- Workshop with subject matter experts

• Delivery

- Questionnaire devised in collaboration with project partners
- Stakeholders identified and contacted
- Questionnaire responses collated and reviewed
- Expert workshop organised

• Outputs

- Stakeholder Engagement Report

<https://forms.office.com/e/6XLMnYFjdU>



INSIGHT Stakeholder Engagement Questionnaire

INSIGHT Innovation Network Status Intelligence Gathered by Public use of telemetry and simulation

Recent developments, typically seen as the result of steady growth, have led to the growth of the network. These developments are influenced by the increasing demand for synchronous generators (SG), and typically occur in the low frequency range (0.1-1 Hz). With the rapid increase of renewable based generation (RBG), e.g. wind, solar and HVDC, new types of power system oscillations have been observed in real world power systems. These oscillations can occur in a wide frequency range, and are typically caused by RBG controller behaviour in weak system conditions or undesirable interaction among various RBG control actions. This can be driven by different factors e.g. system strength, converter design, etc.

INSIGHT aims to address the challenges from conventional and new forms of power system oscillations by gathering a real time view and control actions that can monitor and mitigate different types of oscillation events on the network. INSIGHT will combine expertise and learning from past events with new modelling and analysis to build confidence in the nature of different oscillations and investigate the potential solutions for preventing such conditions. Some of the key objectives for identifying, monitoring, and responding to oscillation events will be reviewed, evaluated and tested. The project will also inform codes and standards relating to new oscillations, and generally lead to a new bank of events triggered at control actions for real-time damping.

Project Partners
Scottish and Southern Electricity Networks, The National HVDC Centre, University of Strathclyde, National Grid ESO.

The project is funded by network users and consumers under the Strategic Investment Fund (SIF) in 10-year programme investment or performance and for Research and Innovation, from 2018 to 2023.

Project Discovery Phase
<https://www.youtube.com/watch?v=GLSD4w7Hr0s>

The project will be conducted in three phases:

Discovery Phase (April - June 2023) will develop a comprehensive understanding of the problem, and the current best practice from across the world. It will document the methods that could be used to mitigate network oscillation patterns, reviewing their suitability, and developing a list of the key datasets that would be required for modelling and testing new solutions. This phase also involves engagement of stakeholders to shape the activities of the later phases.

Analysis Phase (July - September 2023) will create a common framework for the design and evaluation of potential solutions. It is anticipated that solutions will be sent out to manufacturers to present their solutions that can meet the INSIGHT requirements. The solutions proposed by new entrants will be evaluated, with the aid of the real modelling and simulation, to assess their suitability and effectiveness for further tests and trials.

Real-World Testing (October - December 2023) will focus on detailed testing and validation of the technology proposed by manufacturers and document the experience of the solution by the practical operational environment. This phase can also involve Public trials.

Key Dates

Use of data
As a respondent to this questionnaire, you have rights over your personal data and can request it be erased at the end of the INSIGHT project. Please email insight@scsn.co.uk if this is your wish or you have any queries.

1. Organisation Name:
Enter your answer

2. Respondent Name:
Enter your answer

3. Respondent Role:
Enter your answer

4. Respondent Email:
Enter your answer

5. What term best describes your organisation? If 'Other', please enter a brief description.

Network owner or operator (e.g. TSO, DSO, NTSO)

Developer, owner or operator of other equipment (e.g. wind farms, HVDC transmission)


Supplier of primary equipment (e.g. high-voltage plants, wind turbines, HVDC, FACTS)


Supplier of instrumentation, monitoring, protection or control equipment

Other

Have you got your password? [Sign in](#)

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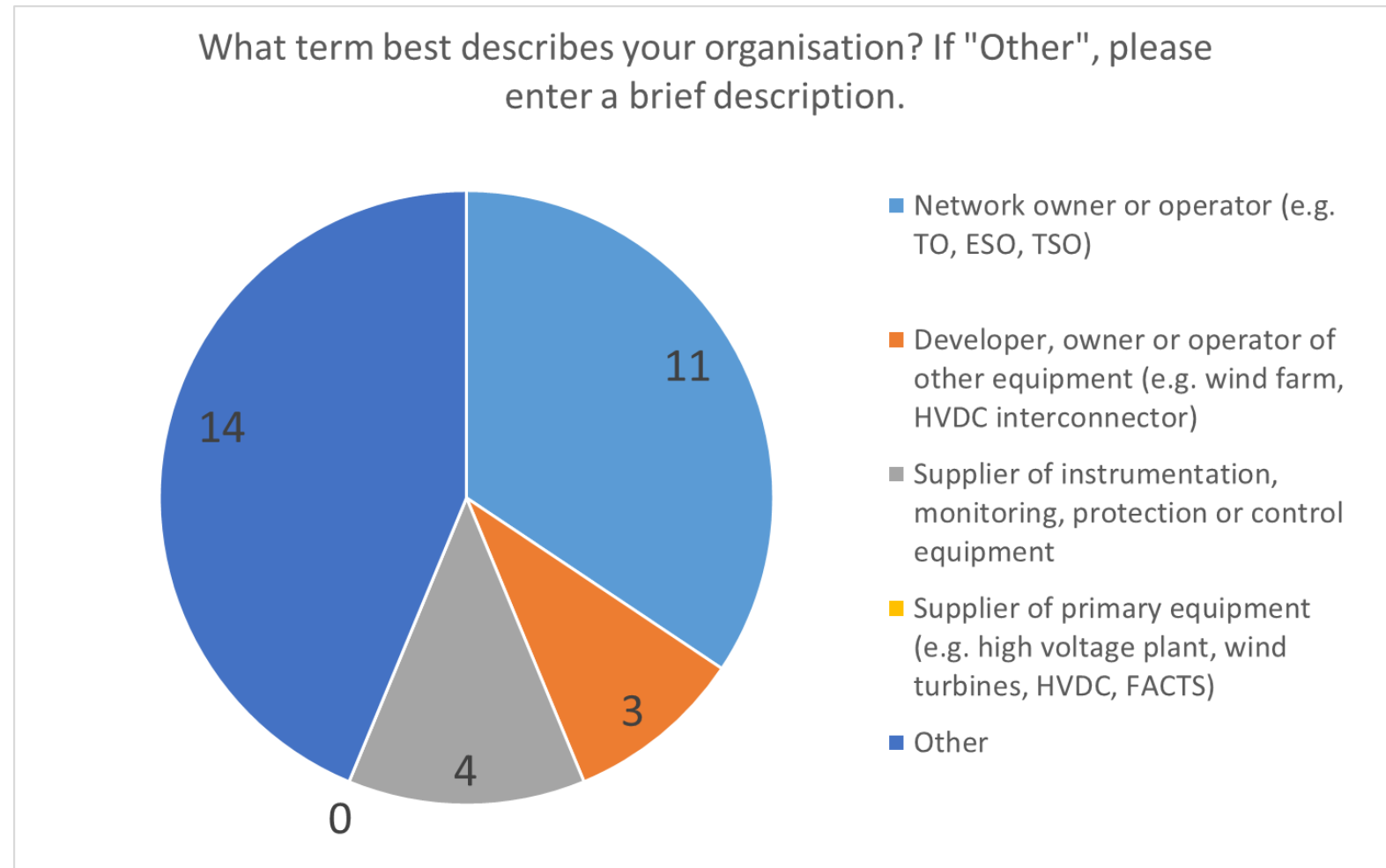
INSIGHT Project Discovery Phase Stakeholder Engagement Report

Document Reference	TR-SSEN-2219-001
Revision	A
Confidentiality	Public
Date of Issue	08/06/2023
Client	SSEN Transmission

Revision Record					
Revision	Date	Author	Reviewer	Approver	Description
A	08/06/2023	Fabian Moore	Colin Foote	Ben Marshall	Initial version for review

Industry Questionnaire

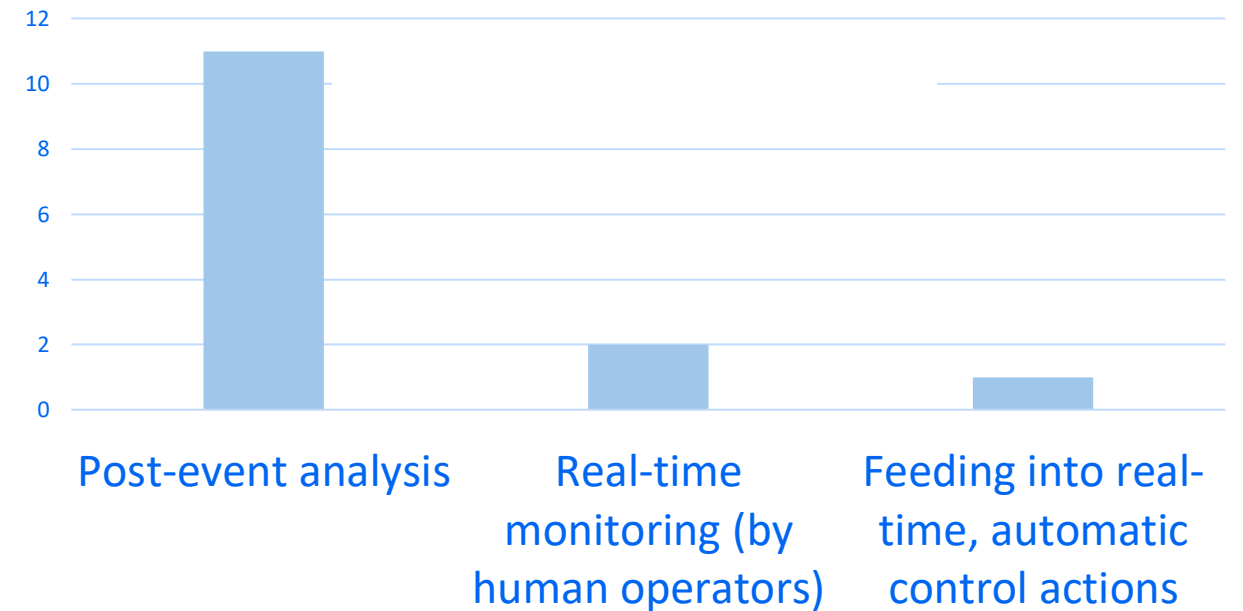
- Industry survey
- Invitations to 55 organisations from across the industry worldwide
- 32 responses
- Including 11 from electricity system owners and operators



User Needs

- Most system operators/owners had some capability to detect and analyse oscillation events
- Almost all were concerned that this capability was not sufficient for future:
 - Increased risk of oscillation events in future (due to IBR events)
 - Existing monitoring systems are reliant on manual analysis of data offline after the event

How is oscillation monitoring being used?
(Please tick all that apply.)

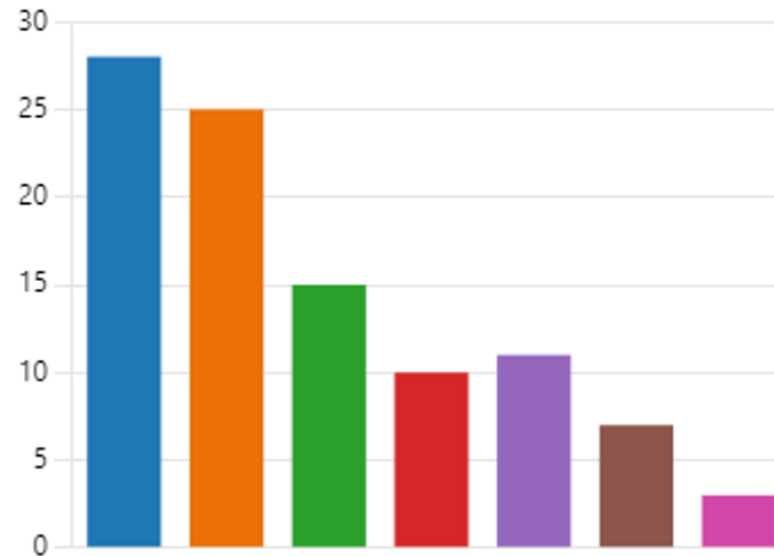


Not automatic: a control action policy for Very Low Frequency Oscillations (VLFOs). When oscillation observed, operators will switch off frequency response at the sources of the oscillation.

Significant Interest in Project

If yes, how would you like to participate? (Please tick all that apply.)

● Receive project updates	28
● Participate in project workshops...	25
● Sharing oscillation event inform...	15
● Sharing information on solution...	10
● Participate in solution developm...	11
● I'm interested in becoming a pr...	7
● Other	3



- High level of interest in receiving project updates and participating in workshops
- Significant interest in greater level of involvement

Project risks, issues overcome and lessons learned

● Fully mitigated (negligible impact) ● Partially mitigated (small impact) ● Not properly mitigated (major impact)

Risks on project management

- Partners fail to finalise collaboration agreement before project kick-off ●
- Not being able to secure suitable researcher for the work ●
- Engineer leading the work not being available or having role changed ●
- Shortage of researcher with sufficient skills and knowledge for the work ●

Risks on technical work

- Limited literature and research work available informing system oscillation issues. ●
- The effort required for assessing modelling requirement is beyond budgeted amount ●
- Access limit to associate documents and papers ●

Risks on stakeholder engagement

- Not being able to identify sufficient stakeholders ●
- Stakeholders not returning to questionnaire on time ●
- Stakeholders not providing high quality feedbacks ●

Risks relating to data confidentiality

- Targeted data not being available or taking too long to access ●
- Restrictions on data sharing/dissemination ●
- Restrictions on data use and reporting ●

Barriers, issues overcome and lessons learned

- Technical objectives generally achieved, and significant interests received from stakeholders
- Short project duration remains a big challenge for execution, e.g. impact of staff and public holiday
- Access to and dissemination of real world data requires further planning and dedicated considerations

Project Specific Conditions

3. PROJECT SPECIFIC CONDITIONS

In accepting funding for the Project, the Funding Party is subject to the following Project-specific condition(s):

Condition 1

¹² The Compulsory Contribution is defined in the SIF Governance Document.
¹³ The SIF Funding Return Mechanism is defined in the SIF Governance Document.

The Office of Gas and Electricity Markets
Commonwealth House, 32 Albion Street, Glasgow, G1 1LH Tel 020 7901 7000
www.ofgem.gov.uk

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Making a positive difference
for energy consumers

The Funding Party must not spend any SIF Funding until contracts are signed with the Project Partners named in Table 1 for the purpose of completing the Project.

Table 1. Project Partners

NATIONAL GRID ELECTRICITY SYSTEM OPERATOR LIMITED
UNIVERSITY OF STRATHCLYDE

Condition 2

The Funding Party must report on the financial contributions made to the Project as set out in its Application. Any financial contributions made over and above that stated in its Application should also be reported and included within the Project costs template.

Condition 3

The Funding Party must participate in all meetings related to the Project that they are invited to by Ofgem, UKRI and BEIS during the Project Phase.

Condition 4

In the Discovery Phase, the Funding Party must engage with and disseminate its findings from the Discovery Phase to stakeholder groups which may form part of the supply chain for future solutions, such as technology vendors for control systems and power electronics asset managers, to help build an understanding of their requirements into the Project as potential key users. The Funding Party must provide to the monitoring officer prior to the end of the Discovery Phase a summary of the stakeholder groups it engaged with during the Discovery Phase.

Condition 1

- Payment received 15/06 from NG ESO

Condition 2

- Financial contributions to be reported in July 2023

Condition 3

- Compliant

Condition 4

[Networks Transmission INSIGHT SIF Discovery Rd2 Project Extranet - Home \(sharepoint.com\)](https://www.sharepoint.com/Networks/Transmission/INSIGHT/SIF/Discovery/Rd2/Project/Extranet-Home)

Comms and Engagement Plan

- Plan is being developed, so only a high-level view is given here
- Propose to engage with a wide group of stakeholders and technology providers to understand what solutions are available and how they could be implemented
- Approach will need to be tailored to the needs of the Beta phase:
 - Initial thoughts are to run a "competition" to assess provider's solutions
 - Is this still the preferred option and what will the competition look like?
 - What information do we need to share with potential competitors?
 - What is the best way to do that? Webinars? Workshops?

Plans for Alpha

- Decision to submit Alpha Application as part of SIF Round 2
- Partners as per Discovery with Technology Providers to be identified during Alpha Phase
- Focus areas:
 - Oscillation events modelling
 - Wider engagement: Stakeholders and Technology Providers
 - GB System Monitoring Roadmap
 - Project Management

[Networks Transmission INSIGHT SIF Discovery Rd2 Project Extranet - Home \(sharepoint.com\)](#)

Project Contact Details:

Jonathan.Powell@sse.com



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