VISOR – Visualisation of Real Time System Dynamics using Enhanced Monitoring

Introduction and Overview

Priyanka Mohapatra

VISOR Stakeholder Event, 18 August 2015

SP Energy Networks, Future Networks

pmohapatra@spenergynetworks.co.uk

SP Energy Networks (SPEN)

Iberdrola

ScottishPower

ScottishPower Retail and Generation
- Power stations
- Electricity and Gas tariffs to customers

ScottishPower Renewables
- Onshore and Marine Projects UK
- Offshore Projects Worldwide

SP Energy Networks
- Management of electricity network
- Separate company, separate branding

SP Energy Networks (SPEN)

Manages the transmission network in Southern Scotland and distribution networks in Southern Scotland and North Wales

Transmission

- SP Transmission (SPT) 132kV – 400kV
  - ➢ 4% of annual electricity bill
  - ➢ 56% of Scotland's transmission connected renewable generation

VISOR NIC project (2014-2017)

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Manages the transmission network in Southern Scotland and distribution networks in Southern Scotland and North Wales

Transmission

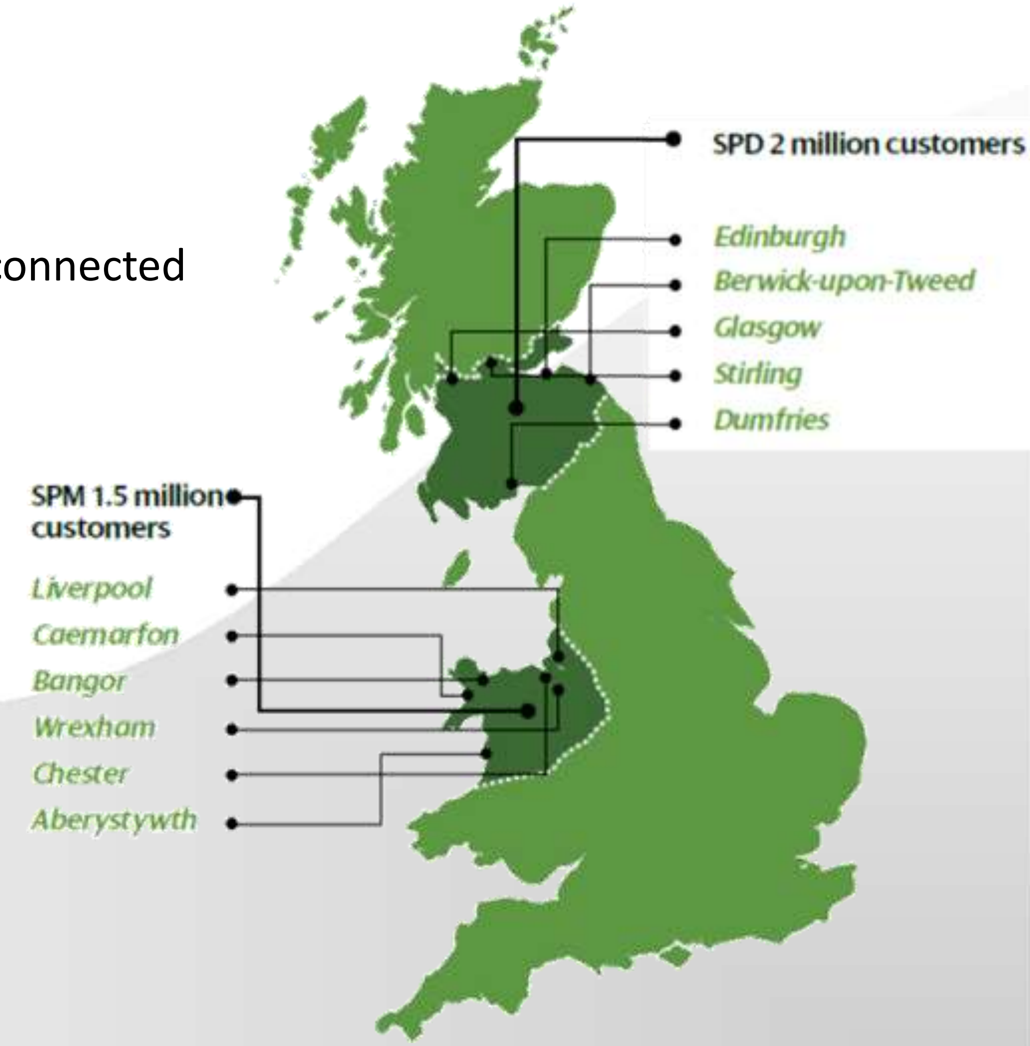
- SP Transmission (SPT) 132kV – 400kV
  - 4% of annual electricity bill
  - 56% of Scotland's transmission connected renewable generation

VISOR NIC project (2014-2017)

Distribution

- SP Distribution (SPD) and SP Manweb (SPM)
  - 3.5m connected customers
  - 16% of annual electricity bill
  - Host 28% of UK's distributed renewable generation but only 14% of customer base

ARC LCNF Tier 2 project (2013-2016)



The VISOR Team

	PROJECT TEAM	STEERING BOARD
SPEN:	Priyanka Mohapatra Jamie Campbell Finlay MacLeod	James Yu Colin Taylor
NGET:	Mark Osborne Phil Ashton Nick Hird Sanjeev Gopalakrishnan	Duncan Burt John Haber Martin Bradley Ray Zhang
SSE:	Chris Nendick	Stewart Reid

UoM:	Vladimir Terzija Peter Wall Papiya Dattaray	Academic Partner
Alstom:	Richard Davey Stuart Clark Douglas Wilson	WAMS Supplier

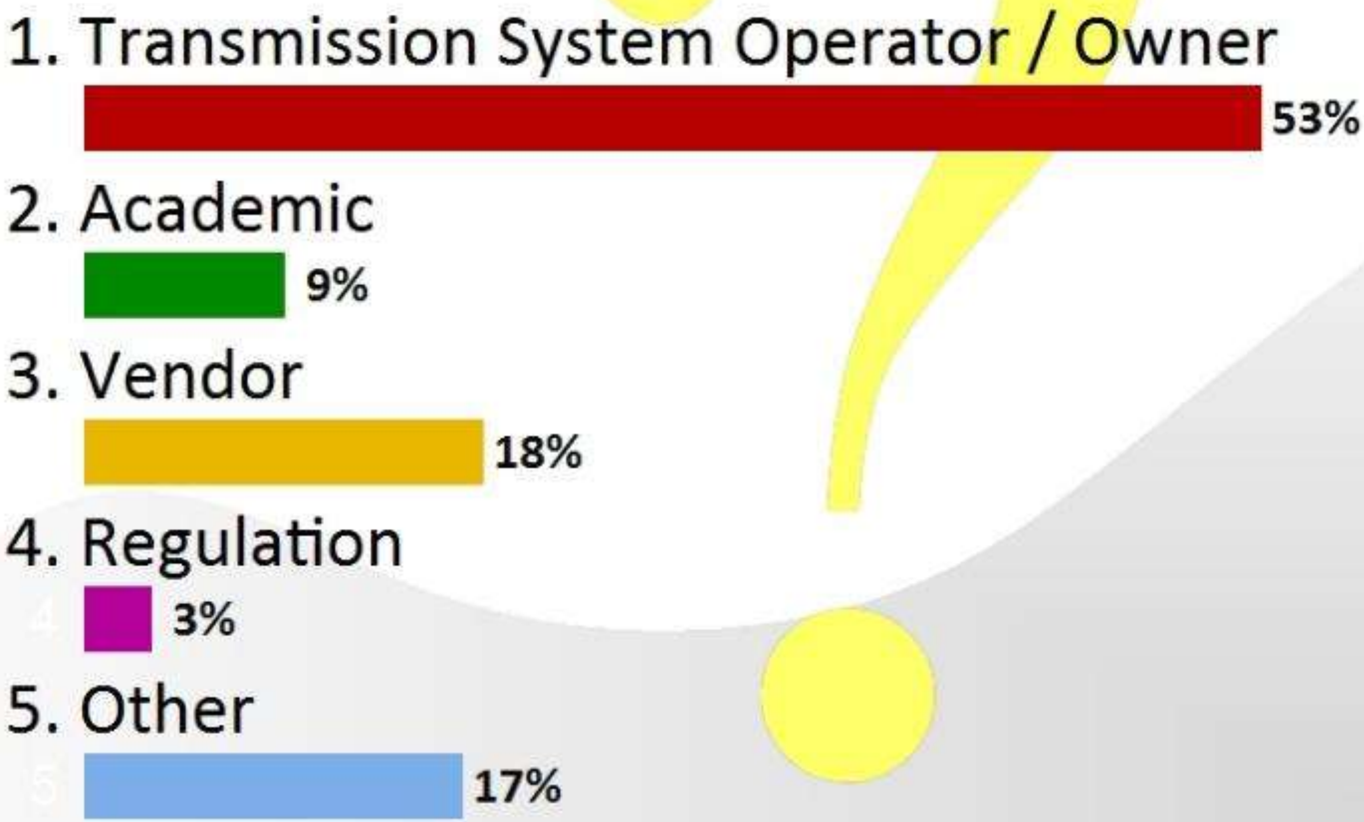
Agenda

1.	Welcome and overview to VISOR	Priyanka Mohapatra
2.	TO Motivation and Experience	Phil Ashton
3.	VISOR Applications	Stuart Clark
	Lunch break	
4.	VISOR Research	Peter Wall
5.	VISOR Q&A Session	*Project Team*
6.	Guest presentation	Charlotte Grant (EFCC Project)

Interactive questions

RIIO NIC
NETWORK INNOVATION COMPETITION

Q1: What sector are you from?



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RIIO NIC NETWORK INNOVATION COMPETITION

Q2: How well did you know VISOR before this event?

1. Aware of VISOR with a full understanding

32%

2. Aware of VISOR with a fair understanding

26%

3. Aware of VISOR with little understanding

35%

4. Not aware of VISOR but understand the technology

3%

5. Not aware of VISOR and unfamiliar with technology

4%

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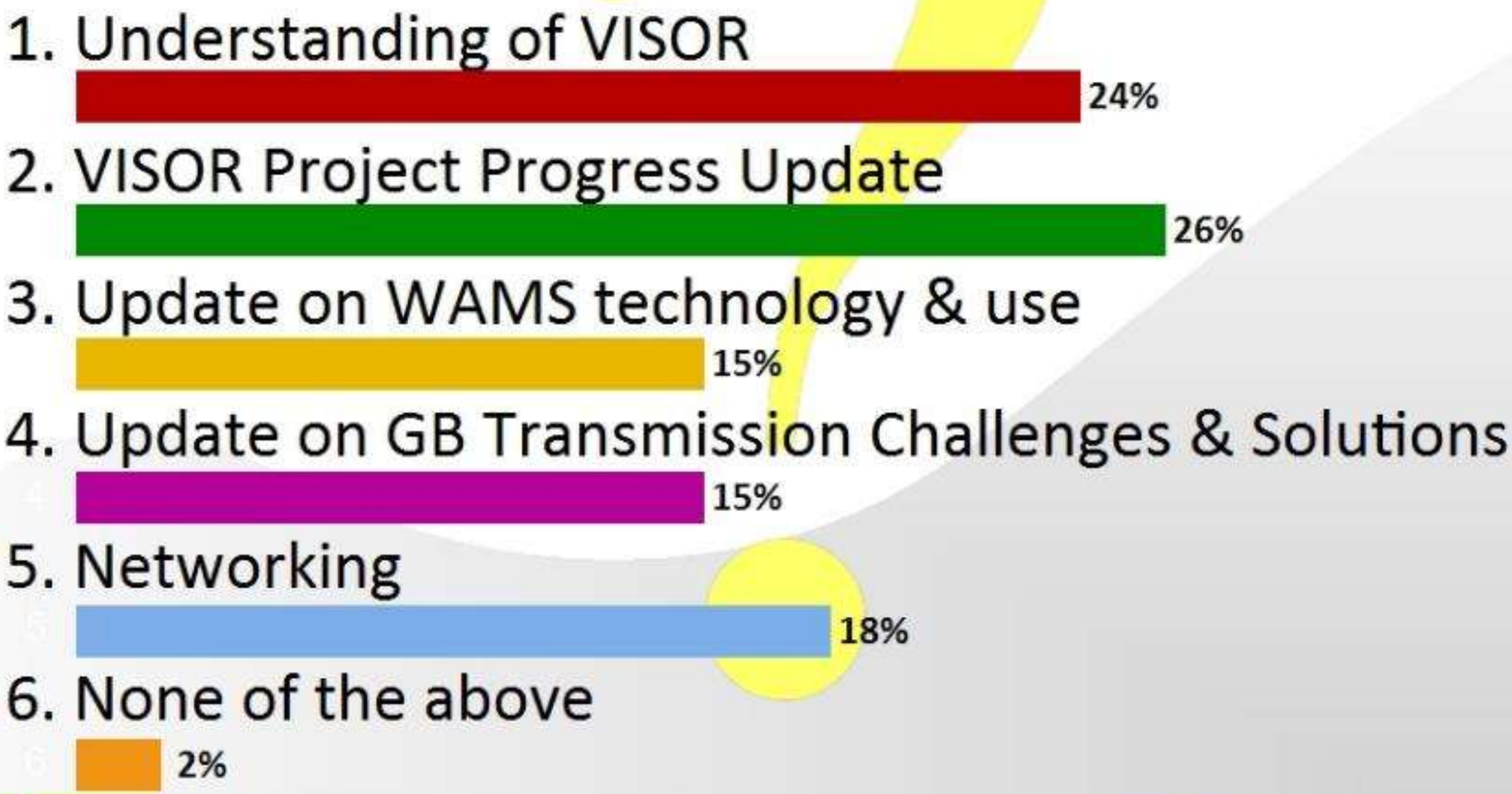
Q3: What is your main objective of today?



VISOR

Visualisation of Real Time System Dynamics using Enhanced Monitoring

Problem:
New plant (HVDC, Series Comp, Wind) raises risk of sub-synchronous oscillations (<50Hz) interacting between generators, series comp & HVDC/wind controllers. No visibility of SSO at present. In addition, Anglo-Scottish boundary ("B6") is a major bottleneck - restricting use of Scottish Renewable generation.

Method:
Create the first GB Wide Area Monitoring System (WAMS) to study, analyse and integrate synchronised measurements across all three transmission network regions in real time to provide new insight into the capability and dynamic performance.

Duration:
January 2014 – March 2017

Project Cost:
£7.44m (£6.55m funded by NIC)

Industrial Partners
NGET, SSE

Academic Partner:
University of Manchester

Technology providers:
Alstom Grid Psymetrix

Solution:
Through advanced real-time monitoring, detection and Hybrid State Estimation enabled by WAMS, VISOR will manage system risks, combat uncertainty and maximise capacity in both network planning and operation, by providing Transmission Network Owners and the System Operator with:

- Enhanced visibility & source location of Sub-Synchronous Oscillations, between 0.002 - 46 Hz;
- Improved management of constraints through use of voltage angle;
- Greater confidence in system operating state through Hybrid State Estimation;
- Greater confidence in system limits through validation of models

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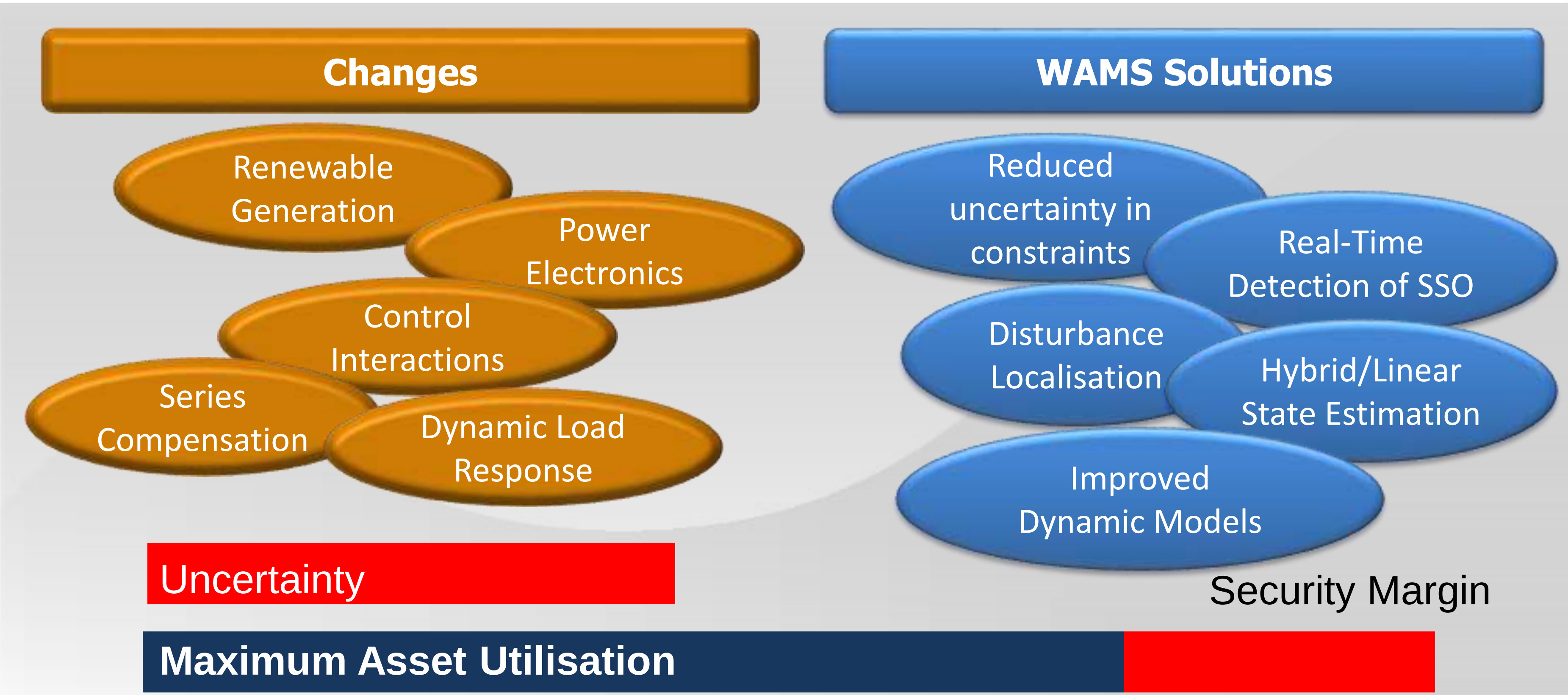
Visualisation of Real Time System Dynamics using Enhanced Monitoring

RIIO NIC NETWORK INNOVATION COMPETITION

VISOR will showcase the role of WAMS in combatting uncertainty and helping to maximise asset utilisation in a secure way.



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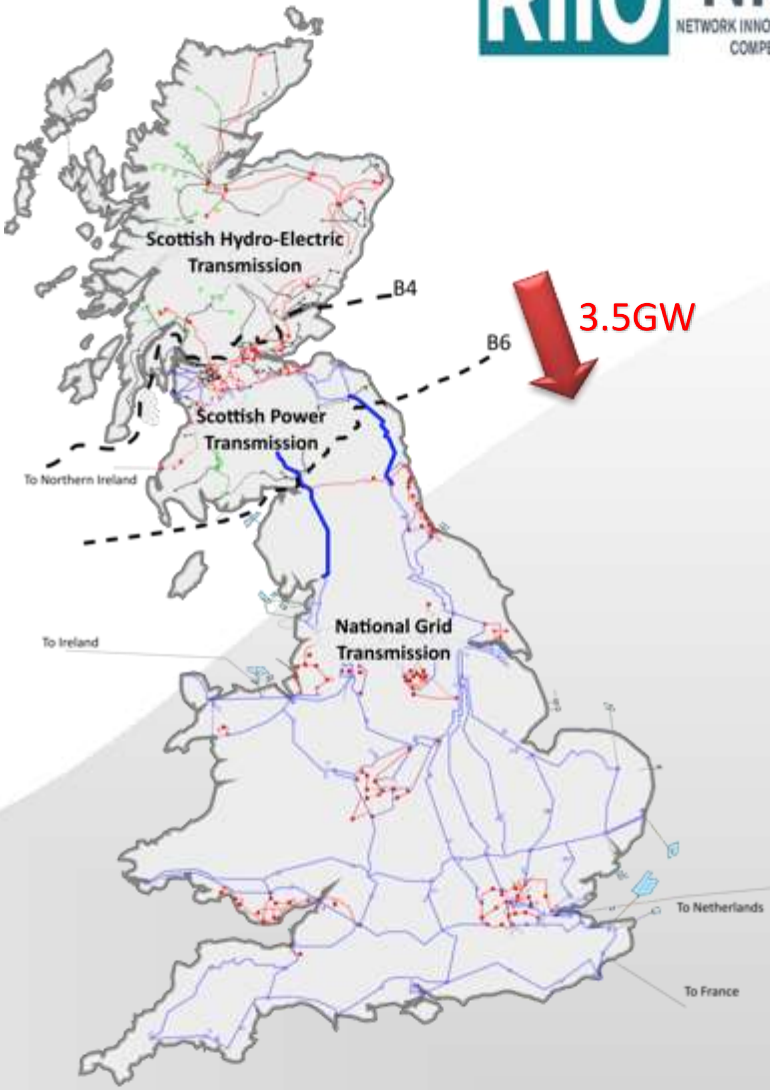
The VISOR Wide Area Monitoring System

- Deploying a GB wide WAMS is a critical aspect of VISOR
- The WAMS will monitor the networks of all three GB Transmission Owners (TOs)
- The data from each TO will be collected together by the System Operator (SO)
- Enhance export capacity across B6 boundary (~3.5GW in 2015)



VISOR Project: Visualisation of real time system dynamics using enhanced monitoring

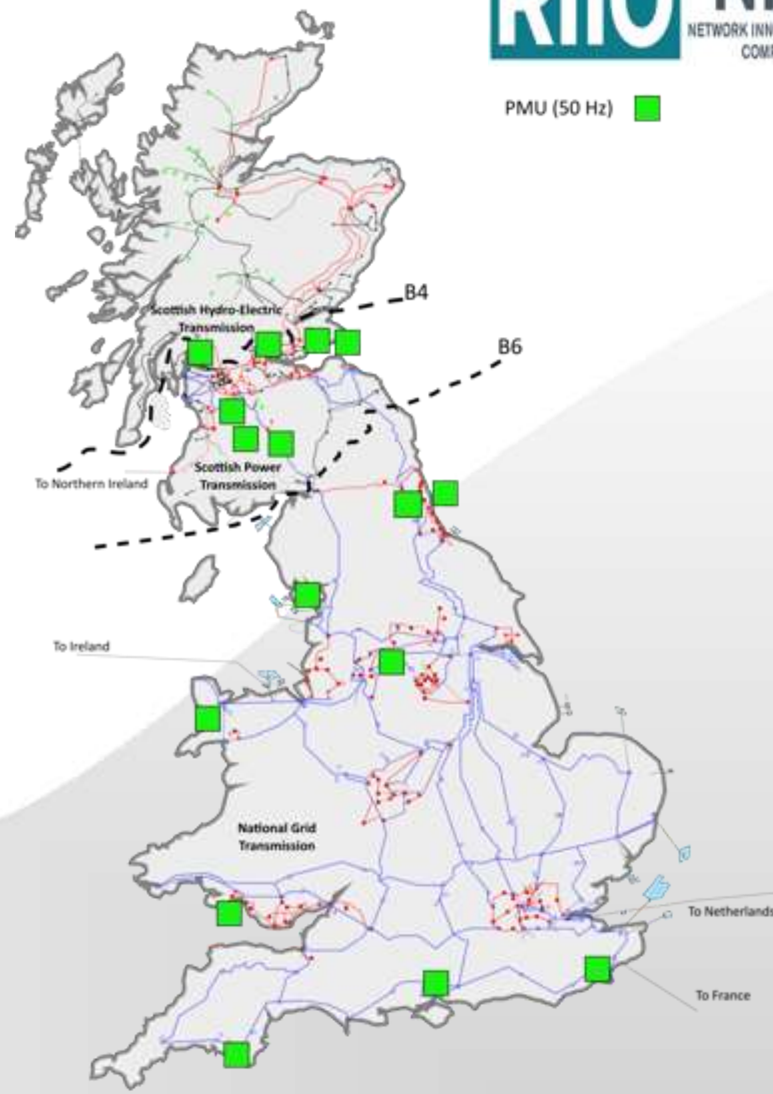
VISOR – the B6 boundary

- Constant investment in upgrades since 1990 driven by need to increase export capability
- Installation of series compensation equipment will increase export capacity to 4400MW
- West coast HVDC will further increase export capacity to 6600MW
- Reinforcements will also increase Scottish import capacity
  - increasing security of supply and providing flexibility to support intermittent generation

VISOR

The VISOR Wide Area Monitoring System

- VISOR will exploit existing Phasor Measurement Units (PMUs) in GB system



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RIIO NIC NETWORK INNOVATION COMPETITION

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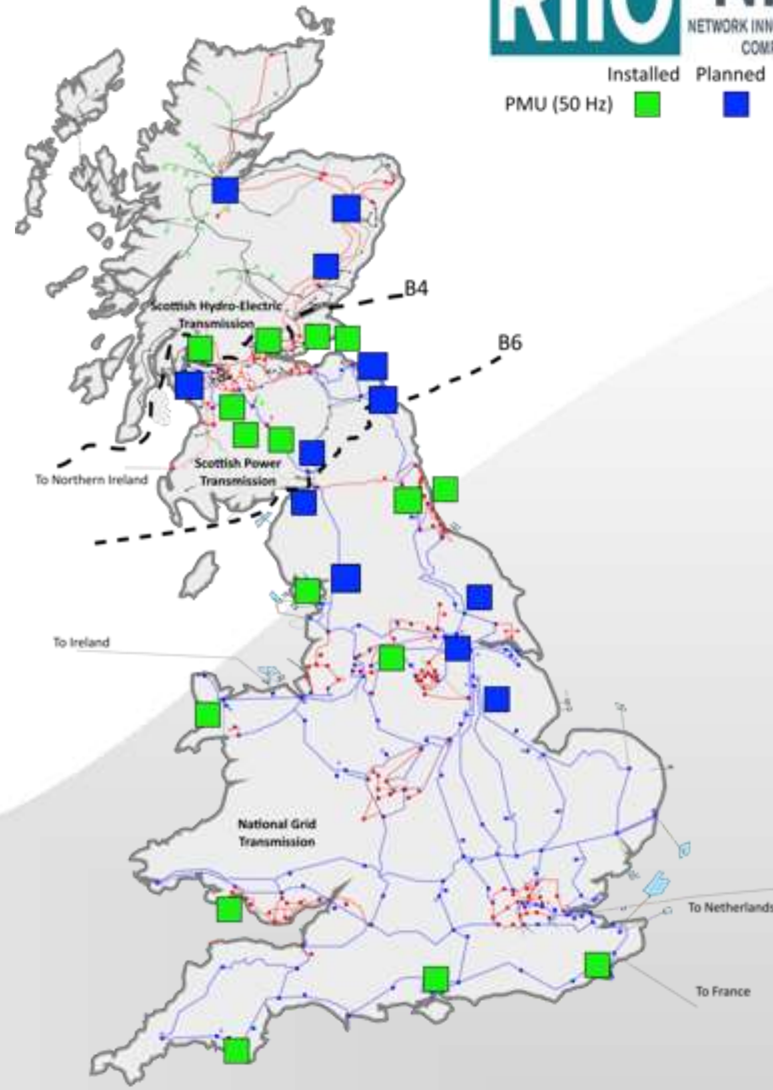
The VISOR Wide Area Monitoring System



- New PMUs will be installed to improve monitoring across the B6 Boundary
- PMUs report measurements at 50 Hz (V/I phasors, Frequency and RoCoF)
- Oscillation monitoring up to 10-15 Hz

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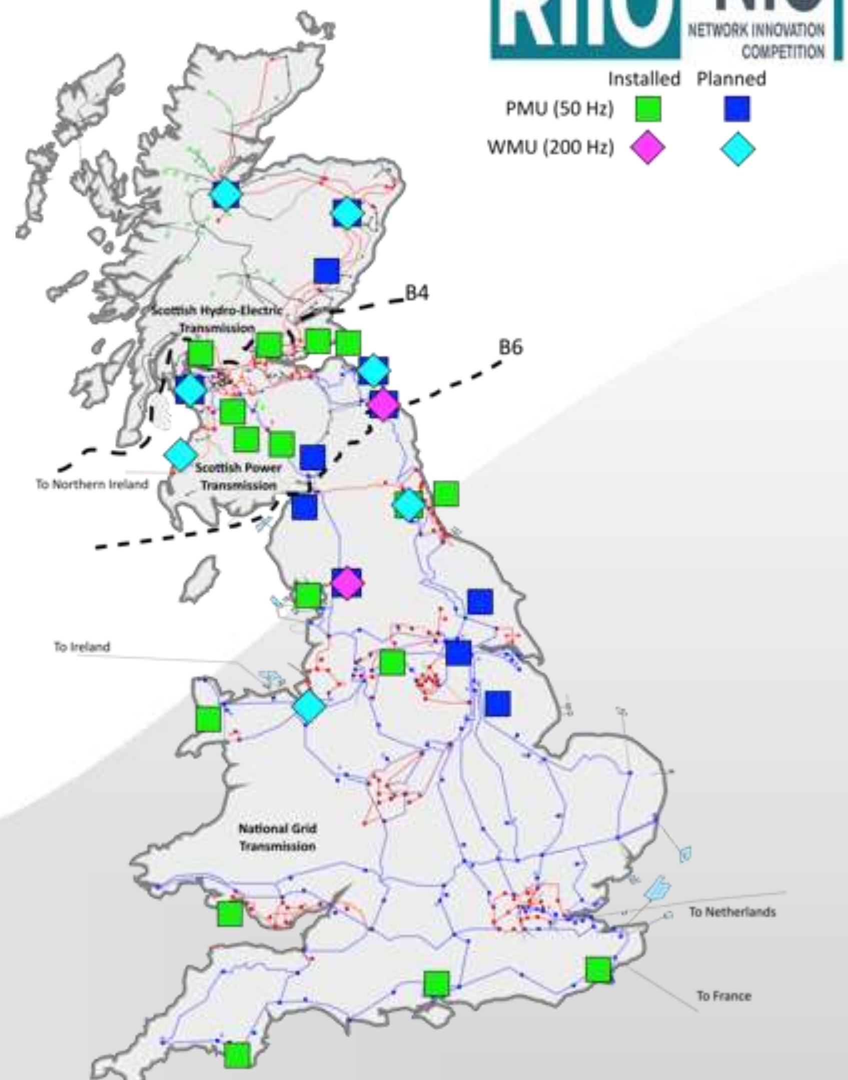
The VISOR Wide Area Monitoring System

- Waveform Monitoring Units (WMUs) installed for dedicated SSO monitoring
  - WMUs are enhanced PMUs produced for VISOR WAMS applications
  - They report waveform samples at 200 Hz (200 samples/second)
  - Increases the range of SSO monitoring up to 46 Hz



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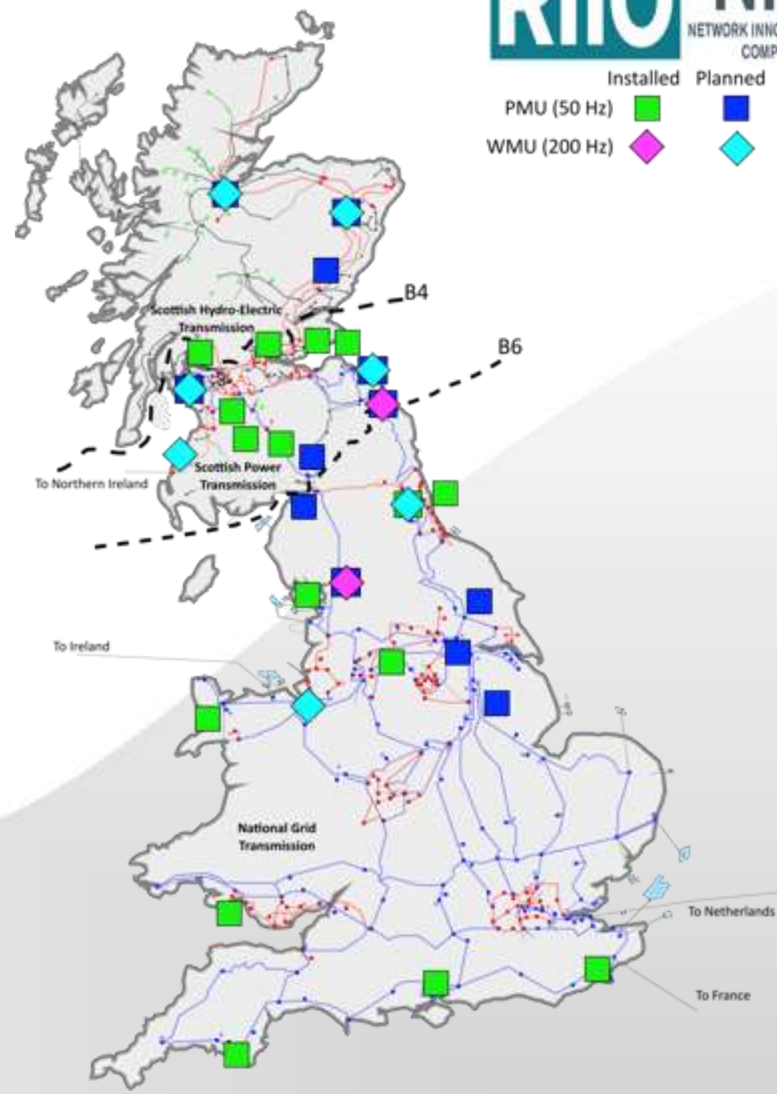
The VISOR Wide Area Monitoring System

Measurement devices are not the only part of a WAMS



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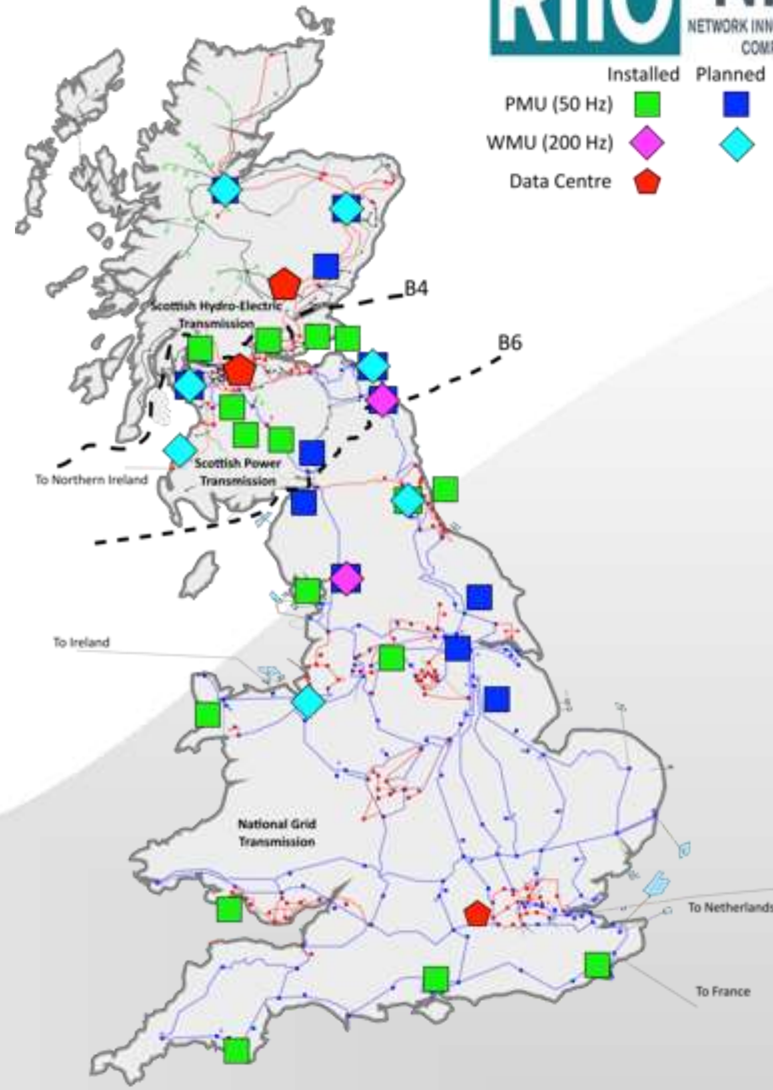
The VISOR Wide Area Monitoring System

Measurement devices are not the only part of a WAMS

- A new Data Centre (DC) has been installed in each of the three GB TOs



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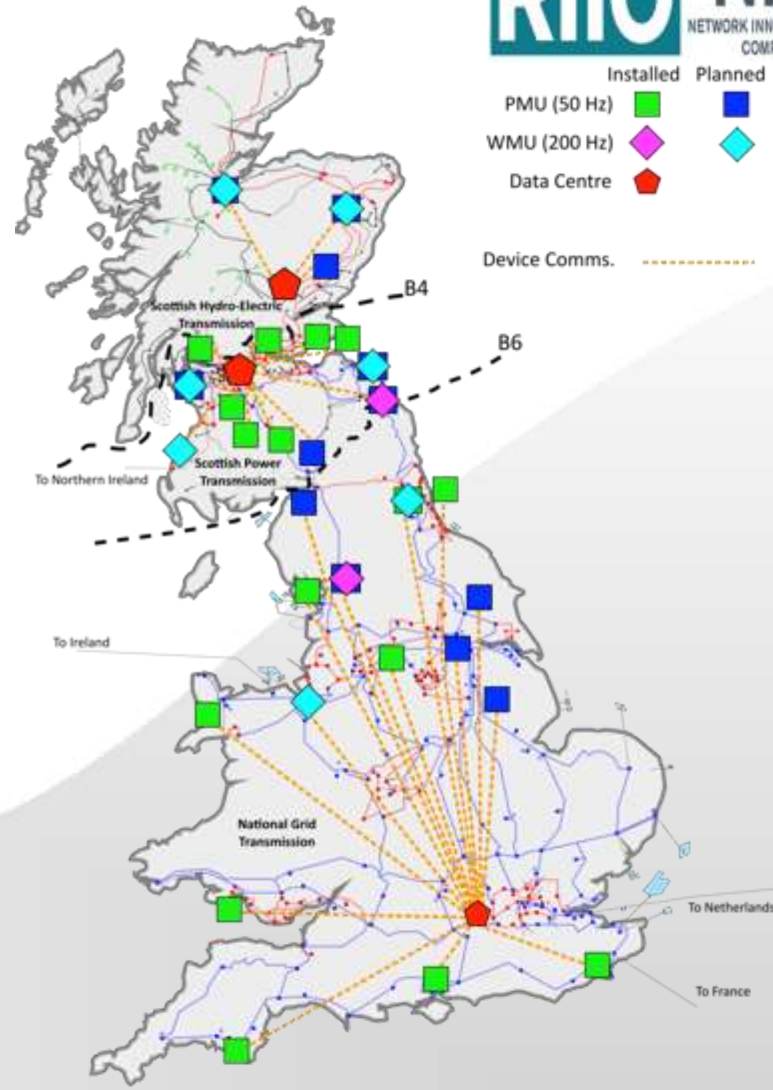
The VISOR Wide Area Monitoring System

Measurement devices are not the only part of a WAMS

- A new Data Centre (DC) has been installed in each of the three GB TOs

- Data is communicated from the measurement devices to these TO DCs



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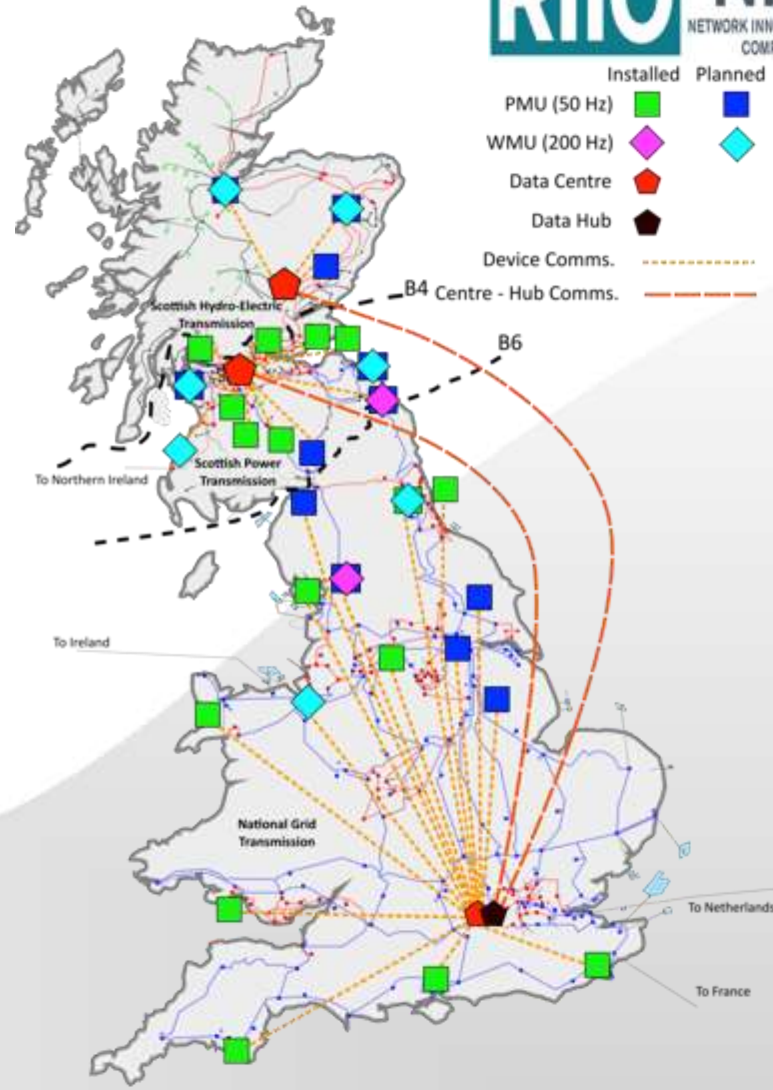
VISOR

The VISOR Wide Area Monitoring System

Measurement devices are not the only part of a WAMS

- A new Data Centre (DC) has been installed in each of the three GB TOs
- Data is communicated from the measurement devices to these TO DCs
- A Data Hub collects data from each DC to provide real time monitoring of GB to the SO



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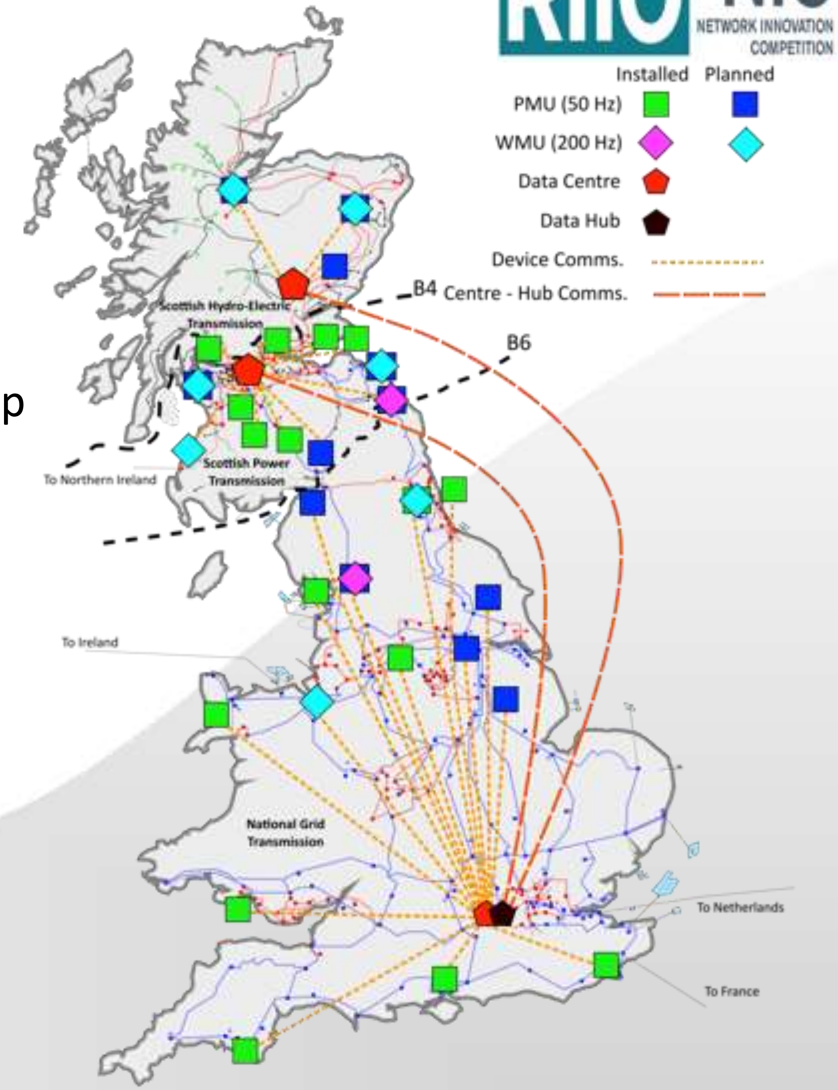
VISOR – Quick status update

- Installed Phasor Data Concentrator servers (Data Centres) to collect data from each TO
- Installed central Data Hub at TSO Wokingham
- 10 WMUs installed by early 2016.
- 1 WMU installed at UoM for hardware-in-the loop testing to monitor the enduring performance
- SSO Application installed at SPT and NGET – SSO monitoring is running!



The VISOR WAMS

Proposed WMU outstation device locations and status

#	VISOR Partner	Locations (circuits)
4	SPT	Eccles (Stella West 2)
		Torness (Eccles 2)
		Hunterston (Inverkip 2)
		Coylton (Auchencrosh)
4	NGET	Hutton (Harker 1 & 2)
		Stella West (Spennymoor1 &2)
		Connor's Quay (Pentir)
		Grain
2	SSE	Kintore
		Beauly

Over the next 6 months VISOR will:

- Progress with WMU installations (early 2016 target)
- Deploy applications for the monitoring of SSO (4-46Hz) at SSE
- Develop VLF applications for monitoring SSO (0.002 – 0.1Hz)
- Develop real-time source location display
- Validate the representation of SSO in the GB system model using data from the WAMS
- Report on SSO observed in GB using the VISOR WAMS
- Demonstrate angle based security margins for B6 (SDRC 9.4.1 element)
- Analyse the impact of uncertainty in line parameters on security margins

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nationalgrid RIIO NIC NETWORK INNOVATION COMPETITION

WAMS Development on the GB System

Dr Phil Ashton, Strategy and Innovation

VISOR Stakeholder Event Westminster, London

Tuesday 18th August 2015

Presentation overview

- Introduction to National Grid
  - Context
- Future Challenges
  - Motivations for WAMS / WAMPAC
- System Monitoring National Grid
  - Existing Systems
- Experience of PMUs to date
  - Applications
  - Key challenges
- Future plans and projects
  - Trials and Innovation
  - Moving towards BaU

GB Transmission Network

	nationalgrid	SP ENERGY NETWORKS	SSE
km of Circuit	14,000 400, 275kV	4,000 400, 275, 132kV	5,000 400, 275, 132kV
# of Substations	340	80	40
Demand GW	54.3	4.39	1.65

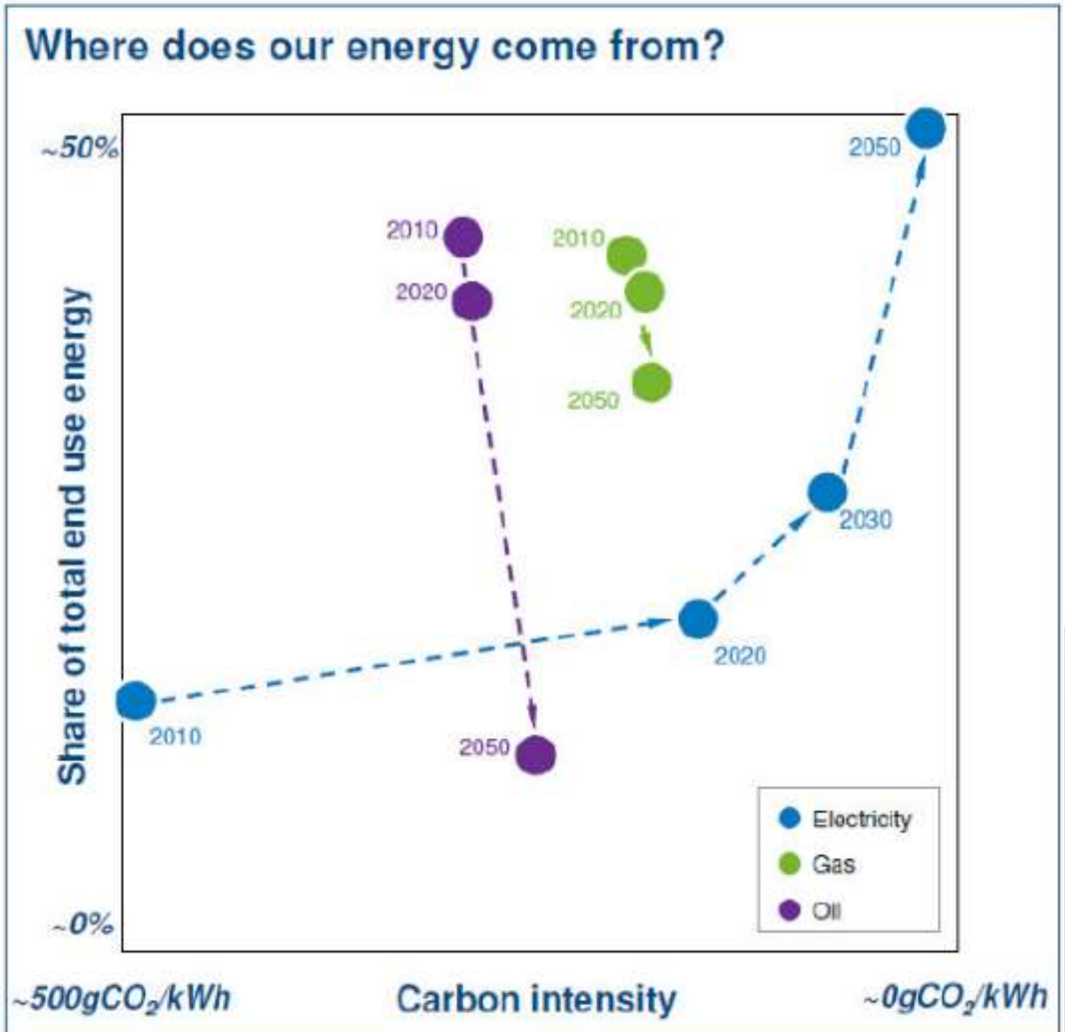
Operational View

Winter Peak Demand	**~ 60GW**
Generation Capacity	**~ 80GW**

GB Interconnectors

France	**2GW**
N. Ireland	**0.5GW**
Ireland	**0.5GW**
Netherlands	**1GW**

Changing Energy Landscape



Power station closures

~25%

of total capacity by 2020 vs 2010 levels

Decarbonise electricity

80% CO_2

reduction by 2050

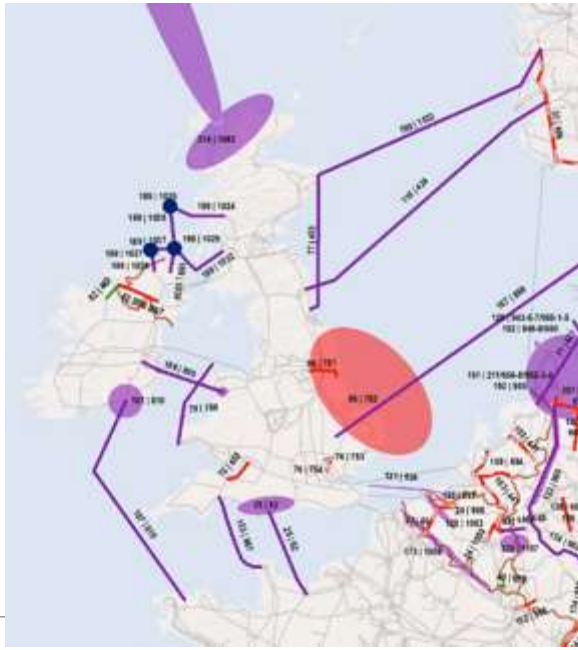
Energy from renewables

~15%

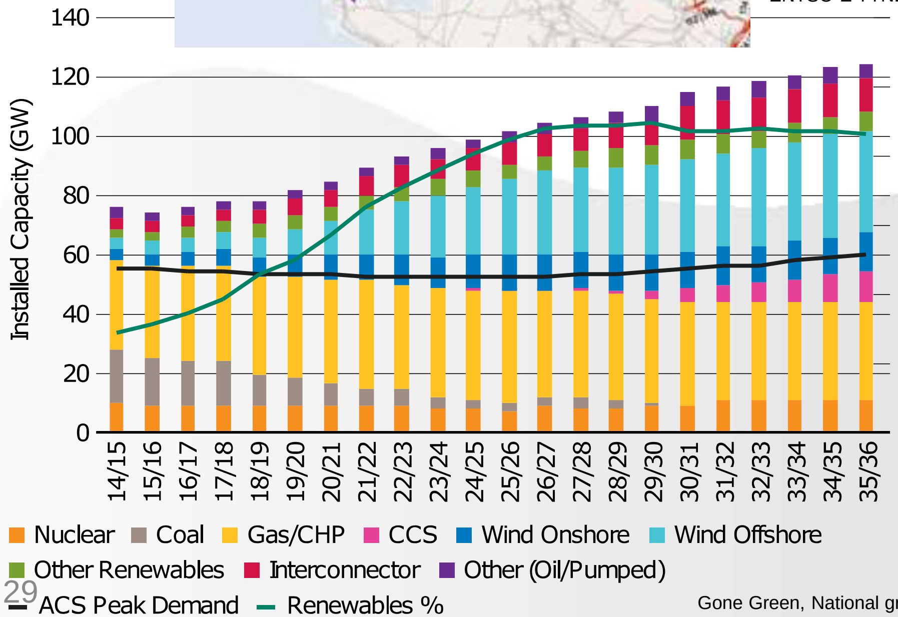
of total supplies by 2020

Environmental targets influencing industry changes

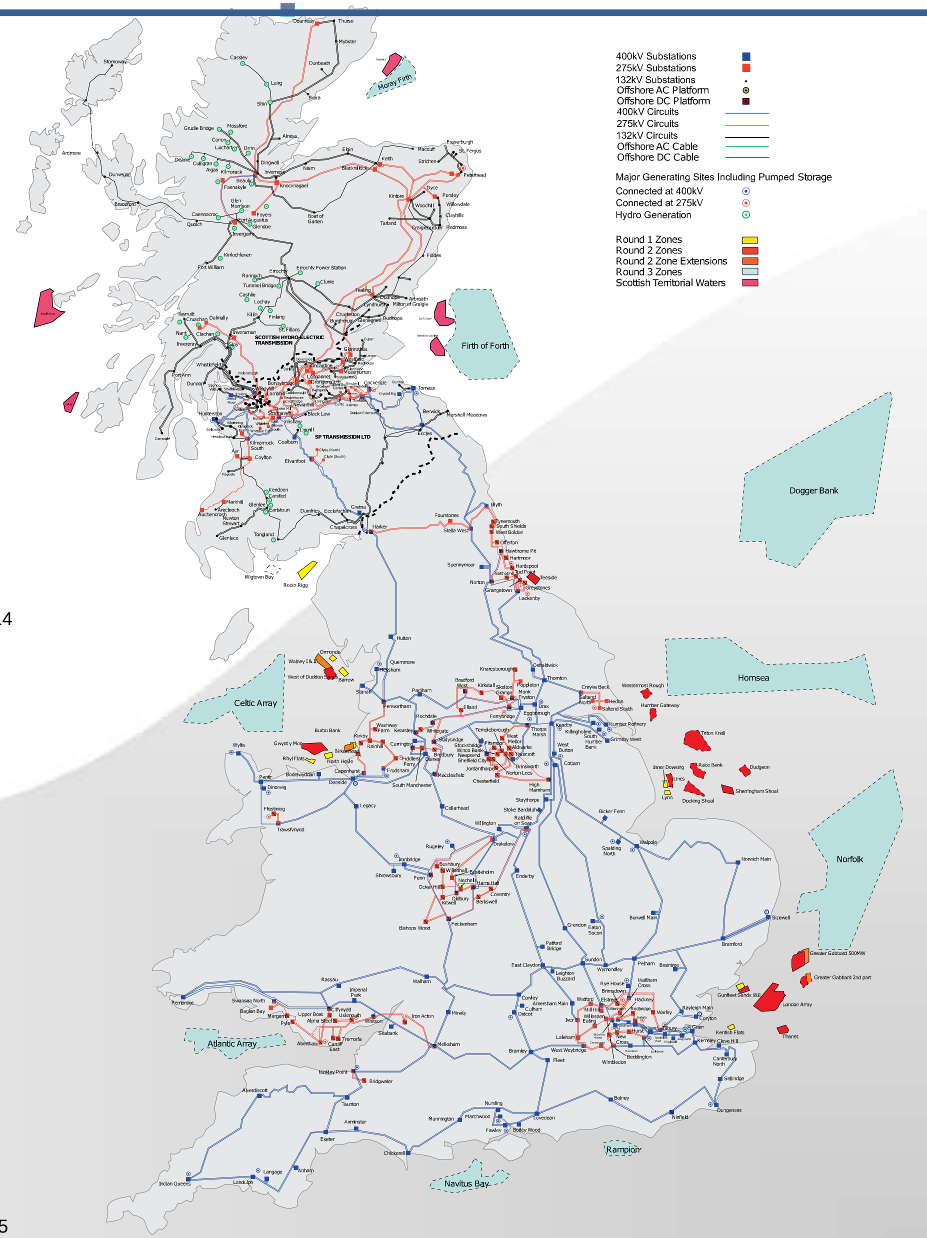
The Evolving Network



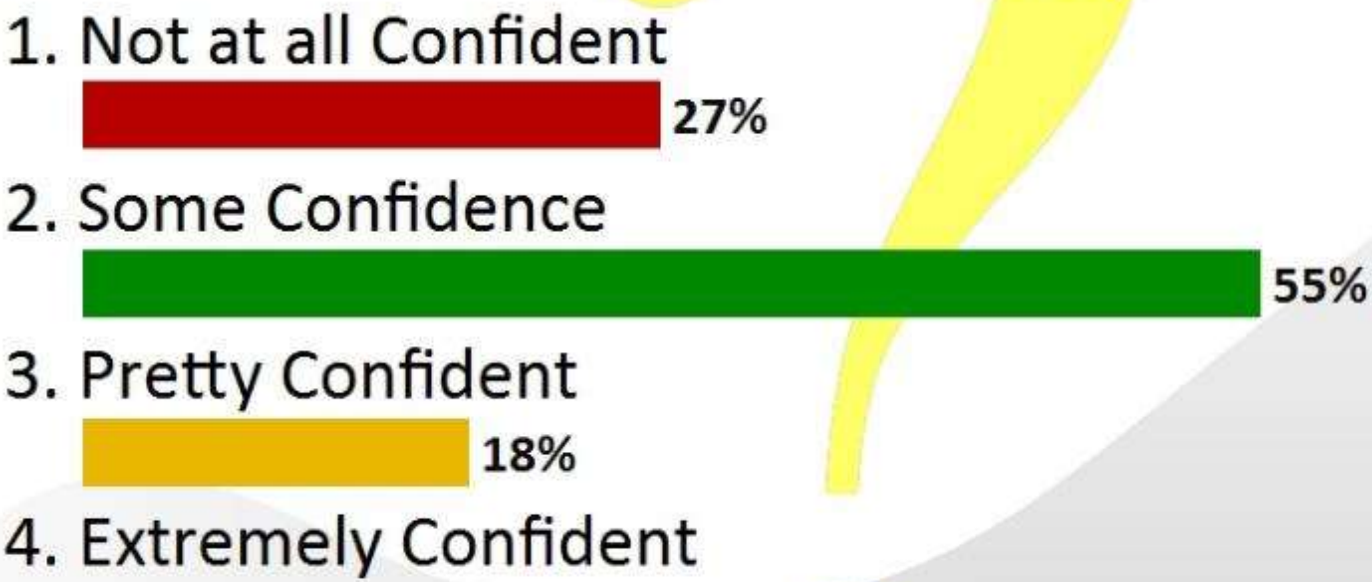
ENTSO-E TYNDP - 2014



Gone Green, National grid - 2015



Q1: How confident do you feel that we have all the tools necessary to meet the future challenges??



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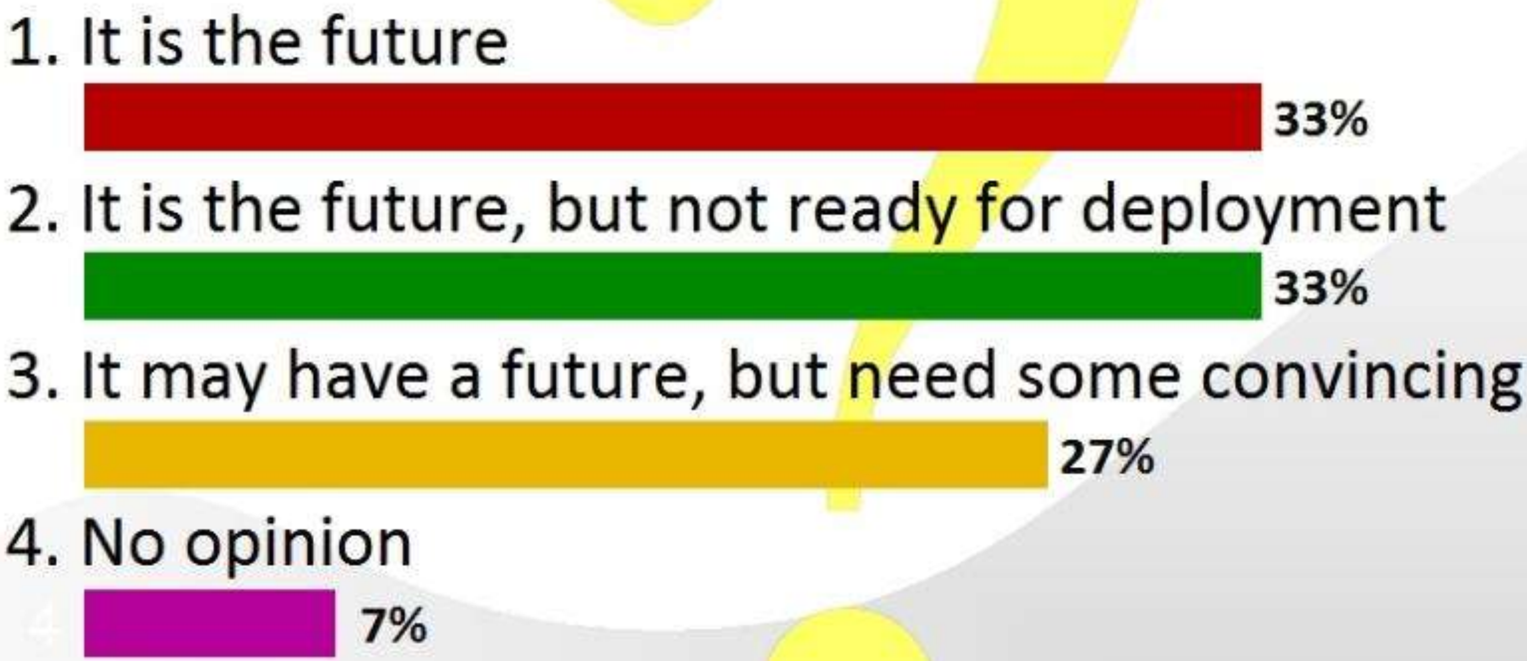
Q1: What is your view on WAMPAC technology?



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TO PMU locations

Scottish and Southern Energy

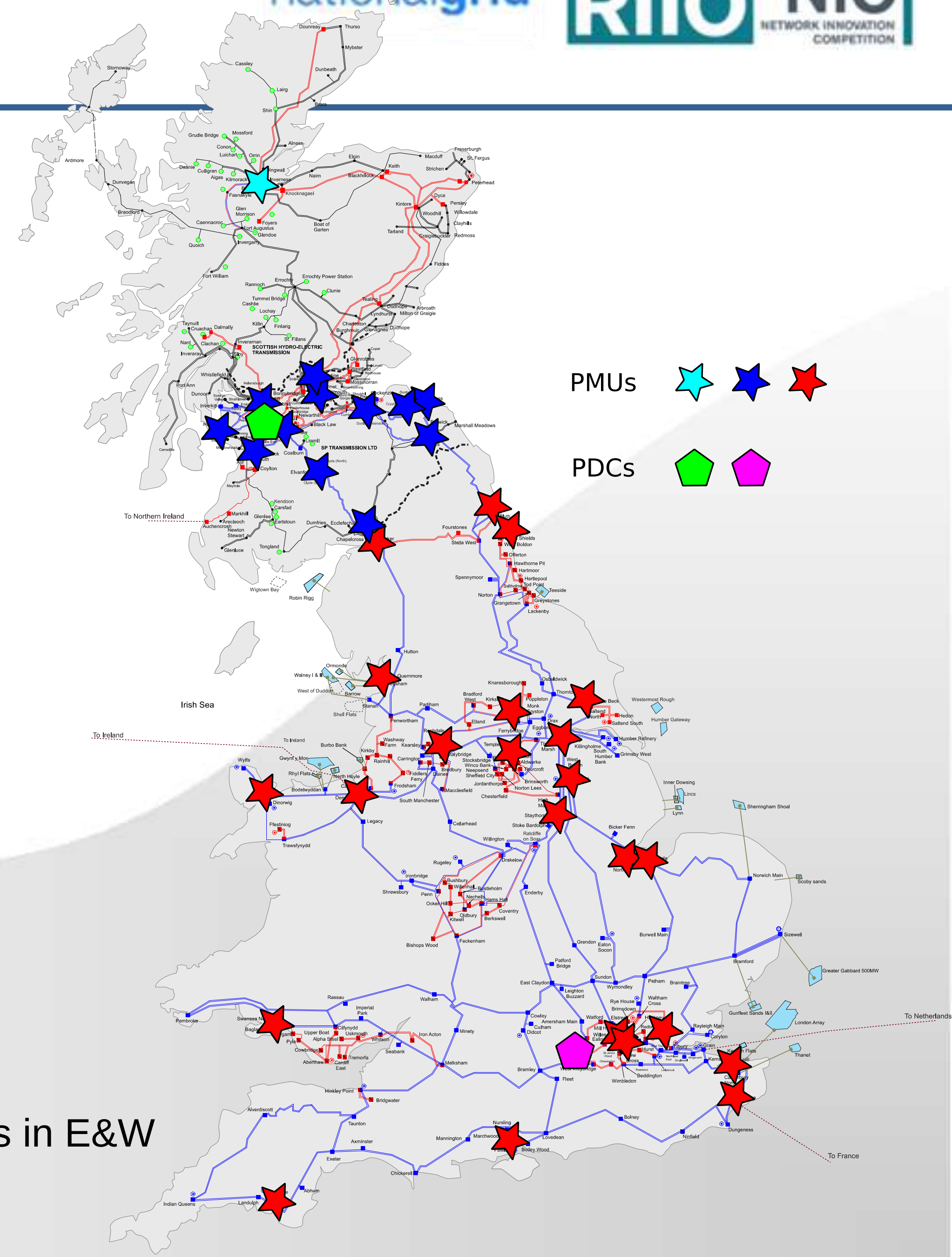
TO North Scotland
1 PMU (recently installed)

SP ENERGY NETWORKS

TO South Scotland
Around 30 PMUs to 1 PDC

nationalgrid

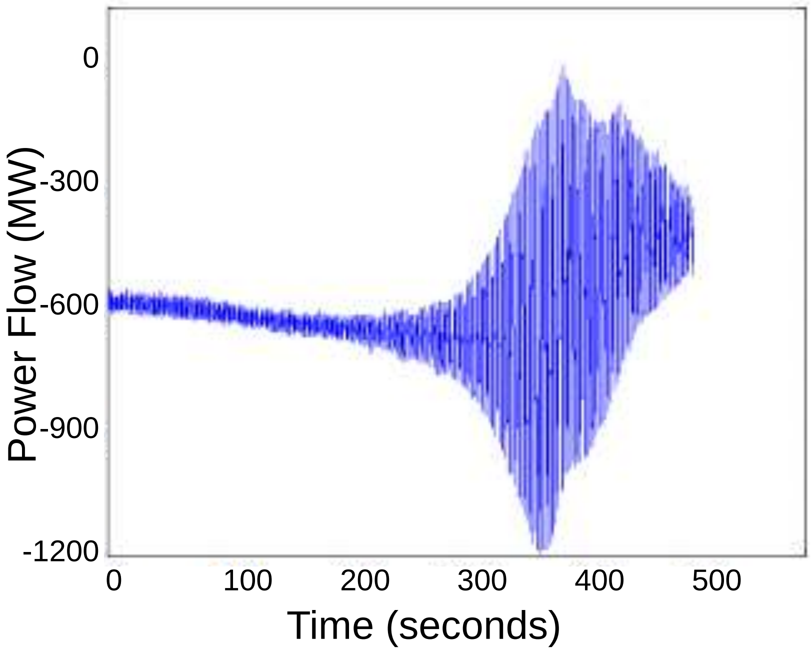
GBSO and TO England and Wales 40 PMUs to 1 PDC

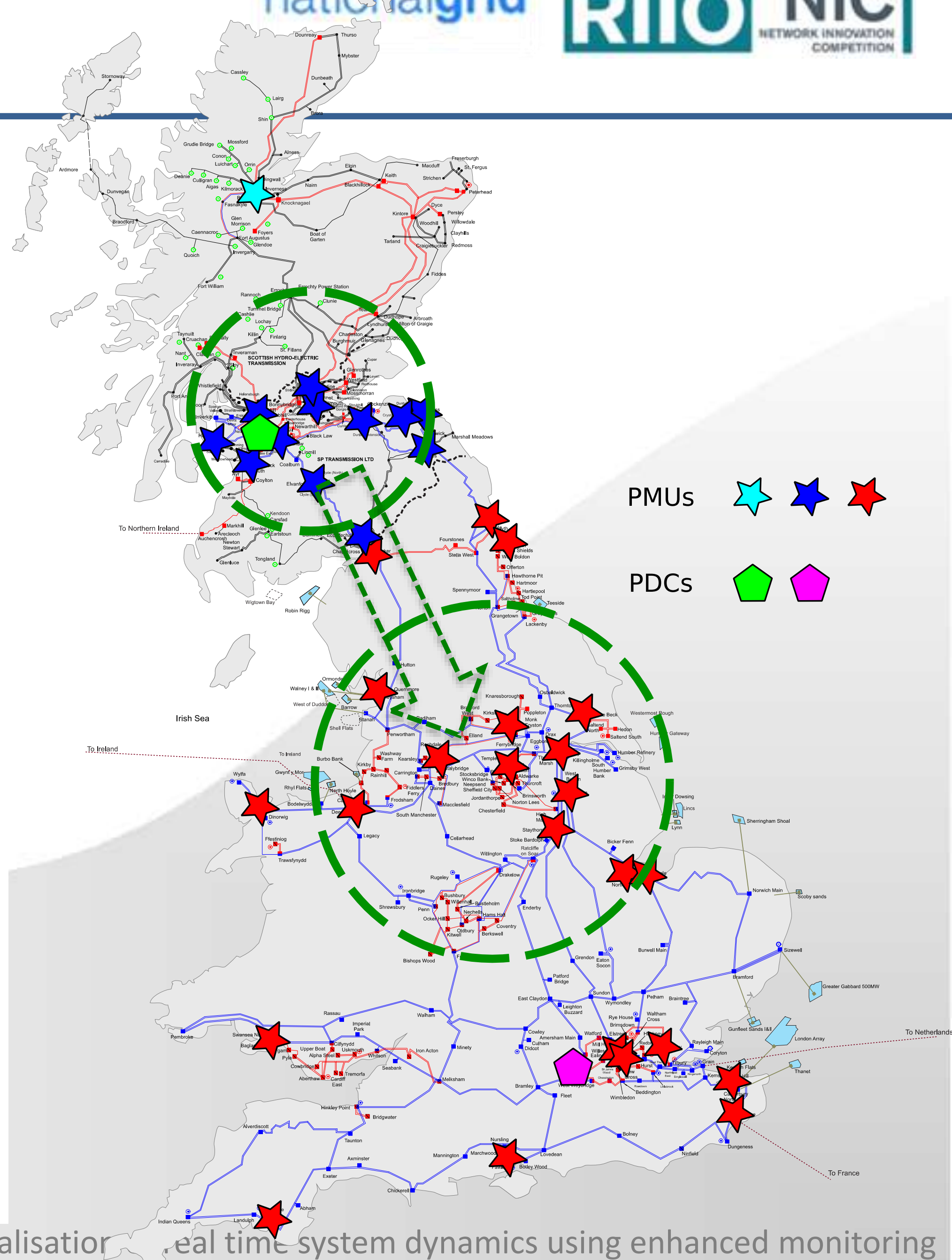


All devices are upgraded DFRs except 4 PMUs in E&W
Not solving problems as such

Oscillation Analysis

- 0.5Hz Oscillations between Scotland and E&W since late 1970's, involving the whole GB system
- Real-time Wide Area Oscillation Monitoring (early warning) live in control room since 1998
- Upgraded to PMU-based system in 2011





Increased potential for oscillation

Increased level of power electronics raises the potential for oscillations

<u>Onshore Incremental (Joint SPT & NGET)</u>

- B6 to ~4400MW
  - Series Compensation
  - Shunt compensation
  - East-West 400kV Upgrade
  - Harker – Hutton Reconductor

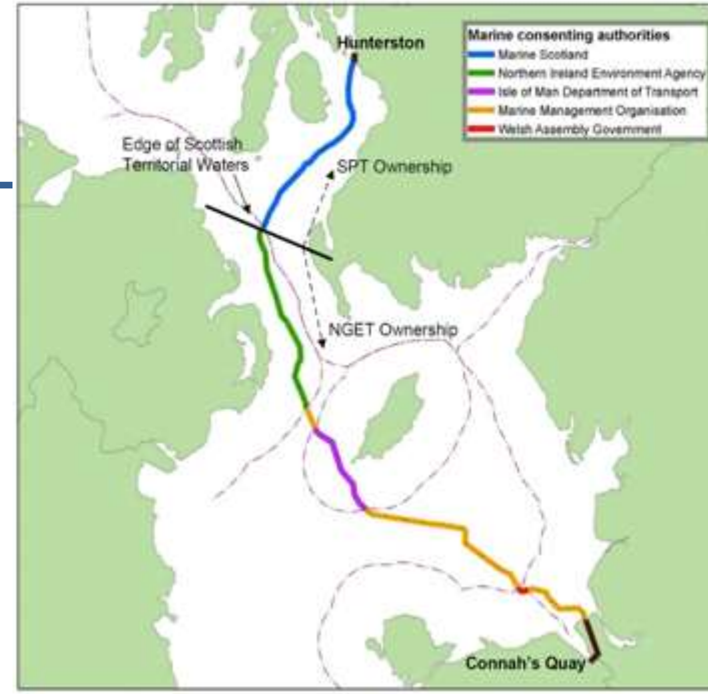
Moffat 400kV Series Compensation Equipment

Increased potential for oscillation

Increased level of HVDC links increases potential for oscillations

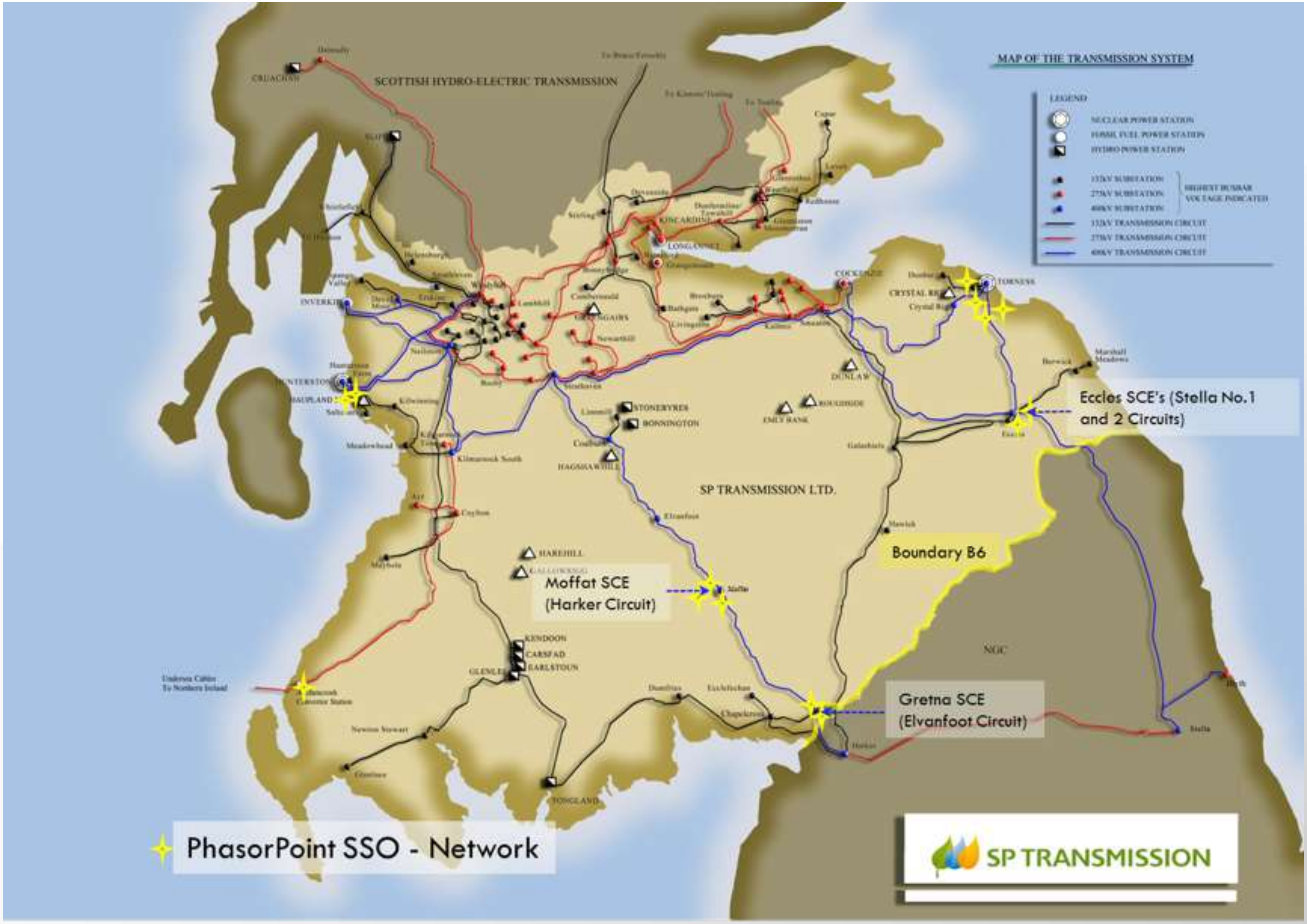
<u>Western HVDC Link (Joint SPT & NGET)</u>

- B6 to ~6600MW 600kV HVDC
- 2250MW
- Bidirectional
- Subsea



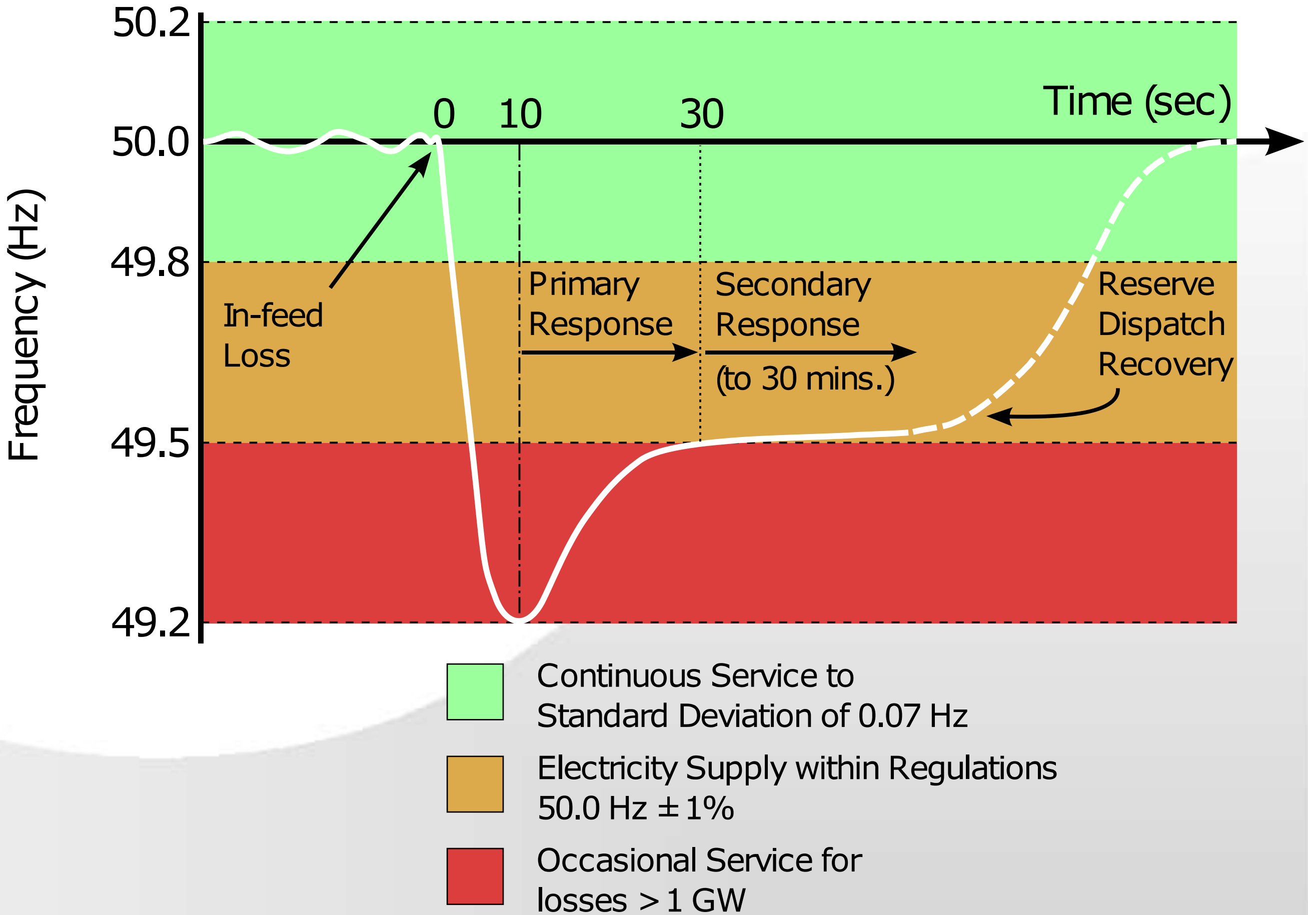
Hunterston Projects – Hunterston Converter (Western HVDC)

WAMS to Manage Oscillations



Analysis – Frequency Response

- Little knowledge on non-generation inertia
- RoCoF relay triggers to Loss of Mains protection on embedded generation
- Around 7-8GW, rising to 15GW by 2020.
- Need to understand regional variations



Important to capture frequency events, they provide the only opportunity to understand the response of the system!

Post-event Analysis Inertia Estimation

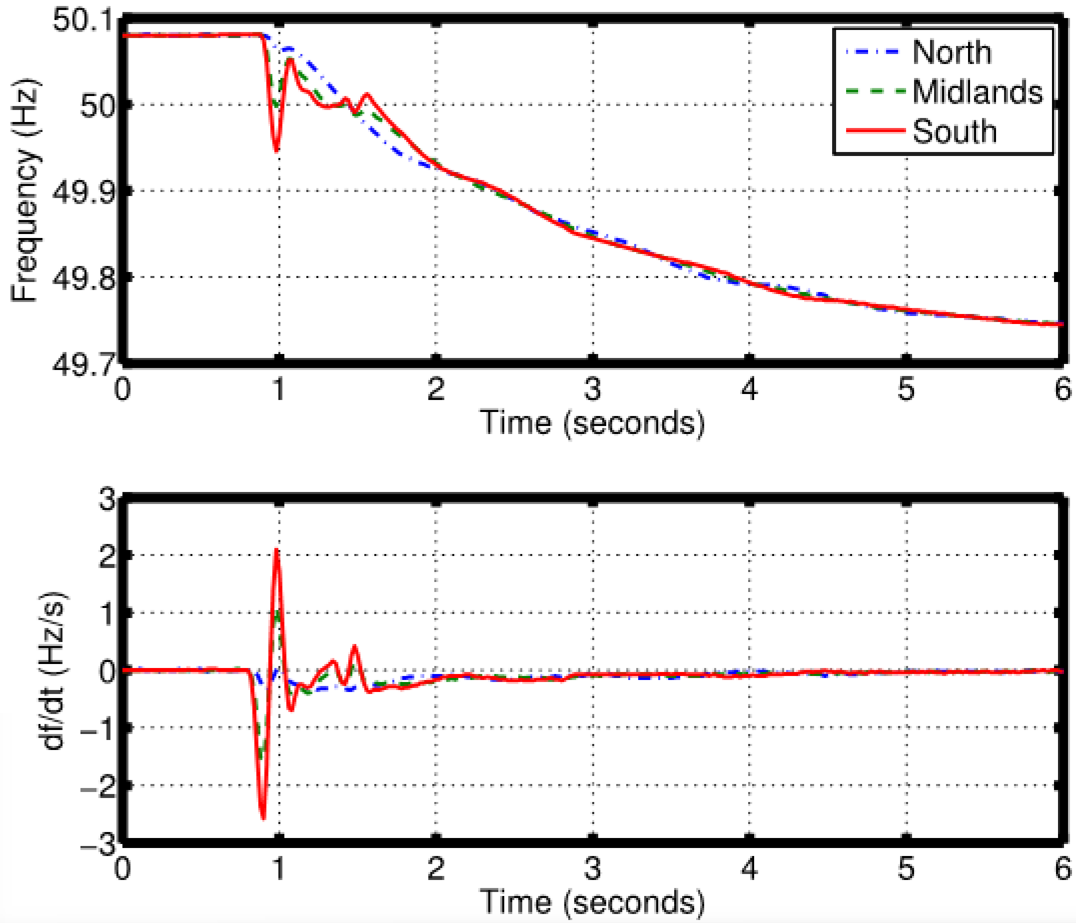
BMr only (1/2hr mean)

DH (1Hz-10Hz)

$$2H = \frac{\Delta P}{\frac{df}{dt}} . f_0$$

PMUs (50Hz)

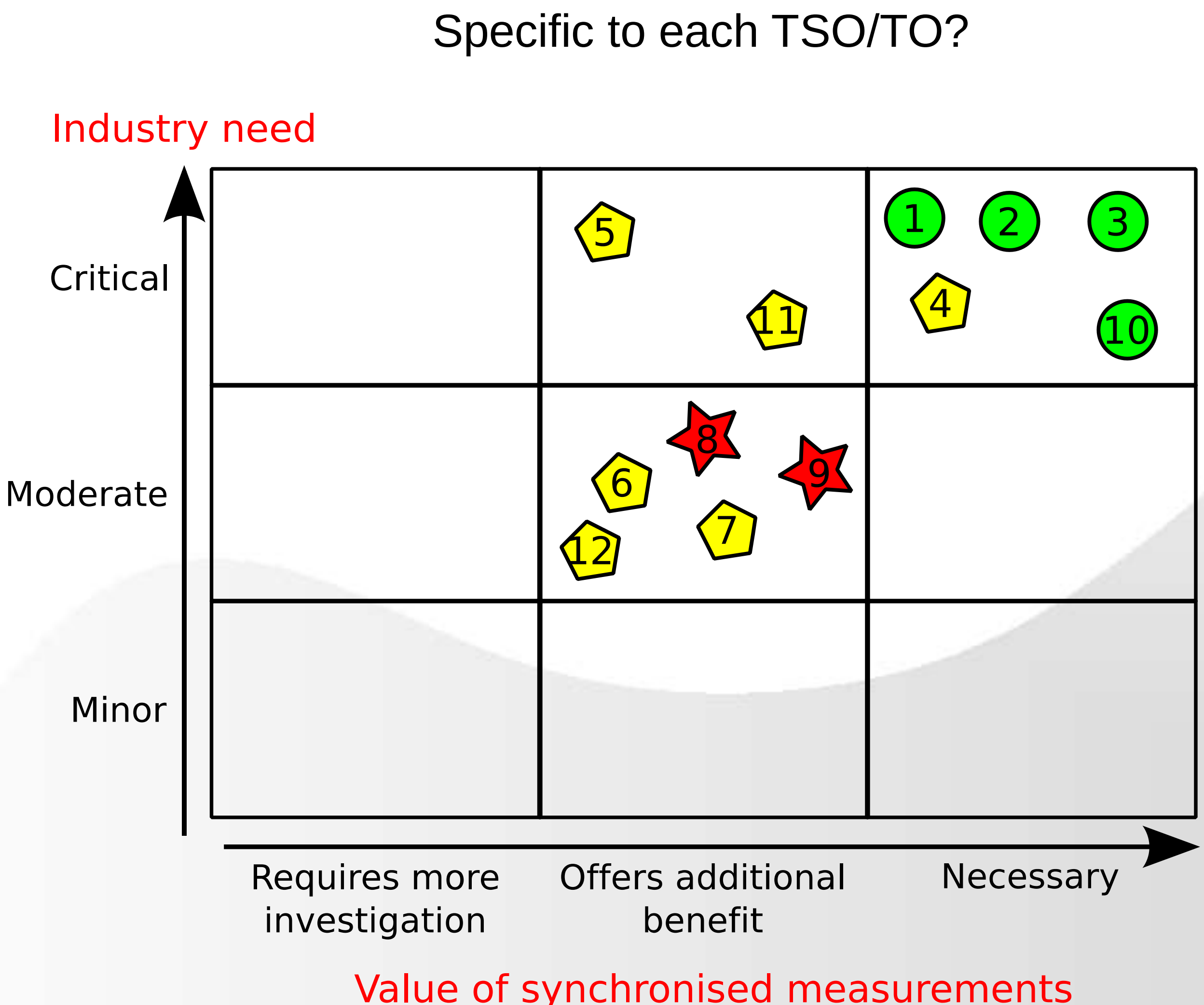
- Frequency – Not constant!
- Hence df/dt isn't either
- How to calculate df/dt?
- Regional influences
- Generation
- Demand
- Network strength
- Data Accuracy!



Can then be used in dynamic model comparisons…

P. M. Ashton et, al "Inertia Estimation of the GB Power System Using Synchrophasor Measurements", IEEE Transactions on Power systems 2014

Synchrophasor Applications



Online Applications
1. Angle/Frequency monitoring
2. Voltage stability monitoring
3. Stability analysis
4. Congestion management
5. Line thermal monitoring
6. Hybrid state estimation
7. Islanding
8. Adaptive protection SIPS
9. Real-time control WAMPAC

Offline Applications
10. Post-event analysis
11. Model validation
12. Inertia estimation

Deployment Challenges

LOW MED HIGH

Damir Novosol, 2008

VISOR Work packages

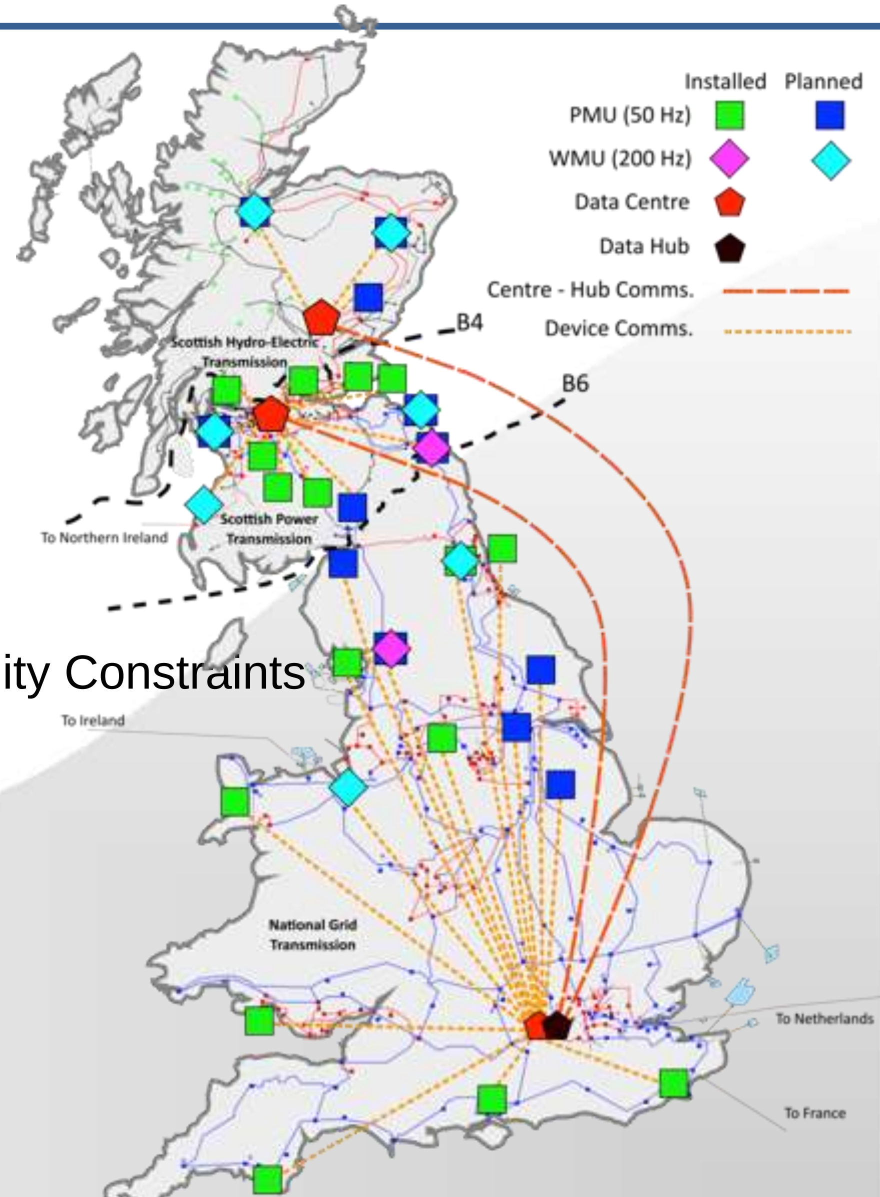
WP1 – Enhanced Oscillation Monitoring
- Sub-Synchronous (4-46Hz)
- VLF (0.005-0.1Hz)
- LF (0.1 – 4Hz) + Source location

WP2 – System Model Validation
- Robust Line Parameter Estimation
- Oscillation Analysis Validation
- Transient Stability Simulations

WP3 – Improvements for Management of Stability Constraints
- HSE – Manchester University
- B6 Boundary Transfer – Angle Based

WP4 – Supporting Infrastructure – **Vital!**
- Servers
- Comms
- WMUs

Pathway to the Control Room?



Summary

- Climate Change Targets Driving Change
  - Networks expanding – New technologies
  - Motivations for WAMS / WAMPAC
- Existing Monitoring Systems
  - Adopted by Synchrophasor Technology?
- Experience of PMUs to date
  - How to Prove Real-time Benefits?
  - Key Challenges – IT/Comms and Measurement Accuracy
- Future plans and projects
  - Trials and Innovation
  - Moving towards Business as Usual?

WAMS Development on the GB System

Dr Phil Ashton, Strategy and Innovation

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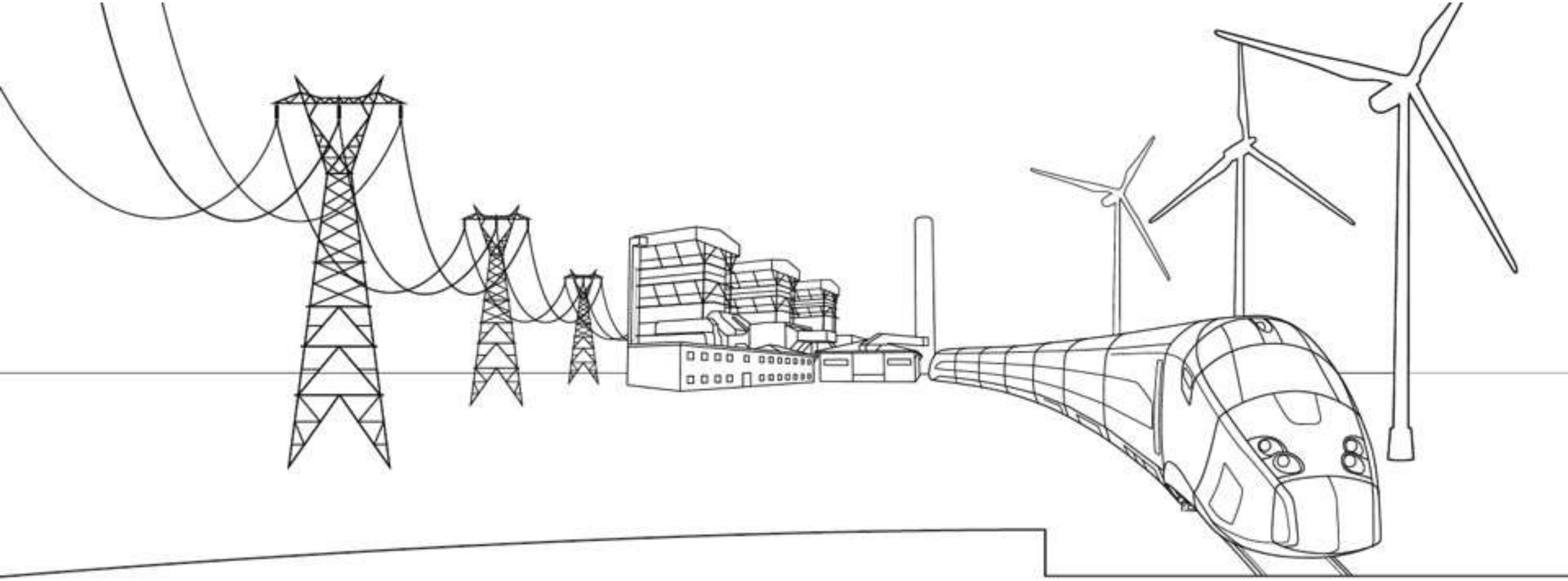
Coffee Break



VISOR Applications

Douglas Wilson, Stuart Clark
Alstom Grid - Psymetrix

VISOR Stakeholder Event, London

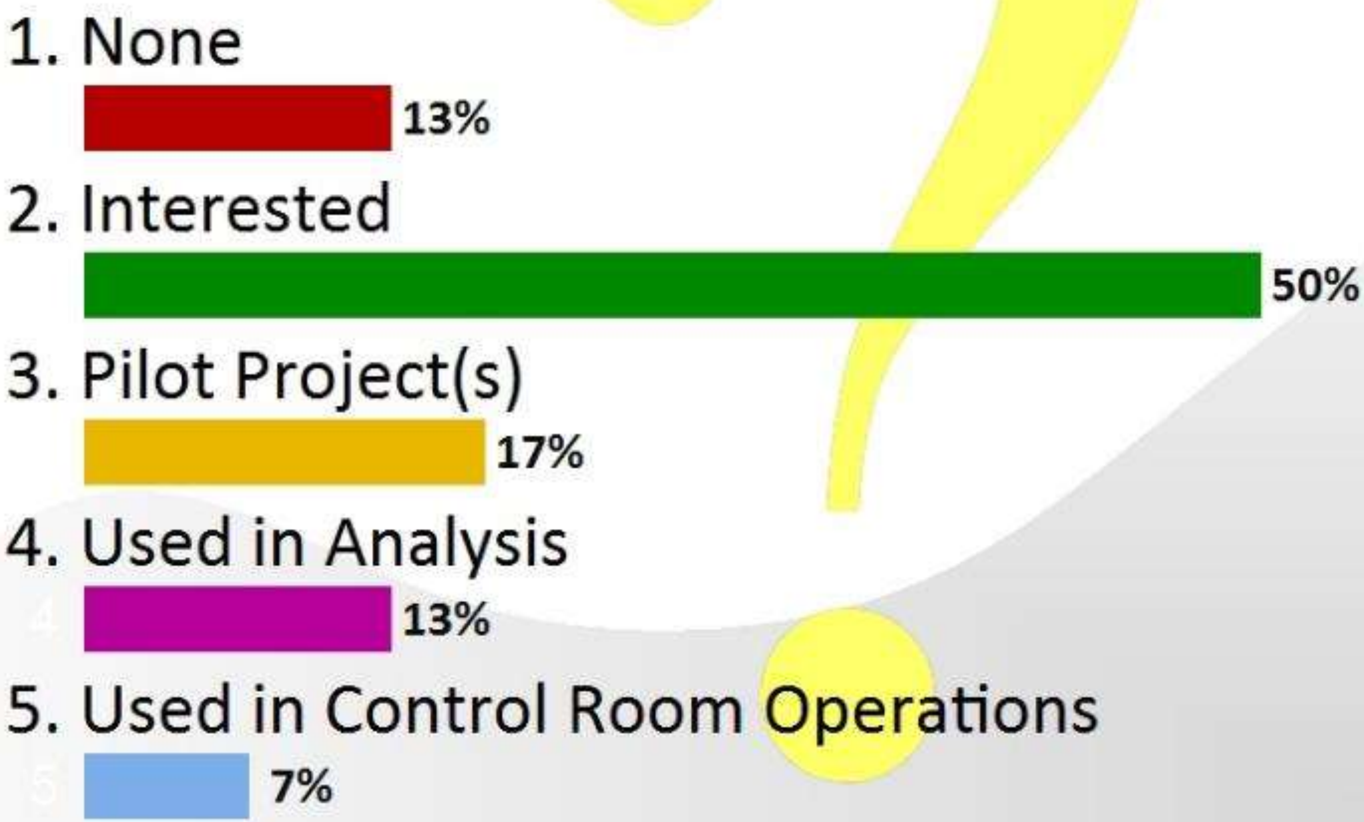
18/08/2015

ALSTOM
Shaping the future

Outline

- VISOR Motivation & Objectives
- Overview of VISOR Applications:
  – Function
  – Motivation
  – Theory, Challenges & Innovation
  – Results so far

Q1: What is your experience with WAMS?



VISOR Motivation

The GB power system is changing:

- **Generation**
  - Closure of large synchronous generation
  - Increased wind generation
- **Network**
  - Intra-network HVDC link, new HVDC interconnectors
  - Series Compensation (Fixed & Thyristor-Controlled)
  - Heavily constrained boundaries (B6 Scotland-England)

This creates a need for enhanced monitoring, to:

- Give **early warning** of emerging problems
- **Give operators a more confident picture** of the system operating state and true limits
- **Provide study data** to improve models & understanding

VISOR Scope

RIIO NIC NETWORK INNOVATION COMPETITION

- **Demonstrate the concepts & benefits** of WAMS applications in business-as-usual
- **Focusing** on three key areas:

Managing Risk & Events

- Oscillation Monitoring & Source Location
  - 0.002 – 0.1 Hz Governor & Common
  - 0.1 – 4 Hz Electromechanical & Voltage Control
  - 4 – 46 Hz Torsional, Resonance & Control interaction
- Disturbance Detection, Location & Characterisation

Maximising Assets

- Demonstration & Evaluation of Angle-Based Security Limits
- WAMS Infrastructure Requirements, Evaluation & Rollout Recommendations

WAMS Software Applications

*Demonstrated in Alstom Grid's **PhasorPoint** WAMS software*

Reducing Uncertainty

- Demonstration & Evaluation of Hybrid State Estimation
- Impact of Uncertainty on Security Margins
- Dynamic Model Validation
- Robust Line Parameter Estimation

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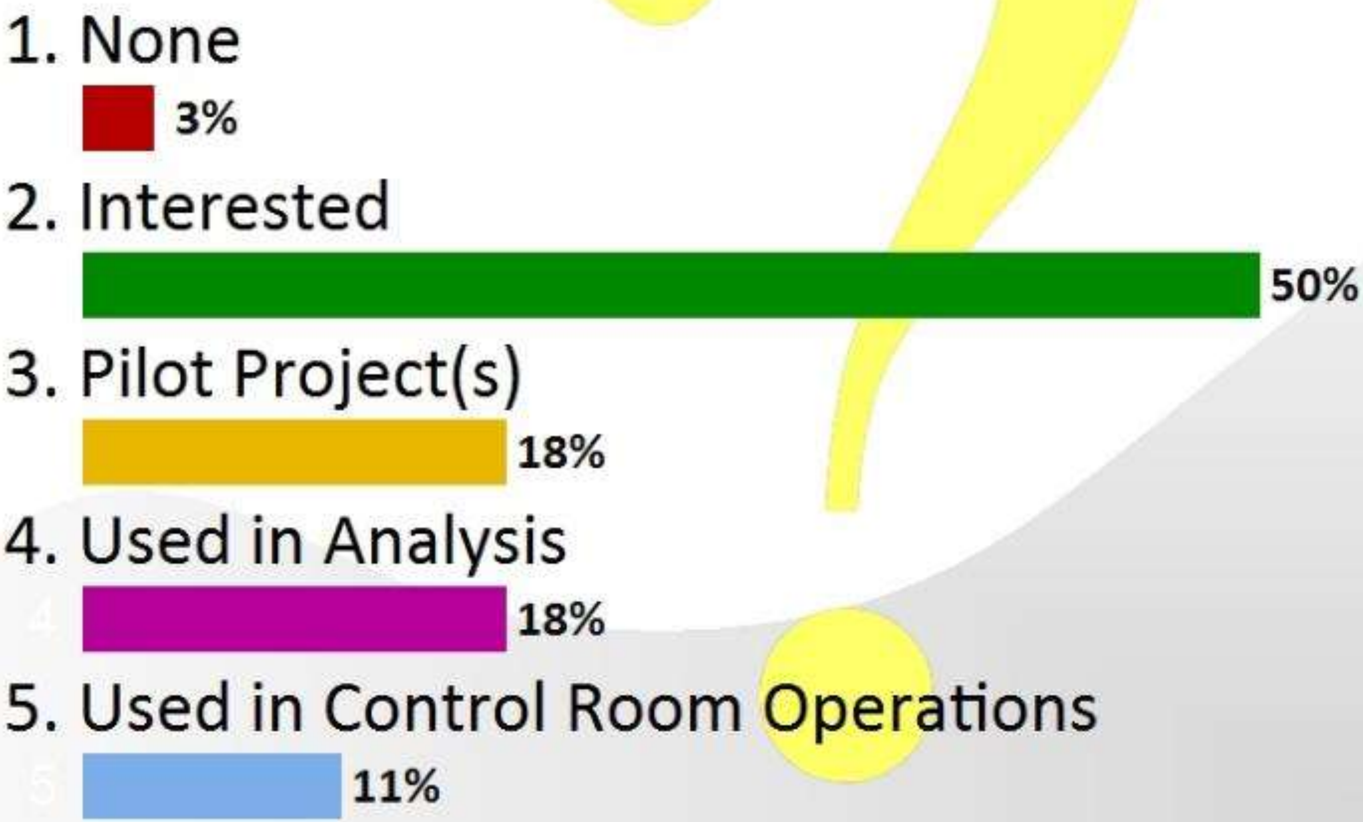
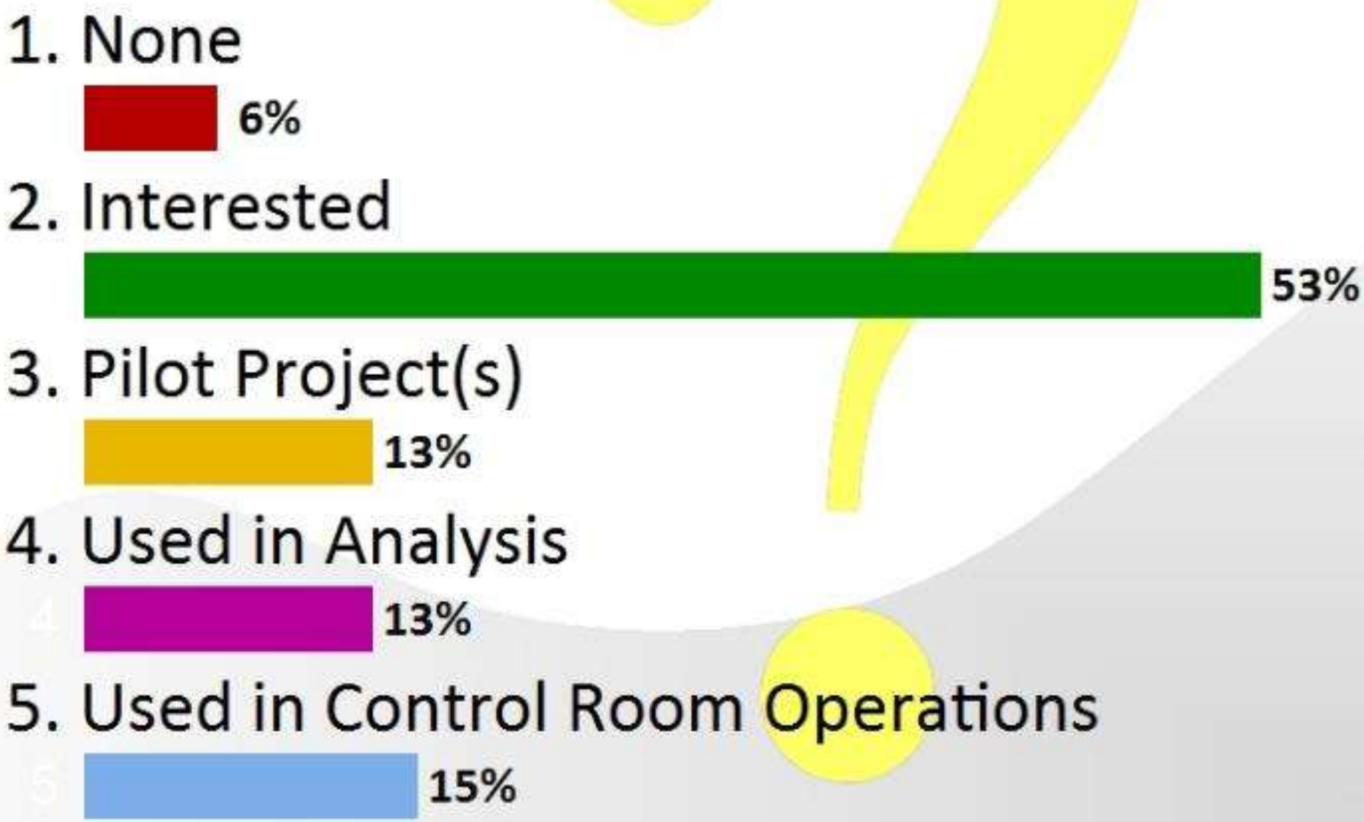
Q3: What is your level of use/interest in using WAMS for Oscillation Monitoring?



RIIO NIC NETWORK INNOVATION COMPETITION

Q4: What is your level of use/interest in using WAMS for Wide-Area situational awareness (angle, voltage, PQ condition...)?



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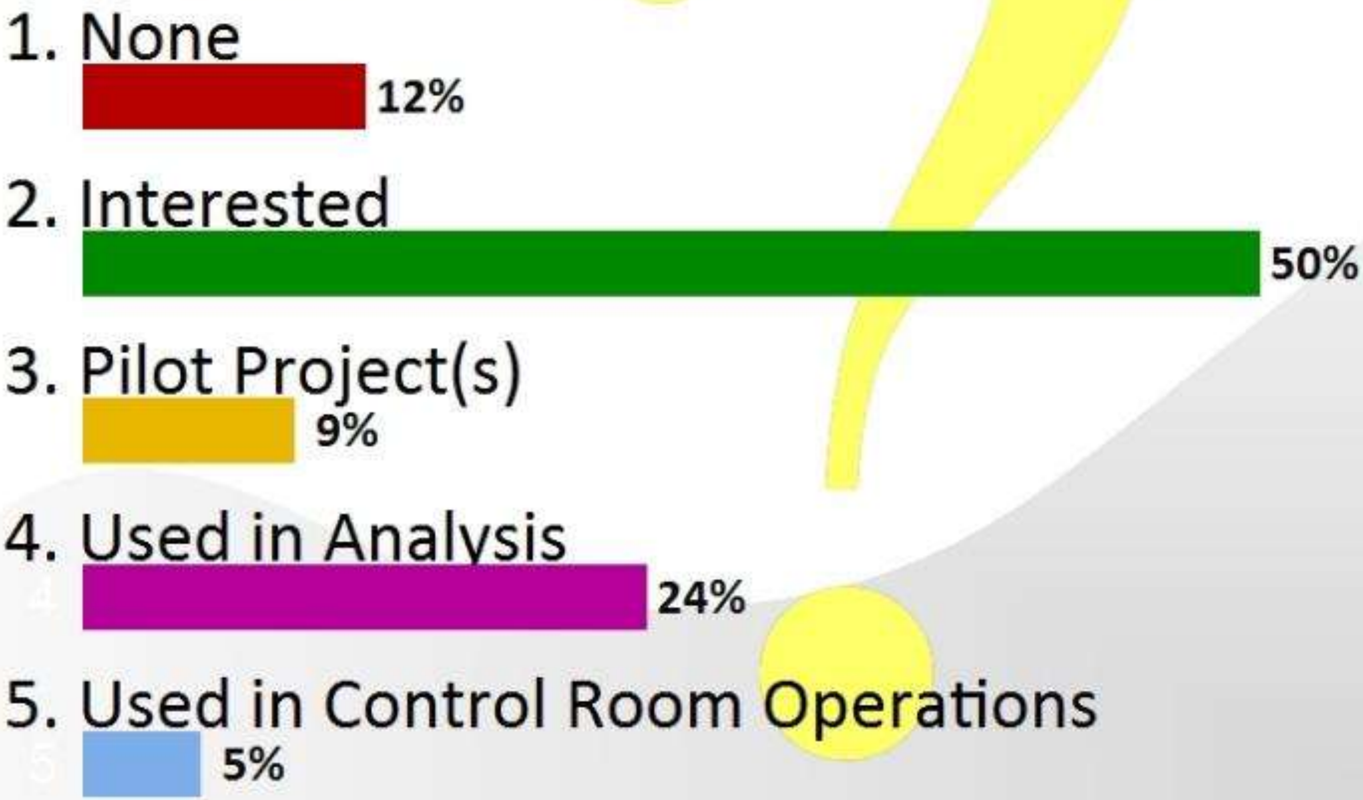
VISOR Project: Visualisation of real time system dynamics using enhanced monitoring

Q5: What is your level of use/interest in using WAMS for Managing System Disturbances?



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NETWORK INNOVATION COMPETITION

Q6: What is your level of use/interest in using WAMS for Hybrid State Estimation?

1. None
   9%
2. Interested
   68%
3. Pilot Project(s)
   15%
4. Used in Analysis
   8%
5. Used in Control Room Operations

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Q7: What is your level of use/interest in using WAMS for Line Parameter Estimation?

1. None
   3%
2. Interested
   61%
3. Pilot Project(s)
   18%
4. Used in Analysis
   18%
5. Used in Control Room Operations

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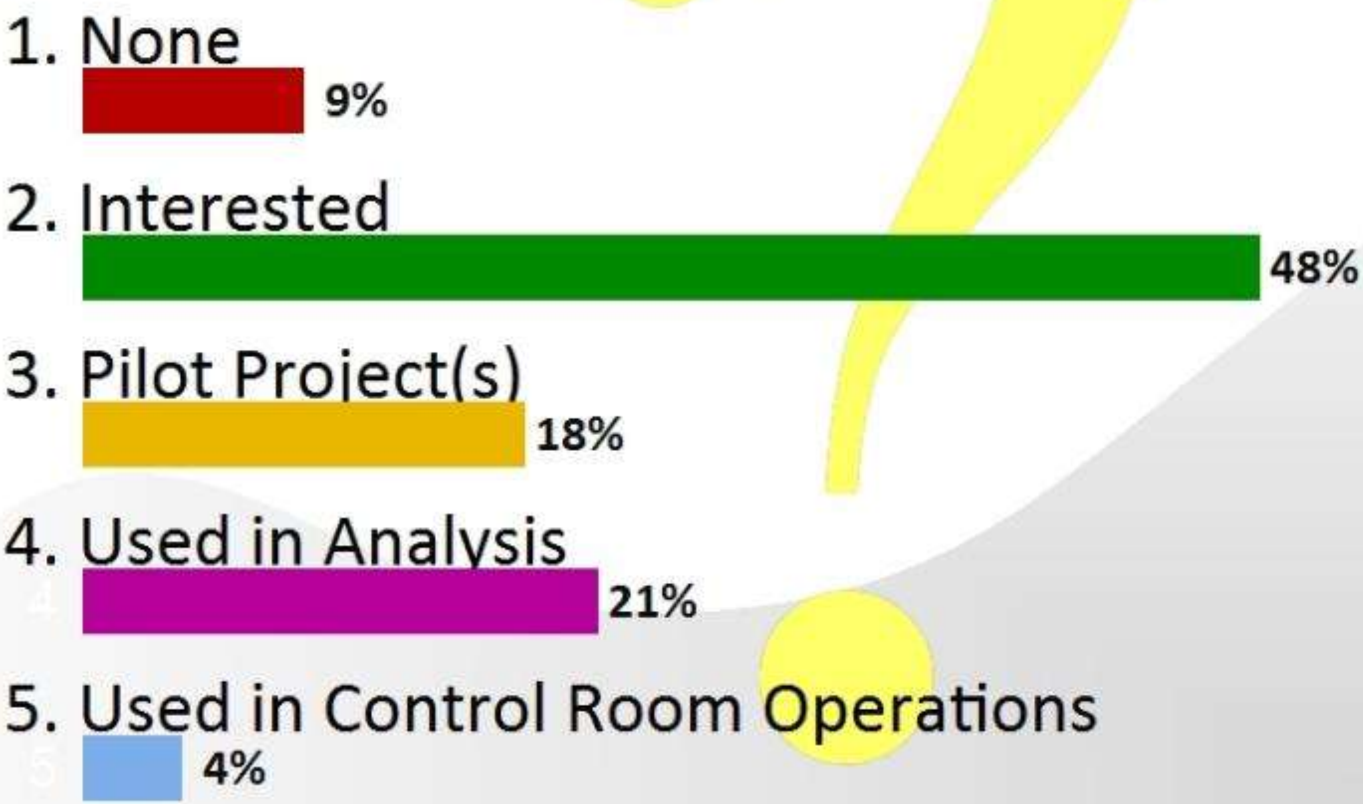
Q8: What is your level of use/interest in using WAMS for Model Validation / Tuning?



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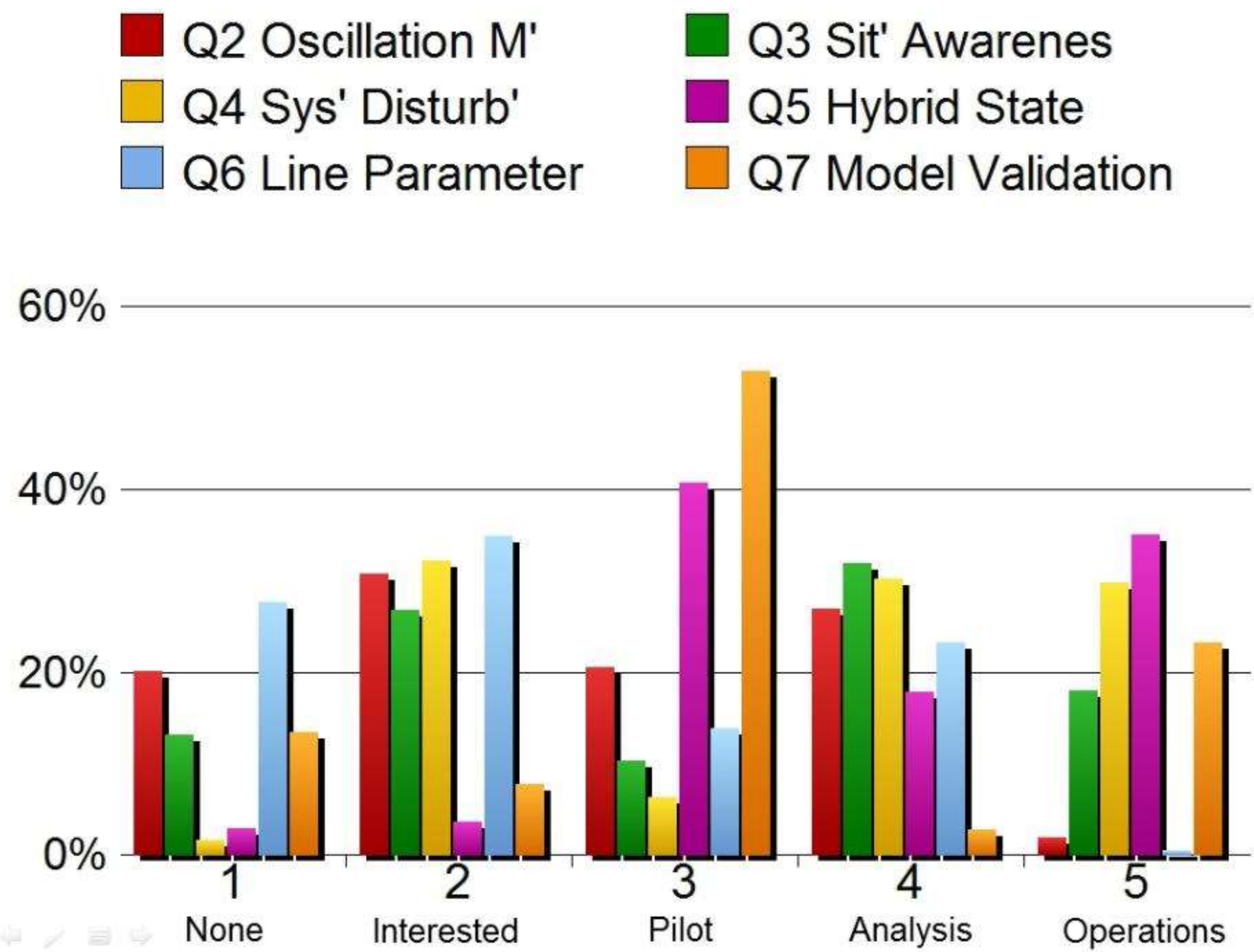
Q2 Oscillation M'
Q3 Sit' Awarenes
Q4 Sys' Disturb'
Q5 Hybrid State
Q6 Line Parameter
Q7 Model Validation
60%
40%
20%
0%
1
None
2
Interested
3
Pilot
4
Analysis
5
Operations

OSCILLATIONS

Oscillations: Motivation

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- **Risk of Sub-Synchronous Oscillation (SSO)**
  - Series Compensation
  - Power Electronic Controllers (HVDC, wind)
  - Generator shaft torsional modes
- **Changing system dynamics**
  - Loss of generators with a Power System Stabilising role
  - Reduced inertia (less synchronous generation, more wind)
  - New plant, of increasing complexity (HVDC, wind, FACTs)
- **Existing monitoring limited**
  - Covers Electromechanical & Voltage Control modes (0.1–4Hz)
  - Identification of sources of oscillations is complex

Need enhanced monitoring to <u>compliment</u> studies, models & protection

- **Extended visibility** to include SSO & governor modes (0.002–46Hz)
- **Clear, actionable information** for operator decision making
- **Long-term Study** for baselining of behaviour & validation of models

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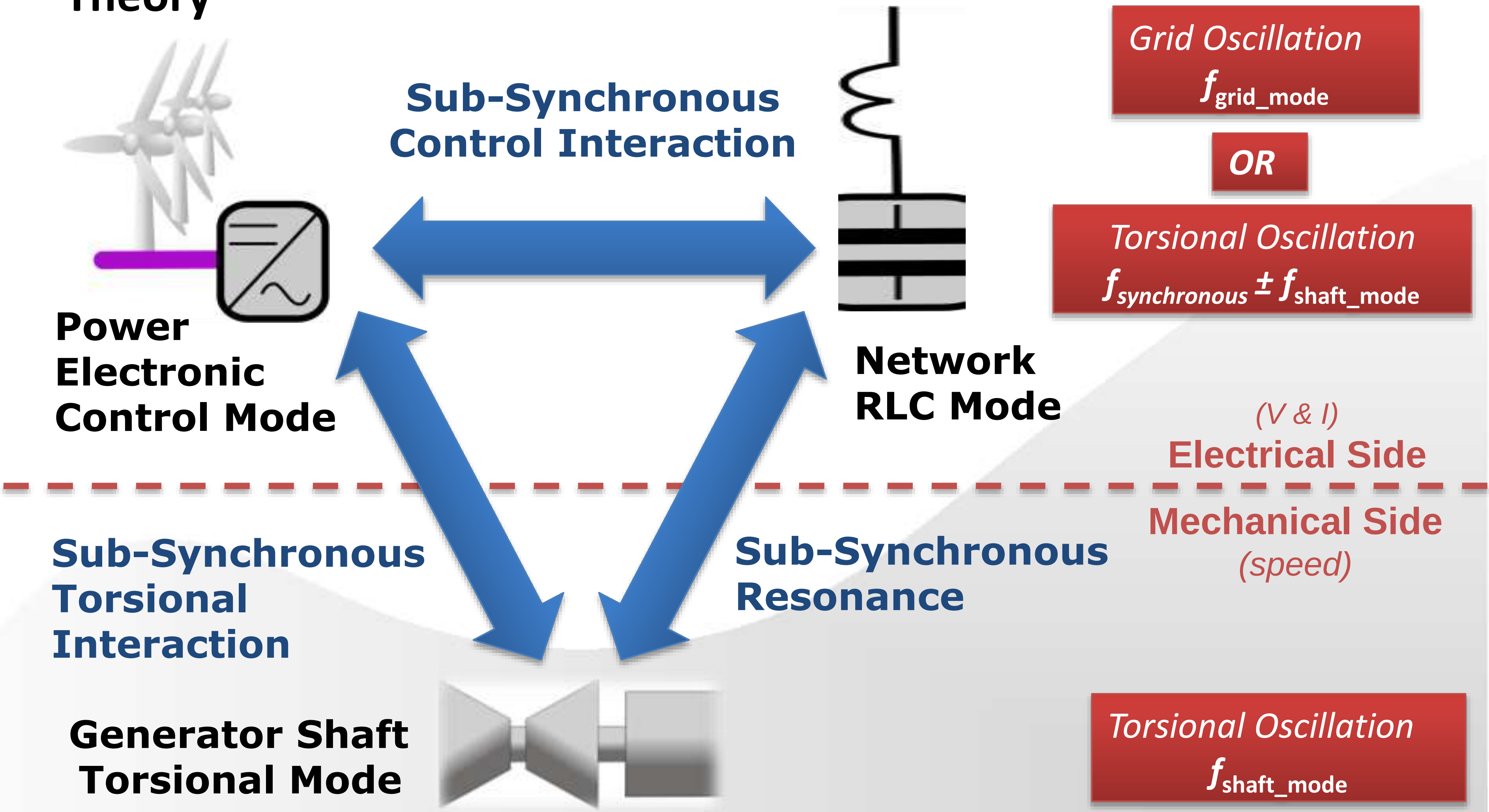
Oscillations: Function

VISOR will demonstrate:

- **Extended oscillation monitoring**
  Visualisation & alarming of frequency, damping & amplitude:
  - Governor modes *(new)* **0.002 – 0.1 Hz**
  - Electro-mechanical Modes *(existing)* **0.1 – 4 Hz**
  - Sub-Synchronous Oscillations *(new)* **4 – 46 Hz**
- **Oscillation source location**
  - Determine relative contribution of each monitored location to an oscillation
  - Present to users in a clear way
- **Long-term analysis of oscillations**
  Real-time analysis results stored over project, feeding:
  - Annual reviews of power system dynamics
  - Validation of system model *(University of Manchester)*

Oscillations: SSO

Theory



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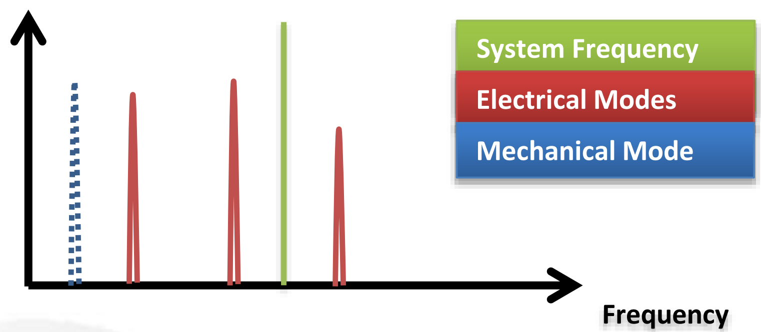
Q9: What is your level of concern about: Sub-Synchronous Oscillations (4 - 46/56 Hz)

Oscillations: SSO

Challenges

- **Electrical - Mechanical relationship**
  Mechanical modes appear as modulations of V & I, at $f_{synchronous} \pm f_{mechanical\_mode}$
  – Need qualitative visibility of modes in the 54-96Hz range, to tell grid modes from mechanical modes



- **Bandwidth of existing monitoring**
  PMU data at 50fps gives accurate visibility up to ~10Hz
  – Need new data acquisition approach with visibility up to 96Hz, accurate up to 46Hz

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Oscillations: SSO

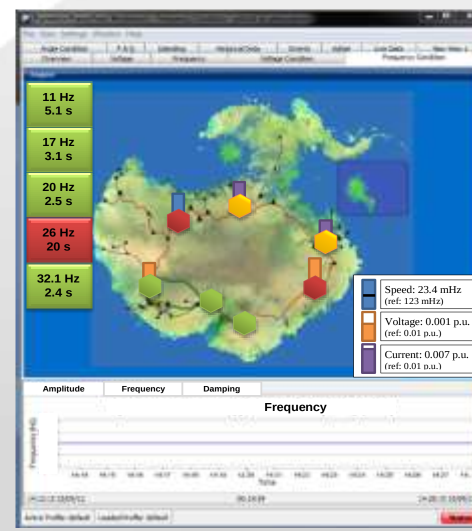
Implementation

- **“Waveform Measurement Unit”**
  - New: **1st demonstration under VISOR**
  - Streams time-synchronised waveforms at **200 samples/s**
  - Sent as **IEEE C37.118** (PMU) stream “analogs” – fully compliant
  - Implemented within **Alstom Reason RPV311**
    simultaneous PMU, WMU, DFR and 800fps continuous recording

RPV311
Central Unit

RA33x
Acquisition Unit

- **SSO Management Application**
  - **Frequency, amplitude & damping** of SSO modes in real time
  - Analyses **Voltage, Current & Shaft Speed**
  - **Alarming** on high amplitude or poor damping
  - Geographic view to **identify interacting locations**
  - Results stored for long-term study



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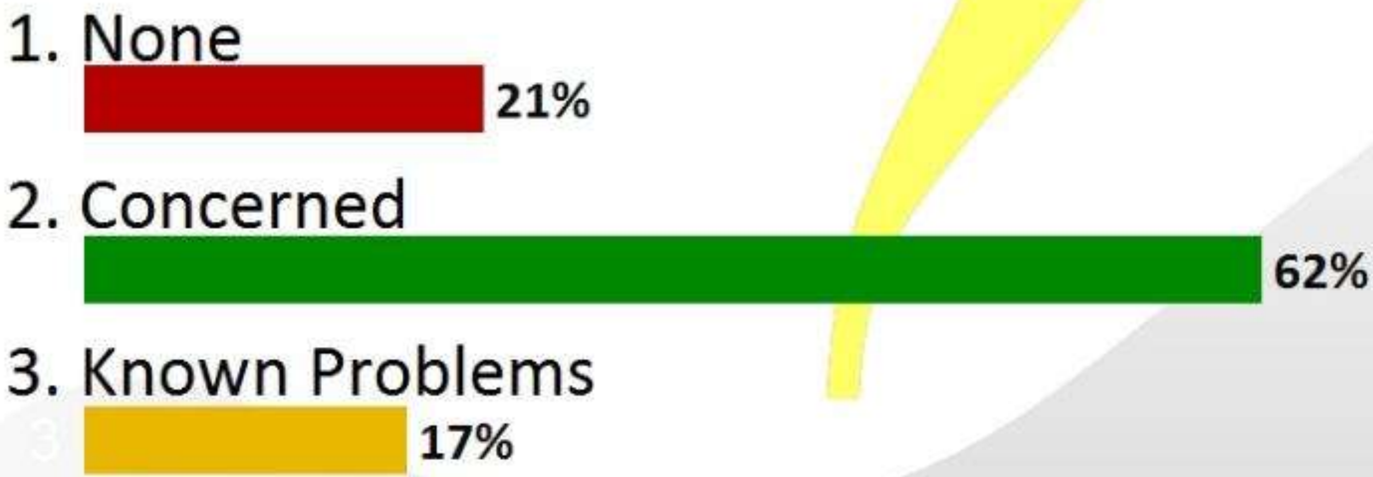
Q10: What is your level of concern about: Governor / Common Mode Oscillations (0.002 - 0.1 Hz)



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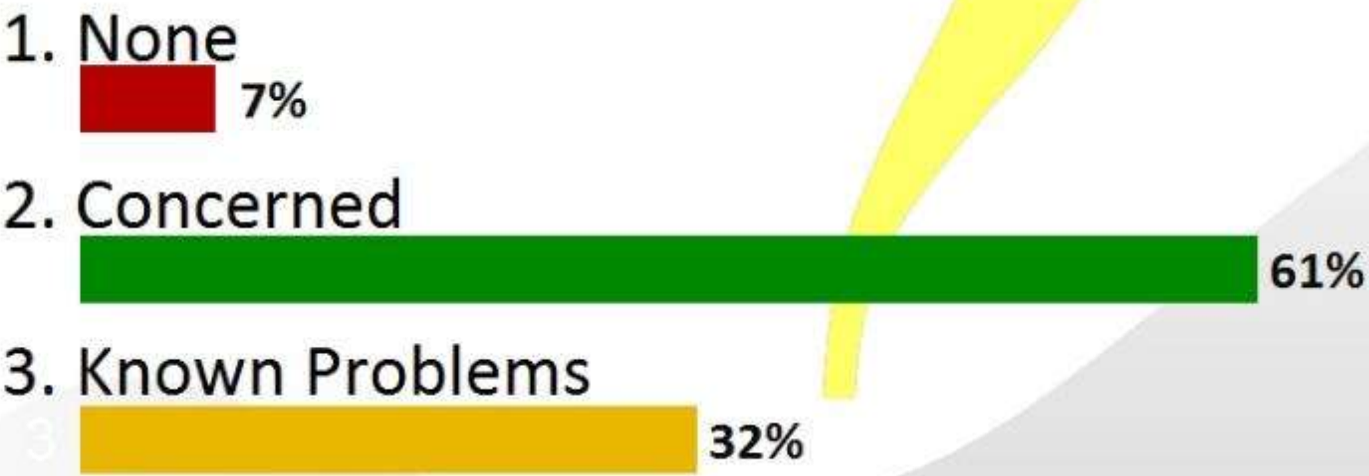
Q11: What is your level of concern about: Electromechanical / Control Oscillations (0.1 - 4 Hz)



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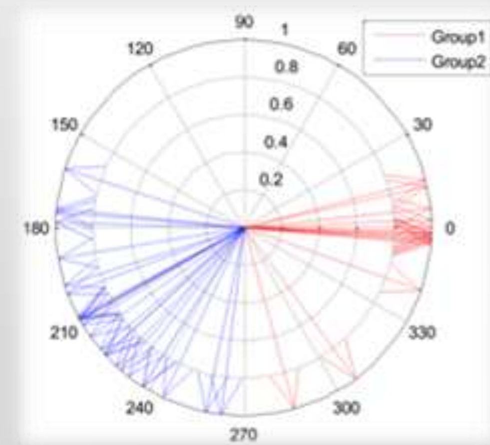
Oscillations: LF - Source Location

Theory, Challenges & Implementation

How to locate oscillation sources?

- Largest amplitude ≠ source!
- Previous measurement-based techniques include:
  - **Analysis of oscillation power flows to trace sources**
    Need high penetration of PMUs on generators and interconnectors, effective only on very poorly damped oscillations
  - **Statistical SCADA analysis** to link behaviour with dispatch
    Historical method, needs repeat occurrences

Solution: analyse relative phase of voltage angle oscillation



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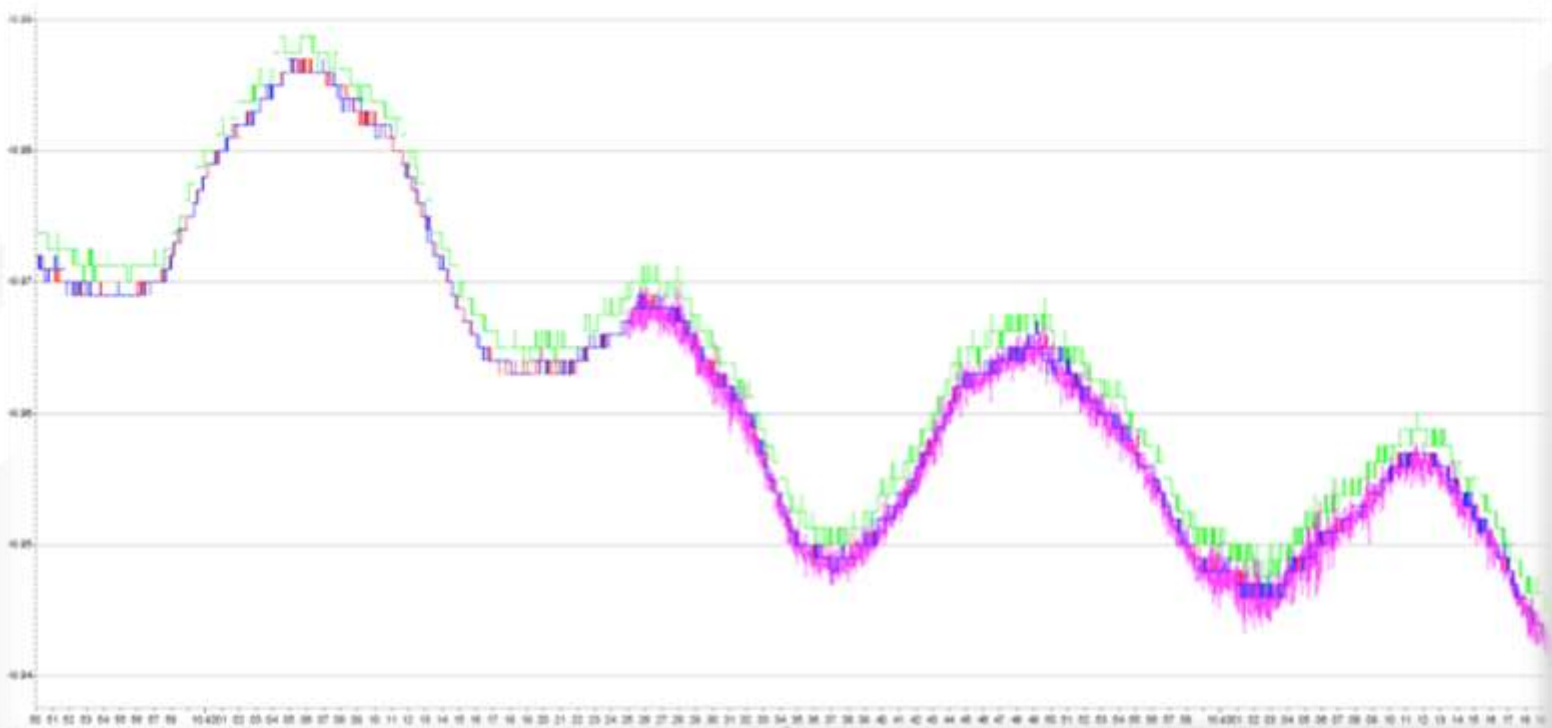
Oscillations: VLF - Source Location

Theory, Challenges & Implementation

VLF - Common Mode Oscillations

Generators accelerate and decelerate in near-unison

V*ery difficult to spot the leader!*



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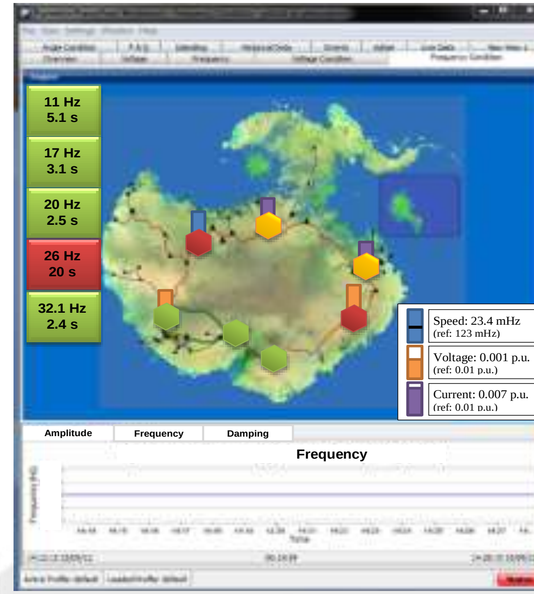
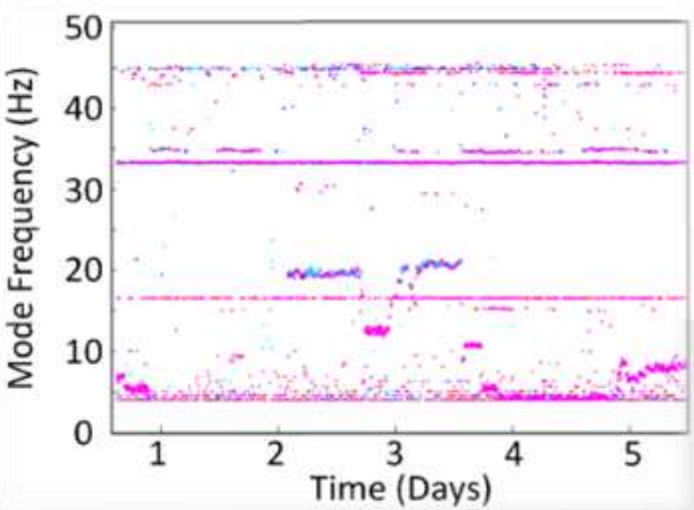
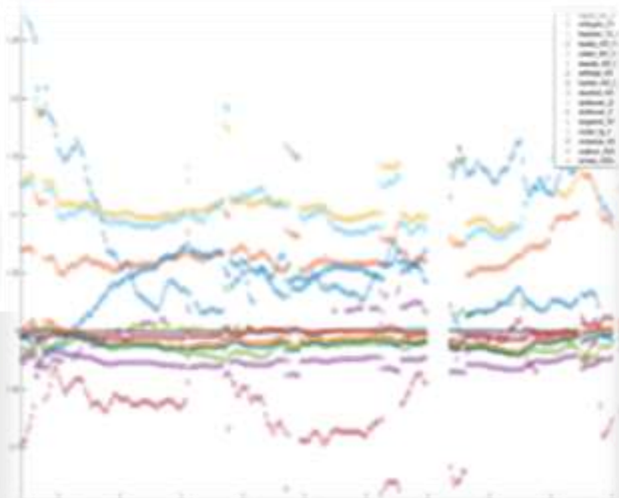
Oscillations

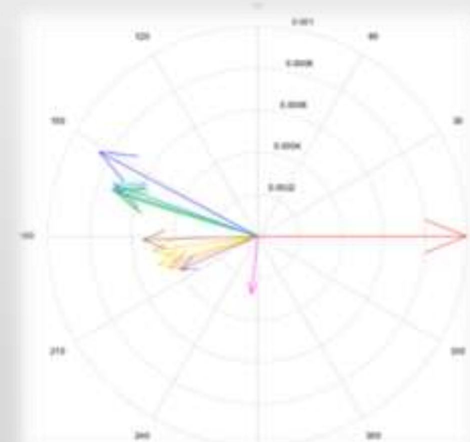
Results so far

- **4 WMUs deployed**
  at Series Capacitor & Generator sites
- **SSO Management application deployed** at SP & NG
- **1st System Performance Report**
  Full 0.002–46Hz analysis, including offline source location









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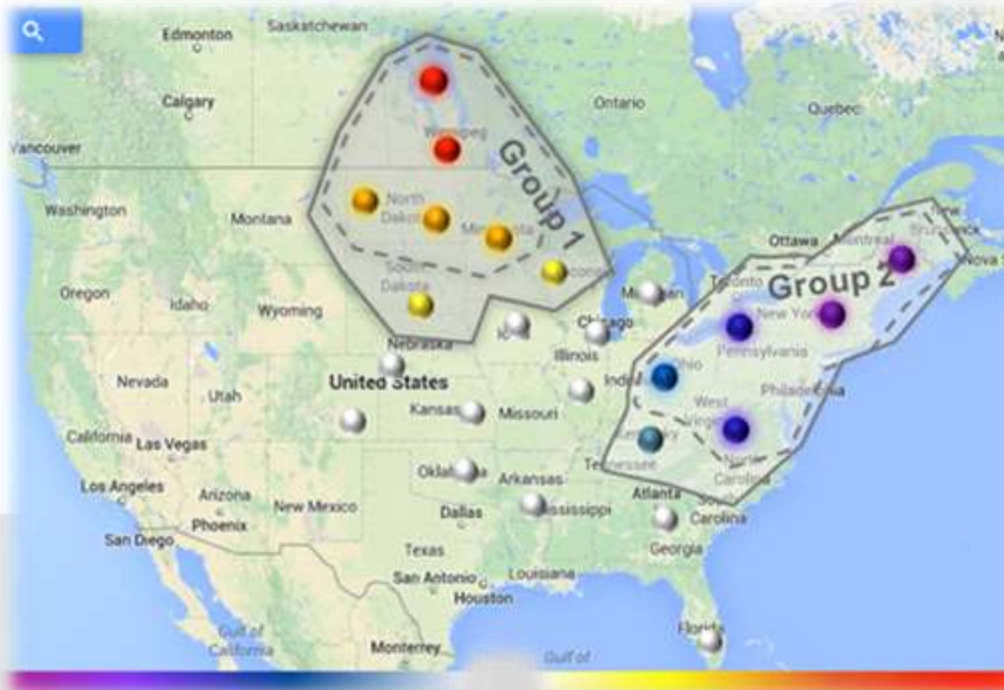
Oscillations

Next Steps

- **5 further WMU installations**
- **VLF Management application** (0.002–0.1Hz)
- **Real-time source location display**



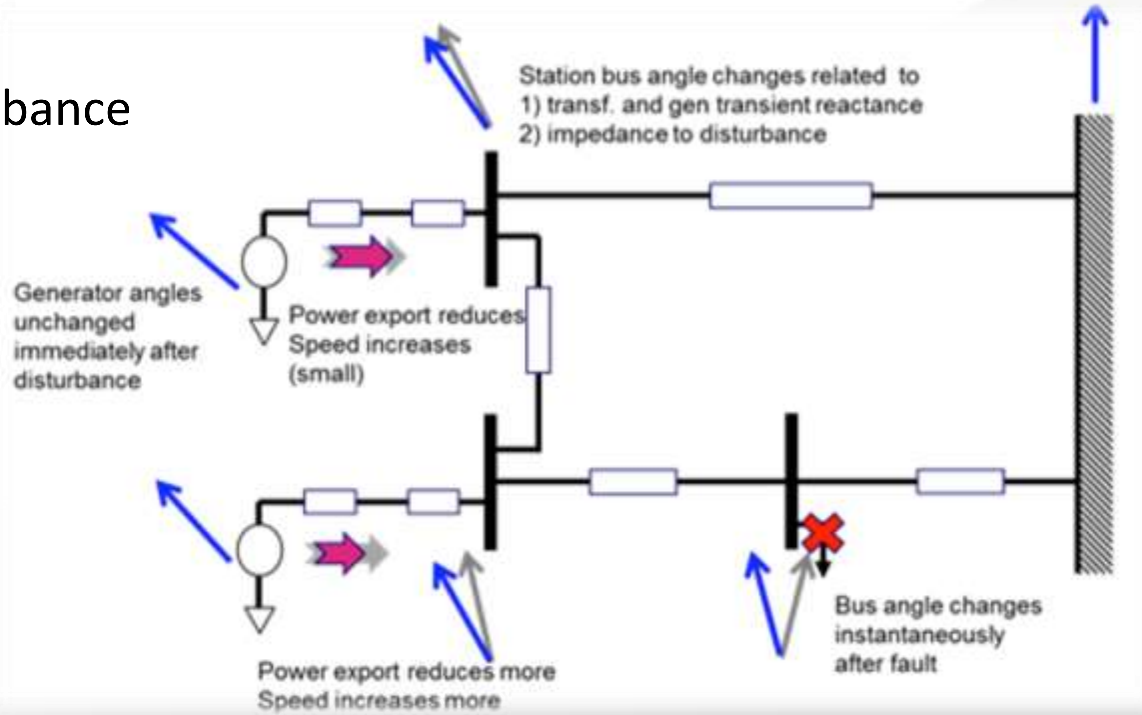
Disturbance Management

Motivation

- Need for fast location & characterisation of disturbances
  Especially for TOs who don't have full external visibility
- Need for metrics to identify significant events for study

Concept

- Angles closer to a disturbance are the first to move
- Disturbances can be characterised based on frequency & angle behaviour (gen / load loss, line trip…)



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Disturbance Management

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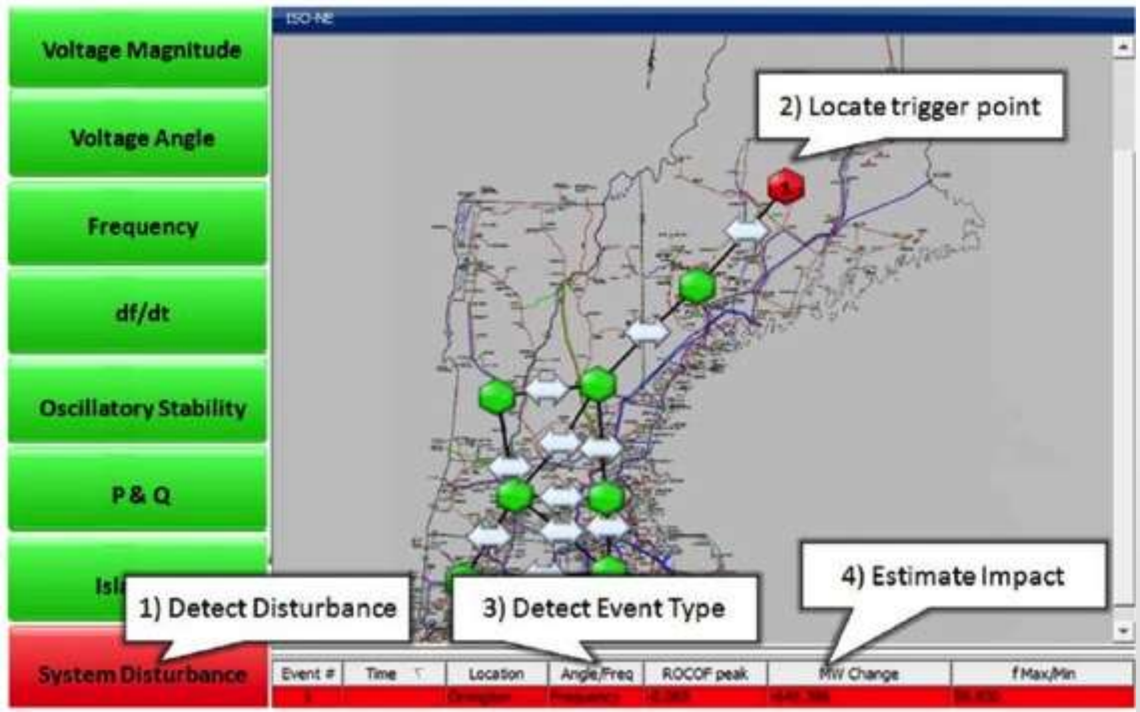
Implementation: Real-time application

- To detect, localise & characterise system disturbances, using PMU voltage & frequency measurements



- Will include event metrics to aid in selecting disturbances for academic model validation work

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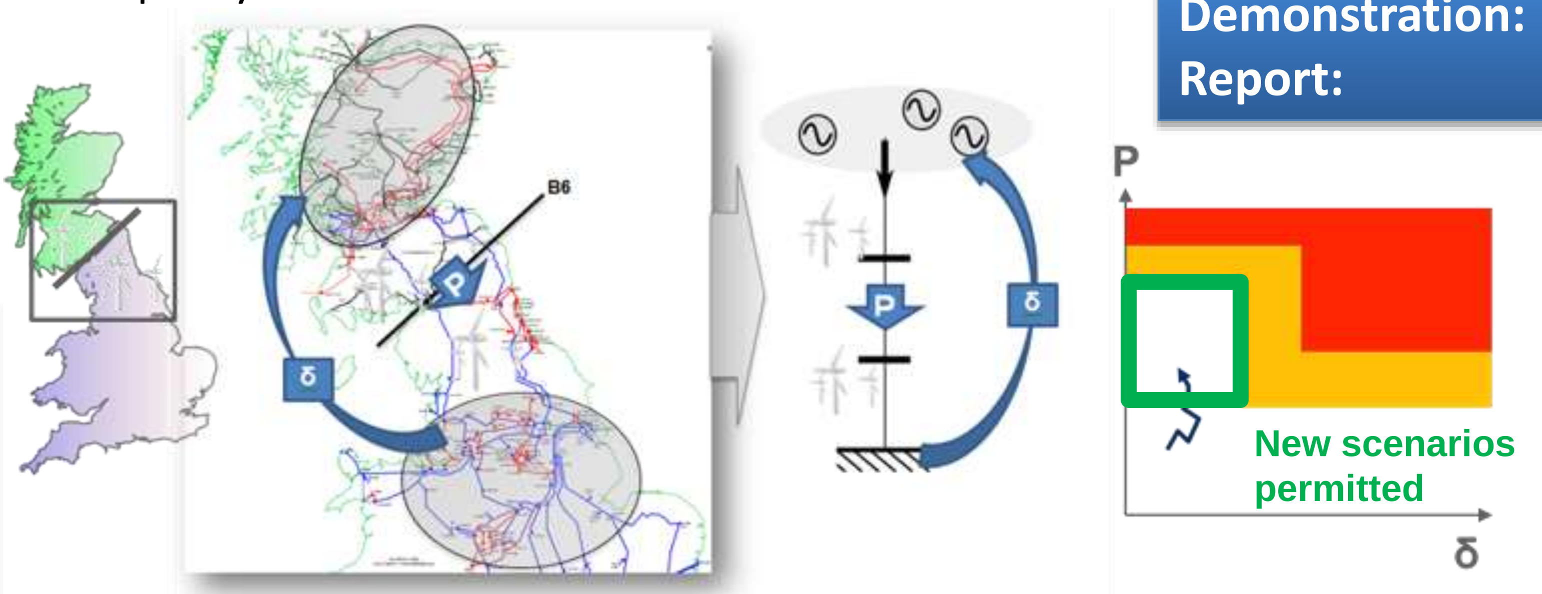
Power-Angle Boundary Display

- **Scotland-England transmission boundary "B6"** Limited by Transient Stability, currently expressed as MW limit
- **Large amount of wind generation**
  Adds to MW flow but no inertia: less effect on stability
- **Angle is a more direct measure of stability**
  Composite power-angle constraint should allow new operating scenarios, releasing capacity.

Demonstration:	**2015**
Report:	**2016**



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Line Parameter Estimation (LPE)

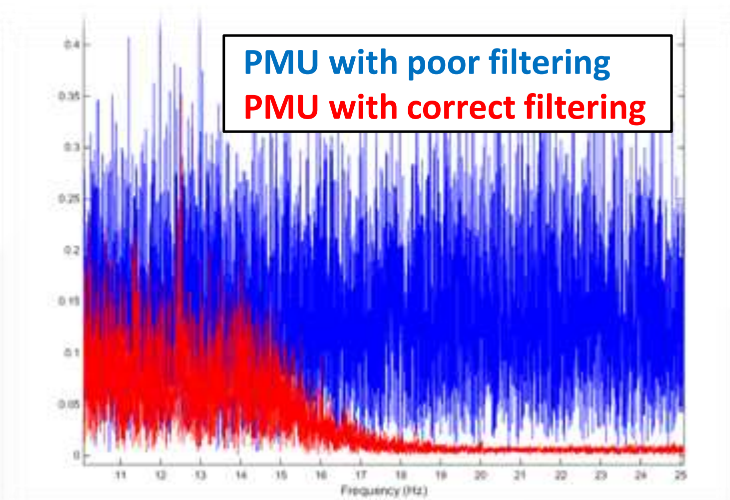
Motivation:

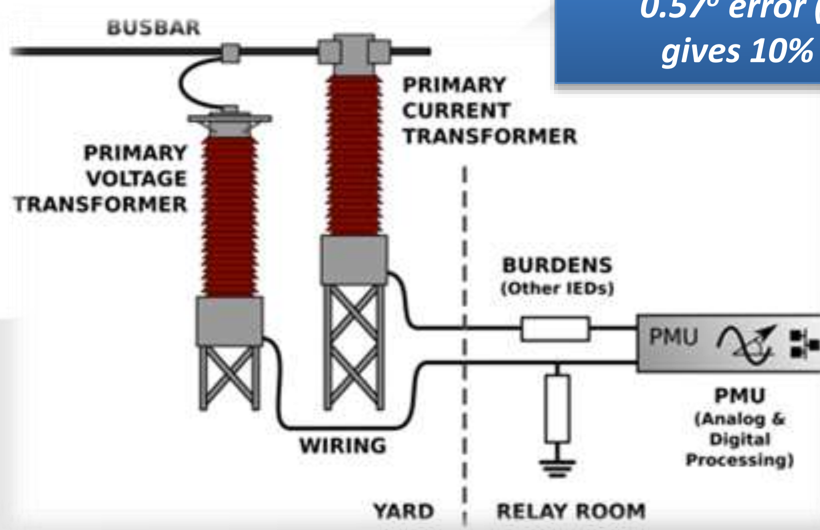
- System limits are determined using assumed parameters
- Measurement-based estimation of parameters provides:
  Validation of network models, visibility of parameter variation: scope for dynamic ratings

Theory: V & I phasors from both line ends allows LPE

Challenge: Compensating for measurement errors
*Primary CT/VT, wiring, PMU – noise **and** systematic*

For a typical line, X/R ≈10, 0.57° error (1% TVE) gives 10% R error





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Line Parameter Estimation (LPE)

Solution: Robust Line Parameter Estimation

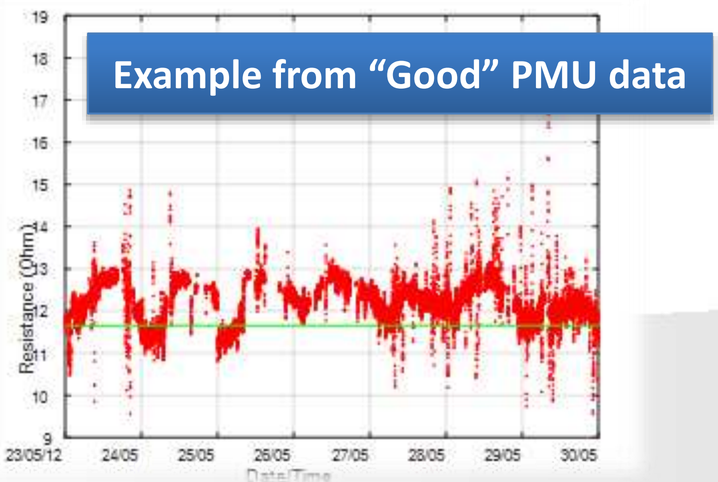
To mitigate errors where possible

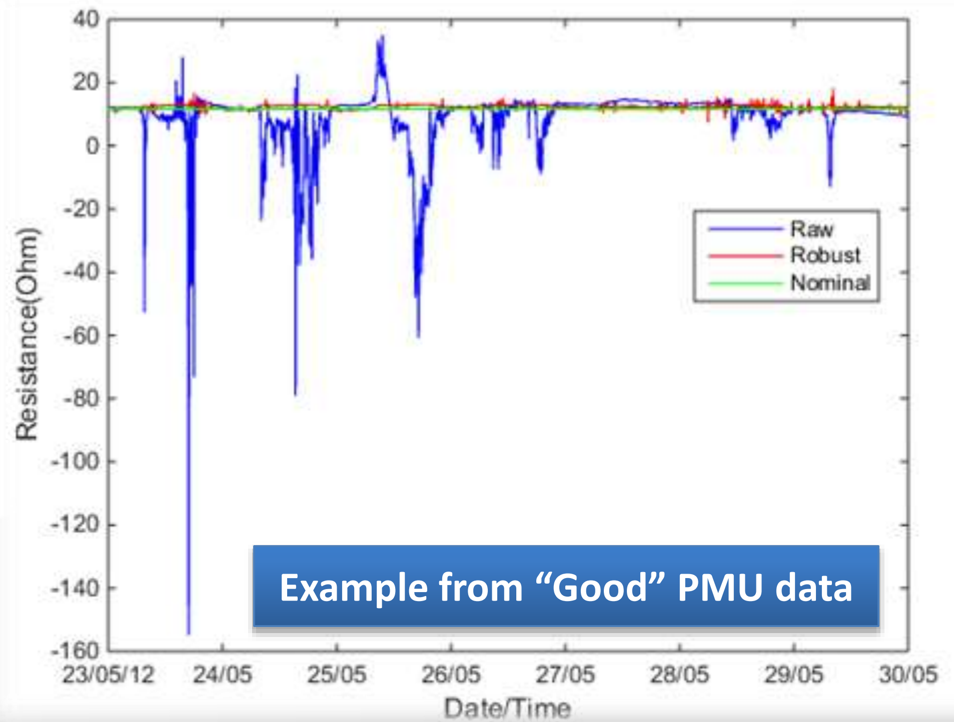
Results so far: Initial study & report – offline Robust LPE

Highlighted impact of data quality issues *(clock drift, filtering)*

Next steps:

- Robust LPE application
- Addressing data quality issues





Conclusions

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VISOR goal: *to demonstrate WAMS applications & their benefits*

Oscillation Monitoring & Source Location (0.002 – 46 Hz)

- **Very Low Frequency**: Study, Application
- **Electromechanical & Control**: Monitoring, Source Location
- **Sub-Synchronous**: Application

System Disturbance Management

- Detection, Location & Characterisation
- Additional Event Metrics

Power-Angle Boundary Display

- Application
- Evaluation Report

Robust Line Parameter Estimation

- Offline Analysis & Report
- Application

Power System & WAMS Performance Reviews *Data Quality, Oscillations…*

- 2014
- 2015
- 2016

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Lunch Break

VISOR Stakeholder Engagement

The University of Manchester
Helicopter View of UoM Research in VISOR

Peter Wall
Papiya Dattaray
Vladimir Terzija (The University of Manchester)
peter.wall@manchester.ac.uk

Helicopter View – Study Areas

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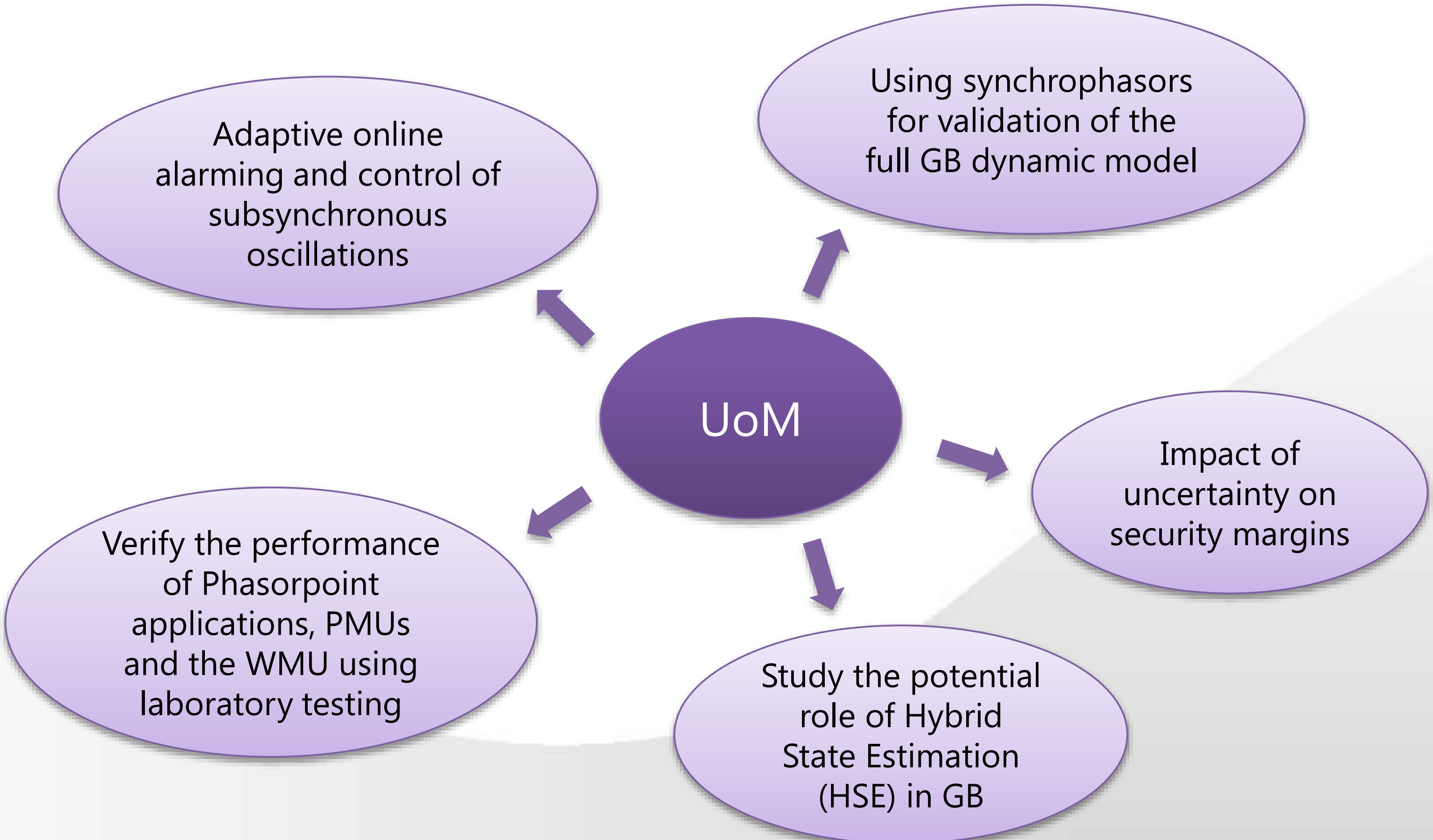

Focus: use offline simulations and WAMS data to perform work with lower technical readiness

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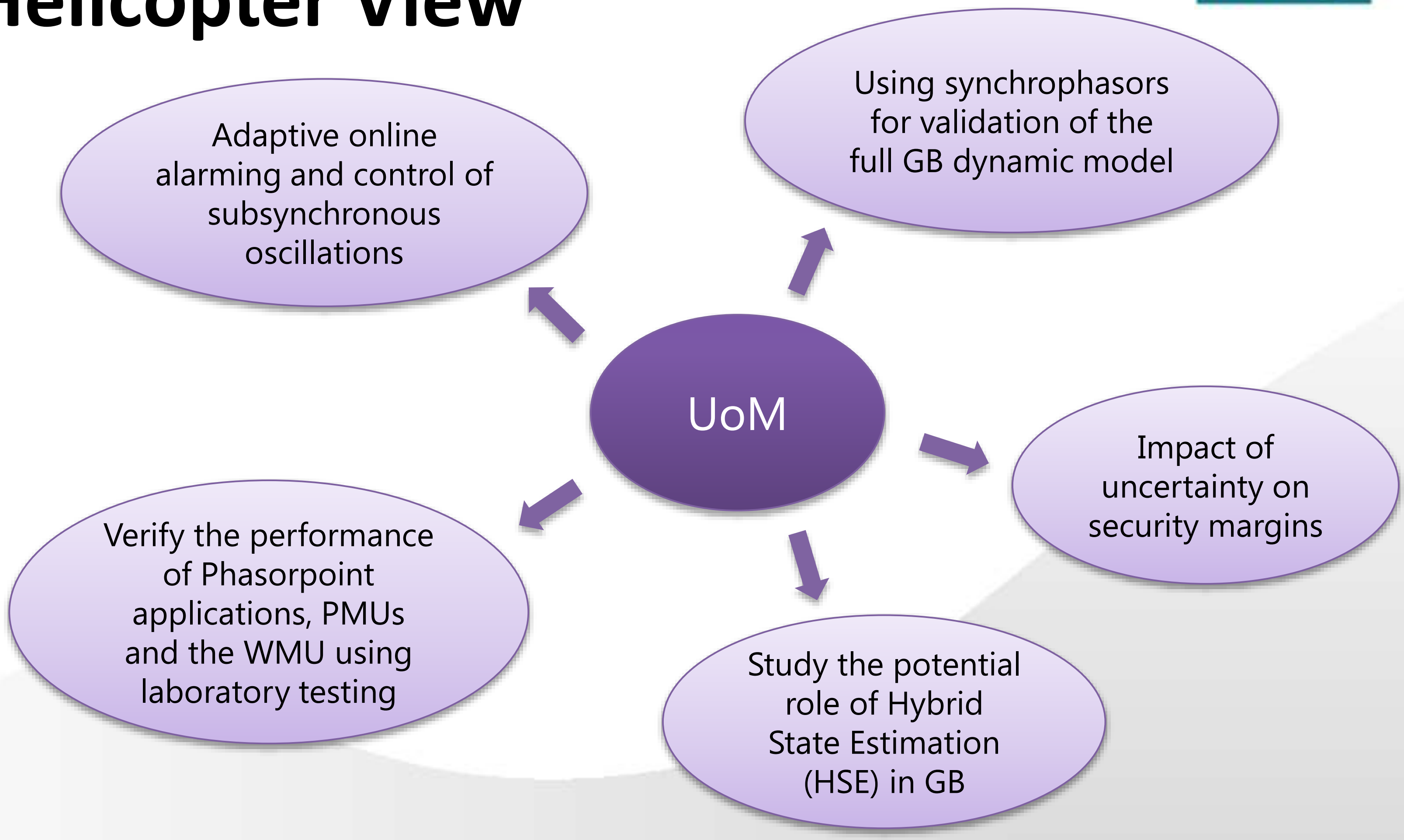
Q1: "WAMS has a key role to play in ensuring economic and secure system operation as power systems move toward a low carbon future"

1. Strongly Agree — 48%
2. Agree — 34%
3. Don't Know — 10%
4. Disagree — 3%
5. Strongly Disagree — 5%

Helicopter View

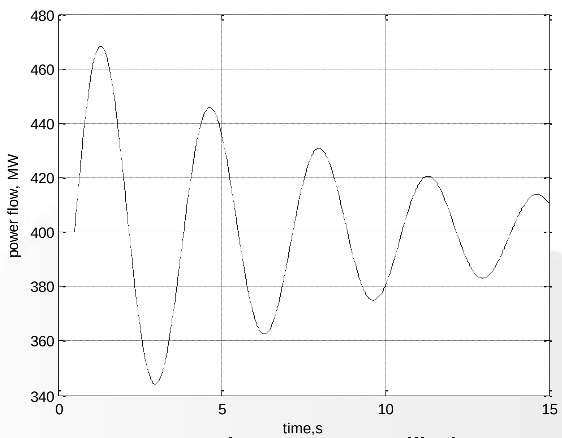


Subsynchronous Interactions

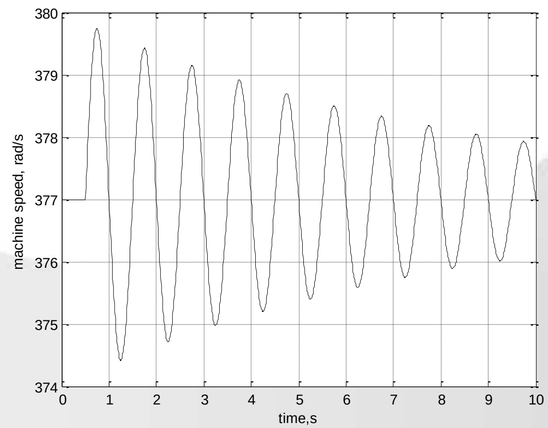
- Inter-area oscillations – less than 1 Hz
- Local plant oscillations – 1 to 2 Hz
- Intra-plant oscillations – 2 to 3 Hz
- Control mode oscillations
- Torsional mode oscillations – 10 to 46 Hz

Bruce English, "Reactive Power Solutions, Subsynchronous Oscillations (SSO): Risk Analysis, Protection, and Mitigation Techniques", GE Digital Energy. Available: http://www.slideshare.net/GEEnergyConsulting/v5-ssr-ssciwebinar

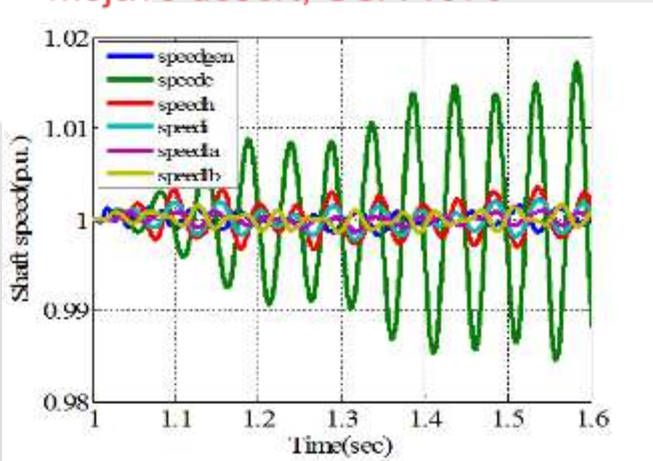
Hole burnt in shaft after SSR event: Mojave desert, USA 1970



0.3 Hz inter-area oscillation



1Hz local plant mode oscillation



Typical example of torsional interactions

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Subsynchronous Interactions

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Physical interactions involving exchange of energy at frequencies below the nominal

SSR

- Series compensated transmission system and generator shaft
- Interaction between fixed components
- Oscillations can cause critical failure of turbine shaft

SSTI

- HVDC link, FACTS device or other power electronic controller and generator
- Easily mitigated through damping controllers

SSCI

- Series compensated transmission system and power electronic control system (Type 3 wind turbine generator)
- No fixed frequency of concern (based on configuration of controls and system configuration)
- No mechanical time constants so high rate of oscillation growth

Review SSI studies investigating a plant to make informed decisions whether or not to install additional protection.

Subsynchronous Interactions

RIIO NIC NETWORK INNOVATION COMPETITION

Types of SSR interactions

- Induction Generator Effect
- Torsional Interaction Effect
- Transient Torque Effect

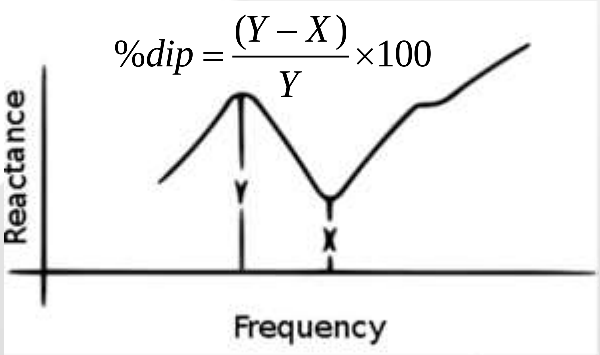
→ Steady State SSR

Analytical tools for Study of SSR

- Frequency Scan
- Eigen Value Analysis
- Electromagnetic Transient Simulations

Potential transient torque problems

5% reactance dip within **3 Hz** of a 50/60 Hz complement of the modal frequency [1].



Frequency Scan

- The 'dips' in a frequency scan are effective for targeting more detailed transient simulations
- It is not suitable for direct use online as it would create too many false alarms

[1. B. L. Agrawal and R. G. Farmer, "Use of Frequency Scanning Techniques for Subsynchronous Resonance Analysis," Power Apparatus and Systems, IEEE Transactions on, vol. PAS-98, no. 2. pp. 341–349, 1979]

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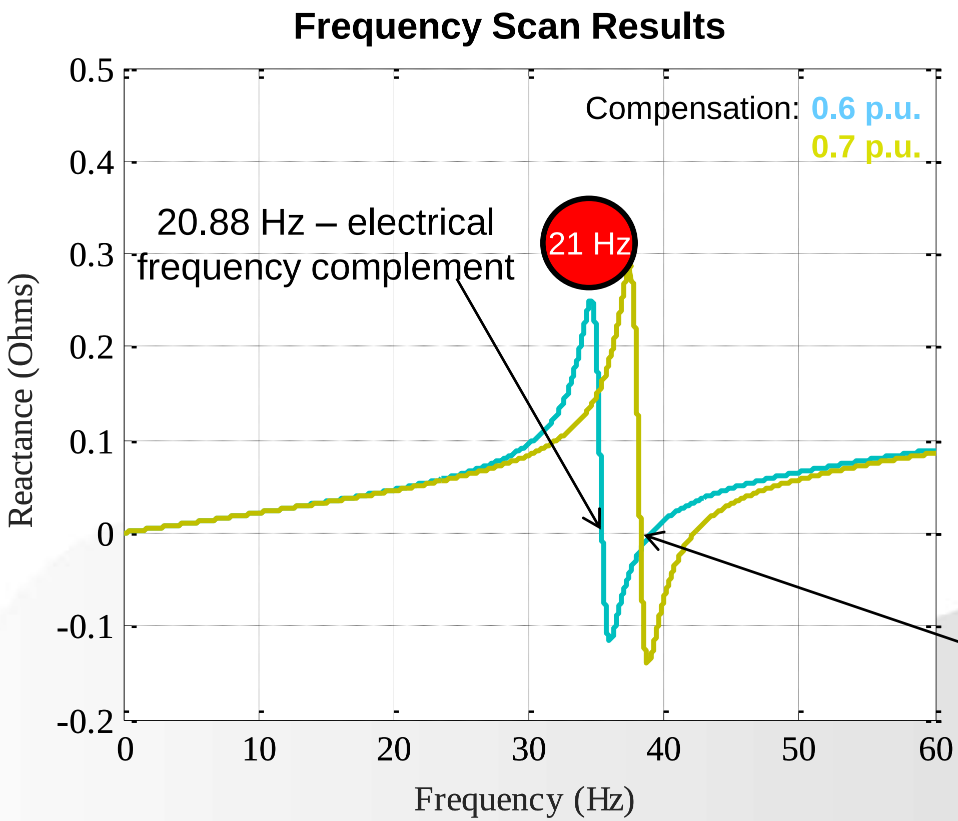
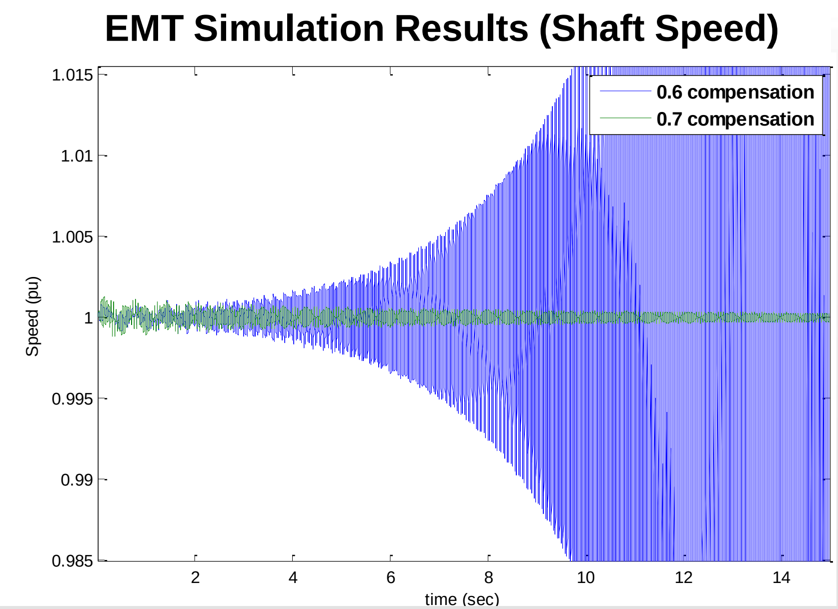
Subsynchronous Interactions

Two of the dips are greater than 5 % and within 3 Hz of a torsional mode complement

However, transient response is profoundly different





17.75 Hz – electrical frequency complement

15 Hz

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Online alarming and control of subsynchronous interactions

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Motivation

New technologies will increase the risk of subsynchronous interactions (SSI) in the range of 4-46 Hz in the GB power system

SSI can severely damage system assets, disrupt operation and introduce constraints

Planning actions to mitigate SSI can incur high costs to counter an infrequent event

Planning tools do not yet exist for SSCI

Research

Can the existing planning tools for managing SSI be adapted for use in an online tool?

Optimal placement of monitoring devices (PMUs or WMUs) to monitor SSI

Estimation of electrical mode damping from wide area signals

Identify the available control resources

Can an online, wide area alarming and control system be created for subsynchronous interactions?

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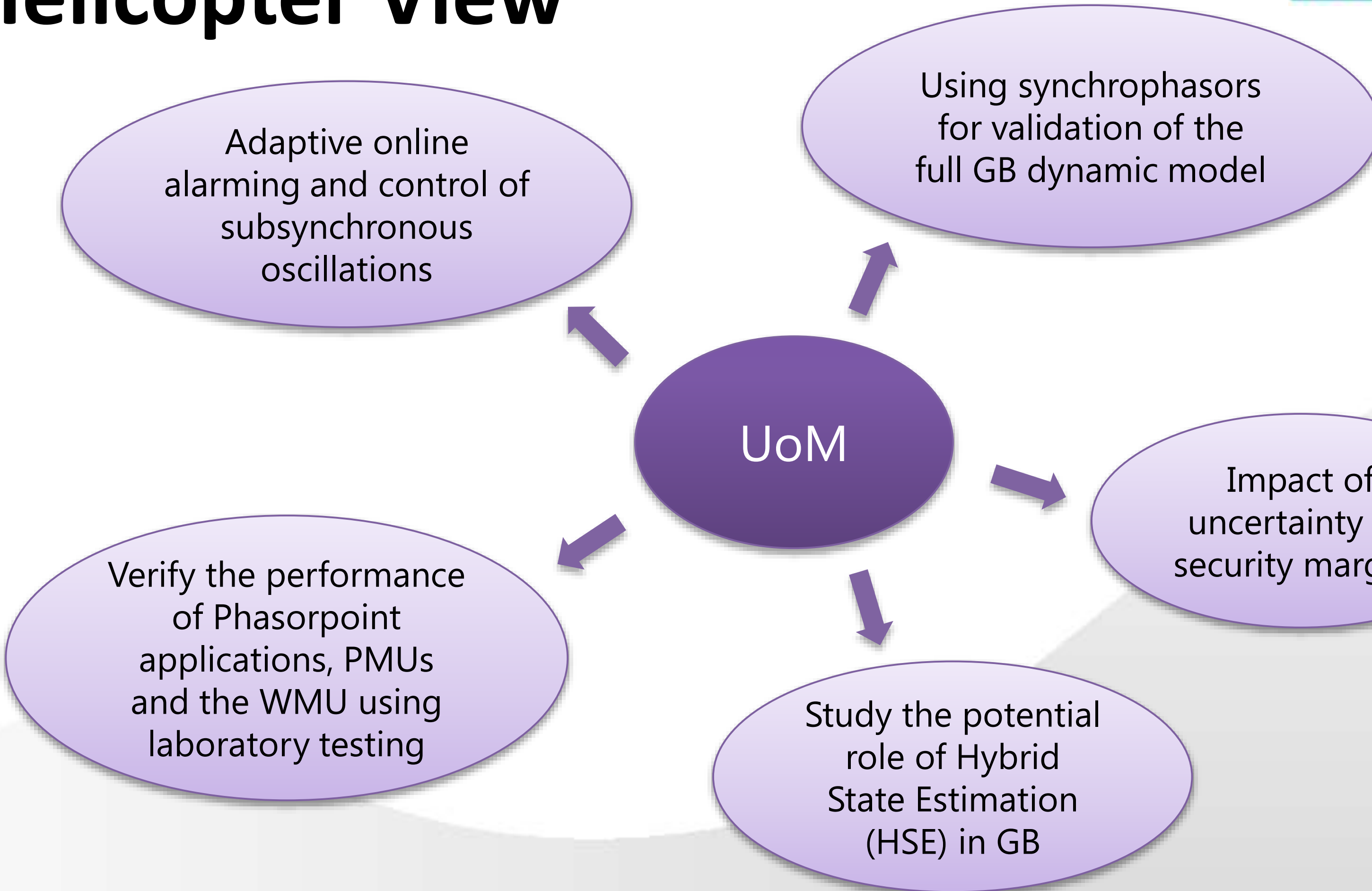
Q2: "Adaptive, online alarms are necessary to overcome the emerging threats to economic and secure power system operation in GB"

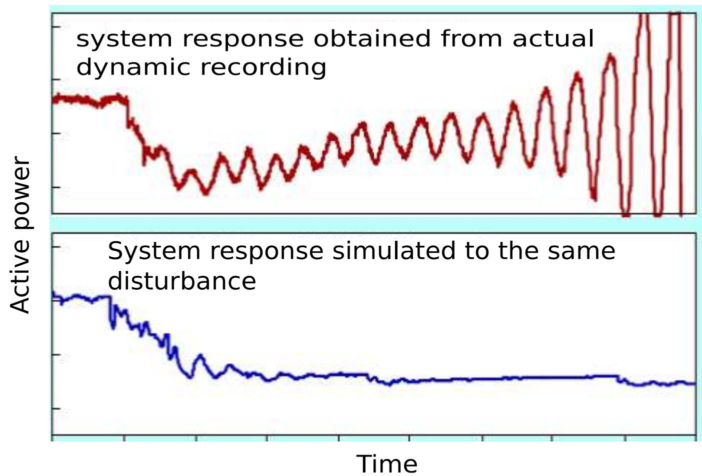
1. Strongly Agree
   20%
2. Agree
   53%
3. Don't Know
   27%
4. Disagree
5. Strongly Disagree

Helicopter View



Importance of Models

- Dynamic models are a key part of system planning and operation
- Flawed simulations can have very real consequences



E. Allen, S. Member, D. Kosterev, and P. Pourbeik,
"Validation of Power System Models," *IEEE PES General Meeting*, pp. 1–7, 2010.

1996 WSCC (now WECC) system separation: simulations did not emulate the shaft oscillations that caused the separation

- Reduced confidence in system models may lead to increasingly conservative operating margins

Importance of Models

RIIO NIC NETWORK INNOVATION COMPETITION

Validation Studies → To identify correct system reinforcements and operating practices

Enabler → WAMS – records synchronized phasors, capturing dynamics → Discrepancies reveal model inadequacies

Why?

- Optimistic simulation – system RISK
- Pessimistic simulation – wastage of investments
- Market economy forces systems closer to their stability limits

For small signal stability assessment → Most critical & Uncertain models → Loads & Gen. excitation controls

Challenges

REPLAY

- **Time consuming** to set-up the pre-event power flow for the whole system (SCADA)
- Difficult to collect **sequence of events information** across the system (relay actions, operation, control adjustments)
- Requires **expertise** to pinpoint problems

Benefits

- Real time line ratings
- Congestion management
- Increased renewable generation throughput

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VISOR Project: Visualisation of real time system dynamics using enhanced monitoring

Using synchrophasors for validation of the full GB dynamic model

Motivation

More complex systems will require more complex models that must be studied for a broader range of scenarios and interactions

Synchrophasors are naturally well suited to improving rms model validation

Loss of confidence in models causes more conservative (i.e. more costly) operation

Flawed simulations can have very real consequences

Research

What is the state of the art for dynamic model validation using synchrophasors?

Is data quality/availability from VISOR WAMS sufficient for model validation

Comparison of different methods for synchrophasor based model validation

Develop automated tools to support model validation using synchrophasors

What benefits can the synchrophasors from the VISOR WAMS offer to model validation in GB?

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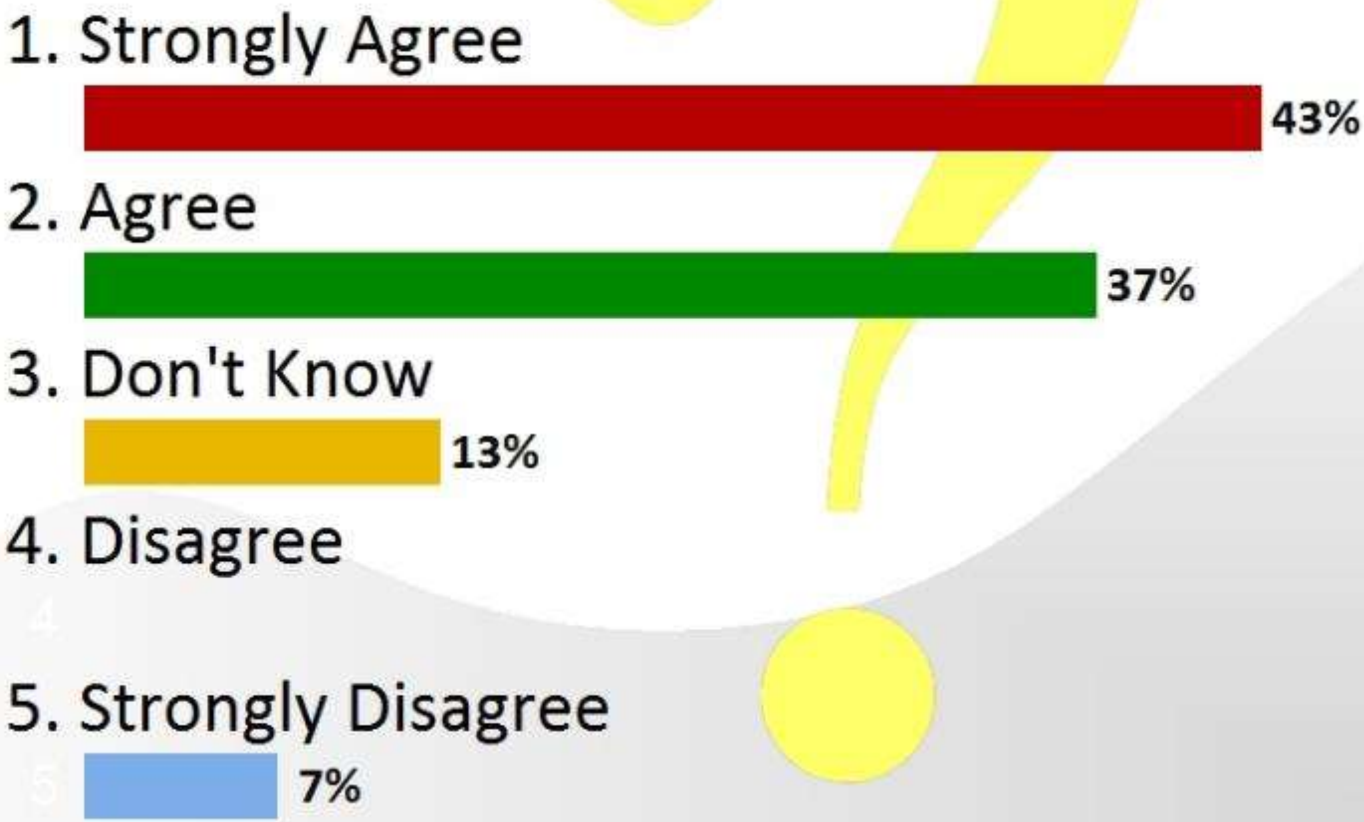
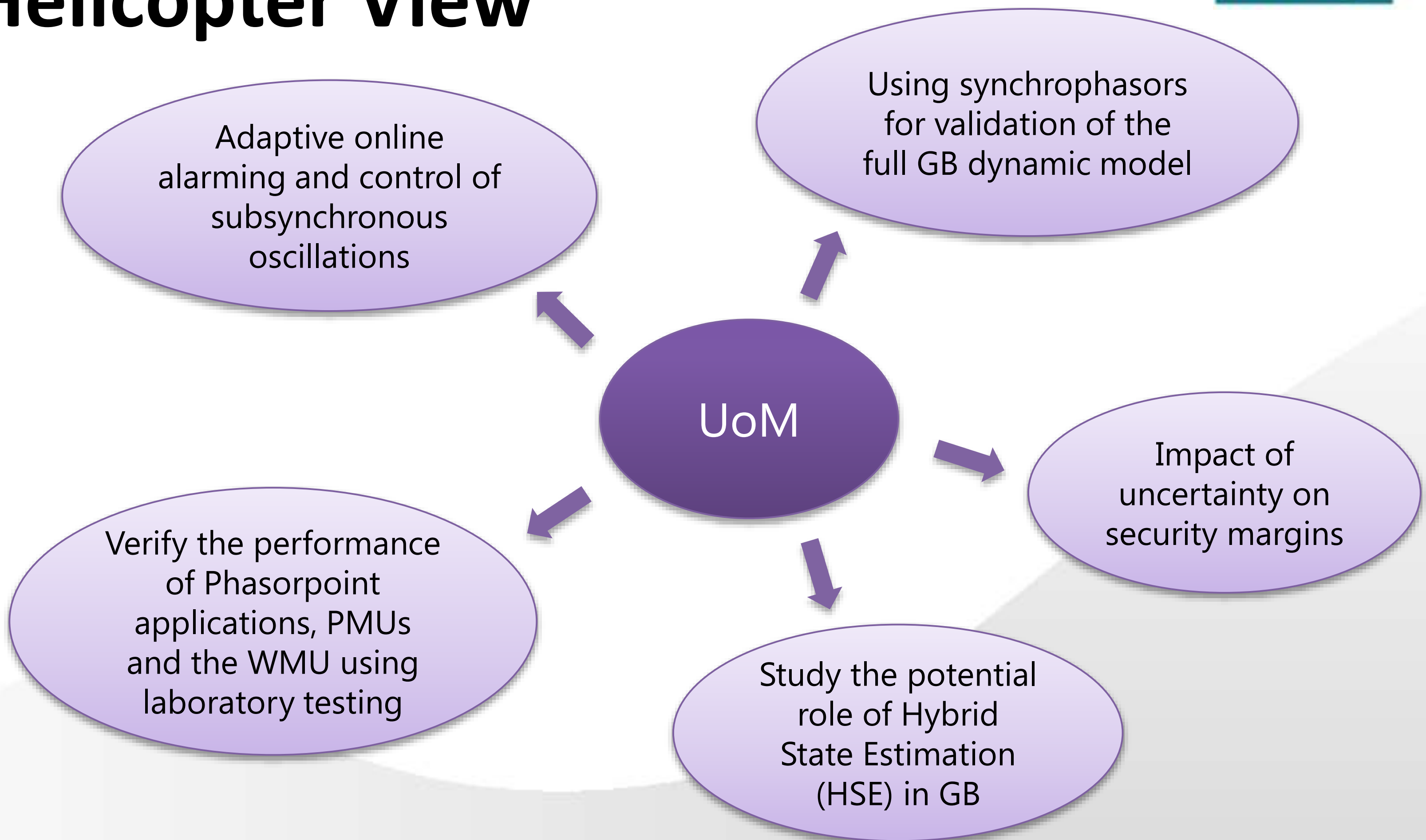
Q3: "It is important for the dynamic models of a power system to be validated and refined"

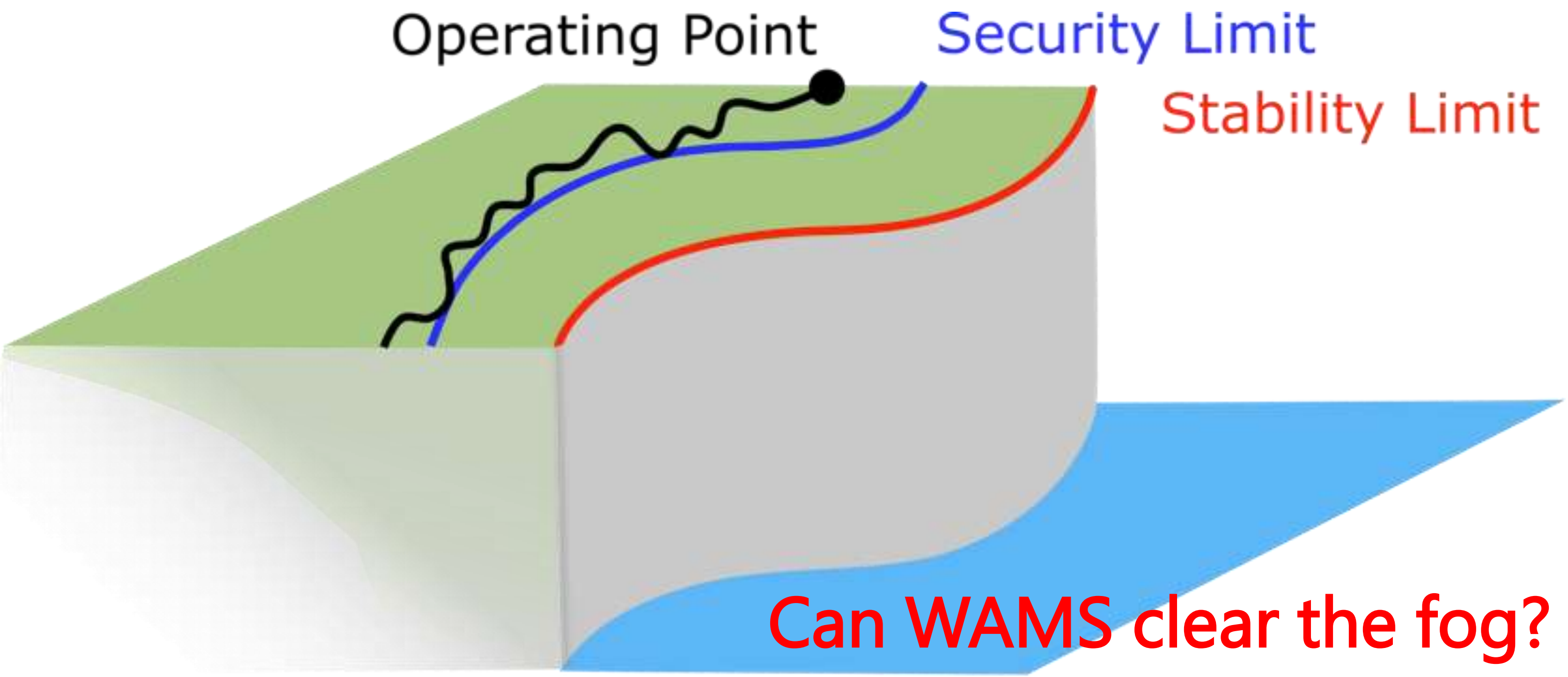


Helicopter View



Impact of Uncertainty

Operating with uncertainty is like walking along a cliff in heavy fog



Increased uncertainty increases the cost of operation

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Impact of Uncertainty on Security Margins

Motivation

If actual operation exceeds limits, the system may fail and widespread blackouts could occur.

If actual operation is below limits, the system is operating uneconomically

It is desirable to operate as close to the limits as possible whilst retaining confidence that the limits will not be violated at any time

Improved monitoring an obvious solution for reducing uncertainty

Research

Identify the sources of uncertainty and the impact they have (e.g. generation forecasts, model parameters, load flow)

Study how the impact of uncertainty can be reduced by WAMS based tools (e.g. visualisation, parameter estimation, measurements

Balance between complexity of WAMS based tools and benefit offered

Quantify the impact of uncertainty and how synchrophasors can be used relieve it

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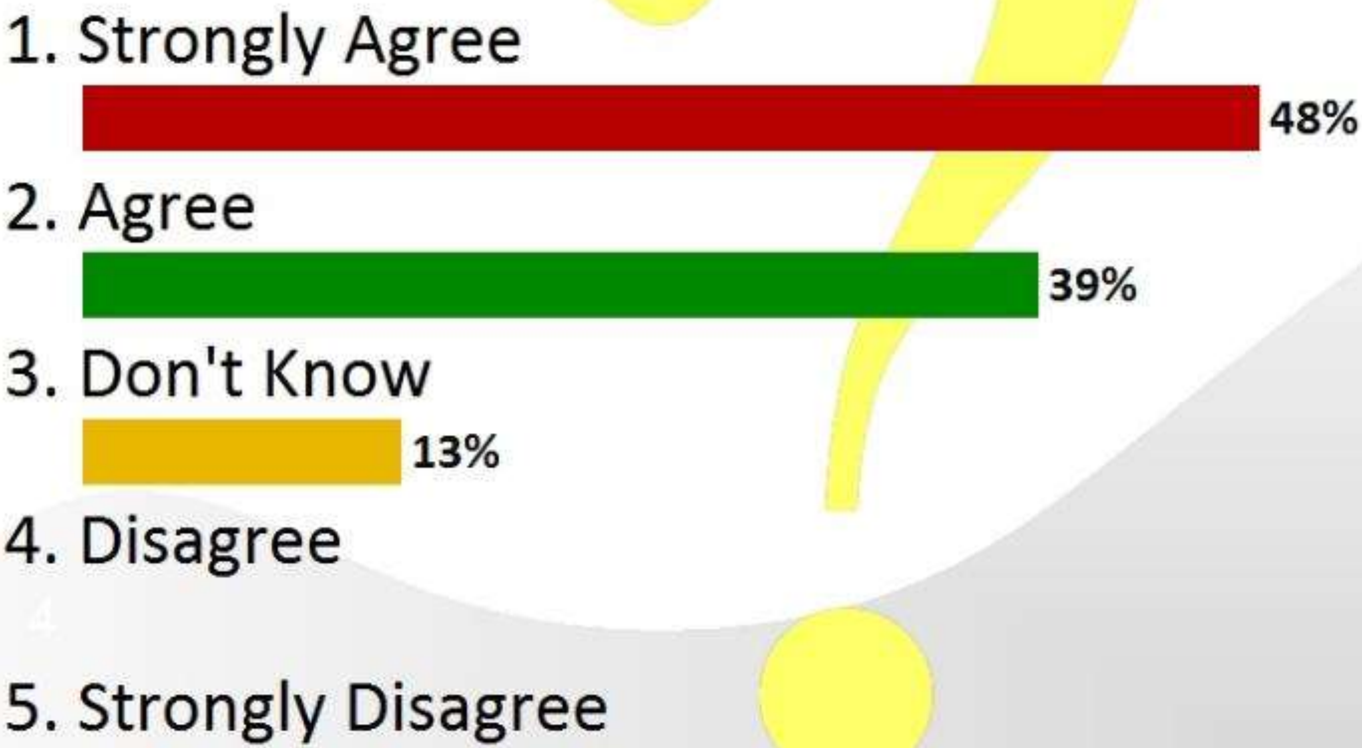
Q4: "Increasing uncertainty is one of the greatest threats to the ongoing secure and economic operation of the GB power system"



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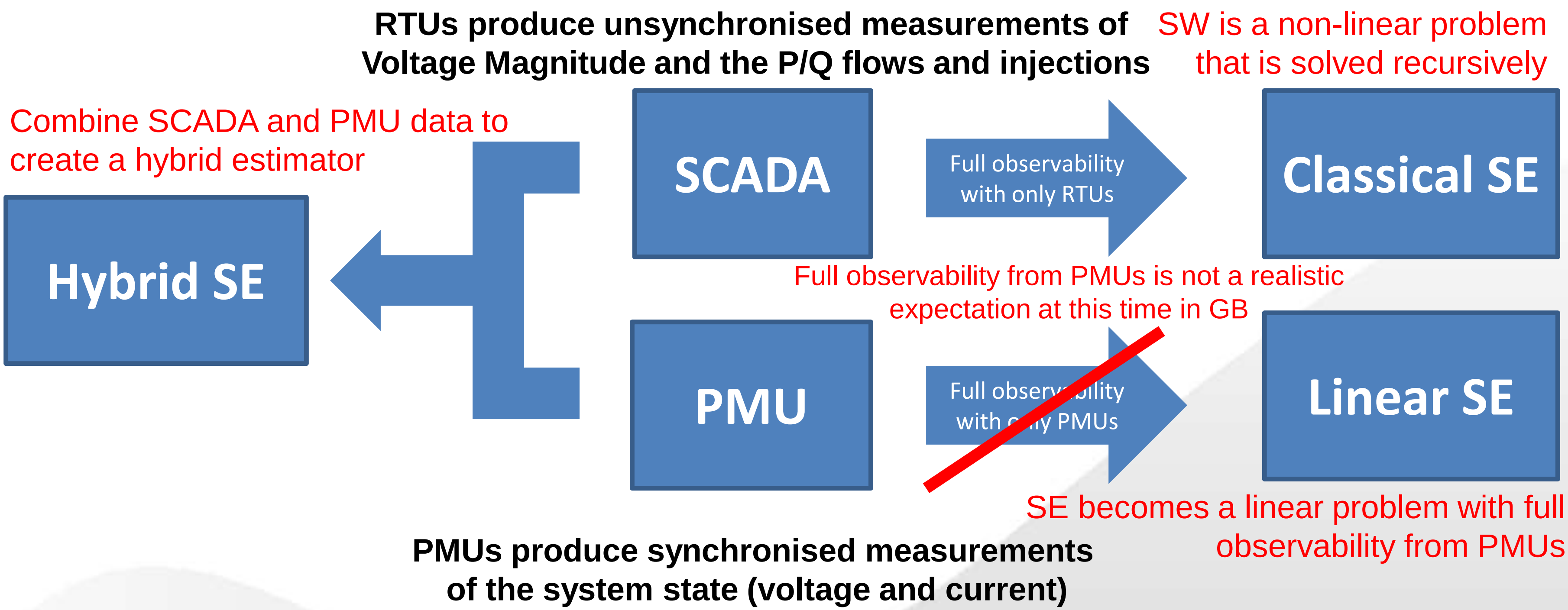
Helicopter View

UoM

- Adaptive online alarming and control of subsynchronous oscillations
- Using synchrophasors for validation of the full GB dynamic model
- Impact of uncertainty on security margins
- Study the potential role of Hybrid State Estimation (HSE) in GB
- Verify the performance of Phasorpoint applications, PMUs and the WMU using laboratory testing

Hybrid State Estimation (HSE)



- HSE is a middle ground between classical SE and LSE and helps the system realise the benefits of PMUs for state estimation with only partial observability of the system from PMUs

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Study the potential role of Hybrid State Estimation (HSE) in GB

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Motivation

State estimation is a key aspect of managing modern power systems

PMUs directly measure the state so are a natural asset for improving state estimation

HSE uses phasor data and SCADA data to create an improved estimator, without requiring full observability from PMUs

Observability for some HSEs use a mixture of PMUs and RTUS

Research

Offline simulations of part of the GB system to study the benefit of HSE

Study the relationship between the number of PMUs and benefits of HSE

Develop an optimal PMU placement algorithm for deployment of HSE in GB

Consider feasibility of deploying HSE relative to when LSE becomes practical

Is the deployment of HSE in GB feasible and worthwhile in the near term?

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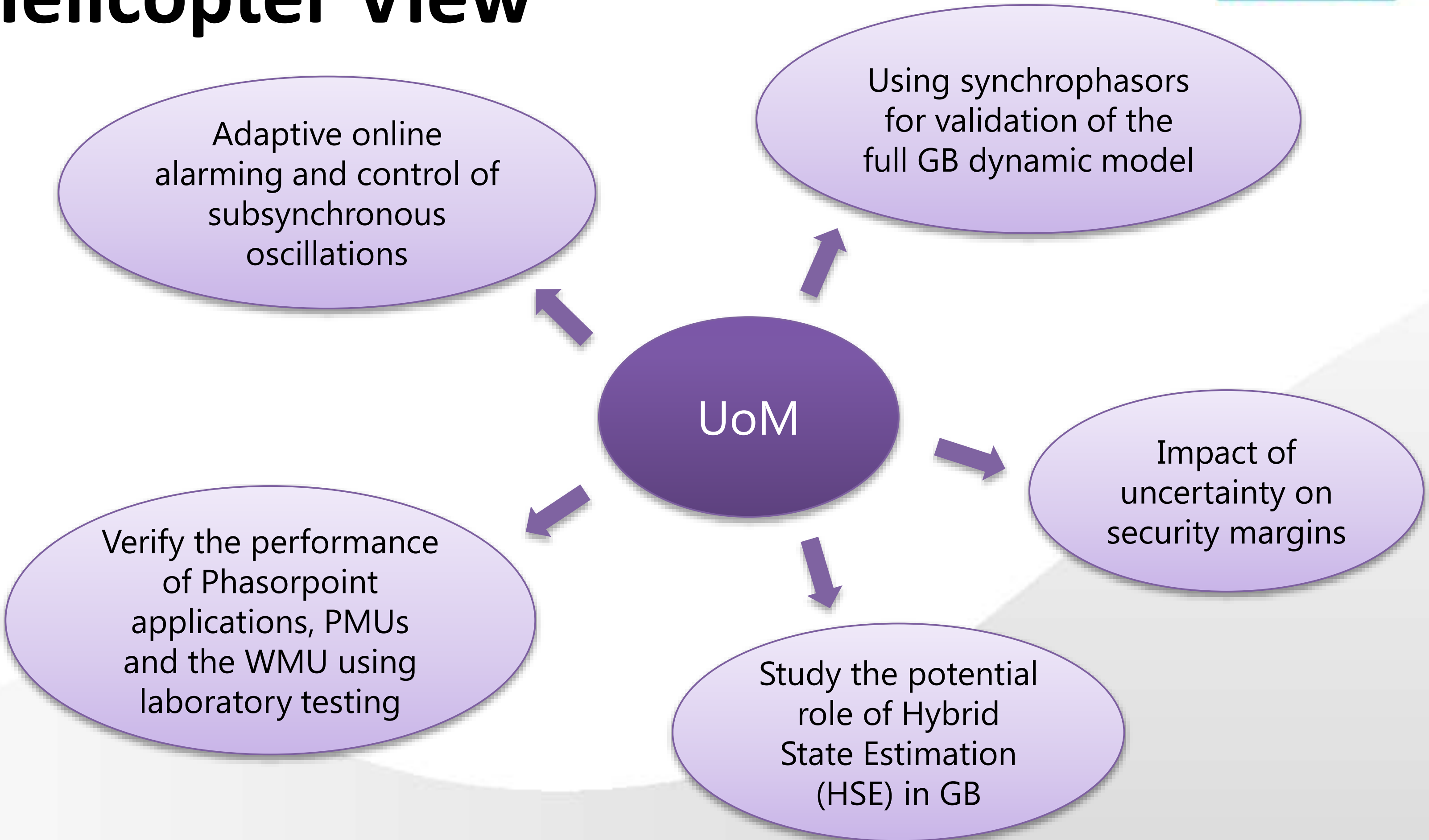
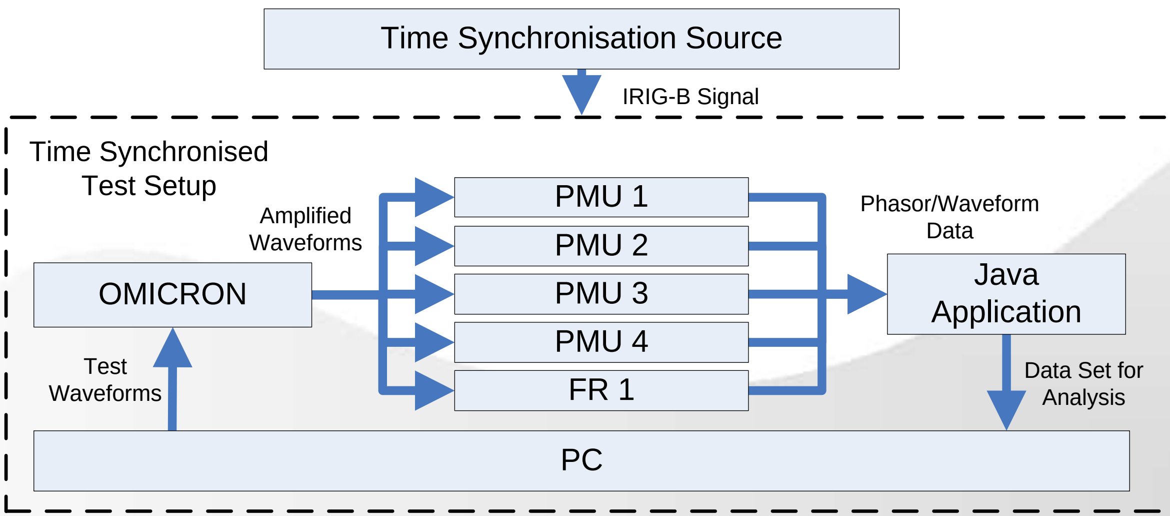
Helicopter View



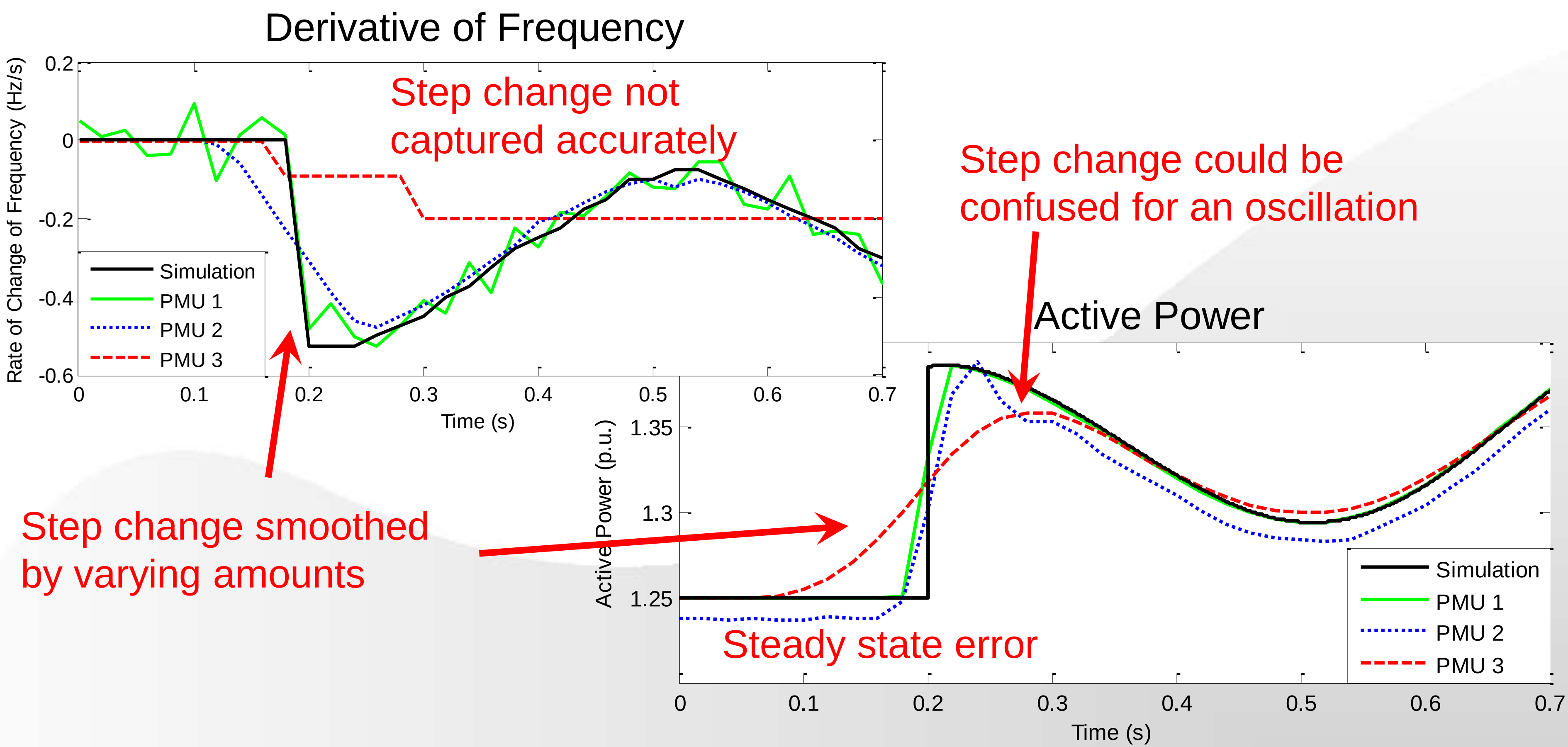
Laboratory Testing at UoM

- Simulated signals used to test devices and applications
- Assessment of the performance of a PMU depends on the primary role of the PMU



Examples of Varied Response:

Active power and derivative of frequency for a large infeed loss



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Verify the performance of Phasorpoint applications, PMUs and the WMU using laboratory testing

Motivation

Sensors (i.e. PMUs and the WMU) are essential components of WAMS

WAMS applications and the outputs they generate are a key part WAMS

The Phasorpoint application is used to deliver the WAMS applications in VISOR

Laboratory testing allows controlled assessment of devices and applications

Research

Laboratory testing with constructed and simulated signals to understand/verify the performance of monitoring devices and WAMS applications

Develop automated procedure for standardised testing of PMUs

Study the primary monitoring role of PMUs in a WAMS

How accurate and reliable are the sensors and applications on which VISOR depends?

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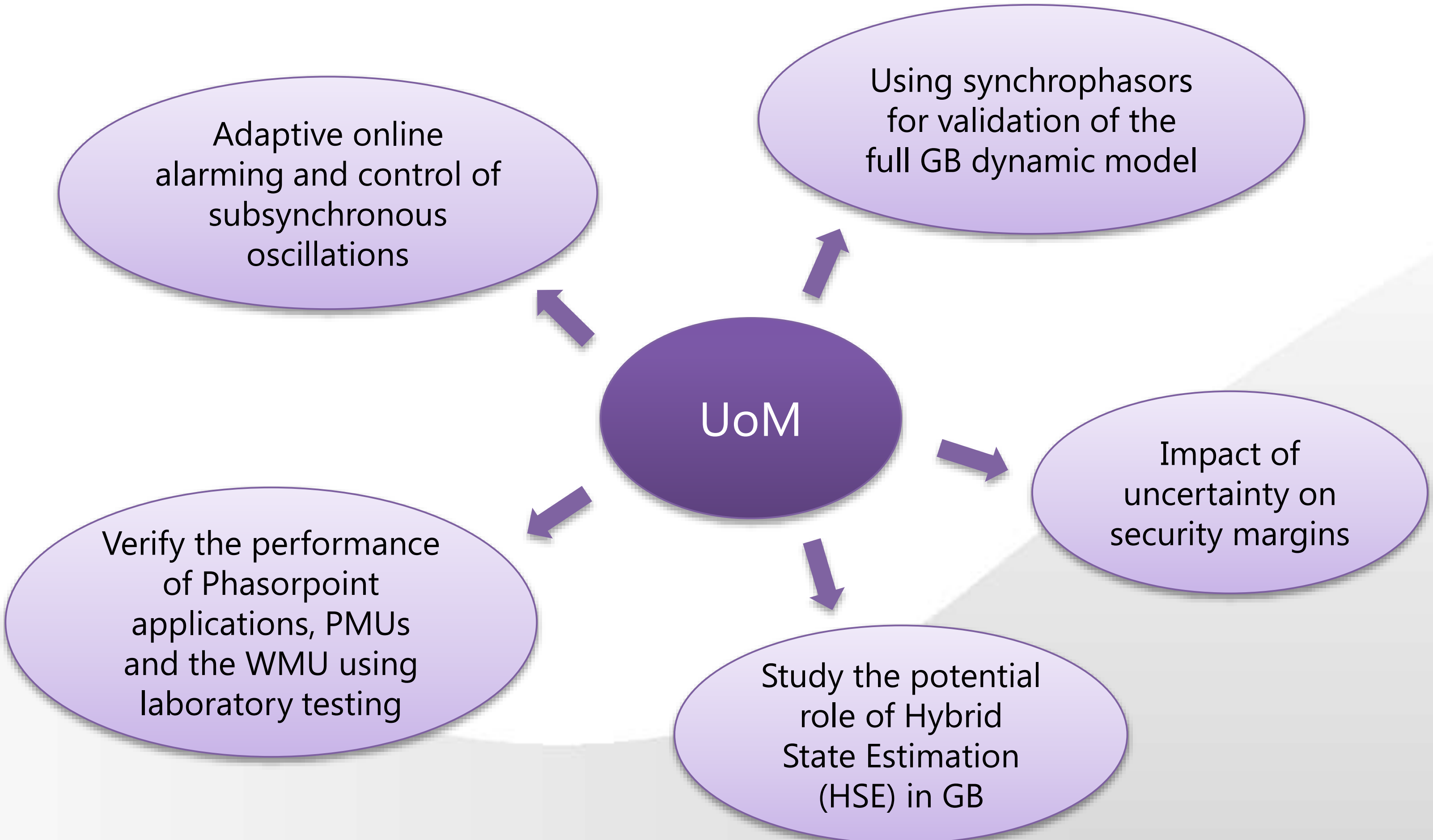
Helicopter View – Study Areas



Focus: use offline simulations and WAMS data to perform work with lower technical readiness

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Helicopter View – Key Questions

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UoM

- Can an online, wide area alarming and control system be created for subsynchronous interactions?
- What benefits can the synchrophasors from the VISOR WAMS offer to model validation in GB?
- Quantify the impact of uncertainty and how synchrophasors can be used relieve it
- Is the deployment of HSE in GB feasible and worthwhile in the near term?
- How accurate and reliable are the sensors and applications on which VISOR depends?

Focus: use offline simulations and WAMS data to perform work with lower technical readiness

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VISOR Stakeholder Engagement

The University of Manchester
Helicopter View of UoM Research in VISOR

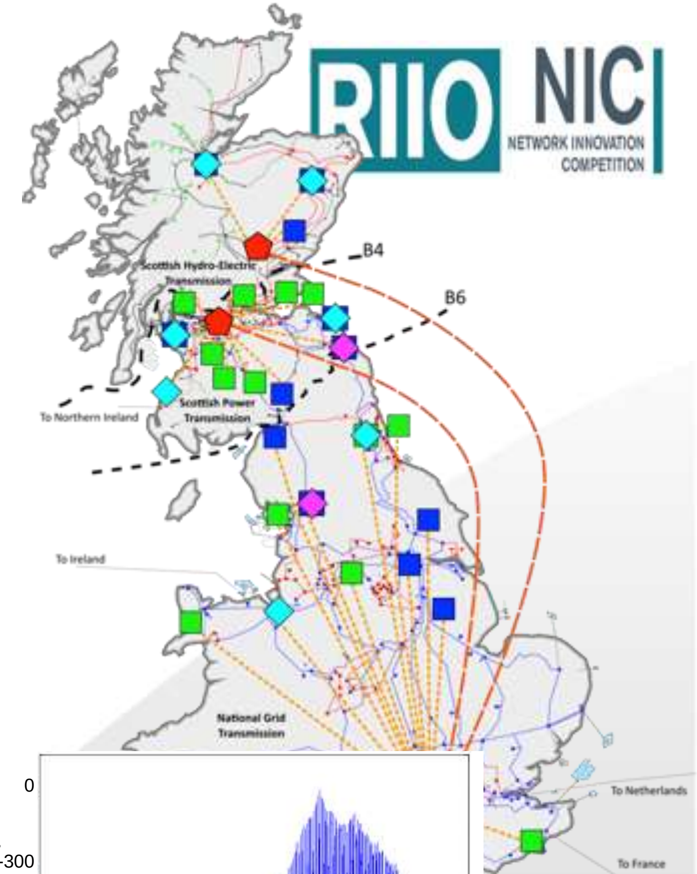
Peter Wall

Papiya Dattaray

Vladimir Terzija (The University of Manchester)

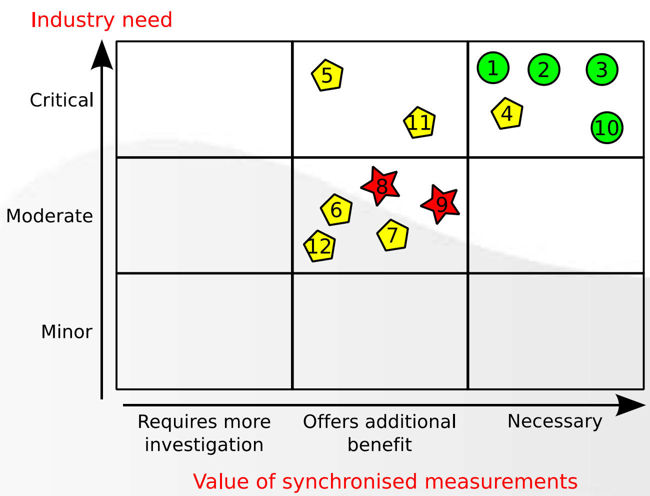
peter.wall@manchester.ac.uk

Today's VISOR presentations



1. **Welcome and overview to VISOR**
   Priyanka Mohapatra, SP Energy Networks

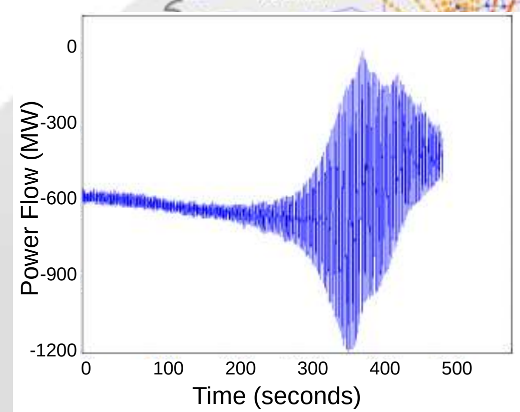
2. **TO Motivation and Experience**
   Phil Ashton, National Grid



Online Applications
1. Angle/Frequency monitoring
2. Voltage stability monitoring
3. Stability analysis
4. Congestion management
5. Line thermal monitoring
6. Hybrid state estimation
7. Islanding
8. Adaptive protection SIPS
9. Real-time control WAMPAC

Offline Applications
10. Post-event analysis
11. Model validation
12. Inertia estimation

Deployment Challenges
LOW MED HIGH



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Today's VISOR presentations

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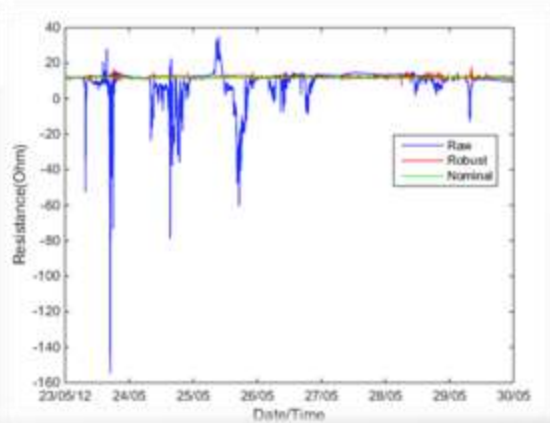
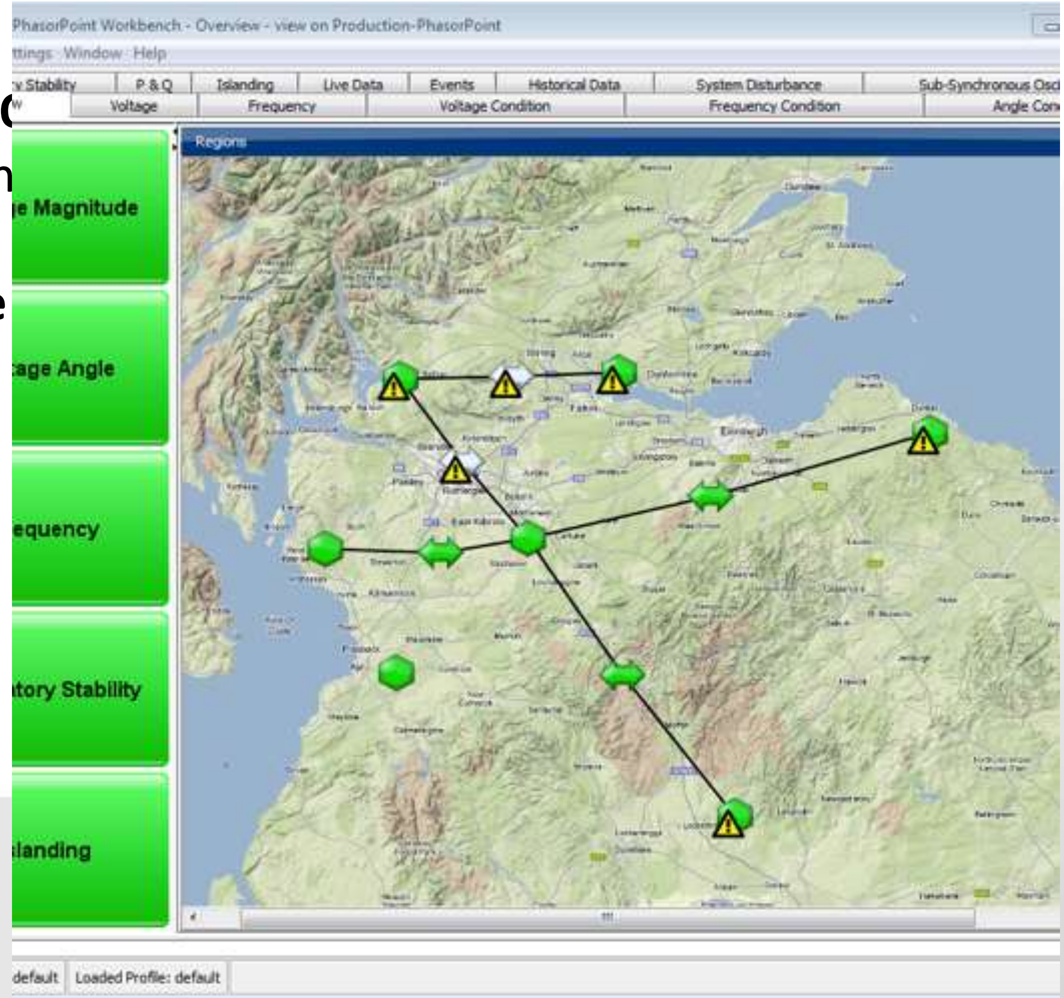
3. **VISOR Application**
   Stuart Clark, Alstom-Grid





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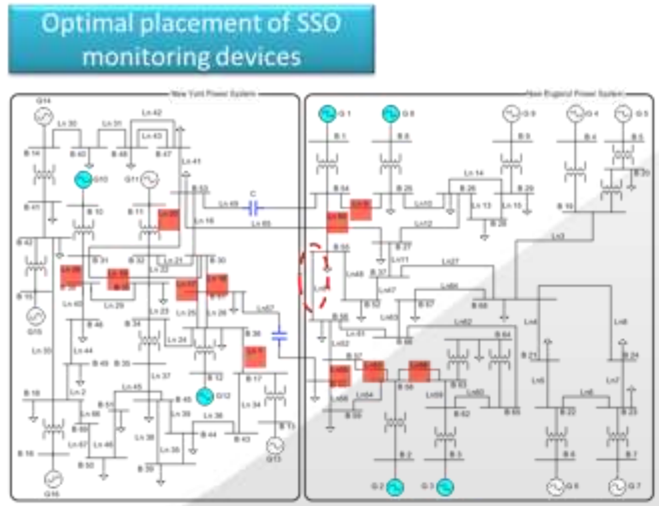
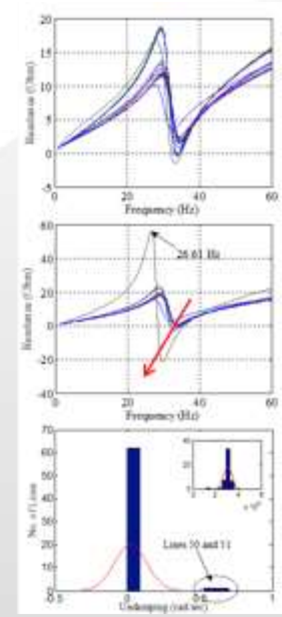
4. **VISOR Research**
   Peter Wall, University of Manchester





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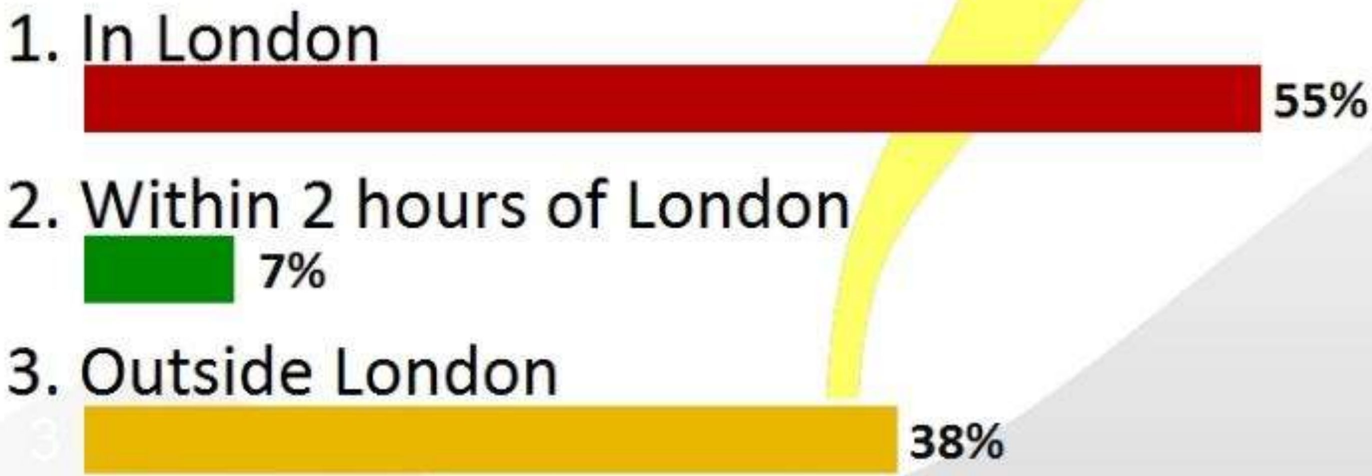
Q1: Where would you like your next VISOR event?



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Q1: How well do you know VISOR following this event??

1. A full understanding of motivation and objectives

   66%

2. A fair understanding of motivation and objectives

   34%

3. Little understanding of motivation and objectives

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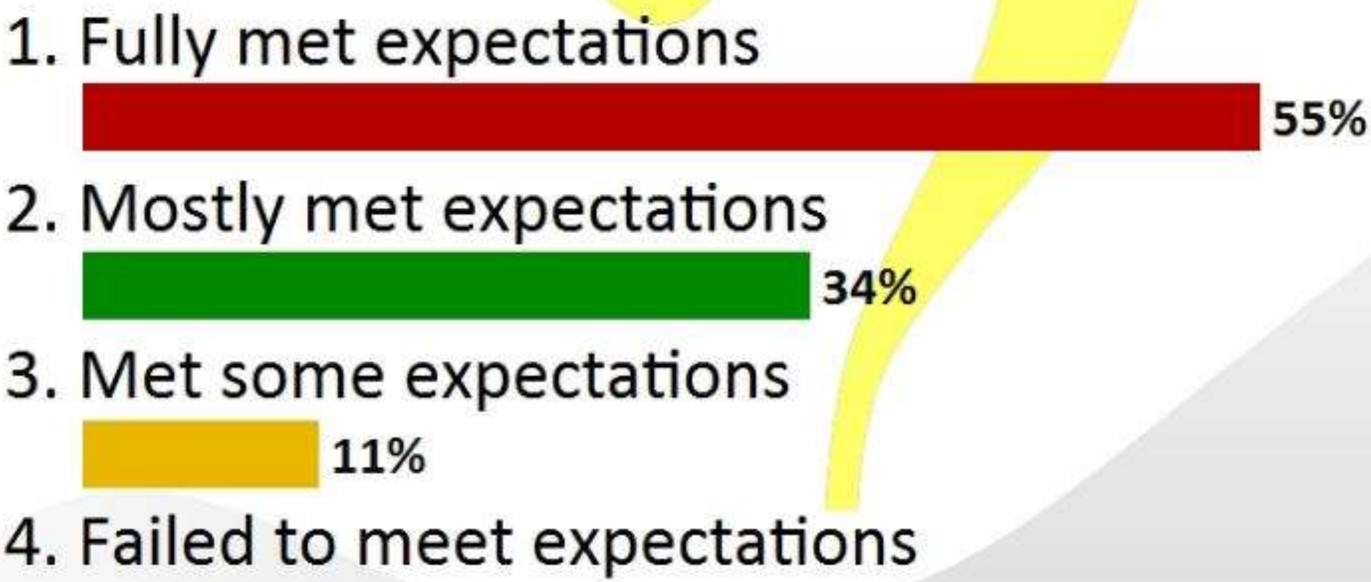
Q2: How did the day perform against expectations?



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To close the day…

1. Welcome and overview to VISOR — Priyanka Mohapatra
2. TO Motivation and Experience — Phil Ashton
3. VISOR Applications — Stuart Clark

Lunch break

4. VISOR Research — Peter Wall
5. VISOR Q&A Session — *Project Team*
6. Guest presentation — Charlotte Grant (EFCC Project)

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