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VISOR Project

Visualisation of Real Time System Dynamics of the GB Power System using Enhanced Monitoring

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Presentation Outline

- Wide Area Monitoring
- Overview of VISOR Project
- Background of GB Power System
- WAMS Applications and Research Goals
- Next Steps
- Summary

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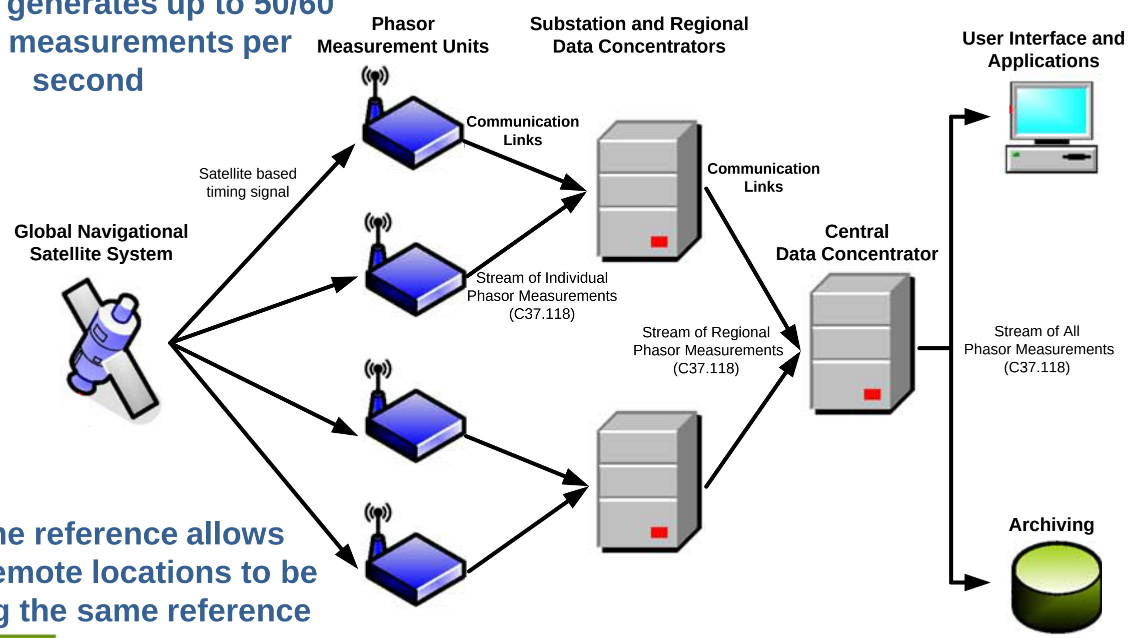
Wide Area Monitoring Systems (WAMS)

Wide Area Monitoring

- Synchronised measurements from across a wide area system are combine together to provide real time monitoring
- Example of a simple hierarchical WAMS and its elements:

Individual phasor are continuously streamed to data concentrators that combine them together to provide a wide area view of the power system

Each PMU generates up to 50/60 phasor measurements per second



WAMS data provides a radical change in power system monitoring and enables a wide variety of new applications

However, communicating, processing and storing the vast quantity of WAMS data requires significant investment in new infrastructure

A common time reference allows phasors from remote locations to be calculated using the same reference

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Overview of VISOR Project

1. What is VISOR?
2. Funding and Project Partners
3. Motivation for VISOR
4. Benefits offered by VISOR

What is VISOR?

Visualisation of real time system dynamics using enhanced monitoring

- A £7.44m Network Innovation Competition (NIC) project that is led by SP Energy Networks
- A collaborative project that includes all three GB Transmission Owners, the System Operator, researchers and suppliers
- Began January 2014, Reporting March 2017
- visor-project.org.uk

What is VISOR?

Create the first integrated GB Wide Area Monitoring System (WAMS) to collate, analyse and store synchronised measurements from all three GB Transmission owners (TOs) in real time.

Enhanced Visibility of Power System Oscillations	Validation of Dynamic Models	Better Understanding, Visibility & Representation of True System Limits

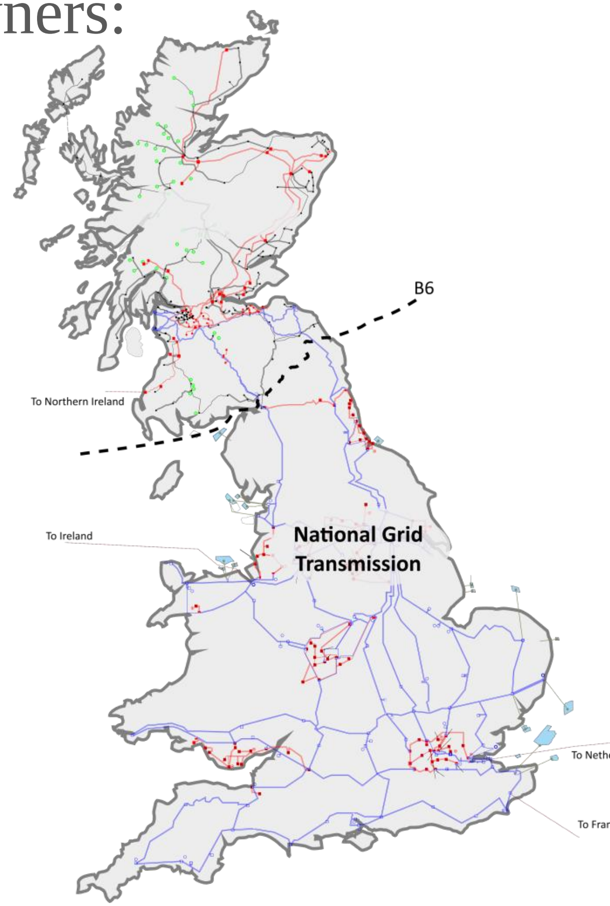
Wide Area Monitoring offers many **potential** opportunities for mitigating risk & maximising asset utilisation - but **demonstration** is required to make the case for Business-As-Usual implementation.

Project Partners

- Funding provided by ofgem, the GB regulator

Project Partners

- Funding provided by ofgem, the GB regulator
- GB power system has three transmission owners:
  - National Grid



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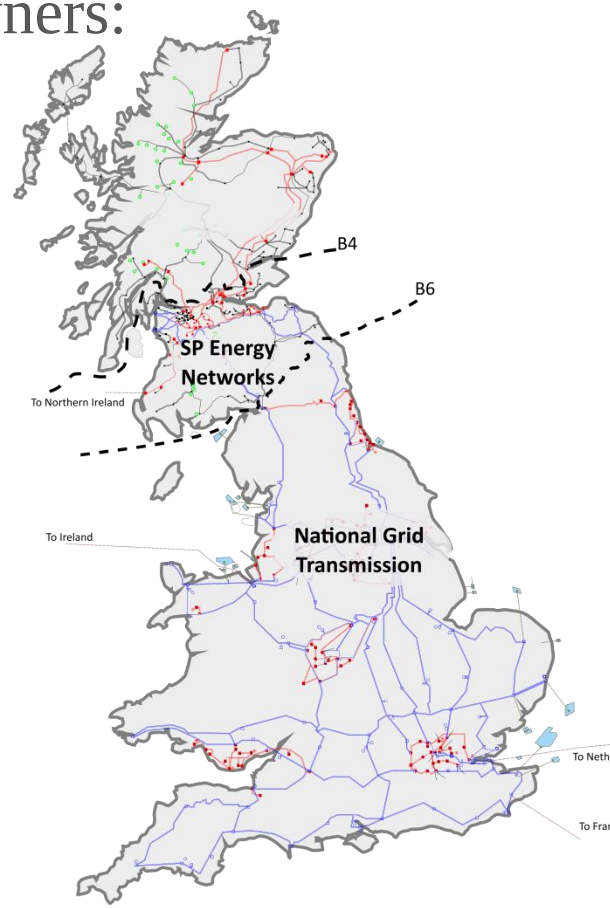
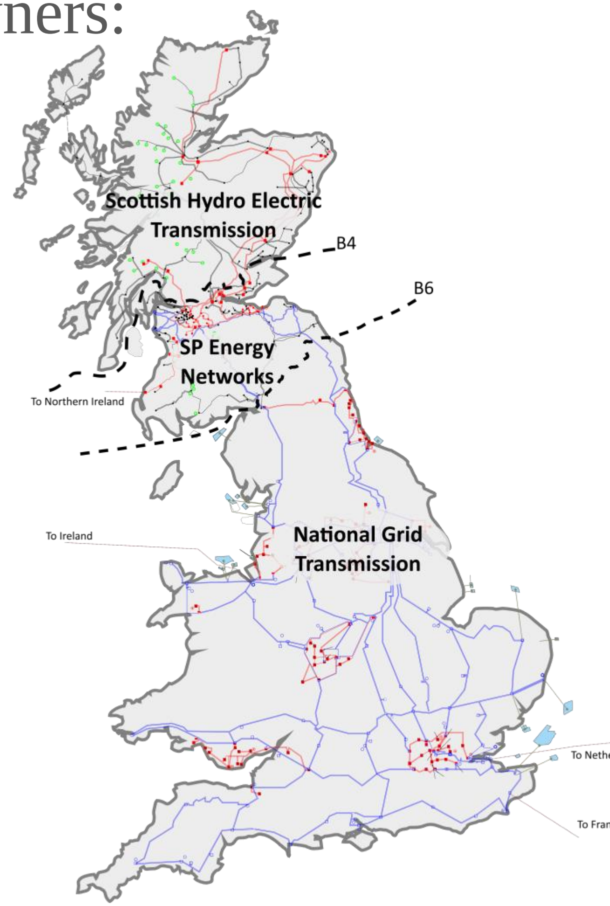
Project Partners

- Funding provided by ofgem, the GB regulator
- GB power system has three transmission owners:
  - National Grid
  - SP Energy Networks



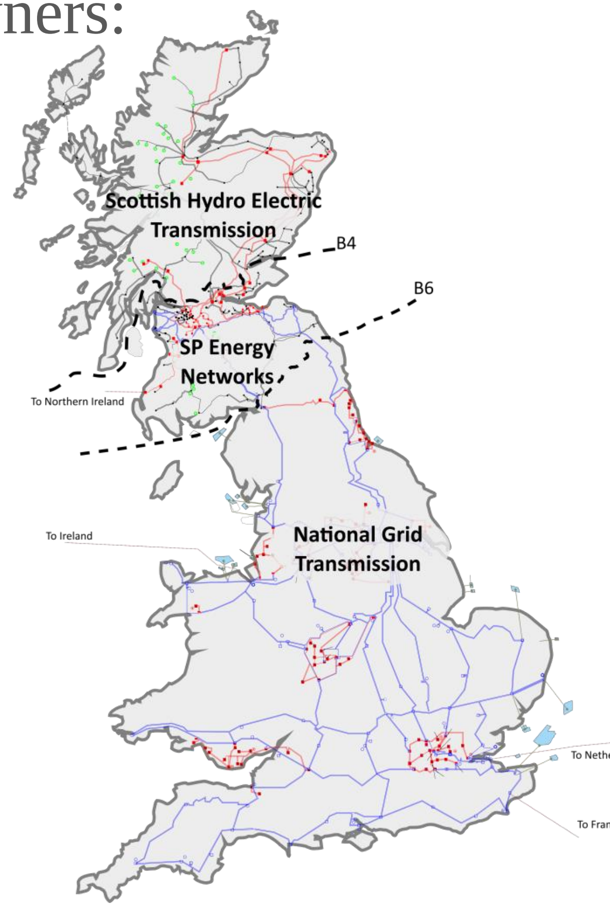
Project Partners

- Funding provided by ofgem, the GB regulator
- GB power system has three transmission owners:
  - National Grid
  - SP Energy Networks
  - SHE Transmission



Project Partners

- Funding provided by ofgem, the GB regulator
- GB power system has three transmission owners:
  - National Grid
  - SP Energy Networks
  - Scottish Hydro Electric Transmission
- GB has only one system operator:
  - National Grid
- Academic Partner
  - The University of Manchester
- WAMS Supplier
  - Alstom-Psymetrix



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Innovation Funding in GB

- VISOR funded by ofgem as an innovation project
- GB SO obligated to provide cost effective supply without risking quality/security of supply
- Innovation projects allow new technologies/arrangements to be trialled in the GB system without violating this obligation
- Therefore, investing in new technologies/arrangements as part of normal operation is challenging:
  - Any level of investment must have a clear, quantifiable level of benefit
  - Vulnerabilities must be well understood to ensure that any potential threats to security of supply have been fully considered and mitigated
- This limits scope of deployment but is an essential stage of developing new solutions for the GB power system

Motivation for VISOR

RIIO NIC NETWORK INNOVATION COMPETITION

To showcase the role of WAMS in mitigating risks with a changing grid, and helping to maximise asset utilisation in a secure way.

Changes

- Renewable Generation
- Power Electronics
- Control Interactions
- Intermittency
- Dynamic Load Response
- Loss of Synchronous Generation: fewer PSS, low inertia

WAMS Solutions

- Monitoring & Characterisation of Constraints
- Real-Time SSO Monitoring
- Fast Disturbance Localisation & Characterisation
- Hybrid/Linear State Estimation
- Validated / Improved Dynamic Models
- Oscillation Source Location

Security Margin

Maximum Asset Utilisation | Uncertainty

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Motivation for VISOR

- Build on success of WAMS around the world
- Demonstrate that WAMS can provide improved observability and understanding of the GB power system
- VISOR hopes to show three main benefits of this:

    1. Maximise asset utilisation
    2. Improve management of risk and major events
    3. Reduce the impact of uncertainty

These benefits are not entirely independent from one another

Contribution of VISOR

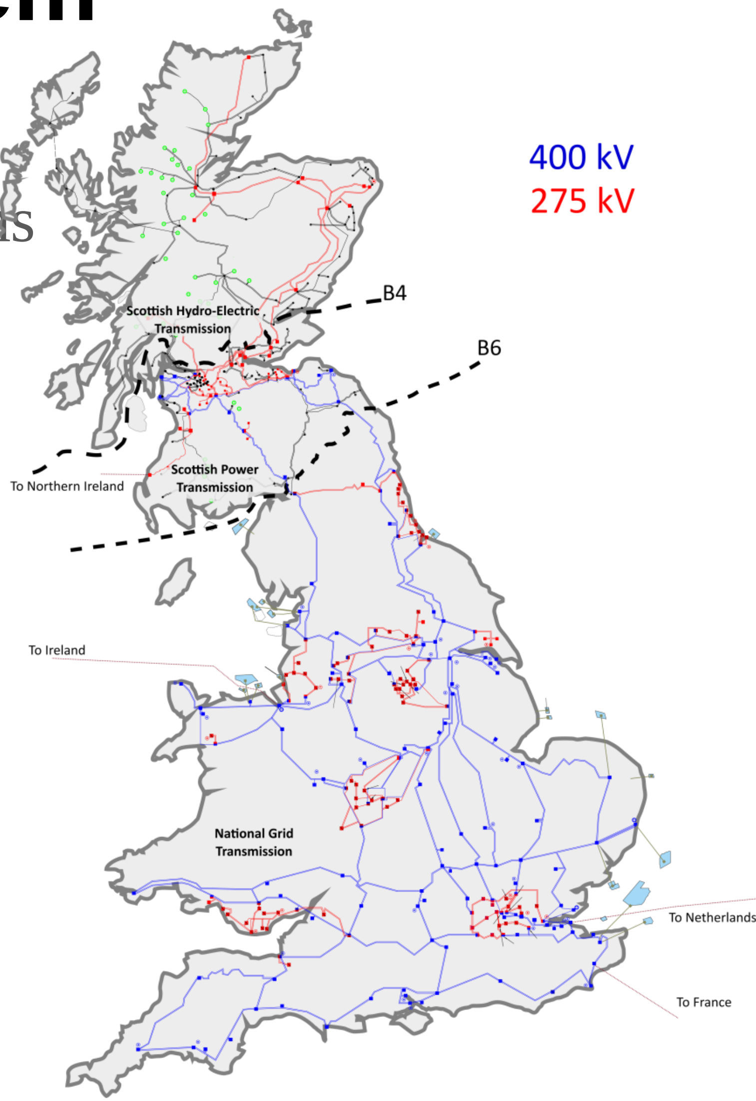
- Establish GB wide WAMS infrastructure that can support new innovation projects in the future
  - e.g. the NIC funded Smart Frequency Control project
- Showcase potential benefits of existing WAMS applications to GB power system using online demonstration
- Demonstrate how WAMS could help the system operator extract maximum benefit from the capital expenditure on both existing assets and new assets
- Generate valuable lessons learned for future WAMS innovation or the roll out of WAMS as Business-as-Usual

Background of GB Power System

1. New Technologies
2. B6 Boundary
3. VISOR WAMS

GB Transmission System

- Isolated power system with no AC connections to its neighbouring systems
- HVDC links to:
  - Northern Ireland (500 MW)
  - Republic of Ireland (500 MW)
  - France (2 GW)
  - Netherlands (1 GW)
  - Isle of Man (40 MW)
- Peak transmission load 55 GW
- Installed capacity ~ 80 GW
  - Gas/CHP ~30 GW
  - Coal ~ 18 GW
  - Renewables ~ 10 GW
  - Nuclear ~ 9.4 GW



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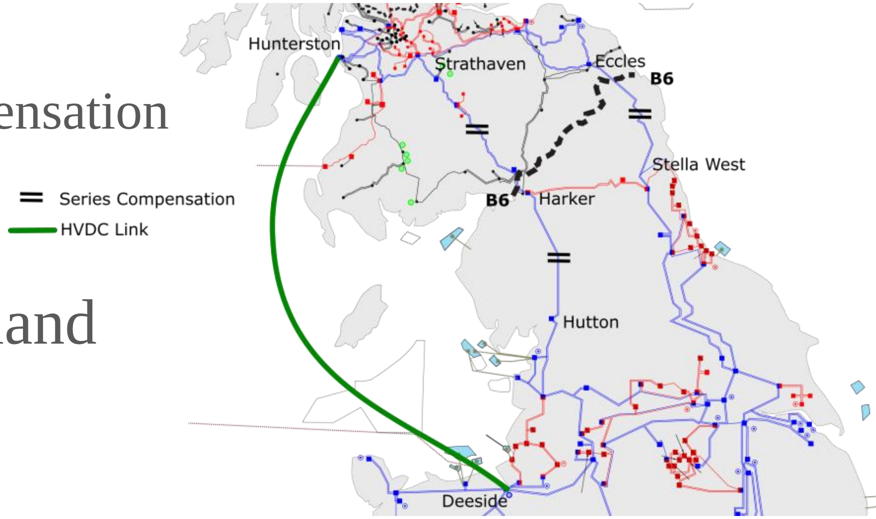
New Technologies

- New Technologies and changes in the system include:
  - Introduction of series compensation (Fixed and Thyristor Controlled)
  - Increased use of HVDC (CSC and VSC) for inter ties to neighbours
  - Deployment of HVDC (CSC and VSC) in parallel to AC system
  - Continued increase in non synchronous, intermittent generation peak recorded output of renewables: 7.2 GW (10 GW capacity)
  - Increasing number and complexity of control loops (PE converters)
  - Increase in offsetting of demand with embedded generation
  - Large offshore wind farms, new nuclear units and CCGT units required the largest credible contingency to be increased from 1320 to 1800 MW

B6 Boundary

- Boundary between transmission network owned by SP Energy Networks (Southern Scotland) and National Grid (England)
- Made up of two 400 kV double circuits
- Usually characterised by power flow from Scotland to England and is stability limited to 2500 MW or 3300 MW (with intertrip)
- New technologies deployed:
  - HVDC
  - Thyristor controlled Series compensation
  - Fixed Series compensation
- Increasing capacity required to accommodate renewables in Scotland
  - 6600 MW by 2017
  - >11000MW by 2035

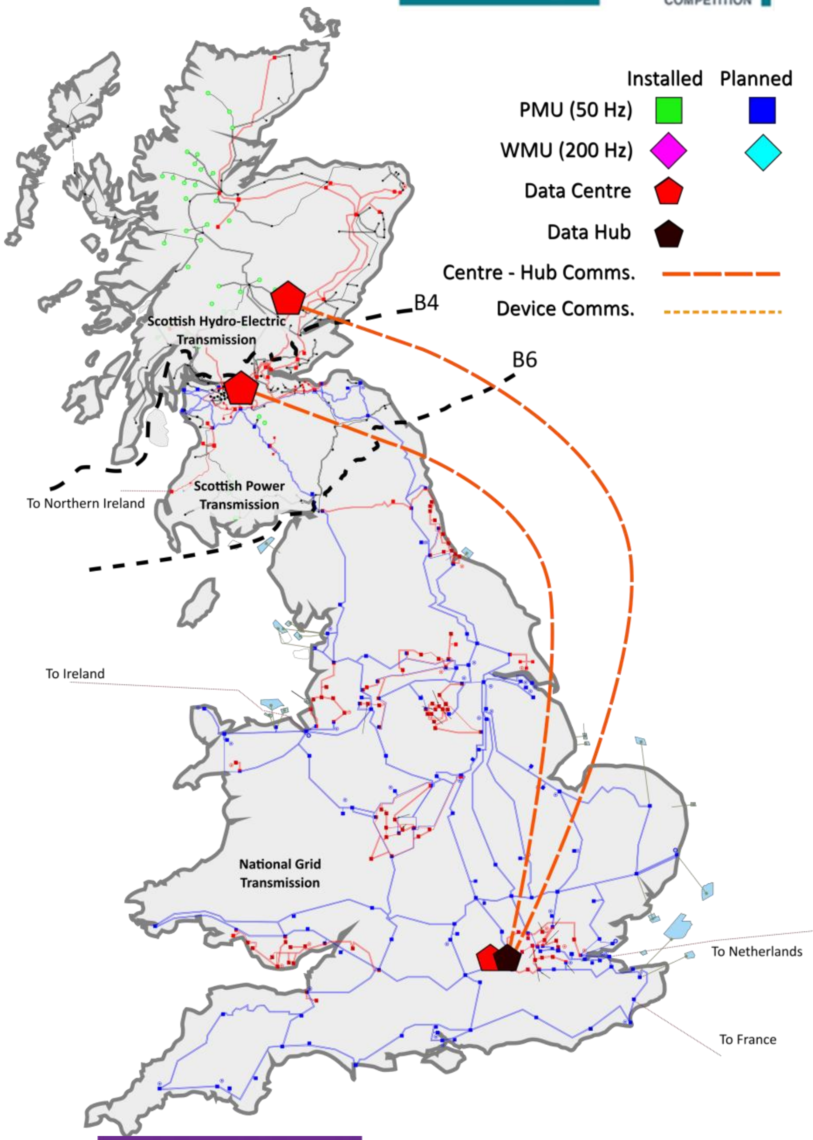


B6 Boundary

- The B6 boundary is the main study area for VISOR
- Importance of Scotland to England power flow for delivering a secure and cost effective supply in GB
- Existing Inter Area oscillation makes it an area of interest for VISOR's oscillation monitoring
- Installation of Fixed Series Compensation introduces some risk of SSR occurring
- Installation of HVDC in parallel to AC corridors makes this a unique part of the GB power system

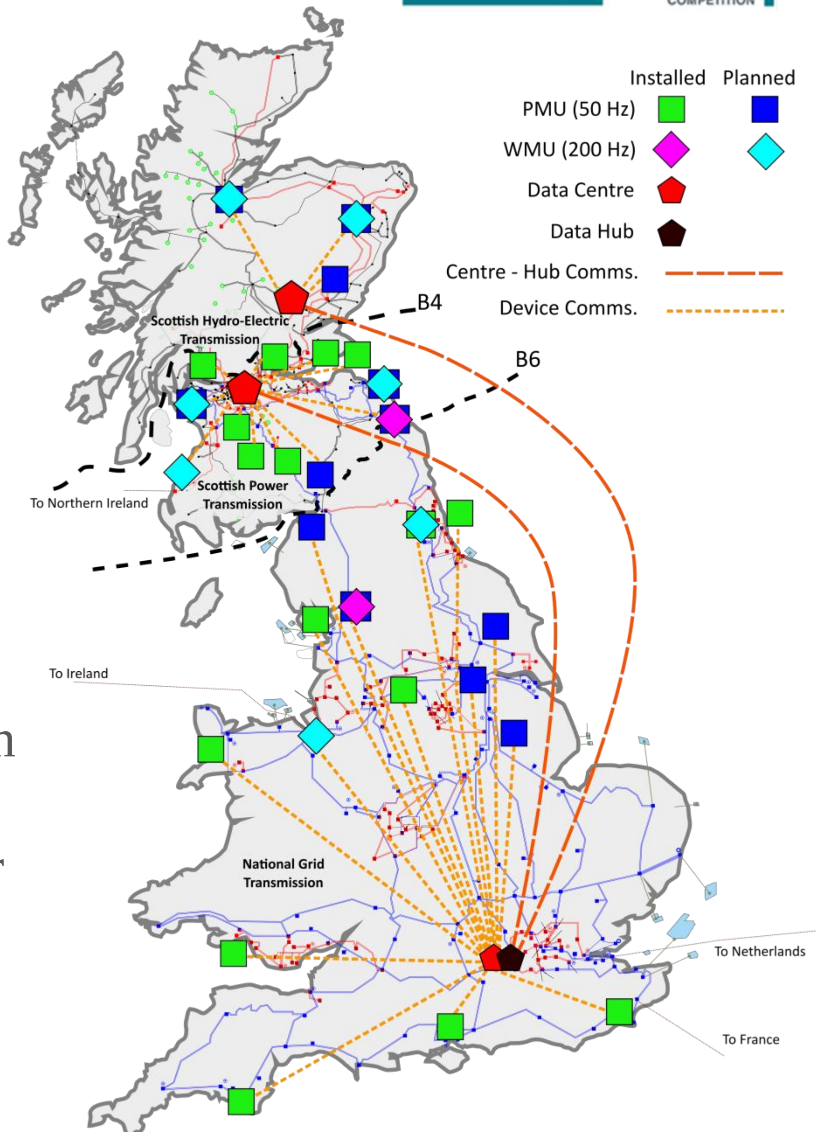
VISOR WAMS

- VISOR will install the first WAMS to monitor all 3 TOs in real time
- Four new data concentrators are being installed
  - One in each TO area (Three)
  - One at the System operator



VISOR WAMS

- VISOR will install the first WAMS to monitor all 3 TOs in real time
- Four new data concentrators are being installed
  - One in each TO area (Three)
  - One at the System operator
- Data concentrator in each TO area will be responsible for:
  - Receiving data streams from the SMT in their TO area
  - Forwarding this data to the concentrator at the system operator
  - Providing buffering and archiving for this data



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WAMS Applications

1. Subsynchronous Oscillation (SSO) Monitoring
2. Dynamic Model Validation
3. Hybrid State Estimation
4. Power – Angle Boundary Transfer Limits

Subsynchronous Oscillation (SSO) Monitoring

Types of SSO

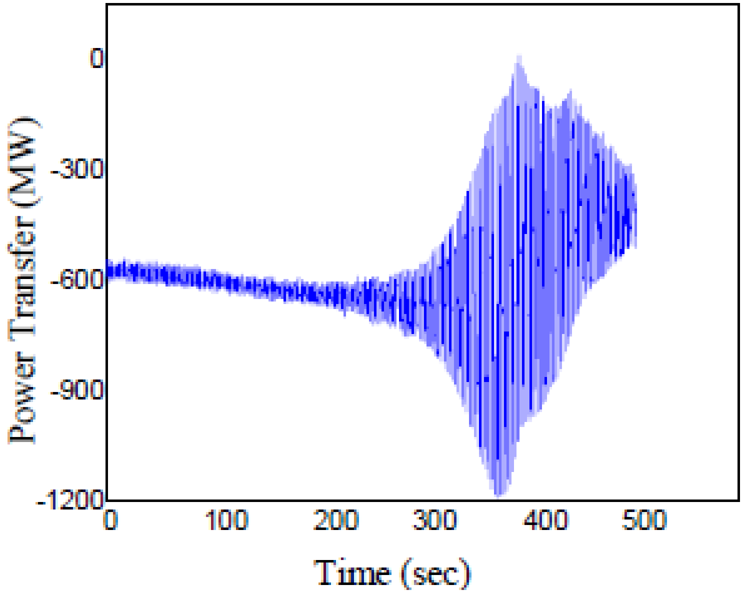
- Subsynchronous oscillations are inherent part of power systems and come in many forms:
  - Common mode oscillations - less than 0.04 Hz
  - Inter-area oscillations – less than 1 Hz
  - Local plant oscillations – 1 to 2 Hz
  - Intra-plant oscillations – 2 to 3 Hz
  - Torsional mode oscillations – 10 to 46 Hz
  - Control mode oscillations

Types of SSO

- Oscillation in the upper part of this range (4 – 46 Hz) arise from:
  - **Subsynchronous Resonance (SSR):**
    Interaction between **generator shaft torsional modes** and the **electrical modes of oscillation** created by series capacitors/network impedance
  - **Sub-Synchronous Torsional Interaction (SSTI):**
    Interaction between **power electronic converters** , e.g. HVDC links and doubly-fed or fully-converted wind turbines, and **generator shaft torsional modes**
  - **Sub-Synchronous Control Interaction (SSCI):**
    interaction between **power electronic converters**, e.g. HVDC links and doubly-fed or fully-converted wind turbines, and **electrical modes of oscillation** created by series capacitors and network impedance.
- Poorly damped oscillations and resonant conditions can have severe consequences for power systems

Threat of SSO

- Examples of the impact of subsynchronous interactions:



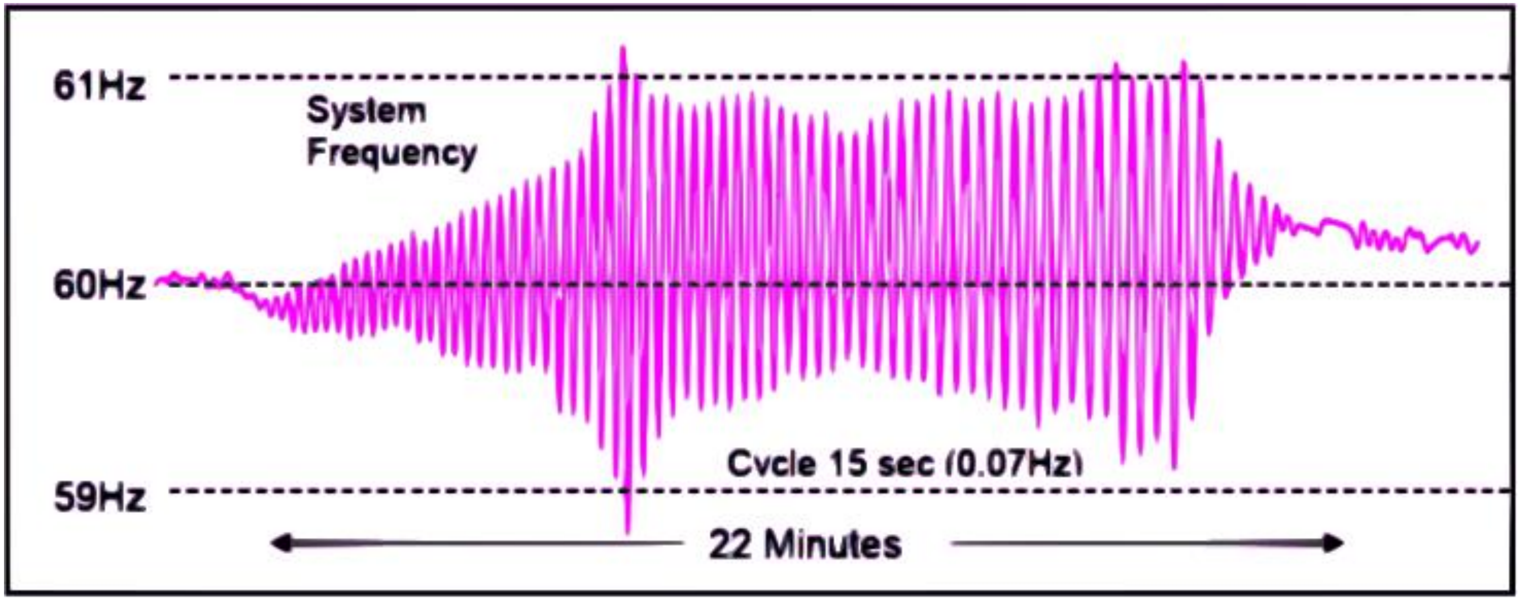
Unstable 0.5 Hz inter area oscillation: 900 MW swings, GB 1982

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

Threat of SSO

- Examples of the impact of subsynchronous interactions:



Natheer Al-Ashwal, “VISOR Application Specification: VLF Oscillation Monitoring & Source Location,” VISOR internal report, 2014

Unstable 0.07 Hz oscillation: 2 Hz swing in frequency, South America

SSO in GB system

- Inter area oscillations between Scotland and England at ~0.5 Hz are a known issue in the GB system
- Changes in the generation mix and network may cause the nature of inter area modes to become more variable
- SSR may occur due to the use of fixed series compensation; however, this is usually mitigated at the planning stage
- SSCI is a concern due to the deployment of series compensation and the increasing number of PE converters in the system
  - unlike torsional interactions (SSR/SSTI), SSCI does not require an interaction with a specific torsional frequency
  - Oscillation grows more quickly as no long mechanical time constants
  - Consequences worsen as short circuit level is decreased
  - Interactions with wind turbines have already occurred (2009, Texas)

SSO Monitoring

- Subsynchronous oscillations are inherent part of power systems and come in many forms:
  - Common mode oscillations - less than 0.04 Hz
  - Inter-area oscillations – less than 1 Hz
  - Local plant oscillations – 1 to 2 Hz
  - Intra-plant oscillations – 2 to 3 Hz
  - Torsional mode oscillations – 10 to 46 Hz
  - Control mode oscillations

Existing range of SSO monitoring in GB

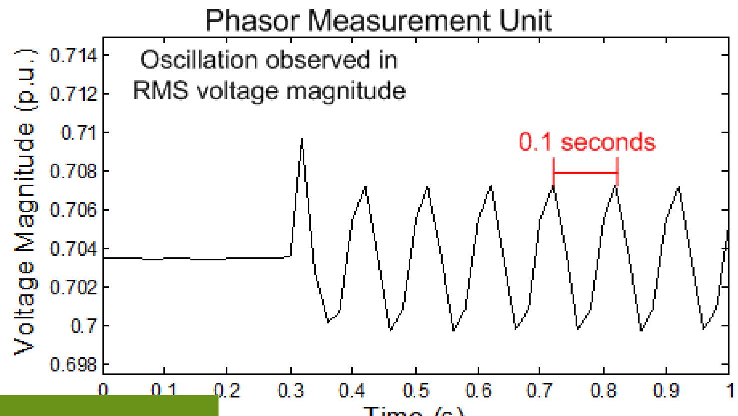
SSO Monitoring

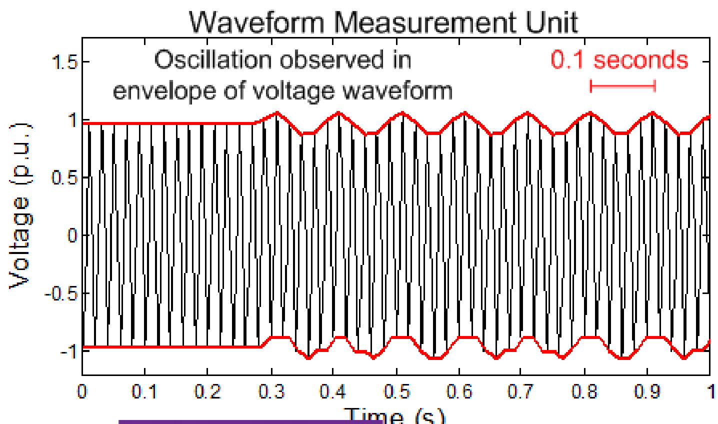
- Subsynchronous oscillations are inherent part of power systems and come in many forms:
  - Common mode oscillations - less than 0.04 Hz
  - Inter-area oscillations – less than 1 Hz
  - Local plant oscillations – 1 to 2 Hz
  - Intra-plant oscillations – 2 to 3 Hz
  - Torsional mode oscillations – 10 to 46 Hz
  - Control mode oscillations

VISOR will extend this to 0.002 – 46 Hz

SSO Monitoring

- PMUs are capable of accurately monitoring oscillations with frequency of up to 10 – 15 Hz
- To extend the monitoring range up to 46 Hz the VISOR project will deploy Waveform Monitoring Units (WMUs)
- WMUs are new devices based on a fault recorder platform and generate waveform samples (not phasors) at 200 Hz
  - Waveform sample stream is C37.118 – 2005 compliant





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SSO Monitoring

RIIO NIC NETWORK INNOVATION COMPETITION

Goal of VISOR

- Provide continuous monitoring in the range 0.02 to 46 Hz for visualisation and archive data for:
  - Analysis of correlation between oscillations observed and running arrangement
  - Selection of suitable alert/alarm thresholds for oscillation amplitude & damping
- Source location to be developed to help target solutions
- Source location may be particularly beneficial when dealing with SSCI/SSTI that may come and go with changes in control settings
- Consider methodologies for guiding the placement of SSO monitoring devices to help ensure the cost effectiveness of deployment if solution rolled out

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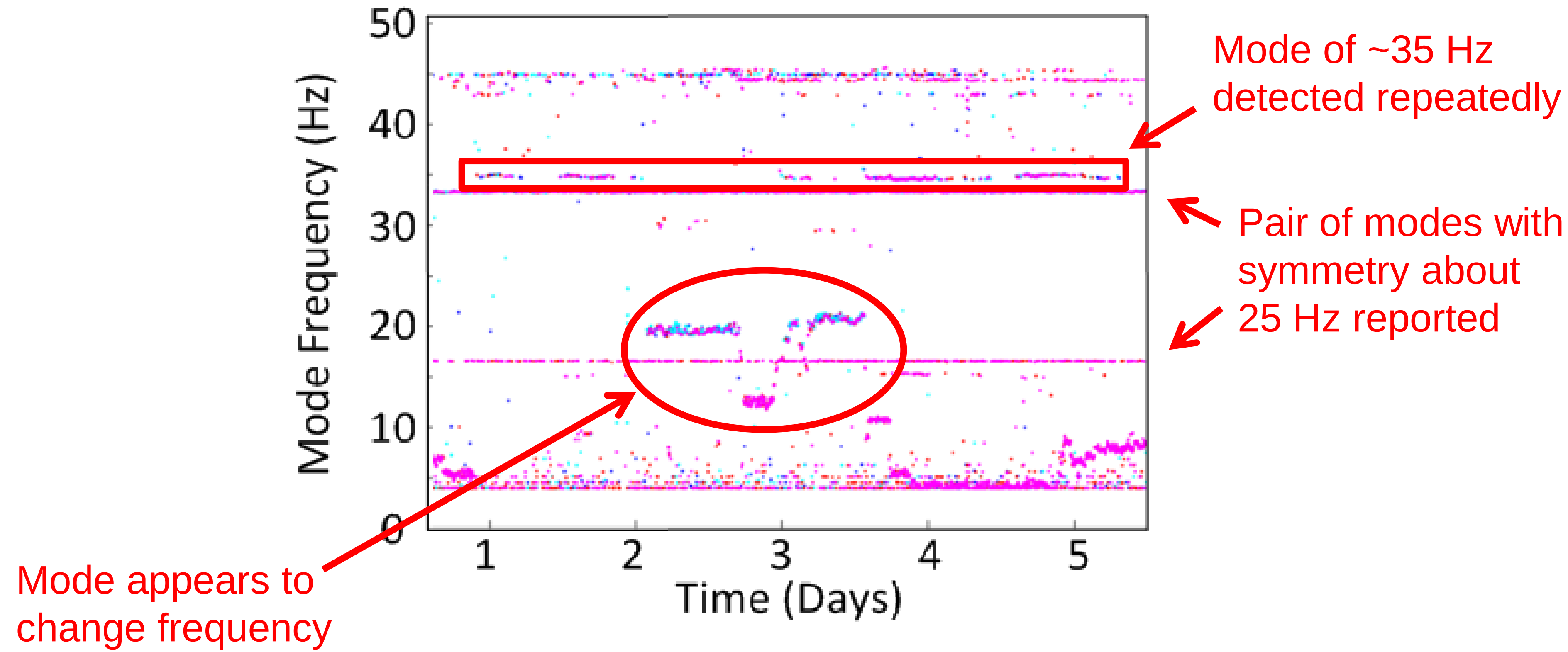
SSO Monitoring

- The broader monitoring range implemented by VISOR will provide the GB SO with unprecedented observability of SSO
- However, it will also provide them with an unprecedented amount of SSO data, which may become a burden
  - For example, the new monitoring will be able to ‘see’ small oscillations that have always been there and investigating all of these cases may become a significant waste of resources and raise undue concern
- New tools needed to determine if observed SSO is:
  - An actual threat to system efficiency, reliability and/or security
  - Which elements are interacting and to what extent
  - Which solutions are possible and which should be pursued

SSO Monitoring

- Example of 4 – 46 Hz monitoring from VISOR WAMS



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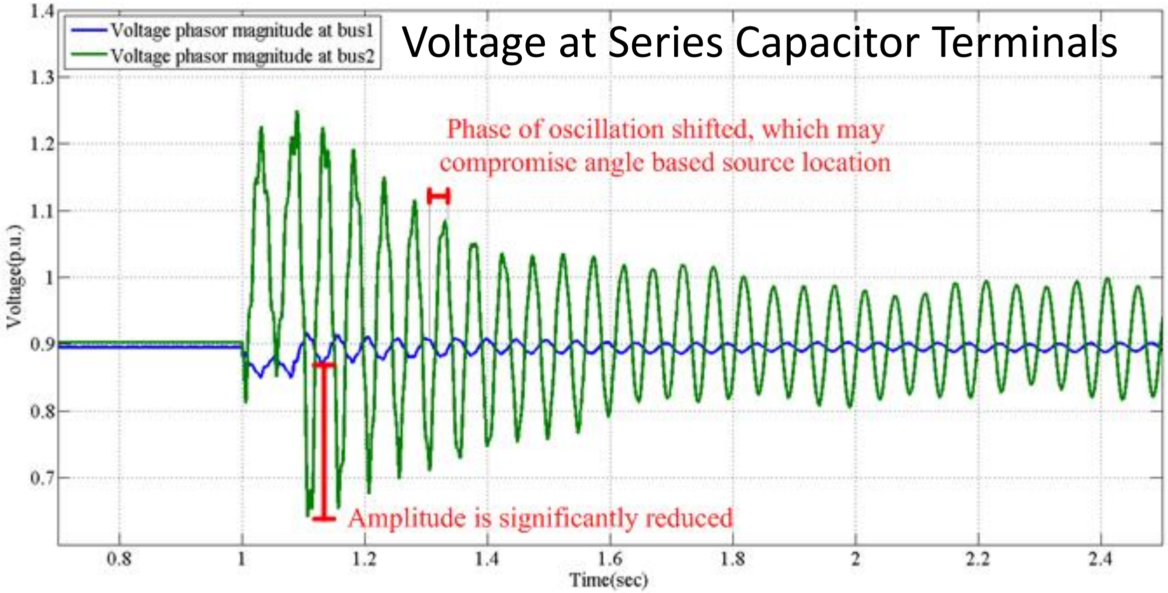
SSO Monitoring

- Determining the best device placement for ensuring sufficient SSO monitoring must consider:
  - Frequency of oscillation expected at a location (i.e. install a PMU or WMU)
  - Existing SSO monitoring results should be used to determine areas that may need additional monitoring
  - How other equipment will influence the oscillation as it propagates



Dynamic Model Validation

Dynamic Model Validation

RIIO NIC NETWORK INNOVATION COMPETITION

- Model based studies are and will remain a critical part of the proper planning and operation of power systems
- The quality of these studies is directly determined by the quality of the models that are used
- Updating and verifying the performance of dynamic models is an ongoing and essential task in any power system
- In the future, the wider use off dynamic security assessment to ensure system security will only further increase the vital role of ensuring models are accurate representations of system dynamics

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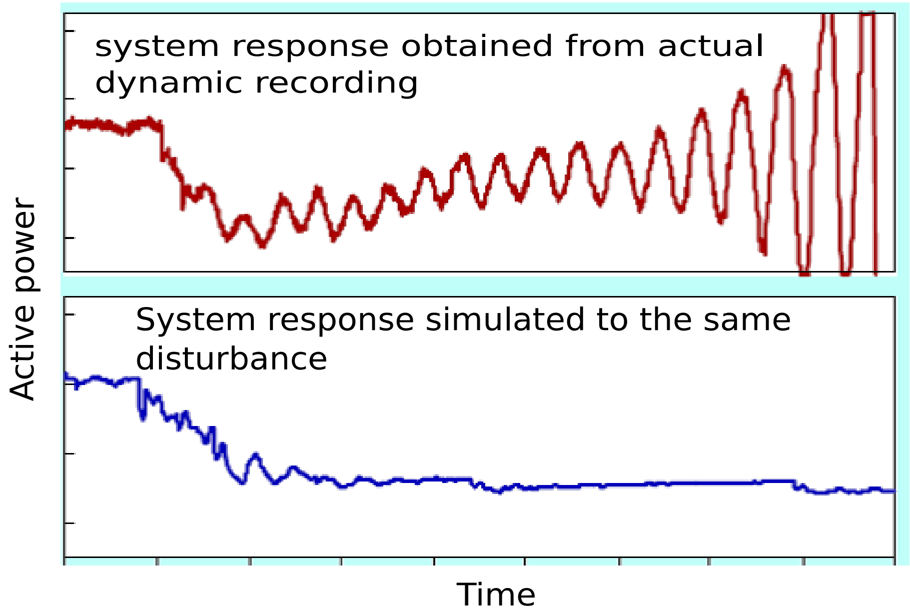
Dynamic Model Validation

- Importance of dynamic model based studies means that a failure to properly simulate the power system offline can have very real consequences for the power system online



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

Dynamic Model Validation

RIIO NIC NETWORK INNOVATION COMPETITION

- No single new technology is driving the inclusion of using WAMS for dynamic model validation in VISOR
- Indeed, new technologies are already included in the GB model and the models created for future scenarios
- However, increased complexity of system will make model validation more challenging and time consuming

More complex systems mean more feasible operating conditions
which will require more dynamic simulations that include more distinct technologies

Greater risk of unforeseen interactions/behaviour

Resources available: time/skill shortages

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Dynamic Model Validation

- WAMS data known to be a valuable asset for model validation
- Importance of model validation and known benefits of WAMS made it a logical choice for inclusion in VISOR
- Validation will use synchronised records from the VISOR WAMS and information from the EMS (running arrangement, known events, pre-event load flows, etc)
- Work will be performed by UoM researchers on National Grid premises, necessary due to confidentiality of full model

Dynamic Model Validation

RIIO NIC NETWORK INNOVATION COMPETITION

Goal of VISOR

- Demonstrate and document the benefits of model validation using WAMS data in terms of:
  - Accelerating model validation and maintenance
  - Expanding the number of cases that can be used for validation
- Study the representation of SSO in the range 0.002 to 46 Hz for both small and large disturbances
- Comparison of the modelled and measured system response for major contingencies observed by the VISOR WAMS
- Comparison of Line Parameters estimated using WAMS data with those used in the system model

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Hybrid State Estimation

Hybrid State Estimation

- PMUs directly measure the state of the bus they are monitoring, so have obvious potential benefits for state estimation
- With sufficient observability a linear state estimator is possible
- However, this level of monitoring is not in GB SO plans
- Hybrid State Estimators (HSE) allow phasor data to be combined with SCADA data to create an improved state estimators
- HSE offers benefits for:
  - Accuracy
  - Speed of Convergence
  - Stability of Convergence

Hybrid State Estimation

- Focus of VISOR will be improving the stability of convergence
  - Reducing the likelihood of no state estimate being available was seen as the most significant benefit of HSE to National Grid (SO)
- VISOR will study the performance of HSE for a limited part of the GB system (likely the area around the B6 boundary)
- This study will include the following stages:
  - Determine accuracy improvement offered by candidate HSEs by comparing their output to the existing state estimators for recorded data in varied conditions
  - Understand the mechanisms that cause non convergence of the existing SE and introduce them into simulations of the area being studied
  - Use simulations to study the performance of the candidate HSEs when exposed to these mechanisms for different numbers and distributions of PMUs

Hybrid State Estimation

Goal of VISOR

- Determine the potential improvement in convergence offered by HSE for varied levels of PMU deployment in GB
- Understand how this improvement varies with the:
  - Number of PMUs
  - Distribution of PMUs
  - Operating condition
  - Generation mix
- Based on existing research in the literature, develop a methodology for the optimal placement of PMUs in the GB system for a given level of investment

Hybrid State Estimation

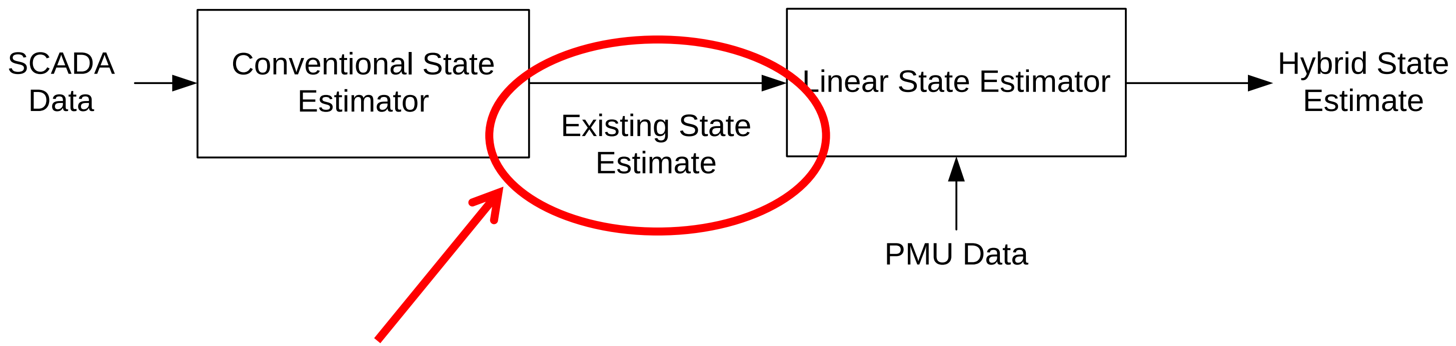
- Several different approaches have been proposed for combining the SCADA measurements and phasor data:

1. Post processing
2. Fusion
3. Distributed
4. Integrated

Hybrid State Estimation

- Several different approaches have been proposed for combining the SCADA measurements and phasor data:

1. **Post processing**
   - WAMS data combined with output of existing SE to form a LSE

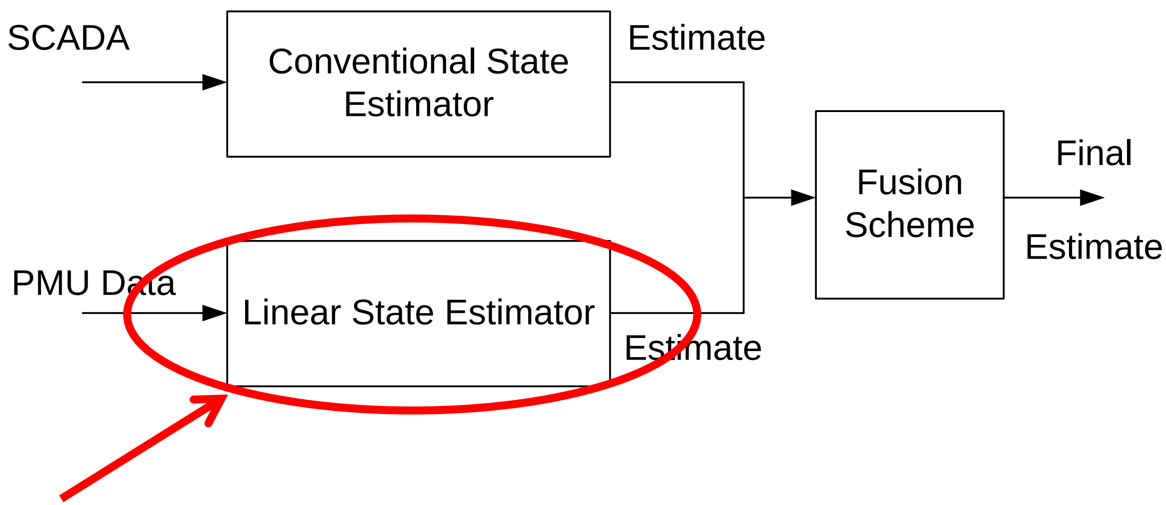


Dependence on output of existing state estimator prevents it from improving convergence

Hybrid State Estimation

- Several different approaches have been proposed for combining the SCADA measurements and phasor data:

2. **Fusion**
   - Output of SE and a new LSE are combine together



Requires a fully observable linear state estimator, so is unsuitable for VISOR goals

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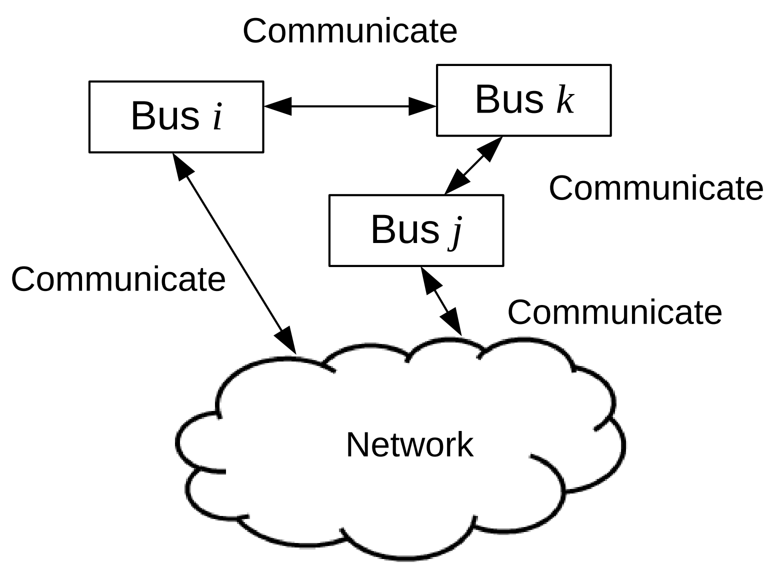
Hybrid State Estimation

- Several different approaches have been proposed for combining the SCADA measurements and phasor data:

2. **Distributed**
   - **Distributed agents used to perform state estimate based on interactions with their neighbours and no central processing**



Decentralised approach is too far remove from existing GB SO practice

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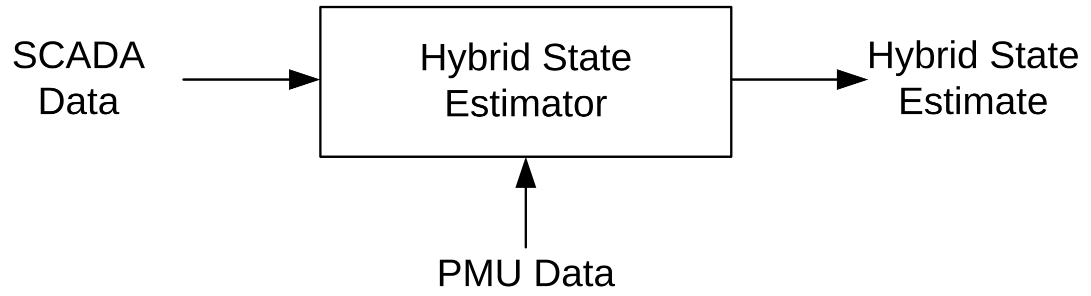
Hybrid State Estimation

- Several different approaches have been proposed for combining the SCADA measurements and phasor data:

4. **Integrated**
   - SCADA and WAMS data combined together into a single calculation



Combined SCADA/WAMS calculation can improve convergence, must study the performance of the different forms of integrated HSE

Next Steps

1. Complete WAMS Installation
2. Begin Deploying New WAMS Applications
3. Data Quality/Availability Issues
4. Laboratory Testing of Measurement Devices

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Summary

Summary

- The VISOR project is an industry led innovation project that is funded by the GB regulator (ofgem)
- Objective is to showcase the benefits of a GB WAMS and contribute to the case for business as usual deployment of WAMS
- Key objective is to create the first WAMS to monitor all three GB Transmission owners (TOs) in real time
- Study the benefits of the WAMS applications to GB, including:
  - SSO monitoring, alarming and localisation
  - Dynamic Model Validation
  - Hybrid State Estimation
- Study the impact of uncertainty on the Security margins and the operation of the GB system and how WAMS can combat this

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