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

In collaboration with

Project Progress Report

[External]

June 2015

For enquiries please contact:

Priyanka Mohapatra
VISOR Project Manager
SP Energy Networks
Email:
pmohapatra@spenergynetworks.co.uk
Telephone: 0044 (0)1416142789

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

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1 Executive Summary

SP Transmission (SPT), supported by other the transmission licensees and the academic partner, made a full proposal submission for 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 will showcase the role of an enhanced Wide Area Monitoring System (WAMS) in overcoming the challenges faced by the GB power system as it moves toward a low carbon future. It will create the first WAMS for the GB network and will also mark the first deployment of new Waveform Measurement Units (WMUs), which generate 200 frames per second data for the detection of sub-synchronous oscillations (SSO), anywhere in the world.

VISOR will create the first WAMS to collate, store, visualise and analyse synchronised measurements in real-time from across all three of the GB TOs. The WAMS will incorporate wide area synchronised phasor measurements produced at a rate of 50 frames per second that will 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.

VISOR will focus upon 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 sub-synchronous oscillations in the range 0.002Hz to 46Hz,
- Dynamic model validation using post mortem analysis of WAMS data,
- Hybrid state estimation using Phasor Measurement Unit (PMU) and SCADA data, and,
- The potential use of angle based security limits to increase power flow on the B6 boundary between Scotland and England.

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1.1 Project Highlights

This is the third progress report and covers six months of the project delivery December 2014 - June 2015, “the reporting period”.

The project delivery so far 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 Successful Delivery Reward Criteria (SDRC) have been delivered on schedule:

SDRC 9.1.1:

- ✓ Visualisation of multiple SSO information sources at data centre
- ✓ Baseline and comparator report for SSO behaviour (first in series of three annual reports of this kind)

SDRC 9.3.1:

✓ Report on PMU based line parameter estimation and variability (WP 2.1, March 2015)

SDRC 9.1 and 9.3 are scheduled to be fully met in 2016 and 2017 pending completion of other elements of supporting evidence.

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

- VISOR WMU installations completed at Hutton (NGET) and Eccles, Hunterston (SPEN) - significantly ahead of schedule.
- WAMS server installation and firewall configuration completed at Wokingham (NGET) and Kirkintilloch (SPEN)
- WAMS & WMU SAT successfully completed at NGET on the 11th and 12th of May and at SPEN on the 14th and 15th of May.
- Contract placed with Verizon to establish communication Multiprotocol Label Switching (MPLS) link between Kirkintilloch (SPEN) and Wokingham (NGET) and IPSEC link between Perth (SSE) and Wokingham (NGET).
- Demonstration of Sub-Synchronous Oscillation (SSO) application at Wokingham and Kirkintilloch: collection, analysis and visualisation of wide-area SSO information.
- MPLS link between Kirkintilloch PDC (SPEN) and Wokingham Data Hub (NGET) in delivery.
- Additional WMU installations planned for 2015 at Stella-West, Connor's Quay, Grain (NGET) and Torness, Auchencrosh-Coylton (SPEN).
- B6 boundary specification and SDM specification were submitted by Psymetrix and reviewed by project delivery team.
- The following reports were produced by Psymetrix based on actual system data from NGET and SPEN (Jan 14-Mar 15)
    - Report on PMU based line parameter estimation and variability
    - System Performance Review incorporating:
        - ✓ WAMS Infrastructure performance
        - ✓ Power System Oscillatory behaviour: baseline & events
        - ✓ Power System Disturbances

  These reports were thoroughly reviewed by project delivery team and forwarded to project steering board for approval. External versions of these reports will be published at http://www.visor-project.org.uk/ by the end of June 2015.

- The System Performance Review (Jan 14-Mar 15) was discussed in detail at a workshop held on the 14th and 15th of April, 2015 at Psymetrix, Edinburgh.
- NGET facilitated ECM workspace for Project VISOR to have common SharePoint for documents management and version control.
- VISOR PDT collaboratively made efforts to capture all significant learning outcomes generated in this period in a co-ordinated manner to enable us to articulate all significant learnings in future progress reports.

The GB wide WAMS deployment overview Paper synopsis submitted for VISOR & Smart Frequency Control (EFCC) project VISOR is shown in Figure 1.

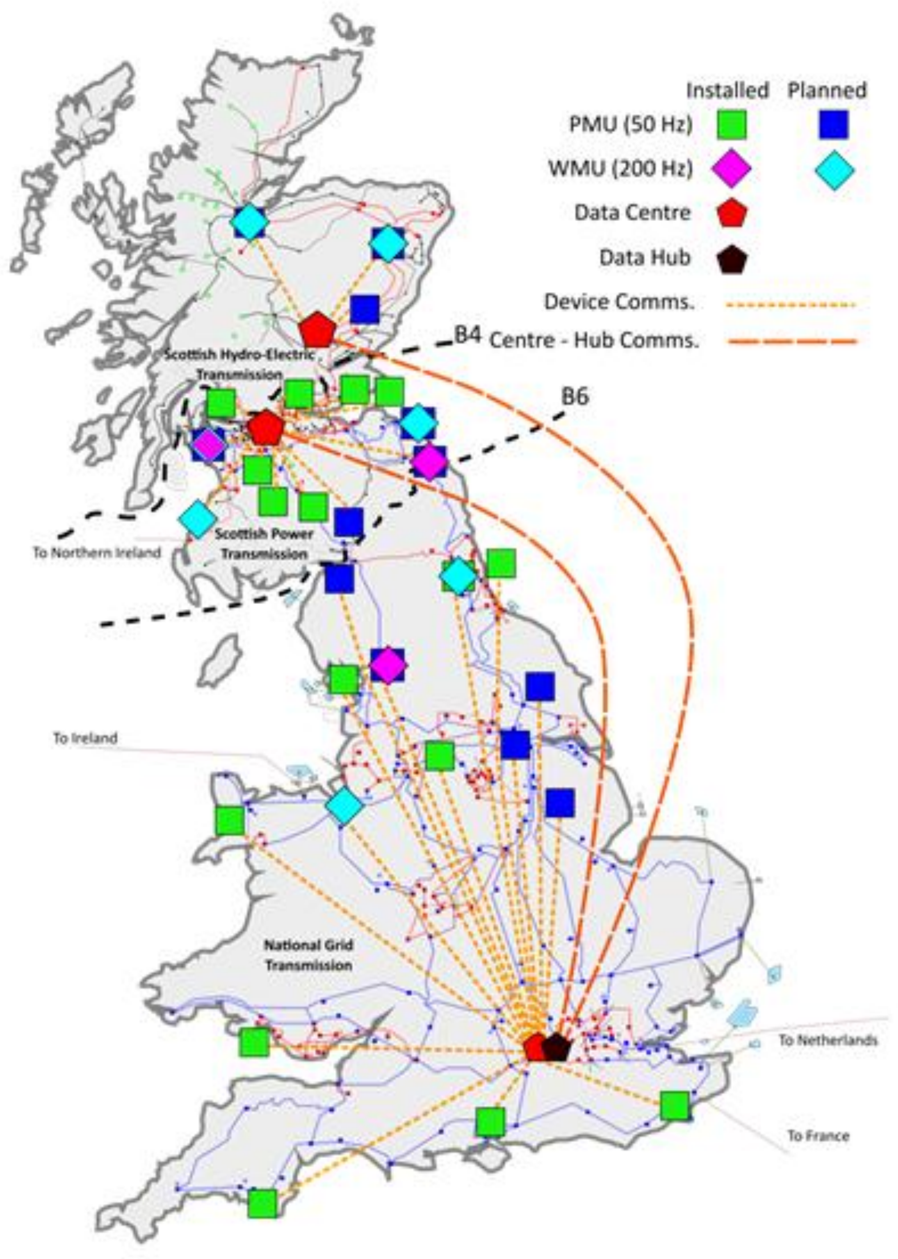

Figure 1 VISOR WAMS Deployment Overview

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, including the potential risks that were documented in the Full Submission. These are described in detail 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 from December'14 to June'15:

- At SPEN and NGET firewall configurations required to enable UDP data transmission from Substation to PDC proved to be challenging. Additional approval was required from business IT security department causing delay in receiving WMU data.
- At NGET the on-going changes to business communications infrastructure required VISOR PDT to go through various approval procedures to integrate VISOR infrastructure with business.
- Analysis of system data measured at currently installed PMUs on SPT and NGET transmission network highlighted many data quality issues. NGET and SPT were aware of many of the issues and ongoing mitigation actions are continuing to progress. The quality of reports generated during this period was adversely affected by these issues.

1.2.2 Project Management Risks

- The project management risk in this period is an ongoing risk of different levels of progress amongst TOs. Whilst NGET and SPT have significantly progressed and completed hardware and software installation. SSE still has not commenced WAMS installations.

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

Successful WMU installations are now complete at Eccles, Hunterston (SPT) and Hutton (two circuits) (NGET). WAMS PDCs are now receiving data from pre-existing PMUs (50Hz) and newly installed WMUs (200Hz). The WAMS SAT was successfully carried out at NGET and SPT. There have been many key learning outcomes regarding WAMS installations in this period. During the WAMS commissioning and configuration phase, both at NGET and SPT, various issues related to communications infrastructure, data quality and cyber security emerged. Some of the issues were unprecedented and others could have been identified and catered for earlier provided the TOs had more information regarding the nature of infrastructure changes and level of accuracy required for successful WAMS deployment.

Significant learning outcomes were also generated from the two reports based on actual system data for project VISOR. The Line Parameter Estimation report proved that the new algorithm developed under this project produces better quality results than any other algorithm currently being studied or used for the same purpose. The SSO System Behaviour report provided an insight into the series of dynamic interactions in the system leading to or following an actual system event and/or state change.

The aforementioned reports also reiterated that poor data quality/availability can adversely affect the quality of results and, in the long term if not properly addressed, can be a major issue in a successful WAMS rollout. The reports successfully predicted various factors that could be responsible for poor data quality. These are now being addressed in line with pre-existing activities to review and improve the quality of monitoring data. Detailed system data and event analysis was carried out during the system data workshop at Edinburgh on the 14th and 15th of April, 2015.

NGET and SPT have performed an audit on their existing PMUs to analyse these issues further. Manufacturers of the installed PMUs at NGET and SPT have been contacted regarding issues that can be fixed with simple firmware updates and crystal oscillators for improving GPS signal management. Some issues, for example, poor data availability caused by communication delays in NGET networks, are being managed through ongoing network changes and upgrades. Monthly data checks are also to be carried out by the VISOR team to ensure that the data quality is maintained throughout the period of assessment and beyond, so that it does not degrade the quality of results presented in key reports.

A key learning outcome of this exercise has been that the business needs to invest time and capital to improve infrastructure and adapt network management policies for better communication reliability and accuracy. A significant shift is observed in the nature of infrastructure requirements for modern power grid monitoring solutions when compared to previous business as usual approaches (e.g. SCADA and dial-up Fault Recorder connections), and these requirements need to be handled in a timely manner to avoid delays in the project delivery phase.

Effective management and ensuring progress in project deliverables in project VISOR is simplified by the efficient project delivery team. Members of the PDT have taken up tasks in a dedicated and responsible manner and have timely delivered, leading to successful achievement of key project milestones. PDT members have also regularly assessed risks and raised them with the project manager. Mitigation measures were planned and implemented for individual risks and project delivery delays were avoided by fast tracking actions as and when required.

The knowledge sharing and effective engagement with stakeholders can be found in our presentations at the IET Birmingham Conference (21st of April, 2015) and All-Energy Conference (6-7th of May, 2015).

2 Project Manager's Report

This section highlights the VISOR projects key activities, milestones, risks and learning over the reporting period (December 2014-June 2015).

2.1 Project Progress Summary

VISOR remains on course for a satisfactory delivery over this reporting period regarding the project programme. The significant achievements during the reporting period are:

- ✓ WAMS & WMU SAT successfully completed at NGET on the 11th and 12th of May and at SPEN on the 14th and 15th of May. Psymetrix also conducted an additional SSO demonstration for stakeholders in combination with the SAT.
- ✓ Demonstration of Sub-Synchronous Oscillation (SSO) application at Wokingham and Kirkintilloch: collection, analysis and visualisation of wide-area SSO information.
- ✓ MPLS link between Kirkintilloch PDC (SPEN) and Wokingham Data Hub (NGET) in delivery).
- ✓ Reports were produced by Psymetrix based on actual system data from NGET and SPEN (Jan 14-Mar 15)
    - Report on PMU based line parameter estimation and variability
    - System Performance Review incorporating:
        - ✓ WAMS Infrastructure performance
        - ✓ Power System Oscillatory behaviour: baseline & events
        - ✓ Power System Disturbances
- ✓ The conclusions from the System Performance Review (Jan 14-Mar 15) and subsequent follow-on actions were discussed in detail at a workshop held on the 14th and 15th of April, 2015 at Psymetrix, Edinburgh.
- ✓ WAMS SAT successfully completed at NGET on the 11th and 12th of May and at SPEN on the 14th and 15th of May. Psymetrix also conducted an additional SSO demonstration for stakeholders in combination with the SAT.

To achieve these milestones, the following key pre condition elements had been completed:

- ✓ VISOR WMU installations completed at Hutton (NGET) and Eccles, Hunterston (SPEN).
- ✓ WAMS server installation and firewall configuration completed at Wokingham (NGET) and Kirkintilloch (SPEN).
- ✓ Contract placed with Verizon to establish communication MPLS link between Kirkintilloch (SPEN) and Wokingham (NGET) and IPSEC link between Perth (SSE) and Wokingham (NGET).

Other achievements include:

- ✓ B6 boundary specification and SDM specification were submitted by Psymetrix and reviewed and approved by project delivery team.
- ✓ The next tranche of WMU installations has been planned for 2015 at Stella-West, Connor's Quay (NGET) and Torness, Auchencrosh-Coylton (SPEN). Additional WMU units have been ordered for NGET installations.

Following the System Performance Report, audits of existing PMU installations have been carried out at NGET and SPT as a first step in investigating data quality issues. Some subsequent steps have already been taken to address some of the issues highlighted. In addition to the positive technical contributions named above, three elements set out in SDRC were completed, regarding visualisation of SSO data at PDCs, use of system data for accurate line parameter estimation and system data analysis for NGET and SPT from Jan'14-Mar'15.

2.2 Monitoring and Management of Constraints

2.2.1 B6 Display Specification

The B6 display specification describes the functions that will be presented in the Phasorpoint application for monitoring the power flow across the Anglo-Scottish interconnection, referred to as the B6 Boundary, a prominent constraint boundary in the GB system.

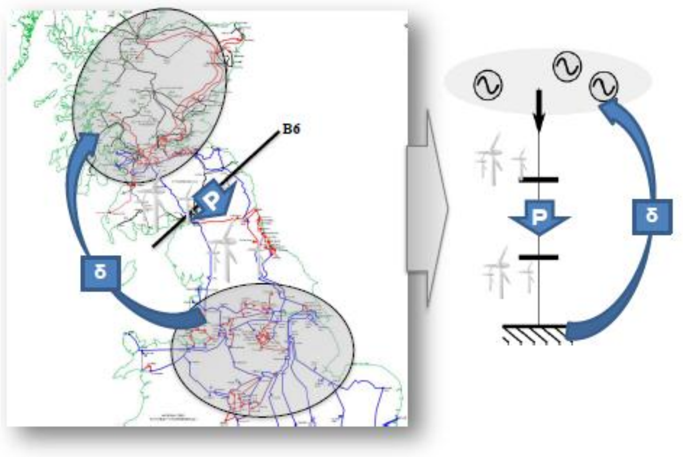

Figure 2 B6 power and angle boundary representation concept

The application involves deriving an aggregated representation of angle in each of the centres of inertia that are involved in the stability limit. These aggregate angles are calculated from PMU measured voltage angles, and user-defined inertia values. An angle limit will be expressed in terms of the equivalent angle difference between the two centres of inertia. In addition to the power and angle limits, cut-off limits are also defined corresponding to secondary constraints e.g. thermal / angular separation. An alarm event is triggered if the network operation point is outside both the angle and power limits, or reaches one of the cut-off limits.

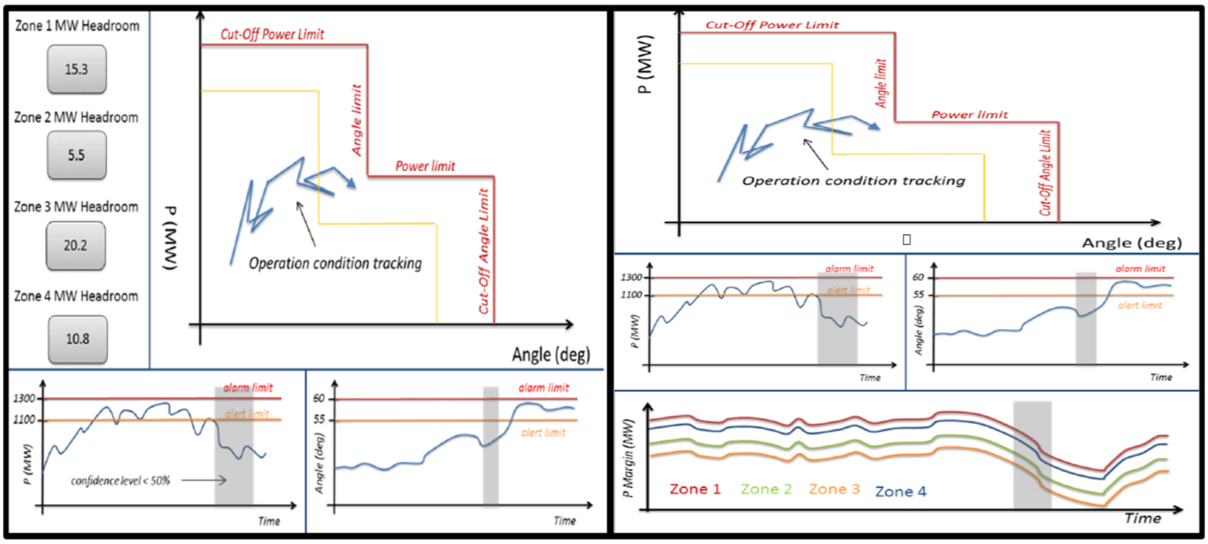

Figure 3 Live and Historical Display

The key advantages of including angle in constraint management include:

- Dynamic limits are more closely related to the area angle movement than to the power through a cut-set. Both first-swing (transient) and damping limits are physically related to the following phenomena:
- Effective impedance between the areas: *Angle increases with weakening of corridor between areas*
- Loading of the interconnection lines *Angles increase with power interchange between areas*
- Distribution of power within the connecting areas: *Angles increase as greater proportion of power far from the boundary*

2.2.2 System Disturbance Monitoring (SDM) Specification

The System Disturbance Monitoring: Disturbance Characterisation (SDM: DC) application utilises PMU voltage angle and frequency data to detect, localise and characterise system disturbances such as line trips and generation losses. The application uses the principle that during a transient disturbance, the frequency and angle of the power system move more rapidly close to the source of the disturbance.

The end result in the first moments after the disturbance (e.g. 0.5 seconds) is:

- Very rapid angle movement near the disturbed bus.
- Larger, faster angle movement at the station buses close to the disturbed bus.
- Smaller angle movement at generators further from the disturbed bus.
- Initial acceleration or deceleration greater close to the disturbance.

2.3 Waveform Measurement Unit and Server Installation

A total of ten "Waveform Measurement Units" (WMUs - SSO outstation devices) and 3 additional data acquisition units have been procured under VISOR. All devices should be installed onto the GB transmission network by the end of 2015 apart from one unit that will be used by the University of Manchester to facilitate hardware-in-the loop testing (which will monitor the enduring performances of the unit with simulated network signals). The proposed locations are listed below.

#	VISOR Partner	Locations (circuits)	Status
4	Scottish Power	Eccles (Stella West 2) Torness (Eccles 2) Hunterston (Inverkip 2, to be Strathaven) Coylton (Auchencrosh)	Installed June'15 Installed Sep'15
4	National Grid	Hutton (Harker 1 & 2) Stella West (Spennymoor1 &2) Connor's Quay (Pentir) Grain	Installed June'15 August'15 tbc
2	Scottish Hydro Electric	Kintore Knocknagael	Tbc
1	University of Manchester	Manchester	Received by University of Manchester 19th Nov
1	Spare	NGET	Received at NGET'15. Stella West

Table 1. Proposed WMU outstation device locations and status

Those outstation devices will then transfer the data to a local data centre (installed at each TO control centre) before going to a national VISOR Data Hub (installed at the GBSO control centre).

#	Description	Responsible VISOR Partner	Location	Status
1	Data Centre	Scottish Power	Kirkintilloch	Installed and Receiving data
1	Data Centre	Scottish Hydro Electric	Perth	Tbc
1	Data Centre	National Grid (TO)	Wokingham	Installed
1	Data Hub	National Grid (SO)	Wokingham	Installed and MPLS connection established with Kirkintilloch
1	Study Platform	University of Manchester	Manchester	University of Manchester server installed and configured. PhasorPoint software near commissioning.

Table 2. Location & status of VISOR WAMS Servers

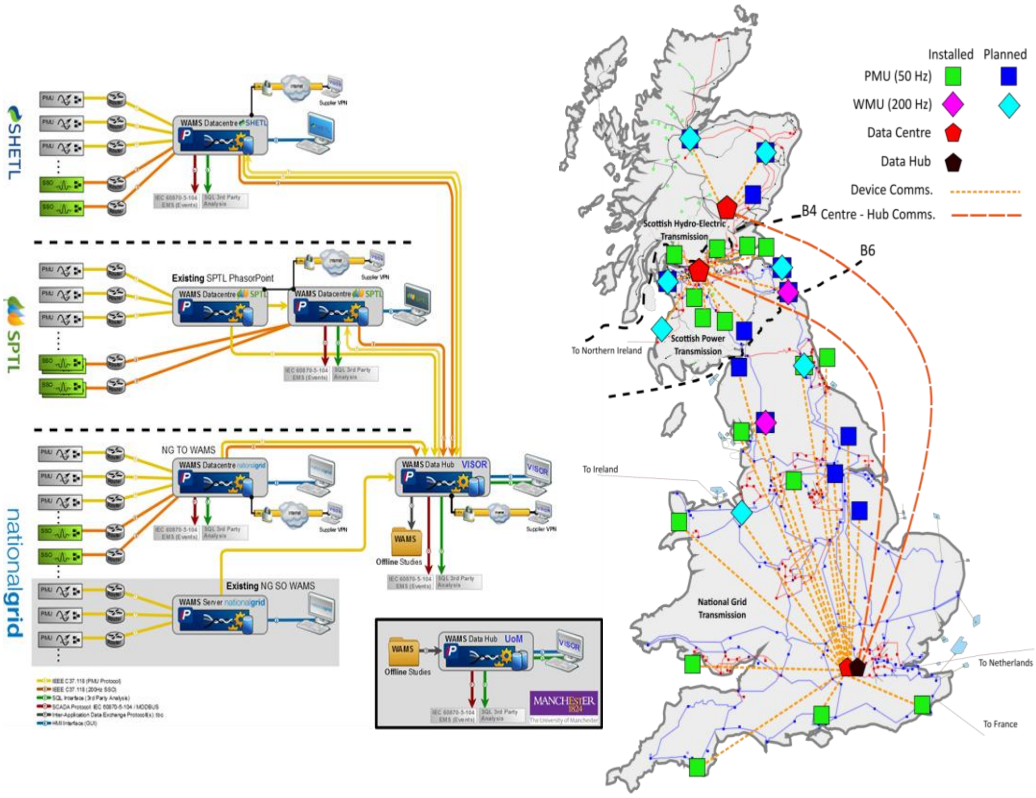

Figure 4 Schematic and geographical views of the VISOR WAMS

2.4 Report on PMU based line parameter estimation and variability (WP 2.1, March 2015) [CONFIDENTIAL]

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2.5 System SSO Behaviour Report and VISOR Workshop

Project VISOR successfully delivered the 1st System Performance Review and associated Technical Workshop in March and April 2015, respectively. The Performance Review analysed collected PMU data for the period of 2014-2015 and WMU data for period of March 2015 collected from NGET and SPEN. Significant learnings generated from both the report and workshop are highlighted below:

- ✓ The oscillatory behaviour observed and highlighted in the VISOR System Performance Review, was discussed. A number of particular issues were discussed in detail - though these were not necessarily of immediate concern:
    - Electromechanical modes in the 0.04 – 4Hz range (derived from PMU data)
    - Sub-synchronous modes in the 4-46Hz range (derived from data from the two VISOR Waveform Measurement Units (WMUs) installed at Hutton and Eccles)
    - In particular, distinct changes in oscillatory behaviour seem to coincide with the arming of the Time-Series Cross-Sectional (TCSC) data were discussed:
        - The apparent improvement in damping of pre-existing modes (this seemed also to be related to B6 MW flow).
        - The introduction of multiple new and fast-varying frequency modes. There is very limited pre TCSC monitored data, so it is difficult to quantify the nature of these to differing system conditions. These modes are very small in amplitude and thus present no major concern and are expected to be related to the TCSC controller. Further work is underway to confirm this.
- ✓ A review of selected System Disturbances observed during the review period was conducted.
- ✓ A number of WAMS Performance issues as listed below were discussed at the workshop and are detailed in the VISOR System Performance Report. The conclusions and actions related to these are listed in WAMS workshop report:
    - Issues of PMU data availability in the National Grid and SP Transmission WAMS.
    - The primary issue in the National Grid system related to failed TCP connections, with some sites also reporting significant numbers of missing data packets.
    - The primary issue in the SP Transmission WAMS related to consistent 3-4 % loss of data frames at some sites. It is believed that this is related to a new firmware version deployed at some sites – there is a near-100% overlap between sites showing high packet loss and sites with the new firmware version, with two exception
    - The majority of PMUs in the GB WAMS are reporting system frequency measurements with integer format precision (1MHz) or less. The impact of this is that small-signal frequency oscillations cannot be observed (only when they exhibit raised amplitude can they be detected).

Further to these specific areas, it was suggested that more regular and disciplined communication on WAMS and Power System performance issues might be helpful, rather than a surge of action and information around the annual reports and workshops each winter

2.6 WMU and WAMS SAT

The WMU and WAMS server SAT was successfully completed at NGET, Wokingham on the 11th and 12th of May and at SPEN, Cambuslang (connected to Kirkintilloch) on the 14th and 15th of May. The SAT procedures were signed by respective PDT members from NGET and SPEN and are available for review.

The WMU and WAMS SAT is an important milestone in VISOR project delivery as it proves the technology readiness level of the hardware and software procured for implementing GB WAMS system and mitigates the risk of time delays and financial impact on the project.

2.7 Knowledge Sharing and Stakeholder Engagement

The VISOR Team has a strong commitment in knowledge sharing and effective stakeholder engagement. This is 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.

During the project period, the PDT have presented the VISOR project updates and learning at the following events:

1. Presentation at IET Preparing for the Grid of the Future Event, Birmingham, 21st April 2015
   http://www.theiet.org/events/2015/215421.cfm
   https://tv.theiet.org/?videoid=6753
2. All Energy Conference, Glasgow, 7th May, 2015
   http://www.all-energy.co.uk/
3. Presentation at IET Synthetic Inertia Breakfast Event, Birmingham, 14th May, 2015
   http://www.theiet.org/events/2015/217904.cfm
4. Presentation at 1st International Symposium on Smart Grid Methods, Tools and Technologies, Jinan, 18th – 20th May 2015
   http://idclab.sdu.edu.cn/sgmtt/

In the forthcoming period, the PDT have confirmed slots to provide VISOR project updates and learning at the following events:

1. Paper and Presentation at PAC World Glasgow, 29th June – 2nd July 2015
   http://conference.pacw.org/
2. Presentation at IEEE General Meeting, Denver, 26th – 30th July 2015
   http://www.pes-gm.org/2015/
3. Paper and Presentation at APAP Conference, Nanjing, 20th -26th Sept 2015
4. Paper and Presentation at Cigre Study Colloquium B5, Nanjing, 20th 26th Sept 2015
   http://www.cigre-scb5-nanjing2015.com/registration.php
5. Journal Paper describing VISOR in Special Issue of Modern Power Systems and Clean Energy (MPCE) – http://www.mpce.info/ch/index.aspx
6. SGTech Europe Smart Grid conference, , Amsterdam, 22nd – 24th Sept, 2015
   http://www.sgtech-europe.com/
7. LCNI Conference 2015, Liverpool, 24 – 26/11
   http://www.lcniconference.org/

8. Cigre 2016 , VISOR and SMART Frequency Control projects http://www.cigre.org/Events/Session/Session-2016

Further ahead, the following tasks are targeted to produce knowledge dissemination of the VISOR project updates to the wider audience:

1. Submit Paper for IEEE General Meeting 2016
2. Submit Journal Paper on Laboratory Testing of Synchronised Measurement Device Performance
3. Submit Journal Paper on Line Parameter Estimation
4. Organise Stakeholder Engagement Event, Aug-Sept 2015

2.8 Outlook to the Next Reporting Period

The milestones set for next reporting period in VISOR project direction are as follows:

9.4.1 Display incorporating power, angle and associated thresholds (WP 3.3, Dec 2015)

VISOR PDT has successfully defined the B6 boundary display specification outlining the requirement and details of display to be developed as a part of the project delivery incorporating power, angle and associated thresholds. A prototype of the live and historical display is shown in Figure 5. The current progress in developing this specification is indicative of the project being on track to deliver this milestone on time.

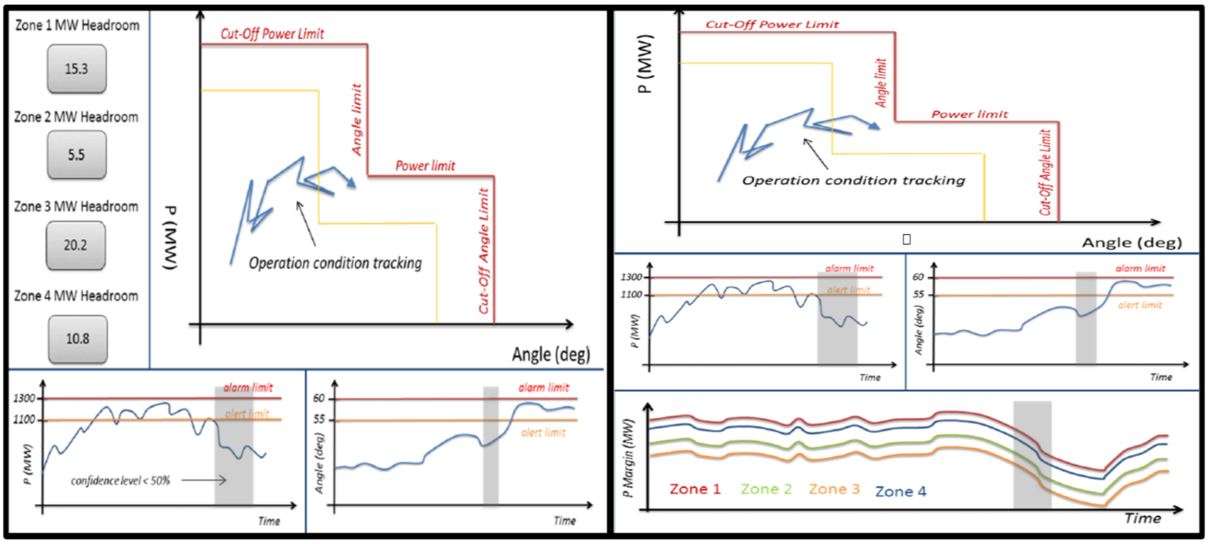

Figure 5 Live and Historical Display

9.5.1 System commissioning report (WP 4A, Dec 2015)

The system commissioning of WMUs, WAMS server and communication links has generated significant learning regarding processes, risks and challenges involved in large scale installations like that in project VISOR. The interaction of the innovation and project delivery team with the business planning, procurement and operations team is particularly of interest and needs to evaluate for future innovation projects. The key challenge during commissioning is communication and understanding of the system requirements between key parties involved. The time scale of innovation projects and the nature of services required needs to be better understood and appreciated. The VISOR commissioning report will capture all aspects of engineering involved, aforementioned challenges and give an insight into VISOR PDT's planning and risk mitigation strategies for successful project delivery.

9.5.1 Visualisation of data in SPT, NGET, SHE Transmission including real-time and historic (WP 4A, Dec 2015)

This milestone has been partially achieved by visualisation of real time and historic data at SPT and NGET. SSE is still to achieve this milestone; however current progress is indicative of this milestone to be completed on time.

9.6.1 Presentations and show-casing at the annual innovation conferences (WP 5.4, Dec 2015)

Project VISOR will be presented under network resilience and network performance category at the annual LCNI conference to be held at Liverpool from the 24th – 26th of November'2015.

In addition to achieving the above mentioned milestones VISOR PDT also plans to concentrate its efforts on working on various action items generated from VISOR workshop and system report to improve the quality of real-time monitoring data (PMUs) in GB and thus improve quality of learning generated through this project.
Additional sites have also been identified by NGET (Grain) where SSO is a potential issue due to interactions when operating HVDC links adjacent to wind-farms and thermal plant. Although not initially planned in project VISOR, monitoring of Grain will represent the importance of WAMS in GB and generate qualitative knowledge for GB SO, using this enhanced capability, this will provide reference data against which we can compare monitored results from B6.

- Top Tail Engagement, Southampton, 17-18th Nov

3 Consistency with full submission

Eighteen months into the project delivery, VISOR has been consistent with the original full submission with regards to resources allocation, project management and project programme.

These consistencies demonstrate the level of detail of the original submission, robust project management currently in place and set a solid foundation for the future delivery.

4 Risk Management [Confidential]

5 Successful Delivery Reward Criteria (SDRC)

The Successful Delivery Reward Criteria set out in the Project Direction links with the Project Milestone 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. **Error! Reference source not found.** lists all the required evidences in line with VISOR project direction for reporting period Dec'14 – June'15.

Successful Delivery Reward criterion	Evidence
9.1. Successful delivery of Sub-Synchrononous 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	9.1.1 • 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)
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)

Table 3. VISOR SDRC Update, Dec'15 June'15

The following SDRC elements have been achieved during the reporting period:

SDRC 9.1.1

- *Baseline and comparator report for SSO behaviour (WP 1, March 2015)*

Successfully achieved described in section System Report and VISOR Workshop

- *Visualisation of multiple SSO information sources at data centre (WP 1A, prior to the commissioning of series compensation reinforcement)*

Successfully achieved described in section Waveform Measurement Unit and Server Installation

Both elements in 9.1.1 demonstrated the expectation the major part of VISOR hardware system have been tested, approved and functional by June 2015.

SDRC 9.3.1

- *Report on PMU based line parameter estimation and variability (WP 2.1, March 2015)*

Successfully achieved described in section Report on PMU based line parameter estimation and variability (WP 2.1, March 2015

The element of 9.3.1 is the first milestone of enhanced software function successfully demonstrated in March 2015. Project VISOR project is in a challenging software development period from March 2015 to June 2016. It is our aim to outperform all our successful delivery criteria and generate useful and leading innovative outcomes to be disseminated to our stakeholders and published for future research and development.

6 Learning Outcomes

Following the Authority formal approval in December 2013, VISOR made good progresses 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.

6.1 Project Management

Lessons Learnt (+/-)	Lesson Learnt	Recommended Action
Positive	Installed all dependant monitoring equipment's as early as possible by flexible use of existing outages	Future projects could coordinate with such planned outages by early engagement with planner/installers
Positive	Flexible scheduling of customer events, e.g. FATs, SATs and workshops, helped with mitigating impacts of installation delays and ensuring maximum usefulness of events and reports.	Future projects should focus on early hardware and software testing and engage in a continuous improvement process through constant evaluation of results.
Negative	Engagement of procurement team much earlier into the delivery and having a assigned resource from that team	Earlier engagement of procurement SPOC (preferably during Start-Up) and request for an assigned resource who would own this project from procurement team
Negative	Need for greater emphasis on IS Infrastructure on System monitoring projects	Early engagement from all IS Partners from all involved parties to arrive at realistic estimates for the project
Negative	Early 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 early in project delivery and specification stage to avoid potential risks and delays.
Negative	Activity Internal resource is difficult to secure and subject to business change/prioritisation. Lessons Learned – try to seconde resource onto the project rather than keeping them in their original post – need to back fill, although this is difficult where "Smartgrid skills" are required	Innovation activities need to be better co-ordinated with business activities for seamless project delivery.

6.2 Technical Learning

6.2.1 System Commissioning Learning

The ambitious engineering target set in VISOR requires innovative and coordinated approach. From the hardware development perspective, the initial tendering procedure during the proposal stage (back in 2013 and Feb 2014) introduced the topic to the market. The project team was informed the potential suppliers and identified the data acquisition frequency range. Detailed functional specifications were included in the contract.

The specifications post contract award has been governed by a robust technical review procedure. By the end of 2014, the following specifications to enable the detection of SSO have been approved:

Enhancement Specification:	200Hz IEEE C37.118 stream processing
Application Specification:	Sub-Synchronous Oscillations

Communication infrastructure between outstation device and the local data hub (within each TO) and between the TOs (including GBSO) is the key enabler of the VISOR demonstration. The Wide Area Network for the communication between the SPT Hub, the SHE Hub and the VISOR Data Hub will be supported by National Grid through its share of the NIC funding.

In order to support the data transfer rate between the SPT, and SHE T WAMS and the NG WAMS Data Hub, there will be a 2Mbps non redundant MPLS link between NG and each of the Scottish TOs. This should provide the bandwidth required to support the needs of the project.

An IPSec tunnel over the internet was initially considered, but it has been concluded that this would not be reliable enough or support sufficient bandwidth to guarantee reliable data transfer. OPTEL services have also been considered for this project, but don't currently support connections. Therefore the project intends to use Verizon as the WAN supplier between Wokingham and Kirkintilloch, and Inveralmond House.

6.2.2 WAMS Based Alarming on the Proximity of Electrical and Torsional Modes

The University of Manchester has been using model based studies to perform research into the development of WAMS based tools for assessing the likelihood of a system being exposed to dangerous subsynchronous interactions (e.g. SSR). During this research it has been found that some of the traditional measures used to determine if there is a risk of these dangerous interactions occurring are unsuitable for use as part of a WAMS based strategy for assessing the threat posed by subsynchronous interactions. This is primarily due to the contrast between the requirements of a WAMS based strategy and the planning/design based solutions traditionally used to mitigate subsynchronous interactions. For example, when assessing the potential threat of SSR (interaction between an electrical RLC mode complement and a torsional mode) when deploying series compensation in a power system, the literature states that if frequency scan results indicate a reactance dip (an indicator of an electrical RLC mode) within +/- 3 Hz of a known torsional mode further studies should be performed. This approach, whilst well suited to guiding the necessary planning studies is far too conservative to apply as part of a WAMS based solution, e.g. it has been observed to result in an electrical RLC mode being classed as interacting with multiple torsional modes simultaneously. EMTP simulations include models of the entire non-linear system, so do not make the same assumptions as the simplified tools used to guide planning studies. As such, they can be used to precisely define bands around a torsional mode in which electrical mode complements would pose a threat and based on this create WAMS based alarms. However, the increased computational requirements mean that it is not possible to run EMTP simulations for large systems so new solutions must be explored.

Furthermore, it has been identified that the susceptibility of Subsynchronous interactions for any generator with series capacitors, apart from being dependant on the electrical and mechanical mode proximity, is also a function of the negative damping of the electrical system for a given torsional mode. This is important as for any exchange of energy between the mechanical and electrical system to be sustained the damping of the torsional modes need to be poor, this damping is usually found by comparing the mechanical and electrical damping of any given mode. Mechanical damping is usually provided by the generator manufacture and this is usually provided in the form of mode damping. However, for SSR studies both mechanical mode damping and electrical mode damping are required. Therefore, the modal inertias and frequencies must be estimated for each torsional mode to allow the corresponding electrical damping to be estimated. However, mechanical mode damping and the modal frequencies are seldom known accurately, unless the machine is tested directly. Most manufactures can provide only an estimate of the machine modal damping for each subsynchronous mode and a close approximation of the modal frequencies. In the absence of direct testing this uncertainty in the modal frequency can be accommodated by calculating the negative damping for a frequency range around the estimated modal frequency.

6.2.3 Limitations of Existing Software Tools for Sub-Synchronous Oscillation Studies

The predominant analytical techniques reported in the literature for the study of SSR are Frequency scan, Eigenvalue analysis and EMTP simulations. DIgSILENT PowerFactory has shown limitations in both Frequency Scan and Modal analysis. Modal analysis results for a given scenario have been observed to differ grossly from the EMTP simulation results, such that the applicability of the Modal analysis application within DIgSILENT PowerFactory has deemed unsuitable for the SSR studies performed within VISOR and for the estimation of mode damping. To overcome this modal analysis could be performed by using EMTP simulation to initialize the system model and then perform the necessary eigen analysis in Matlab. However, the computational requirements of this process will mean that it will prove to be unsuitable for the study of systems with more than approximately 10 to 20 buses.

6.2.4 Necessity for Base Lining PMU performance

When performing the initial laboratory testing, it became increasingly apparent that the response of each PMU was highly specific and the lessons learned for one PMU could not be readily transferred to another, despite the existence of standards on the measurement performance of PMUs. Therefore, in the absence of proper base lining of the devices for constructed signals, any trends perceived or conclusions drawn based on complex, dynamic (oscillatory) test signals from the VISOR WAMS could be misleading. Consequently, tests corresponding to the 'Dynamic compliance standards' as provided by IEEE C37.118.1a-2014 and further tests tailored to the needs of monitoring power system oscillations would help baseline each devices performance against small signals which would help improve the generalization of device performances/capabilities. These tests will be undertaken before further device performance evaluations and will form part of an attempt to characterise the response of each PMU in terms of the filtering applied. For example, the PMUs in the laboratory that are P-class should be better at detecting the oscillations or transients than their M-class counterparts; however, the filters used may distort the subsynchronous waveform and require post-processing to identify the true oscillatory modes within the signal. Therefore, it has become clear that when deploying any WAMS applications it is important to understand the PMU performance it will require, the extent to which the PMUs in the system can provide this and if any compensation of the PMU data will be required.

6.2.5 Hybrid State Estimation

The Hybrid State Estimation (HSE) work package within VISOR was intended to study the benefits of combining phasor data (a direct measurement of the state of the monitored bus, voltage magnitude and phase) and existing SCADA data (Voltage magnitudes and power injections/flows) to form a hybrid state estimator that can improve the accuracy of the state estimate, the speed that the iterative estimator converges a solution and the stability/reliability of this convergence. After conversations within the project delivery team it was decided that using a hybrid state estimator to improve the stability of convergence would offer the most benefit, as it would reduce the likelihood of no state estimate being available to the system operator. Therefore, the study of HSE will be limited to integrated HSEs (which combine the phasor and SCADA data into a single calculation). The other forms of HSE proposed in the literature were deemed unsuitable either because they could not improve the stability of convergence or because they had requirements that were not consistent with the goal of the VISOR project to demonstrate WAMS applications that can be of benefit to the GB system today.

Furthermore, whilst disseminating knowledge from the VISOR project at an international conference, conversations with researchers, outside of the VISOR project, revealed that opportunities exist to use phasor measurements to improve the performance of state estimation without replacing the existing state estimator with a hybrid state estimator. The study of this use of phasor data for pre-processing is now being considered by the researchers delivering the Hybrid State Estimation work package, as it may offer opportunities for WAMS to play a role in improving the performance of state estimation in the near term.

6.2.6 Potential Synergy with the NIC Funded EFCC project

The NIC funded EFCC project will address the use of WAMS based, closed loop control to deliver fast, coordinated frequency control from various new service providers (e.g. battery storage), or smart frequency control, to overcome the challenges posed by the anticipated reduction and variability in system inertia. Researchers from The University of Manchester are involved in both VISOR and EFCC and it is important that the lessons learned are shared between projects to help maximise the benefit offered by these projects. For example, EFCC will consider the WAMS requirements for wide area, closed loop control and the knowledge generated within that work could help inform the WAMS testing (end to end and device testing) performed within VISOR or the roll out recommendations made in the VISOR close down report.

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 SPTL 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.

9 Intellectual Property Rights (IPR) [CONFIDENTIAL]

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10 Other

N/A

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): ________James Yu___________

Title: ________Future Networks Manager___________

Date: _________24/06/2015__________

Signature: ____________________

Name (Print): ______Priyanka Mohapatra_____________

Title: _______Senior Project Manager____________

Date: _______24/06/2015____________

11.1 Appendix 1 Project Risk Register [CONFIDENTIAL]

11.1.1 Active Risks

11.1.2 Closed Risks

11.2 Appendix 2 Bank Account Statement [CONFIDENTIAL]