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

In collaboration with

Project Progress Report

[Public]

December 2016

For enquiries please contact:

Priyanka Mohapatra
VISOR Project Manager
SP Energy Networks

SP Power Systems Limited Registered Office: 1 Atlantic Quay Glasgow G2 8SP
Registered in Scotland No. 215841 Vat No. GB 659 3720 08

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 with 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 is due to conclude in March 2017.

The VISOR project aims to showcase 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) in the 4-46Hz range.

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 will focus 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 18 months, the project has taken new initiatives to allow further monitoring and training to safeguard the transition into respective business functions and a project extension has been sought to enrich the business cases 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 enable training workshops within the Wide-Area Monitoring System training and testing facility (aka. the "Sandbox") expected to be commissioned in early 2017.

The WAMS technology & services 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 sixth progress report and covers six months of the project delivery from July 2016 – December 2016, “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 9.4.1

- ✓ *Report on findings from benefits of hybrid state estimator (WP 3.2, Dec 2016)*
- ✓ *Report on long-term monitoring of area angle measurements (WP 3.4, Dec 2016)*

SCRC 9.6.1

- ✓ *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)*

The following reports are on schedule to be delivered in December 2016 but have not yet been released:

SDRC 9.3.1

- ✓ *Report on accuracy of simulation models for small-signal and large-signal against naturally occurring events (WP 2.2-2.3, Dec 2016)*

SDRC 9.4.1

- ✓ *Report on quantification of uncertainty in stability calculations (WP 3.1, Dec 2016)*

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

- Change Request letter submitted to Ofgem seeking project extension from March 2017 through to December 2017, to undertake a number of activities that will enrich understanding of system dynamics and benefit quantification forming the basis of GB roll-out strategy.
- WAMS Roadmap development and business case development meetings with key internal stakeholders across SPEN and NGET departments to progress development of business and technological roadmap.

- Successful commissioning of WMU devices in Beauly and Kintore, including resolution of GPS-clock configuration of WMU at Beauly.
- A team of engineers from SPEN, NGET, and GE collaborated to investigate communication problems between Data Centres and the Data Hub identified an issue parallel pair of network controller interface cards which has been fixed and appears to have resolved issues of packet loss at the central Data Hub.
- GE have issued the monthly reports for April 2016 to September 2016 covering the SPEN region:
    - Power System performance, based on analysis of data from the VISOR WAMS:
        - Oscillatory behaviour, highlighting significant oscillation events and general trends.
    - Presentation of system response to disturbances such as generator loss and transmission line faults.
    - WAMS performance: high-level statistics to highlight areas for further investigation such as PMUs with poor communications or data performance.
- Preliminary business case and benefit quantification matrix is currently under review for the GB roadmap, considering both Transmission Owner and System Operator perspectives.
- The computing equipment for the WAMS-EMS training and testing environment within the SPEN high-security operational network has been purchased. Assembly and configuration of the facility is underway and due for commissioning in March 2017.
- Beta version of independent web-browser tool to provide high-level presentation and interaction with PMU data received by PDT and currently under trial.
- UoM have recently submitted two reports following work package 3.2 in relation to the quantification of uncertainty in stability calculations in respect of SDRC 9.4.1
    - PMU Placement for GB Transmission System,
    - Comparison of Hybrid State Estimators.
- UoM are on schedule to deliver the following reports in accordance with the December 2016 milestone date but, at the time of writing, these are not yet released:
    - Report on accuracy of simulations models for small-signal and large-signal against naturally occurring events
    - Report on quantification of uncertainty in stability calculations

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:

- Key Knowledge Dissemination and Stakeholder Engagement Event in London, 6th July 2016 Hosted by SP Energy Networks

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 the following presentations and attendance at the following conferences:

- LCNI Conference 2016, 11th-13th October, Manchester, UK
  - Session presentation, published paper booklet and videos at stand
- PSCC Conference 2016, 20th-24th June 2016, Genoa, Italy
  - Two papers presented, entitled *"Impact of Load Dynamics on Torsional Interactions"* and *"Addressing Emerging Network Management Needs with Enhanced WAMS in the GB VIsSOR Project"*
- PAC World Conference 2016, 13-17th June, Ljubljana, Slovenia
  - Paper and poster presented entitled "VISOR Project: Initial learning from Enhanced Real Time Monitoring and Visualisation of System Dynamics in GB"
- IEEE PES General Meeting, 17th-21st July 2016, Boston, USA
  - Panel Session
- CIGRE Session, 21st-26th August 2016, Paris, France
  - Presentation of paper entitled "*Advances in Wide Area Monitoring and Control to address Emerging Requirements related to Inertia, Stability and Power Transfer in the GB Power System*"
- IEEE PES Innovative Smart Grid Technologies (ISGT), 9th – 12th October 2016, Slovenia
  - Paper presentation "Mitigating SSR: The Threat of Hidden Critical Lines and WAMS as a Solution"
- CEPSI 2016, Bangkok, Thailand
  - Presentation of paper, "Best in Conference", entitled *"Advances in Wide Area Monitoring and Control to address Emerging Requirements related to Inertia, Stability and Power Transfer in the GB Power System"*

In terms of upcoming knowledge dissemination and sharing events in 2016, the following events will be held or attended by members of the VISOR PDT:

- 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.

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 risks were encountered during commissioning and system analysis for project VISOR in the reporting period:

- **Satisfactory performance of the MPLS link between SPT and NGET**: This risk was escalated to an issue within the reporting period, as problems hindered the ability to conduct meaningful comparative assessments with the IP-Sec link to inform the GB WAMS Roadmap. A team of IT engineers identified the potential cause and remedial action taken to resolve the problem. The risk remains open as performance is being monitored.

The following risks are retained from the previous period:

- **Configuration of data transfer and firewall - Cyber Security (Critical National Infrastructure):** The interactions between Monitoring Devices (PMUs & WMUs), the VISOR TO Datacentres and VISOR SO Data Hub presents security risks. The different companies have different IT policies and security arrangements to protect from external threats. The key challenge is in ensuring that security of national infrastructure is not adversely affected, with the risk being that a mutually acceptable solution will not be agreed between all parties.
- **Configuration of operational control room demonstration 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, EMS/DMS and analysis applications in an operational control room demonstration environment. The risk is that timely delivery of this facility, in order to successfully demonstrate and undertake training within the environment, will not be achieved.

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:

- **Project extension is not approved by Ofgem:** without which the scope of following tasks will be limited and the potential benefits therefore not fully achieved:
    - Western HVDC commissioning capture and analysis
    - On-line demonstration of integrated WAMS-EMS and analysis applications
        - Additional stakeholder engagement & training

The overall objective of the extension is to maximise the learning generated by VISOR by extending the monitoring period and creating an operational WAMS integration and training facility, utilising existing budget. This will incorporate the WAMS applications demonstrated under VISOR, and further tools, together with a full replica of the control room EMS – serving as a fully capable environment to demonstrate the full extent of potential WAMS-EMS integration. Further information regarding the objectives of the project extension are detailed in Section 0 of this report.

The following risks are retained from the previous period:

- **Integration of innovation into business as usual activities:** Uncertainty surrounding the true benefits of phasor information will hinder the roll-out into BaU – the WAMS-EMS Demonstration System plays a key role in mitigating this risk.
- **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 – the WAMS-EMS Demonstration System also plays a key role in mitigating this risk.

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:

Pilot: Corporate vs Critical Network

Situating the VISOR WAMS within the Corporate Network was the easier and less time-exhaustive approach and, as stated above, it may not have otherwise been possible to establish the cross-TO system within the strict timescales of the project. This has, however, increased challenges down the line, particularly in relation to Cyber Security.

- As the original architecture did not have to adhere to the same levels of Cyber Security required for the Critical Network, a key challenge has stemmed from the successes of, and interest in, the technology leading to demand for and use by other functions of the business as part of business-as-usual. The demand for this integration has introduced data-transfer complexities and Cyber Security concerns.
- In particular, this issue has raised the question "is WAMS a system critical function, or is it just for post-mortem?". To which the general consensus has been that WAMS should be considered as a critical function going forward, and therefore either a requirement placed on the SO, or within the Grid Code to clearly define this requirement from which network operators can establish a framework with appropriate cyber security measures.

The importance and necessity of a Roadmap

The transition beyond a pilot project into the business requires strong evidence and business cases for the deployment of the technology. Some of the largest benefits of the technology may not be realised unless each TO has greater visibility of the wider network outside of their license area. Some benefits may be realised before this point, but these may be harder to quantify, such as the avoidance of catastrophe and asset damage. Benefits for the SO will depend on the level and reliability of monitoring coverage (placement, number and reliability of monitoring devices installed).

The development of the WAMS Roadmap for the GB is a complicated task affecting multiple parties with both benefits for TOs and SO intertwined. The key lesson here is that this particular task has such breadth and significance that it could have formed a standalone work package from the outset.

2 Project Manager's Report

This section highlights the VISOR projects' key activities, milestones, risks and learning over the reporting period (July 2016 – December 2016).

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 to boost the business readiness following completion of the project as the project enters the final year.

"The changes in generation on the transmission network, particularly in Scotland, means that the intuition of system behaviour our experienced control engineers have developed over the past 20 years no longer applies. Sophisticated software applications are now becoming crucial to understand and manage the network within the parameters set." Joe Hunter, SPT Senior Control Engineer.

The significant achievements during this reporting period are:

- Meetings with between key internal stakeholders (senior management) to progress development of business and technological roadmap.
- Successful commissioning of WMU devices in Beauly and Kintore, including resolution of GPS-clock configuration of WMU at Beauly.
- A team of engineers from SPEN, NGET, and GE collaborated to investigate communication problems between Data Centres and the Data Hub causing issues with certain PhasorPoint applications on Data Hub interface. The team identified an issue parallel pair of network controller interface cards which has been fixed and appears to have resolved issues of packet loss at the central Data Hub.
- GE have issued monthly Power System performance reports covering the SPEN area, that summarise oscillatory behaviour – highlighting trends and events – and present significant disturbances (e.g. generator or transmission line loss) detected by the VISOR WAMS.
- GE have also issued monthly WAMS performance reports which provided high-level statistics to highlight areas for further investigation such as a PMU with poor communications or data performance.
- The development of a comprehensive GB roadmap considering both Transmission Owner and System Operator perspectives is underway. A preliminary business case document and benefit quantification matrix is currently under review.
- A draft design architecture has been prepared including the provision of a new server within the SPEN high-security operational network. Final authorisation is required along with approval of project extension from Ofgem.
- Beta version of independent web-browser tool to provide high-level presentation and interaction with PMU data received by PDT and currently under trial. Intended as a high-level awareness and educational tool aimed at a wider audience, to complement the operational situational awareness and analysis provided by the primary WAMS software.

- Change Request letter submitted to Ofgem seeking project extension through to December 2017, to undertake a number of activities that will enrich understanding of system dynamics and oscillation stability of the GB system, offering greater clarity in the quantification of benefits forming the basis of GB roll-out strategy.

- The University of Manchester (UoM) have recently submitted two reports in accordance with their delivery milestones that are currently under review:

    - PMU Placement for GB Transmission System,

    - Comparison of Hybrid State Estimators.

- UoM are on schedule to deliver the following reports in accordance with the December 2016 milestone date but at the time of writing these are not yet released:

    - Report on accuracy of simulations models for small-signal and large-signal against naturally occurring events

    - Report on quantification of uncertainty in stability calculations

- In addition, GE have submitted the following report in accordance with their delivery milestones:

    - Report on long-term monitoring of area angle measurements

Knowledge dissemination activities:

- Key internal stakeholders within SPEN and NGET have been engaged by facilitating interviews and workshops between Quanta Technology for the development of the post-project rollout strategy.

- To maximise knowledge-sharing with international experience of synchrophasor implementations and developments, the wider industry has been engaged through hosting and presentation at the following events:

    - Highly successfully dedicated knowledge-sharing and stakeholder engagement event was hosted by SP Energy Networks in London on 6th July 2016.

    - LCNI Conference 2016, 11th-13th October, Manchester, UK

    - CIGRE Session, 21st-26th August 2016, Paris, France

The following conferences were also attended by members of the VISOR team and new learning shared through the publication and presentation of the following technical papers:

- PAC World 2016, 13th-17th June 2016, Ljubljana, Slovenia
    - VISOR Project: Initial learning from Enhanced Real Time Monitoring and Visualisation of System Dynamics in Great Britain

- PSCC Conference 2016, 20th-24th June 2016, Genoa, Italy
    - Impact of Load Dynamics on Torsional Interactions

- Addressing Emerging Network Management Needs with Enhanced WAMS in the GB VISOR Project

- IEEE PES General Meeting, 17th-21st July 2016, Boston, USA
  - Panel Session

- CIGRE Session, 21st-26th August 2016, Paris, France
  - Advances in Wide Area Monitoring and Control to address Emerging Requirements related to Inertia, Stability and Power Transfer in the GB Power System

- CEPSI 2016, Bangkok, Thailand
  - Presentation of paper, "Best in Conference", entitled "Advances in Wide Area Monitoring and Control to address Emerging Requirements related to Inertia, Stability and Power Transfer in the GB Power System"

- IEEE PES Innovative Smart Grid Technologies (ISGT), 9th – 12th October 2016, Slovenia
  - Paper presentation "Mitigating SSR: The Threat of Hidden Critical Lines and WAMS as a Solution"

The project is now in its second phase, the *operational 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.

The new insight gained during this stage will form 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, most significantly of which is the provision of a new dedicated demonstration and training facility.

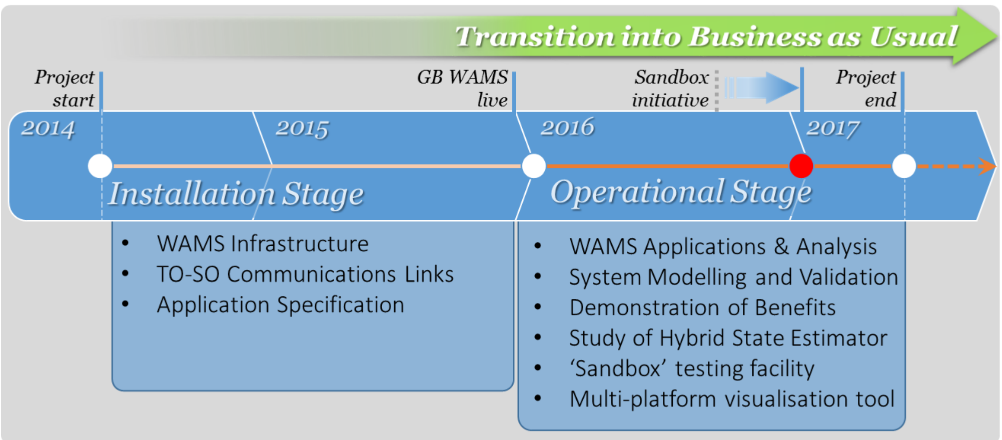


Figure 1. VISOR high-level timeline

2.2 VISOR WAMS Roadmap Update

VISOR demonstrates the implementation of synchronised monitoring technology in order to incorporate and accelerate its integration into the GB electricity industry by addressing technological and commercial challenges and uncertainties to provide necessary confidence to be considered in future business planning.

Whilst the full potential WAMS may not be realised until future advances in applications, technology, and infrastructure, this project is currently developing a technological and commercial roadmap document that will look to clearly identify the business drivers, needs, and the benefits of implementing various synchrophasor applications, including those piloted in the VISOR project to help establish the business case for the capital investment required for such a deployment effort.

The Roadmap is intended to:

- Facilitate the transition from a synchrophasor infrastructure implemented through the VISOR project and previous efforts 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 the already deployed synchrophasor system infrastructure to minimize the additional investment while achieving the desired business and operational goals
- Better coordinate the use 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, and the growing reliability and power quality requirements from customers
- Elicit further consensus among stakeholders on the additional business needs to be supported by the enhanced full-scale production-grade synchrophasor technology deployment
- Obtain buy-in among stakeholders on their business needs to be supported by the synchrophasor 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 SPT and its project partners' stakeholders needs;
- Identify budgetary constraints, corporate goals and preferences; with technology and regulatory constraints with voluntary and cooperative agreements among SPT and its partners
- Facilitate better coordination of the plans with all the involved utilities' area of responsibility.
- Assist management of SPT and its partners in approving further investments required for the full-scale production-grade synchrophasor technology system deployment

2.2.1 Roadmap Update

Quanta Technology have completed an extensive information collection exercise to inform the benefit quantification use-case tables, identifying major benefit areas, and the prerequisites required to achieve them.

A further series of meetings have been held between Quanta Technology and senior personnel in TO and SO organisations to develop a benefit quantification matrix applicable to each organisation circumstances. Whilst still under development, these benefits have been categorised as follows:

- Benefits to Markets
    - Reduced Ancillary Services
    - Reduced Curtailment Costs
- Benefits to Operations
    - System Monitoring
    - Improved network models for applications
    - Potential Future Applications
    - Integration of Distributed Generation
    - Oscillation Monitoring & Analysis
    - Risk Mitigation – Avoidance of Widespread Outages
- Benefits to Reliability
    - Outage Avoidance
    - Developments in Protection
    - Benefits to Asset Management
    - Capital Deferral – Reduced Grid Reinforcement Costs
    - Detection of Inverter Failures, Generator Rough Running, and other Asset Conditions
- Benefits to Planning
    - Benefits of more Accurate System Models
    - Benefits to Interconnection Analysis and Understanding Impacts of High Renewable Penetration and Embedded Generation
- Benefits to Post Mortem Analysis
    - Benefits of Faster and more Certain Analysis of Events and Causes

Each of the above benefits are considered in terms of beneficial impact and complexity to achieve, before a subsequent prioritisation ranking can be assigned accordingly. The roadmap assessment report covers all of these applications and benefits but the quantification effort is focused on a smaller list of benefits which are economically tangible and significant.

Many of the other benefits are difficult to quantify economically as they serve to mitigate high impact-low probability events such as major power system outages, or because the particular benefit is a "foundational" benefit or improvement in operations and planning processes which contribute to more tangible benefits in market operations or asset management. A number of benefits can be estimated to produce tangible savings in productivity, but the economic benefits while real are minor.

Rather than perform a comprehensive quantification of the individual areas, Quanta Technology and the VISOR team have selected a small number of "headline" benefits which are tangible, substantial, and credible for economic quantification. These benefits can be described as improvements in the market costs of balancing energy and preserving reliability; improvements in asset management costs for grid reinforcement; and insurance against risks to system performance and reliability under future conditions.

In developing the GB Roadmap, future scenarios have been considered to target and specify the level of integration and application of WAMS-based applications and the respective outcomes these would achieve. As the GB Roadmap is still currently being developed, the following timeline provides an example illustration of the possible objective statement and the expected outcome, along with the identified missing infrastructure, applications or processes that must be put in place to achieve them.

Short-term (2018-2019)
VISOR has been completed; lessons learned have been studied and shared; and a high-level system architecture is in place.

- ***Objective:*** *make the VISOR technology suitable for introduction to control centre*
- ***Expected Outcome:*** *WAMS available in the control room, but not integrated; users comfortable with quality of data and can understand and explain the information received via WAMS system; project plans for mid-term roadmap execution in place; funding secured for Mid-term roadmap execution*

[redacted]

The GB Roadmap report is currently under review and due to be published in early 2017.

2.3 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, ten 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 also has 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 have been made to purchase additional WMU units to be installed onto the VISOR WAMS. A suitable outage window is required within which the units can be installed and commissioned. An overview of the status of the installed and proposed WMUs locations is provided below in Table 1 and Figure 3.

National Grid have installed two WMUs at newly identified sites, beyond the original scope of the project. The interconnector between the UK and the Netherlands has been identified by NGET where SSO is 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 safeguard this.

The Western HVDC link between Scotland and England will be monitored using the WMU technology. The commissioning of the WMU at Deeside substation is awaiting an available outage window, expected in February 2017. In Scotland, SPT will complete the monitoring of the Western HVDC link by installing WMU monitoring on the circuits connecting the link, at Hunterston, which, when coupled with the WMUs on the other end at Connah’s Quay, will provide comprehensive monitoring of the operational behaviour of the high capacity HVDC link.

#	VISOR Partner	Locations (circuits)	Status
4	Scottish Power	Eccles (Stella West 2) Torness (Eccles 2) Hunterston (Inverkip 2, to be Strathaven) Auchencrosh (Coylton)	Installed and operational Installed and operational Installed and operational 2016/17
3	National Grid + one project spare	Hutton (Harker 1) Stella West (Spennymoor 1) Deeside/Connah’s Quay (Circuit 1)	Installed and operational Installed and operational Installed
5	above original scope	Hutton (Harker 2) Stella West (Spennymoor 2) Deeside/Connah’s Quay (Circuit 2) Grain (Circuits 1 & 2)	Installed and operational Installed and operational 2016/17 1 of 2 Installed and operational
2	Scottish Hydro Electric	Kintore Beauly	Installed and operational Installed and operational
1	The University of Manchester	Manchester	Operational

Table 1. WMU outstation device locations and status

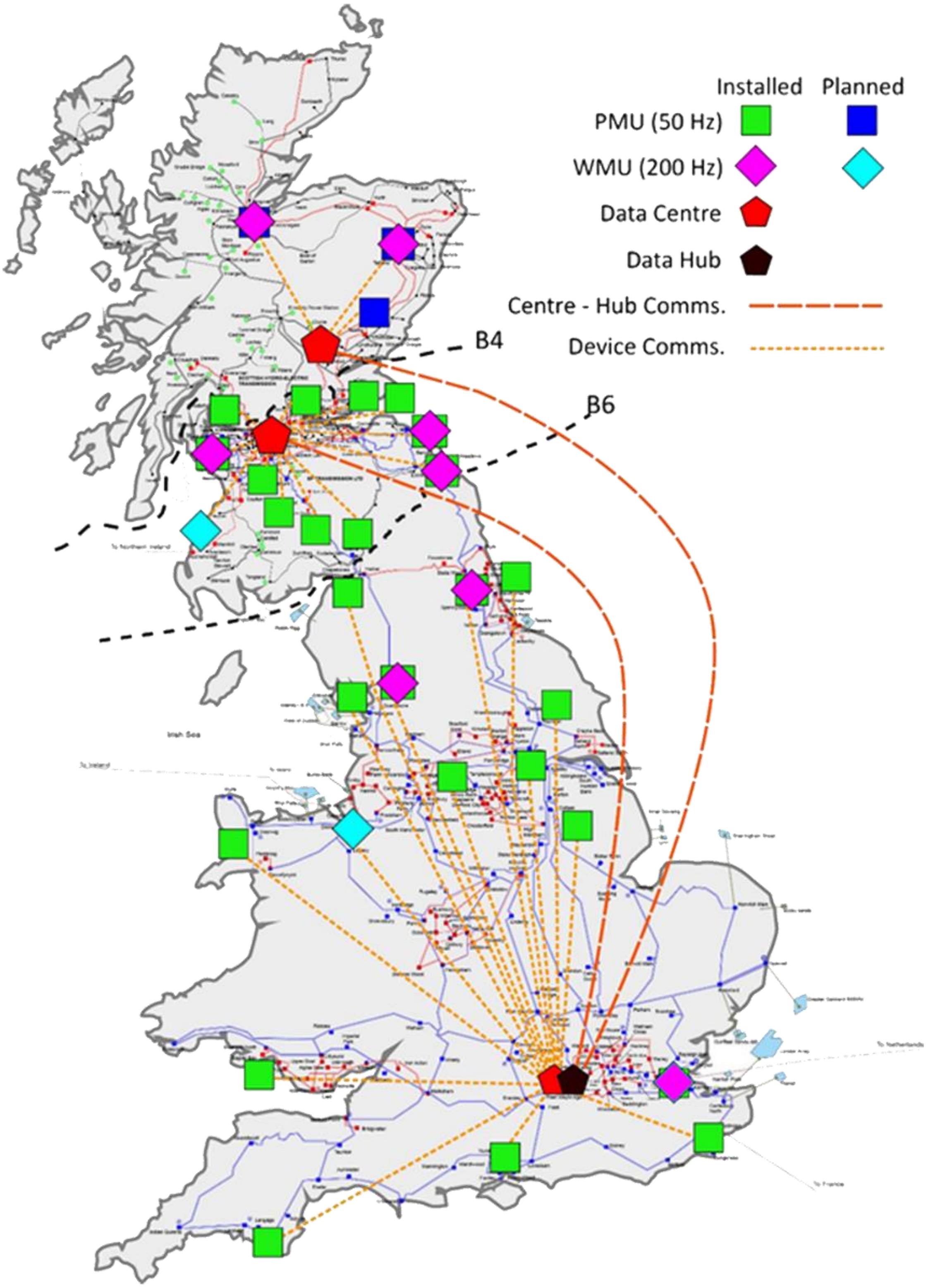


Figure 3 VISOR WAMS Deployment Overview

2.4 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].

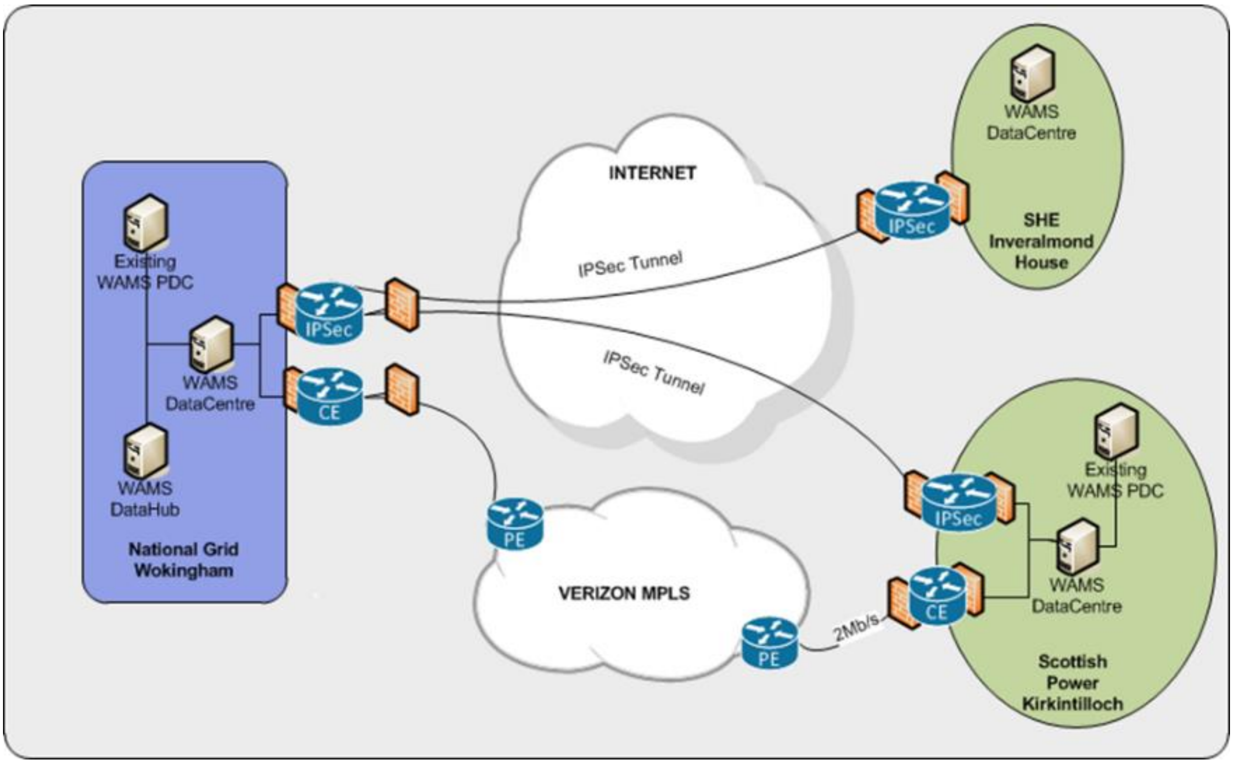


Figure 4. VISOR Communication Links between SHE TL, SPT, NGET and NGET SO

2.4.1 Data communication update

A GPS clock configuration issue at one of the SSE sites has now been addressed with support from GE – valid data is once again being received.

The dedicated MPLS connection was established as the preferred communication medium for data transfer between SPEN and NGET but has continued to experience issues that prevent the full potential to be realised and subsequently affect the performance resulting in spurious packet loss in data streams between the SPEN Data Centre and the Data Hub server, which, in turn, has affected the performance the VISOR Data Hub.

An extensive investigation was undertaken by a team of engineers from SPEN, NGET and GE engineers and the following mitigation measures were put in place:

- MPLS bandwidth has been increased from 2Mbps to 4Mbps to alleviate possibility of bandwidth-related issues and to also account for the additional WMU data obtained from the WMUs above the original scope of the project, and greater than expected PMU data streaming

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

requirements Increased bandwidth allows for simultaneous data streaming and historical data recovery transfers with additional headroom now available as a contingency.
- Shifting data streams between MPLS and IP Sec links to determine whether communication network medium is a factor in packet loss.
- Data transfer path investigations, route tracing and transit time tests to highlight potential causes, locations and/or configurations that exist within corporate IT infrastructures.
- Software updates to resolve issues with particular experimental applications.

As a result of the investigation, the potential cause of the packet data is believed to have been found; a parallel pair of network interface controllers installed at the SPEN PDC had slight discrepancies in their routing. The configuration issue has since been corrected which appears to have resolved the issue as the data flows between SPEN PDC and the Data Hub.

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

VISOR is demonstrating new WAMS analyses, 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	[redacted]	Type of Mode
NEW	Very Low Frequency (VLF)	0.002-0.16		Common Modes
NEW	VLF Source Location	0.002-0.16		Common Modes
EXISTING	Low Frequency (LF)	0.1-4 (Legacy 0.04-4)		Local and inter-area modes
NEW	LF Source Location	0.1-4		Local and inter-area modes
NEW	Sub-Synchronous Oscillations (SSO)	4-46		Sub-Synchronous Oscillations (e.g., torsional, network LC modes)

Figure 5. Oscillatory Stability monitoring in PhasorPoint

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.

The figure below depicts an oscillation which has been detected and tracked by the VISOR WAMS over the previous year. This particular oscillation is intermittent with a relatively small magnitude however an investigation to determine the root cause is currently ongoing.

[redacted]

Figure 6. 36-37Hz Oscillation detected by VISOR WAMS (CONFIDENTIAL)

2.5.1 Oscillation Monitoring and Management Reports

To supplement the real-time displays used to analyse and interpret this new data, a series of monthly performance reports are produced by GE to capture the findings of the monitoring:

- **Monthly Power System Performance reports** monitoring and reporting the oscillatory stability of the GB system, providing baselining trending of overall system stability dynamics and behaviour across the different oscillatory frequency modes.
- **Monthly Power System Disturbance reports** presenting power system behaviour during of significant disturbances e.g. generator loss or transmission line faults.

The information gathered from the VISOR WAMS is collated and concisely reported across the relevant business functions using the above reports. These reports are designed to bring value from the continuous monitoring and detection of oscillations and disturbances that bring a completely new level of visibility that will help educate operators into the oscillatory behaviour of the system - how system dynamics are vary throughout the day and under different operating conditions and, in the longer term, track how these dynamics evolve in time.

Histograms represent a valuable way of identifying reoccurring oscillations across a frequency range and the 200Hz WMUs provide monitoring across a wider frequency spectrum than conventional PMUs.

[redacted]

Figure 7. SSO Histogram over 6 months (CONFIDENTIAL)

An example of the new insight given in these reports is presented in Figure 8, whereby histograms allow tracking of overall system dynamics over several months.

[redacted]

Figure 8. Monthly reports (May-Aug) of Mode Frequency Histogram of Overall System Dynamics Behaviour (CONFIDENTIAL)

2.5.2 VISOR WAMS Monitoring and Management Reports

In addition to the Power System reports listed, the operational health of the VISOR WAMS system is itself monitored and managed through:

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

The above reporting not only ensures the network information gathered by VISOR is reported effectively and translate to meaningful learning and but also provides recommendations for how WAMS processes 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 monthly dashboards produced by GE which provide a very useful high-level diagnostic view of overall system performance. These dashboards provide monthly 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.

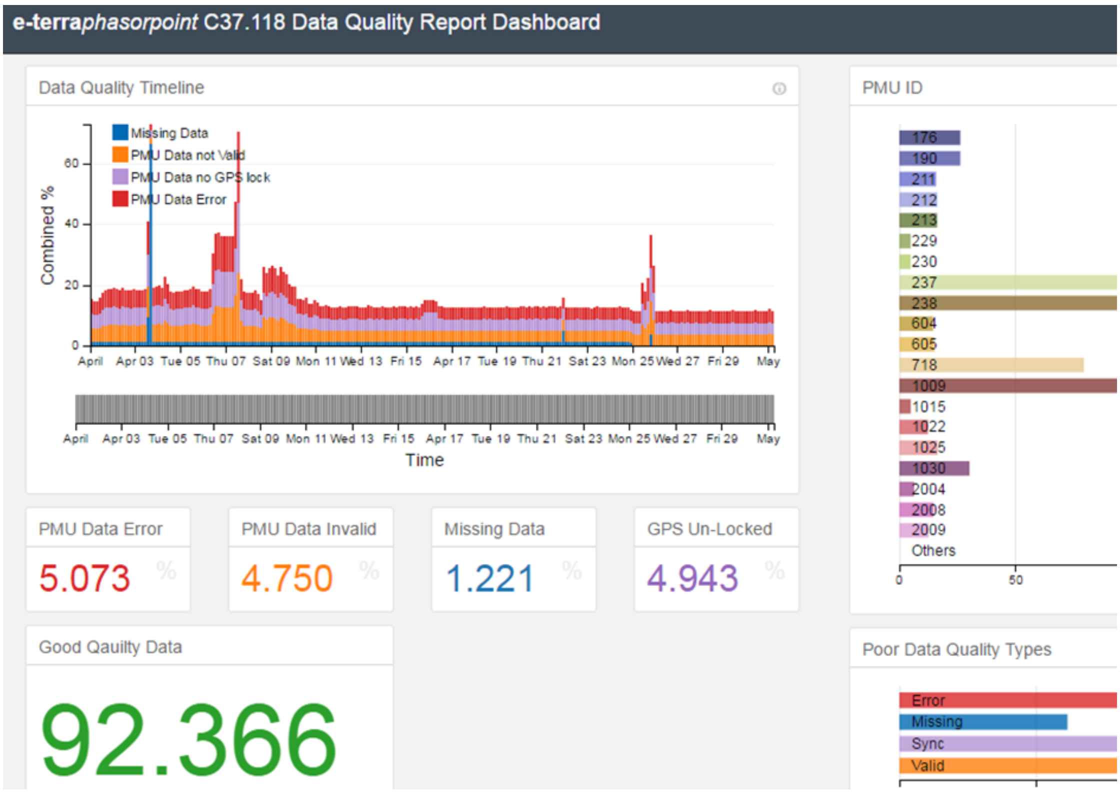


Figure 9. Example of VISOR Monthly Data Quality summary dashboard

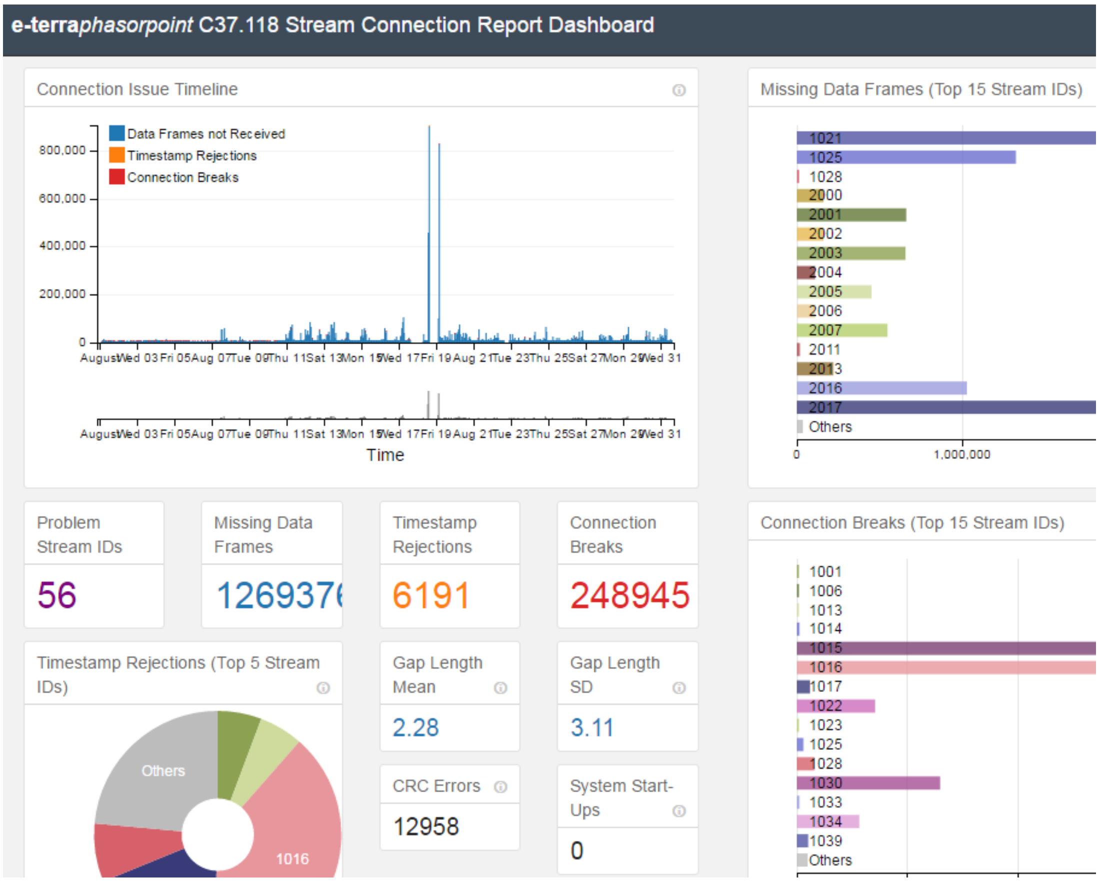


Figure 10. Example of VISOR Monthly Stream Connection summary dashboard

2.5.3 Line Parameter Estimation

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. Following this, a number of actions have been implemented with the aim of addressing the issues highlighted. A follow-up study into Line Parameter Estimation using synchrophasors was produced on 16 December 2016 and is currently under review by SPEN

2.6 WAMS Integration 'Sandbox' Facility at SPEN

Many of the application modules being used are new, seeing their world-first demonstration under VISOR. Workshops and presentations have demonstrated these new applications and the capabilities available to potential end-users of the technology; however, an opportunity was identified to enhance this effort, by establishing a dedicated WAMS integration and testing facility within SPEN, referred to as the Sandbox.

The Sandbox would provide SPEN with the opportunity to directly address the concerns surrounding future integration of new WAMS data into the operational control room environment, and in particular Energy Management System (EMS), **e-terra***platform*. Given that engineers would require new training for the new EMS system, the timing of the inclusion of WAMS data was highly favourable, and would provide users with greater appreciation of the benefits of the interface between EMS and WAMS.

The facility is designed to:

- Integrate WAMS data and alarm information into core EMS displays in **e-terra***browser* and operator situational awareness displays in **e-terra***vision*.
- Provide a new tool – **e-terra***phasoranalytics* for offline combined analysis of WAMS, SCADA and other data such as power system disturbance captures from Digital Fault Recorder (DFR) field devices.
- Feed WAMS data into a full replica of the SPEN state estimator
- Demonstrate additional new real-time applications through **e-terra***stability:* Grid Stability Assessment (GSA) - which leverages both WAMS and SCADA data – combining topology and system model information from the EMS with synchronised measurements from WAMS.

Whilst the facility will be located within the SPEN Control Centre, a series of demonstration and training events will be held to allow representatives from NGET and SHETL to witness the integration of PMU and WMU data.

2.6.1 Sandbox Update

In order to fulfil the objectives of the Sandbox the system must be installed within the high-security operational layer of network. There are two main issues to consider:

- In order to interface with the EMS and other BaU functions, the system must be moved from the Corporate LAN into the CNI LAN. To do this, a new PhasorPoint WAMS server will be required in the CNI.
- The current system, has a direct connection from the Corporate LAN in SPEN to the Corporate LAN in NGET SO. This connection can only be retained if both ends of the connection reside within the same high-security layer.

The architecture of the Sandbox facility has been agreed between SPEN and GE and is depicted in Figure 11. There is, however, less certainty regarding the technical specifics regarding the direct communication link with the Data Hub given the potential extension of VISOR and the potential transition of the systems into Critical National Infrastructure (CNI), as referred to as the Real-Time System (RTS) network.

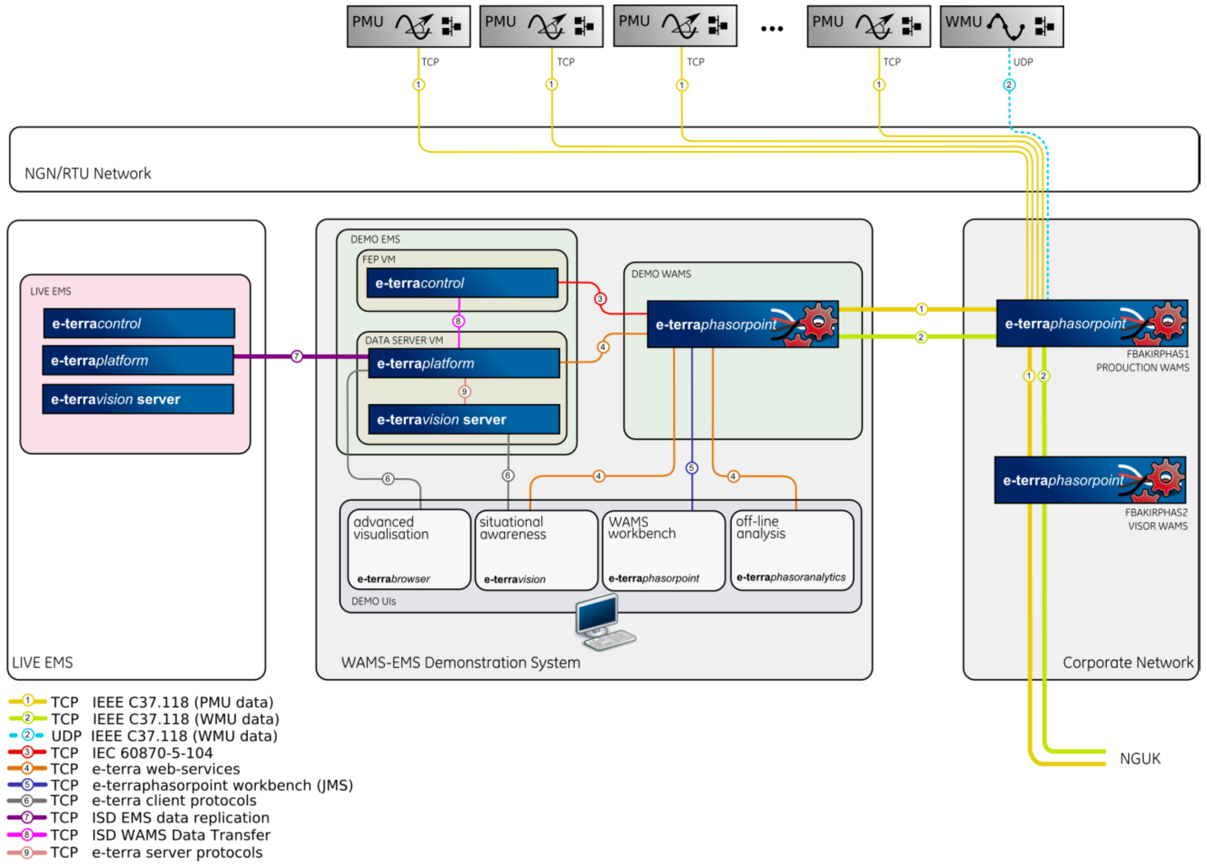


Figure 11. WAMS-EMS "Sandbox" Demonstration System Architecture

The Sandbox marks the transition of the VISOR WAMS system from Corporate to the CNI network; both SPEN and NGET are evaluation options regarding the implementation of an enduring solution. The project extension has been designed to enable the use of the Sandbox for on-line demonstrations and training workshops of the WAMS-EMS interface; showing operational control engineers and others exactly how WAMS / PhasorPoint can benefit different business functions.

The ultimate goal of the Sandbox is to build expertise and experience in using the WAMS system within our control centres and for post-event analysis teams. One such example of a successful WAMS deployment for post-event is the New York ISO (NYISO), who have reportedly found a particular application to be a very useful post-event analysis tool for the Grid Operations group to research system disturbances for preparation of internal Disturbance Reports by NYISO operations analysis team.

Figure 12. Example of WAMS system used on the NYICO control centre video wall (encircled)[2]

2.6.2 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 use of **e-terra***phasorpoint* in an integrated WAMS-EMS environment.

A number of initial training sessions shall therefore 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 2. 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-terra***phasorpoint*	Classroom with practical examples	⅓ day	3
Use of WAMS in improving real-time Situational Awareness	Classroom with practical examples	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-terra***phasoranalytics*	Classroom and practical examples	½ day	2
Training for IEC 60870-5-104 configuration for State Estimation and integration	Hands-on	½ day	2
Typical software configuration and system administration tasks pertaining to Sandbox	Hands-on	1 day	1

[2] D. Sobajic, "NYISO Situational Awareness Dashboard", Int. Workshop on Electric Power Control Centers, May 2015

2.7 PMU/WMU data visualisation tool for mobile platforms

This workstream was initiated in the previous reporting period to develop an independent framework/tool to provide high-level presentation of and open access to the PMU data in order to assist educate non-technical stakeholders, such as senior managers, that are unfamiliar with the power system operation & analysis concepts involved and with operational tools such as the EMS or PhasorPoint. This tool would be development to complement the existing proprietary solution and had the following primary objectives:

- To provide a means of accessing, visualising and interacting information attained by VISOR across multiple platforms, i.e. mobile phones and tablets
- To bolster efforts to bring VISOR to the wider stakeholder community, in particular non-technical engineers without access to PhasorPoint

This will allow access to the data using a web browser for local and remote access and provide the ability to illustrate and interact with PMU/WMU data at a high-level outside of the control room and help describe the benefits of WAMS-related information.

The tool is currently at beta stage with the software now being trialled by engineers and feedback on the operational performance and capability will be given to the developer. The first release of this tool is on track to be delivered in Q1 2017.

2.8 Research at the University of Manchester

Research has continued into three areas of study regarding the potential applications made available by the implementation of WAMS. The research topics were chosen as key areas of consideration in transitioning the technology into practical applications within the network operators; the findings from which will outline the underlying principles in each field, evaluate opportunities and providing recommendations where necessary

Hybrid State Estimation (HSE)

By comparing the performance of different HSE technologies to evaluate the behaviour with gross measurement errors of different type and severity, the impact of model errors and the influence of proximity of PMUs on estimation error. The Initial conclusions drawn include:

- The mean error is a poor way of assessing performance, the HSEs show a tendency toward outliers and a very good/bad performance for certain placement and error combinations
- Integrated HSEs make better use of the PMU data than the post processing HSE, e.g. better resilience to gross errors, more reliable performance (relative to placement) and better accuracy in general
- The Pseudo-Voltage HSE seems to be the least accurate of the integrated HSEs in general
- The constrained formulation has a significantly longer execution time and this further increases with PMU number and system size in a very non-linear way

PMU Placement

By converting an approximation of the GB topology (based on information from the National Grid Electricity Ten Year Statement) into the appropriate form for solving the optimal placement problem UoM have performed a number of different optimal placements to try and understand the required number/type of PMUs (e.g. many PMUs that monitor only 1 or 2 channels vs a smaller number of PMUs that monitor many channels).

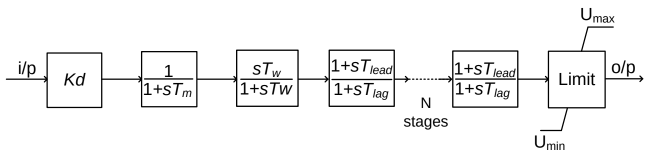
Sub-synchronous Resonance (SSR) mitigation

UoM have proposed a new controller that enables power plant auxiliary loads to provide SSR mitigation, as illustrated in the figure below. Specifically, a novel damping controller for SSR mitigation using existing 11 kV Variable Frequency Drive (VFD) interfaced auxiliary power plant loads (induction motors rated at 10 % of generator rating). The input of the proposed Auxiliary Damping Controller (ADC) is the turbine output power (P_t). This is a standard signal that is monitored in power plant control rooms and is available locally without the need for additional measurement and/or communication infrastructure. The ADC adds an auxiliary speed signal to the existing speed reference in the closed-loop motor drive control in response to any torsional range oscillations seen in Pt, via a feedback compensator. The lead-lag compensator used extracts damping by exploiting SSR Load Interactions (SSR-LI) and is tuned using a residue based pole placement technique.

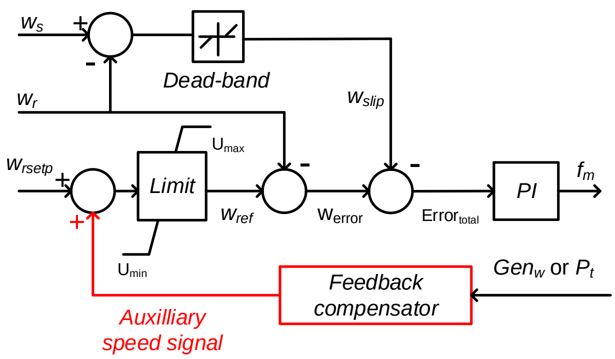
The ADC performance is evaluated for both Torsional Interaction (TI) and Torque Amplification (TA) types of SSR in the IEEE First Benchmark (FBM) and 68 bus networks. The results show that the ADC is effective in providing positive torsional damping to mitigate unstable SSR oscillations under a range of operating conditions. The novel solution proposed is a simple yet effective means of providing local control of SSR with minimal additional cost.

The findings from the above research activities has contributed to the following technical papers during the reporting period:

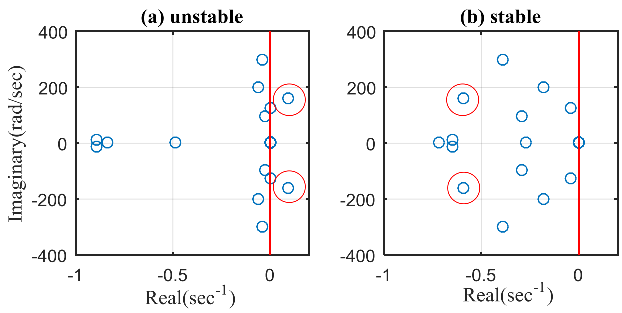
1. Completed the third revision of the paper entitled “A Screening Rule Based Iterative Numerical Method for Observability Analysis” that has been submitted to the IEEE Transactions on Power Systems.
2. Submission of the paper entitled “Novel Damping Control for SSR Using 11kV VFD Based Auxiliary Power Plant Loads” to the IEEE Transactions on Power Delivery.
3. A paper entitled “SSR Mitigation: Threat of Hidden Critical Lines and WAMs as the Solution”, accepted by the ISGT Europe Conference.
4. A paper entitled “Creating a WAMS for the GG Power System and the Lessons Learned So Far”, accepted by the MedPower Conference.



Typical linear feedback compensator



Feedback compensator incorporated into the frequency control loop of the VFD closed loop control to derive the auxiliary speed signal.



Modal analysis for IEEE FBM (a) without feedback damping controller and (b) with the damping controller where the unstable mode is pushed to the left half of s-plane to ensure system stability.

Figure 13. Modelling Sub-Synchronous Resonance mitigation

2.9 Project extension

Whilst the project is on track to successfully meet all objectives an 8-month project extension is proposed to both fully utilise the Sandbox training facility and to enrich our understanding of overall system dynamics and oscillation stability of the GB system through an increased monitoring and system performance reporting period, in particular extending to capture WHVDC commissioning. This will in turn allow greater clarity in the quantification of benefits and bolster our efforts in establishing a realistic and effective continuation plan for the technology.

The following steps will be taken to lead the transition of WAMS technology into BaU for the benefit of all Network Licensees:

- Extending monitoring period to capture and analysis commissioning of the Western HVDC link
- Bringing WAMS technology & applications physically and operationally closer to the control rooms in SPEN by establishing the new WAMS-EMS facility at OCC within the secure network,
- Bringing WAMS technology & applications operationally closer to the control rooms in SSE, NGET, NETSO, through demonstration and training workshops
    - Demonstrating the operational benefits of WAMS based on a live environment
- Documenting the optimum communication and cyber security requirements of the underlying infrastructure and data sharing processes requirement
- Establishing enhanced business cases for each aspect and application of the WAMS data in supporting the Roadmap by which these benefits can be realised, from both TO and SO perspectives

The steps VISOR plans to 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, SPT and NGET 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 will allow for the continued joint effort of the VISOR project partners, whose experience in conducting detailed analysis of this nature and drawing conclusions from which, would represent significant learning under the VISOR project for dissemination and a more informed business case.

The installation delays diminish the possibility of VISOR capturing and analysing the commissioning behaviour within the current timescales. As such, the proposed extension would lengthen the monitoring period that would allow for detailed analysis of the area surrounding

Connah's Quay and Hunterston but also study the wider impacts on system dynamics that would ultimately enhance understanding of underlying trends and instances of SSO, with the Western HVDC link as a key case study.

b) WAMS-EMS interfacing

VISOR puts PhasorPoint 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 the potential end-users and key personnel to pro-actively support and explore PhasorPoint as effectively as possible, however the VISOR system has resided within the corporate network, away from control operators and incapable of interacting or replicating the true control-room environment.

Through stakeholder engagement and growing support an opportunity arose to make use of an existing SPEN EMS upgrade programme completing that, by repurposing elements of the upgrade environment and aligning with the necessary training, would enable the PhasorPoint system to be situated within the secure network domain, allowing direct interface with SPEN's online EMS and establishing a dedicated WAMS integration and testing facility within the SPEN Operational Control Centre, Kirkintilloch.

The facility provides the opportunity to directly address the concerns surrounding future integration of new WAMS data into the EMS, ***e-terra**vision*. Given that engineers would require new training for the new EMS system, the timing of the inclusion of WAMS data was highly favourable, and would provide users with greater appreciation of the benefits of the interface between EMS and WAMS, including:

- **Improved situational awareness capabilities**
  e-terra*vision* will be able to show WAMS events and key data within the geospatial visualisation environment
- **Improved data integration**
  e-terra*stability*: Grid Stability Assessment (GSA) will allow WAMS data and oscillatory stability results and alarms to be viewed within **e-terra***browser*
- **New historical analytics tooling**
  The addition of **e-terra***phasoranalytics* can be used in both the new Sandbox environment and the current VISOR systems to provide easy off-line analysis tools and reporting capabilities

The proposed extension will allow time for any integration issues to be rectified and the various applications to be verified ahead of the overall interface between PhasorPoint and EMS to be realised.

c) WAMS-EMS demonstration and training

PhasorPoint includes may 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 generations and phases of WAMS-EMS integration and visualisation capabilities.

The proposed extension 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 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.

d) Production architecture design and network requirements

Establishing and operating the WAMS-EMS training and demonstration with live data streams and alarming functions will help evaluate and specify the optimum hardware and cyber security and network / firewall requirements for each specific aspect of the WAMS system. This will include assessing the amount of PMU & WMU data passing communicated processed prior to entering the secure environment 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

A workstream has been identified to develop an independent framework to provide high level presentation of and open access to the PMU data, to complement the existing proprietary solution. This will allow access to the data using a web browser for local and remote access with the data stored separately from the existing solution in an open-standard format, and make this data more open and accessible to other users outside the existing PMU analysis environment.

The development of this tool has the following primary objectives:

- To provide a means of accessing, visualising and interacting information attained by VISOR across multiple platforms, i.e. mobile phones and tablets
- To bolster efforts to bring VISOR to the wider stakeholder community, in particular non-technical engineers without access to PhasorPoint

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. Quanta Technology will support the PDT develop an extensive GB Roadmap.

2.10 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 operational phase it is essential that 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 project VISOR has focused on both external and internal knowledge dissemination through the following key activities.

The following dedicated events have been hosted by the project:

- Key Knowledge Dissemination and Stakeholder Engagement Event, hosted by SPEN at the IET London, 6th July 2016
- A series of WAMS Roadmap and Investment strategizing interviews with different function areas of the TO and SO businesses, taking place in July, August and November 2016.

Furthermore, to increase engagement and involvement with external stakeholders, in particular to share international experience of WAMS deployment, VISOR has been presented at the following events:

- PAC World Conference 2016, 13-17th June, Ljubljana, Slovenia
    - Paper and poster presented entitled “VISOR Project: Initial learning from Enhanced Real Time Monitoring and Visualisation of System Dynamics in GB”
- PSCC Conference, Genoa, 20th-24th June 2016 – two papers are being presented:
    - Impact of Load Dynamics on Torsional Interactions
    - Addressing Emerging Network Management Needs with Enhanced WAMS in the GB VISOR Project
- IEEE General Meeting, Boston 17th-21st July 2016
    - Panel Session
- CIGRE Conferences, Paris, 21st-26th August 2016
    - A joint paper with the National Grid “Smart Frequency Control” NIC project, entitled “Advances in Wide Area Monitoring and Control to address Emerging Requirements related to Inertia, Stability and Power Transfer in the GB Power System”
    - A joint presentation in the GE suite on the VISOR and Smart Frequency Control projects.
- CEPSI 2016, Bangkok, Thailand, 23rd-27th October 2016
    - Presentation of paper, “Best in Conference”, entitled *“Advances in Wide Area Monitoring and Control to address Emerging Requirements related to Inertia, Stability and Power Transfer in the GB Power System”*
- IEEE Innovative Smart Grid Technologies (ISGT) Europe, Ljubljana, 9th-12th October
    - Paper presentation “Mitigating SSR: The Threat of Hidden Critical Lines and WAMS as a Solution”
- Low Carbon Networks and Innovation (LCNI) Conference, Manchester, 11th-13th October
- Mediterranean Conference on Power Generation, Transmission, Distribution and Energy Conversion (MedPower), Belgrade, 6th-9th November 2016
    - Creating a WAMS for the GG Power System and the Lessons Learned So Far

2.10.1 Key Stakeholder Event 2016

Undertaking stakeholder engagement activities is crucial in successfully delivering innovation projects in order to best position the project for transition to BaU by sharing the learning generate through the project, addressing concerns from within the industry, and discussing future development and implementation plans.

VISOR has continued the strong commitment to knowledge-sharing and stakeholder engagement by hosted the second key stakeholder event on 6th July 2016 at the IET London. Representatives from each project partner gave presentations covering different aspects and perspectives of the project, with valuable questions answered throughout the course of the day. Project collaborators Quanta Technology and Open Grid Systems also presented updates on their respective tasks - the development of the GB roadmap and a demonstration on the mobile phasor-data visualisation tool.

To supplement the presentations, and to further communicate the learning generated through the project the most pertinent technical papers written by members of the PDT were collated into a single booklet and given to all guests at the event. This booklet will be updated toward the end of the project as further learning is made and will be available through the public website.

2.11 Outlook to the Next Reporting Period

The original completion date of the VISOR project is March 2017 however SPEN have requested an 8-month extension to facilitate full delivery and training and the WAMS-EMS integration facility (aka. The Sandbox) and to extend the WAMS monitoring period to covered the commissioning stages of the delayed Western HVDC link, which presents a substantial learning opportunity for all Network Licensees. If granted, the following final SDRC will be delivered later than originally forecast:

SDRC 9.1.1

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

SDRC 9.5.1

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

Whilst the above deliverables will be extended to reflect extended operation of the VISOR WAMS, the following deliverables remain scheduled for delivery in the forthcoming months:

SDRC 9.2.1

- 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)

SDRC 9.6.1

- 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)

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.

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 is on track to deliver all SDRCs according to the Project Direction however an extension is sought from March 2017 to December 2017 to maximise the efforts to transition the pilot system into BaU. The project extension will utilise existing project budget that has been retained through cost efficiencies achieved throughout the project.

As a result, to reflect the proposed change to the completion date of the project the following changes are proposed to the remaining SDRCs:

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 to existing milestones, the following additional milestones are proposed 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

4 Risk Management (Confidential)

[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 June'16 – Dec'16.

Table 5. Achieved SDRC in reporting period

Successful Delivery Reward criterion	Evidence
9.3 Successful model validation activity completion The definition of transient stability limits in particular is highly dependent on the quality of the static and dynamic equipment models, the design of control systems, and interpretation and resolution of problems occurring in the grid. It is essential therefore that the models and their associated parameters can be demonstrated to be sufficiently accurate to be fit for purpose. The components of the model validation activities will include: Line parameter estimation for key circuits using PMU data Oscillation analysis validation to quantify observed damping against simulated Transient stability simulations to reconstruct observed disturbances	9.3.1 • Report on PMU based line parameter estimation and variability (WP 2.1, March 2015) • **Report on accuracy of simulation models for small-signal and large-signal against naturally occurring events (WP 2.2-2.3, Dec 2016)**
9.4 Successful improvement options for management of transient stability constraints The demonstration and evaluation of a PMU-based presentation of a transient stability limit, and the assessment of the applicability to the B6 boundary constraint is an important outcome for the project. The project delivery includes: Quantification of the uncertainty in transient stability calculations Improvement in model initial conditions using hybrid state estimation Consultation on visualisation approach for transient stability limit Trial reliability of area angle measurements	9.4.1 • **Report on quantification of uncertainty in stability calculations (WP 3.1, Dec 2016)** • Display incorporating power, angle and associated thresholds (WP 3.3, Dec 2015) • **Report on findings from benefits of hybrid state estimator (WP 3.2, Dec 2016)** • **Report on long-term monitoring of area angle measurements (WP 3.4, Dec 2016)**
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	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)**

• Influencing and updating policies and standards • Public Engagement	• **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)**

6 Learning Outcomes

Following the Authority's formal approval in December 2013, VISOR has made good progress regarding project partner collaboration agreement, 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.

Lessons Learnt (+/-)	Lesson Learnt	Recommended Action
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 pilot projects which can follow 'unconventional' routes into the business.	Ensure the successes of the new technology are controlled in such a way that 'new users' do not breach IT practices.
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 PG&E and Quanta Technology in particular.	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 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

6.1 Technical Learning

The key learning generated to date is summarised below

The need for careful architecture design:

- Plans need to be comprehensive and clear from the outset (though this can be difficult on innovation projects). Information should include data flow details including direction, ports and protocols; and should cover both data streams and the support interfaces required – e.g. for remote configuration, debugging, and software / firmware upgrade. Access to control room and substation networks in particular is strictly controlled, for obvious reasons.

The need for flexibility and redundant approaches on inter-TO communications links:

- Original plans for a dedicated MPLS link between TOs – the technical and logistical option – were delayed by external contractors for 12 months. Escalation options were limited due to the multi-layered contractual relationships in place. The use of an IPsec link – initially rejected in favour of MPLS – was adopted as a short-term stopgap.

6.1.1 Pilot: Corporate vs Critical Network

At the beginning of this project the decision was made to establish the VISOR system outside the project partners Critical Network Infrastructure and within the Corporate Networks as this was the easiest, quickest, and perhaps only justifiable approach - it may not have been possible to otherwise establish the cross-TO system within the strict timescales of the project.

As the original architecture did not have to adhere to the same levels of Cyber Security required for the Critical Network, a key challenge has stemmed from the successes of the technology subsequently being used by other functions of the business as part of business-as-usual - raising complexity and Cyber Security concerns.

The key lesson here is to consider such an eventuality wherein the scope for the technology may broaden or deviate based on the successes of the project, which must either be controlled or decoupled from the core project. Equally, serious consideration should be given at the design and planning stage to the potential for broadening of scope – such opportunities should not create delays or dependencies for the project, but consideration at an early stage will potentially lead to additional benefits being realised with minimal disruption and effort.

6.1.2 The importance and necessity of a Roadmap

The need to develop a GB Roadmap for WAMS deployment was highlighted in the previous progress report (Jun'16) to inform strategic decisions on capital investment plans and in particular to highlight areas where external factors such as the cooperation of third parties or regulatory barriers may present risks that hinder the full benefit to be immediately realised.

Defining the tangible benefits of such a technology is a complex task, with many variable and uncertainties involved. Such benefits include a number of potential approaches to release network capacity. Some approaches are relatively “low-hanging fruit” such as improved confidence in models and operating conditions – covered under VISOR. Other approaches will require real time contingency analysis and control, for which the System Operator may require other dependant infrastructure upgrades. These also require increased readiness and confidence from the industry to adopt such technology – the learning and demonstrations in VISOR are the critical first step in this.

6.1.3 Changes to business practices to achieve full benefits

The development of the future roadmap examines near and long term benefits and in doing so highlights areas for change. One such area highlighted by VISOR has stemmed from the study into the B6 boundary:

- The ability of a transmission Network Licensee to gain visibility beyond the license area boundaries to improve the accuracy and robustness of certain applications that rely on accurately network modelling. For applications such as oscillation source location and disturbance management to deliver most benefit to TOs, a high-level GB-wide view is required to allow detected oscillations and disturbances to be placed in their proper context. Currently, such data-sharing arrangements are not in place.

6.1.4 TCP and UDP

The conclusion on TCP/UDP data transmission is retained from previous reports:

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 13 December 2016. The accompanying VISOR bank statement is provided Appendix 1.

[redacted]

9 Intellectual Property Rights

VISOR complies with the Ofgem default position regarding the IPR ownership.

Throughout the project, the supplier, GE Grid Solutions, generates new Intellectual Property in the form of WAMs detection and analysis applications. The supplier will retain the IPR which they independently create.

No further IPR has been generated or is expected to be generated.

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 (Confidential)

[redacted]

12.2 Appendix 2 Project Risk Register (Confidential)

[redacted]