INSIGHT: ‘End of Phase’

22nd June 2023

INSIGHT - Innovative **N**etwork **S**tatus **I**ntelligence **G**athered by **H**olistic use of **T**elemetry and Simulation

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

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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

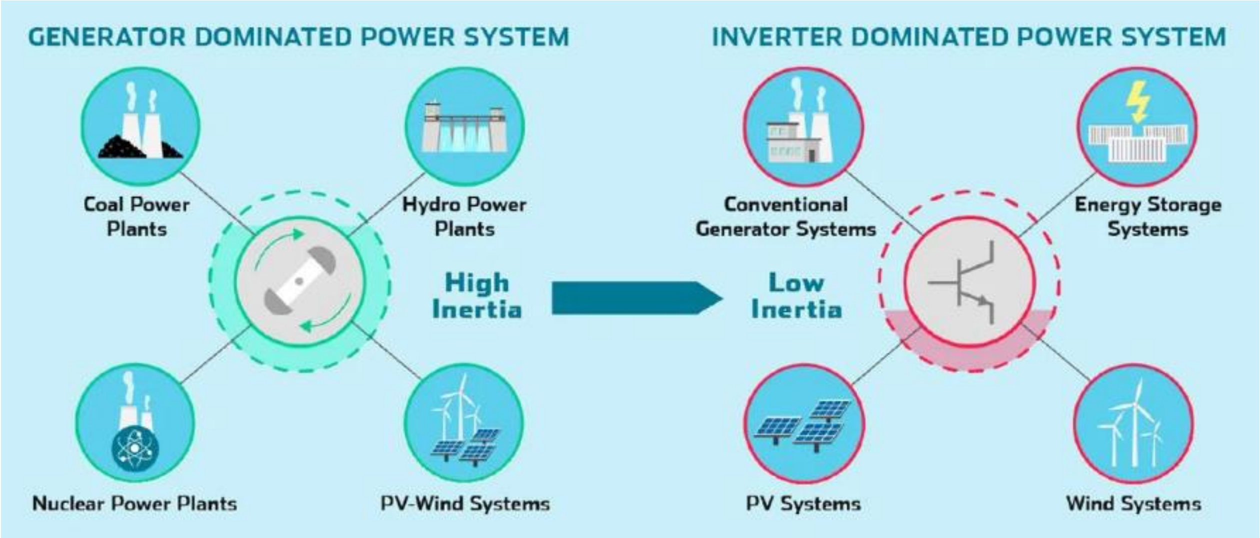
SSEN-T Project Sponsor: David McKay (Director)

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)](skeletontech.com)

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SIF Discovery Project Milestones.xlsx (sharepoint.com)

INSIGHT - All Documents (sharepoint.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**

CBA

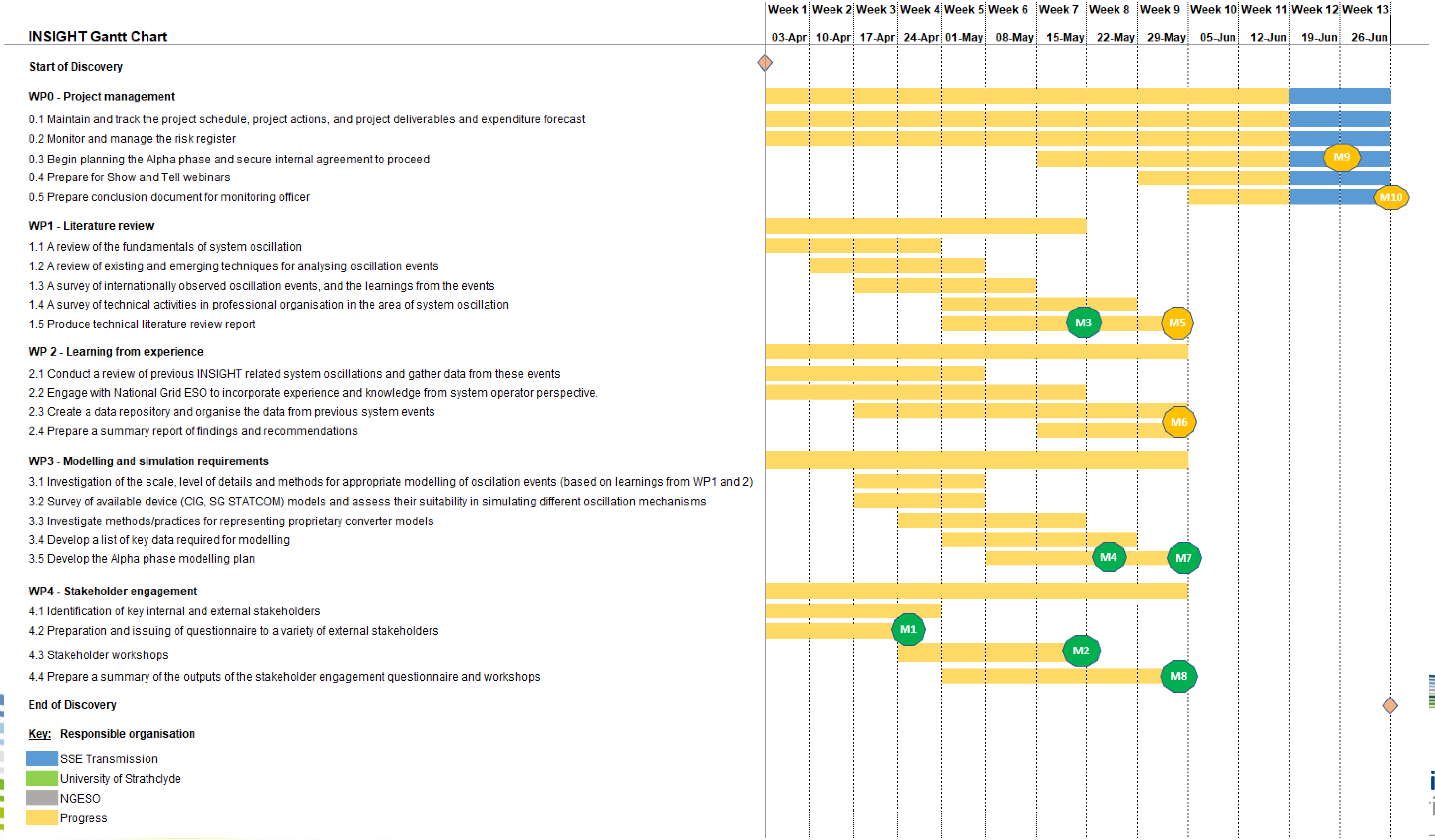
Lessons Learnt

- 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



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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	• Mainly driven by Synchronous Generation (SG) dynamics (Swing Equation). • Potential interactions among (groups of) SGs • Control interactions possible • Damping properties are important	• Interaction between DFIG and series compensated network • Control interaction with weak network or other IBR controls • Harmonic Resonance (power electronic switching)
Frequency Ranges	• Low frequency oscillations (LFO) • ~0.1 – ~2Hz	• $0 < f_{sso} < \sim 2f_n$ Sub/Super Synchronous Oscillations (SSO) for control interactions • Up to switching frequency for Harmonic Resonance
Modelling Requirements	• N (usually 6th) order SG model – minimum requirement is the swing equation • Standard exciter, governor, PSS models • RMS domain suitable	• Representation of converter controller • EMT modelling required
Measurement Requirements	• PMUs demonstrated accurate monitoring of real-world events	• PMUs subject to aliasing • Instantaneous waveform measurements have shown multiple (sideband + fundamental) oscillation components in real-word events

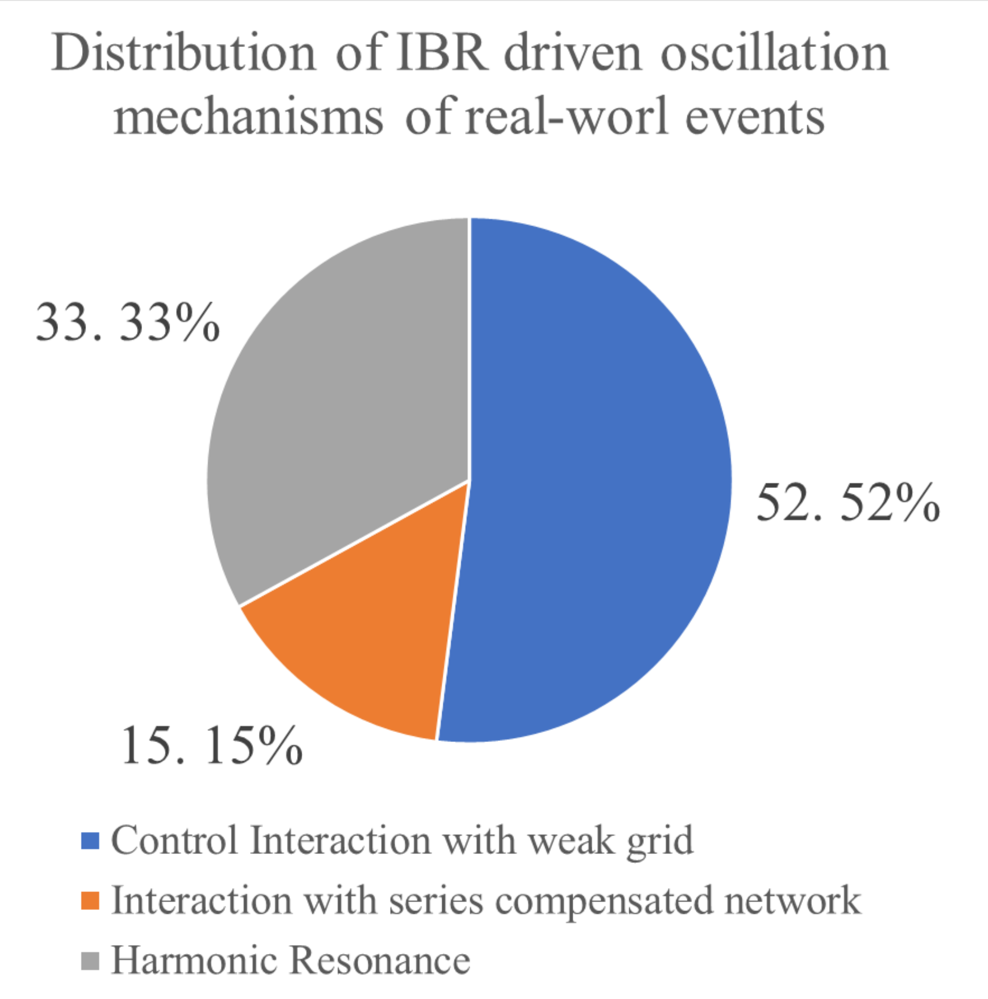
- Underlying mechanisms well understood
- Frequency ranges predictable
- Modelling, measurement and mitigation fairly mature

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

WP 1 Literature Review

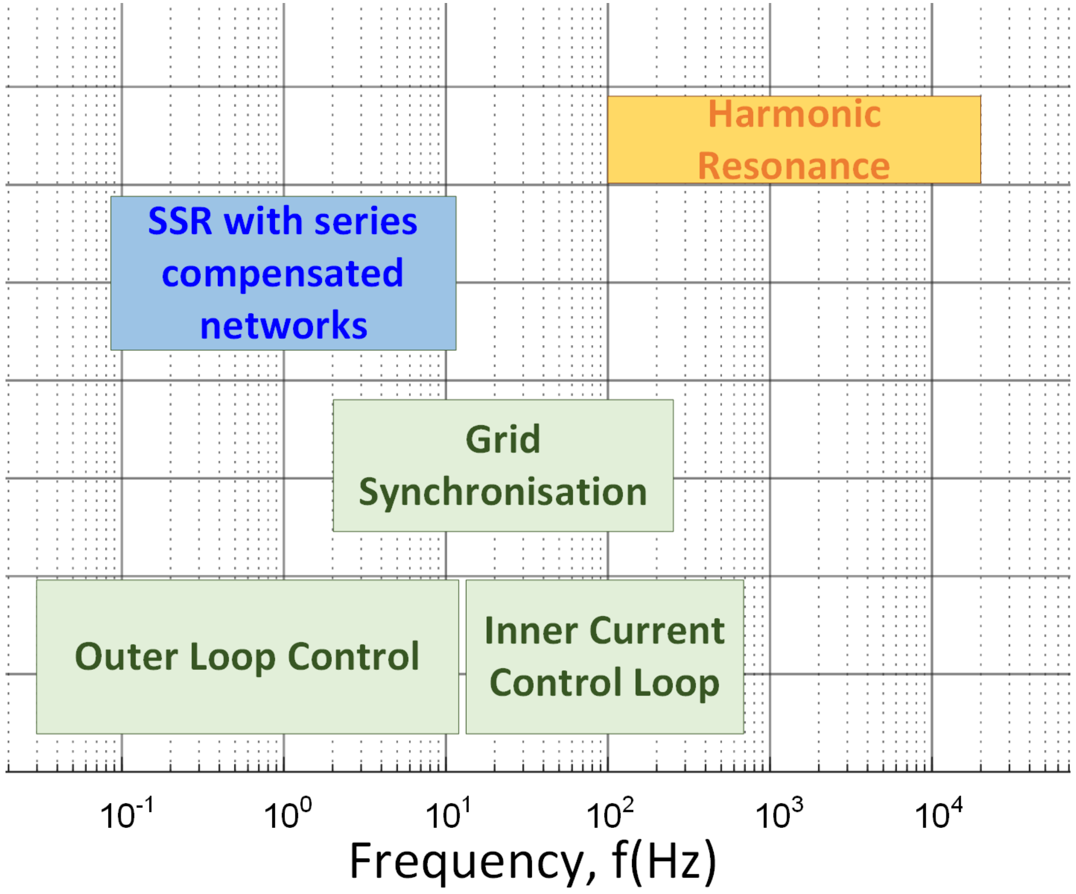
Review of real-world IBR driven oscillation events

- 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)



WP 1 Literature Review

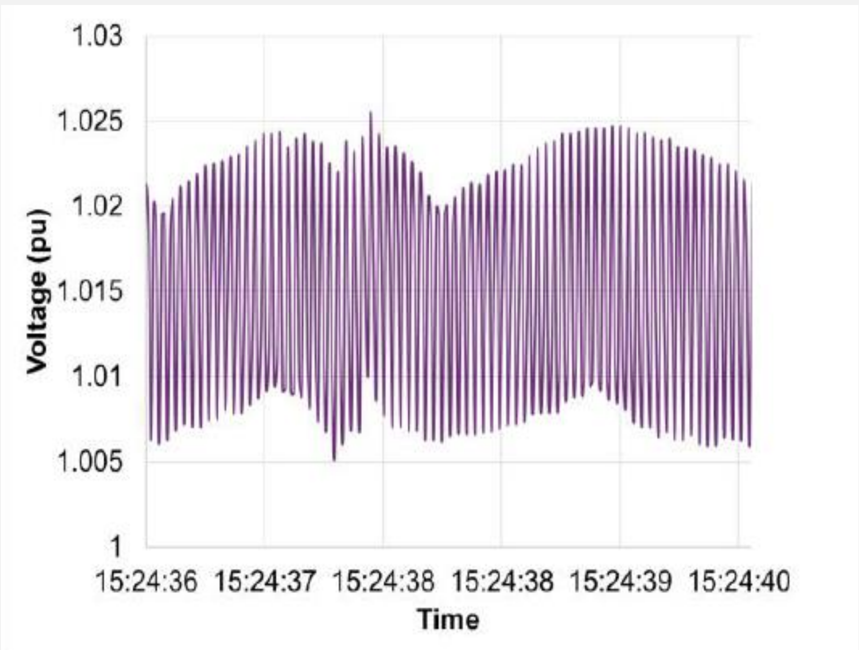
Learning from past events



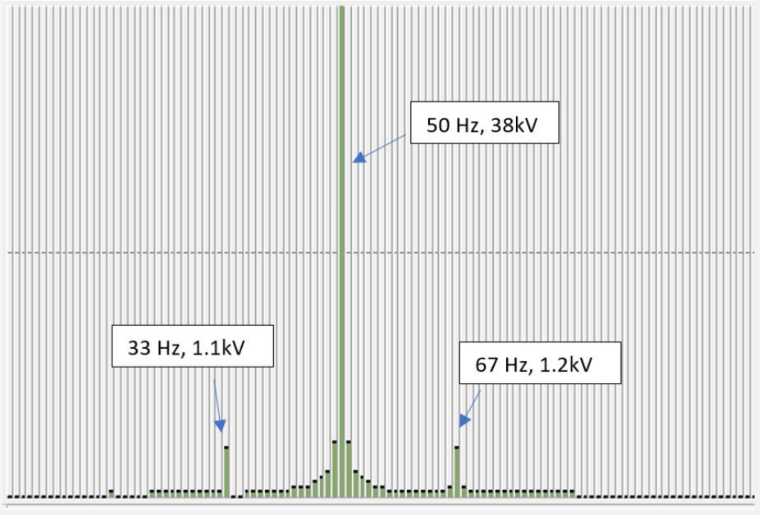
← f_n → ~f_{PWM}

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

Learnings from implementing wide area control

Limited oscillation source location/ mitigation

EFCC

VISOR

Improved EMT tools to assess risk of IBR Driven oscillations

TOTEM: Transmission Owner Tools for EMT Modelling (NIA_SHET_0032)

Co-simulation (NIA2_NGET0020)

2016

2018

2020

2022

2024

Transient Voltage Stability of Inverter Dominated Grids (NIA_NGET0187)

Sub/Near Synchronous Instability in the GB Network (NIA_NGTO044)

GridDamper

Potential solution provider

Automated Identification of Sub-Synchronous Oscillations (SSO) Events (NIA2_NGESO018)

- 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?

Wide area monitoring/control

Stability Analysis / Modelling

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- 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

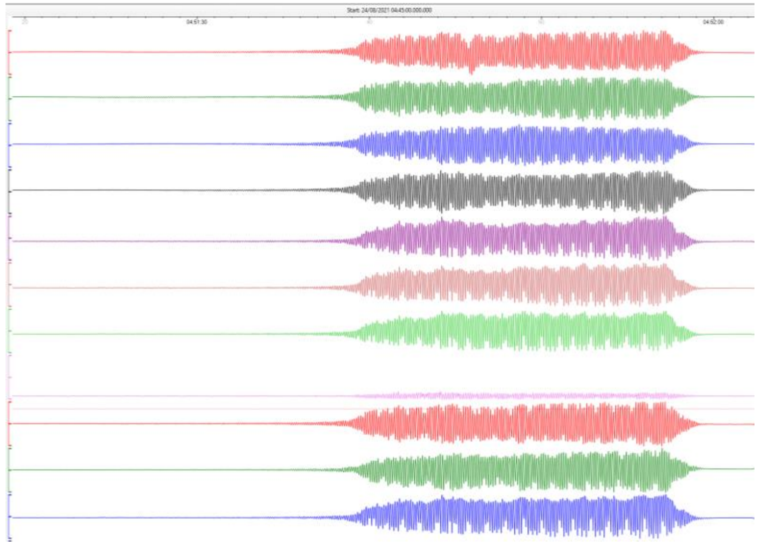
Gaps with business-as-usual approaches

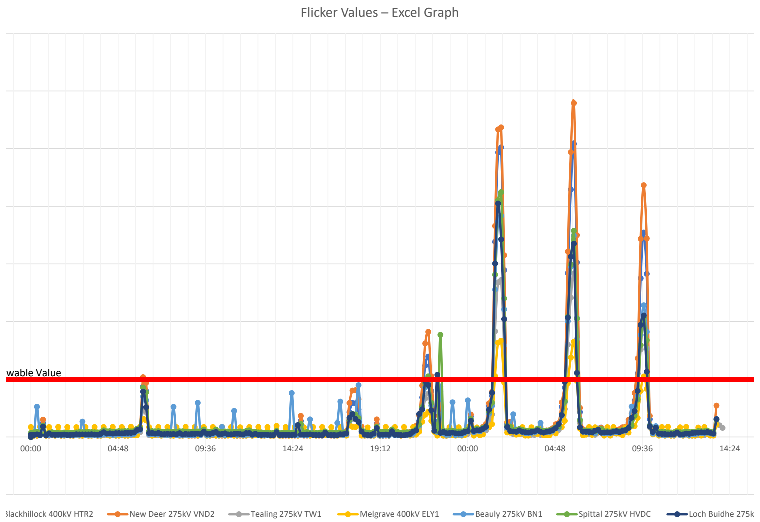
- Improved monitoring tools needed to supplement PMUs
- System planning approach difficult to achieve due to complexity of IBR control interaction
- Real-time monitoring/control solutions available not readily suitable for IBR driven oscillations
  - **Post-event analysis** typically done for understanding 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)





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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

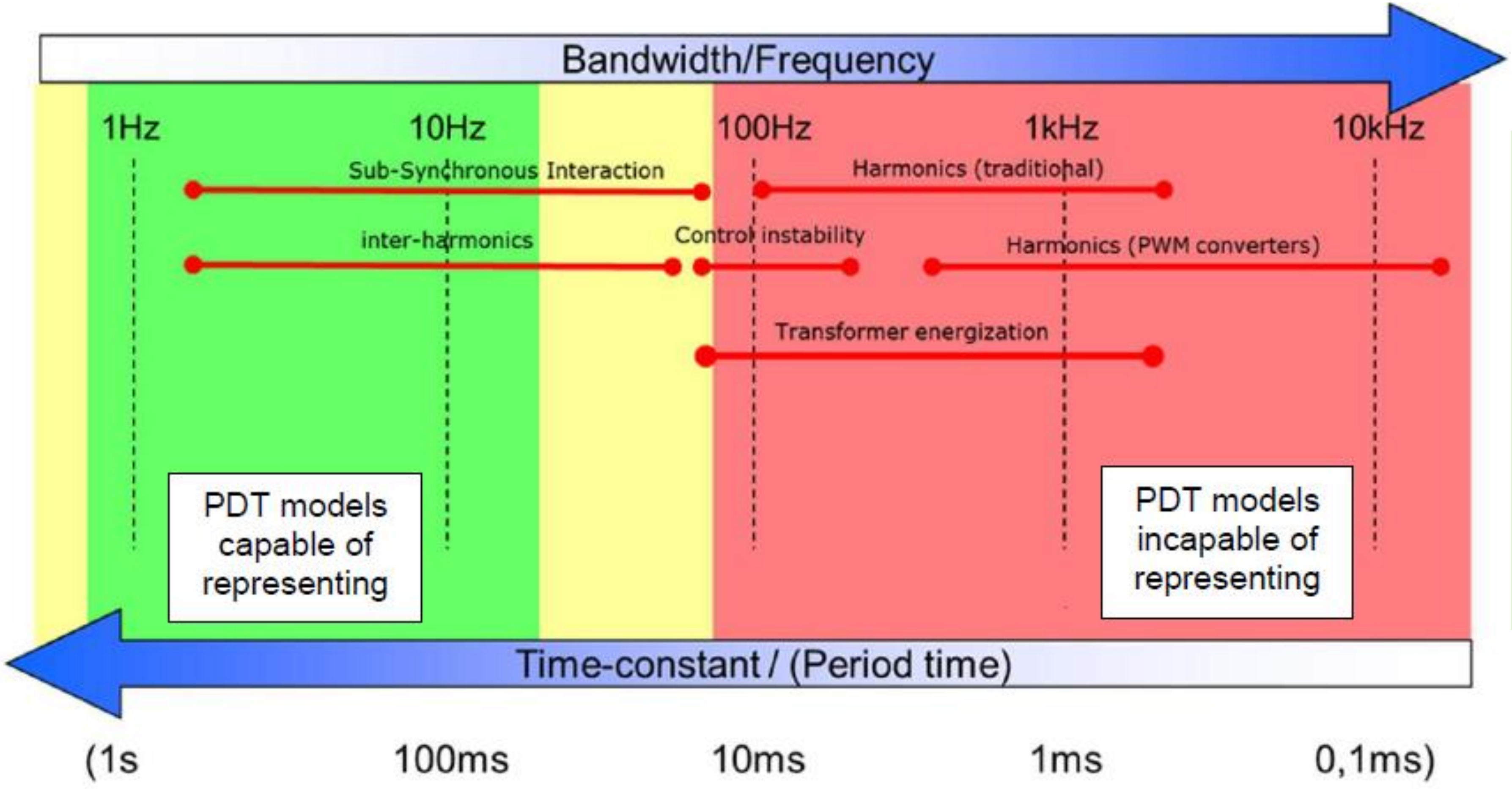
- Review of Electromagnetic Transient vs Phasor Domain modelling
- Review of EMT modelling of real-world IBR driven oscillation events
- Review of proposed benchmark IBR driven oscillation models

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

Figure: [1] International Council on Large Electric Systems, Ed., *Electromagnetic transient simulation models for large-scale system impact studies in power systems having a high penetration of inverter-connected generation*. in Technical brochure / CIGRE, no. 881. Paris, France: CIGRE, 2022.

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

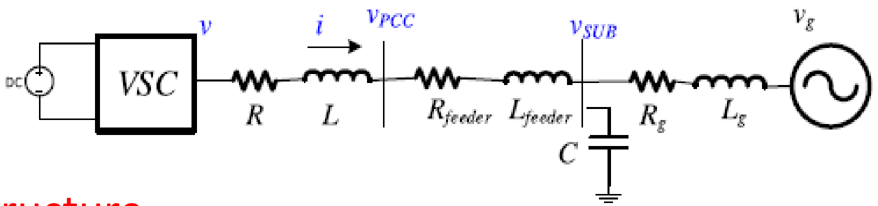
- IBR transient response also an important consideration

WP3 Modelling Requirements

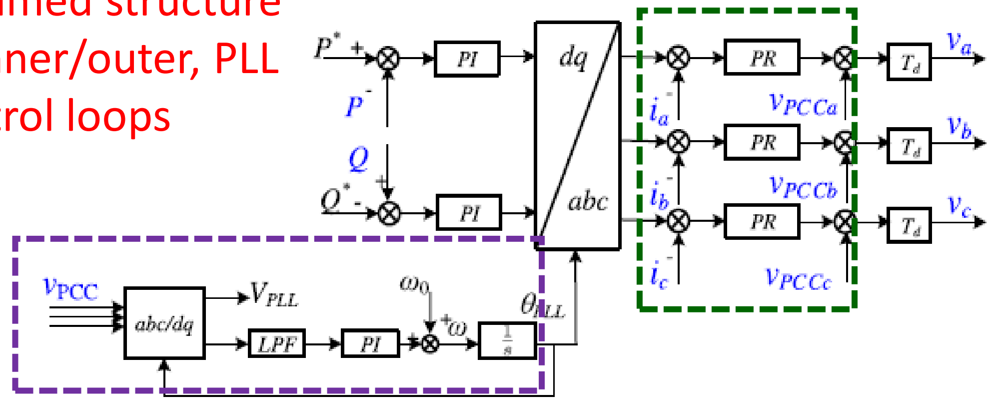
EMT Models of IBR: Generic vs Detailed

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



Assumed structure of inner/outer, PLL control loops

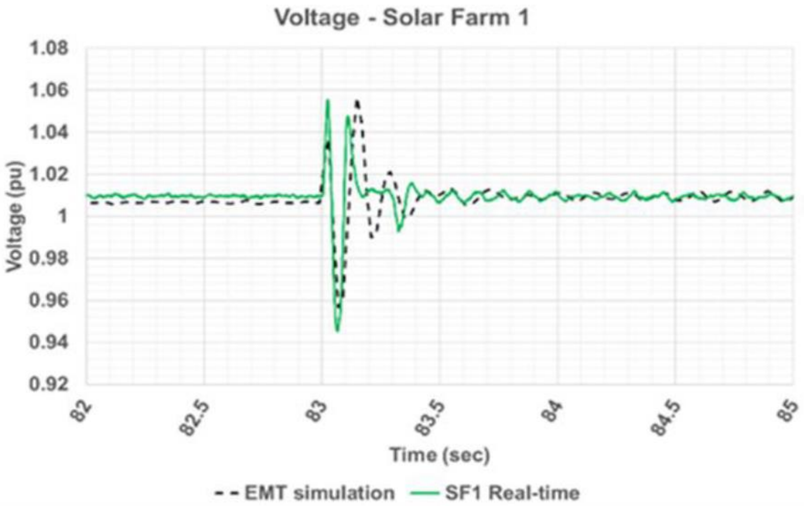


Detailed Model

- 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

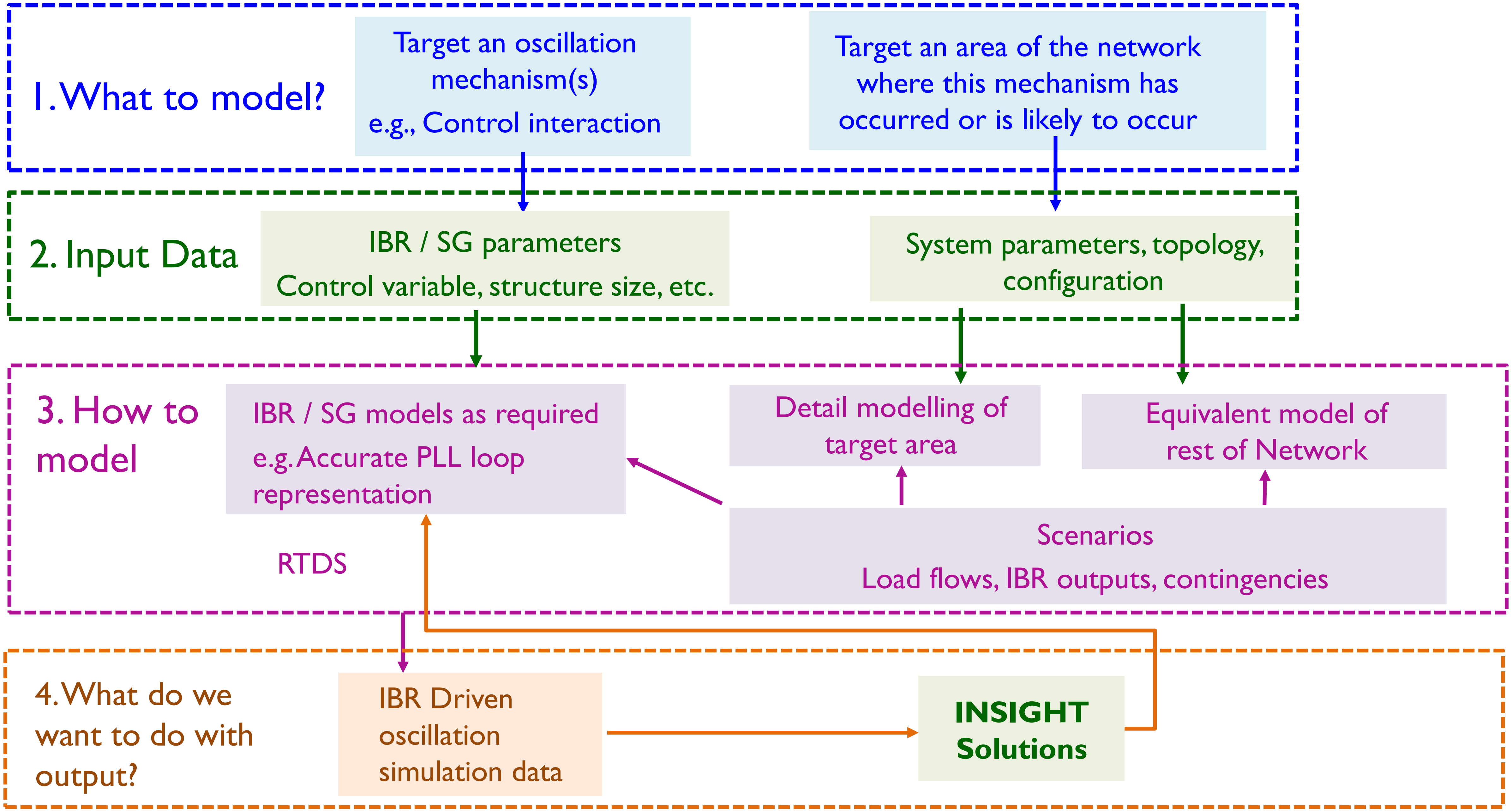
EMT model with updated site-specific inverter settings

- Accurate representation of real-world event (Australia)



WP3 Modelling Requirements

Alpha Phase Modelling Consideration



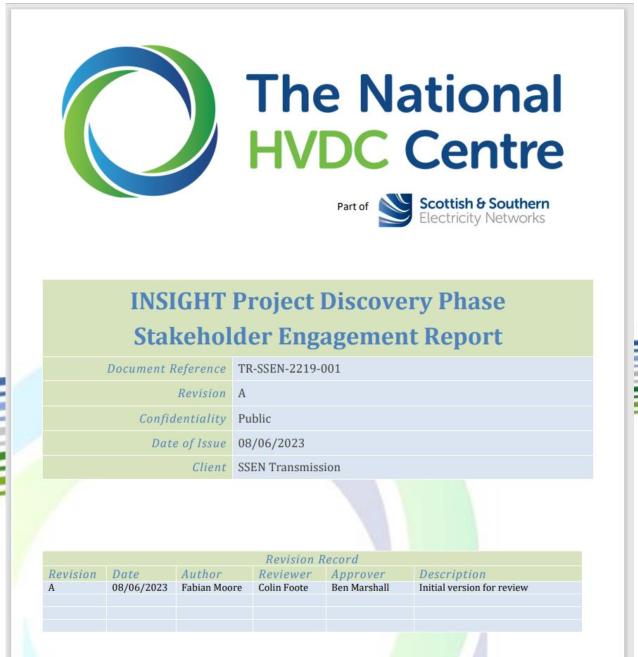
https://forms.office.com/e/6XLMnYFjdU

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


INSIGHT Stakeholder Engagement Questionnaire


The National HVDC Centre

Part of Scottish & Southern Electricity Networks

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

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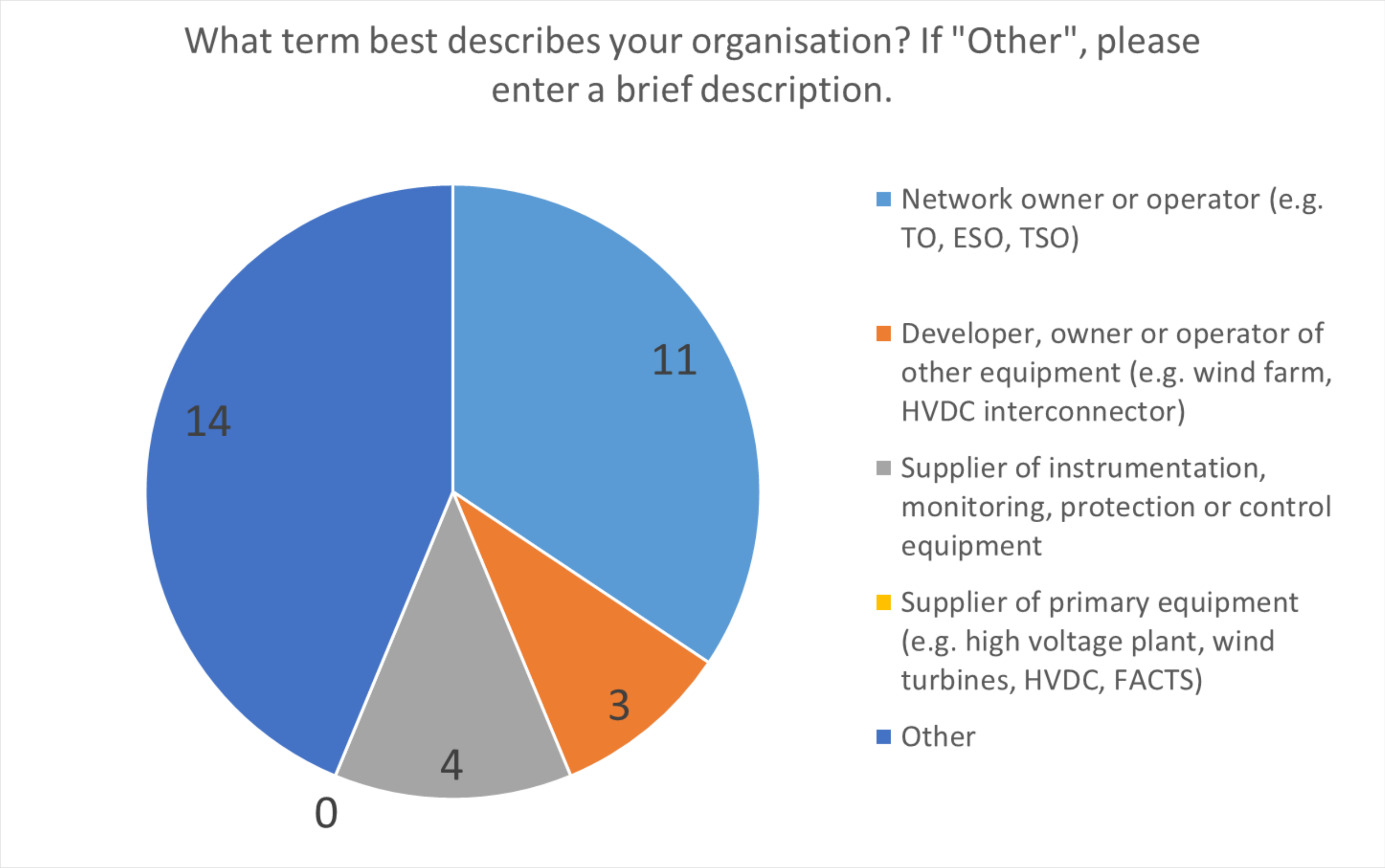
Industry Questionnaire

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



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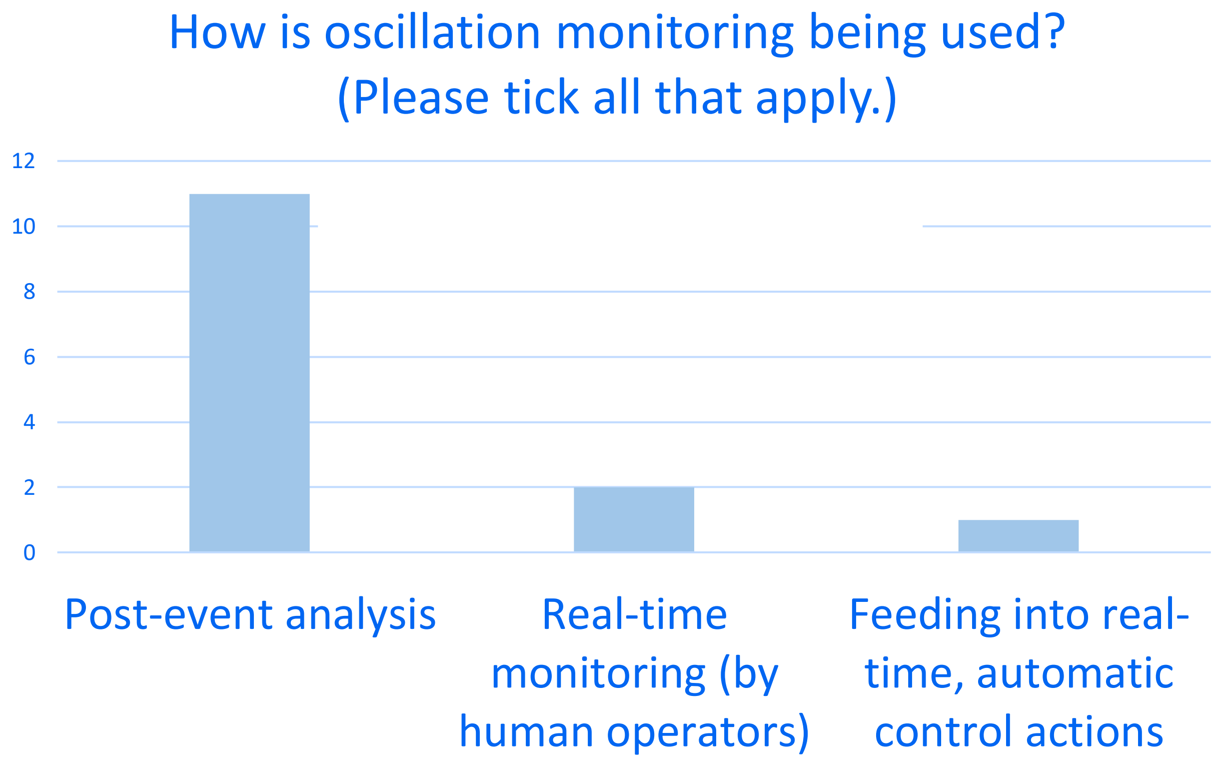
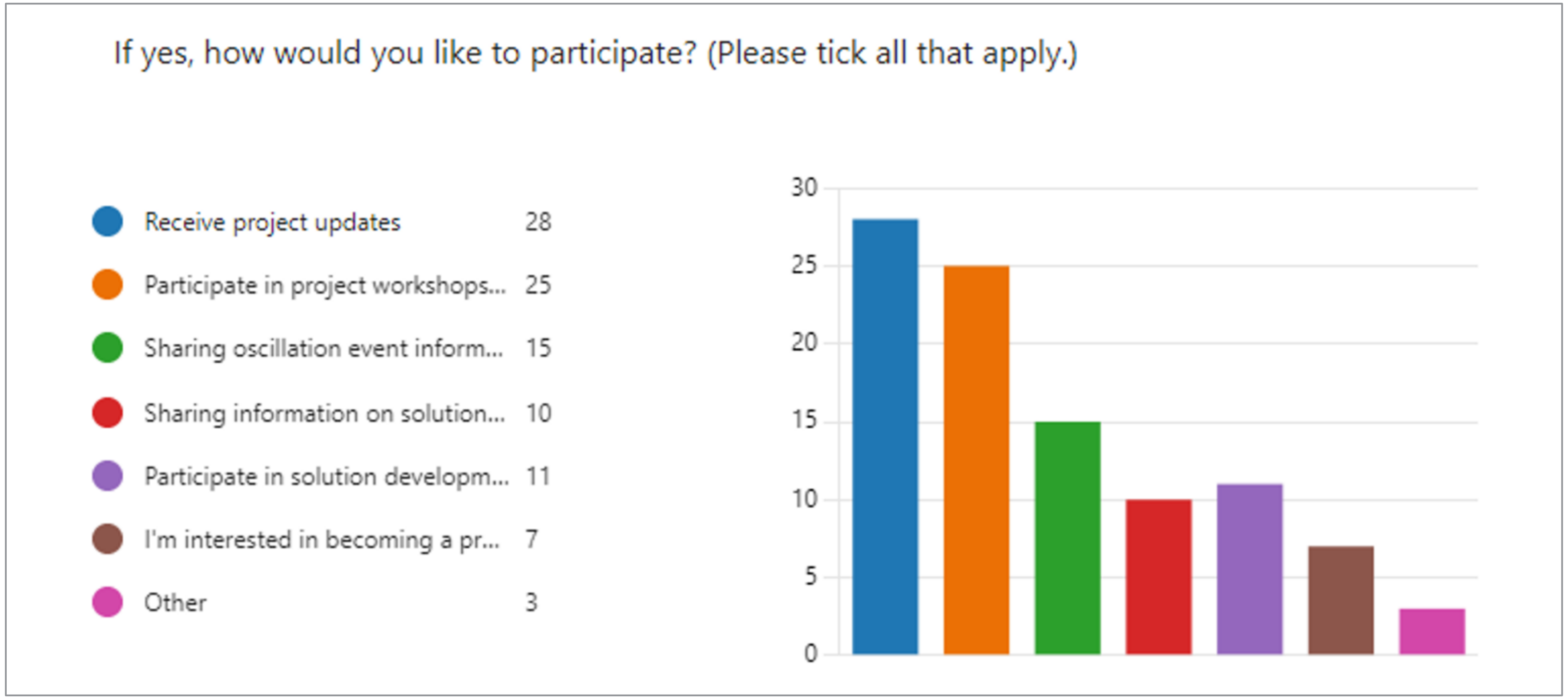
User Needs

- 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



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



- 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 — Partially mitigated
- Not being able to secure suitable researcher for the work — Fully mitigated
- Engineer leading the work not being available or having role changed — Fully mitigated
- Shortage of researcher with sufficient skills and knowledge for the work — Fully mitigated

Risks on technical work

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

Risks on stakeholder engagement

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

Risks relating to data confidentiality

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

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
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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)

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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)

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