SP ENERGY NETWORKS

Visualisation of Real Time System Dynamics using Enhanced Monitoring (VISOR)

In collaboration with

nationalgrid

Scottish & Southern Electricity Networks

MANCHESTER 1824
The University of Manchester

RIIO NIC NETWORK INNOVATION COMPETITION

Project Progress Report

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Table of Contents

1 Executive Summary

SP Transmission (SPT), supported by the other transmission licensees and the academic partner, made a full proposal submission for the project: Visualisation of Real Time System Dynamics using Enhanced Monitoring (VISOR), under the Network Innovation Competition (NIC) mechanism in 2013. Ofgem approved the proposal and issued the Project Direction on the 19th of December 2013. The project commenced in January 2014 and was due to conclude in March 2017 but Ofgem approved an extension request until December 2017 to allow additional work to be carried out.

The VISOR project showcases the role of an enhanced Wide Area Monitoring System (WAMS) in overcoming the challenges facing the GB power system as it moves toward a low carbon future. It has created the first integrated GB WAMS and has also marked the first deployment anywhere in the world of new Waveform Measurement Units (WMUs), which generate 200 frames per second data for the detection of sub-synchronous oscillations (SSO).

The VISOR WAMS is the first to collate, store, visualise and analyse synchronised measurements in real-time across all three of the GB Transmission Owners (TOs). The WAMS incorporates wide area synchronised phasor measurements produced at a rate of 50 frames per second that provide unparalleled monitoring and understanding of the dynamic behaviour of the GB system, when compared to unsynchronised SCADA data that is sampled at one frame per second or less.

VISOR focuses on the following key areas that are expected to be of the most benefit to the GB system in the short to medium term:

- Real-time monitoring and alarming of oscillations in the range 0.002Hz to 46Hz - from low frequency generator governor behaviour, to inter-area oscillations, to sub-synchronous resonance introduced by series compensation and sub-synchronous interaction introduced by power electronic converters,
- The use of WAMS data to aid and enhance post-event analysis and network & dynamic model validation,
- Hybrid state estimation using Phasor Measurement Unit (PMU) and SCADA data, and,
- The potential use of angle based security limits to relieve power flow constraints across the B6 boundary between Scotland and England.

Following engagement with a variety of stakeholders over the last 24 months, the project has taken new initiatives to allow further monitoring and training to safeguard the transition into BaU and a project extension has been granted to enrich the business case and maximise the value of the new initiatives, in particular, to account for the delayed commissioning of the Western HVDC link, which is a key focus area of VISOR and to enable further training workshops within the WAMS-EMS integration training and testing facility which will be established in 2017.

The PhasorPoint and technology supplier for VISOR, Psymetrix, part of Alstom Grid, was acquired by General Electric as of November 2015. The company name has subsequently changed to GE Grid Solutions: a GE and Alstom Joint Venture and is referred to as "GE" within this report.

1.1 Project Highlights

This is the seventh progress report and covers six months of the project delivery from January 2017 – June 2017, "the reporting period".

The project delivery is in line with the original proposal regarding project programme, resources, budget, risk management, intellectual property rights (IPR) and knowledge sharing; and over the reporting period supporting evidence for the following elements contributing to the Successful Delivery Reward Criteria (SDRC) have been delivered on schedule:

SDRC 9.2.1

- ✓ *Report on PMU roll-out requirements for the applications (WP 4B, Mar 2017)*
- ✓ *Simulation cases for presentation & training (WP 5.2, Mar 2017)*

SDRC 9.6.1

- ✓ *Academic partner delivery of knowledge capture and publications (Dec 2016 - Mar 2017)*

SDRC 9.6.2

- ✓ *Delivery of Independent Phasor Data Visualisation and Interaction Tool (Mar 2017)*

The Project Delivery Team (PDT) has successfully undertaken the following activities during the reporting period:

- The project was extended from 31st of March 2017 to 31st of December 2017 to allow additional activities to be included in the project scope. The extension allows the project team to undertake a number of activities that will enrich understanding of system dynamics and benefit quantification forming the basis of GB roll-out strategy. The extension includes 4 additional SDRCs:
  - Delivery of Independent Phasor Data Visualisation and Interaction Tool (Mar 2017)
  - Commissioning of WAMS-EMS interface and training facility (Jun 2017)
  - Undertaking of WAMS-EMS training within dedicated training facility (Sep 2017)
  - Baseline and comparator report for SSO behaviour (Dec 2017)
- Review of WAMS and Power System performance during 2016 – delivered through a report and workshop attended by all project partners – excerpts from the report are included in this PPR.
- National Grid SO, SPEN and GE have been working to optimise the performance of the VISOR WAMS infrastructure – including communications network and data stream configuration.

- Following approval of extension, SPEN and GE have started work to implement the "Sandbox" WAMS-EMS Demonstration System in the SPEN Control Centre.
    - Technical Architecture Document has been signed off
    - Cyber Security Risk Assessment has been signed off
    - Clients and servers initial builds have been completed
    - Networking configuration has been completed
    - Admin/user accounts setup has been completed

- SPEN and NGET with support from GE have made provisions to capture the present 'fingerprint' of the system behaviour before and during the multi-stage commissioning of the Western HVDC link, by procuring and installing monitoring devices at Auchencrosh and Connah's Quay, respectively.
- SSE are progressing with IDM+ PMU connection at Crossaig, currently undertaking some work on the IT side. SSE expects more IDM+ PMU connections to follow on from this installation. SSE successfully demonstrated WAMS/PhasorPoint to Protection and Control Room colleagues, initial feedback received was positive
- NGET are looking to extend wide area monitoring into the South East Region where NEMO HVDC and ElecLink will be connecting in 2018.
- National Grid SO, as part of an ongoing process, are defining the requirements for the future of the Energy Management System (EMS) and with this are evaluating how a "production-grade" WAMS would be integrated; specifically looking at what information would be transferred. In addition the SO is reviewing the wider system monitoring requirements.
- GE supported SPEN in analysis and investigation of a number of significant oscillatory events and recurring behaviours detected by the VISOR WAMS – one example is highlighted in the 2016 WAMS & Power System Performance Review section of this PPR.

- GE issued the annual WAMS and Power System performance report for September 2015 to December 2016 covering:
    - Power System performance: GB system performance, SSO baseline performance and investigation of abnormal events detected by VISOR WAMS.
    - WAMS performance: high-level statistics to highlight areas for further investigation such as a PMU with high repetitions of connection drop-outs.

During the reporting period, knowledge dissemination has focused on key internal stakeholders to continue building support of the application of this technology so that there is ample enthusiasm for future implementation following the conclusion of the project by hosting the following highly successful events:

1. Workshop to review WAMS and Power System performance during 2016 attended by all project partners including PDT members and other experts from within each business.
2. A full day UoM workshop was been held at the SPEN premises where the results from the UoM research were presented and discussed in detail with relevant SPEN teams such as System Analysis, Control Room Operations and Planning.

3. Steering Board Meeting with directors and senior management, where the achievements of the project were recognised and the future of GB WAMS was discussed and planned.

In addition to the dedicated knowledge dissemination events organised and hosted by the project team, the knowledge gained by the project has been shared with the wider industry through papers, presentations and attendance at the following conferences:

1. **"Learning from GB Wide Area Monitoring and Progress towards Operations Integration"** - S. Clark et al accepted for presentation and paper for PAC World 2017 (27-29 June 2017 Wroclaw, Poland)
2. **"Impact of Location and Composition of Dynamic Load on the Severity of SSR in Meshed Power Systems"** - P. Dattaray, P. Wall, P. Mohapatra, J. Yu, V. Terzija accepted for presentation at the IEEE PES Powertech conference (Manchester, UK)
3. **"Integrating Wide-Area Monitoring and Energy Management System for Power System Operations"** – C. Halliday accepted for Special Sessions Industry perspective on Synchrophasor technology presentation at the IEEE PES Powertech conference (18-22 June 2017, Manchester, UK)
4. **"A Screening Rule Based Iterative Numerical Method for Observability Analysis"** - Z. Jin, P. Dattaray, P. Wall, J. Yu, V. Terzija accepted by IEEE Transactions on Power Systems
5. **"A Novel Control Strategy for Subsynchronous Resonance Mitigation using 11kV VFD based Auxiliary Power Plant Loads"** - P. Dattaray, D. Chakravorty, P. Wall, J. Yu, V. Terzija accepted by IEEE Transactions on Power Delivery

In terms of upcoming knowledge dissemination and sharing events in 2017, the following events will be held or attended by members of the VISOR PDT:

1. Dedicated VISOR External Stakeholder Event
2. Internal stakeholder engagement and training events at the Sandbox facility
3. Workshop and Presentation of WAMS use-cases, benefits, investment options and implementation strategies conclusions from the VISOR Roadmap.

In addition to the dedicated knowledge dissemination events organised and hosted by the project team, the knowledge gained by the project will be shared with the wider industry through the following presentations and attendance at the following upcoming conferences:

1. IEEE PES General Meeting, 16th-20th July 2017, Chicago, USA. There will be two presentations made related to roll-out scenarios for VISOR titled: "The Role of GB WAMS System in Managing the Risk and Impact of Cascading Failure in GB Power System" and "Power Network Planning for Integrating High Penetration of Windfarms".
2. Low Carbon Network Innovation Conference, 6-7 December 2017, Telford, UK
3. "Application of Advances in Wide Area Monitoring to Address the Challenges from an Evolving Power System" - S. Clark et al submitted abstract for CIGRE 2018 (Paris, France): Abstract under consideration by the UK National Committee

1.2 Project Risks

There are currently no uncontrolled risks that could impede the achievement of any of the SDRCs outlined in the Project Direction, or which could cause the Project to deviate from the Full Submission. We monitor risks on a continuous basis with regular review at monthly progress meetings. The key risks are summarised below, with more details in Section 4.

1.2.1 Technical and Roll-Out Risks

The following technical and roll-out risks were encountered during this reporting period:

- **Delayed deployment of Sandbox:** Uncertainty regarding extension of the project led to a delay in starting the build of the test facility. The aim was to start work at the end of 2016.
- **Delayed commissioning of the Western Link:** National Grid and SPEN's joint venture to build the Western Link is a £1 billion project which has faced delays amidst the significant challenges associated with such a significant and innovative project. There remains a risk that even with the project extension, further delays to the Western Link might result in VISOR being concluded before the link is commissioned.
- **No clear directive for TOs sharing data:** TOs currently send PMU/WMU data to the SO as part of the scope of VISOR. If the TOs do not receive a clear directive from SO regarding the requirement for WAMS, the SO will stop receiving this data post VISOR as there will no requirement to maintain the communication links currently used for WAMS data, this will inhibit the SO's ability to visualise the whole GB WAMS. This requirement could potentially be added to the System Operator -Transmission Owner Code (STC) which defines the high-level relationship between the GB SO and TOs. Failure to achieve a clear directive will result in individual TO WAMS systems without continuation of GB WAMS post VISOR.

The following technical and roll-out risks were retained from the previous reporting period encountered during commissioning and system analysis for project VISOR in the reporting period:

- **Configuration of test facility:** The new facility is intended to bridge the gap between innovation and Business as Usual (BaU) for all project partners by providing a live demonstration of the integration of WAMS in EMS applications. The risk is that timely delivery of this facility, in order to successfully demonstrate and undertake training within the environment, will not be achieved.
- **Production architecture design and network requirements:** The successful demonstration of WAMS-EMS interface will require WAMS to be upgraded to a critical infrastructure. This will require actual investment for implementation as approved by each business.

1.2.2 Project Management Risks

The key project management risks that have been encountered during the reporting period are listed below. Project Managers at each of the project partners have ensured that these risks are continuously monitored and actively managed to ensure the project milestones are not jeopardised:

- **Resources being re-assigned:** Continuation of resource through extended duration of uncertainty regarding extension introduced the possibility that key personnel may be assigned to different project and not available to continue working on the project.
- **Establishing a successful continuation plan:** The ultimate success of the project will be determined by the onward progression into BaU. In order to best position the technology the VISOR project must address the uncertainty of the business case for both TO & SO, the low level of internal experience and confidence in the WAMS technology and applications, and the concern that increased data must not impede other BaU practices.

Further details of Risk Management including Technical Risk and Project Management Risk can be found in Section 4 of this document.

1.2.3 Summary of Learning Outcomes

The main learning outcomes over the reporting period are summarised below:

Key Process Learning - "Sandbox" WAMS-EMS Demonstration System

A vital aspect of transitioning new technology from an innovation project into the daily operations is the thorough demonstration of the complete system operation to applications, visualisation and analysis screens that operators will use and the associated data connections and cyber security protocols required to do so. VISOR introduced new monitoring system practices to examine new capabilities and benefits in, and doing so, has also emphasised the necessity of a pre-production facility in order demonstrate this new technology in an operational environment to demonstrate the interface with the EMS and other BaU functions such as real-time operations in control centre.

Key Deployment Learning – Maximum benefit through preventative investment

Experience from abroad is to invest prior to the blackout as this is where the benefit is realised. If we wait for the blackout and then invest (since this is what an investigation will recommend) we will have missed the benefit opportunity.

Key Infrastructure Learning - Limitations in Using OPTEL

SPEN and GB SO have established a 10 Gbps OPTEL-grade Multiprotocol Label Switching (MPLS) network. The GB SO Operation Network (OPTEL) services were considered when establishing the initial GB WAMS through VISOR. The setup of the GB WAMS infrastructure would certainly benefit from using this network. This network is used to support control traffic within National Grid SO and TO, so it is a fast private network that has exceptional reliability, and the connection has already been established between National Grid and SPEN. The main issue is that the OPTEL is a Critical National Infrastructure (CNI) component, and GB WAMS setup for an innovation project as the VISOR project is a non-CNI system which cannot be connected to the CNI WAN. In order to use WAMS for decision making in control room WAMS data quality, availability and reliability will require WAMS to be considered as system critical application similar to the EMS.

Key Security Learning – Limitations of UDP packets on Data Security

The introduction of a 200 fps WMU has highlighted a security versus performance issue. The WMU has been designed with performance of the network as a consideration, and therefore uses UDP and not TCP. UDP has performance advantages over TCP as it is a connectionless method of communication. This means that the UDP protocol has very little overhead, but it also means that if a packet does not arrive the data is lost. Conversely TCP is a connection oriented transport method. It will open a socket or a connection between the two IP addresses and will provide error checking and packet receipts to ensure all the packets have arrived. If packets fail to arrive they will be resent. This means that there is a lot of overhead and extra information in a TCP datagram, but it does provide greater reliability in the data transmission.

The use of UDP causes an issue with configuration of the firewall as the connectionless transport protocol means that the UDP ports need to be opened up on the firewalls so that it allows data inbound to the data centre from the substation. As TCP is connection oriented, the TCP socket can be initiated from the WAMS server out to the WMU at the substation, and therefore means that the firewall rules at the data centre are opened to allow connection out from the data centre and not into the datacentre from the outside.

Further details of Learning Outcomes can be found in Section 6.1 of this document.

2 Project Manager's Report

This section highlights the VISOR projects' key activities, milestones, risks and learning over the reporting period (January 2017 – June 2017).

2.1 Project Progress Summary

VISOR remains on course for a satisfactory delivery over this reporting period regarding the project programme, with all milestones on schedule and the undertaking of extra initiatives as a part of approved extension to boost the business readiness following completion of the project at the end of the year.

The project is now in its third phase, the *transitional stage*, whereby the continuous flow of new data gathered by the project is collated, analysed, and translated into new information on the dynamic behaviour of the system on a wider and more precise scale than ever before. There is also substantial focus on integrating VISOR within the BaU.

The insight gained during the *operational phase* is informing the basis of the development and justification for implementation into the daily operations of the Network Licensees. To supplement this stage of the project, the PDT have undertaken new initiatives to support this transition, including the provision of a new dedicated demonstration and training facility and a simpler high-level geographical, multi-platform, visualisation tool to demonstrate a potential use case and build confidence in live deployment.

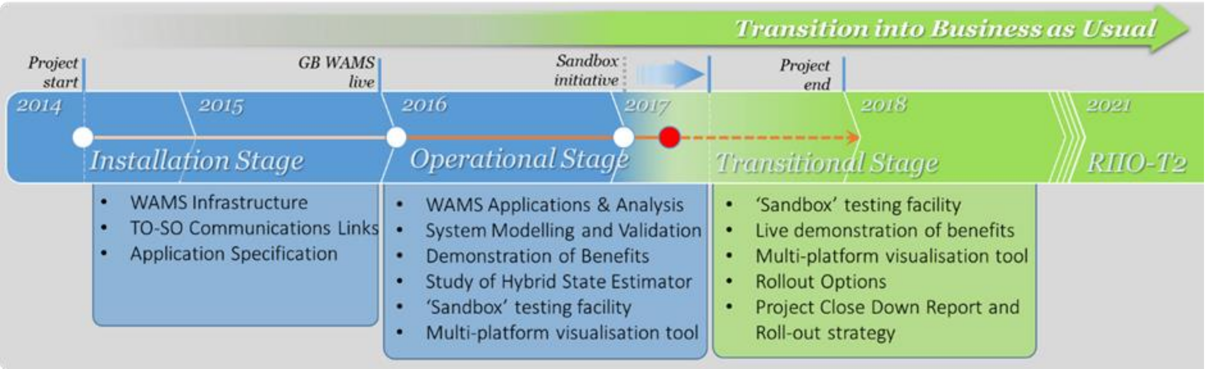

Figure 1. VISOR high-level timeline

2.2 Project extension

A project change request was sent in September 2016 and Ofgem approved this request on the 31st of March 2017. The project was extended from 31st of March 2017 to 31st of December 2017 to allow additional activities to be included in the project scope including

- Extend the monitoring and analysis window to capture the delayed WVHC commissioning
- Extend the Project's scope to integrate the developed system into SP Transmission's Energy Management System (EMS) within their network control room.
- Update the scope to provide training to the control centre staff within a 'sandbox environment' and incorporate the system within their critical infrastructure.
- Create an Independent Data Visualisation/ Interaction Tool

Ofgem agreed with the proposals and are satisfied that the changes are in the interests of consumers. Enabling VISOR to capture data during the commissioning and possible live operation of the Western Link on the GB Network will create useful knowledge which can be disseminated to all network operators. Through project VISOR there are WMUs installed on either end of the link to capture data and provide enhanced visibility both at SPT and NGET control centre. Ofgem also noted that interfacing VISOR PMU and WMU data with the EMS will lead to it becoming a useful network tool which, in turn, has the potential to save network customers money through reduced operation costs and risk avoidance.

As a part of the approved 9-month extension following steps will be taken to lead the transition of WAMS technology into BaU for the benefit of all Network Licensees:

- Bringing WAMS technology & applications physically and operationally closer to the control rooms in SPEN (new facility at SPEN Control Centre and within the secure network)
- Bringing WAMS technology & applications operationally closer to the control rooms in SSEN, NGET, NETSO, through demonstration and training workshops
- Demonstrating the operational benefits of WAMS based on a live environment
- Establishing business cases for each aspect and application of the WAMS data
- Documenting the optimum communication and cyber security requirements of the underlying infrastructure and data sharing processes requirement
- Setting out a Roadmap by which these benefits can be realised, from both TO and SO perspectives

The steps VISOR will take to achieve these goals are explained in more detail below.

a) Western HVDC: capture and analysis of 'finger print' post-commissioning

The installation and commissioning of the new intra-network HVDC link represents a significant new type of asset within the network and a noteworthy opportunity for the VISOR project to document detailed analysis and insight into the potentially new behaviour this may introduce to the network. Through VISOR, SPEN and NGET with support from GE have made provisions to capture the present 'fingerprint' of the system behaviour before and during the multi-stage commissioning of the Western HVDC link, by procuring and installing monitoring devices at Auchencrosh and Connah's Quay, respectively

Whilst the VISOR monitoring devices will still be able to capture the commissioning and operation of the HVDC link, the project extension has allowed the continued joint effort of the VISOR project partners, whose experience in conducting detailed analysis of this nature and drawing conclusions from which, represents significant learning under the VISOR project for dissemination and a more informed business case. The co-ordination as exists for VISOR will be difficult to replicate.

Without the extension, the installation delays removed the possibility of VISOR capturing and analysing the commissioning behaviour. The extension granted allows VISOR to lengthen the monitoring period, allowing for detailed analysis of the area surrounding Connah's Quay and Hunterston but also study the wider impacts on system dynamics that will ultimately enhance understanding of underlying trends and instances of SSO, with the Western HVDC link as a key case study. VISOR project partner GE produces system reports using the system data, which are reviewed in a co-ordinated manner by the VISOR team. Without the proposed extension GE would not have produced the system analysis report. GE also does data quality analysis as a part of the report which has been extremely beneficial in improving the data quality of the WAMS data in GB.

Figure 2. Western HVDC Converter Stations

b) WAMS-EMS interfacing

VISOR has put WAMS in front of system operators for the first time, with many entirely new application modules seeing their world-first demonstration under VISOR. These new applications and capabilities have been presented and demonstrated to the potential end-users and key personnel to pro-actively support and explore WAMS as effectively as possible, however the VISOR system has resided within the corporate network, away from control room operators and incapable of interacting or replicating the true control-room environment.

WAMS-EMS interfacing was not a planned deliverable from VISOR. However, after extensive stakeholder engagement with other utilities in Europe and US, as highlighted in our previous 6 monthly reports, creating a WAMS-EMS demonstration interface was viewed as the only possible step forward to use WAMS truly real time in control centres of TOs/SO. Control centre engineers and operators have provided feedback that they don't want to view an additional application for WAMS. They would rather visualise WAMS alarms on their existing EMS. Following an opportunity which arose as a result of SPEN's EMS upgrade programme in 2016, the new EMS provides a good ground to test this WAMS-EMS interfacing. The facility provides the opportunity to directly address the concerns surrounding future integration of new WAMS data into the EMS. Without the extension, each TO/SO would have had to make its own decision regarding WAMS/EMS interface without any actual experience of working and simulating on such a system. This process would have taken longer without a demonstration and each TO/SO would have lost critical time trying to obtain approvals for the necessary critical infrastructure to enable WAMS which is required right now.

The Sandbox facility provides the opportunity to directly address the concerns surrounding future integration of WAMS data into the EMS. The timing of the inclusion of WAMS data is highly favourable and will provide users with greater appreciation of the benefits of the interface between EMS and WAMS, including:

- **Improved situational awareness capabilities** that will be able to show WAMS events and key data within the geospatial visualisation environment
- **Improved data integration** allowing WAMS data and oscillatory stability results and alarms to be viewed within an enhanced EMS user interface
- **New historical analytics tooling** that can be used in both the new Sandbox environment and the current VISOR systems to provide easy off-line analysis tools and reporting capabilities

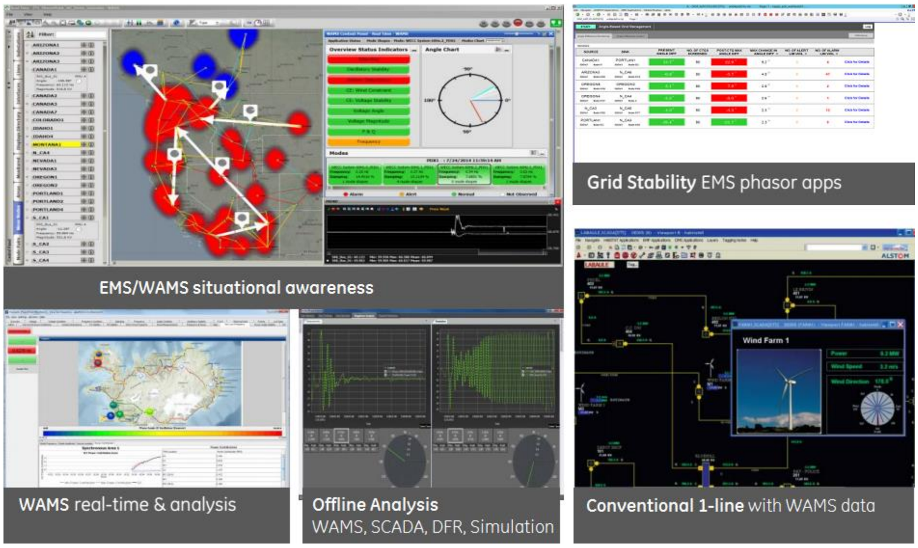

Figure 3. Components of the Integrated WAMS/EMS User Interface

The extension will allow time for any integration issues to be rectified and the various applications to be verified ahead of the implementation of any interface between WAMS and the real operational EMS to be realised.

c) WAMS-EMS demonstration and training

The VISOR WAMS includes many applications that are fundamentally new for control operators. The new facility is intended to make the VISOR WAMS more accessible for all project partners by providing a live representative environment in which operators can learn, configure and build screens to meet their needs' whilst also providing a safe environment for exploring and trialling the next generation and phase of WAMS-EMS integration and visualisation capabilities.

The extension granted by Ofgem will allow for multiple workshops and training sessions to be held within the test facility for personnel from SPEN, NGET, and SSE so that they may be appropriately trained to utilise and interrogate these new capabilities in order to visualise, and potentially quantity, the true benefits facilitated by WAMS; identify the supplementary benefits; and determine areas for future exploitation.

After establishment of the WAMS-EMS interfacing sandbox, the greatest value of this proof of concept will be extracted by providing training to engineers and operators. VISOR provides a great platform to arrange co-ordinated trainings and stakeholder engagement. The dedicated VISOR WAMS team in each TO and SO will arrange for necessary end users to attend training at the dedicated Sandbox facility. Without the collaboration that exists through VISOR arranging such training would have been more difficult.

d) Production architecture design and network requirements

Establishing and operating the WAMS-EMS training and demonstration system within the control room type environment of the Sandbox, with live data streams and alarming functions, will help evaluate and specify the optimum hardware, cyber security and network/firewall requirements for each specific aspect of the WAMS system. This will include assessing the bandwidth and quality of service requirements of PMU & WMU data communicated prior to entering the secure environment of the real control room and the policies governing its transmission and sharing whilst minimising the duplication of data storage and processing between TOs and SO.

e) Independent Phasor Data Visualisation and Interaction Tool

Many stakeholders are unfamiliar with power system operation and analysis conveyed through existing proprietary solutions for WAMS. This work stream developed an independent framework/tool to provide high-level presentation of an open access platform to view PMU data in order to help non-technical stakeholders appreciate the benefits of the work carried out as part of VISOR.

Open Grid Systems have completed the development of the data visualisation tool which enables the ability to illustrate and interact with PMU/WMU data at a high-level outside of the control room. The tool will be used in upcoming future training workshops and demonstrations in conjunction with the WAMS-EMS demonstration facility. This tool is a knowledge dissemination approach deployed by the VISOR team to enhance stakeholder base and increase interest in WAMS as a tool to help visualise grid dynamics. This independent tool provides high level presentation of PMU data, that complements the existing proprietary solution.

f) GB roadmap and enhanced strategic business planning

The transition beyond a pilot project into the business requires strong evidence and business cases for the deployment of the technology. Each of the above points will support the accuracy of the business case development, allowing for quantification based on experience rather than assumption, to support a GB Roadmap applicable to all TOs and the SO.

2.3 “Sandbox” WAMS-EMS Demonstration System

This facility, to be hosted at SPEN, will enable demonstration and exploration of integrating the VISOR WAMS capabilities with existing operational tools and practices, including the control room EMS. The goal of this is to provide an environment where training and evaluation of new operational tools and procedures incorporating WAMS data can be conducted, without interference with or cybersecurity risks to the live operation of the real power system.

The Sandbox will include a “mirror” of SPEN’s real EMS and SPEN’s VISOR WAMS within a self-contained environment. It will receive both conventional SCADA data and key WAMS information including measurements, analytics and alarms (Figure 4).

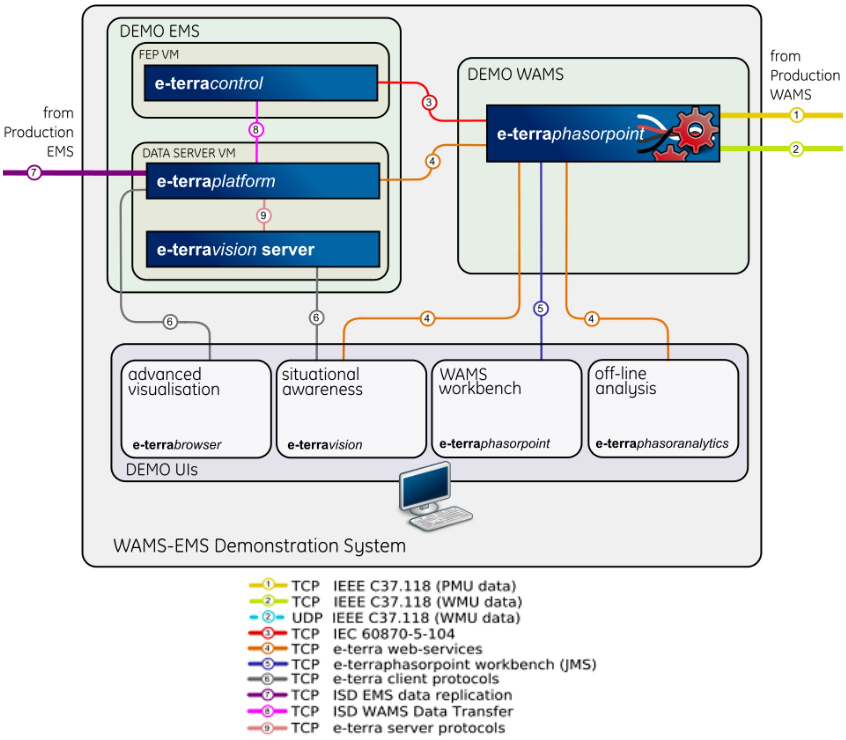

Figure 4. The "Sandbox" WAMS-EMS Demonstration System

In addition to the traditional WAMS and EMS facilities, the Sandbox will incorporate new tools for operators and analysts that combine EMS / SCADA and WAMS data with other sources (Figure 5). Some examples of the use cases to be demonstrated are highlighted in this section.

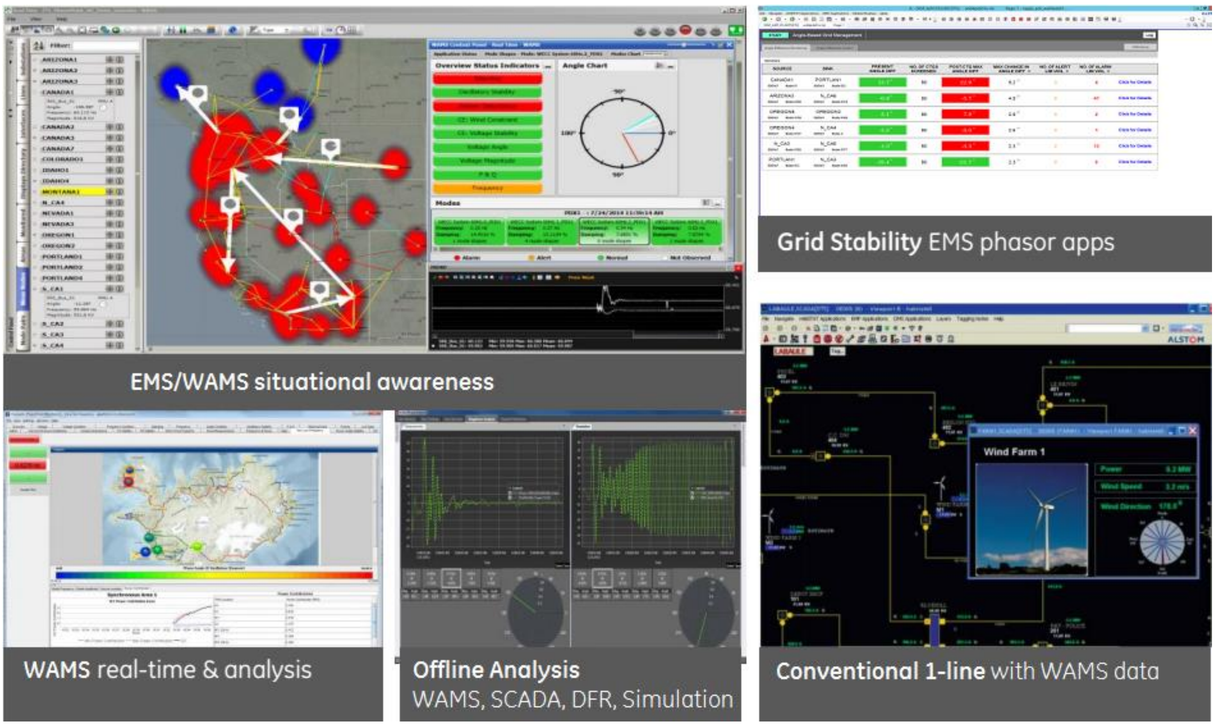

Figure 5. Components of the Integrated WAMS/EMS User Interface

Hybrid State Estimation: incorporation of phasor measurements into the State Estimator.

New situational awareness displays: effectively combining WAMS information with the traditional SCADA/EMS information and displays that operators are accustomed to. WAMS information must be relevant and comprehensible to operators – displayed clearly and concisely, without extraneous detail. Two particular examples are:

1. **Voltage angle condition:** to clearly illustrate system stress, highlighting where actions such as planned line outages have led to stressed conditions that were not predicted by models – e.g. large angle differences – either due to model inaccuracies or distribution system loading. Such differences can also block line restoration. Visibility of angle across the grid can assist operators in identifying re-dispatch actions to address this excess stress and enable reclosure of lines (Figure 6).
2. **Oscillatory stability status:** whilst a powerful tool in managing problematic oscillations when they occur, the detailed picture of system oscillatory behaviour delivered by the VISOR WAMS applications is, during the typical stable state of the power system, of little interest to operators. It is vital therefore that key status information is presented clearly in operator displays to highlight conditions requiring attention and more detailed examination (Figure 7).

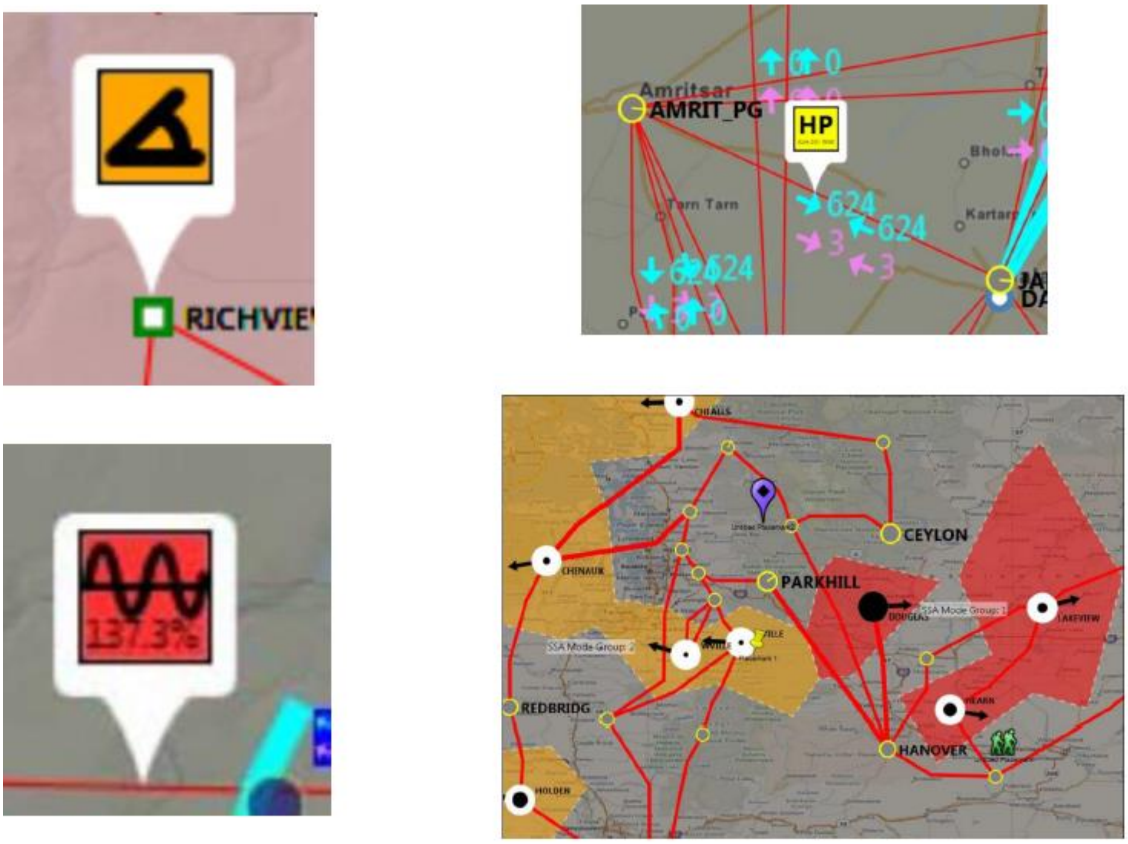

Figure 6. New Situational Awareness Display (simulated data)

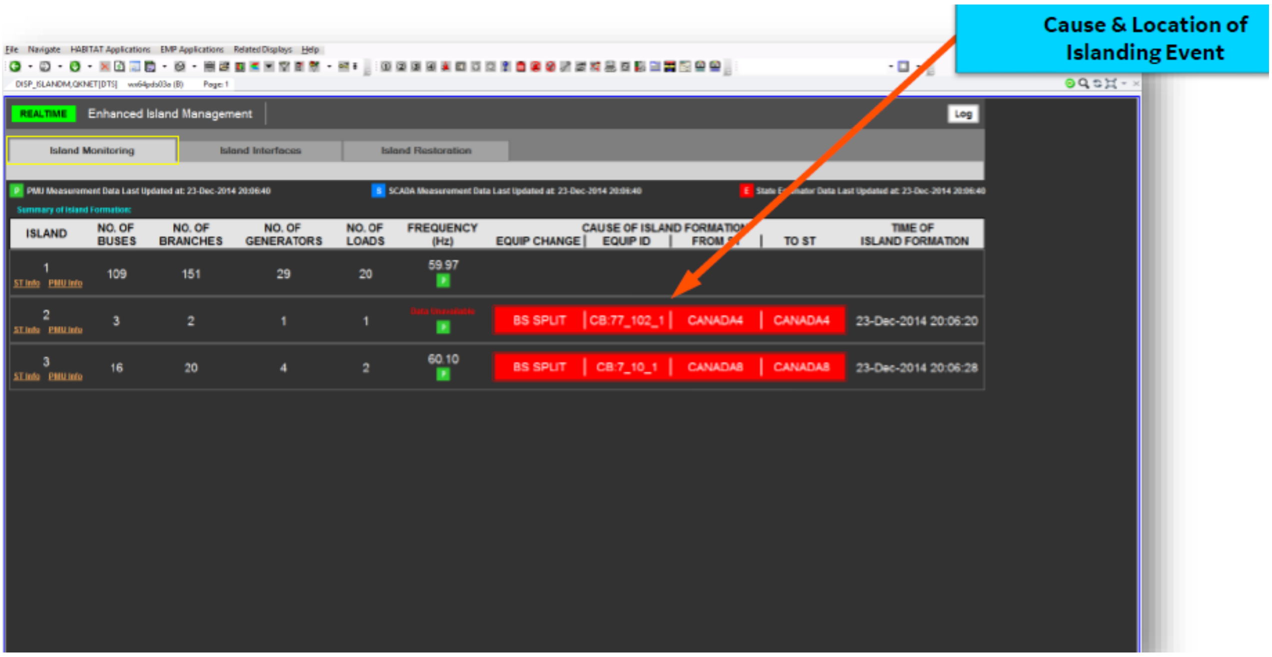

Figure 7. New Situational Awareness Display (simulated data)

Hybrid WAMS-EMS Applications: combining measurement-based analysis from WAMS with model-driven prediction from the EMS. As stated above, WAMS measurements provide operators with direct visibility of stresses in their system. This can be combined with limits and contingency analysis driven by the EMS model to highlight potential constraint issues in present or post-fault operating conditions. Model-derived angle difference sensitivities can then advise operators on the most effective and efficient redispatch action to return within limits.

Model validation & post-event analysis: the Sandbox includes tools for combined analysis of WAMS, SCADA, and simulation data (Figure 8). These tools enable:

- System models to be validated, by comparing the response to disturbances, as captured by WAMS, to the modelled response from contingency analysis.
- Easier, more effective study of events – by being able to view and analyse WAMS, SCADA and Digital Fault Recorder (DFR) data in one single tool.

Figure 8. Model validation & post-event analysis

2.3.1 "Sandbox" WAMS-EMS Demonstration System Update

The project extension will allow the Sandbox interface with EMS and other BaU functions to be fully tested and commissioned and enable business integration activities to be conducted, namely, application demonstration and full user training incorporating the use of WAMS data in daily operations. Following approval of extension, SPEN and GE have started work to implement the "Sandbox" WAMS-EMS Demonstration System in the SPEN Control Centre (Figure 8). Unfortunately, uncertainty regarding the project extension led to a delay in starting the build of the test facility. Some of the key achievements include

- Technical Architecture Document signed off by SPEN IT and Real Time Systems
- Cyber Security Risk Assessment signed off Real Time Systems and Cyber Security UK
- Clients and servers in situ with initial builds complete
- Networking configuration complete
- Admin/user accounts setup

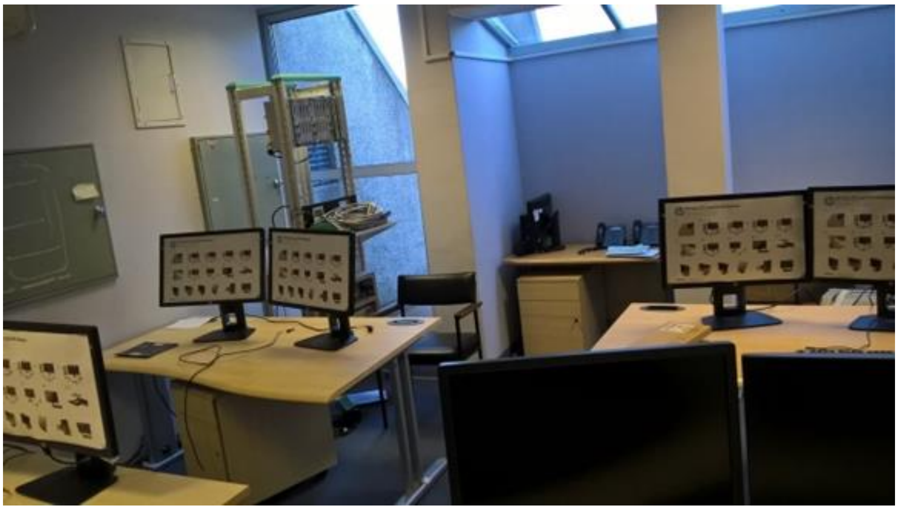

Figure 9. "Sandbox" WAMS-EMS Demonstration System Training Facility

2.3.2 Sandbox Training

A primary intention of the WAMS-EMS Demonstration System is to enable familiarisation of operators and other key control room personnel with the benefits of Wide Are Monitoring within an integrated WAMS-EMS environment. VISOR will continue to provide a great platform to arrange co-ordinated trainings and stakeholder engagement. The dedicated VISOR WAMS team in each TO and SO will arrange for necessary end users to attend training at the dedicated sandbox facility. Without the collaboration that exists through VISOR arranging such training would have been more difficult.

A number of initial training sessions shall be held, to introduce the core principles, functionality and hands-on usage of the integrated WAMS-EMS software. Repeated sessions shall be arranged to allow for availability of personnel. The following topics shall be covered:

Table 1. Training topics to be held at the Sandbox demonstration facility

Training Topic	Format	Duration	No. sessions
Introduction to WAMS concepts	Classroom	⅓ day	3
Introduction to use of e-terraphasorpoint	Classroom with practical	⅓ day	3
Use of WAMS in improving real-time Situational Awareness	Classroom with practical	⅓ day	3
WAMS data integration using Grid Stability Assessment (GSA) tools, alarm integration and State Estimation	Classroom and practical examples	½ day	3
Historical phasor analytics capabilities using e-terraphasoranalytics	Classroom and practical	½ day	2
Training for IEC 60870-5-104 configuration for State Estimation and integration	Hands-on	½ day	2

Training Topic	Format	Duration	No. sessions
Typical software configuration and system administration tasks pertaining to Sandbox	Hands-on	1 day	1

There will also be training upon request for WAMS analysis tools. The following topics shall be covered:

Table 2. Training topics to be held at the Sandbox demonstration facility

Time	Item	Content	Participants
Day 1 08:30-11:30	01	WAMS basics and Analysis Tools • WAMS Intro & Basics • PhasorPoint Analysis Tools	All (for WAMS basics), Planning & Analysis Staff
Day 1 12:30-16:30	02	WAMS analysis tools (cont.) • Module 2.2 (cont): PhasorPoint and PhasorAnalytics analysis tools	Planning & Analysis Staff
Day 2 08:30-11:30	03	Advanced WAMS applications • PhasorPoint Advanced Applications: OSM, VLF, LF Source Location, SSO	Planning & Analysis Staff
Day 2 12:30-16:30	04	Advanced WAMS applications • PhasorPoint Advanced Applications (IRB, SDM, LPE, B6 boundary monitoring)	Planning & Analysis Staff
Day 3 08:30-11:30	05	PhasorPoint & PhasorAnalytics Admin • PDC Admin, troubleshooting, Disaster Recovery PhasorAnalytics Admin PhasorPoint & PhasorAnalytics Configuration • PDC and Workbench Configuration	IT/Network Staff, PhasorPoint Admin, Lead engineer
Day 3 12:30-16:30	06	Demo & Close-Out Meeting • Demonstrate fully configured PhasorPoint and PhasorAnalytics (30 mins) • Use cases and business benefit for SPEN participants	All

2.4 VISOR WAMS infrastructure update

A total of nine "Waveform Measurement Units" (WMUs), three localised *Data Centres,* and one centralised *Data Hub* were originally intended to be installed on the Transmission Network under VISOR to provide synchrophasor measurements and monitor Sub-Synchronous Oscillations (SSO) across GB. To date, fourteen WMUs have been fully installed and commissioned across GB collecting new data on SSO behaviour in the system. In addition to the above, the University of Manchester has also a WMU for testing.

In light of the new valuable information gathered by this new WMU technology, and a reflection of the business commitment to WAMS, further provisions were made to purchase additional WMUs to be installed onto the VISOR WAMS. The timing and commissioning of each WMU has depended on a suitable outage window being available. An overview of the status of the installed and proposed WMUs locations is provided below in Table 3 and Figure 10.

National Grid has installed two WMUs at an additional site, beyond the original scope of the project. The interconnector between the UK and the Netherlands was identified by NGET where SSO could be a potential issue due to interactions when operating HVDC links adjacent to wind-farms and thermal plant. A WMU has been installed at the primary substation, Grain, to further observe and help baseline interactions which may arise across the B6 boundary as a result of the new HVDC link.

Through VISOR, SPT and NGET have also made provisions to capture the present ‘fingerprint’ of the system behaviour before and during the multi-stage commissioning of the Western HVDC link, by procuring and installing monitoring devices at Auchencrosh and Connah’s Quay, respectively. These installations will provide comprehensive monitoring of the operational behaviour of the high capacity HVDC link.

Table 3. VISOR WAMS infrastructure locations and status

#	VISOR Partner	Locations (circuits)	Status
4	SPEN	Eccles (Stella West 2)	Installed and operational
		Torness (Eccles 2)	Installed and operational
		Hunterston (Inverkip 2, to be Strathaven)	Installed and operational
		Auchencrosh (Coylton)	Installed and operational
3	National Grid	Hutton (Harker 1)	Installed and operational
	+ one project spare	Stella West (Spennymoor 1)	Installed and operational
		Deeside/Connah’s Quay (Circuit 1)	Installed and operational
5	above original scope	Hutton (Harker 2)	Installed and operational
		Stella West (Spennymoor 2)	Installed and operational
		Deeside/Connah’s Quay (Circuit 2)	Installed and operational
		Grain (Circuits 1 & 2)	Installed and operational
2	Scottish Hydro Electric	Kintore	Installed and operational
		Beauly	Installed and operational
1	The University of Manchester	Manchester	Operational

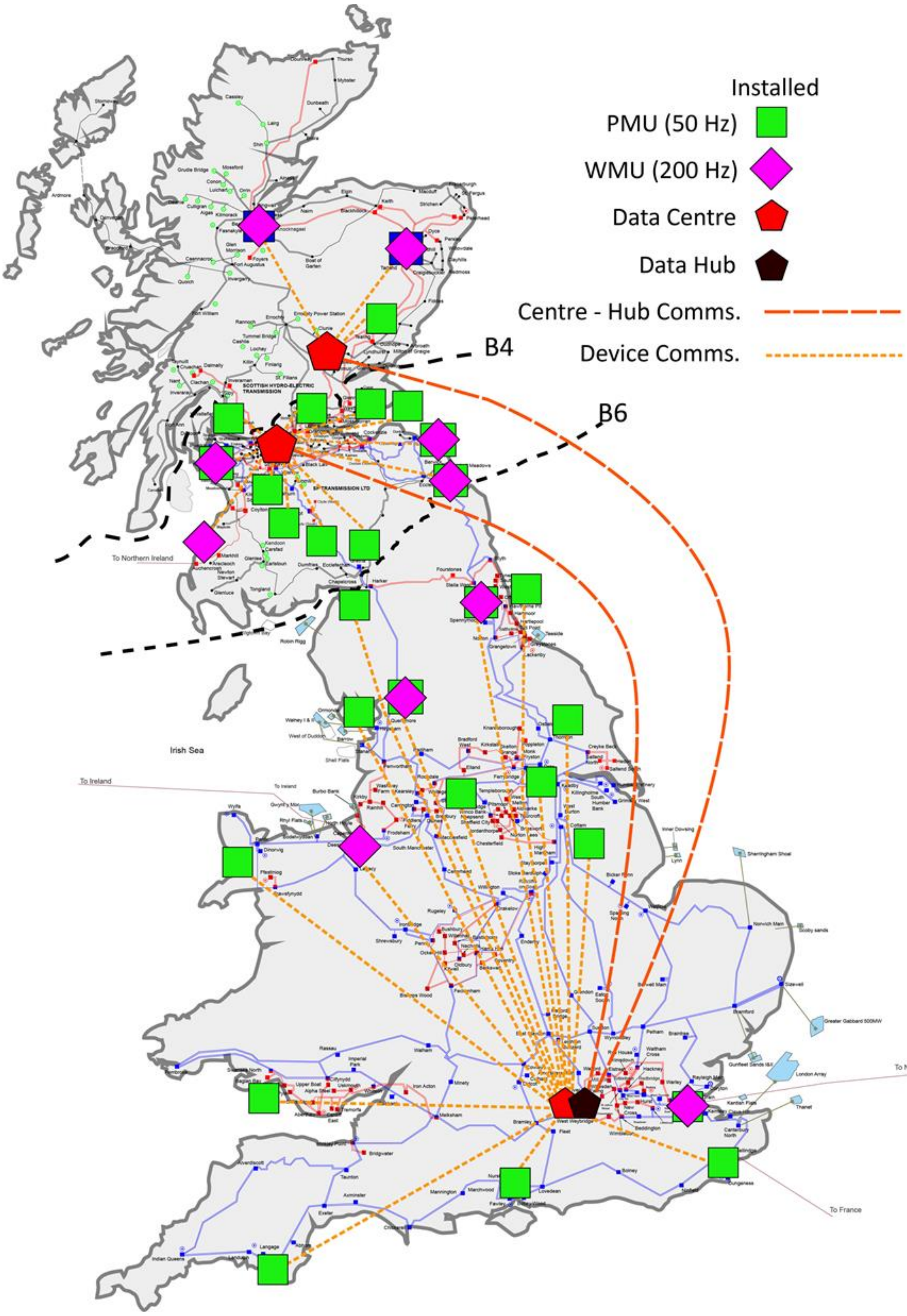

Figure 10 VISOR WAMS Deployment Overview

2.5 WAMS and Power System Performance Review 2016

GE carried out a detailed review of the performance of the GB power system and of the VISOR WAMS over the year 2016, with the results presented in a report and discussed at a workshop involving all VISOR project partners. The aim of this was to extract the most important observations on the behaviour of the power system and WAMS, highlighting concerns and suggesting practical next steps. These observations feed into the core objective of the VISOR project: to have GB WAMS infrastructure, applications, processes, learning and implementation recommendations that can deliver tangible benefit to real-time control room and historical analysis operations in GB.

The review covered a total of 456 phasor measurements (equivalent to around 80 monitored transmission circuits) and 88 waveform measurements (around 44 circuits) over 49 locations across the GB system, shown in Figure 11. Some of the key findings from the review are outlined below.

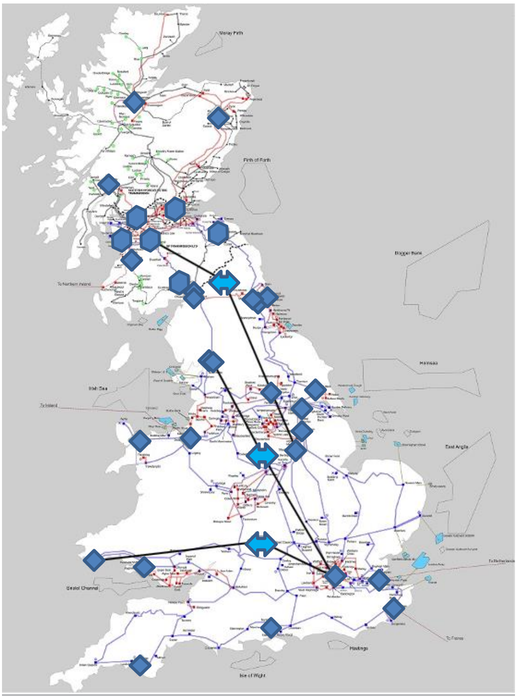

Figure 11. GB WAMS Overview

2.5.1 WAMS Performance

Late 2015 and 2016 saw further expansion of the VISOR WAMS:

- The SSEN WAMS was commissioned in December 2015, incorporating monitoring at Beauly and Kintore.
- Further PMU/WMUs were deployed in National Grid at Grain, and performance improvements were made at a number of sites.
- Further monitoring was deployed in SPEN, including at the Auchencrosh HVDC link, the Beauly-Denny and Hunterston-Crossaig interconnections to SSEN, and Series Compensation at Gretna.

- Communications links between the VISOR Data Hub and SPEN/SSEN VISOR Datacentre servers were commissioned, marking the achievement of real-time full-GB visibility for the VISOR WAMS.
- A number of new applications including the oscillation analysis and source location were deployed on the VISOR servers.

Hence, it could be said that 2016 saw the VISOR WAMS infrastructure built up to full operational capacity – with corresponding increased loading of the VISOR server hardware, software, and the communications infrastructure between and within each TO. As would be expected given the nature of VISOR as an innovation demonstration platform rather than a production-grade system, this increased loading led to the emergence of some issues. Significant steps were taken to investigate and address these issues, for example, tuning of communications networks and data stream configurations with performance improving as a result. The VISOR PDT continues to monitor and optimise performance, whilst also delivering learning for future management of WAMS in GB.

2.5.2 GB Power System Performance

The key aspect of power system performance assessed by VISOR is that of oscillatory behaviour. This involves frequencies of oscillation (or "modes") across different ranges:

- **"Very Low Frequency" (0.002-0.1Hz) behaviour**. These typically take the form of common-mode oscillations, where the entire power system accelerates and decelerates in near-unison. They tend to be caused by generator speed governor systems, the control system which opens or closes the "tap" of water/steam feeding a generator, to maintain a certain speed (mains frequency).

- **"Low Frequency" (0.1-4Hz) Electromechanical behaviour** typically involving generators and their faster control systems – where segments of the GB power system "swing" against each other, resulting in see-saw like power flows across the network. These can involve the entire GB network, or be restricted to a smaller area around a particular power station.

  A number of specific modes have been known in the GB system for some time, and are managed through the use of generator "Power System Stabiliser" control systems and monitored using the pre-existing isolated WAMS installed in National Grid and SPEN.

- **"Sub-Synchronous Oscillations" (4-46Hz)** introduced by control systems in power electronic converters such as those found in wind farms and HVDC links, by mechanical resonant torsional frequencies in generator shafts, and by series capacitors installed on the transmission network.

One of the tasks of VISOR has been to better characterise and assess the behaviour of these modes, given the greater visibility and new analysis capabilities offered by the VISOR WAMS. This is critical as the GB system continues to evolve; becoming more complex, with new plant being connected and old conventional generators being decommissioned, and the network itself undergoing continuous development to accommodate these changes.

2.5.3 Detection and assessment of significant oscillations that emerge under uncommon operating conditions.

The present period of continuous evolution in the GB power system can result in system conditions which, although within design limits, may not have been seen or specifically and accurately modelled before, this presents a risk of maloperation or instability. Some significant events of this nature have been observed during VISOR, featuring behaviour that, though not a threat to the wider system, has required active investigation and corrective action.

An anonymised example of one such event is shown in Figure 12 this involved a brief and relatively low amplitude, but still significant oscillation observed in active power, in a segment of the GB system. The oscillation was detected in real time, an alarm was triggered in the WAMS software, and source location information was available (shown with locations anonymised) both in real-time and for post-event replay. This source location display correctly pointed to the region containing the source of the oscillation (bright red).

Analysis of the oscillation data in this region, at the time of the event, highlighted specific conditions correlated with occurrence of the mode. This was consistent with a more detailed manual investigation using Digital Fault Recorder (DFR) data, and the source was identified as a specific grid user in the region indicated.

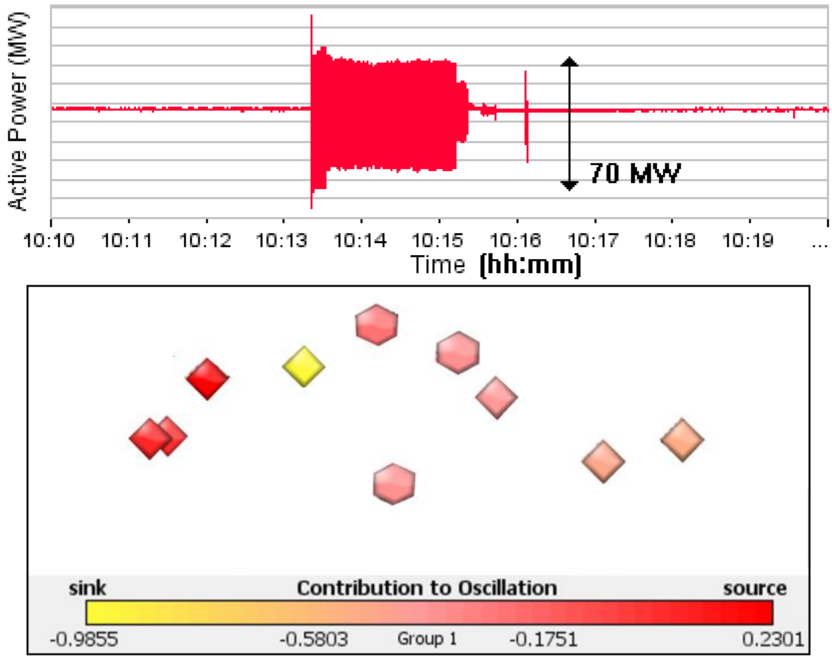

Figure 12. Example (anonymised) of a significant oscillation event observed in active power (top) and real-time source location display (bottom) for the relevant segment of the GB network. The reported "contribution to oscillation" can take any value in the range

2.5.4 Influence of Differences in PMU Measurement Performance

It may be noted that subtle differences in source location "contribution" were observed between different models of PMU, particularly at higher frequency. This is believed to be related to differences in PMU measurement performance. Due to the nature of VISOR, as a non-production innovation project, some PMUs are legacy DFR devices not qualified to the IEEE C37.118.1-2014 PMU standard. The 2014 standard builds on the original 2005 standard by adding requirements around dynamic performance. This issue was manageable in VISOR by cross-checking of behaviour:

- Comparison between neighbouring PMUs of different models, which highlighted the issue
- Comparison across the power system of instances of the same PMU model, which showed a consistent pattern of reporting a slightly higher contribution than other models.

This highlights the importance, when employing WAMS for production use in analysis applications, of verifying the measurement performance of all PMU models in the system to identify such differences in performance. Once identified, these differences are best addressed at the PMU, through a firmware update. However, they could also be mitigated through PMU model-specific correction on the WAMS server side, or through operational procedures.

As a minimum, conformance to the IEEE C37.118.1-2014 standard is strongly recommended. Performance assessment should be carried out to confirm conformance to the standard, and to identify differences between PMU models for consideration in future analyses.

2.5.5 Assessment of System-Wide Oscillatory Modes

A number of inter-area modes are already known in GB, with power system stabilisers and oscillatory stability monitoring having been in place since the 1980s-90s. Whilst these modes have been relatively stable in recent years, some are less well understood and this behaviour is likely to change as the power system continues to evolve.

The GB-wide visibility delivered through the VISOR project, coupled with the new oscillation source location tools demonstrated, has allowed these modes to be characterised through long-term direct observation, to a level not achieved before. This has included baselining of normal characteristics and the capture and analysis of a number of instances of degraded behaviour (such instances are often expected, due to atypical network topology or generator running arrangements). These observations can then be compared against predictions from the system model, and will also inform future operational procedures and monitoring arrangements.

Figure 13 shows two examples of this characterisation, as seen in the oscillation source location tool demonstrated under VISOR. It should be emphasized that these two examples do not correspond to unstable or otherwise problematic scenarios, the oscillations in question are known expected system modes at low amplitude. However, such instances do help system analysts to characterise the behaviour observed and see if it agrees with models. It also helps operational procedures to be formed, so that in the event of an unstable oscillation, the same tool can be used to highlight the source region. In such situations, comparison with the normal characteristic previously identified can also be useful.

The example shown on the left of Figure 13 indicates the involvement of two opposing regions; with the north of GB, led by South Scotland/North England (strong red), oscillating against South England led by the Kent/London region (strong blue). The oscillation is observed as opposing-phase swings in frequency in the two regions, which can be considered as two ends of a metaphorical see-saw and in power flows between them.

The example shown on the right of Figure 13 suggests only one, GB-wide group, led by the Humber/Midlands region.

It should be noted that these characterisations are based on the limited observability of the GB system available to VISOR. Southwest England, for example, is relatively unmonitored and might be playing an unseen role. A production WAMS deployment would provide system-wide coverage of key generation regions.

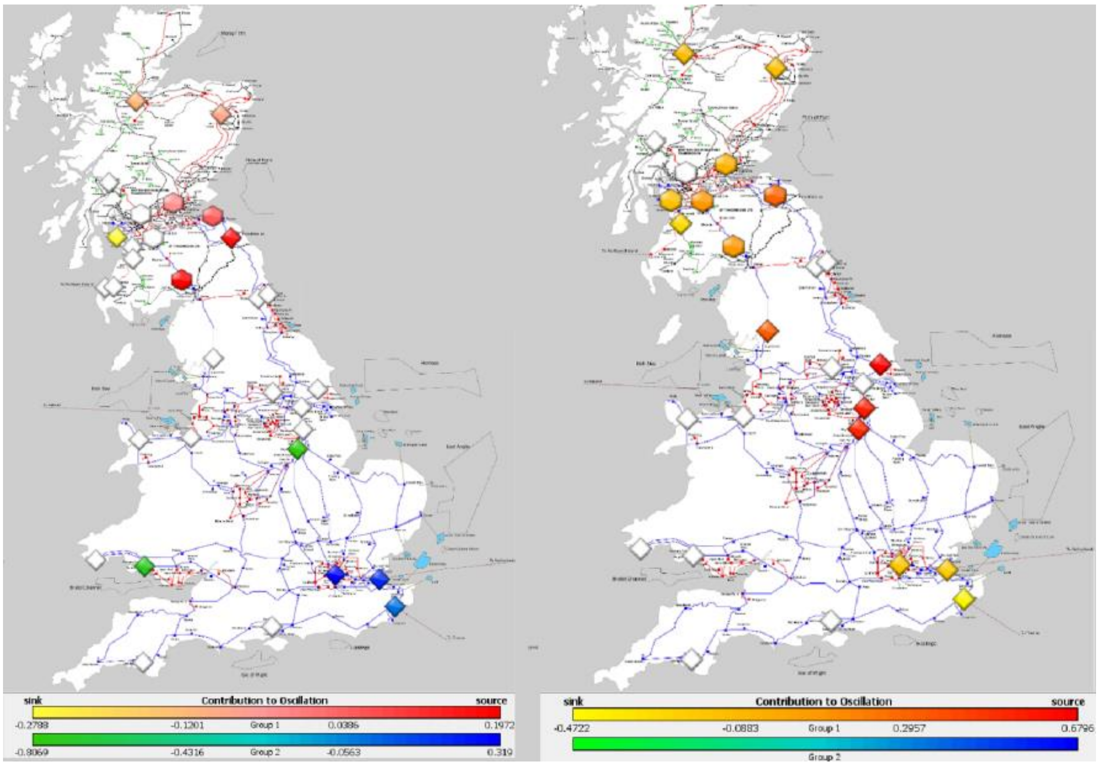

Figure 13. Two examples of the oscillation source location analysis, applied to different known GB inter-area modes. Left: two groups are observed, with the largest contributions coming from South Scotland / North England and from Kent. Right: one group is observed, with the largest contribution coming from the Humber/Midlands region.

2.5.6 Low-Level Localised Behaviour

A number of oscillations observed in both the electromechanical and SSO ranges have been fairly localised and low-level. Such behaviour includes local electromechanical modes, power electronic or voltage control modes, and the torsional modes of generators. In particular, the new visibility of the 4-46Hz range has revealed many previously unseen frequencies in the grid – most are believed to originate from power electronic converters and controls.

These observations are of value to system design and analysis teams as they flag up behaviour that might represent grid code non-compliance, or be relevant to future system studies. The information is also valuable to asset owners, as it can highlight plant faults as well as validating mechanical or controller models.

2.5.7 Visibility and Pre-Emptive Investigation of Interactions Before They Present a Problem

Whilst most of the many modes observed by VISOR in the 4-46Hz "SSO" range are low in amplitude and visible over a limited area, some present a risk of interaction, being relatively less well behaved, close in frequency to known plant modes, and present in the wider network. A number of very low-level but nonetheless distinct interactions have been observed, an example is shown in Figure 14. This Figure illustrates a variable-frequency mode moving close to a known plant mode, and a corresponding degradation in mode damping and amplitude at the plant in question.

All events observed were very low-level, well below values which would trigger any generator stress protection. By capturing these minor interactions however, they can be investigated, their risk assessed and any necessary action taken. This allows necessary action to be taken before they might become a problem under different grid conditions.

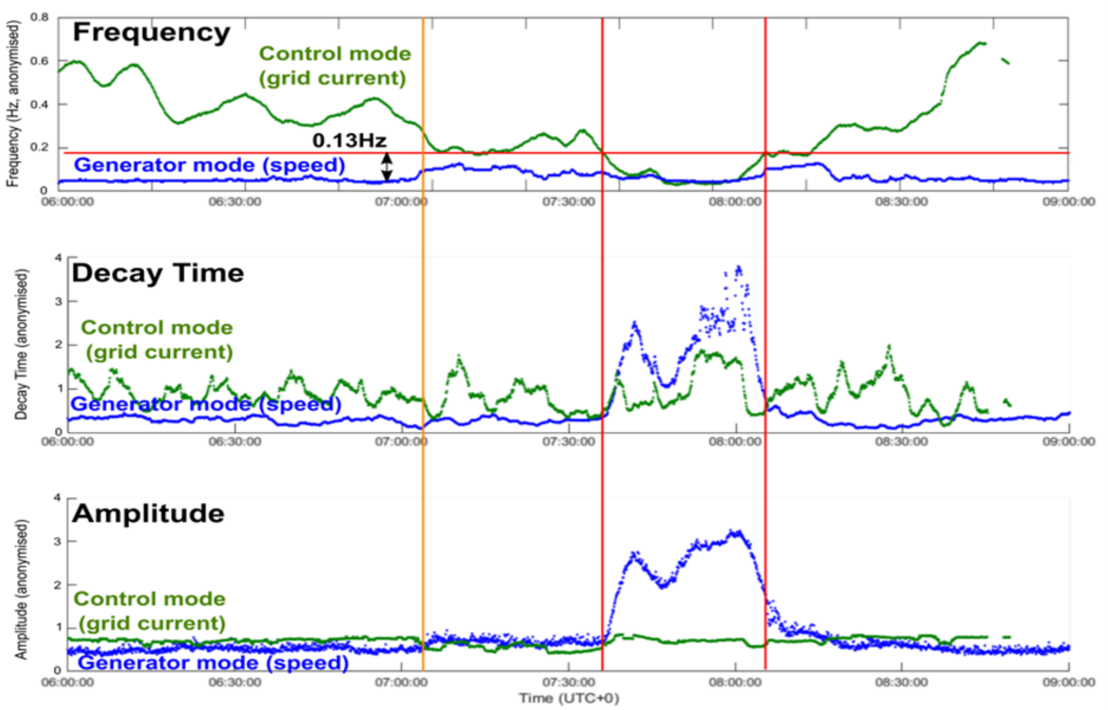

Figure 14. Example of very low-level sub-synchronous interaction observed (anonymised).

2.6 Communications infrastructure between TO and SO

A key challenge of the project has revolved around the commissioning of the new communication links between the three transmission network regions. There are currently two types of communication connections between Scottish Data Centres and the Data Hub, IP-Sec and MPLS[1].

[1] More information on these connections can be found in the June 2016 Project Progress Report.

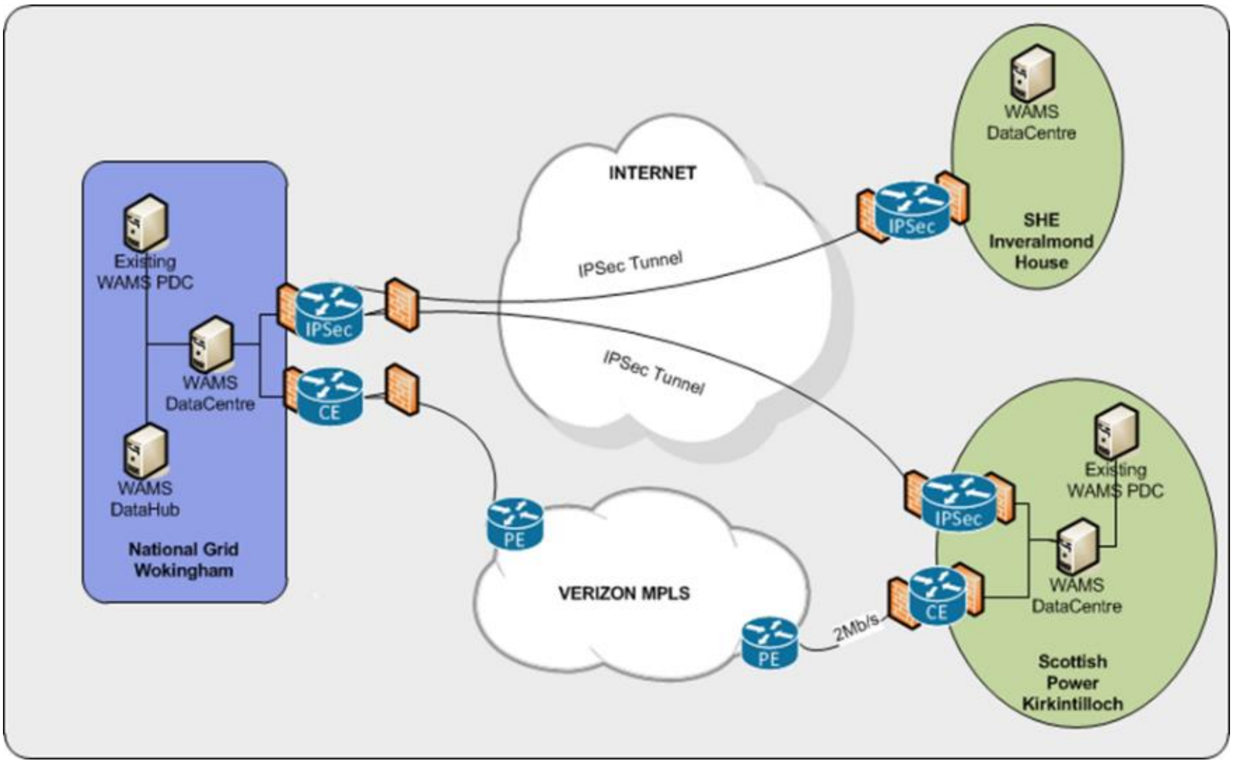

Figure 15. VISOR Communication Links between SHE TL, SPT, NGET and NGET SO

2.6.1 VISOR WAMS Monitoring and Management Reports

The operational health of the VISOR WAMS system is itself monitored and managed through:

- **Annual Data Quality summaries**, providing a concise and interactive high-level timeline and statistics to easily identify problematic devices
- **Annual Data Stream Connection summaries**, in a similar form to the above, high-level statistics provide a quick overview to identify devices with poor data quality
- **PMU Connection Analysis reports** investigating poorly performing devices or issues identified coupled with proposed recommendations to resolve.

The above reporting not only ensures the network information gathered by VISOR is reported effectively and translated to meaningful learning and but also provides recommendations for how WAMS data can be best integrated into business processes, e.g. what information should be included in reports, how frequently should reports be produced, who should receive what reports etc.

The figures below illustrate the annual dashboards produced by GE which provide a very useful high-level diagnostic view of overall system performance. These dashboards provide statistics and timelines that allows periods of worsened performance and poorest performing devices to be easily identified for follow-up investigation. Through VISOR, our engineers are encouraged to engage with the designers to provide feedback on these reporting tools so that improvements are made to ensure the needs' of the users are met fully.

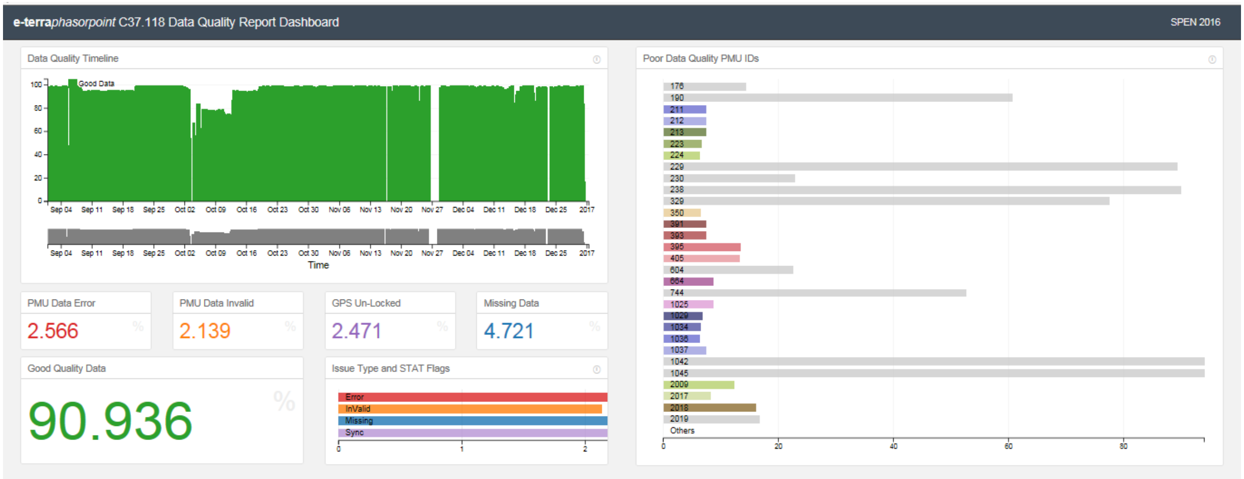

Figure 16. Example of VISOR Annual Data Quality summary dashboard

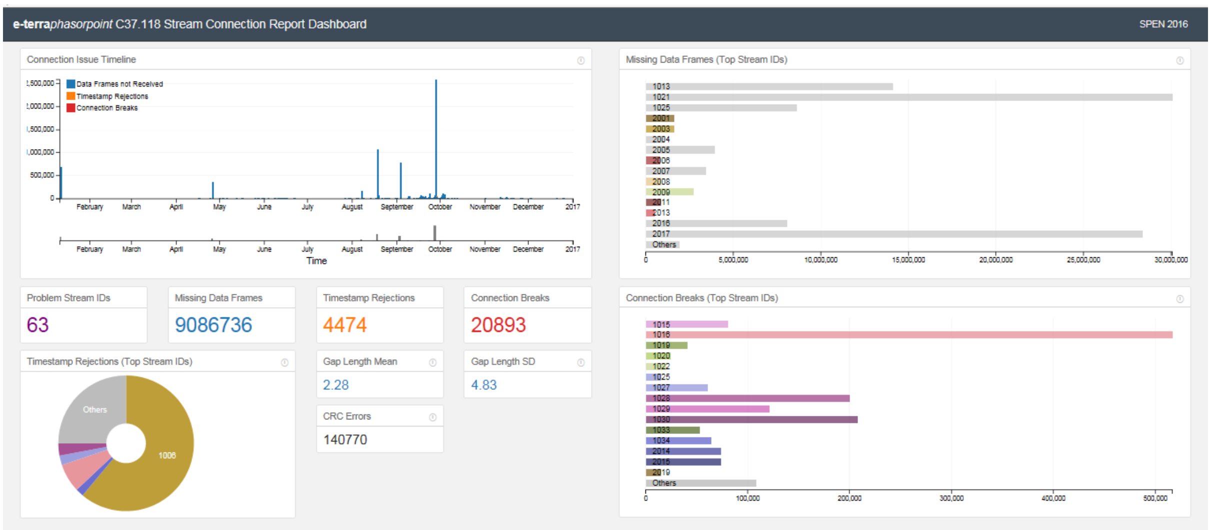

Figure 17. Example of VISOR Annual Stream Connection summary dashboard

2.6.2 Data communication update

A large portion of data unavailability is due to PMUs that never report any data, so if some of these PMUs are deliberately disabled, overall availability statistics may not be as poor as they initially seem. Equally, some sites may have communications or PMU device issues that have gone unnoticed for the long-term. It is recommended that regular health checks of PMU availability should be performed; either manually through the WAMS workbench interface, or through automated statistics reports such as those GE have provided throughout the project.

2016 saw the VISOR WAMS infrastructure built up to full operational capacity – with corresponding increased loading of the VISOR server hardware, software, and the communications infrastructure between and within each TO. As would be expected given the nature of VISOR as an innovation demonstration platform rather than a production-grade system, this increased loading led to the emergence of some issues. Significant steps were taken to investigate and address these issues, with performance improving as a result:

- Tuning of communications networks:
    - Network send/receive socket buffer sizes
    - Network interface bonding
- Increased bandwidth on the MPLS link between SPEN and NGET – from 2Mbps to 4Mbps.
- Tuning of data streams (the principles behind this are described more fully in the PAC World 2017 paper: Learning from GB Wide Area Monitoring and Progress Towards Operations Integration):
    - Wait times: the length of time a Phasor Data Concentrator will wait each time sample for data from all PMUs to arrive, before transmitting the data it has received for that time sample and considering the rest to be lost. A shorter wait time means smoother data throughput, at the expense of discarding delayed data packets.
    - Organisation: bundling PMU data streams into multiple aggregated PDC streams grouped by PMU reliability, versus fewer larger PDC streams. This again results in smoother data throughput despite poor stream performance from some PMUs, at the expense of increased configuration complexity and slightly increased bandwidth overhead.

The VISOR PDT continues to monitor and optimise performance, whilst also delivering learning for future management of WAMS in GB.

2.7 Visualisation of data in SPT, NGET, SHE TL Transmission including real-time and historic

VISOR is demonstrating new WAMS analysis, applications and infrastructure to help meet the needs of the changing GB system by enhancing the monitoring capability providing more insight across a wider frequency spectrum.

	Application	Frequency Range	Inputs	Outputs	Type of Mode
NEW	**Very Low Frequency (VLF)**	0.002-0.1	Frequency	Mode Frequency Mode Amplitude *(system–wide values)*	Common Modes
NEW	**VLF Source Location**	0.002-0.1	Angle Power	Source Location	Common Modes
EXISTING	**Low Frequency (LF)**	0.1-4	Frequency Power Angle difference	Mode Frequency Mode Amplitude Mode Damping	Local and inter-area modes
NEW	**LF Source Location**	0.1-4	Angle	Source Location	Local and inter-area modes
NEW	**Sub-Synchronous Oscillations (SSO)**	4-46	Voltage waveform Current waveform (@ 200Hz)	Mode Frequency Mode Amplitude Mode Damping	Sub-Synchronous Oscillations *(e.g., torsional, network LC modes)*

Figure 18. Oscillatory Stability monitoring capabilities demonstrated in the VISOR project

The tools being demonstrated provide real-time wide-area monitoring of oscillations across the entire 0.002-46Hz range. The results are presented in real-time geographic displays for operator situational awareness, feed alarms to warn of emerging issues, and are stored for historical trend and event review.

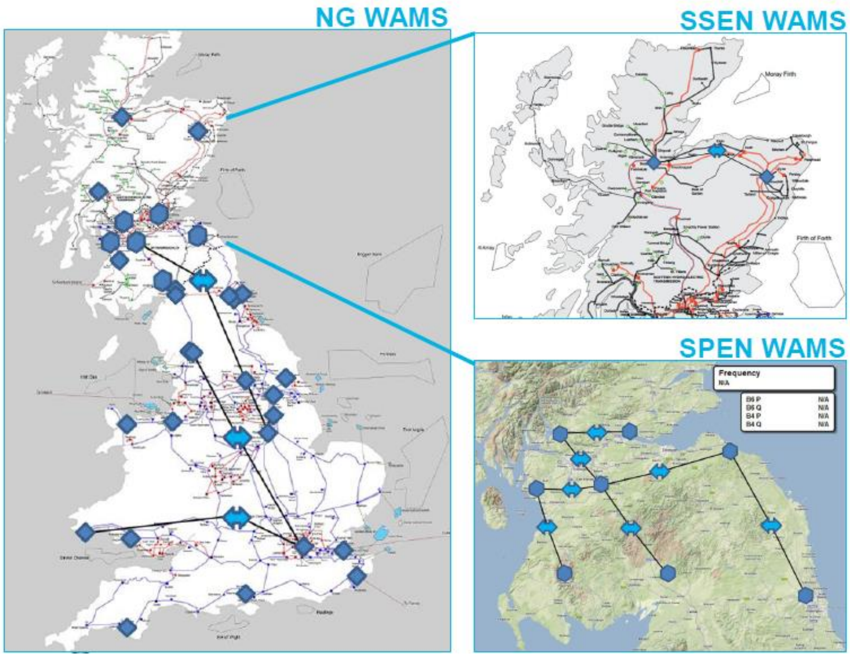

Figure 19. Real-time geographic displays for operator situational awareness

2.8 Deployment of New Applications & Enhancements

This section describes some of the new WAMS applications and enhancements deployed by GE to the VISOR WAMS during the period January – June 2017.

2.8.1 Enhancements to System Disturbance Monitoring

The System Disturbance Monitoring WAMS application module has already been demonstrated under the VISOR project. Recently however, a key enhancement was introduced - new disturbance impact measures. These are derived metrics which provide qualitative indicators of the impact of a disturbance on the power system, both at individual locations and over the system as a whole. This delivers two particular capabilities:

- Quick assessment of an event's overall impact: this informs operators on the size of the "kick" to the power system during a disturbance, which provides an indication of the strength of the grid and the risk of cascading events. It also facilitates quick identification of significant events for historical analysis.
- Quick identification of locations most affected by a disturbance: this can be valuable in highlighting plant or areas of the network which did not behave as expected during an event, which might indicate grid code non-compliance or inaccuracies in system models.

2.8.2 Simulation cases for presentation & training

Analysts and engineers are now able to replay historical events through the new oscillation monitoring displays previously deployed under VISOR, enabling them to observe these events as they would appear to operators in real-time. This has been a powerful tool in analysis of GB-wide events, as well as for presentation and training on the VISOR applications.

2.8.3 A new application for real-time Line Parameter Estimation

The Robust Line Parameter Estimation analysis was demonstrated previously in the project as an offline study – it has now been implemented as a real-time application module. Initial studies into the Line Parameter Estimation were conducted in 2015 but concluded that poor data quality hindered the ability of the software to accurately perform this analysis. Steps have been taken to have since improve the quality of the measurement data, and further improvements continue to be made. The requirements for high-quality real-time Line Parameter Estimation can be seen in Figure 20.

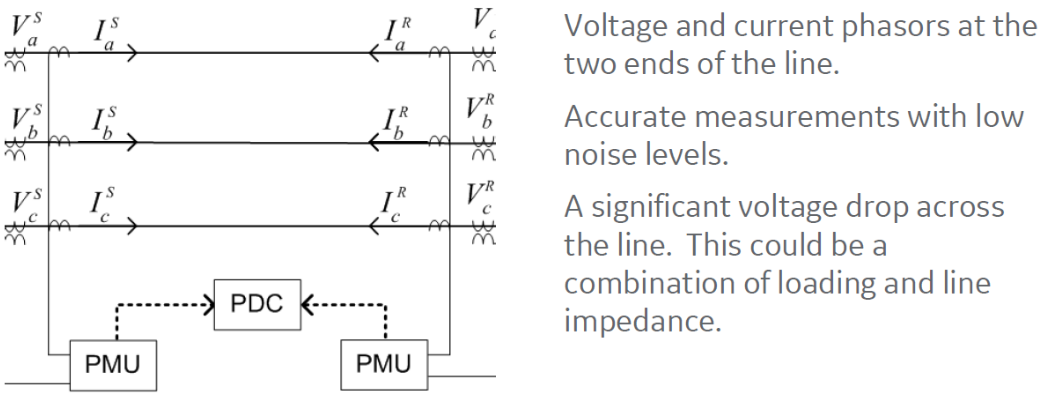

Figure 20. Requirements for high-quality Line Parameter Estimation

2.9 VISOR WAMS Roadmap Update

A technological and commercial roadmap is being developed to identify the key business drivers and benefits of implementing WAMS applications in GB to establish a sound business case for the capital investment required for such a deployment effort. This roadmap represents a key output of the VISOR project and is intended to:

- Facilitate the transition from a WAMS infrastructure implemented through the VISOR project to an integrated production-grade operation tool to support business-as-usual operations of the GB transmission network across the control room, analysis, and planning environments
- Better leverage of the already deployed WAMS infrastructure to minimize the additional investment while achieving the desired business and operational goals
- Better coordination of the existing phasor technology and the complementary real-time and planning systems
- Address how synchronized measurement technology can help improve real-time monitoring, protection, automation and control to deal with the increasingly high level of renewable energy resources coupled with the growing reliability and power quality requirements of customers
- Elicit further consensus among stakeholders on the additional business needs to be supported by the enhanced full-scale production-grade WAMS deployment
- Obtain buy-in among stakeholders on their business needs to be supported by the WAMS technology
- Accommodate post-VISOR project additional PMU installations as necessary and the implementation of additional selected applications that will be identified through the roadmap development process
- Define optimal extensions of the installed base (in terms of infrastructure, applications and processes) to be in concert with VISOR project partners' stakeholders needs
- Identify budgetary constraints, corporate goals and preferences; with technology and regulatory constraints with voluntary and cooperative agreements among VISOR project partners
- Facilitate better coordination of the plans with all the involved utilities' area of responsibility
- Assist management in approving further investments required for the full-scale production-grade WAMS

In 2016, Quanta Technology were commissioned to support the project team by utilising their experience of WAMS deployment in the North and South America and providing an assessment of the role of WAMS within the GB system, highlighting the five key benefit areas and providing recommendations on application, infrastructure and process requirements necessary to achieve these benefits and in which timeframe. Quanta have now completed their initial investigation and handed over their final findings to VISOR PDT.

The GB Roadmap is being developed by the VISOR delivery team, with inputs given by key representatives from all GB TOs, SO, to produce a set of WAMS objectives and applications, deployment and operating options, and recommendations for steps to be taken to facilitate an effective wide-scale GB WAMS.

The GB Roadmap report, due in Q4 2017, is structured so that key topics are covered in standalone chapters, to provide the reader with a full understanding of the topic without having to read the full report; for instance, there will be dedicated chapters covering each of the following topics:

- **Project VISOR**, summarising the background and objectives of the project
- **Current status of the GB WAMS and outstanding challenges**, detailing the infrastructure and applications currently installed or available in the GB, listing the main learning outcomes from the WAMS deployment to date, and highlighting the key outstanding challenges
- **Global WAMS deployment and Business Case,** reporting on examples of international WAMS deployment, the objectives, implementation, applications, from which lessons and considerations can inform the business case for GB WAMS deployment.
- **VISOR to Business**, detailing the short, medium and long-term WAMS capabilities in terms of applications and estimated benefits these may bring, highlighting what changes are required to achieve these benefits, and also listing key challenges and potential solutions to each.
- **Roadmap options,** clearly sets out the available options for roll-out, including the operating principle, the TO/SO responsibilities, and the key challenges and the changes required for each option.
- **Roadmap Recommendations,** highlighting the recommended Roadmap option to pursue, with supporting recommendations on related subjects such as internal procedures, investment planning and regulatory requirements.

The GB Roadmap will provide an outline of the potential deployment strategies across short, medium and long terms, with a primary focus on setting out the next steps to successfully transition the technology from a standalone, innovation-funded project, into a justifiable capital investment project. In doing so, four potential deployment options are under consideration:

1. Option 1 – NETSO to lead the overall GB WAMS deployment with TOs supplying the data – US ISO and RC model, Brazil ONS model
2. Option 2 – NETSO and TOs deploy their respective WAMS independently with TOs also sending all available data to NETSO – Large US TOs model
3. Option 3 – Deploy a GB WAMS for post-event analysis only – Could be either option 1 or option 2 model
4. Option 4 – NETSO and TOs jointly deploy a GB WAMS as a shared decision making tool for all entities – A joint TO/SO model

The latest iteration of the deployment roadmap matrix used in our assessment is shown in Figure 21.

	SHORT	MEDIUM	LONG TERM
Applications	• Wide Area Visibility and Situational Awareness (WAMS) online in control room • Enhanced System Oscillation Monitoring online in control room (SSO, VLF, LF)Monitoring of V, f, df/dt, P, Q, and angle difference at boundaries • Oscillation Detection Location tool • Post Event Analysis tools with accurately time-tagged data • Offline Planning Model Validation tool	• Dynamic Model Validation and Calibration tool • Hybrid State Estimation (HSE) application • Angle-Based Transfer Limit Monitoring in the control room • Model-less Voltage Instability Monitoring in the control room	• Linear State Estimator (LSE) • Fast analytics (Contingency Analysis, OSA, Voltage Stab. Analysis) based on HSE/LSE • Trialing SIPS for curtailment cost reduction, blackout avoidance, containment & recovery • Islanding Operation, Reconnection & Restoration tools • Black Start Process tools • Volt-Var Control • Operator Training Simulator based on PMU and SCADA data • Data analytics tools (Complex Event Processing and Alarming) • Enhanced Frequency Control Capability (EFCC) • Wide Area Visibility of GB system (TO Web Portal)
Infrastructure	• Production-Grade PMUs/WMUs Installation Completed • Historical Database system installation completed • TO OPNet and Internal WAN Setup • TO-SO OPNet WAN Setup • Control Room Production Grade system upgrade: QA/Staging and Training/Test environment • Data Quality Issues Resolved (latency, dropped data frames, stalled data, etc) • Equipment Interoperability from Various Vendors Resolved • Automatic DFR time-tagged data access available	• Data Bandwidth needs met (communication infrastructure) • Cyber Security Implementation in place • System Redundancy in place (system architecture) • High Availability in place (system architecture) • High Availability in place (system architecture) • WAMS Integration with EMS operational • Data Sharing: SO to TO and TO to TO operational	*Impractical to forecast longer term infrastructure*
Processes	• Training Plan and Training Materials for VISOR applications developed • Training on VISOR Applications delivered to relevant users • Data retention and access procedures in place (historical data base, size and data retrieval) • Post-event analysis manuals and procedures developed and in use by relevant users • Data baselining and alarm limits procedures developed • PMU & WMU Placement studies for all applications completed	• Operating Procedures and training for use of PMU technology in control room in place • Cyber security procedures and training in place • Institutional awareness and maintenance of current industry standards in place • Procedures for data sharing between TOs and SO developed and deployed • Model validation procedures for system planning and engineering developed and deployed • Procedures developed for adding and removal of equipment • Maintenance procedures developed and deployed	• Procedures for system islanding incorporating PMU technology completed • Procedures for Integration with Back Office applications developed and deployed

Figure 21. Draft WAMS Deployment Roadmap for GB

2.10 Independent Phasor Data Visualisation and Interaction Tool

Many stakeholders are unfamiliar with the power system operation and analysis conveyed through existing commercial WAMS solutions. This work stream developed an independent phasor data visualisation and interaction tool to provide high-level presentation of an open access platform to view PMU data in order to help non-technical stakeholders appreciate the benefits of the work carried out as part of VISOR.

Open Grid Systems have completed the development of the data visualisation tool which enables high-level visualisation of PMU data outside of the control room. The tool could be used in upcoming future training workshops and demonstrations in conjunction with the WAMS-EMS demonstration facility. This tool is a knowledge dissemination approach deployed by the VISOR team to enhance stakeholder base and increase interest in WAMS, to help visualise grid dynamics. This independent tool provides high level presentation of PMU data that complements the existing proprietary solution. A screenshot taken from the tool using simulated data can be seen in Figure 22.

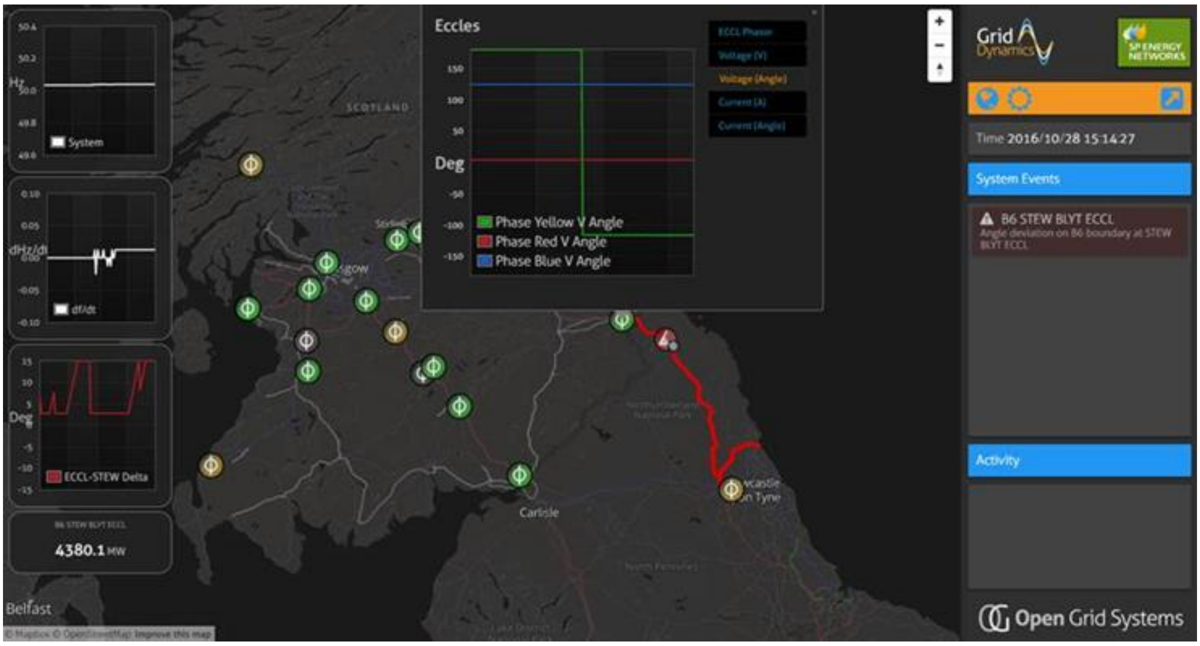

Figure 22. PMU/WMU data visualisation tool screenshot

2.11 Research at the University of Manchester

At the end of the last reporting period all of the deliverables (a set of five reports on the various aspects of UoM research namely on Sub-synchronous resonance, Hybrid state estimation, Optimal PMU placement, Impact of network parameter uncertainty, Dynamic model validation) were successfully completed, on time and delivered. A full day UoM workshop has also been held at the SPEN premises where the results from the UoM research were presented and discussed in detail with relevant SPEN teams such as System Analysis, Control Room Operations and Planning. UoM have continued to identify future avenues for research and collaboration with industry that will build on their research work in VISOR. In this reporting period the research work at UoM has led to two accepted IEEE transactions papers and one IEEE conference paper. In addition to this success, two further IEEE journal papers are currently under preparation for submission. The contributions of the accepted papers are summarised below.

1. "**A Screening Rule Based Iterative Numerical Method for Observability Analysis**"
   Z. Jin, P. Dattaray, P. Wall, J. Yu, V. Terzija accepted by IEEE Transactions on Power Systems

The paper proposed a new method for determining if the measurements available to a state estimator will make the system fully observable and, if not, the observable islands (i.e. sub systems) the system can be separated into for state estimation. Observability is a fundamental requirement for state estimation and ensuring suitable observability is an ongoing challenge for many of the state estimators used in practice. The new method, unlike existing methods, is able to correctly solve the observability problem without any risk of error and within a feasible time. A novel formulation of the problem is solved iteratively, which ensures accuracy, while a novel termination condition for the iterations was developed to ensure that the solution is available quickly.

2. **“A Novel Control Strategy for Subsynchronous Resonance Mitigation using 11kV VFD based Auxiliary Power Plant Loads”**
   P. Dattaray, D. Chakravorty, P. Wall, J. Yu, V. Terzija accepted by IEEE Transactions on Power Delivery

The paper proposed a new controller for mitigating the threat of subsynchronous resonance (SSR) in series compensated transmission systems that modifies the control of the auxiliary motor loads (variable frequency drives) installed at vulnerable generators (e.g. boiler feed pumps). This controller offers the potential to realise an effective, low cost means of SSR mitigation in the future, which may enable a broader uptake of series compensation by reducing the operational costs/impact of providing secure operation of compensated networks.

3. **“Impact of Location and Composition of Dynamic Load on the Severity of SSR in Meshed Power Systems”**
   P. Dattaray, P. Wall, P. Mohapatra, J. Yu, V. Terzija accepted for presentation at the IEEE PES Powertech conference

This paper studied how the inclusion (or exclusion) of dynamic loads (e.g. induction motors) can influence the results of SSR studies. Existing practice is to ignore loads or model them purely as static, impedance loads. The presented results show that including dynamic loads (which make up a significant portion of the actual system load) can have a significant impact on SSR studies and cases are described both where a stable case becomes unstable and a stable case becomes unstable, with the inclusion of dynamic load. This means that the no load/static load case that is usually considered may not be the worst case for an SSR study, which could compromise the suitability of the preventative/corrective control measures developed to mitigate the threat of SSR.

2.12 Knowledge Sharing and Stakeholder Engagement

The VISOR team is committed to knowledge sharing and effective stakeholder engagement to ensure that VISOR can adopt the latest technology advancements, share the lessons learned by/with other stakeholders, facilitate new entry to the market and disseminate the key learning captured along the VISOR delivery.

As the project progresses through the transitional phase, it is essential that the VISOR PDT maximises the project extension by ensuring generated learning is communicated throughout the businesses, and the wider audience, to guarantee the project is on the right path for further progression into the businesses.

During the reporting period, knowledge dissemination has focused on key internal stakeholders to continue building support of the application of this technology so that there is ample enthusiasm for future implementation following the conclusion of the project by hosting the following highly successful events:

- Workshop to review WAMS and Power System performance during 2016 attended by all project partners including PDT members and other experts from within each business.

- A full day UoM workshop held at the SPEN premises where the results from the UoM research were presented and discussed in detail with relevant SPEN teams such as System Analysis, Control Room Operations and Planning.
- Steering Board Meeting with directors and senior management, where the achievements of the project were recognised and the future of GB WAMS was discussed and planned.

In terms of upcoming knowledge dissemination and sharing events in 2017, the following events will be held or attended by members of the VISOR PDT:

- Dedicated VISOR External Stakeholder Event.
- Internal stakeholder engagement and training events at the Sandbox facility.
- Workshop and Presentation of WAMS use-cases, benefits, investment options and implementation strategies conclusions from the VISOR Roadmap.

2.13 Outlook to the Next Reporting Period

The original completion date of the VISOR project was March 2017 however the project has been granted a 9-month extension to facilitate full delivery and training, the WAMS-EMS integration facility (aka. The Sandbox) and to extend the WAMS monitoring period to cover the commissioning stages of the delayed Western HVDC link, which presents a substantial learning opportunity for all Network Licensees. The following deliverables remain scheduled for delivery in the forthcoming months:

SDRC 9.1.1

- Baseline and comparator report for SSO behaviour (WP 1, December 2017)

SDRC 9.5.1

- Roll-out report (WP 4A, December 2017)

SDRC 9.6.1

- Presentations and show-casing at the annual innovation conferences (WP 6, December 2017)

SDRC 9.6.2

- Commissioning of WAMS-EMS Interface (WP 6, June 2017)
- Undertaking of WAMS-EMS training within dedicated training facility (WP 6, September 2017)

In addition to the project deliverables, the PDT will focus efforts in ensuring the project is best positioned for transition into the businesses with particular focus on internal engagement with senior management and through the following activities:

1. Internal stakeholder engagement and training events at the Sandbox facility

2. Workshop and Presentation of WAMS use-cases, benefits, investment options and implementation strategies conclusions from the VISOR Roadmap.
3. Begin preparations for close-down event, date to be decided.

When the VISOR project concludes, it will form a roadmap for the roll-out of WAMS in GB. This will outline, both for transmission owners and the system operator, the benefit of the different applications demonstrated under VISOR, the next steps for their development and roll-out, how they could be integrated into business operations, and what supporting soft and hard infrastructure will be required.

3 Consistency with full submission

As the project draws to a close, VISOR has remained consistent with the original full submission with regards to overall resource allocation, project management and project programme.

As discussed in Section 2 the project was on track to deliver all SDRCs according to the original Project Direction however an extension was granted from March 2017 to December 2017 to undertake additional work and maximise the efforts of the transition from pilot system into BaU. The project extension will utilise existing project budget that has been retained through cost efficiencies achieved throughout the project.

To reflect the project extension, the completion date of the below SDRCs have been revised:

SDRC	Evidence	Current Completion Date	Revised Completion Date
9.5.1	Roll-out report (WP 4A, Dec 2016 - March 2017)	Mar 2017	Dec 2017
9.6.1	Presentations and show-casing at the annual innovation conferences (WP 5.4, Dec 2014, Dec 2015, Dec 2016 and June 2017 for Close-down report dissemination)	June 2017	Dec 2017

In addition to the changes made to the original milestones, the following additional milestones were also included and approved to ensure the full learning and benefits gained through the extension are disseminated effectively:

SDRC	Evidence	Completion Date
9.1.1	Baseline and comparator report for SSO behaviour (WP 1, December 2017)	Dec 2017
9.6.1	Timely delivery of project progress reports (WP 5.4, Sep 2017)	Sep 2017
9.6.2	Delivery of Independent Phasor Data Visualisation and Interaction Tool	Mar 2017
9.6.2	Commissioning of WAMS-EMS interface and training facility	Jun 2017
9.6.2	Undertaking of WAMS-EMS training within dedicated training facility	Sep 2017

[redacted]

[redacted]

[redacted]

5 Successful Delivery Reward Criteria (SDRC)

The Successful Delivery Reward Criteria set out in the Project Direction links with the Project Milestones and the identified targets directly. This SDRC can be used to check the progress of the project delivery and position the progress against the original proposal. Table 5 lists all the required evidences in line with VISOR project direction for reporting period January 2017 – June 2017.

Table 5. Achieved SDRC in reporting period

Successful Delivery Reward criterion	Evidence
Successful delivery of Sub-Synchronous Oscillation (SSO) monitoring prior to start of Series Compensation commissioning. It is important that the project delivers an SSO monitoring capability in time to capture a baseline of the SSO frequency range performance before the series compensation is commissioned. The changes in behaviour can then be assessed against known historic behaviour. The components that should be delivered for success in this domain are: • Validation of SSO substation equipment • Installation, commissioning of SSO substation equipment & communication to central location • Integration to visualisation of SSO geographically	• SSO Device qualification report (WP 4C, Dec 2014) • Visualisation of multiple SSO information sources at data centre (WP 1A, prior to the commissioning of series compensation reinforcement) • **Baseline and comparator report for SSO behaviour (WP 1, March 2015, March 2016, March 2017, December 2017)**

Enhanced stability tools delivered, including Oscillation Source Location and Disturbance Impact
The applications to analyse and present stability information to real-time and analysis users is a key part of the project. The applications should be delivered and the necessary enhancements made to fulfil this criterion. Also, the test cases to prove and demonstrate the applications to end users are important for knowledge dissemination. The delivery includes:
• Oscillation tools delivered to display wide area oscillations, including oscillation frequency, damping and mode shape
• Source location tools for identifying contributions to oscillations
• Disturbance detection, location, sequence and impact measures in application to manage high impact / low probability
	• Applications delivered and configured to include (WP 1.2, 2.3, March 2016)
	  ○ Geographic oscillation alert presentation
	  ○ Oscillation source location presentation for analysis & real-time
	  ○ Disturbance detection, location identification and impact measures
	• **Report on PMU roll-out requirements for the applications (WP 4B, March 2017)**
	• **Simulation cases for presentation & training (WP 5.2, March 2017)**

events • Review of the implications for future roll-out of PMUs for full GB-wide use of the applications	
9.6 Successful dissemination of knowledge generated from VISOR project. Knowledge dissemination within the transmission network owner is a key component to transfer experience for the pre-trial training and post–trial knowledge exchange. The key objectives of this work package are to successfully achieve the following: • Internal knowledge dissemination • External knowledge dissemination • Influencing and updating policies and standards • Public Engagement	9.6.1 • Establish on-line portal and keep up to date throughout project (WP 5.2, Sep 2014) • **Timely delivery of project progress reports (WP 5.4, Sep 2014, Mar 2015, Sep 2015; Mar 2016, Sep 2016, Mar 2017)** • **Academic partner delivery of knowledge capture and publications (WP 5.2, Dec 2016 - Mar 2017)** • Presentations and show-casing at the annual innovation conferences (WP 5.4, Dec 2014, Dec 2015, Dec 2016 and June 2017 for Close-down report dissemination) 9.6.2 • **Delivery of Independent Phasor Data Visualisation and Interaction Tool (Mar 2017)** • Commissioning of WAMS-EMS interface and training facility (Jun 2017) • Undertaking of WAMS-EMS training within dedicated training facility (Sep 2017)

6 Learning Outcomes

Following the Authority's formal approval in December 2013, VISOR has continued to make excellent progress regarding project partner collaboration, project management and governance establishment, procurement and knowledge sharing. There are challenges and risks (as detailed in the section above and the Risk Register in Appendix 2) along the development, and lessons are derived from every aspect.

Table 6. Learning Outcomes Table

Lessons Learnt (+/-)	Lesson Learnt	Recommended Action
Positive	Multiple innovation projects are attempting to improve the way the GB network operates, these projects need to utilise the same IT resources which could lead to delays with delivering the projects.	Ensure collaborative planning and team awareness at all stages of the projects.
Positive	Valuable specialist skills and knowledge are developed through successful projects like VISOR. Failure to share learning can result in issues if a key person is unavailable.	Ensure collaborative learning and knowledge sharing throughout the project to reduce dependency on certain individuals and guarantee success is still achieved when someone may be unavailable.
Positive	WAMS-EMS demonstration will provide valuable insight into "usability and compatibility" of both systems and possibility of using WAMS data in control centre decision making process. This will potentially provide enough evidence to update WAMS infrastructure to a system critical infrastructure. Thus providing a business case with proof of concept for future investment.	Accurately document performance of the WAMS-EMS interface. This should be noted in terms of visibility of system dynamics through alarms and events. Collect feedback based on operator experience regarding usability of the system. Compare visibility of system events with end of the project system dynamics report.
Positive	The presence of a contingency plan and coordination between PDT to overcoming uncontrollable delay, in particular those experienced with cross-TO communication links and data transfer.	By closely monitoring and managing the process, teams have been assembled to focus on problems and identify solutions or contingency plans which have ensured project milestones, and other dependant work streams, are not adversely affected.
Positive	Project milestones and workpackages should be capable of changing in order to achieve overall objective of the project in response to project findings or changes in landscape.	VISOR has identified aspects that require development that were not foreseen from outset. By undertaking additional initiatives, the project is in a stronger position to deliver successful outcome
Positive	Ensuring IT Security personnel are engaged with changes / developments in architecture design, particularly in	Ensure the successes of the new technology are controlled in such a way that 'new users' do not breach IT practices.

	pilot projects which can follow 'unconventional' routes into the business.	
Positive	Importance of internal and external stakeholder engagement. The stakeholder events enable the project team to engage with external expertise with similar experience that the project can share learning with, as VISOR has done so with experience from New England ISO, V&R, PG&E and Quanta Technology.	VISOR has highlighted the value of strong external stakeholder engagement which has added great value to the project especially in terms of highlighting steps to transition from pilot project to BaU. Similarly, the project has also shown the importance of internal stakeholder engagement to ensure the Business' needs are understood and satisfied.
Negative	Early, direct engagement with business IT experts is important for assuring technical requirements are understood on both sides that deployment schedules are realistic. This should be done at the tendering stage.	Business IT experts should be engaged and directly involved early in project delivery and specification stage to avoid potential risks and delays.
Negative	Need for greater emphasis on IT Infrastructure on System monitoring projects	Early engagement and direct involvement from all IT Partners from all involved parties to arrive at realistic estimates for the project
Negative	Need for greater emphasis on telecommunications bandwidth and Quality of Service on System monitoring projects	Early engagement and direct involvement from internal telecommunications department and external service providers to ensure services arrive at realistic estimates for the project

6.1 Technical Learning

6.1.1 Key Process Learning - "Sandbox" WAMS-EMS Demonstration System

A vital aspect of transitioning new technology from an innovation project into the daily operations is the thorough demonstration of the complete system operation to applications, visualisation and analysis screens that operators will use and the associated data connections and cyber security protocols required to do so.

VISOR introduced new monitoring system practices to examine new capabilities and benefits, and in doing so, has also emphasised the necessity of a pre-production facility in order demonstrate this new technology in an operational environment, including the interface with the EMS and other BaU functions.

Key Learning:

- **Sandbox WAMS-EMS Demonstration System facility critical to replicate live environment and demonstrate interface with EMS to enable operators to be trained appropriately and**

understand capabilities of new system, view alarms from WAMS on existing screens, and instil necessary operator confidence to deploy applications in daily operations of live system.

- **Expert resource in cyber security and IT-solution architects required in order to design a suitable environment with architecture and configurations to support secure data transfer and secure management of outgoing and incoming data connections.**

6.1.2 Key Infrastructure Learning - Limitations in Using OPTEL

SPEN and NETSO have established a 10 Gbps OPTEL-grade Multiprotocol Label Switching (MPLS) network. The NETSO Operation Network (OPTEL) services were considered when establishing the initial GB WAMS through VISOR. However, as OPTEL supports the Critical National Infrastructure (CNI) it would have been problematic to connect a VISOR system, which could not be considered CNI, to the CNI through OPTEL. OPTEL does, however, offer a fast private network with exceptional reliability and there are no technical or security issues preventing WAMS in this environment but migrating the existing system across will require coordination regarding the data transfer and the existing communication links to external parties.

There are currently mechanisms in place to use the OPTEL network as a carrier network for non-CNI traffic, which may benefit future innovation projects. However, such connections will need to be managed carefully, since connecting non-CNI systems to CNI facilities may create security issues that will need to be addressed properly.

Use of OPTEL could be looked at as an option for deploying a production grade GB WAMS system. However, while the OPTEL network has a handoff to the SPT control WAN, there is currently no path to SSE. Significant work would be required from SSE to get their network connected to the OPTEL network, either directly or via SPT's network. This will need to be resolved before OPTEL can be used GB WAMS.

Key Learning:

- **In order to use WAMS for decision making in control room WAMS data quality, availability and reliability will require WAMS to be considered as system critical application (similar to EMS)**

6.1.3 Key Security Learning – Limitations of UDP packets on Data Security

The introduction of a 200 fps WMU has highlighted a security versus performance issue.

UDP has performance advantages over TCP as it is a connectionless method of communication. Through UDP, data is simply sent to a defined IP address and there is no error checking or verification - either the data arrives or it does not. This means that the UDP protocol has very little overhead, but it also means that if a packet does not arrive the data is lost.

Conversely TCP is a connection oriented transport method. It will open a socket or a connection between the two IP addresses and will provide error checking and packet receipts to ensure all the packets have arrived. If packets fail to arrive they will be resent. This means that there is a lot of overhead and extra information in a TCP datagram, and that retransmissions consume additional bandwidth, but it does provide greater reliability in the data transmission.

The data stream coming from a normal PMU sampling at 50 fps is approximately 45 Kb/s using TCP packets. However, a WMU sampling at 200 Hz, and providing both 200 Hz and 50 Hz data streams requires nearer 130 Kb/s using UDP packets. The WMU has been designed with performance of the network as a consideration, and therefore uses UDP and not TCP.

The use of UDP causes an issue with configuration of the firewall as the connectionless transport protocol means that the UDP ports need to be opened up on the firewalls so that it allows data inbound to the data centre from the substation. As TCP is connection oriented, the TCP socket can be initiated from the WAMS server out to the WMU at the substation, and therefore means that the firewall rules at the data centre are opened to allow connection out from the data centre and not into the datacentre from the outside.

Key learning:

- **Experience to date suggests that for the roll-out of WAMS as an operational tool in GB, data must be received at the control centre via TCP. However, in situations where network performance is a concern and/or PMU-based control is employed, UDP will likely form the first stage of the PMU data route. Aggregation for monitoring purposes and bandwidth reduction can then be carried out at a regional or central level, followed by conversion to TCP for reliable and security-compliant delivery into the Data Centres.**

7 Business Case Update

We are not aware of any developments that have taken place since the issue of the Project Direction that affect the business case for the Project.

8 Bank Account

A dedicated bank account was made available by SPT to act as the Project Bank Account in to which NGET, as the GBSO, deposited the appropriate project funds through 12 monthly transfers in the Regulatory Year commencing 1 April 2014, such that the total amount transferred equals the net amount set out in the Funding Direction.

The table below documents the breakdown of the overall spend as of 31 May 2017. The accompanying VISOR bank statement is provided Appendix 1.

[redacted]

[redacted]

9 Intellectual Property Rights (IPR) [CONFIDENTIAL]

[redacted]

10 Other

11 Accuracy Assurance Statement

I therefore confirm that processes in place and steps taken to prepare the PPR are sufficiently robust and that the information provided is accurate and complete.

Signature: ____________________

Name (Print): ____________________

Title: ____________________

Date: ____________________

Signature: ____________________

Name (Print): ____________________

Title: ____________________

Date: ____________________

12 Appendices

12.1 Appendix 1 Bank Statement

[redacted]

12.2 Appendix 2 Project Risk Register (Confidential)

[redacted]