Project Code/Version No: SPTEN01/V1

Electricity Network Innovation Competition Full Submission Pro-forma

Section 1: Project Summary

1.1 Project Title:

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

1.2 Funding Licensee:

Scottish Power Transmission Ltd (SPT)

1.3 Project Summary: (A Glossary of abbreviations is in Appendix A16)

The three GB transmission owners are tasked under their licence and the System Operator Transmission Owner Code (STC) to develop an efficient, coordinated and economic transmission system. This obligation sits in a background of challenging renewable generation targets that have triggered significant transmission infrastructure reinforcements. The drive on sustainable development has led to the application of new technologies such as HVDC links and Series Compensation to avoid where possible the construction of new circuits.

The safe and secure integration of these technologies requires exhaustive system design studies. However experience tells us that it is not possible, let alone economic to design a power system that is guaranteed free from unforeseen and potentially damaging events.

In network planning time-scales the determination of network capability and hence the need for generation constraints, is based on the application of Security Standards to network models with prudent assumptions regarding generation and network backgrounds. The Wide Area Monitoring (WAM) system proposed for development and trial in **VISOR** will provide a new insight to the capability and dynamic performance of the transmission system in both planning and operational time-scales.

The VISOR project is proposing new Phasor Measurement Units (PMU) deployment and innovative applications for using phasor data to understand and analyse real-time dynamics of the transmission network. The VISOR trial will demonstrate a potentially **avoided investment benefit of £45m for every 100MW** capacity realised. It will provide the system operator with the ability and confidence to utilise the full capacity of the network where increasing volumes of wind generation lead to more volatile system flows, resulting in greater operating margins to maintain and manage network security. A conservative estimate of **operational savings is £4m per annum**. The WAM system will also provide transmission network owners with a risk-mitigating measure in a period of uncertainty to help safeguard the network against low-probability high-impact events that may result in partial or widespread system failure. An estimate of the financial impact of a GB wide black-out is in the order of £30bn.

The project duration is 40 months and will commence as soon as funding is provided with the issue of an Invitation to Tender.

1.4 Funding

1.4.2 NIC Funding Request (£k): £6,493

1.4.3 Network Licensee Contribution (£k): £737

1.4.4 External Funding - excluding from NICs/LCNF (£k): n/a

1.4.5 Total Project cost (£k): £7,370

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Section 1: Project Summary continued

1.5 Cross industry ventures: If your Project is one part of a wider cross industry venture please complete the following section. A cross industry venture consists of two or more Projects which are interlinked with one Project requesting funding from the Electricity Network Innovation Competition (NIC) and the other Project(s) applying for funding from the Gas NIC and/or Low Carbon Networks (LCN) Fund.

1.5.1 Funding requested from the LCN Fund or Gas NIC (£k, please state which other competition): n/a

1.5.2 Please confirm if the Electricity NIC Project could proceed in absence of funding being awarded for the LCN Fund or Gas NIC Project: n/a

☐ **YES – the Project would proceed in the absence of funding for the interlinked Project**

☐ **NO – the Project would not proceed in the absence of funding for the interlinked Project**

1.6 List of Project Partners, External Funders and Project Supporters:

Project Partners

National Grid Electricity Transmission plc	(in-kind support, £62k)
Scottish Hydro Electric Transmission Ltd	(in-kind support, £62k)
The University of Manchester	(in-kind support, £150k)

Project Supporters

Scottish Executive, Réseau de transport d'électricité (RTE), Electric Power Research Institute (EPRI), European Network of Transmission System Operators for Electricity (ENTSO-E), Pan-European Grid Advanced Simulation and State Estimation (PEGASE), Université Libre de Bruxelles, École Polytechnique Fédérale de Lausanne (EPFL), RenewableUK, Scottish Renewables, Hub-Net (Academic Consortium).

1.7 Timescale

1.7.1 Project Start Date:	**1.7.2 Project End Date:**
December 2013	March 2017

1.8 Project Manager Contact Details

1.8.1 Contact Name & Job Title: James Yu Transmission Innovation Lead, SPEN	**1.8.3 Contact Address:** Network Development, Ochil House, Hamilton International Park, Blantyre, G72 OHT
1.8.2 Email & Telephone Number: James.Yu@scottishpower.com 07872 330 964	

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Section 2: Project Description

This section should be between 8 and 10 pages.

VISOR: A Trail-blazing trial to pave the way for smarter transmission networks monitoring and control.

2.1 Introduction

The transmission and generation sector in GB is undergoing an unprecedented level of technological change which is presenting the existing methods and solutions with challenges that they were not developed to cope with. The recent experience of the Series Compensation project on the Anglo-Scot interconnector capacity upgrade drove home the need to approach these new problems in a different direction.

Scottish Power Transmission (SPT) as a Transmission Network Owner has the requirement to ensure that transmission network investment is undertaken in an efficient and coordinated manner in order to ensure a robust and secure network for GB consumers.

As a part of this role, SPT has identified a number of new circumstances (e.g. large scale wind farms interactions with series compensation devices) that if not addressed may lead to a reduction in the ability to plan suitable investment in a timely and efficient manner. As such, it was considered timely and essential to trial new technology and approaches to gain better understanding and visibility of the existing and future transmission network. This requirement has led to the Visualisation of Real Time System Dynamics using Enhanced Monitoring (VISOR) project.

Fundamentally, the nature of the system is changing, therefore we need to change the way that we observe and control it.

The scope of VISOR outlined in this Full Submission pro-forma is consistent with, and not materially different from, that approved by the NIC Initial Screening process.

2.2 Aims and Objectives

Problems to be Resolved

The Status Quo of monitoring the GB transmission system is based on unsynchronised measurements that are collected from the various substations across the country and displayed in the control room SCADA systems. This has been broadly sufficient in the past, and represents the international benchmark standard for transmission network owner practice.

However, major international events in the last 10 years such as the black-outs in Eastern US/Canada, California, Italy, and India have highlighted the limitations in this approach in an environment with new faster acting technologies, and networks being pushed harder than previously. A prudent network owner and operator will only push the network to the visible limit that they have confidence in, however the international consensus is that a new generation of monitoring and control is required. This should include time-stamped synchronised measurements with greater visibility of dynamic behaviour and sub-synchronous oscillations, with easy data recall and analysis capability.

In the GB transmission network, the primary and most costly network constraint is the B6 or Cheviot boundary between Scotland and England (Figure 2 - 1) although now other boundaries are becoming increasingly constrained as well. This boundary is now constrained about 50% of the time and the operational cost of the constraint is currently running between £80m and £130m per year.

This large operational cost for this boundary is being progressively addressed through the bootstrap HVDC and series capacitors and this project is intended to be a complementary wider solution. While the boundary reinforcements are themselves very valuable for enabling renewable generation on the GB system, they do introduce a number of additional complexity that needs to be managed in future network investment and operation.

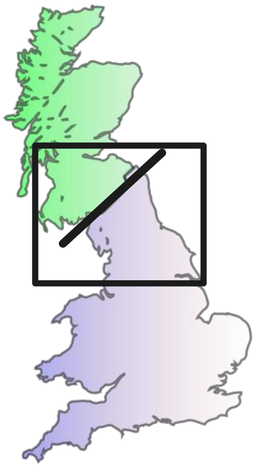

Figure 2 - 1: B6 Boundary (area of interest)

The introduction of series compensation introduces the risk of Sub-Synchronous Oscillation (SSO), a class of problems relating to interaction between network equipment and generation plant. This can result in plant damage and network outage, if not addressed.

At present there is *very limited* visibility of SSO within the GB system. Existing observations are geographically sparse and limited to a maximum frequency of 10Hz. This does not cover all potentially important risks, as SSO interactions may occur in many locations and over a broad frequency range. There is evidence to suggest that with the deployment of new technology, modes up to 45Hz may become significant, however the infrastructure requirements and ability to detect source locations are not well established.

Simulation tools are a key part of the system planner's approach to assessing and ensuring that the system remains robust and secure. However there are a number of limitations with these tools both in terms of the *accuracy of the underlying mathematical models*, as well as the *certainty of the data within them*, and critically, *the number of permutations in network configuration* that can be studied within a reasonable time during network planning. The increasing influence of volatile power injection from wind generation on the network introduces new uncertainty in planning and operation. As it is not possible to guarantee that all eventualities have been uncovered (known-unknowns and unknown-unknowns), it is pragmatic to consider other ways in which the new risks presented to the system can be managed.

It is important for the on-going security of supply and development of the low carbon economy, that risks are identified and managed at an early stage. If there is no facility to observe early warnings, there is a risk that problems are only identified through the occurrence of events involving significant network disturbance and outage, or equipment damage. This outcome would be a serious setback and delay in commissioning and operating renewable energy resources, and would impact public confidence.

2.3 Methods being trialled to solve the problem

There are two methods proposed as part of VISOR to enable the transmission network owners and system operator to maintain efficient network investment and constraint minimisation, while managing risks arising from new technologies being added to the transmission network and major changes associated with the shift in generation portfolio to renewable resources. The two methods VISOR seeks to trial are as follows; with the focus on reducing cost to the consumer through increased system efficiency and lower network investment:

- **Better Understanding** – this will improve the characterisation of the transmission network and thus reduce model and measurement uncertainty that currently requires higher operational safety margins to be applied.
- **Better Visualisation** – this will provide control room operators and network planners with increased visibility and diagnostics of network operation and post-event diagnosis and recovery. It will also reduce the uncertainty in real-time of the network state to allow the network to be run closer to the true physical limits.

2.4 Solutions enabled by VISOR

The trials and analysis within this project will provide the experience, knowledge base as well as appropriate equipment/infrastructure to enable the appropriate and cost effective deployment of the next generation control and monitoring systems for the GB transmission network owners and operator. The premise is that control-room monitoring based on PMU, SSO and WAM technology, with associated data storage and analysis capability, will provide the necessary capability required for the Methods and to deliver the Solution.

Through the demonstration and the associated studies of VISOR, the TO/TSO will be able to judge the tools and practices that would be of value for operation and analysis of the system. This will lead to the development of the necessary robust business cases for efficient and coordinate network investment using this new knowledge in the subsequent roll-out as a normal business function.

An important outcome of the project is to define an approach for specifying functionality, penetration and location of monitoring that provides the necessary visibility of the power system.

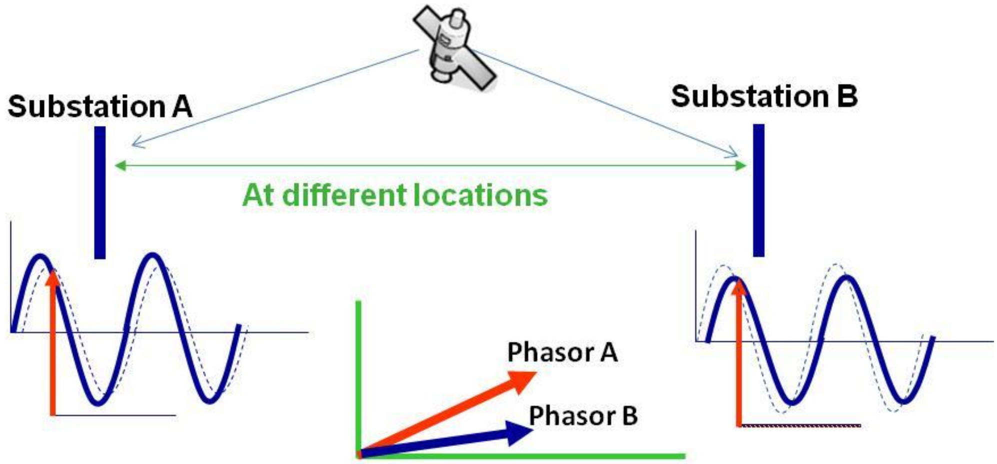

Figure 2 - 2: Synchronised Measurement Technology

By synchronizing the sampling processes for voltage/current measurement - which may be hundreds of miles apart (Figure 2 - 2), their phasors can be put on the same phasor-diagram and used in a single application. Without the time synchronisation, the phase angles would be meaningless.

2.5 Technical Description of project

To enable solutions to the problems, the project has developed five specific work packages. The first focuses on developing improved observation and diagnosis of oscillatory behaviour of the transmission system, the second is on quantifying the uncertainty with the existing simulation models, the third outlines provision of incremental capacity enhancement through improved modelling and visualisation, the fourth is the deployment of the trial hardware, and the final work package is to manage the knowledge capture and dissemination.

The following is a more technical description of the key points of the specific work packages of this project including key objectives and innovation elements. Further details of the technical packages are provided in Appendix A3.

WP1 Enhanced System Oscillation Monitoring

The GB system has known oscillatory modes that have been observed and subsequently managed in the past, the most notable of which is the Scotland-England 0.5Hz mode as shown in Figure 2 - 3. This is a steady-state oscillation that develops between the conventional generators in Scotland and those in northern England. This was subsequently rectified by the introduction of Power System Stabilisers (PSS) onto the large generators involved in the oscillations.

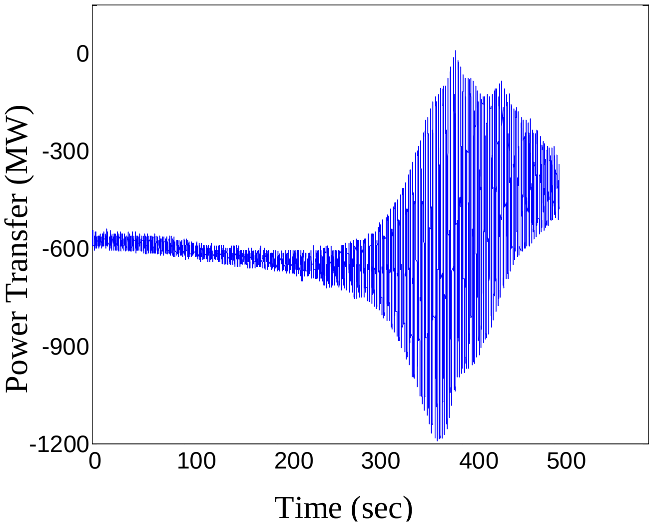

Figure 2 - 3: Example of Unstable 0.5Hz Oscillations in Scotland-England Transfer, 1982

However, the structure and technology of the GB network is changing extensively and there is the need to introduce a much more detailed observation and management facility to identify new risks to the system operations and asset integrity at an early stage. These new issues (such as the 2011 example of instability in Appendix A3) are not always well known and so the exhaustive preventative studies are not always possible or practical.

These factors lead to a new environment in which asset owners and operators must work together to create a common visibility of the system that enables both operational oversight and asset supervision. This in turn allows trade-off in network investment design decisions against operational risk management safeguards such as increased observability of the system and real-time detection of abnormalities.

As well as the operational visibility of the risk issues, there is also a value in historic review of the trends. The recorded information will be used for data mining to extract emerging risks, and assist in prioritising risk mitigation strategies.

Project Description continued

WP1 – Key Objectives

The key issues addressed in this work package include:

- **Sub-Synchronous Oscillation** management, observing and characterising the wide-area performance of the grid and identifying early warning signs of SSO. The focus of the work in the VISOR project is the known risk of interaction between natural frequencies of series capacitors and long-shaft generators (classical Sub-Synchronous Resonance, SSR), as well as the other newer forms of SSO involving control system interactions with HVDC and wind farm controllers.
- **Oscillation Analysis & Source Location** to baseline the dynamic performance of the grid, identify occurrence of early warnings as well as instability, and determine the locations of equipment that are degrading the stability of the system.

WP1 - Innovation

- Sub-synchronous oscillation has been dealt with so far from local observation. There is no monitoring of SSO that provides an immediate wide-area view of where the oscillations occur. Also, existing SSO mitigation is considered as a digital trigger. The innovation provides a continuous view differentiating normal and abnormal behaviour, and can provide an early warning indication of a less severe condition that may be a precursor to large-scale instability.
- Oscillation *detection* has been used for a long time in the UK, but not source location. Without source location, the wrong decisions can be made that incur a cost but do not effectively address the problem. The source location method proposed is only feasible with WAMS measurements, and has only been applied to date as consultancy studies carried out on historic data. This project will make source location available to the utility personnel in real-time and in the analysis domain.

WP2 System Model Validation

The power system simulation model underpins all aspects of transmission network planning and system operation, hence the importance of the need for secure assumptions in the component models and their associated parameters.

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. Any problems that may affect the validity of the conclusions drawn from it should be identified and rectified promptly.

Modelling is by nature a simplification of the actual behaviour of the system. Most power system models are therefore applied in such a way that the model-based representation is generally conservative compared with the actual system behaviour so as to provide implicit safety margins, to which operators generally also apply explicit safety margins when interpreting results. The challenge therefore is to achieve the appropriate minimum level of safety margin for the techno-economic trade-off of risk versus security. At present, the B6 boundary has an operational safety margin applied to the calculated technical transient stability limit that varies between 100MW and 500MW depending on the operating state of the network and generation mix.

The synchrophasor measurements proposed to be trialled in this project are a key enabling technology for power system model validation for a number of reasons:

- It provides continuous visibility of the dynamic response of the system, which can be directly compared with simulated behaviour

- It provides identification of locations where plants are degrading the stability of oscillations, often an indication of a deviation of the plant from modelled behaviour
- Since the data is wide-area and time-synchronised, it is very valuable for post-event reconstruction, and simulations reconstructing the event can be validated.

WP2 – Key Objectives

The applications to be trialled in this work package relate to modelling that influences the B6 boundary, but can also be applied more generally to the quality of static and dynamic models and other boundaries. The components of model validation to be addressed include:

- **Line parameter estimation** where parameters derived from measurements are compared with the values used in the network model. The variability due to weather, network loading and other effects is characterised. Conductor sag on long transmission lines may have a material effect on transient stability simulations and so needs to be quantitatively assessed.
- **Oscillation analysis validation** where the frequency, damping, amplitude and mode shape is compared with the expectation. In cases where there is a degradation of oscillation damping, the source location can identify where there is a suspected deviation from the model of the network, generator or HVDC link.
- **Transient stability simulations** for reconstruction of disturbances can be compared with records of measured wide-area disturbances to qualitatively assess the accuracy of the full system simulations.
- **Generator model validation:** where naturally occurring disturbances and control set-point changes are captured and used with synchronised generator and wide-area monitoring to identify deviations and improve generator and control system modelling.

WP2 - Innovation

- Line parameter estimation has been carried out with phasor measurements before, but the proposed approach provides improved accuracy through reduction in error sensitivity. This will improve model accuracy and therefore confidence in the use of the calculated transient stability limits.
- Oscillation analysis validation using continuous dynamic analysis of phasor measurements is not standard practice in the GB system. Furthermore, the use of the phasor-based source location techniques for damping contributions has not been used by any utility worldwide.
- Generator model validation conventionally uses mainly local measurements of invasive tests. Model tuning by non-invasive methods, capturing the plant-system interaction, is innovative.

WP3 Improvements for management of stability constraints

The transient stability limit of a boundary is <u>the limit at which a critical fault results in generation acceleration leading to loss of synchronism</u>. Transient stability can limit the power flow capability of some boundaries to less than the thermal capacity of the transmission circuits, thus reducing the efficient utilisation of these assets. The limit is assessed using computer simulation models based on the expected network configuration, critical outages, forecast loading, inertia, generation characteristics, and generation scenarios. Transient instability is a critical system issue that **must be avoided** as it may result in generation disconnections, network separation, blackouts, or serious equipment damage.

Transient stability is primarily an issue for synchronous generation connected through relatively long transmission lines. The B6 (Cheviot) boundary between Scotland and England is a clear example of this issue. The Scotland-England transmission corridor is

Project Description continued

becoming significantly more complex as 1.5GW of non-synchronous wind generation connects into the corridor as the plant does not contribute to the system inertia. The wind generation decouples the MW boundary flow from the angle separation between synchronous generation clusters as well as increasing the volatility of the boundary flows. The <u>VISOR thesis is that direct measurement of system angles, as enabled by PMU technology, is a better and more reliable measure of transient instability risk</u> than MW flow at an arbitrary boundary.

At present, the technical stability limit is calculated using many runs of the complex and computationally intensive simulation model, and this is then further reduced by the application of an empirical operational safety margin. The operators have authority to use some discretion to increase the margin from 100MW up to circa 500MW when system conditions are volatile; typically when there is high wind.

This work package is focused on developing an increased understanding of the true boundary limit, and addressing the methodology for deriving and applying an appropriate safety margin. The work will investigate how PMU's and other advanced tools can help to manage the system uncertainty. This will provide an incremental benefit to the current and future safety margin.

Better understanding of the actual transient stability state of the network, and the true distance to instability, will allow network owners to utilise and plan asset investment to deliver more efficient and coordinate network investment. The alternative for the network owners is to significantly increase investment with new circuits or major damping equipment to manage this risk.

WP3 – Key Objectives

This work package aims to improve the understanding and visualisation (Figure 2 - 4) of the network stability limits for the system planners and operators by:

- **Understanding of uncertainty** – quantify the effect of model parameter variation and how the dynamic model validation in WP2 can improve confidence. Review transient measurement records to calibrate accuracy of the simulation model. Assess the influence of generation forecast accuracy on stability limits.
- **Improvement of model initial conditions** – trial the use of a hybrid state estimator that uses PMU data to improve reliability and accuracy of the solution. Test through on-line and off-line techniques to determine the benefit of this more sophisticated approach on the stability limit calculations. Hybrid state estimators have been shown in a USA trial to improve accuracy by between 0.5% and 2%.
- **Improved visualisation of stability limits for operators** – the ability of system operators to run a system at high levels of utilisation depends on the confidence they have in their monitoring data. The trial will test a power-angle representation of the boundary state based on weighted angle differences and contrasting against conventional power-flow representation. This will consult the system operators and owners to define approaches. The benefit to transmission network owners will allow the release of incremental capacity without requiring additional primary network investment. Such benefits will be further passed onto customers in the form of carbon reduction and reduced constraint costs, as detailed in Section 4.
- **Trial the reliability of area angle measurements** – Understand the system conditions that arise and cause angle movements across the boundary, identify any that could cause difficulty for deciding actions. Determine if the signals provide good visibility of disturbances and therefore can reliably provide the observability required for control of equipment such as HVDC links.

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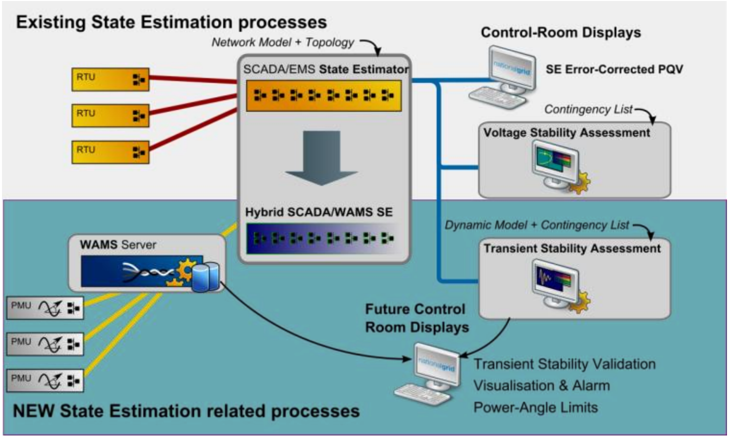

Figure 2 - 4: Proposed WAMS based Visualisation of Stability Limits

WP3 - Innovation

- Robust quantification of the appropriate transient stability safety margin under different system conditions
- Quantifying the benefit of WAMS and PMU on managing stability limit uncertainty including the effect of PMU data on State Estimator solution reliability
- New visualisation of power/angle operating point and stability limits for security and constraint management
- Understanding the feasibility and challenges of using the angle measurement approach for future control system design of HVDC links

WP4 Supporting Infrastructure

This work package provides the supporting infrastructure for the method work-streams, as well as developing an effective future roll-out strategy. The design of the WAMS supporting infrastructure is based as far as possible around the existing PMU equipment already installed to reduce the overall trial deployment costs.
The existing PMU systems deployed within the SPT and NGET networks only provide partial coverage and limited functionality. The SHE Transmission deployments are all new installations. The existing and new PMUs have been carefully selected to ensure good observability of the system and minimisation of the need for new installations – both to reduce trial cost as well as reduce programme risk. Two installations have been held as project contingency in the event of equipment failure, or if an additional location is required. The following table (Table 2.1) lists the new equipment installations required for VISOR. The map in Appendix A2 of the GB transmission system shows the locations of the existing and new PMU and SSO units that will be used in this project.
The measures obtained continuously over an extended period of time will naturally provide extensive statistical information. The distribution of disturbances will include relatively frequent low-impact disturbances, and the "normal behaviour" will be defined by the occurrence of these events. The central VISOR data concentrator will also have facilities for fast and easy extraction of data for post-event analysis and diagnosis to support the control room operator and network owners.

The supporting infrastructure of this project will also be assessed in terms of the availability and data quality over a three year period. During this time, performance statistics will be gathered, and assessed, dealing with system availability, PMU data availability and data quality issues such as loss of GPS synchronism. The data will also be reviewed for anomalous behaviour that seems inconsistent with power system behaviour, and any events will be checked for data validity to identify if these are artefacts of the measurements or are true power system events.

	New		Existing		WAM Data Concentrator
	PMU	SSO	PMU	SSO	
SPT	5	5	8	0	Existing
NGET	2	2	8	0	Existing
SHE Transmission	4	2	0	0	New
Reserve	2	2	0	0	---
VISOR	---	---	---	---	New

Table 2.1: PMU requirements for VISOR

Using experience gained in the demonstration, an optimal WAMS infrastructure will be defined for rolling out. Although it is expected that the longer-term central infrastructure will follow the same functional plan as in the VISOR project, the scaling of the infrastructure and applications may change. Also, aspects such as the high availability implementation will be considered and elements which need enhancing and security strengthening will be identified. An important part of the optimal WAMS architecture is the PMU placement. This will be studied for the applications considered in the VISOR project, and for other application areas that prove to be significant in the course of the project.

WP4 – Key Objectives

The project will also look at the performance of the power system in terms of baselining the performance over a long period of time so that known and unforeseen abnormalities can be more easily detected. This performance assessment includes:

- **Continuous analysis of oscillations** and retention of significant dynamic behaviour
- **Impact assessment of disturbances** over a long period of time, noting the statistical distribution of occurrences of events with varying impact
- **Data-Storage:** Providing the necessary data collection, storage and retrieval facilities to facilitate the other key work packages

WP4 - Innovation

- An integrated WAMS system with sharing between TO/TSOs has not been implemented within the GB system. The project will draw from international experience in developing an appropriate infrastructure.
- Data sources for Sub-Synchronous Oscillation management have not been integrated into WAMS systems; SSO has previously only ever been treated independently using local data sources.
- Optimal PMU/SSO placement for multiple criteria is not usual, and has never been done for the specific GB requirements.
- A novel approach to long-term performance baseline is proposed that has not previously been applied to WAMS measurements and derived analytics

A detailed Technical description of Work Packages 1 – 4 is included in Appendix A3.

WP5 Knowledge Dissemination

This work package provides a built-in measure in the project plan to ensure that learning generated from this trial project can be captured and delivered. The work package is composed of a number of related but discrete activities.

Knowledge dissemination within the transmission network owner is a key component to

Project Description continued

transfer experience for the pre-trial training and post–trial knowledge exchange. This is carried out in the form of a general WAMS technology workshop which will be organised at the beginning of the project to enable the start of the work package. Also there will be dedicated sessions on important topics such as equipment deployment and maintenance; Data Security; Software application skills; SSR issues and its impact on transmission planning.

The Visualisation of Real Time System Dynamics using Enhanced Monitoring (VISOR) proposal is the first of its kind to be delivered on an integrated GB transmission network. Therefore, it is important to ensure that efforts are not duplicated, even in other countries. European experts who are involved in a R&D project on similar topic, sponsored by FP7, have been consulted and this interaction will bridge the learning from a delivered project to VISOR. In addition, contacts with Electric Power Research Institute (EPRI), a USA research institute focused on electrical power sector) have been established, as EPRI has been involved actively in the R&D and project delivery in the USA under a government incentive scheme. The VISOR Academic partner will take on the responsibility of capturing real system knowledge and sharing this with wider community i.e. academic papers and industrial reports. Participation in IEEE and CIGRE committees and working groups will be valuable for sharing experiences.

As VISOR seeks to address issues associated with new power transmission development, there will be some parts in the existing policy or standards framework which will require assessment. VISOR has a duty to identify those issues and report to Ofgem ("the Authority"), to aid amendments which reflect the changing nature of the transmission network and technology.
An Annual Innovation Conference has been identified as the appropriate platform to inform the stakeholders of project progress, results generated, changes and knowledge garnered.
The most important part of Knowledge Dissemination, which may require a dedicated three-month-period, is the project close-down report and project evaluation. During this period, all relevant learning will be listed, compared, updated and evaluated in the presence of the Authority and any interested parties. The outcome will feed into a National Roll-Out plan.

WP5 – Key Objectives (details are included in Section 5 of Pro-Forma)

The key objectives of this work package are to successfully achieve the following:

- Internal Knowledge dissemination
- External Knowledge dissemination
- Influencing and updating policies and standards
- Public Engagement

WP5 - Innovation

- The project actively involves international advisers to contribute to the specification review and knowledge dissemination seeing as the VISOR proposal is innovative.
- The work package also has innovative arrangements with the academic partner, The University of Manchester, that VISOR can make full use of the existing equipment at the University, and the university will provide free laboratory accommodation as an enduring arrangement so that a tailor-made training course on a real closed-loop system can be carried out even after the RIIO-T1 period.
- Such a training course will be open for TO employees who are interested in the network operation, and could form part of a MSc course.

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Section 3: Project Business Case

This section should be between 3 and 6 pages.

3.1 Context

The GB transmission network is congested and facing challenges to network investment and operation due to changes in the generation mix and deployment of new technology including series compensation and High-Voltage Direct Current (HVDC).
Transmission network owners in GB have a licence requirement to ensure that transmission network investment is undertaken in an efficient, coordinated and economic manner in order to ensure a robust, secure and cost effective network for GB consumers. As a part of this role, Scottish Power Transmission has identified a number of new circumstances that if not addressed may lead to a reduction in the ability to plan suitable investment in a timely and efficient manner.

This project proposes development and deployment of a Wide Area Monitoring (WAM) system using existing and enhanced system monitoring as a means of optimising existing infrastructure, and alleviating constraint limits on flows between England and Scotland, particularly across Boundary 6.

The project-Methods are targeting Better Understanding and Better Visualisation of the transmission network with the following key business objectives:

- Efficient network investment, using measurement-based technologies to provide incremental capacity enhancement to existing physical plant
- Operational release of capacity through more precise and up-to-date knowledge of the true physical constraints of the system and the real-time stability headroom
- Enhancing oscillation observability and disturbance detection to allow the network to be operated closer to the real technical limits

These objectives support the wider business case of Scottish Power Transmission in deploying means for cost effective and rapid incremental capacity release in addition to larger reinforcements, while still maintaining a secure and robust transmission network.

3.2 Business-as-Usual Baseline

The GB transmission network is congested and is likely to remain congested for some time given the volume of wind generation connecting in the northern part of GB, and the infrastructure delivery programme required to accommodate the increased power flows. Presently, constraints are based on studies undertaken in advance using the most pessimistic system conditions e.g. wind, demand and network parameters. Therefore the results are conservative and there is an additional operational safety margin or "buffer" of 100MW applied as a minimum to the calculated technical stability limit.

The B6 (Cheviot) boundary between England and Scotland is now constrained for significant periods of time, and operational cost of this constraint is in excess of £100m per annum [1]. The current investment programme to provide incremental and major capacity upgrades on the B6 boundary comprise of the following:

- Series compensation project – Costs £160m, Releases 1100 MW – due 2015
- Western HVDC – Costs £1000m, Releases 2250 MW – due 2016

The series compensation project provides very good value for money in terms of capacity released, however this cannot be replicated across the B6 boundary. Therefore the incremental cost comparator is now the Western HVDC link for further upgrades.

[1] National Grid, May 2011, UK, Accessed 17th July 2013 *http://www.nationalgrid.com/NR/rdonlyres/1B6B81A0-7583-4EC0-B16D-A814E2100546/46801/BSIS_Outturn_Web_16May2011_Final.pdf*

Project Business Case continued

The residual uncertainty around the level of exposure to Sub-Synchronous Resonance (SSR) between the series compensation and generators has resulted in the need for exhaustive design studies to inform a complex equipment functional specification. It is impractical and uneconomic to study every conceivable extreme operating condition and failure mode, hence the need to ensure full monitoring visibility of potential adverse interactions should they arise.

3.3 The case for VISOR

3.3.1 Overview

The conventional solution when faced with transient stability limits or oscillatory stability problems is either to impose operational constraints on the network, or further network investment. Transient stability limits are generally resolved by reducing the network impedance between the synchronous areas through the use of series compensation or additional transmission lines across the boundary – these are both significant investments and long delivery options.

Oscillatory stability problems are less critical but still highly undesirable as they increase system risk due to the potential for equipment damage and rapidly changing power-flows. These are generally managed through prohibition of certain operating configurations, constraint of boundary flows, or further investment in physical network equipment that can create additional system damping such as power oscillation damping controllers (POD) on generators, HVDC links or Static VAR Compensators (SVCs) etc.

The ability to observe these oscillatory conditions is key to being able to manage them and then target any necessary investment in the most cost effective and efficient manner. This issue is further compounded by the introduction of new, faster and more flexible technology such as HVDC systems and wind turbines, which create the risk of new oscillation modes that have not previously been a concern for the GB system.
The system-problems VISOR intends to address can be summarised as:

- Integration of new technologies with complex power electronics control systems may cause unforeseen adverse oscillatory interactions
- Need to improve system dynamic monitoring to cover SSR frequencies
- GB PMU coverage required for B6 observability improvement
- Disturbance location tool required
- Need to validate offline modelling tools using PMU data
- GB System Operator (GBSO) has no visibility of the real time stability/voltage limits and so the network needs to be run in a conservative manner

3.3.2 Case Studies

The following case studies show examples of how WAM based systems similar to those planned to be deployed in VISOR have been used to improve management of the transmission systems and helped inform effective network investment for incremental capacity release.

a) California Transmission Network

Electric Power Group (EPG) with the Consortium for Electric Reliability Technology Solutions (CERTS), has developed the California Independent System Operator (California ISO) Real-Time Dynamics Monitoring System (RTDMS). The application monitors and tracks phase-angles between generation and demand buses within the Western Interconnection, local and system frequencies and MW/MVAR flows calculated from Voltage and Current phasor measurements.

Project Business Case continued

b) Australian Transmission Network

The Australian Energy Market Operator (AEMO) has used real-time damping monitoring since the commissioning of the 600km Queensland-New South Wales Interconnector (QNI) in 2001, which was built to connect the previously asynchronous Queensland network and to ensure the interconnector-dynamics were stable.

Small-Signal Stability limits within three separate test-areas improved by 128MW (13.5%), 160MW (38%) and 200MW (12%) respectively, with damping monitoring.

Alarms were also installed so that if a particular mode was observed to be poorly damped, the constraint management system would revert to a more pessimistic value.

A new approach involving comparison of phase angles of oscillations was also developed to facilitate identification of relative damping contributions at different parts of the grid. This then allowed the system operator and network owner to take preventative actions and inform future network investment.

c) Icelandic Network

The Icelandic network (Figure 3 - 1) has a number of significant transient stability limitations. The system has two centres of inertia that are connected via weak transmission lines making the network susceptible to system separation events. In addition to this the grid has large load centres e.g. aluminium smelting facilities that are prone to trips during grid disturbances. Generally disturbances had resulted in angular instability occurring too quickly to be arrested by human response.

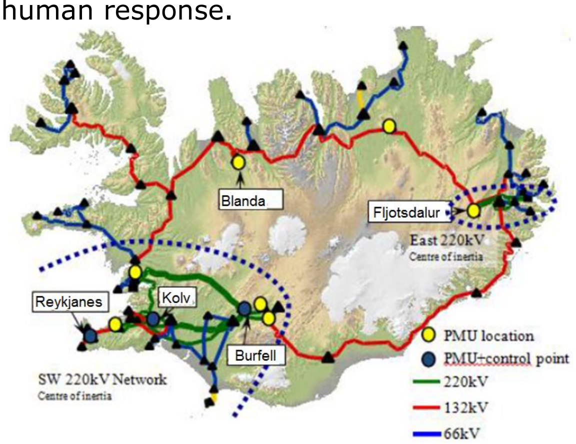

Figure 3 - 1: Icelandic Transmission Network [2]

Since the installation of PMUs in 2007, it has been possible to understand the underlying dynamic process and sequence of events that result in the separation. An automated system was implemented to prevent the propagation of disturbances and disconnections on the rest of the network. This automated system uses relative angular-movement, which is related to the network stress, as a trigger to prevent system separation. This phasor-based defence is a more direct, simpler, low impact solution compared to equivalent Special Protection Schemes.

Now in the event of a major disturbance, generating plants are tripped in a specific order until the south-west system is no longer accelerating with respect to the east, or until all possible generation has been tripped. These actions either fully arrest the system-separation or minimise its impact. This thereby reduces disruptions to domestic and industrial customers.

[2] Douglas H. Wilson, Natheer Al-Ashwal, Hallgrimur Halldorsson, Stephen Boroczky, *Discrete Control for Transient Stability and Oscillations: Applications and Case Studies,* IEEE Power and Energy Society, 2013 General Meeting, 2013

d) San Diego Gas and Electric Company

Research of modern Energy Management Systems with wide-area measurement started after the 1965 North East U.S. blackout. The network applications consisted of State Estimator (for the current state of the power system), Power Flow and Contingency analysis. The August 14 2003 blackout in the Eastern Interconnection affected 50 million people. Subsequently, wide-area visibility and situational awareness measures were recommended to enable detection and resolution of system problems before they spread.

- SDG&E was able to successfully integrate PMU measurements with SCADA readings for use in a State Estimator
- Phasor measurements were found to offer the greatest benefit when SCADA measurements were not reliable or unavailable as the State-Estimator gains from additional phasor measurements

These case studies illustrate that a system-health management tool which monitors angular instability and the development of generation de-loading order/hierarchy to arrest instability which could result in system-separation, would be applicable to B6 boundary too.

3.4 Net Financial Benefits of VISOR

There are a number of routes for financial benefit to be obtained, some of which are direct to Scottish Power (and the transmission customers indirectly), and others are wider to the GB consumer, either directly through network charges, or indirectly through balancing system costs. These are described in the following section although many are challenging to quantify explicitly. The value of the VISOR project to Scottish Power Transmission as a transmission (network) owner however comes from the following two key areas:

- Avoided investment cost through provision of incremental capacity
- Risk mitigation of unstable system oscillations

a) Avoided Investment Cost

The VISOR method provides the means to create incremental capacity on the existing system through the ability to reduce the existing safety margins through reduction of uncertainty and better understanding of the underlying transient stability limits.

The value of this to the transmission network owner is to contrast this against their other alternatives for creating the same incremental capacity using conventional reinforcement methods. The following table (Table 3.1) shows the cost of provision of incremental capacity across the B6 boundary compared to the VISOR scheme. This demonstrates that the VISOR scheme is very cost effective relative to the major reinforcements, and has an avoided cost value of **£45m for every 100MW** of capacity released.

B6 Scheme	Capital Cost	B6 Increment	£m/MW	£m/50MW (VISOR Equiv)
Series Compensation	£160m	+1100 MW	0.145	£7.25m
Western HVDC link	£1000m	+2250 MW	0.444	£22.2m
VISOR	£8m	> +50MW	0.160	£8.0m

Table 3.1: Avoided Investment Cost

b) Risk Mitigation

Risk mitigation is difficult to explicitly quantify as unforeseen unstable oscillatory events are classified at this stage as low-probability, high-impact events. An unstable oscillatory event that occurs without prior knowledge and in the absence of monitoring can result at the low-cost end in generation trips and boundary flow limitations, through to at the mid-range of major equipment damage in the form of major generator repairs, and at the high-end system separation and black-out.

A system wide blackout for the GB at system peak demand would be likely to take up to three days to recover from. This may even be optimistic in the event of equipment damage

Project Business Case continued

and depending on the root-cause. Based on the recent work (July 2013) done to establish the value of lost load for GB consumers by London Economics for Ofgem and DECC, economic impact to GB has been calculated to be in the order of **£30bn**. This is based on a peak demand of 50GW, 50% load-factor, 3 day duration, and the reported weighted average Value of Lost Load (VoLL) of £16,940/MWh.

c) Industrial Reputation

A wide area monitoring protection and control system developed with synchronised PMUs will help improve grid reliability and reduce probability of blackouts. Utility stock price is affected by blackouts albeit temporarily [3], as the stock price is generally affected by 3 factors: expected profits, expected profit growth and perceived risk. Blackouts and the utilities' response to them could affect perceptions of risk and in turn, affect share price. Share price has a direct link to a utility business capitalisation, and therefore its ability to raise capital for investment on a cost effective basis. It must be pointed out that the public perception and confidence in the whole power transmission industry, rather than individual company, will be affected in the event of a black-out.

After the August 2003 blackout in the USA, 5 different utilities experienced an average of 1.24% loss the day after the event. However, utilities not involved in the blackout averaged a gain of 0.5% in the same period. By a similar metric then Iberdrola, the parent company of Scottish Power Transmission, has a market capitalisation of around £20billion, therefore a 1% share price reduction would be equivalent to a £200m reduction in market capitalisation. While this is likely to be a temporary reduction, it may influence investors' perspective of the relative stock strength, hence reputation.

d) Reducing Customer Bills

Successful deployment of the GB-PMU network and Hybrid State Estimator should result in a better understanding of the network and increased reliability and increased confidence in the system operating margins. This would facilitate a reduction in constraint payments and delay transmission investment - which feeds into Transmission Network Use of System (TNUoS) charges - and should translate to reduced costs for end-users.

In 2011 the constraint costs for the B6/Cheviot boundary was £132million [1]. A conservative estimate of capacity constraint saving of 50MW for 50% of time should result in an annual saving of £4m. This significant cost saving would feed through into GB consumer bills.

e) Post Disturbance Analysis

To diagnose an unforeseen major power system disturbance, it is important to replay the scenario(s) that resulted in the event. Phasor measurements from PMUs are time-synchronised using GPS, and so post-disturbance analysis time is reduced significantly. The financial value of this is difficult to robustly quantify, however from prior international experience, the availability of PMU based data and central data concentrator reduced the post-blackout diagnostics from over 12 months to approximately one month. This resulted in a significant saving of data collation and analysis time, as well as time in understanding and resolving the problem. During the uncertainty period, it is likely that the recovered system would be operated in a conservative manner with operational constraints imposed.

f) Lost Opportunity Cost

There have been a number of events in recent years due to unforeseen oscillatory behaviour on transmission networks that have ultimately been linked back to the deployment of new technology.

[1] National Grid, May 2011, UK, Accessed 17th July 2013 *http://www.nationalgrid.com/NR/rdonlyres/1B6B81A0-7583-4EC0-B16D-A814E2100546/46801/BSIS_Outturn_Web_16May2011_Final.pdf*

[3] Damir Novosel, *Final Project Report – Phasor Measurement Application Study*, Prepared for CIEE by KEMA, Inc, *June 2007*

Project Business Case continued

During the problem identification and resolution periods, the system is generally run in a heavily constrained manner to try to prevent further undesirable behaviours. A classic recent example was the Electric Reliability Council of Texas (ERCOT) system where large wind farms were exhibiting sub-synchronous oscillations with series compensation in a new and previously unreported manner. This resulted in heavy constraints on the wind farms and system until the problem was identified and adequately resolved.Similar problems have occurred in the past with the integration of HVDC links where their control systems and harmonic filters combined to reduce system damping in the sub-synchronous region. This has always been eventually resolved, but not after a number of large conventional generator trip events due to fast power transients. Generally due to the lack of observability of these events, the events go unexplained for a considerable period of time resulting in losses for various parties and delays in resolution of the underlying problem.
The Sub-Synchronous Oscillation monitoring system in VISOR aims to prevent these losses through an early warning and detection approach combined with system characteristic benchmarking.

3.5 Summary

In conclusion for the business case, the VISOR project has clearly demonstrated that it can provide significant value to the GB consumer through system risk mitigation and incremental capacity increase across constrained boundaries. The timing is highly appropriate given the impending deployment of series compensation and the commissioning of the Western HVDC link.
The generation mix in GB is changing rapidly with the combination of the increase in onshore and offshore wind, as well as the impact of the Large Combustion Plant Directive (LCPD) in shutting down a significant tranche of conventional generation. These generation background changes will significantly change the system inertia and dynamic behaviour and the VISOR project will provide an early indication of network integrity and security issues.
The NIC Funding Request is £6.49 million, total Project Cost is £7.37 million over 40 months. Projected Benefits from VISOR are difficult to explicitly quantify, however have been shown to range from **£45 million per 100MW** of capacity released through to £30 billion in the event of GB black-out prevention.

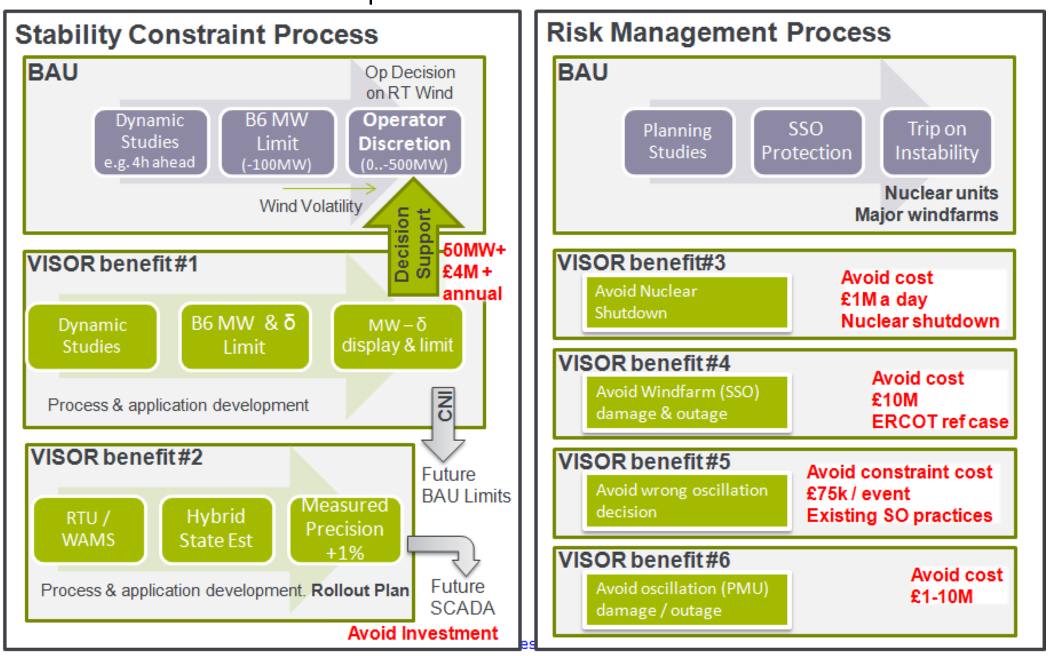

Figure 3 - 2: Summary of Business Case

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Section 4: Evaluation Criteria

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The Visualisation of Real Time System Dynamics using Enhanced Monitoring (VISOR) project will implement new GB-wide monitoring technology with innovative functionality and data-sharing arrangements to optimise existing, and to facilitate the utilisation, of new low-carbon generation. Therefore it offers value for money to electricity consumers and also provides a wide range of learning opportunities for project partners.

a) Accelerates the development of a low carbon energy sector

The transfer constraints in the GB system and particularly the Anglo-Scottish B6 boundary presently restrict the development of a low carbon energy sector by reducing the availability of Transmission system access to renewable generation north of the B6 boundary.

There are measures being implemented to address the B6 constraint with new equipment, including Series Compensation and HVDC (as shown in Figure 4 - 1). However, the new equipment takes time to deploy and commission, and it is important that new low-carbon energy sources can "actively participate" in the generation mix while this work is carried out. The use of monitoring technologies to release capacity in B6 has the potential to reduce constraints prior to the B6 boundary reinforcements.

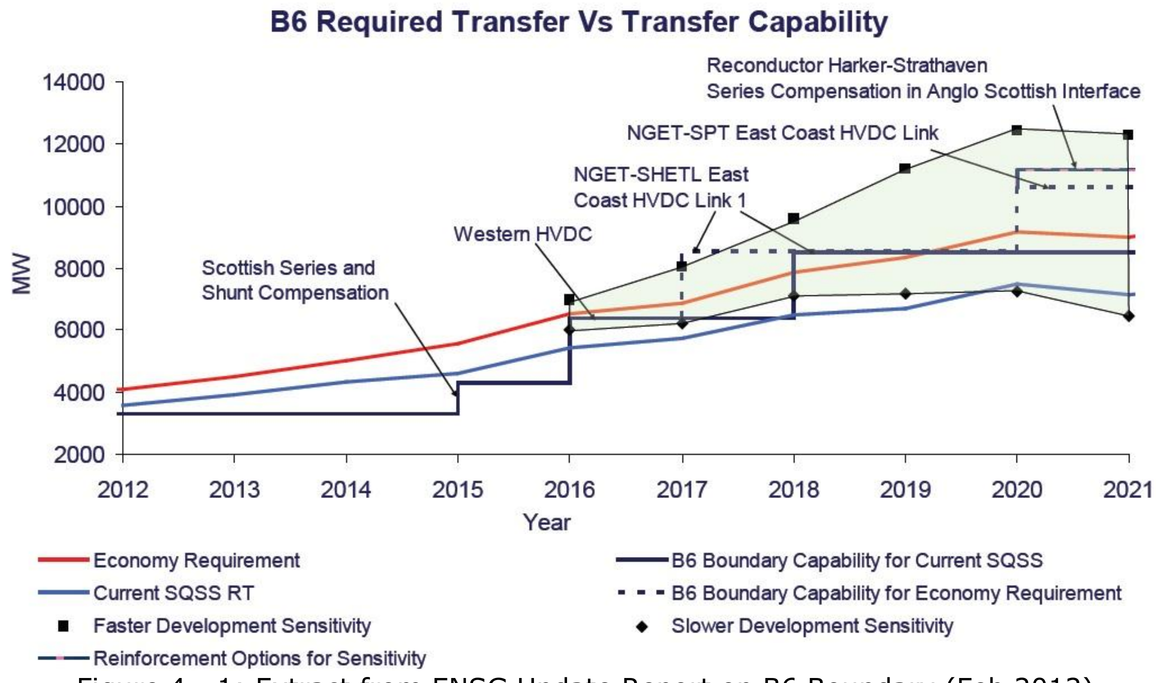

Figure 4 - 1: Extract from ENSG Update Report on B6 Boundary (Feb 2012)

The dynamic characteristics of the power system are changing with the change in generation profile and operational characteristics i.e. increased renewable generation, more interconnection with European networks, decommissioning of existing conventional plant. Therefore the nature and control of power system oscillations and frequency are changing too, and there is an increased risk of recurrence of the severe unstable oscillations of the 1980s, that may involve different regions of the grid and occur at different frequencies. There has been some more recent experience of unstable oscillations, reinforcing that power system oscillations should be managed in a way that new issues can be discovered and resolved at an early stage.

Evaluation Criteria continued

VISOR would give Transmission Owners (TOs) better visibility of system behaviour and system margins, and help identify potential risks to system stability. Better visibility of the network would also give system operators a more accurate margin-requirement value which would release more system margin and relieve some constraints.

Releasing more margin generally means more generation, especially from renewable sources would be transmitted across the B6 Boundary to supply large demand centres in the south of GB, thereby reducing the requirement to use "dirty" conventional generation. This in turn results in a carbon-saving.

The Scottish Government estimates that a 134MW wind farm, running at 30% capacity with an annual energy output of 352GWh/year, would result in a potential carbon dioxide saving or abatement of 215000 tCO_2/year. In comparison, Scottish Renewables website states that in 2011, Longannet was the largest fossil fuel based power station in Scotland and emitted 8.5 million tCO_2 that year.

VISOR also addresses several of the goals stated in Department of Energy and Climate Change (DECC) Carbon Plan relating to the overall approach to achieving emission reduction to 67% of 1990 levels by 2020 and 50% by 2027. One of which is the need for greater interconnection, including North Sea countries. North Sea interconnections imply large injections at specific locations, and potentially the integration of a DC grid. It is important to understand the performance of the AC grid in various scenarios, particularly relating to the loss of very large power infeeds. The dynamic response of the AC system and the potential for regional instability is important. WAMS improves knowledge of the dynamic performance of the grid, including both local and system-wide dynamic responses.

b) Provides value for money to electricity transmission customers

The cost of installing and maintaining the National Electricity Transmission System (NETS) required to transfer power between connection sites (customers) is recovered by the Transmission Network Use of System (TNUoS) charges.

The use of VISOR's monitoring-based constraint management provides:

- Efficient use of transmission assets and enables deferral of capital investment thereby reducing TNUoS charges
- Accelerated generation connection, as an extensive review of Sub-Synchronous Oscillations (SSO) would not be required each time a wind farm or generator was added close to the series compensated lines or HVDC terminals. This also results in a secondary benefit of reducing Balancing Services Use of System (BSUoS) charges
- Reduction of the risk of equipment damage or on-load tripping at generators
- Accelerated grid reinforcement, as risks that would otherwise need to be studied exhaustively can be addressed through monitoring and identification of early warning signs. Certain mitigation strategies and schemes can be judged unnecessary with a stability monitoring system
- The presence of constraints increases the overall societal cost of energy. Since new monitoring-based constraint management provide one of the most cost-effective routes to relieving constraints, the benefit is significant in comparison with the costs. (B6 or Cheviot constraint costs are the order of £80m-£130m per year)

The monitoring approach taken in this project is effective in comparison with other monitoring-based approaches because:

- It builds on existing monitoring equipment and systems, using the experience gained and the installed base of monitoring.
- It uses standard monitoring technologies with data processing enhancements.
- It makes use of recent experience in North America where large-scale WAMS infrastructure projects have been implemented with the support of Smart Grid Investment Grants.

Evaluation Criteria continued

c) Generates knowledge that can be shared amongst all relevant Network Licensees

The project includes the participation of all three network licensees, as there are interests related to both the TO and TSO roles. The knowledge outcomes of the project include:

- Design of an optimal WAMS infrastructure that requires involvement from TOs and TSO
- Experience with implementation and testing of the infrastructure
- Demonstration of applications for both TO and TSO roles, including
  - Monitoring asset performance, particularly dynamic performance and compliance
  - Model validation and identifying locations of sources of deviations from the model
  - Approaches to increasing the use of assets
- Identifying risks to continued operation of the system and integrity of assets is in the common interests of all three licensees. They will share the knowledge gained in the procedures and outcomes of baselining, performance and risk identification.
- While VISOR benefits TO and NETSO primarily, there are potential benefits and lessons to be derived by Offshore Transmission Owners (OFTOs).

d) Innovative (i.e. not business as usual)

While phasor measurement infrastructure is well established, and there are commercial software solutions available, the number of cases where the technology has been used in the control room environment is limited. Presently, there are a few PMUs in the Scottish Power and National Grid transmission system, and none in SHE Transmission's system.

However VISOR would facilitate a GB-wide PMU-based WAM system and implement a new central server to receive and store data from the three TOs as illustrated in Figure 4 - 2. Also, there is a requirement for a novel data-sharing arrangement among project partners and where applicable, generators.

This project's approaches are innovative because:

- Sub-Synchronous Oscillation (SSO) monitoring has only been deployed locally so far, and VISOR will co-ordinate a centralised control-room observation and response.
- Oscillation source location is a new invention; it has been used off-line in consulting services with phasor measurements, but will be deployed in a real-time environment on VISOR to aid system-health monitoring.

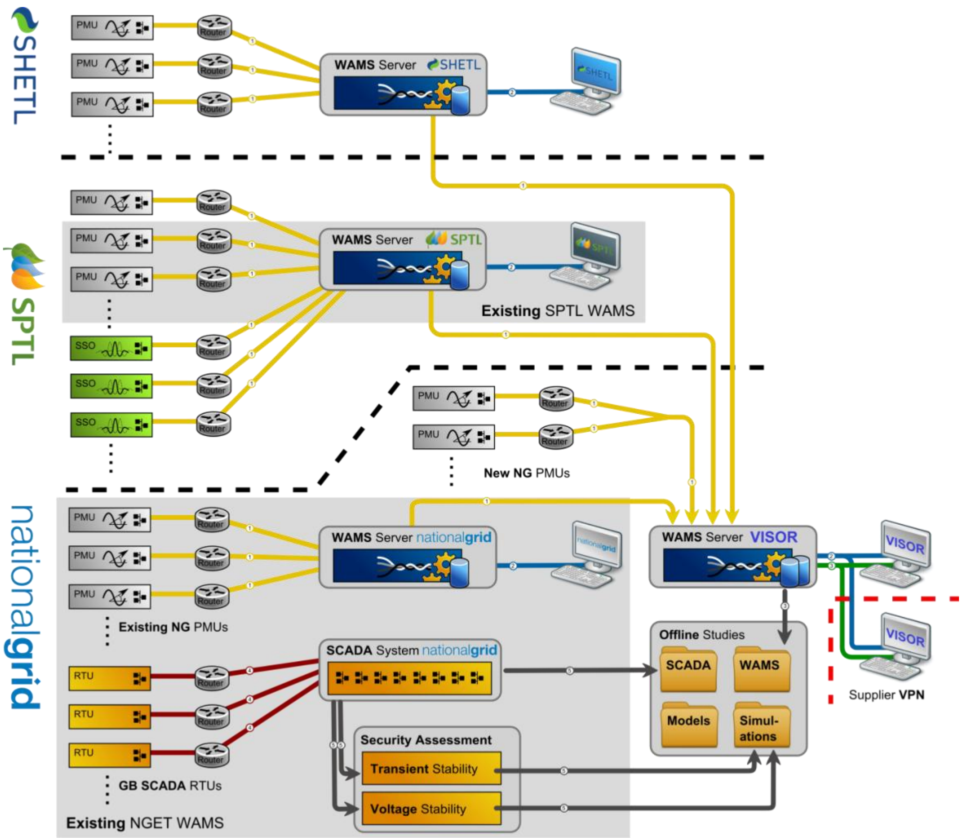

Figure 4 - 2: Overview of Supporting Systems, Data Flows and Infrastructure

e) Involvement of other project partners and external funding

Given the application and potential benefit of VISOR, it is appropriate to involve the GB TOs, and the NETSO as partners of VISOR. The costs of TO-handled procurement associated with this project have been estimated at £62k from each TO. TOs have agreed to provide this as in-kind support. The total contribution from the project consortium, incorporating both direct funding and in-kind support, is aiming to be above £1.0million i.e. equivalent to 12.5% - 15% of the overall cost. This demonstrates SPT's commitment as VISOR project originator which is underlined by a Letter of Commitment from the Managing Director, included as Appendix A8.

Scottish Hydro Electricity Transmission plc (SHE Transmission)

SHE Transmission is the owner of transmission network in the North of Scotland. There is a net export of electricity from the SHE Transmission region to the SPT network, which in turn places severe strain on the Anglo-Scottish transmission boundary. It is important for the VISOR project to have the visibility of real time behaviours from SHE Transmission network due to their consequential impacts on the Anglo-Scottish transmission boundary.

As stated previously, there are currently no PMU devices installed on the SHE Transmission network. To obtain appropriate levels of visibility of the real-time network performance, SHE Transmission has identified about 10 principal transmission sites to support VISOR. Among them, the four installations along the newly constructed Beauly-Denny circuits can be partly funded via the project funding due to the integrated fault recording function provided by the PMUs.

Evaluation Criteria continued

National Grid Electricity Transmission plc (NGET)
NGET owns and operates the National Grid high-voltage electricity transmission network in England and Wales. In addition to facilitating the transfer of electricity flows from North Scotland, the region between England and Scotland (i.e. the network owned by NGET and SPT respectively) would also have 1.1 GW of new generation connected under the Gone Green 2011 Scenario. NGET is at the receiving end of such a high volume of power.
The analysis of the Anglo-Scottish boundary has to rely on the appropriate coverage and visibility on the NGET transmission network. NGET is also the GB electricity network operator (National Electricity Transmission System Operator, NETSO), and responsible for the safe operation in line with Good Industry Practice. The information obtained from the individual transmission owners will be sent to a central server capable of exchanging real time PMU data and hosted by National Grid within the NETSO compound or at a remote location.

SP Transmission Plc
Scottish Power Transmission owns and maintains the transmission network in southern Scotland. SPT is also jointly responsible for the Anglo-Scottish boundary (B6) which facilitates flows from Scotland to England. SPT has established extensive experience over the past years in addressing the unique characteristics of the boundary concerned. This expertise has been further reinforced by successful delivery of various small scale demonstration projects related to Wide Area Monitoring System (WAMS), as detailed in Section 5 and Figure 5.1. Learning from those projects has fed directly into the VISOR proposal and supported the proposal development.
SPT has an obligation under STC (System Operator/Transmission Owner Code) to provide necessary information to enable the NETSO to operate their assets, and an obligation under the Grid Code to develop, maintain and operate an efficient, coordinated and economical system for the transmission of electricity. This previous learning and statutory responsibility enable SPT's leading role in initialising the VISOR proposal and proposal delivery.
SPT is required to contribute 10% of the total funding for this project, as the funding licensee. SPT will be the focal point of this project to contact the Authority, and is also taking on the responsibility of the overall project costing, management and successful delivery. In addition, each identified project partner has demonstrated willingness to contribute resources to the project including their staff time, overheads and use of facilities during different stages of the project.

The University of Manchester
The University of Manchester has been selected as VISOR's main academic partner. The university has an experienced research team with an excellent testing laboratory in the relevant areas such as WAM, Power System State Estimation and Network Analysis and has a good record of academic publications. It is envisaged that the academic partner will:

- Provide expertise and independent review regarding the proposal integrity and specifications appropriately;
- Facilitate regular knowledge dissemination (see Figure 4 - 3 for a summary of this role, which is further elaborated in Section 5: Knowledge Dissemination)
- Be the main work-force in carrying out the Work Package of Validation & Testing of Situational Awareness Tools and Synchronized Measurement (as detailed in Appendix A4).
- Provide enduring ownership of the testing facilities
- Maintain the continuity of the project, carry out appropriate simulation/desktop studies, laboratory tasks for the future projects

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Evaluation Criteria continued

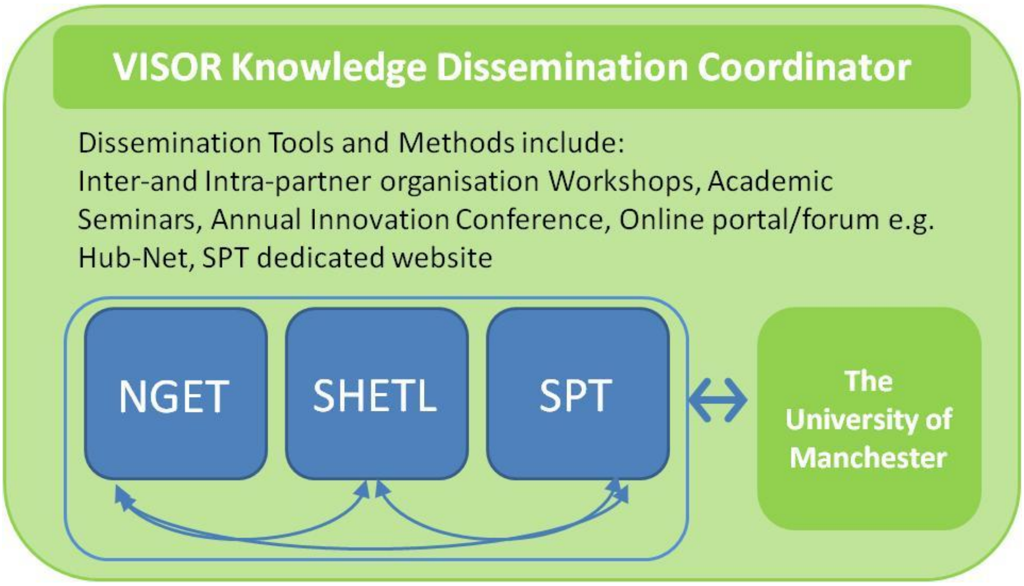

Figure 4 - 3: Knowledge Dissemination role

Tests performed in the university's laboratory will be tailored to support the VISOR project. In return, the university would get the opportunity to work with TOs directly and educate high calibre candidates on the real transmission system.
The University of Manchester will host and maintain the testing equipment for free. The university will also provide dedicated resource to work on the equipment on an enduring basis. This in-kind support is estimated at £150k for the remaining RIIO-T1 period and demonstrates proportional commitment and support to the project.
Industrial suppliers of certain hardware and software will be identified via a full competitive tendering process. To ensure the value for money for the electricity customers, six manufacturers have been short-listed based on their research and development capacity, projects records and resources in the relevant area. It is expected that the successful supplier will also make a significant contribution to the project.

Summary of the project partners and their contribution is provided in Table 4.1.
The VISOR project will form a catalyst for further NIA or NIC projects at a later stage. For example, the VISOR data-management and phasor-measurement experience will be relevant to research into options for Next Generation Special Protection Systems (SPS) to replace the Remedial Action Scheme (RAS) schemes applied to B6 and other boundaries; Optimal control strategy for the embedded HVDC links and Inertia assessment, ROCOF settings and other loss-of-mains options.

	Contribution (£k)
NGET	62 (in-kind support)
SHE Transmission	62 (in-kind support)
Academic Partner	150 (in-kind support)
Licensee extra contribution	--
Initial Net Funding Required (Total minus in-kind support)	7,370
Licensee Compulsory Contribution/Direct Benefits	737
Outstanding NIC Funding Required	6,633
NIC Funding Request (minus projected inflation & interest)	*6,493*

Table 4.1: Partner Contributions

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Evaluation Criteria continued

f) Relevance and timing

In the context of the GB power system and environmental challenges it faces, this project is very relevant to current issues being faced in the transmission business, and the new technology is expected to form an important part of the assessment and management facilities for the infrastructure enhancements in the near future.

- With Series Capacitors (SCs) being installed between Q4 2014 and Q4 2015, it is important that the new system monitoring approaches are validated before this phase of B6 boundary upgrades is complete. An early outcome of this project will be demonstration of control room monitoring and off-line study capability for a wide-area view of Sub-Synchronous Oscillations. If this component is not carried out in this NIC funding-round, the TO/TSOs will miss the opportunity to observe the effect of the introduction of Series Capacitors and assess risks using this new technology as the SCs are added.

- The Western HVDC link is scheduled for Q2 2016. The project will reduce uncertainties related to the performance and control of this connection, including dynamic modelling uncertainties and the effect of control by the HVDC system. The tuning of the HVDC system controls for key contingencies depends on the dynamic performance of the AC system, and the inertia north and south of B6. The project will also provide facilities for system tests on commissioning the HVDC link. It is therefore important and timely that the project goes ahead at this time, in order that these facilities will be available, and the knowledge gained in time for this major augmentation of the system.

- **The rate at which the power system characteristics are changing is faster than the GB system has experienced for several decades.** The generation characteristics are changing with the proportion of conventional generation reducing in comparison with renewable generation, associated with a change in loadflow pattern and inertia. The distribution system characteristics are changing rapidly with active network management and large-scale distributed generation.
  It is essential to introduce a mechanism for baselining dynamic performance of the system as soon as possible, so that any new risks associated with these changes may be identified at an early stage and characterised quickly and effectively and avoid outages or equipment damage that would lead to further operational restrictions, delays in capacity release and potentially impact customer confidence.

In the context of the Electricity Networks Strategy Group (ENSG) 2009 report and the 2012 updates, it should be noted that WAMS is identified by the Group as an important field to address the constraints and associated costs. The VISOR work on WAMS infrastructure and constraint relief applications would be transferable to other constrained boundaries, e.g. SPEN 275kV Central Belt, the B6 and B7 boundaries, as well as North Wales and southern corridors, on which there are severe strains.

The ENSG 2012 update particularly notes the need for Wide-Area monitoring for co-ordinated control of new technologies in the transmission network, such as Quadrature Booster control and co-ordinated HVDC control with the AC grid. To this end, the VISOR project addresses the infrastructure and testing requirements, and provides a monitoring basis that provides key data and information on the dynamic performance of the grid that will support the development and implementation of new control methodologies.

On a global perspective, it should be noted that the North American Smart Grid Investment Grants accelerated the widespread deployment of PMUs and the supporting infrastructure. These projects are now at close-out, and there is a body of knowledge and practical experience from this widespread deployment that can be applied in the GB system context.
Combining the implementation experience from the North American industry with the GB leadership in using WAMS technology in the context of integrating large-scale renewable energy, will provide a very valuable worldwide reference.

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Section 5: Knowledge dissemination

This section should be between 3 and 5 pages.

☐ Please cross the box if the Network Licensee does not intend to conform to the default IPR requirements.

VISOR project will conform to Ofgem (NIC) default IPR principles. It is not anticipated that the project will develop foreground IPR that will fall outside of the default IPR requirements.

It is anticipated that suppliers may wish to fully contribute certain Solution Development Costs (for example, the development of a new software application or extension of an existing one), in order to retain the resulting IPR. It is understood that this will fall under the category of "Foreground IPR within Commercial Products" as described in 9.14 of the Electricity NIC Governance Document. With this in mind, such software will be made available by the supplier for purchase by other Network Licensees on fair and reasonable terms. *This compliance with the default IPR principles will be reflected in the public tendering.*

The innovative and wide-reaching nature of VISOR makes it imperative to develop a robust method of disseminating knowledge and lessons learned from the project to other Network Licensees and interested parties. The Knowledge Dissemination Work Package is composed of the following streams:

- Internal Knowledge Dissemination
- External Knowledge Dissemination
- Influencing and Updating the Policies/Standards
- Public Engagement

5.1 Internal Knowledge Dissemination

Given that there are several projects feeding into VISOR (Figure 5 - 1), it is important to stay informed of their developments to maximise learning and also to avoid unnecessary duplication.

Therefore a Knowledge Dissemination Coordinator (KDC) will be appointed and will be tasked with continuously liaising with other relevant projects (at both national and international level), reviewing specific project documents and working with other IFI/LCNF/NIA & NIC project teams in areas such as PMU device technologies, communications infrastructure, software improvements, model variations and WAMPAC road map.

Furthermore, in agreement with NGET and SHE Transmission, a workshop with the operational and planning staff involved with state-estimation, will be organised within the first year of the project to discuss their experiences.

Section 6: Project Readiness describes the Project Governance structure which includes a Project Steering Group (PSG) made up of directors and senior managers from across the businesses (refer to Figure 6 - 2). In addition to the PSG, Project Champions from each of business areas will be appointed to act as ambassadors and lead engagement within their business unit. This will involve providing updates, monthly team-briefings and delivering presentations to staff.

In 2010, SP held a Technology Innovation Conference which almost 100 staff attended to find out about the various developments in LCNF and IFI initiatives within Scottish Power

Knowledge dissemination continued

and other DNOs. A similar event will be used to inform SP staff of developments on VISOR and other NIC projects.

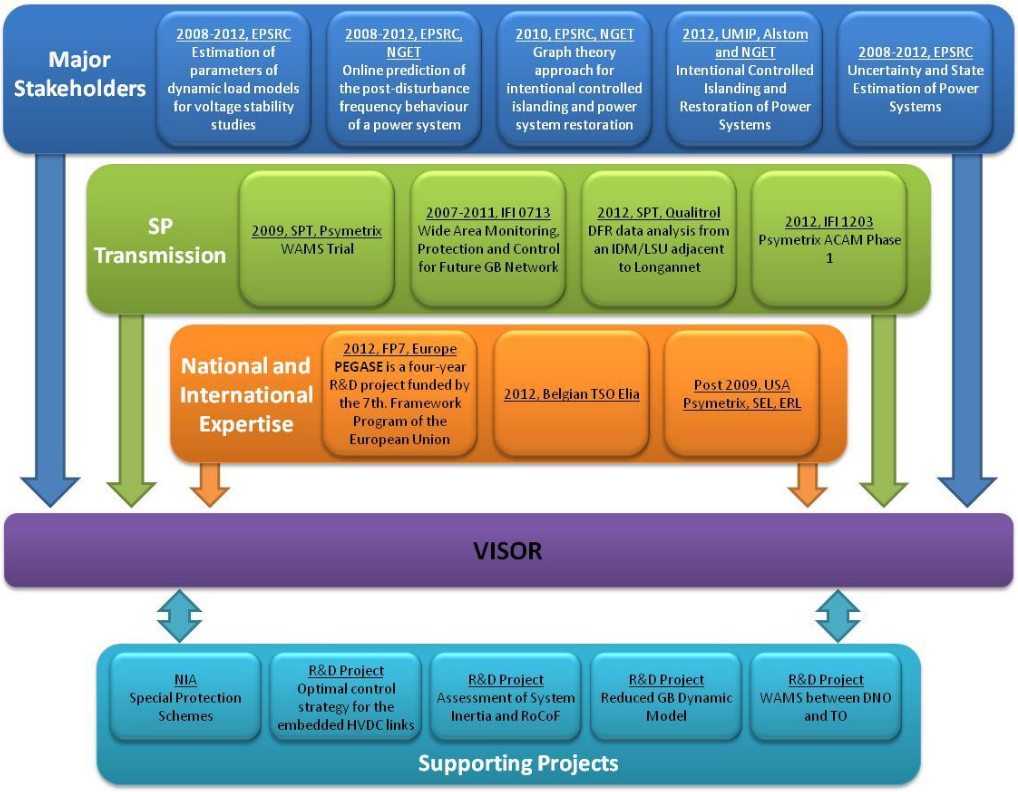

Figure 5 - 1: VISOR and supporting projects

5.2 External Knowledge Dissemination

The VISOR project is the first in its kind to be delivered on an integrated GB transmission network. Therefore it is important to inform external interested bodies of the progress of VISOR, for example, experts working on the Pan-European Grid Advanced Simulation and State Estimation (PEGASE) R&D project sponsored by FP7. Also, contact has been made with the Electric Power Research Institute (EPRI), a USA research institute focused on electrical power sector. Liaising with projects like these will maximise learning, avoid unnecessary duplication and would be a means of extracting commercial or technical innovation from the project and partners.
It also informs policy-makers in relevant areas of transmission and distribution companies about the benefits of WAMS and its effects on long-term system security.

An online portal has been identified as the important publication platform. It is intended that this portal will also be cross-referenced with a dedicated area on the SPT official website.

VISOR's academic partner is responsible for capturing real-time system knowledge and sharing this with the wider community, via academic papers and industrial reports. A project progress report (PPR) will be published every six months (Work Package 5.4).

Knowledge dissemination continued

5.3 Influencing and Updating the Policies/Standards

VISOR seeks to address issues associated with transmission system utilisation and development so findings from the project may affect existing policy or standards. VISOR has a duty to identify these and report them to the Authority (Ofgem), so that they can be assessed, and affected standards/policies can be modified to reflect the changing nature of the transmission network and technology.
The delivery of this project, in a collaborative manner between TOs and the NETSO, raises market and regulation issues with respect to the ownership of the collected data, their value and secure transmission, as well as the nomination of agreed standards and protocols for managing such data.

The Smart Grids Strategic Research Agenda 2035 of the Smart Grids European Technology Platform suggests that *"the novel approach in power systems should rely on role-based data access. Data must be owned by, and located at the data-originator".*
So data collated from the various work packages under VISOR would be utilized for their respective relevant purposes - but with restricted access to what is relevant to the owner of the data.
Also, one of the project deliverables is a detailed study regarding potential changes required to existing regulatory mechanisms such as the STC (System Operator and Transmission Owners Code) and how it may be used to better facilitate more proactive information exchange.

5.4 Public Engagement

The Annual Innovation Conference has been identified as the appropriate platform to inform the stakeholders of on-going project progress, results generated, changes and learning obtained.
Also of importance is the project close-down report and project evaluation, which may require a dedicated three-month-period. During this period, all relevant learning will be listed, compared, updated and evaluated in front of the Authority and any interested parties. The outcome will feed into a National Roll-Out plan.

Summary

An approach incorporating all these measures will be the most efficient and cost-effective method of disseminating information to the various interested parties in the most accessible way. It also informs policy-makers in relevant areas of transmission and distribution companies about the benefits of WAM and long-term system security. This would also be the best way to extract commercial or technical innovations from the project and partners.

With each of the dissemination methods, there will be periodical checks to confirm their efficacy and suitability.

Electricity Network Innovation Competition Full Submission Pro-forma

Section 6: Project Readiness

This section should be between 5 and 8 pages.

Requested level of protection require against cost over-runs (%): 5

Requested level of protection against Direct Benefits that they wish to apply for (%): 50

VISOR project has engaged with partners and external suppliers, undertaken due-diligence exercises on the costings and the proposed technology with TRL between 5 and 8. Also, measures are in place to secure resources for a prompt project kick-off and to manage project changes efficiently.

6.1 Background

The VISOR proposal was initialised as the direct outcome from various previous projects carried out either by the funding licensee directly or the partners. The current proposal has evolved over the past years and has taken into account the collective experiences, latest technology development and ongoing studies/trials in a global context.
Previous work undertaken in this field (listed in Figure 5 - 1) was beneficial for the conception of the VISOR proposal in the following ways:

- Helping to raise awareness of Wide Area monitoring and PMU technology within the electricity transmission sector;
- Highlighting the potential technology risks associated with the new network reinforcements strategy;
- Understanding the technology and infrastructure requirements;
- Roadmap exploration;
- Training and fostering in-house expertise within each partner's organisation in related areas, such as unit deployment, maintenance, data transfer, data analysis etc;
- Raising the profile of the innovation within each organisation involved, and facilitating culture change

6.2 Stakeholders Participation

Participation in various innovation initiatives such as Innovation Funding Incentive (IFI), Low Carbon Network Fund (LCNF) (Tier 1 and Tier 2) have resulted in changes in stakeholders' business culture and perception of risks and innovation. Such changes, in addition to the experiences gained from the previous projects, create an optimal climate for larger scale innovation projects such as VISOR.

Therefore business units (including the funding licensee, licensee partners, suppliers and academic institutions) involved in VISOR, have responded positively and have agreed to adopt the responsibility of delivering this proposal.
For example, Scottish Hydro Electricity Transmission plc (SHE Transmission) had originally planned basic fault/disturbance recorder installations along the Beauly-Denny 400/275kV circuit. However, following attendance of various workshops, meetings and undertaking feasibility studies, SHE Transmission has agreed to support the VISOR project by installing PMUs on their sites, and to fund the installation costs from their business-as-usual budget. Similarly, Scottish Power Transmission (SPT), joint with National Grid (NGET), is reinforcing Anglo-Scottish Boundary with Series Compensators (SCs). The VISOR proposal will support this project and provide a timely safeguard measure by baselining the network characteristics prior and post the commissioning of the reinforcement.

Project Readiness continued

Each TO has confirmed their commitment and resources by Letters of Support from NGET and SHE Transmission (Appendix A9). This further reinforces the relevance of the VISOR project and industrial commitment and support to the project and its objectives.

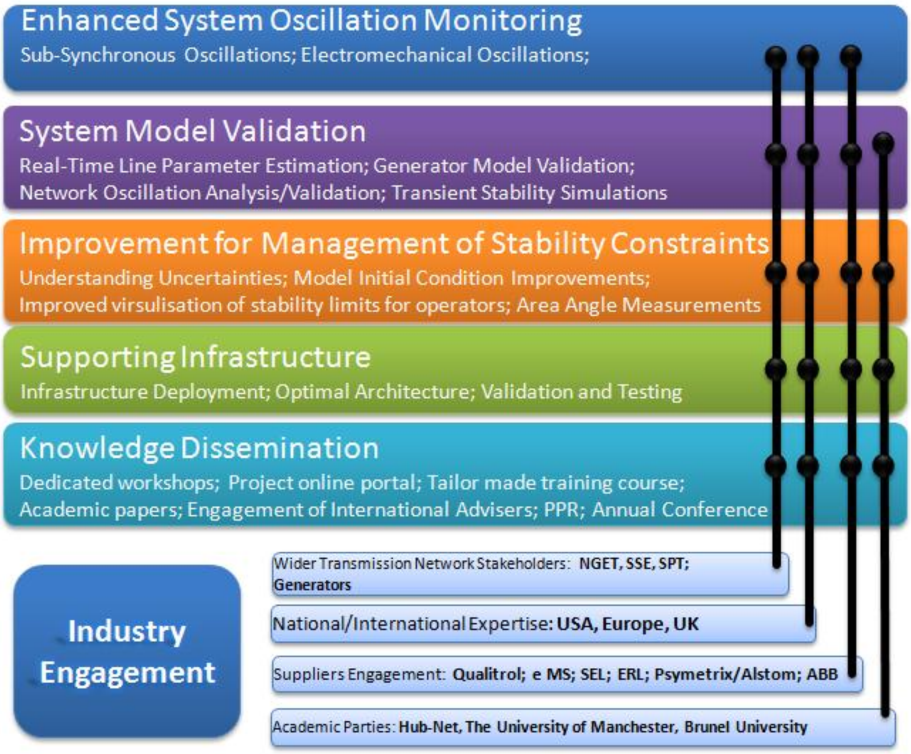

Figure 6 - 1: Project Breakdown

6.3 Project Governance and Resource Management

It is recognised that effective project co-ordination and partner communication (Figure 6 - 1 shows the project breakdown) are extremely important to the success of this project. The main project partners are SHE Transmission, SPT, NGET and The University of Manchester.

Scottish Hydro Electricity Transmission plc (SHE Transmission): is the owner of transmission network in the North of Scotland. Generation in SHE Transmission is assumed to significantly increase with onshore and offshore wind and marine renewable all contributing; over 6GW of new generation would be connected by the end of 2020 in SHE Transmission's area.

National Grid Electricity Transmission plc (NGET): NGET owns and operates the National Grid high-voltage electricity transmission network in England and Wales. In addition to facilitating the transfer of electricity flows from North Scotland, the region between England and Scotland (i.e. the network owned by NGET and SPT respectively) would also have 1.1 GW of new generation connected under the Gone Green 2011 Scenario.

The University of Manchester: This university will act as the academic partner and will support the VISOR project by capturing and disseminating the latest knowledge. The university has an experienced research team with good publication records and testing laboratory in the relevant areas such as WAM, Power System State Estimation and Network Analysis.

Project Readiness continued

Scottish Power Transmission Plc (SPT): Scottish Power Transmission owns and maintains the transmission network in southern Scotland. SPT is required to contribute 10% of the total funding for this project, as the funding licensee.

Each TO has various internal business units to liaise with, and TOs will work in a co-ordinated manner to ensure the successful delivery of the project and its objectives, and to minimise cost overruns or benefit shortfalls. To achieve this, each funding licensee will provide a full time project manager (PM). The SPT project manager will be supported by the Transmission Innovation Lead at SPT. Apart from internal project coordination, the PM will also oversee the whole project delivery.
To empower this PM, a Project Steering Board comprised of senior managers from each TO and NETSO, will be established. NGET and SHE Transmission will also have a designated PM each to co-ordinate the internal delivery and report to the SPT project manager.

Figure 6 - 2 provides the structure of the project management proposed.

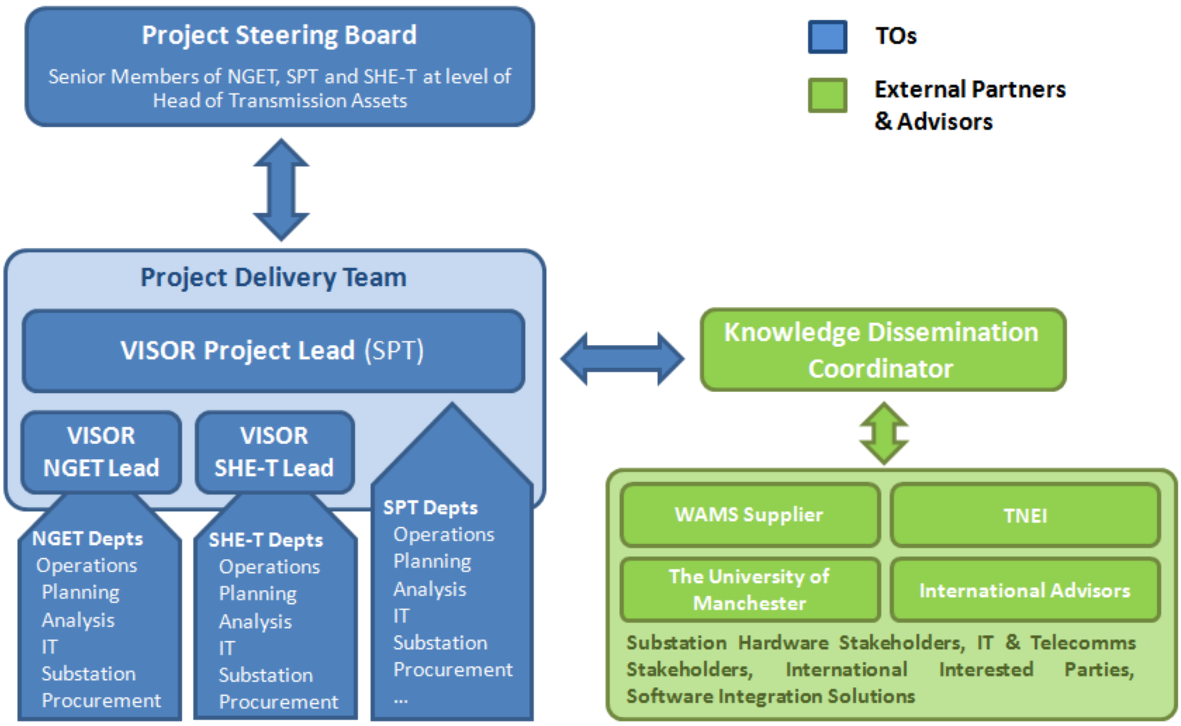

Figure 6 - 2: Project Team Structure

6.3.1 Interim Arrangements

Effective and constant communication is important during all stages of the project. It is the intention of the consortium (SPT, SHE Transmission & NGET) to have appropriate resources appointed following the formal Ofgem approval in November 2013. An interim project delivery team will function until resources are in place (which is due from April 2014). Such an arrangement will ensure the continuity of the project and to maintain the consistent ownership. The interim project team is headed by:

- Antonio Del Castillo, Business Development Manager, National Grid Electricity Transmission Ltd
- Frank Clifton, Project Development Manager, Scottish Hydro Electric Transmission
- James Yu, Transmission Innovation Lead, Scottish Power Transmission

Project Readiness continued

James Yu will act as the focal point with the Authority (Ofgem). Proposal advisers such as TNEI Services and Psymetrix will continue to support the internal project delivery team when required.

The principal functions of the interim project delivery team will include:

1. Co-ordinate and allocate internal resources to ensure sufficient support to the Project, including:
   1.1. Outage co-ordinating and detailed equipment installation plan;
   1.2. Internal project delivery resources and ownership

2. Co-ordinate the activities among TOs and SO from the Project level, namely:
   2.1. Legal documents draft and approval (including the R&D Collaboration Agreement, and the Agreement with the Authority);
   2.2. Tendering Specification review, Tender Documents Issue and Evaluation;
   2.3. Recommendation and confirm of the Project Steering Group;
   2.4. Recruitment and appointment of Project Delivery Team

6.3.2 Project Delivery

In accordance with the aim to deliver a cost-effective solution, the following components will be publicly tendered, namely:

- Sub Synchronous Oscillation Detection Substation Hardware (WP4A)
- PMU Substation Hardware (WP4A)
- WAMS Platform & Application Demonstration, including:
  - WP1: Enhanced System Oscillation Monitoring
  - WP2.1: Line Parameter Estimation & 2.4 Generator Model Validation
  - WP3.2-3.4: Improvement of Initial Conditions, Improved Visualisation of Stability Limits, and Trial of Area Angle Measurement Reliability
- The following will be undertaken by the academic partner:
  - WP2.2: Oscillation Analysis Validation & WP2.3: Transient Stability Simulations
  - WP3.1 Understanding Uncertainty
  - WP4B.1.3 & 2.1: Development & Application of Optimal Monitoring Placement Methodologies
  - WP4C: Validation & Testing

Equipment Specification: Hardware will be specified at the VISOR project level, but individual TOs will be free to carry out tendering, procurement and deployment of certain components (such as substation hardware) as part of their business-as-usual activities
Technical specifications are being prepared and will be independently ratified before mid Jan 2014, to be put out for tender. Responses are expected within 4 weeks, so that a decision can be ready by March 2014.

PMU and SSO Detection hardware will be given priority in the procurement process, to ensure that these can be deployed as early as possible, in particular to allow for sufficient data for system baselining before the installation of Series Compensation in early 2015.
Vendor selection for the WAMS Platform and Applications should be completed at the very latest by June 2014 – following this, the existing WAMS servers in SP and NG can provide a stopgap to aggregate power system data for studies, should the deployment of the main VISOR server be significantly delayed.

Installation: Each TO will be responsible for the installation of measurement equipment, Phasor Data Concentrator (PDC) server and communication infrastructure on their network in a timely manner in accordance with the project plan.

Deployment: Deployment of new equipment will make use of the TO's existing outage plan and be divided into two stages.
The first stage (Spring-Summer 2014) will deploy the necessary monitoring to enable the early project components – in particular WP2 (Enhanced System Oscillation Monitoring), which must be under way before the introduction of Series Compensation in 2015, as discussed in Section 4.
The second stage (Spring-Summer 2015) will allow further contingency monitoring to be deployed, informed by a review of the first stage. This will provide sufficient system visibility prior to the commissioning of the Western HVDC link in 2016, and add value in the remaining stages of the project including system studies. It will also allow for the installation of any devices which could not be accommodated in planned 2014 outages.

6.4 Technology Readiness

Based on research projects, literature reviews and trial installations which precede VISOR, this project has appropriate technology readiness levels (TRL) with realistic deliverables. In summary, it is comprised of a balanced portfolio of developments with TRL ranging between 5 and 8.
a) WAMS technology platform has been deployed in North America extensively and is standard in most other countries. Therefore its technology readiness level is high (8). However, it is yet to be deployed in the GB system to the scale of VISOR, nor has inter-organisation data-sharing been used.
b) The integration of Sub-Synchronous Oscillation monitoring in a wide-area monitoring platform has a TRL of 7, as the components of measurement, wide-area presentation, and communication are all known, but have not previously been integrated in a single system.
Application areas such as oscillation source location have been used in studies and consulting projects, and are proven approaches, but the innovation involves deploying these approaches in commercially usable applications. Where new application development is required, the TRL is typically 6-7.
c) Another area of innovation involves applying new TO/TSO practices in real-time power system monitoring. For example, using angle-differences to manage transient stability limits is a new control-room process that uses established monitoring and modest user interface adaption (TRL 8).

6.5 Derivation and Benchmarking of Project Costs

A tender process was used for the VISOR proposal development (this was capped at £175k including the funding licensee's internal costs). The tender was used to identify suitable partners, helped to raise awareness of the project among suppliers and the wider industry, and provided the latest market price information e.g. contractors daily rates.
Extensive literature review and market due-diligence have been undertaken to ensure confidence in the price estimates in the proposal. For example, the PMU equipment unit cost quoted by a supplier is cross-checked with publicly available prices. In addition to this, the price information is corroborated by *Université Libre de Bruxelles' School for Engineering, Belgium*, which has previous experience of PMU-related research projects.
Other means of cost derivations were:

- WAM system costs, including Phasor Data Concentrator (PDC) and applications were sourced from an external supplier and checked against another independent supplier
- The TOs' internal resource rate has been checked with the RIIO- T1 published data.
- Software developer/Contractors' rate was derived from feedback received from previous tendering processes
- University rates were verified by using records in other previous innovation projects

Project Readiness continued

However, significant price differences have emerged due to potential variations of specifications and/or suppliers availability. For example, a Control-Room level PDC (phasor data concentrator) ranges between £30k-£350k depending on the IT implementation (e.g. the choice of a virtual/physical machine, associated software/hardware licences, maintenance costs and TO IT requirements such as security and backup).

Therefore the prices currently included in the pro-forma represent the best view of the project team and this information is based on active market engagements and suppliers information. As identified in the Risk Register, the market-prices may change significantly with technology and market developments despite the consortium's best endeavours to accurately source the information. Mitigation/Control measures have been suggested under "Total Lifetime Costs" and "Capital Costs" in the Risk Register (Appendix A6).

6.6 Knowledge Accumulation

A dedicated knowledge dissemination work package (WP5) is proposed in this submission's Project Description. A full-time coordinator will be appointed within SPT to ensure that the learning generated from the project are captured and shared among partners and other external bodies. Examples of innovative elements of VISOR's work packages from which knowledge capture would be highly valuable include:

Work packages 4B1 (Methodology for Optimal Placement of monitoring equipment) and **4B2** (Optimal WAMS Recommendations) which start from the engineering decision, review the initial installation results, and generate the purpose oriented optimal PMU placement methodology. This work will be led by academic partners, but supported by the TOs, equipment suppliers and software developers.

Work package 4C (Performance Evaluation, and end-to-end testing) will have direct impact on international standards of PMU manufacturing and data communication, which will facilitate multi-vendor wider area monitoring, protection and control system. This work package will also undertake a feasibility study on the WAMS national roll-out mechanism. Such learning will contribute to the standards of Wide Area Monitoring, Protection, and Control (WAMPAC).

Work Package 2: System Model Validation – here, responses from the offline model will be compared with measurements. Short term outputs would include derivation of transmission line parameters. More complex outputs include a fully evaluated dynamic model of the network.

Work Package 1: Enhanced System Oscillation Monitoring - first implementation of a comprehensive situation awareness platform in the world, to cover the oscillation phenomenon at range of 0-45Hz for the transmission operator and owners. Integrating outputs from various monitoring devices is challenging, but feasible. This work package will apply existing software to a new application.

Work Package 3: Improvements for Management of Stability Constraints – an innovative dynamic measurement system is proposed. This work package will provide a unique opportunity to address congestion on an integrated transmission network with changing inertia.

Given that the B6 Boundary is already congested and will continue to be due to increasing wind generation connections in the north of the boundary, it is unlikely that VISOR will not deliver any system margin or system-health monitoring benefits across the B6 Boundary. Therefore significant contribution will be made in educating the industry and the GB electricity customers. Also, the information and expertise garnered from VISOR would be applicable to other boundaries and data from PMU equipment would be extremely useful for system-health monitoring.

6.7 Risk Assessments and Safeguard Measures

Detailed risk assessment has been carried out on project as a whole and on each work package. The details can be found in Appendix A6.

For Project Delivery, involvement and corresponding interfaces between each project partner and suppliers are critical to the success of the project. Dedicated project managers will be appointed within each organisation, in addition to the project delivery resources identified. Additionally, the two main risk elements identified are the Technical Specification document and Software Development. The Technical Specification (TS) will be a comprehensive document to set out the existing network (and related infrastructure) conditions (across different TOs), and the expectations on equipment to be deployed. Active industrial engagements are on-going to ensure that the technical specifications are innovative, fit for purpose and achievable. Examples of such engagements can be found in the Section 6 and Figure 6-1. One important aspect of the TS is to facilitate market-entry for innovation suppliers. As such, it is important to ensure the TS is not exclusive and can encourage interests from existing/new PMU/WAMS/State Estimator technology suppliers. With this in mind, a clear specification will also help to minimise the risk of delayed software development. The risk of delayed software deployment is also mitigated by active industrial engagement which ensures that suppliers with established track records are used.

With regards to the Work Packages, the most significant risk element will be the Availability of Dynamic model data (with overall risk of 30 in WP2). The risks associated with this element are due to Data Confidentiality and Ownership. Therefore, this element was assigned to the academic partner who as a public body is further covered by the Non-Disclosure Agreement, which will mitigate the concerns regarding conflict of interests. The arrangement is also made so that researchers can work from NGET premises if required.

Integration of SSO monitoring with a PMU-based Wide-Area Monitoring Solution, and Custom SSO algorithms from equipment vendors (WP2) are also identified among the risks. These are the innovative components of the project, and as such represent the risks associated with new product/function development. The mitigation measures are to ensure the tender technical specification stipulates the format in which the algorithms should be provided. SSO Monitoring is also the most time-critical project component, as it is important that monitoring is in place sufficiently early so that a baseline study of system SSO behaviour can be made prior to the installation of Series Compensation in mid 2015. This has been mitigated by placing the highest priority on the procurement and installation of SSO monitoring hardware, and the availability of existing SP and NGET WAMS servers to receive and store their data for later analysis.

6.7.1 Control of Project Over-run

The VISOR project has proposed a dedicated project delivery team, under the guidance of a Project Steering Group (the structure of the project management team and the corresponding description can be found in Section 6.3). Such robust project management will safeguard the interests of investors and will ensure that the project can be delivered on time and on budget.
However, it should also be recognised that a trial project such as VISOR will involve certain unknown risks. Some risks such procurement strategy and known technology risks have been highlighted in the risk register (Appendix A6).

As a precautionary measure against cost over-runs, a contingency cost has been built into the project budget (Appendix A5). This contingency cost is intended to cover the potential known risks such as the differences between the TO/SO internal employees and out-sourced

expertise; procurement risks; potential variations of technical specifications.
Presently, the contingency cost is set as 15% of tendered elements only, a value informed by previous similar R&D projects. It is envisaged that this will provide a back-up and control of the potential project overrun at a reasonable level, as well as a cushion against changes in financial rates. The contingency budget is about 4% of the project total, which represents a balanced view on risk as well as value for money. It is the responsibility of SPT, as a funding licensee, to report the details of expenditure and to return any surplus funding to the Authority in due course.
In the very unlikely event when the project is facing overrun, the Project Delivery Team should be able to identify this and report to Project Steering Group, and the Authority, based on the project management mechanism in place (such a mechanism is detailed in the Contingency Section).

6.7.2 Contingency Plans

Compilation of the risk register is a result of thorough research and discussion among the project team and stakeholders
Regarding those identified risks, corresponding mitigation plans have been put in place as detailed in Appendix A6.
To ensure the risk register can be monitored, reviewed and revised on a regular basis (along with the project development), the project management team will have monthly meetings or tele-conferences to review the risk register, check project developments, highlight new risks and suggest any changes.

The Project Steering Group will have meetings every six months where the project progress report is reviewed and commented. Such a mechanism has been proposed and agreed in the Partnership/Collaboration Agreement (which is under-development) between the TOs.
Given the innovative nature of VISOR, it is expected that some aspects will be challenging so it is important to extract every lesson from the project, even if it is to discount or avoid certain methods or approaches. In the very unlikely event where the project management team identifies circumstances with an impact on the project-scope or the future of the project, the project team will write an Exception Report and suggest possible mitigation actions, and send this to each member of the Project Steering Group. The SPT project manager will call for an emergency meeting for the Steering Committee within 3 weeks upon the submission of the Exception report. The Steering Group will have 3 weeks to make a written confirmation to authorise appropriate actions.

If after assessing the Exception report, the Steering Group agrees with the Project Management Team that the best action is to suspend the project, a formal report from SPT will be sent to the authority. This report would detail the reasons, the meeting minutes and recommendations, and sent to the Authority within four weeks following the decision from the Steering Group, to seek the decision of the authority. It has been aware that such report should provide the Authority sufficient information to enable their decisions, and should be available three months bore it incurs any additional costs.

If the authority grants the VISOR project team permission to halt the project (in line with NIC Governance Document 8.30-8.42) all pertinent documentation and data from project-inception to the point of termination will be reviewed and distributed to project partners. The online portal will be updated with this information and (if appropriate), details on the suspension/termination of the project – to ensure these lessons are understood by supporting projects or future WAM/PMU projects.

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Section 7: Regulatory issues

This section should be between 1 and 3 pages.

☐ Please cross the box if the Project may require any derogations, consents or changes to the regulatory arrangements.

It is not anticipated that the project will require any derogations, exemptions or changes to the regulatory arrangements.

Data Ownership and Confidentiality

VISOR is the first in its kind to be delivered on an integrated GB transmission network, with real-time data from 3 TOs.
The main regulatory issue raised by VISOR is with regards to the ownership of the collected data, their value and secure transmission, data-confidentiality, third-party access, as well as the nomination of agreed standards and protocols for managing such data.

Therefore one of the project deliverables is a detailed study regarding potential changes required to existing regulatory mechanisms such as the STC (System Operator and Transmission Owners Code) and how it may be used to better facilitate more proactive information exchange.

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Section 8: Customer impacts

This section should be between 2 and 4 pages.

8.1 Transmission Network Customers

In Scotland, the term "transmission network" refers to the electricity system with voltage higher than (and including) 132kV; while in England & Wales, transmission network includes the network assets over (and including) 275kV. Therefore, transmission customers will seldom include any individual electricity consumers. The following parties have been identified to have direct interactions with transmission licensees for SPT (and direct impact on the Anglo-Scottish transmission boundary which VISOR is mainly concerned):

- Large renewable generators with direct connection boundary at 132kV and above;
- Large new generators contracted with enabling reinforcements on transmission network;
- Existing/new fossil fuel generators;
- Existing/new nuclear generators;
- Distribution Network Owners

In addition to the parties above, it has also been envisaged that large offshore generators may introduce new Offshore Transmission Owner licensees (OFTOs) in the region as part of their project developments.

As this is a trial project, the VISOR (Visualisation of Real Time System Dynamics using Enhanced Monitoring) team proposes utilising existing Transmission-Owner planned outage-windows to install monitoring equipments (PMU and/or SSO devices) on the transmission network. These equipment devices will not pose any additional risk to the network – this is based on evidence from the past few years of testing and monitoring on NGET & SPT's networks.

Therefore it is not expected that VISOR project will have any adverse impact on transmission customers or require access to customers' premises (as set out in NIC Governance Document, 5.14-5.16). Therefore, there is no requirement for a detailed customer engagement plan as detailed in NIC Governance Document, 8.10.

There is also no plan to have personal data (as defined in the Data Protection Act 1988) involved in any part of the VISOR project. The project team is very mindful about the potential impact on transmission customers, and the indirect interaction with non-transmission customers in the region concerned in the event of roll-out of the system as it will result in the system being run and managed differently.

8.2 Customer-Benefits

With regards to conventional generators, such as nuclear generators, large coal generators where long shafts of synchronous generators are potentially exposed to sub-synchronous oscillation (SSO) risks, this project will provide baseline information to support risk-mitigation strategies.

For the new renewable generators in the region, such as onshore or offshore wind farms, the outcomes of the project will provide a timely tool to un-tap the transmission potential without compromising the reliability and security of electricity supply.

The timing of the VISOR trial is highly appropriate given the impending deployment of series compensation and the commissioning of the Western HVDC link.

A conservative estimate of capacity constraint saving of 50MW for 50% of time should

Customer impacts continued

result in an annual saving of £4m. This significant cost saving would feed through into GB consumer bills. Also, the VISOR project can provide significant value to the GB consumer through system risk mitigation and incremental capacity increase across constrained boundaries.

8.3 Dissemination of information to interested parties

Upgrades or improvements to the transmission network will interest the wider community such as:

- Local, regional and national government bodies;
- Academic/research institutes;
- Equipment/technology suppliers;
- Any individuals with an interest in the "health" of transmission assets or supply reliability

The project team will make use of every possible forum to keep the customers (and other interested parties) informed. A transmission stakeholder engagement workshop was organised in June 2013 by SPT. Over 50 participants who represented a wide variety of stakeholders had the opportunity to listen to and discuss the VISOR proposal.

The Knowledge Dissemination work package (WP5 and Section 5) has taken into account the important nature of customer and transmission network stakeholders' involvement. Regular on-line publication (such as Project Progress Report) and Annual Innovation conference become two principal channels to distribute the learning captured from the project, and keep customers informed. In addition, the trial equipment will provide the interested parties first-hand opportunity to understand the technology innovation and its function in future transmission networks.

Tailor-made training courses will further provide educational opportunities for customers (and their staff).

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Section 9: Successful Delivery Reward Criteria

This section should be between 2 and 5 pages.

Criteria 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

Evidence 9.1

- SSO Device qualification report (WP 4C, Dec 2014)
- Visualisation of multiple SSO information sources at data centre (WP 1A, Dec 2014)
- Baseline and comparator report for SSO behaviour (WP 1, March 2015, March 2016, March 2017)

Criteria 9.2
Enhanced stability tools delivered, including Oscillation Source Location and Disturbance Impact

The applications to analyse and present stability information to real-time and analysis users is a key part of the project. The applications should be delivered and the necessary enhancements made to fulfil this criterion. Also, the test cases to prove and demonstrate the applications to end users are important for knowledge dissemination. The delivery includes:

- Oscillation tools delivered to display wide area oscillations, including oscillation frequency, damping and mode shape
- Source location tools for identifying contributions to oscillations
- Disturbance detection, location, sequence and impact measures in application to manage high impact / low probability events
- Review of the implications for future roll-out of PMUs for full GB-wide use of the applications

Evidence 9.2

- Applications delivered and configured to include (WP 1.2, 2.3, March 2016)
    - Geographic oscillation alert presentation
    - Oscillation source location presentation for analysis & real-time
    - Disturbance detection, location identification and impact measures
- Report on PMU roll-out requirements for the applications (WP 4B, March 2017)
- Simulation cases for presentation & training (WP 5.2, March 2017)

Criteria 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

Successful Delivery Reward Criteria continued

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

Evidence 9.3

- 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)

Criteria 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

Evidence 9.4

- 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)

Criteria 9.5

Successful deployment of the supporting infrastructure of the VISOR project.

The base infrastructure required to collect, store, display and communicate phasor data is critical for the success of the project. This infrastructure should be installed and proven, with adequate performance, and the data linkages between the TO/TSOs implemented to confirm that this part of the project has been delivered. The criteria for delivery are:

- Data centres running in SPT, NGET, SHE Transmission, collecting PMU data from own network, including real-time visualisation, storage, and communications (Dec, 2015)
- Central VISOR server and inter-TO data exchanges running
- Optimal GB roll-out investigation

Evidence 9.5

- System specification and supplier contracts awarded (April, 2014)
- System commissioning report (WP 4A, Dec 2015)
- Visualisation of data in SPT, NGET, SHE Transmission including real-time and historic (WP 4A, Dec 2015)
- Roll-out report (WP 4A, Dec 2016 - March 2017)

Criteria 9.6

Successful dissemination of knowledge generated from VISOR project.

Knowledge dissemination within the transmission network owner is a key component to transfer experience for the pre-trial training and post–trial knowledge exchange. The key objectives of this work package are to successfully achieve the following:

- Internal knowledge dissemination
- External knowledge dissemination
- Influencing and updating policies and standards
- Public Engagement

Evidence 9.6

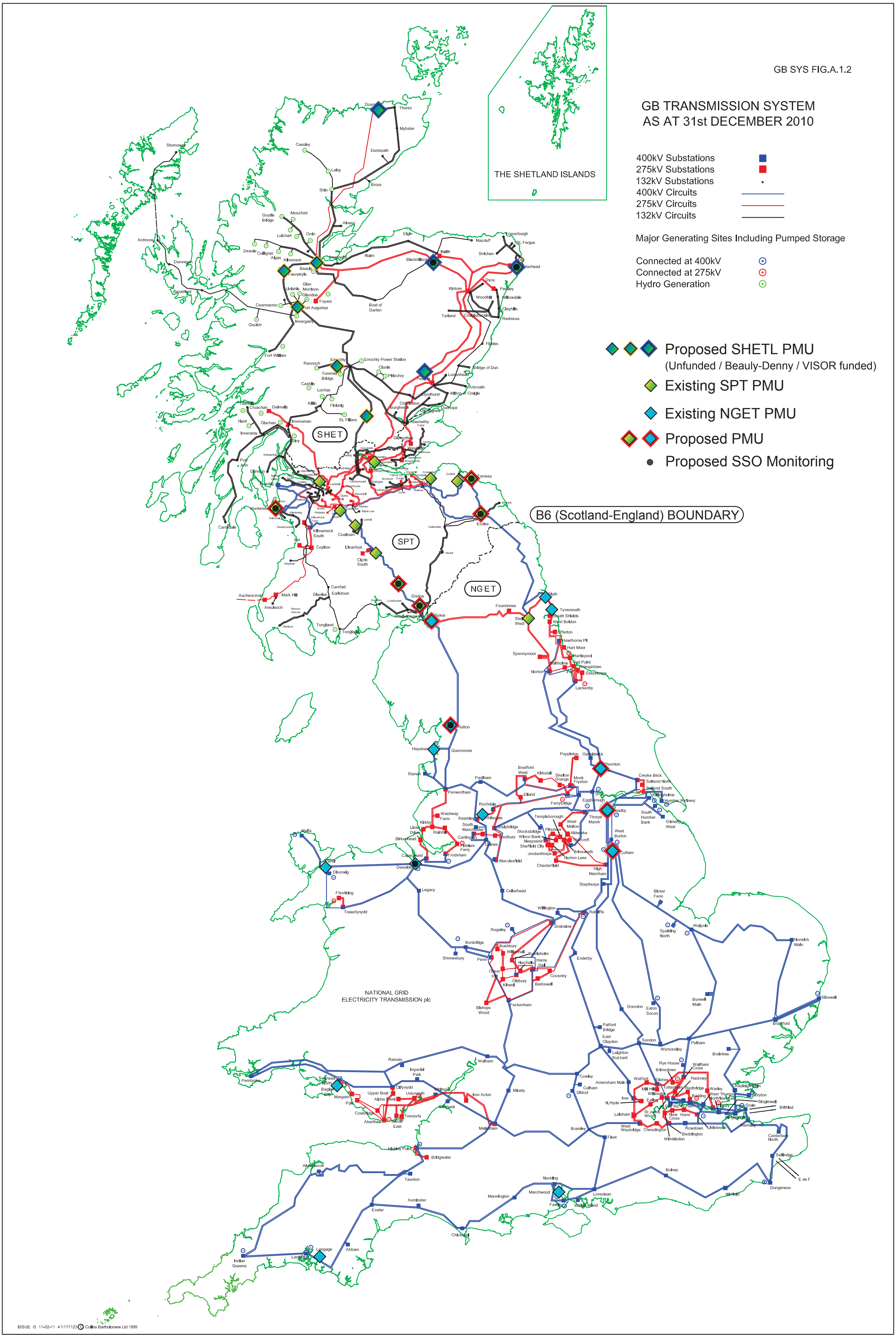
- Establish on-line portal and keep up to date throughout project (WP 5.2, Sep 2014)
- Timely delivery of project progress reports (WP 5.4, Sep 2014, Mar 2015, Sep 2015; Mar 2016, Sep 2016, Mar 2017)
- Academic partner delivery of knowledge capture and publications (WP 5.2, Dec 2016 - Mar 2017)
- Presentations and show-casing at the annual innovation conferences (WP 5.4, Dec 2014, Dec 2015, Dec 2016 and June 2017 for Close-down report dissemination)

Electricity Network Innovation Competition Full Submission Pro-forma

Section 10: List of Appendices

Appendix	Item and Short Summary
A1	Ofgem Full Submission Spreadsheet (**CONFIDENTIAL**): Fully populated cost spreadsheet according to Ofgem template.
A2	Proposed and Existing PMU & SSO Monitoring: Map showing location of existing PMUs and proposed locations of those to be installed for VISOR
A3	Detailed Project Description: Detailed description of Work Packages 1 to 4 of the VISOR project. Work Package 5 is fully described in Section 2: Project Description
A4	Work Package Delivery and Responsibilities, Organogram: Project Structure, Responsibilities and Work Package timeline
A5	Costs Breakdowns of Project Delivery (**CONFIDENTIAL**): Detailed cost breakdown for the project, per work package, participant and cost category (e.g. labour, equipment, software etc)
A6	Project Risk Register, Risk Management and Mitigation and Contingency plans: Detailed Risk Register, scoring, contingencies, mitigation measures etc
A7	Project Partner Details: Description of the main Project partners
A8	Letter of Commitment from SPEN MD: A Letter of Commitment from the Scottish Power Managing Director
A9	Letter of Commitment from TO partners
A10	Letters of Support from External Stakeholders and International Advisers: Excerpts from various leading organisations which have expressed their support for VISOR and its objectives
A11	Base Case Cost Calculation & Description: Cost Derivation and a Summary of the Business Case for the project
A12	Equipment Technical Specification: This describes the technical specification of the PMU and SSO equipment to be installed for the VISOR trial
A13	Suppliers engagement record (**CONFIDENTIAL**): A record of the stakeholders, present and prospective suppliers involved in this project
A14	Evolution of Full Submission Pro-Forma / Revisions after panel: Capturing revisions or amendments made to the pro-forma after it is submitted
A15	Literature Survey: Summary of Literature surveyed for the technical aspects of the project
A16	Glossary of Terms: Definitions of acronyms and abbreviations

Appendix A2 - Proposed and Existing PMU & SSO Monitoring



Appendix A3: Detailed Project Description (This document contains detailed technical explanation of Work Packages 1 – 4. Work Package 5 is fully explained in the main Pro-Forma document)

Introduction

The growth of renewable generation profoundly changes the loadflow patterns and dynamic performance of the GB power system. New stresses are introduced by significant power flows from remote, renewable energy rich areas that are weakly connected. The dynamic characteristics of the grid also change through the use of fast-acting power electronics without the inertia of conventional generation. There are now more flexible options for controlling the network to transfer more power through existing lines, however, the introduction of new technologies introduces risks of interactions and instability across the network.

The VISOR project introduces a new monitoring technology for addressing uncertainties and volatility in the physical limits of the grid, and for identifying early warning signs of potential instability. A particular focus of the VISOR project is the constraints in the Scotland-England (B6) boundary, related to transient stability, and the risks associated with the introduction of series capacitors to raise the constraint.

The project makes use of synchronised Wide Area Monitoring (WAM) of magnitude and relative phase of voltage and current signals (synchrophasor measurements) at a rate that reflects the dynamic characteristics of the system. By contrast, conventional monitoring using SCADA systems capture asynchronous measurements that reflect only the steady-state condition of the grid, typically 200 times slower than WAM technology.
New approaches based on synchrophasor measurement can reduce the uncertainties in the operation of the grid and observe emerging stability issues at an early stage. The technology also supports new applications with a geographic view of the stresses and oscillation issues in the grid, allowing more intuitive warnings and problem-solving. In this project, the observability of dynamics through WAMS is extended to include higher frequency Sub-Synchronous Oscillation (SSO), using synergies between WAMS and SSO monitoring where practical.

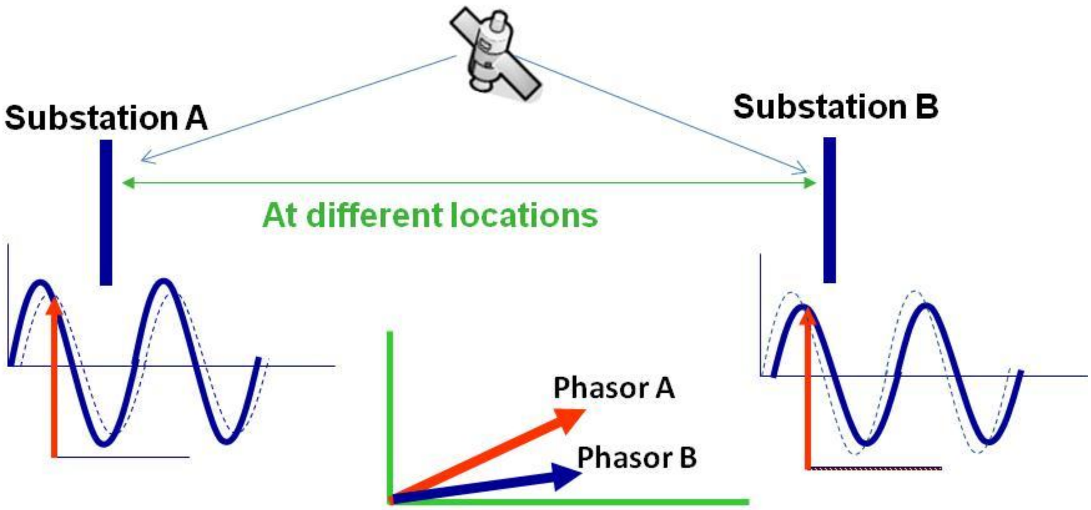


Figure 1: Synchronised Measurement Technology

By synchronizing the sampling processes for voltage/current measurement - which may be hundreds of miles apart, their phasors can be put on the same phasor-diagram and used in a single application. Without the time synchronisation, the phase-angles would be meaningless.

WP1 Enhanced System Oscillation Monitoring

The introduction of actively controlled technologies in the transmission system asset base affords opportunities for more effective use of assets, but also introduces new issues around stability that involve interaction between equipment managed by various stakeholders including the three transmission owners, generation suppliers, and the system operator. The design and operation of the control systems and overall defence against potentially high impact events requires collaboration between the stakeholders to ensure effective, efficient and secure use of the assets.

One of the goals of the project is to demonstrate a wider frequency range of oscillation monitoring than has previously been available. Previously, the focus was on the frequency range between 0.04Hz to 4Hz, covering mainly electromechanical oscillations, whereas the developments will extend the frequency range at both ends from 0.002Hz to 50Hz, and provide geographical capabilities to observe participation and contributions.

Issues with stability of oscillations have generally been effectively managed in the past, however, the structure of the power system is changing so extensively that there is a recognised need to introduce a much more detailed observation and management facility to identify new risks to the system operations and asset integrity at an early stage.

WP1.1 Sub-Synchronous Oscillation

There are various Sub-Synchronous Oscillation (SSO) issues that must be considered with adoption of new technologies to the grid, as there is potential for complex interactions between network and generation plant. There are various forms of SSO, including the well-documented Sub-Synchronous Resonance (SSR) phenomenon where series capacitors and line inductance create a network natural frequency that interacts with torsional natural frequencies in long-shaft generators. Other forms of SSO include Sub-Synchronous Torsional Interaction (SSTI) involving HVDC controls interacting with generator shaft torsional oscillations, and Sub-Synchronous Control Interactions relating to DFIG or fully converted wind farms interacting with series compensation. In this project, the focus is on SSR relating to the series capacitor installations across B6 and the potential for interaction with thermal generation, however the learning outcomes can readily be applied to other forms of SSO.

A significant amount of study work goes into avoiding SSO by design, but due to the potentially serious impact of SSO, it is important to mitigate the risk of SSO occurring in unusual operating conditions. SSO could occur in situations that were not predicted due to modelling uncertainty or the impracticality of testing all possible disturbed network scenarios. It can also arise in future as new equipment is added to the system.

The conventional approach to SSO risk mitigation includes:

- Exhaustive model-based study prior to installation of series capacitors
- Detailed review of SSO when any susceptible equipment is added, including wind farms, or any new transmission infrastructure alters the effective impedance
- SSO-based tripping mechanisms recommended for susceptible generation

There are drawbacks to the conventional approach, such as:

- The extent to which model-based study can capture all of the risks, and the possibility that problems are discovered only after an event has resulted in a significant disturbance or damage to plant
- The need for repeated exhaustive study
- Longer-term, but weaker interaction may go undetected and result in early equipment failure.

It is noted that new Grid Code provisions requiring Synchronous Generator owners to provide information for study of Sub-Synchronous Oscillation have been proposed by NGET following Industry Consultation in the Report to the Authority[1].

By nature, the strength of the interactions between oscillations depends on how close the interacting frequencies are, and on how closely the affected equipment is electrically coupled. There is therefore considerable benefit to be gained from observing early warning signs of SSO, and comparing with a baseline of measured oscillation performance. The goal of this work package is to demonstrate

- A centralised visualisation and archiving of SSO
- A baseline of normal performance
- Warnings and alarms on heightened risk
- Information on natural frequencies in normal (not resonant) conditions
- Input to other projects relating to source location and automated SSO management

A centralised view of the SSO behaviour is valuable to enable operator warnings that can be associated with specific guidance. Typically, the mitigation actions include:

- Changing the effective impedance of the network segment creating the resonance through, for example
    - Changing the generation dispatch in the region
    - Changing the network topology, e.g. bus tie split
    - Using Quad Boosters, if available
- Re-dispatch of affected generation to change the torsional mode frequencies
- Operator-instigated bypass of series compensation
- Automatic bypass of the series compensation

The outputs of this work package include demonstration of:

- A system to continuously monitor, log and alarm on SSO behaviour in the range 10-45Hz (using new equipment)
- Feasibility of using existing fault recorders (or Disturbance recorders) to extend geographic visualisation with discontinuous observations
- Geographic visualisation of SSO behaviour, showing location and relative amplitude through consistent analysis processes applied to various data sources

WP1.2 Oscillations Analysis & Source Location

Low frequency oscillations occur in every power system, and are a natural result of rotating machines and the effect of active control systems. Usually, these oscillations are well damped, however unstable oscillations have been experienced in the GB system. In the 1980s, there were several occurrences of the behaviour illustrated in Figure 2, which shows about 1000MW oscillations in power cycling every two seconds (i.e. 0.5Hz oscillation). The problem was resolved at that time through installation of generator excitation control loops known as Power System Stabilisers (PSSs) to introduce damping. Continuous monitoring of the stability of oscillations was applied in the SPT and NGET control rooms and the observed performance was used as part of the justification for constraint relief in the B6 boundary in the 1990s and early 2000s, and has been used continuously as an alarm in the NGET control room since then.

While the mode at 0.5Hz between Scotland and England still exists, it is now consistently stable. However, with changes in the generation profile, technology, loadflow patterns, inertia etc. new oscillation issues may arise, and it is important to manage the early warning signs of stability risks to avoid large-scale disturbances. More recent reviews of dynamic behaviour have revealed that examples of unstable oscillations occasionally do occur (as in Figure 4), and that there can be other wide area oscillations, such as a

[1] GC0040 - Information Required to Evaluate Sub-Synchronous Resonance (A/12), Report to the Authority, 27th June 2013

0.7Hz oscillation mode involving much of the GB network. While significant instability is a rare occurrence, the fact that it can occur demonstrates that the issue must be managed as a risk in the context of the network development.

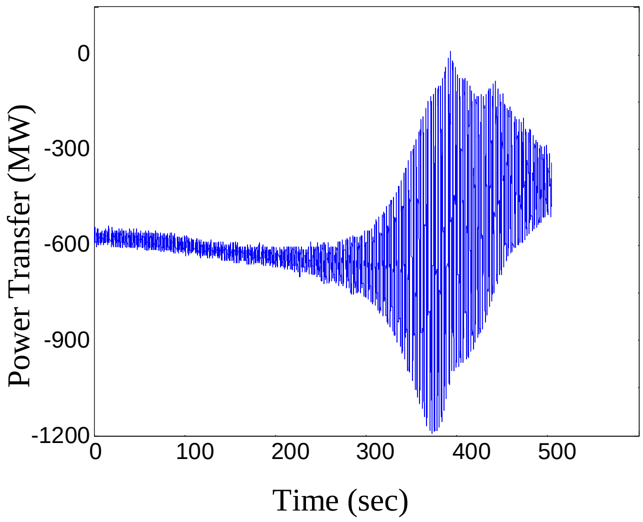


Figure 2 Example of Unstable 0.5Hz Oscillations in Scotland-England Transfer, 1982

The experience of real-time oscillation monitoring in the GB network was focused on detecting only the occurrence and not the location of contributions to the problems. Furthermore, the problems with oscillations are often related to equipment malfunction or unforeseen interactions, and such effects are seldom easily replicated using conventional modelling approaches[2]. Using new techniques applied to synchrophasor measurements, the location of contributions to oscillations and changes in these contributions with dynamic changes can be identified.

The sources of oscillation can be identified to the nearest voltage phasor measurement, through the use of accurately synchronised measurements of the relative phase of oscillations. It should be noted that the sources of negative damping contributions do not necessarily coincide with the largest amplitude, and there are also oscillations that affect the whole power system uniformly, ie the frequency of the whole grid varies with the same oscillation amplitude, and almost exactly in phase.

It is intended in this project to demonstrate a GB-wide monitoring system to provide visibility of:

- Damping, amplitude and phase of dominant modes of oscillations, shown in a geographic context
- Continuous records of oscillation characteristics over an extended period of time
- Baselining the current system behaviour in terms of the normal behaviour and occurrences of poor damping or unstable events in the GB system
- Determining the location of generation contributing to oscillations and presenting this in real-time for operational guidance, and off-line for event analysis. The approach will differentiate locations where there is an active contribution to the oscillation, distinct from locations that are responding to a grid oscillation.

[2] **Discrete Control for Transient Stability and Oscillations: Applications and Case Studies**, D. H. Wilson, N. Al-Ashwal, H. Halldorsson, S. Boroczky, IEEE PES General Meeting, Vancouver, Canada, July 2013

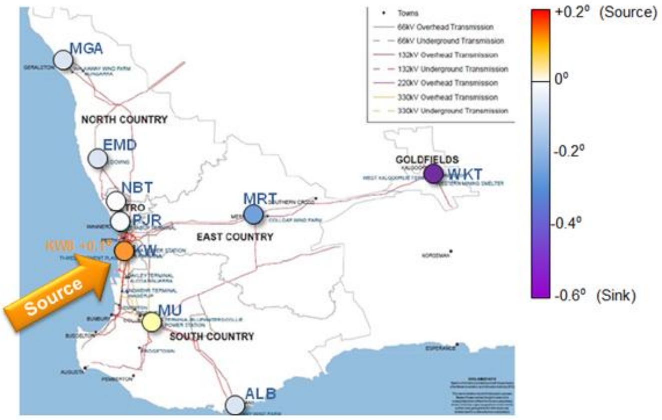


Figure 3 Example of Source Location of 0.045Hz Oscillation in the Western Australian Power System

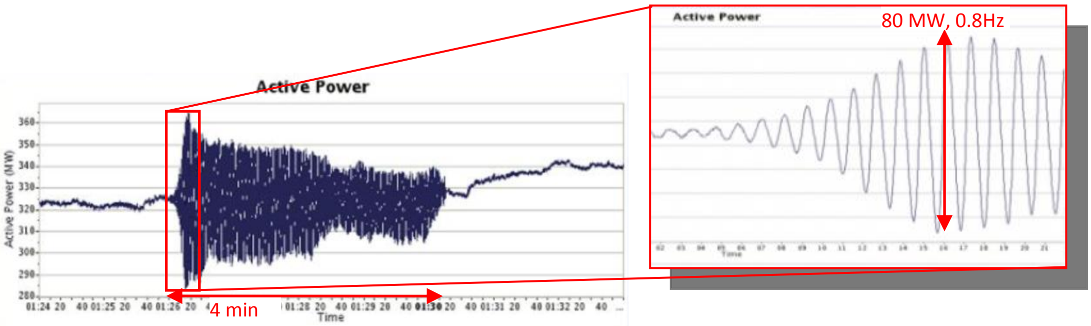


Figure 4 Example of GB System Unstable Oscillation, 2011

WP2 System Model Validation

Network models are used extensively by the transmission licensees for system planning and system operation activities. The static and dynamic models are critical for the definition of transfer constraints, the design of control systems, and interpretation and resolution of problems occurring in the grid. It is important that the models can be demonstrated to be sufficiently accurate to provide precise constraints. Any problems that may affect the validity of the conclusions drawn from it should be identified and rectified promptly. Modelling is a simplification of the actual behaviour of the system, and applied in such a way that the model-based representation is generally conservative compared with the actual system behaviour.

Synchrophasor measurement is a key technology for model validation, enabling:

- Continuous visibility of the dynamic response of the system, which can be directly compared with simulated behaviour
- Identification of locations where plants are degrading the stability of oscillations, often an indication of a deviation of the plant from modelled behaviour
- Direct validation of steady-state load flow modelling using angles, independent of the network model assumptions
- Since the data is wide-area and time-synchronised, it is very valuable for post-event reconstruction, and simulations reconstructing the event can be validated.

The applications to be trialed in this work package relate to modelling that influences the B6 boundary, but can also be applied more generally to the quality of static and dynamic models and other boundaries.

WP2.1 Line Parameter Estimation

Transmission line parameters are modelled as fixed values in the network model, assumed to be the same for all three phases. However, in reality, the values vary with weather conditions and loading, and since GB transmission lines are not transposed, there is a difference between the phase values due to the different conductor heights and position relative to each other.

Transmission lines are usually represented as PI-model equivalents with series resistance and reactance, and shunt capacitance. In the real world, weather conditions including temperature, wind speed, moisture and severe conditions such as ice loading will affect these parameters. Figure 5 shows an example of the variation of line parameters over time, measured using synchrophasor measurements.

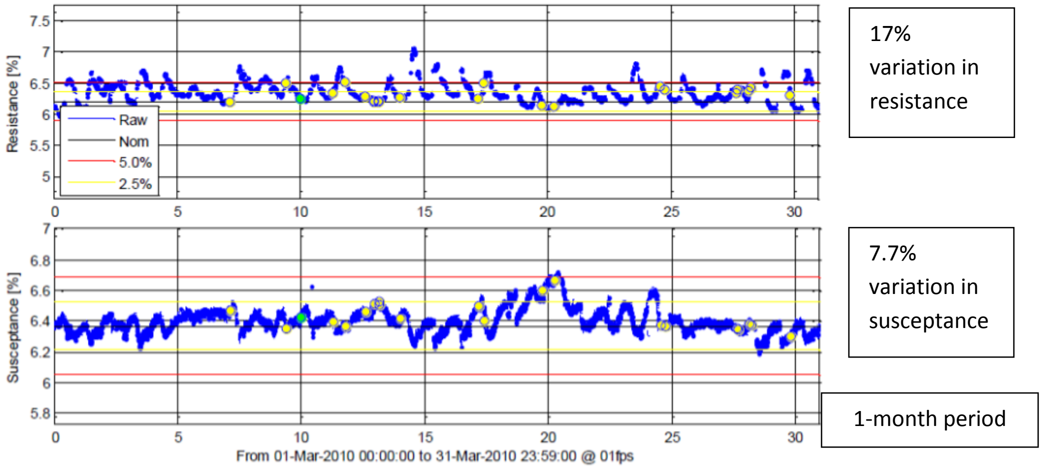


Figure 5 Illustration of variability with line parameters estimation using synchrophasor measurements over 1 month of measurements

The significance and practical implications of line parameter variations relate to the effect on transfer constraints. In particular, it is intended to look at the effect of parameter variation on the physical boundaries (e.g. transient stability) and on the precision of the measurements derived.

Line parameter estimation has been demonstrated using synchrophasor measurements in various locations around the world. However, existing line parameter estimation methods are error sensitive. By contrast, the proposed approach is self-correcting to achieve consistent and reliable results.

WP2.2 Oscillation analysis validation

Power system oscillations are modelled through assessment of the system's response to small disturbances. The power system has several natural frequencies of oscillation, and these can be characterised by:

- Frequency and damping of the modes of oscillation
- Relative amplitude and phase of the oscillations, or the "mode shape"

Estimates of the equivalent values can be extracted for the dominant modes of oscillation through analysis of synchrophasor measurements. A comparison can be made between the model-based estimates of oscillation parameters, and the measurement-based estimates.

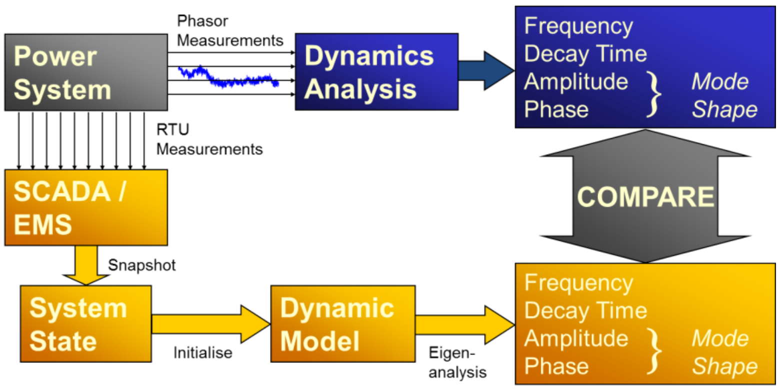


Figure 6 Process of Dynamic Model Validation for Oscillations

In the experience of oscillation monitoring in many power systems and interconnections worldwide, it is noted that there are distinct periods of time in which the damping of a particular mode is degraded. There are various reasons for this, but the dynamic model seldom captures this behaviour accurately. It is therefore important to use measurements to identify where the problem occurs, in order to identify whether it is a problem with the model, or a malfunction of the connected plant. The same oscillation source location method described in WP1 will be applied to Model Validation.

WP2.3 Transient Stability Simulations

Disturbances that happen from time to time in the network can be used to assess the quality of the dynamic model of the system. These events can be used to compare the power system's measured response with the simulated response to the same disturbance. Any significant deviation in behaviour between the simulated and measured wide-area response should be investigated, particularly if the measured response is closer to instability than the simulated response.
The model validation approach is as follows:

- Using WAMS, identify disturbances of interest using triggered event detection, particularly focusing on events that influence the relative angles across the B6 boundary (typically faults occurring in Scotland). Disturbance impact measures will be used to select key events.
- Create a disturbance report automatically from the WAMS measurements, focusing on presenting the angle, power and frequency behaviour at key locations. The report should help to identify a sequence of events for simulation.
- Create a simulation of the same signals using a pre-event snapshot from the SCADA/EMS system and introduce the sequence of events defined jointly by WAMS and the EMS systems, adjusting for fault impact.
- Compare the simulation and measurement results, noting in particular any conditions in which the measured angle and/or frequency movement is greater than the simulated movement.

It should be noted that this element will be collaborative between the TO/TSOs, academic partner and WAMS supplier, in order to trial facilities that are intended to reduce analysis effort and make the measurement and simulation comparisons as straightforward as possible. WAM-based post-event analysis tools will facilitate easy selection of suitable disturbances for validation, and reporting and presentation of these events. Post-event reporting will also use geographic representations of the event for an analyst to visualise the effect of the disturbance on the wider network.
A learning outcome of this work package is to define the most effective reporting approaches for analysts to carry out model validation as efficiently as possible.

WP2.4 Generator Model Validation

Validation of the generator and its associated controllers is important for the overall quality of dynamic modelling, and is particularly important for defining the transient stability limit. Conventional generator model validation involves invasive tests and outages. Consequently there are very limited opportunities for generator model validation beyond commissioning tests, and generally it is necessary to observe a problem before further validation is carried out.
In this project, a process of generator model validation is proposed that uses naturally occurring disturbances to system frequency, and controller voltage, frequency or power setpoint changes that can be applied with the machine on-line. The use of wide-area monitoring is valuable to capture the interactions between the plant and the system. With suitable monitoring and models, it is possible to optimise the model parameters to find the best match to observed performance, and use this to identify the most likely sources of error.

WP3 Improvements for management of stability constraints

In various system conditions, the B6 boundary is constrained because of transient stability, voltage stability or thermal limits, depending on the conditions in the network. Of these constraints, transient stability is currently the most significant limitation in the B6 boundary.

Identifying transient stability constraints using a model in current practice is a computationally intensive task. In the current GB practice, this is done typically 4 hours or more in advance. The transient stability transfer constraint is dependent on variable factors and the inertia of the exporting region. Worst-case assumptions taking account of the wind variability in specific key locations (particularly within the boundary) can affect the stability constraint.

There are approaches to reducing the computation time for model-based constraint calculation to near-real-time, reducing the uncertainty in operating state. This is carried out using a family of tools known as Dynamic Security Assessment (DSA). The learning outcomes of this project include identifying and comparing the relative benefits in the GB system of:

- Improving the accuracy of initialising stability assessment by including phasor measurement in State Estimation
- Reducing the time required for constraint calculation, allowing for simplifications inherent in the process
- Including angle difference in addition to MW in the expression of the constraint.

WP3.1 Understanding Uncertainty

There are various uncertainties that limit the capability to operate to the physical capability of the system, arising from the following sources:

- **Computer model and parameter confidence** Transient constraints levels depend on the accuracy of the dynamic modelling of the system
- **System and forecast volatility** depending on the wind forecast, and conservative assumptions to define the maximum MW transfer.
- **Measurement confidence** noting that SCADA measurement is not always precise or accurately time-aligned.

Of these, the system and forecast volatility is the most significant, as it depends on the wind generation, which can vary rapidly, and in the case of the B6 boundary, relatively local wind effects can influence strongly.

Computer model and parameter confidence is investigated in a number of ways, noting that WP2 results will be used. Line impedance accuracy and variation will be assessed over a long period. Disturbances (including relatively small events such as line switching) will be used to compare with simulations and determine whether the transient simulations are optimistic or pessimistic. If the actual angle movement is smaller than the simulation, then it can be assumed that the model is pessimistic and there is a built-in safety margin.

System and forecast volatility will be investigated through a series of transient stability studies based on observed variations, and evaluating the stability margin that is actually available compared with the limit that would be applied with a conventional approach and forecast time periods. The effect of using the angle limit approach (described in WP3.3) will also be evaluated.

Measurement confidence is assessed using the outcome of WP3.2 on State Estimation, noting that the State Estimator output and PMU measurements should be consistent. If not, some investigation will be carried out where mismatches occur to explain the deviations, and identify what source(s) are most accurate.

WP3.2 Improvement of Model Initial Conditions

State Estimation provides an error-corrected solution of the network operating point that is used directly for observation, and can also be used to initialise other network applications such as transient stability analysis. In the GB system, State Estimation solutions are not yet used to initialise stability analysis, but there is work being undertaken to do this, thus increasing the dependence on SE.

The process of State Estimation conventionally uses slow-scan P, Q, V and breaker status throughout the system and derives a consistent set of values defining the operating state, and minimising measurement errors. The topology of the network is identified from breaker status, and then with the use of the network model, the State Estimation solution is derived.
This solution is then used to present more accurate measurement results than raw SCADA data, and can be used to initialise voltage stability and transient stability analysis processes, where contingency scenarios and loading variations are introduced. The State Estimation solution is important for observation and as a starting point for identifying constraints, and the dependence is expected to increase with the inclusion of transient stability assessment.

The challenges in conventional State Estimation include inaccuracy and lack of time-alignment of the raw data, loss of measured data sources, and the vulnerability to errors in the topology identification.

A reliable State Estimation solution is important for network supervision and contingency analysis. The report on the August 2003 blackout affecting 50 million people and shedding 70GW load states:[3] *"In summary, the MISO state estimator and real-time contingency analysis tools were effectively out of service between 12:15 and 15:41 and were not in full automatic operation until 16:04. This prevented MISO from promptly performing pre-contingency 'early warning' assessments of power system reliability during the afternoon of August 14."* The improvement of the State Estimator and associated tools was included among the binding NERC requirements.

Following the widespread failure of the European Grid system in November 2006, an EU FP7 funded a project "PEGASE" - Pan-European Grid Advanced Simulation and State Estimation, concluded that there were significant benefits to be gained in the integration of PMU's and State Estimators to provide enhanced situational awareness and security tools for grid system operators.

Synchrophasor measurement provides accurate measurements that are time-aligned to microsecond accuracy. Moreover, synchrophasor measurements directly measure the voltage and current phasors that the State Estimator derives as its output. Theoretically, the State Estimator solution could be based entirely on synchrophasor measurement, which would be a very fast and accurate approach, however the installation cost would be prohibitively expensive. The intention of this work package is to trial a Hybrid State Estimator approach that includes synchrophasor measurements as well as SCADA data as input, and investigates the improvement in quality of the State Estimator solution and its effect on constraint calculations.

The solution quality is assessed both in terms the accuracy improvement, and the robustness of the state estimator. The robustness is critical if the state estimator solution is used to initialise Dynamic Security Assessment to derive real-time constraints. The project will consider the implications for PMU placement. The comparison will include:

- **Accuracy improvement** in terms of reduction in an error function
- **Convergence** involving the number of unsolved cases for the two processes
- **Validity** assessing the number of major deviations, for example due to topology error or missing data.

[3] Technical Analysis of the August 14, 2003, Blackout
http://www.nerc.com/docs/docs/blackout/NERC_Final_Blackout_Report_07_13_04.pdf

Figure 7 shows the VISOR State Estimation comparison, in relation to the existing State Estimation process and the transient stability assessment under trial. The VISOR project will determine the business value to creating a PMU-capable State Estimation process.

The State Estimator process will run in a separate environment, with no interaction with the operational system. The necessary model, SCADA measurements, topology, and WAMS measurements will be provided as files. Dynamic simulations will either be taken from existing system or operational planning tools, or if available, from the new Dynamic Security Assessment tools.

The focus of the project is on the network between Central Scotland and the Midlands, characterising the measurements most influential in the B6 boundary. Practically, it is noted that this area is monitored more extensively than other area of the GB network, and angle differences are significant because of the corridor length. Thus, this section of the network is a good testing ground for evaluating the Hybrid State Estimator concept.

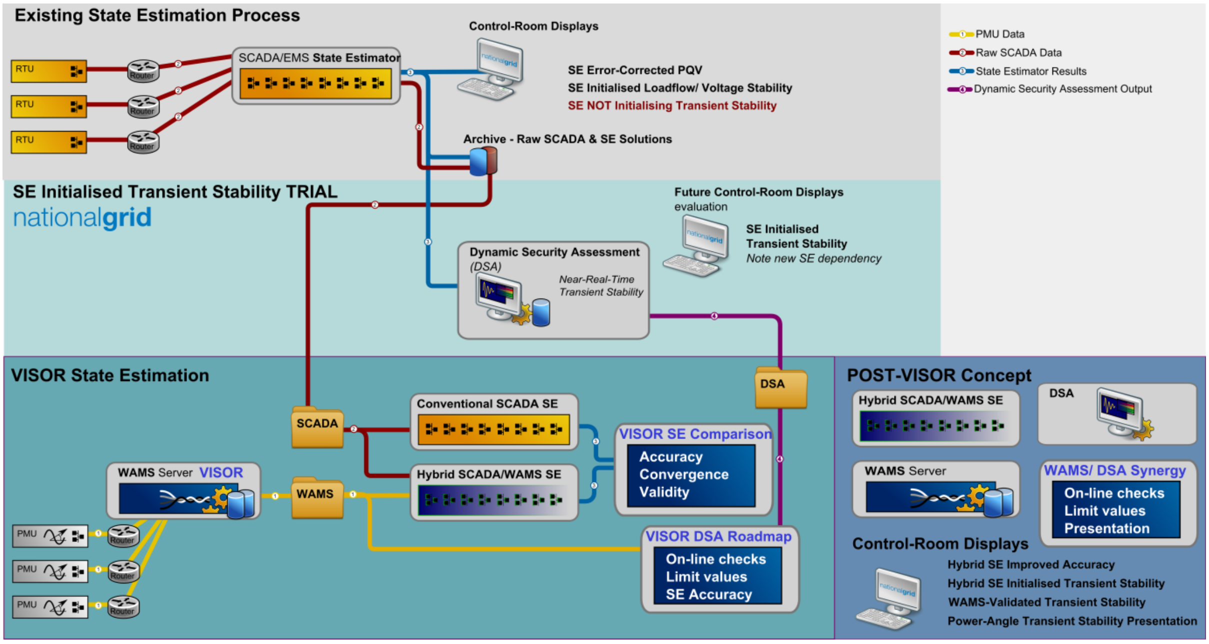


Figure 7 Implementation of Hybrid State Estimation in VISOR, and its relation with existing processes and the related Dynamic Security Assessment project

WP 3.3 Improved visualisation of stability limits for operators

The B6 boundary is a collection of lines forming the corridor between Scotland and England, and there is a significant injection from about 1.5GW of wind power capacity in the border region. The stability studies to derive the constraints result in an active power (MW) value which is the summation of power flows. A change in wind injection within the corridor will change the MW transfer capability for flows across the B6 boundary.

The transient stability limit of a boundary is the limit at which a critical fault results in generation acceleration leading to loss of synchronism. This loss of synchronism is often illustrated in literature with reference to a Power-Angle curve, and a simplified representation of the B6 boundary problem is shown in Figure 8. The Power-Angle curve illustrates the energy that accelerates generation during the fault (thus advancing its angle), and the trajectory after the fault has cleared, noting that the corridor may be weakened by line disconnection. For similar pre-fault synchronous generation scenarios, but different wind scenarios, it can be seen that there is a significant change in the critical MW limit, but a much smaller change in the critical angle limit. This suggests that angle difference between the areas is a much more stable (ie less wind-dependent) value to characterise the limit than power through the boundary cut-set.

Until recently, it has not been possible to measure angle difference, and therefore the only way to characterise the stability of the system has been using power flow. It is now feasible with commercially available equipment. In the VISOR project, the concept will be explored to improve the practical presentation of the boundary limit, and therefore provide a better means to manage the volatility.

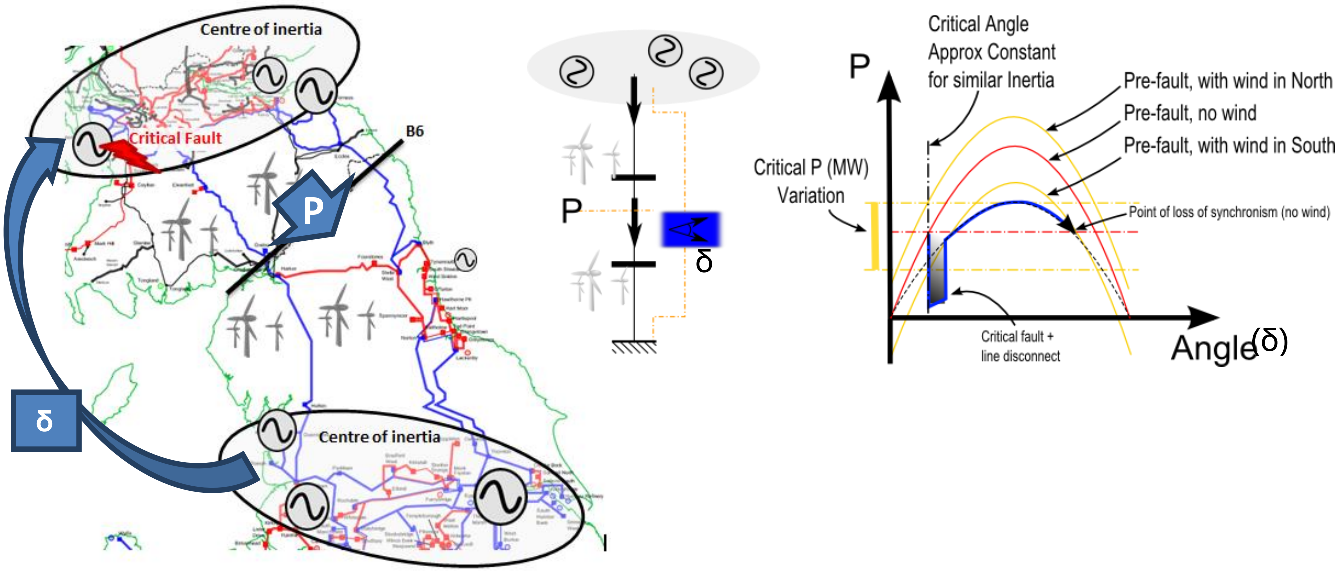


Figure 8 Transient Stability in B6, and Angle Transient Limit Concept

In this project, the expression of the limiting scenarios as angle differences will be investigated, with a view to:

- Identifying the equivalent angle difference measurement that best represents the whole corridor, making use of a group of measurements at each end
- Investigating the variation of angle constraint values in comparison with MW constraints, particularly during periods of rapid variation
- Identifying the short-term MW transfer capacity variation converted from the margin maintained from the angle constraint
- Evaluating the practical economic benefit over an extended monitoring period

WP 3.4 Trial the reliability of area angle measurements

For an angle difference to be used to in visualising and alarming on a transient stability limit, it is necessary that the measure is reliable, and does not create spurious alarms. Variations may occur because of measurement issues or because of the natural random movement of the power system. Furthermore, if the measure is found to be of value in representing transient stability, it could be useful in future to apply to HVDC control. In the scenario of closed-loop control, there is no human judgement to recognise a false measurement and the signal quality is even more important.
There is an aggregation process applied to the raw angle signals so that a single measure can be used to represent angle difference between the centres of inertia, while there may be measurements taken at several points within each area. This process will be tested for robustness against measurement loss / inaccuracy, or topology change.
This task will review the reliability and self-consistency of raw angle measurements over an extended period of time. Outlier values will be reviewed in detail, to determine whether they represent true movement of the power system, or measurement noise. The task will involve assessing how to handle outlier values, and will inform future data quality requirements and application requirements to avoid spurious results.

WP4 Supporting Infrastructure

The supporting infrastructure is illustrated in Figure 9, and comprises WAMS, SCADA/EMS, and modelling tools at various locations. Since the project is intended to demonstrate the value of the solutions in the GB system, it is important that the

information and tools are made available to the TO/TSOs, as they would be seen in a permanent installation. However, requirements around the State Estimation and simulation work require only off-line information for studies.
Since PMUs measure at typically 200 times the rate of RTUs, the archiving of the data must be carried out in a way that is viable for long-term implementation. The study and review aspect is important both for the learning in this project and for future WAMS implementation, and therefore the archiving facilities are a key part of the infrastructure. The system will therefore provide data management facilities for:

- Retaining a full resolution archive for reviewing the detailed dynamic behaviour on a monthly and/or quarterly based basis, and investigating any period of particular interest.
- Longer-term storage of lower resolution data and dynamic performance summary data, to enable long-term baselining and the capability to detect trends and changes in the system, for example for seasonal changes or reviewing the long-term dynamic effects on major new infrastructure projects.
- Long-term storage of detailed data for events of particular interest, triggered either automatically or by manual intervention.
- Retaining disturbance impact measures, to review disturbances to frequency and/or angle, thus enabling intelligent triggering of detailed data record long-term storage and statistical review of performance.
- User facilities to access any of the WAMS data sources seamlessly

Using the approach outlined, the indicative storage and bandwidth requirements for each of the TO/TSOs and the communication between then is outlined in Table 1.

	Scottish Power	**SHETL**	**National Grid**	**VISOR Main Server**
Transmission Owner (TO) WAMS				
# Locations	20	20	20	
# Buses+Circuits/location	4	4	4	
SHARED DATA				
# Locations	40	40		60
# Buses+Circuits/location	1	1		4
Bandwidth per Substation	56 kbit/s	56 kbit/s		56 kbit/s
Bandwidth to TO Server	1120 kbit/s	1120 kbit/s		
Bandwidth to/from VISOR Main	754 kbit/s	754 kbit/s		2MB/s
Storage for 6 months full resolution @50Hz, 3 years @1Hz, 1000 hours triggered @ 50Hz	3.5 TB	3.5 TB		5.5 TB

Table 1 Storage and Bandwidth Requirements for WAMS

Figure 9 shows the collaboration between the TOs and TSO to implement a GB-wide WAMS infrastructure for the purposes of the VISOR project. From this structure, it may be noted that:

- NGET's Operational WAMS that drives control room alarms is not modified, except to make use of an existing basic PDC feature to stream data to the new VISOR WAMS.
- Additional PMUs in NGET may be streamed directly to the new VISOR WAMS (but the structure is flexible regarding where the PMU data connects).
- The SPT system will include not only the PMU data but also the data from all the SSO detection units.

To support the learning outcome of the improvements possible through the Hybrid State Estimator, the VISOR project will make the necessary information available for running a State Estimation process with and without the use of phasor measurements. This involves collating data sets and model information for running the State Estimation in an off-line environment. The data snapshots will be selected to cover a wide variety of system conditions, and will include some extended-time periods to investigate the performance of both State Estimator approaches through system changes.

The “Offline Studies” data sets in Figure 9 refer to the data set snapshots – SCADA, topology, Models, Simulation outputs and WAMS data – to carry out the Hybrid State Estimation Assessment and model validation.

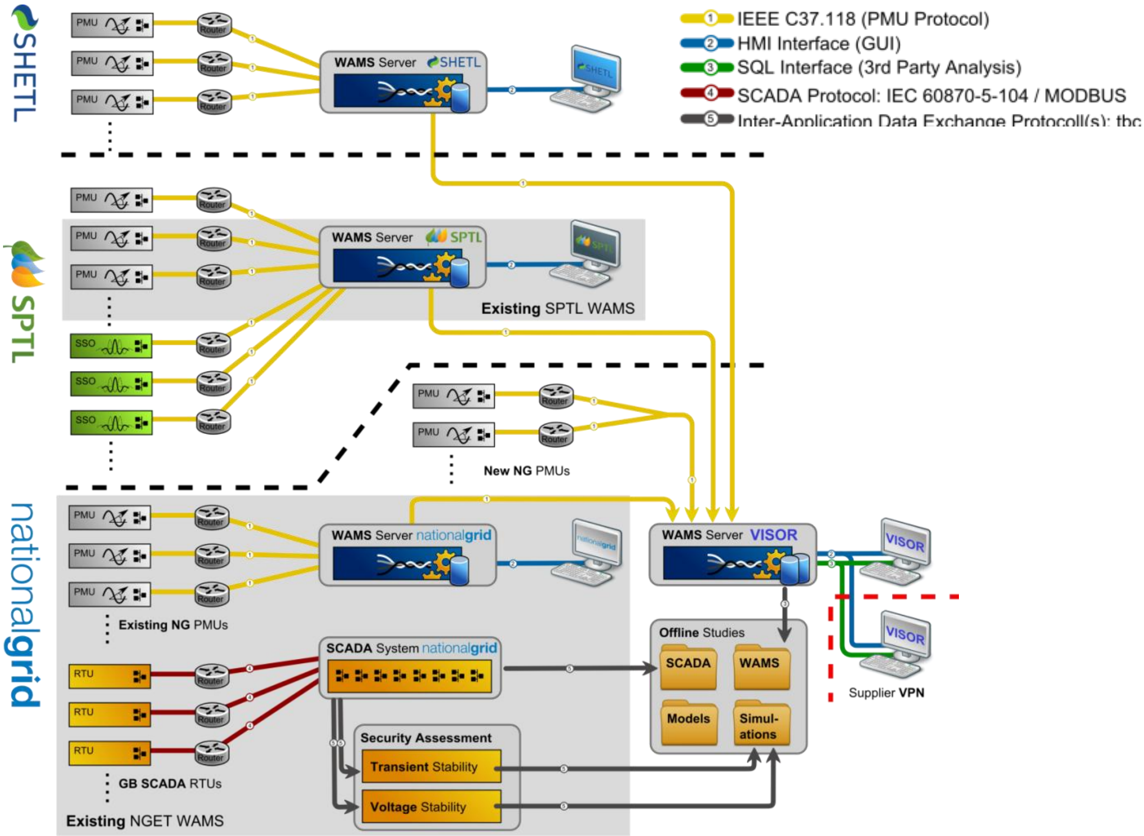


Figure 9 Overview of Supporting Systems, Data Flows and Infrastructure to deliver real-time and study components

There are two implementations of SSO monitoring in the VISOR project, illustrated in Figure 10. The first is a Continuous SSO Monitoring approach that analyses waveforms directly and sends the results to the central server. The second makes use of Existing Fault or Disturbance recorders to extend the geographic observability of the system through discontinuous waveform data retrieved to the central server and analysed for SSO information. The Continuous Monitoring approach alerts that there is an issue, while the Discontinuous Monitoring provides a geographic context and analysis capability.

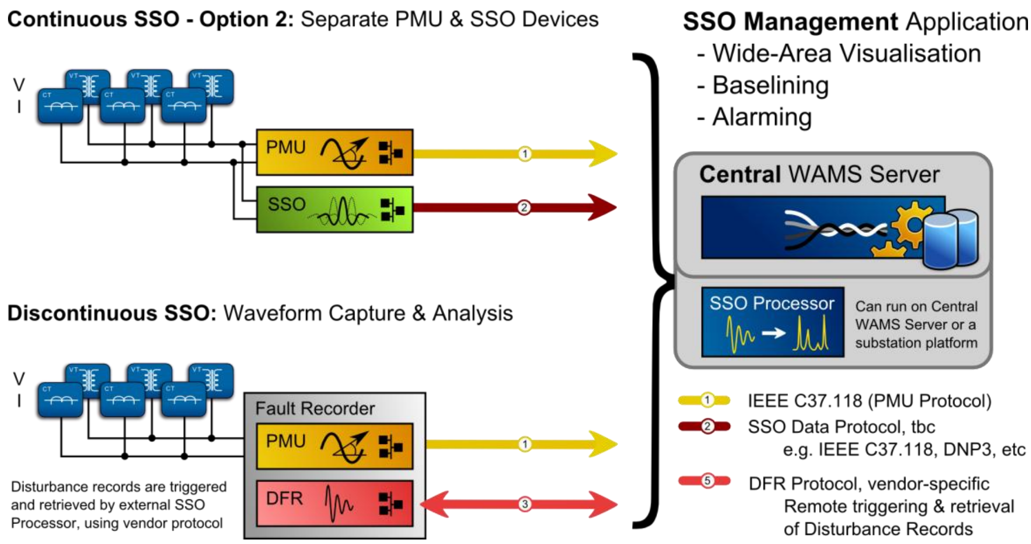


Figure 10 Sub-Synchronous Oscillation Monitoring Approach

Optimal WAMS Architecture
The project will deliver a strategy and demonstration for an optimal WAMS architecture that will deliver the quality and consistency of measured data that will reliably deliver the information that is required by applications, some of which are mission-critical control room tools. It should be noted that synchrophasors can be used in a variety of broad categories of application, each placing different requirements, for example:

- Mission-critical control room congestion and risk management places a high reliability on a central data system, and widespread data coverage, though localised measurement outages should not be critical.
- Historic baselining and performance review depends on a valid data repository being maintained over a long period of time. Some limited downtime is acceptable provided there is retrieval of the data to fill gaps in the data.
- Wide area control and defence requires high reliability and bounded latency from a relatively small group of measurements that participate in the control schemes. Reliability, redundancy and response time of the entire scheme is important.

The focus of this project is on the mission-critical control room applications and historic baselining and review functionality, rather than control and defence, and the implementation to be demonstrated will reflect this. However, the architecture strategy will include the requirements for closed-loop control solutions, as this is important for future WAMS implementation and roll-out of the technology.
It is important that WAM technology can be implemented efficiently, so that the system is fit for purpose, but not over-designed. This project will provide insight into the design of the platform required for the longer-term roll-out of the system, such that investment in monitoring is appropriate to deliver the services and quality required. Key outcomes of the optimal WAMS architecture are:

- Locations of PMUs required to deliver the applications outlined in this project, and other related projects.
- Requirements at the substation for reliable measurements, including the PMU and local area accessibility/security and configurability
- Communications requirements from substation to central location, such as bandwidth, latency and reliability
- Structure of data management for the GB system, including Phasor/SSO Data Concentrator location, specification and data quality.
- Data management for retention and historic access and performance review
- Practical implications of requirements for infrastructure and redundancy
- Review of experience with implementation in this project, in comparison with the requirements outlined, and documenting the lessons learnt

The PMU locations shall be studied from a practical perspective, bearing in mind the applications requiring data for trialing, and the practical availability of existing PMU-capable devices and communications. It should be noted that in general, a relatively light penetration of measurements is envisaged for a high-level operational view of the risks, while a more dense penetration of measurements is envisaged around the B6 boundary.
A review of the process to connect PMUs is required. One of the issues identified in previous WAMS work has been lack of a standard practice for implementing and testing the communications routes. This component should use industry best practice to define the process to implement the communication routes and the performance required, bearing in mind cyber-security issues.
The quality of data transmission also relies on the performance of Phasor Data Concentrators (PDCs) at various locations in the system. PDCs aggregate and time-align incoming data from various sources and route the data to its required locations. High reliability in terms of minimal data loss and downtime are necessary as loss of a PDC can result in loss of several measurement points.

Component Testing
A component of the project is systematic testing of the performance of the entire system from data sources (PMU and SSO) through the **supporting infrastructure**, and the applications. This will be carried out through a variety of approaches including measurement performance testing (especially for dynamic characteristics), scenario simulations for application responses to known conditions, and the use of measured events. The testing will also deal with latency, which is important in future control applications.

Other GB Projects related to VISOR Project

This section includes a selection of projects that are approved or under consideration that would be facilitated through the VISOR project infrastructure, or where there are potential synergies. It is expected that there will be several projects including NIA projects that will make use of the data collection and other facilities within VISOR. The extent to which the infrastructure proves to be useful for projects outside VISOR will provide some insight into the potential value of the infrastructure for the TOs and TSO.

Potential Future innovation projects include:

- Research into options for next generation "Special Protection Schemes" to replace the existing schemes currently in operation on B6 and other boundaries.
- Development of the optimal control strategy for the embedded HVDC links
- Inertia assessment, Rate of Change of Frequency (ROCOF) settings and other loss-of-mains options
- The development of reduced dynamic model of the GB system for studies, simulation, training and application development.

Appendix A4: Work Package Delivery and Responsibilities

This section outlines the Project Plan, highlighting the timeline of the project, the relationships between work packages and the participants involved in each. The diagrams included in this appendix include:

- **Project Gantt Chart**: covering the work packages and tasks
- **Project timeline**: a high-level view of the project period from December 2013 to March 2017
- **Work Package Relationship Diagram**: (below) illustrating the dependencies between work packages

The following figures in the main pro-forma are also of relevance to this section:

- **Figure 4-3**: Knowledge Dissemination process
- **Figure 5-1:** VISOR-related projects and stakeholders
- **Figure 6-1**: Project breakdown, highlighting the involvement of TOs, Suppliers and Academic parties in each workpackage
- **Figure 6-2**: Project Team Structure

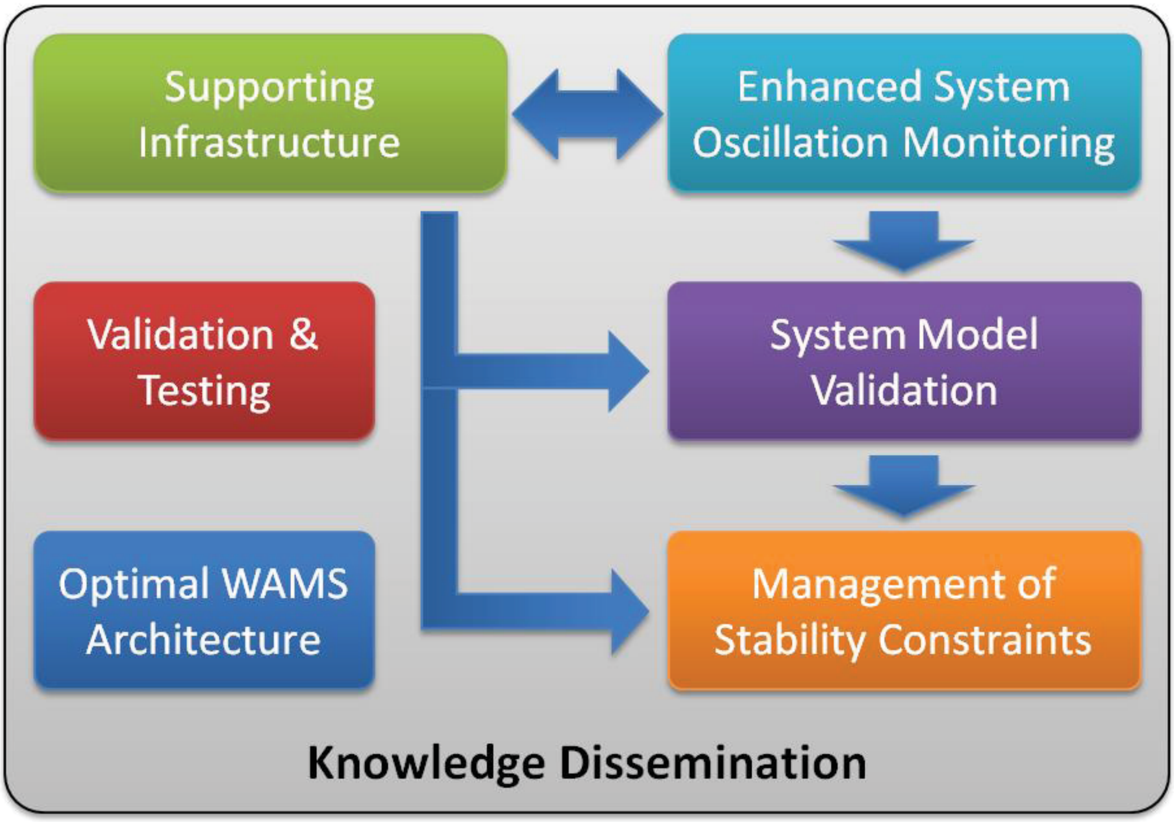
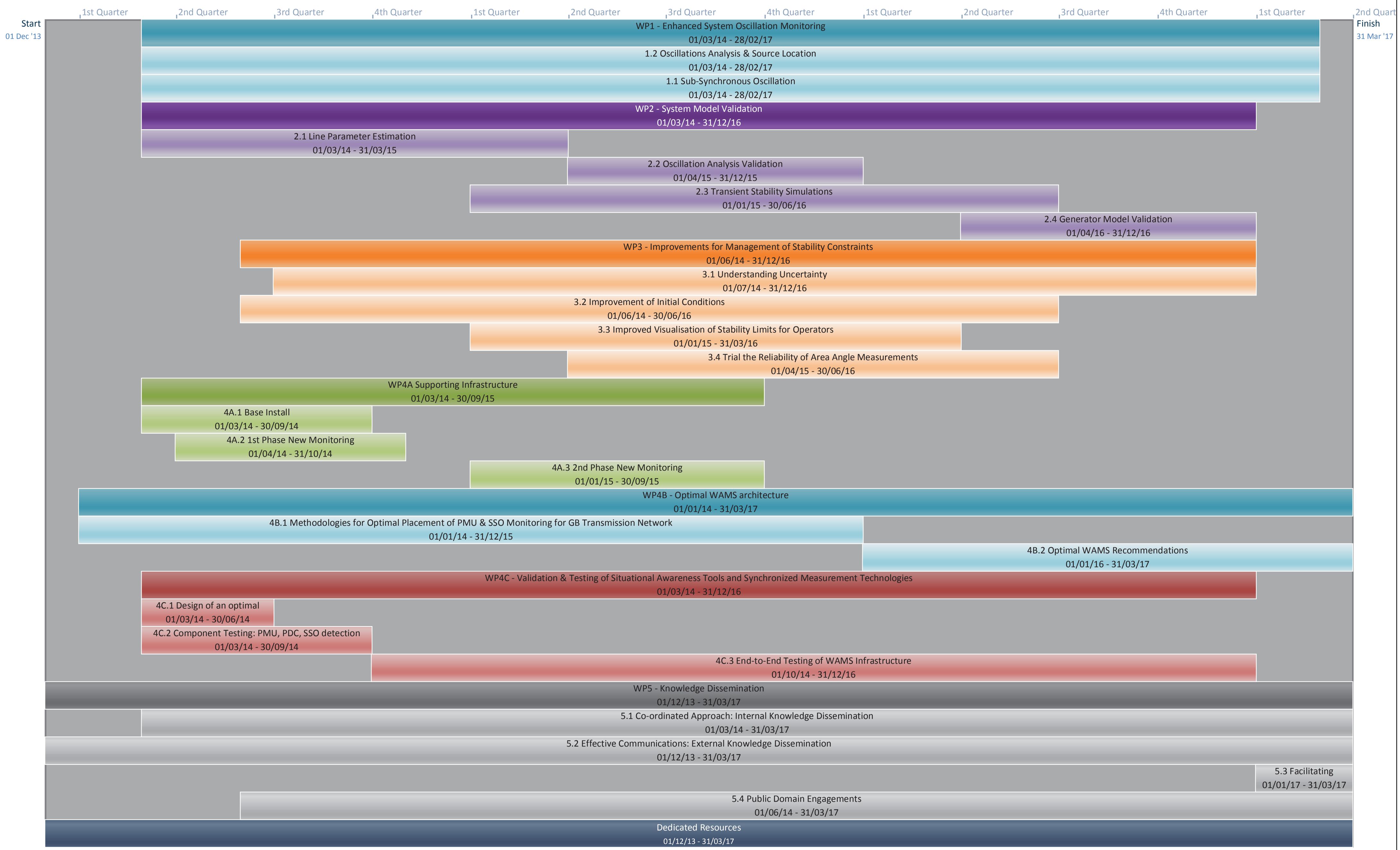
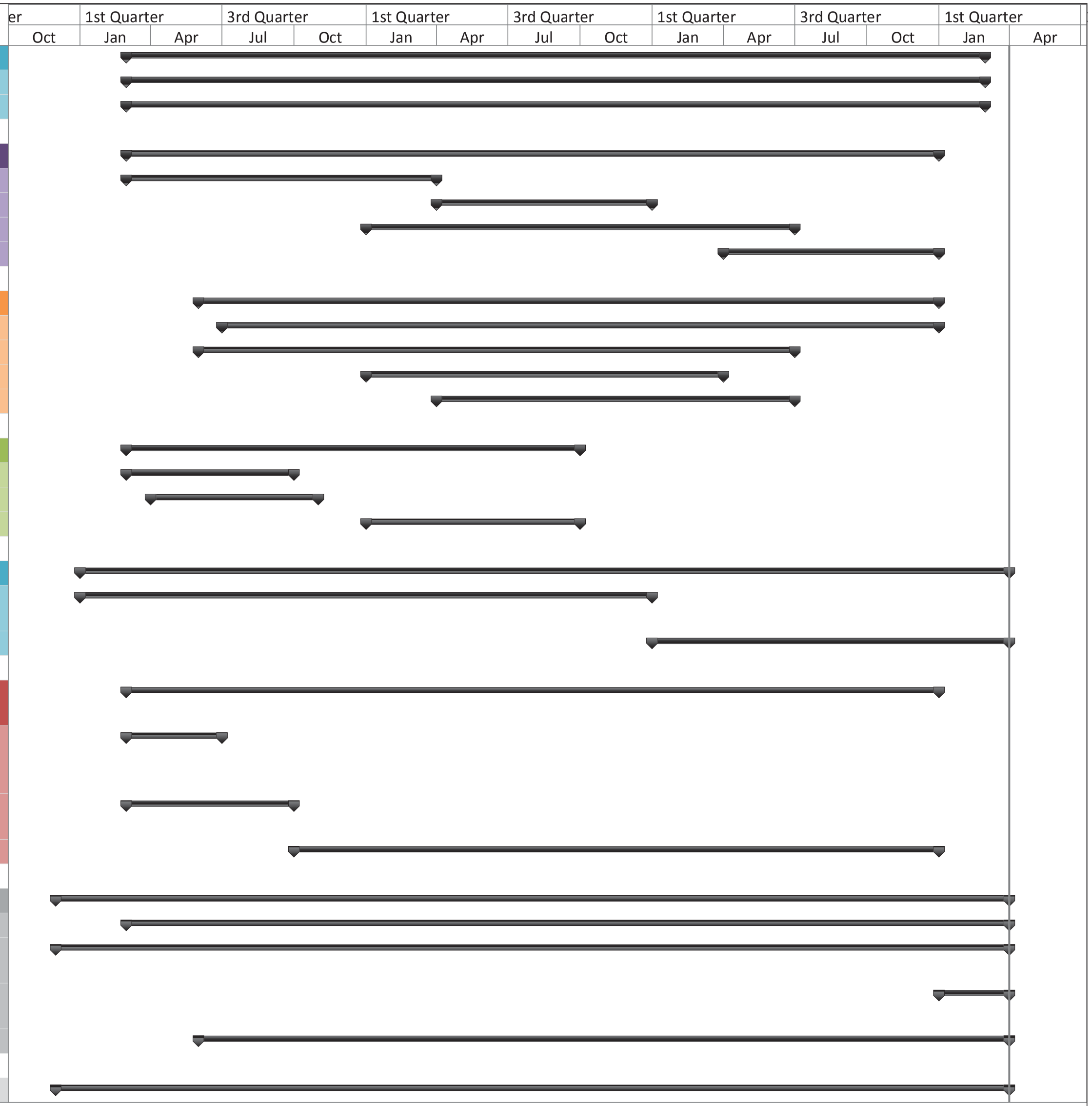


Figure 1 : Project Work Package Relationships


Start
01 Dec '13
1st Quarter
2nd Quarter
3rd Quarter
4th Quarter
1st Quarter
2nd Quarter
3rd Quarter
4th Quarter
1st Quarter
2nd Quarter
3rd Quarter
4th Quarter
1st Quarter
2nd Quart
Finish
31 Mar '17
WP1 - Enhanced System Oscillation Monitoring
01/03/14 - 28/02/17
1.2 Oscillations Analysis & Source Location
01/03/14 - 28/02/17
1.1 Sub-Synchronous Oscillation
01/03/14 - 28/02/17
WP2 - System Model Validation
01/03/14 - 31/12/16
2.1 Line Parameter Estimation
01/03/14 - 31/03/15
2.2 Oscillation Analysis Validation
01/04/15 - 31/12/15
2.3 Transient Stability Simulations
01/01/15 - 30/06/16
2.4 Generator Model Validation
01/04/16 - 31/12/16
WP3 - Improvements for Management of Stability Constraints
01/06/14 - 31/12/16
3.1 Understanding Uncertainty
01/07/14 - 31/12/16
3.2 Improvement of Initial Conditions
01/06/14 - 30/06/16
3.3 Improved Visualisation of Stability Limits for Operators
01/01/15 - 31/03/16
3.4 Trial the Reliability of Area Angle Measurements
01/04/15 - 30/06/16
WP4A Supporting Infrastructure
01/03/14 - 30/09/15
4A.1 Base Install
01/03/14 - 30/09/14
4A.2 1st Phase New Monitoring
01/04/14 - 31/10/14
4A.3 2nd Phase New Monitoring
01/01/15 - 30/09/15
WP4B - Optimal WAMS architecture
01/01/14 - 31/03/17
4B.1 Methodologies for Optimal Placement of PMU & SSO Monitoring for GB Transmission Network
01/01/14 - 31/12/15
4B.2 Optimal WAMS Recommendations
01/01/16 - 31/03/17
WP4C - Validation & Testing of Situational Awareness Tools and Synchronized Measurement Technologies
01/03/14 - 31/12/16
4C.1 Design of an optimal
01/03/14 - 30/06/14
4C.2 Component Testing: PMU, PDC, SSO detection
01/03/14 - 30/09/14
4C.3 End-to-End Testing of WAMS Infrastructure
01/10/14 - 31/12/16
WP5 - Knowledge Dissemination
01/12/13 - 31/03/17
5.1 Co-ordinated Approach: Internal Knowledge Dissemination
01/03/14 - 31/03/17
5.2 Effective Communications: External Knowledge Dissemination
01/12/13 - 31/03/17
5.3 Facilitating
01/01/17 - 31/03/17
5.4 Public Domain Engagements
01/06/14 - 31/03/17
Dedicated Resources
01/12/13 - 31/03/17

ID	Task Name	Start	Finish	Resource Names
1	WP1 - Enhanced System Oscillation Monitoring	01 Mar '14	28 Feb '17	WAMS Supplier
2	1.1 Sub-Synchronous Oscillation	01 Mar '14	28 Feb '17	WAMS Supplier
9	1.2 Oscillations Analysis & Source Location	01 Mar '14	28 Feb '17	WAMS Supplier
14				
15	WP2 - System Model Validation	01 Mar '14	31 Dec '16	
16	2.1 Line Parameter Estimation	01 Mar '14	31 Mar '15	WAMS Supplier
19	2.2 Oscillation Analysis Validation	01 Apr '15	31 Dec '15	Academic
22	2.3 Transient Stability Simulations	01 Jan '15	30 Jun '16	Academic
28	2.4 Generator Model Validation	01 Apr '16	31 Dec '16	WAMS Supplier
32				
33	WP3 - Improvements for Management of Stability Constraints	01 Jun '14	31 Dec '16	WAMS Supplier
34	3.1 Understanding Uncertainty	01 Jul '14	31 Dec '16	Academic
38	3.2 Improvement of Initial Conditions	01 Jun '14	30 Jun '16	WAMS Supplier
42	3.3 Improved Visualisation of Stability Limits for Operators	01 Jan '15	31 Mar '16	WAMS Supplier
46	3.4 Trial the Reliability of Area Angle Measurements	01 Apr '15	30 Jun '16	WAMS Supplier
49				
50	WP4A Supporting Infrastructure	01 Mar '14	30 Sep '15	Supplier,TOs
51	4A.1 Base Install	01 Mar '14	30 Sep '14	Supplier,TOs
56	4A.2 1st Phase New Monitoring	01 Apr '14	31 Oct '14	
63	4A.3 2nd Phase New Monitoring	01 Jan '15	30 Sep '15	
69				
70	WP4B - Optimal WAMS architecture	01 Jan '14	31 Mar '17	
71	4B.1 Methodologies for Optimal Placement of PMU & SSO Monitoring for GB Transmission Network	01 Jan '14	31 Dec '15	
75	4B.2 Optimal WAMS Recommendations	01 Jan '16	31 Mar '17	
80				
81	WP4C - Validation & Testing of Situational Awareness Tools anc Synchronized Measurement Technologies	01 Mar '14	31 Dec '16	
82	4C.1 Design of an optimal laboratory setup for testing Synchronized Measuement Technology and WAMS-based tools	01 Mar '14	30 Jun '14	Academic
84	4C.2 Component Testing: PMU, PDC, SSO detection devices, etc	01 Mar '14	30 Sep '14	Academic
88	4C.3 End-to-End Testing of WAMS Infrastructure	01 Oct '14	31 Dec '16	Academic
92				
93	WP5 - Knowledge Dissemination	01 Dec '13	31 Mar '17	
94	5.1 Co-ordinated Approach: Internal Knowledge Disseminatio	01 Mar '14	31 Mar '17	SPT
100	5.2 Effective Communications: External Knowledge Dissemination	01 Dec '13	31 Mar '17	
107	5.3 Facilitating Changes: Influening and Updating the policies/ standards	01 Jan '17	31 Mar '17	
112	5.4 Public Domain Engagements	01 Jun '14	31 Mar '17	
116				
117	Dedicated Resources	01 Dec '13	31 Mar '17	SPT



Appendix A6: Project Risk Register

See also Section 6.7 of the Main Pro-Forma

Key for New Technology Risk Register

Financial impact	
Score	**£k**
1	<10
2	10-100
3	100-500
4	500-1000
5	>1000

Probability of risk occuring	
Score	**Probability**
1	V. Low
2	Low
3	Medium
4	High
5	V. High

Overall Impact	
Score	**Impact**
0-9	Low Risk
10-29	Medium Risk
30-40	High Risk

Reputation Impact	
Score	**Impact**
1	Minor: Department awareness
2	Medium: Company awareness
3	Major: National awareness

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

Date: **09/08/2013**

General Project Risks

Risk No.	Issue	Risk Description	Potential Impact	Inherent Risk				Control Measure(s)	Residual Risk				Action Taken
				Probability (1-5)	Financial Impact (1-5)	Reputation Impact (1-3)	Overall Risk (1-40)		Probability (1-5)	Financial Impact (1-5)	Reputation Impact (1-3)	Overall Risk (1-40)	
1. : General Risk													
	Technical Specification (TS) preparation	Technical Specification is either too abstract, or descriptive, such to hinder development. Errors within the TS could lead to problems	Specific problems may not be accounted for due to ambiguous specification, else ingenuity of supplier may be prohibited. A substandard TS could lead to omissions from the TS and/or the technology not being suitable for the system	2	5	3	16	Produce a TS which has had input from all relevant business areas including a suppliers review of the TS, giving headroom for supplier to provide innovative solutions. Carry out full analysis of system using TS data, and any related effects of the new technology.	1	2	2	4	
	TS compliance	Technical Specification not met as a result of unrealistic requests or errors made by a stakeholder Manufacturer/Supplier might not be able to meet all requirements. Acceptable non-compliances and some non acceptable non-compliances	Installation may be postponed resulting in unnecessary delays, or unsuitable technology may be installed with the inherent risk of technology failure or network instability	2	3	3	12	Assess technology in accordance with the type registration process to ensure compliance with the TS. Identify and resolve non-compliances	1	1	2	3	
	Misinformed buying	Project Owner may not be fully aware of the most suitable option available.	Technology purchased may not be the most effective solution, with financial and system implications	2	3	2	10	Ensure technical teams communicate effectively with consultants, suppliers and procurement. **Outsource certain tasks/research to external expertise** and use all information produced to its full potential when making any decisions. Only make decisions once implications understood	1	1	2	3	
	Delayed Software Development	Supplier fails to produce fit-for-purpose software on time.	Significant delays to Project	4	3	2	20	Contract clauses in place to protect Project Owners financially in terms of delayed manufacture and to give incentives/punish manufacturer to remain on target with production. Ensure sufficient resources in place to deliver the key parts of the function development. Where practical, software should be built on existing proven solutions using suppliers with appropriate background experience and track record. Project time-critical software components will be prioritised, e.g. SSO monitoring and disturbance reporting. Contingency plans will be put in place to store data for later analysis and playback once the software is fully developed.	2	2	2	8	
	Future Upgrades/National Roll out	Once installed the technology is not easily upgraded.	The installed measurement units, PDC and communications infrastructure may not suit for the future integration of a national WAMS.	3	3	3	18	Understand reasons for future upgrade through discussion with suppliers and enquire into possibility and feasibility of upgrades. Install equipment that allows for alterations to the system, future proof where possible.	2	2	3	10	
	Asset Lifecycle	Reliability, quality and lifespan of new assets could not meet the required standards	Alongside disruption to the network (with an associated cost), poor quality and reliability of assets could lead to high replacement costs	2	3	3	12	Full analysis of suppliers profiles is essential, including international and internal reputation of suppliers (i.e. if there is a history of poor quality). Recognise whether supplier has a feedback procedure in place for active quality assurance. Enquire about each suppliers manufacturing capability. Ensure 'price over product' is not the main motivation behind suppliers choice.	1	2	2	4	
	Changes to the transmission system	Changes to the GB transmission system, generation and demand background during the design phase of the project	part of the proposed work package may not be achieved with the current plan. For example, more HVDC or large generators may change the baseline characteristics of the network, hence the location of oscillation contribution may be limited	3	3	3	18	Project Delivery Team will monitor GB transmission system changes to advise Project plan includes contingency monitoring that can be deployed where necessary in response to significant system changes.	2	2	2	8	
	Total Lifetime Cost	Software license cost for the funding period for the project partners, and the enduring maintenance cost and license cost outside of the funding period should be assessed	Without consideration for the enduring arrangement, the overall project business case may be changed. Lack of ownership post the funding period may compromise the knowledge dissemination.	2	5	3	16	Extensive suppliers engagement to detail various scenarios. Identify cost elements during tender evaluation process. Understand maintenance, mid-life refurbishment and spares holdings requirements. The tender evaluation should be based on the total life time cost	1	5	3	8	
	Summative Risk Scores			20	28	22	122		11	17	18	48	

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

Date: **09/08/2013**

General Project Risks

Risk No.	Issue	Risk Description	Potential Impact	Inherent Risk: Probability (1-5)	Inherent Risk: Financial Impact (1-5)	Inherent Risk: Reputation Impact (1-3)	Inherent Risk: Overall Risk (1-40)	Control Measure(s)	Residual Risk: Probability (1-5)	Residual Risk: Financial Impact (1-5)	Residual Risk: Reputation Impact (1-3)	Residual Risk: Overall Risk (1-40)	Action Taken
2. Technology Assessment: see Work Package Risk Register													
3. Installation Phase:													
	Project Owners' (SPT, National Grid and SSE) Expertise	Insufficient expertise within National Grid regarding commissioning of a hybrid system	potential delay of the project and technical problems arise between TO ownership boundaries	2	2	3	10	Identify techniques and procedures to follow when constructing the system. Provide training courses and work alongside manufacturers/commissioning engineers	2	1	1	4	
	Communication Infrastructure is not fit for purpose	the existing communication infrastructure may not be fit for purpose	the scale of the VISOR may not be appropriate to evaluate a national roll out system	4	2	2	20	Active engagement with suppliers and NETSO to generate an appropriate specifications (for NIC demonstration, but also for real system assessment)	2	1	1	4	
	Lack of appropriate outage required for installation or commissioning of the equiptment	Inability to obtain the relevant outages for installation or commissioning	Possible delays to commissioning programme	2	3	3	12	Outages identified and incorporated in Scheme Requirement Document (SRD). A second phase installation has been designed in Year-2, to accommodate installations missed in 1st phase	1	3	2	5	
	Capital costs	Costs higher than anticipated	Project budget exceeded	2	3	2	24	FIDIC contract, Contractor takes risk. Commodity price to be hedged. Contingency Funding is reasonably sufficient.	1	2	2	4	
	Summative Risk Scores			10	10	10	66		6	7	6	17	
4. Operation, Maintenance and Service:													
	Strategic Spares Policy	Spares Policy for new technology may not be suitable when taking all risks into account	If suitable spares are not identified and available, the risks of losing the PMU/PDC in the network may ultimately result in failure of the project.	2	4	3	14	Contingency hardware has been planned for, and contingency plans will be drawn up to include potential alternative monitoring locations which could be used in the event of equipment and/or communications failure. Off-the shelf products that are readily replaceable are used, and the structure of the 3 TO and 1 VISOR PDC, coupled with IP routing, means that the loss of one PDC can be mitigated to maintain the data-gathering capability of the WAMS as a whole.	2	2	2	8	
	Maintenance requirements	Manufacturer recommends intensive and regular maintenance activities which do not fit with project owner's expectations.	Regular intensive maintenance requires additional resource of field staff and potentially affecting the network operation thus reduce power transfer levels and potential constraint costs.	4	2	2	16	Seek to work with the manufacturers to understand maintenance requirements and the impact on the design or selection of components.	2	1	2	6	
	Telecommunications	Loss of telecommunications between systems	Reduced availability and performance	2	3	3	12	Design equipment for continued operation in the event of a loss of telecommunications, monitoring specification to consider automatic/manual recover in the case of short/long-term communications failures.	1	1	2	3	
	Summative Risk Scores			8	9	8	42		5	4	6	17	
5. Decommissioning:													
	It may be difficult to decommission, potentially compromising the existing network reliability	either too expensive to decommissioning the equipment installed, or no appropriate resources to do so	Increase the complexity of the substation, compromise network security	1	3	3	15	Have clear contingency plan, and enduring ownership of the equipment introduced from the VISOR	1	1	1	10	
	Summative Risk Scores			1	3	3	15		1	1	1	10	
6. Health, Safety and Environmental Risks (HSE):													
	New equipment	Lack of experience and knowledge regarding new pieces of equipment	Health and safety risks present as a result of lack of experience. Inefficient working, errors and high costs could result	2	1	1	4	Specialist tools and training required for maintenance activity. Procedures to be developed.	1	1	1	2	
	Temperature	Hot components due to slow cooling period following on from a fault in the system	Possible injuries to employees during maintenance work	2	1	2	6	Identify the cooling period of the components which become hot. Design equipment to be safe by design, protecting employees from inadvertent contact with hot objects or surfaces. State this as a requirement within the specification.	1	1	2	3	
	Summative Risk Scores			4	2	3	10		2	2	3	5	
7. Data Security: see Work Package Risk Register													

Visualisation of Real Time System Dynamics using Enhanced Monitoring (VISOR) - Risk Register **Date:** **09/08/2013**

Work Package Specific Risks

Risk No.	Issue	Risk Description	Potential Impact	Inherent Risk				Control Measure(s)	Residual Risk				Action Taken
				Probability (1-5)	Financial Impact (1-5)	Reputation Impact (1-3)	Overall Risk (1-40)		Probability (1-5)	Financial Impact (1-5)	Reputation Impact (1-3)	Overall Risk (1-40)	
WP1 : Enhanced System Oscillation Monitoring													
	Centralised SSO monitoring solution not commercially available	While SSO detection is applied locally in commercially available equipment, there is no wide-area co-ordination and system view. Details of communications protocols and interfaces still to be addressed.	Delay of integration of SSO Monitoring	4	4	3	28	(1) Specific details of interface to be stated by equipment vendor in tendering stage. (2) WAMS system should be proven to be capable of managing non-phasor data, so SSO integration not a major change (3) Interim use of manual data transfer if necessary to capture SSO behaviour before integration (4) SSO Application to be given highest software priority as is the most time-critical (installation of Series Compensation early 2015)	2	2	1	6	
	Equipment vendors use custom SSO algorithms	Existing SSO detection applies the equipment vendor's own SSO algorithm. If different models are used, results may not be comparable centrally.	Distortion of wide-area view if different vendor equipment integrated (likely in roll-out, not VISOR demonstration)	4	3	2	20	(1) SSO device should be capable of providing waveform snapshots as well as SSO continuous analysis, so centralised discontinuous process can be compared with local continuous process applied to all data sources. (2) Manufacturer willingness to provide details of algorithms or detailed performance will be assessed at tender.	2	2	1	6	
	Fault recorder support for discontinuous SSO	Use of existing fault recorder data to expand geographic observability depends on capability for remote or regular triggering of waveform recording.	Without suitable triggering, discontinuous approach is not feasible.	3	2	1	9	Assurance provided prior to submission that fault recorders in SP system support regular & remote triggering.	2	1	1	4	
	Not all Low Frequency Oscillation features are commercially available	Very low frequency analysis and source location features are not commercially available solutions. Available oscillation analysis measures (frequency, amplitude and damping) do not reliably indicate a source.	Source location features are required to avoid ineffective corrective action and/or time-consuming analysis	4	3	2	20	WAMS supplier will be requested to provide evidence of applying oscillation source location to solve real-world problems. One approach has been identified, trialed by a Supplier and used in solving real-world problems, and can be applied to the VISOR project.	2	2	1	6	
	Not all disturbance monitoring features commercially available	Disturbance impact and risk indicators not yet widely used, though concept of angle as stress indicator is widely accepted.	If impact/risk not available, study time is increased as longer manual data review required. Event prioritisation in operational context not available.	4	3	2	20	One approach has been identified and trialed by a supplier as extension to existing Disturbance management facilities.	2	2	1	6	
	Summative Risk Scores			19	15	10	97		10	9	5	28	
WP2 : System Model Validation													
	Availability of dynamic model data	Generator control models are commercially sensitive and cannot be shared outside National Grid. 3rd party (supplier or academic) cannot receive GB system full dynamic models for remote work.	Use of dynamic/control model is not practically available in normal supplier/ consultant arrangement with National Grid.	5	3	3	30	Work on the dynamic model is carried out by Academic partner as extended project at National Grid premises, with appropriate legal agreements. Residual risk involves finding an individual with appropriate skill set, willing to do this.	3	3	1	12	
				5	3	3	30		3	3	1	12	

Visualisation of Real Time System Dynamics using Enhanced Monitoring (VISOR) - Risk Register **Date:** **09/08/2013**

Work Package Specific Risks

Risk No.	Issue	Risk Description	Potential Impact	Inherent Risk Probability (1-5)	Inherent Risk Financial Impact (1-5)	Inherent Risk Reputation Impact (1-3)	Inherent Risk Overall Risk (1-40)	Control Measure(s)	Residual Risk Probability (1-5)	Residual Risk Financial Impact (1-5)	Residual Risk Reputation Impact (1-3)	Residual Risk Overall Risk (1-40)	Action Taken
WP3 : Improvements for Management of Stability Constraints													
	Outcome of marginal benefit of Capacity Enhancement with Hybrid State Estimation	The outcome of the project may show insufficient benefit of HSE to justify roll-out, or inclonclusive results i.e. the accuracy & robustness improvement does not justify the deployment cost.	Negative outcome for roll-out	4	2	1	12	(1) Risk of negative or inconclusive results reduced by application to a subset of the network (B6) that is well monitored and where PMU data expected to provide a benefit. (2) If HSE is not justified, then revise goals to use PMU as a cross-check or validation of the SE results, flagging inconsistencies, rather than migrating to an HSE approach. Note that a negative outcome helps to define TO/SO strategy, and is not a project failure.	2	1	1	4	
	Hybrid State Estimator complexity	If adding phasors to SE increases complexity, there is a new risk of SE failure with phasors, balanced against reduced risk with redundant data.	Negative outcome for roll-out	3	3	2	15	(1) HSE process is applied outside the operational environment so no risk is introduced by the project. (2) Ensure that sufficient pre-processing of PMU data is applied so that bad data and dynamic changes are filtered prior to inclusion in the HSE, to avoid degrading the HSE result (3) Trial in a commercial SE environment to give realistic comparison of SE vs HSE results to demonstrate and quantify the effect on robustness, thus quantifying the true risks (4) Make judgement of relative benefits of PMU data either as independent cross-check of conventional SE compared with integrated HSE process, to inform roll-out plan.	2	2	1	6	
	Data conversion for State Estimation	Data supplied to the study may be in proprietary form and require conversion	Delay in work stream.	4	2	1	12	Include contingency for data reading/conversion. No critical dependency, other than roll-out requirements, much later in project. However, it is noted that there is an advantage to an early indication on whether PMUs should be integrated in an EMS refresh. Early indicative results can be obtained using a smaller subset of data, e.g. based on the SPTL network.	2	1	1	4	
	Confidentiality and data sharing for State Estimation	Models and SCADA data are confidential to National Grid, and should be covered by legal agreements to start project. Dissemination activities require partner agreement on presentation of project outputs.	Delayed work stream start with preparation of legal agreements. Limited dissemination	3	2	2	12	(1) Discussion and prior agreement of partners in principle to facilitate the project. No barriers expected. (2) Bilateral agreements between Supplier and information owner (SPTL and/or National Grid) based on precedents of other projects. (3) Project run off-line with historic data to avoid need for real-time SCADA data sharing.	1	2	2	4	
	Constraint relief less than expected using power & angle constraint	It is expected that use of angle information provides constraint relief opportunity. The extent of the constraint relief is not yet known.	Possible negative result that angle presentation not justified on constraint relief grounds	3	2	1	9	(1) Quantifying the benefit of angle difference constraint over an extended period is a useful outcome, whether positive or negative, justifying whether or not the approach should be rolled out. (2) If not justified directly by constraint relief, there is a recognised value in visualisation to reduce uncertainty, thus the assessment of the item includes the value of a power-angle visualisation.	2	1	1	4	
	Redefining constraint relief process	Changes to operational practices and guidelines required for practical use to be made of the power/angle expression for redefining constraints	Further need to review operational procedures prior to use of angle difference in congestion management.	4	3	2	20	(1) Interaction with MEDICI project (if approved) on use of dynamic limits in GB system (2) If indicative results positive, review of operational issues around use of values to be conducted (SP/NG)	4	1	1	8	
	Potential lack of co-ordination of VISOR with NG DSA project	Dynamic Security Assessment to define real-time critical MW and angle difference from simulation should be co-ordinated with VISOR to use the synergies.	Without co-ordination, the ability of TSAT to create angle difference and MW thresholds, and the ability to use these in VISOR will not be demonstrated. Further work will be required beyond VISOR to demonstrate the synergy.	4	3	2	20	(1) Ability to interface DSA limits (from Powertech TSAT) with WAMS in a power/angle display, with contingency analysis, will be demonstrated by the supplier (2) the TSAT operating points and limits will preferably be linked to the VISOR server at National Grid, but if this is not practical, the benefits of integration will be assessed by off-line data review from both systems. (3) If TSAT results are not available in the timeframe, MW and angle limit values will be taken from planning studies.	2	1	1	4	
	Data availability	If angle difference is to be used in congestion management, it is important that the data is reliable and consistent. Data gaps and errors would cause failover to planning values, and require redispatch (applies in future live system).	Reduced value of application in congestion management	3	3	2	15	Ensure that infrastructure provides consistent data, comparing PMUs and collating data availability/quality information. PDC data integrity requirements will be specified for VISOR and for roll-out.	1	2	1	3	
	Summative Risk Scores			28	20	13	115		16	11	9	37	

Visualisation of Real Time System Dynamics using Enhanced Monitoring (VISOR) - Risk Register **Date:** 09/08/2013

Work Package Specific Risks

Risk No.	Issue	Risk Description	Potential Impact	Inherent Risk: Probability (1-5)	Inherent Risk: Financial Impact (1-5)	Inherent Risk: Reputation Impact (1-3)	Inherent Risk: Overall Risk (1-40)	Control Measure(s)	Residual Risk: Probability (1-5)	Residual Risk: Financial Impact (1-5)	Residual Risk: Reputation Impact (1-3)	Residual Risk: Overall Risk (1-40)	Action Taken
WP4 : Supporting Infrastructure													
	Supplier of TO/TSO delay on Base Install	Delays in implementing VISOR platforms and comms routes to PMUs/PDCs	Project delay	4	3	2	20	Select vendor with track record of commercial WAMS installations. Supplier must have experience of deploying in utility environment. Direct support by supplier via VPN for diagnosis. Comprehensive training by Supplier for IT personnel in all 3 partners in IT requirements of WAMS project. Existing SPT and NGET systems are available as a stop-gap to receive and store data, which can be transferred to VISOR system once it is available.	2	2	1	6	
	WAMS Performance issues	PMU data quality issues, or PMU/PDC data integrity issues (gaps), Communications issues	Application value reduced	4	3	2	20	Require proof of prior installations with good data availability. Use PMUs that have evidence of acceptable practical performance, and standards compliance where possible. Applications to be robust to data packet loss. WAMS solution to include recovery of missed data in the event of comms loss, and toption to deploy local substation buffering if repeated comms issues.	1	1	1	2	
	WAMS Central system - Hardware limits	Hardware insufficient to support future application needs	Additional cost	3	2	1	9	(1) Evidence of installations significantly larger than proposed VISOR system. (2) Sope in hardware for expansion: either through use of virtual environment or provision for expansion in server hardware.	1	2	1	3	
	Application development	Software platform unable to support future application development	Project delay, re-implementation of software	3	3	2	15	Supplier evidence of (1) established base of applications, scalable beyond VISOR targets (2) for new application developments, clear technical description of planned design and identification/mitigation of any performance bottlenecks. (3) Need to design/implement applications together with base install, and not disociate infrastructure from applications.	2	1	1	4	
	PMU & SSO Hardware Deployment	Delayed deployment of PMU & SSO monitoring hardware	Insufficient coverage and duration of monitoring to allow for reliable baselining of system performance prior to Series Compensation commissioning in early 2015	3	4	3	21	(1) PMU & SSO hardware highest priority at procurement & deployment stages (2) Preparation of contingency cases where alternative sites could be used (which might have existing communications or planned outages) (3) Local buffering of data at substation an option in the event of delays to the installation of substation communications links	1	1	1	2	
	Insufficient PMU monitoring locations	1st phase PMU selection uses existing devices as far as possible, without rigorous study. There may be gaps in observability that limit the extent of State Estimator benefits and dynamics observability.	Full benefits of the technology may not be realised in the course of the VISOR project.	3	3	2	15	(1) State Estimation component will be focused on B6 boundary, and we ensure that there is sufficient observability in this corridor (2) Define dynamics applications that identify issues to the closest buses, and do not require dense penetration of measurement (3) Project is designed in phases - first, use existing monitoring to set up usable infrastructure; second, add key new measurements to fill gaps; third, plan for future roll-out filling observability gaps	1	2	1	3	
				20	18	12	100		8	9	6	20	
WP5: Knowledge Dissemination													
	Researchers' expertises	Lack of appropriate PDRA working on the project; or the VISOR project may not be on the top of the priority list of the research team at academic partner	Delay of the key elements delivery	3	3	2	25	Start the recruitment of dedicated PDRA; with appropriate clause within the collaboration agreement to enable an alternative arrangements, such as outsoucing, re-tendering for the elements	2	2	2	15	
	Laboratory accommodation	Change of equipments, laboratory refurbishment	no access to the equipment for certain preferred time	2	2	2	20	Joint planning with the academic partner, awareness of the mid-long term strategy of the School/ Department	2	1	1	10	
	Summative Risk Scores			5	5	4	45		4	3	3	25	

Appendix A7: Project Partner Details

Given the application and potential benefit of VISOR, it is appropriate to involve the GB TOs, and the NETSO as partners of VISOR.

Further to this, TOs have agreed to provide significant in-kind support. The total contribution from the project consortium, incorporating both direct funding and in-kind support, is aiming to be above £1.0million i.e. equivalent to 12.5% - 15% of the overall cost. This demonstrates SPT's commitment as VISOR project originator which is underlined by a Letter of Commitment from the Managing Director, included as Appendix A8.

Scottish Hydro Electricity Transmission plc (SHE Transmission)
SHE Transmission is the owner of transmission network in the North of Scotland. There is a net export of electricity from the SHE Transmission region to the SPT network, which in turn places severe strain on the Anglo-Scottish transmission boundary. It is important for the VISOR project to have the visibility of real time behaviours from SHE Transmission network due to their consequential impacts on the Anglo-Scottish transmission boundary.
As stated previously, there are currently no PMU devices installed on the SHE Transmission network. To obtain appropriate levels of visibility of the real-time network performance, SHE Transmission has identified about 10 principal transmission sites to support VISOR. Among them, the four installations along the newly constructed Beauly-Denny circuits can be partly funded via the project funding due to the integrated fault recording function provided by the PMU. SHE Transmission's in-kind contribution to this project is estimated at £62k.

National Grid Electricity Transmission plc (NGET)
NGET owns and operates the National Grid high-voltage electricity transmission network in England and Wales. In addition to facilitating the transfer of electricity flows from North Scotland, the region between England and Scotland (i.e. the network owned by NGET and SPT respectively) would also have 1.1 GW of new generation connected under the Gone Green 2011 Scenario. NGET is at the receiving end of such a high volume of power.
The analysis of the Anglo-Scottish boundary has to rely on the appropriate coverage and visibility on the NGET transmission network. NGET is also the GB electricity network operator (National Electricity Transmission System Operator, NETSO), and responsible for the safe operation in line with Good Industry Practice. The information obtained from the individual transmission owners will be sent to a central server capable of exchanging real time PMU data and hosted by National Grid within the NETSO compound or at a remote location. National Grid has also agreed to contribute £62k as in-kind support to this project.

SP Transmission Plc
Scottish Power Transmission owns and maintains the transmission network in southern Scotland. SPT is also jointly responsible for the Anglo-Scottish boundary (B6) which facilitates flows from Scotland to England. SPT has established extensive experience over the past years in addressing the unique characteristics of the boundary concerned. Such expertise has been further reinforced by successful delivery of various small scale demonstration projects related to Wide Area Monitoring System (WAMS), as detailed in Section 5 and Figure 5.1. Learning from those projects has fed directly into the VISOR proposal and supported the proposal evolvements.

SPT has an obligation under STC (System Operator Transmission Owner Code) to provide necessary information to enable the NETSO to operate their assets, and an obligation under Grid Code to develop, maintain and operate an efficient, coordinated and economical system for the transmission of electricity.
This previous learning and statutory responsibility enable SPT's leading role in initialising the VISOR proposal and proposal delivery.

SPT is required to contribute 10% of the total funding for this project, as the funding licensee. SPT will be the focal point of this project to contact the Authority, and is also taking on the responsibility of the overall project costing, management and successful delivery. In addition, each identified project partner has demonstrated willingness to contribute resources to the project including their staff time, overheads and use of facilities during different stages of the project.

The University of Manchester

The University of Manchester has been selected as VISOR's main academic partner. The university has an experienced research team with an excellent testing laboratory in the relevant areas such as WAM, Power System State Estimation and Network Analysis and has a good record of academic publications. It is envisaged that the academic partner will:

- Provide expertise and independent review regarding the proposal integrity and specifications appropriately;
- Facilitate regular knowledge dissemination
- Be the main work-force in carrying out the Work Package of Validation & Testing of Situational Awareness Tools and Synchronized Measurement
- Provide enduring ownership of the testing facilities
- Maintain the continuity of the project, carry out appropriate simulation/desktop studies, laboratory tasks for the future projects

Tests performed in the university's laboratory will be tailored to support the VISOR project. In return, the university would get the opportunity to work with TOs directly and educate high calibre candidates on the real transmission system.
The University of Manchester will host and maintain the testing equipment for free. The university will also provide dedicated resource to work on the equipment on an enduring basis. Such in-kind support is estimated at £150k for the remaining RIIO-T1 period and demonstrates proportional commitment and support to the project.

Industrial suppliers of certain hardware and software will be identified via a full competitive tendering process. To ensure the value for money for the electricity customers, six manufacturers have been short-listed based on their research and development capacity, projects records and resources in the relevant area. It is expected that the successful supplier will also make a significant contribution to the project.

Summary of the project partners and their contribution is provided in Table 1.

	Contribution (£k)
NGET	62 (in-kind support)
SHE Transmission	62 (in-kind support)
Academic Partner	150 (in-kind support)
Licensee extra contribution	--
Initial Net Funding Required (Total minus in-kind support)	7,370
Licensee Compulsory Contribution/Direct Benefits	737
Outstanding NIC Funding Required	6,633
NIC Funding Request (minus projected inflation & interest)	*6,493*

Table 1: Partner Contributions

Appendix A8 - Letter of Commitment from SPEN MD

SP ENERGY NETWORKS

To whom it may concern,

5th August 2013

Re: Network Innovation Competition Project VISOR Proposal

SP Energy Networks (SPEN) welcomes the opportunity to engage in the RIIO Network Innovation Competition and is pleased to submit the VISOR proposal for consideration.

The VISOR project will play a key role in facilitating and implementing a SMARTER transmission system to accommodate a low carbon economy, by underpinning the safe and secure integration and operation of new technologies for a sustainable future GB transmission system.

The project will develop and trial an innovative system monitoring tool that will be "fit for purpose" for the challenges in planning and operating an economic and efficient future transmission system.

SPEN recognise the benefits of collaborative working with the 3 TO's and also value the support and commitment provided by the GB NETSO in developing this proposal.

The letters of support attached to the proposal from external stakeholders further illustrates the importance and global significance of this project.

The project will be appropriately resourced and directed by SPT's industry leading skills in this area, supported by our project partners NGET, SHETL and academia. The project will be delivered by five discrete work packages, four of which will be competitively procured.

We look forward to delivering this challenging flagship project which will pave the way for the operation and planning of the future transmission system.

Yours sincerely,

Frank Mitchell

CEO, SP Energy Networks

New Alderston House, Dove Wynd, Strathclyde Business Park, Bellshill ML4 3FF
Telephone 0141 614 0008
www.scottishpower.com

Scottish Power Energy Networks Holdings Limited
Registered Office: New Alderston House, Dove Wynd, Strathclyde Business Park, Bellshill ML4 3FF.
Registered in Scotland No. SC389555

SCP1198v2 June 12

Scottish and Southern Energy
Power Distribution

Inveralmond House
200 Dunkeld Road
PERTH
PH1 3AQ

Telephone: 01738 456237
Email: stewart.a.reid@sse.com

Colin H Bayfield,
Network Development Manager,
Scottish Power Transmission plc.
Ochil House, 10 Technology Avenue,
Hamilton International Technology Park,
BLANTYRE,
G72 0HT

Our Reference:
Your Reference:

Date: 6 August 2013

Dear Colin

Network Innovation Competition - Scottish Power Transmission Ltd
Visualisation of Real Time System Dynamics using Enhanced Monitoring (VISOR) Project.

Scottish Hydro Electric Transmission plc is pleased to be a proposed partner for the Scottish Power Transmission VISOR project.

By 2020 the GB electricity transmission system will have evolved to connect extensive renewable generation. The network will include a range of new active technology such as HVDC systems and large volumes of wind turbines this will present a new range of challenges and operational issues for both the Transmission Licensees and the Systems Operators. Managing the transmission systems and balancing electricity supply and demand will become more complex.

As the volume of conventional generation decreases to be replaced by non synchronous generation, HVDC links and other active network controls increase, the network is likely to experience increasing challenges to system stability. The outputs from the VISOR project will generate learning which could provide an early indication of operational issues that may arise from this new technology. This will give Transmission Owners and System Operators the opportunity to develop strategies which will allow them to mitigate any potential adverse impacts.

If the project is successful, SHE Transmission will enter into a Collaboration Agreement with Scottish Power Transmission to ensure the successful delivery of our elements of the VISOR project.

Overall we see VISOR as an exciting project which has the potential to put GB at the forefront of this technology and deliver benefits for customers.

Yours faithfully

Stewart Reid
Future Networks Manager

nationalgrid

NG House
Warwick Technology Park
Gallows Hill
Warwick
CV34 6DA

Mr Neil Copeland
Senior Policy Analyst
Smarter Grids & Governance
Ofgem
Cornerstone
107 West Regent Street
Glasgow
G2 2BA

Chris Train
Director, Market Operation

chris.train@nationalgrid.com
Direct tel +44 (0)1926 655539

www.nationalgrid.com

30th October 2013
ld2145

Dear Neil

Scottish Power Transmission Ltd Visualisation of Real Time System Dynamics using Enhanced Monitoring (VISOR) project

I understand that, after the second bilateral meeting with the Expert Panel, there have been some concerns about the level of commitment from National Grid to implement the findings from project VISOR, if they are favourable. We have been working in conjunction with SPT to submit a suitable bid for NIC funding. The new arrangements under RIIO provide the opportunity to develop proof of concept projects like VISOR and to trial innovative ideas that might bring benefits to the electricity consumers.

Nigel Williams, as Head of Electricity System Operation in my team, is sponsoring the VISOR partnership with Scottish Power Transmission on behalf of National Grid. Last August, Nigel sent a letter of support to Colin Bayfield, SP Network Development Manager, for the VISOR project stating the reasons why this research project is essential for the System Operator. We are fully committed to the successful delivery of the project should it proceed. National Grid is delighted to work in partnership with SPT and the other members of the consortium on this project and we believe that the project will deliver insight knowledge to the SO and the TOs.

In particular deeper understanding of the use of power-angle representation for precisely measuring transient stability and assessing the use of time stamped data for state estimation will allow improvements in boundary capabilities. These new techniques will be specifically applied to the B6 (Cheviot) boundary and quantify the improvement compared to current practices. National Grid will provide the infrastructure required to collate the PMU metering from the 3 TOs into the Electricity National Control Centre.

Should the project secure the innovation funding from NIC, we are committed to putting in place the resources required for the project to support its implementation.

Mike Calviou, Transmission Network Service Director, has been in contact with Jim Sutherland, SP Engineering Director, expressing his support to the project and championing the project across National Grid. I can also confirm to the Expert Panel that as Director, Market Operation of National Grid, that the System Operator would be pleased to, following the advice from the innovation project, put in place those systems and business procedures that will provide benefits for customers.

Yours sincerely

Chris Train
Director, Market Operation

nationalgrid

National Grid House
Warwick Technology Park
Gallows Hill, Warwick
CV34 6DA

Colin Bayfield
Scottish Power Transmission
New Aderston House
Dove Wynd
Strathclyde Business Park
Bellshill
ML4 3FF

Nigel Williams
Head of Electricity System
Operation

www.nationalgrid.com

7th August 2013.

Dear Colin,

Scottish Power Transmission Ltd Visualisation of Real Time System Dynamics using Enhanced Monitoring (VISOR) Project.

National Grid is pleased to be a proposed partner for the Scottish Power Transmission VISOR project. Projects such as this are an important part of how we respond to market changes, possibly paving the way for national benefits and savings.

By 2020 the GB electricity transmission system will have evolved to connect extensive renewable generation to achieve UK renewable and carbon targets. Beyond 2020 the demands on the UK on electricity networks will dramatically increase with increasing levels of variable wind generation, new larger nuclear power stations and increased electricity demand. Managing the transmission systems and balancing electricity supply and demand will become more complex.

As the levels of non synchronous generation, HVDC links and other active network controls increase, the network is likely to experience increasing challenges to system stability. The knowledge that the VISOR project will generate will be valuable in providing early indication of operational issues that may be expected to arise from them and to reduce the potential limiting impacts that high levels of non synchronous equipment could otherwise have.

National Grid intends to provide the resources that we have agreed will be needed to support the VISOR project from the GBSO and England Wales TO in the event that the VISOR project succeeds in securing NIC funding, starting in April 2014.

Yours sincerely

PP. Nigel Williams
Head of Electricity System Operation

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Dr James Yu, PhD CEng MIET MITL
Transmission Innovation Lead
Scottish Power Energy Networks
Ochil House, 10 Technology Avenue,
Hamilton International Technology Park,
Blantyre, G72 0HT
Scotland

19 September 2013

Dear Dr Yu,

After having a conversation with Professor Vladimir Terzija, who is in our School the leading researcher in the field of Wide Area Monitoring Protection and Control, and after receiving a full description and the information about the vision of the VISOR project proposal (project size £5M-£7M), I am pleased to inform you that The University of Manchester is happy to provide an in-kind project support in the scale of £150k.

I am particularly delighted that our School will be in the position to provide you with access to the new £1.2m RTDS hardware in the loop testing facilities, which are currently being procured and will be the largest in the UK and the most modern in Europe.

I wish you a success in your attempts to get the VISOR project proposal approved from Ofgem and look forward to collaborating with your Consortium.

Yours sincerely

Professor A. K. Brown
Head of School

Professor A K Brown
Head of School
Tel: +44 (0)161 306 4703
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Appendix A10: Letters of Support

This appendix contains excerpts of Letters of Support for the VISOR project from various organisations. Full letters are available on request.

Supporting Organisation: Universität Duisburg-Essen: Elektro & Informationstechnik, Fachgebiet, Elektrische Anlagen und Netze
Contact: Univ. Prof. Dr.-Ing. habil. I. Erlich (July 22, 2013)

> *"Our project was one of the larger projects funded under EU's 7th Framework Program and the name of the project was **PEGASE**. My Institute was the leader of one work package and also the task leader in another work package. From what I could gather there is a lot of complementarity and also some parallels between our already accomplished project and VISOR. However, I could notice that VISOR has a substantially higher Technical Readiness Level than the PEGASE project*
>
> *I understand that VISOR will address some of these issues [effect of dramatic changes in European power systems], particularly using approaches based on the extensive utilization of the emerging technology available today (PMUs, fast communication infrastructure, etc.).*
>
> *I also see that VISOR will add to the overall knowledge base in the field of the emerging power system paradigm and will develop new practical tools to support system operation and system decision-making. I am therefor writing this note to express my strong support for the proposed project".*

Supporting Organisation: École Polytechnique Fédérale de Lausanne, Distributed Electrical Systems Laboratory
Contact: Prof. M. Paolone, Ph.D. Chair of the **EPFL** Distributed Electrical Systems Laboratory (July 18, 2013)

> *"I have provided major research contributions on new algorithms for the synchrophasors estimation in Active Distribution Networks (ADNs). In particular, I developed the one the first PMU specifically designed for ADNs. The innovation came from a dedicated synchrophasor estimation process that, for the first time, was able to perform measurements of synchrophasors with parts-per-millions accuracy levels irrespective of the signal dynamics and distortion.*
>
> *This process, and its deployment into a dedicated device, opened a new way to operate these ADNs by integrating monitoring, protection and control functionalities, which is an essential step for the massive deployment of distributed energy sources in ADNs.*
>
> *Concerning the [VISOR] project assessment, I carefully went through the proposal finding it extremely timely and scientifically sound. The technological developments are well focused and described in detail. Additionally, the theoretical and experimental activities appear well cross-linked. In this respect, I would like to mention that the proposed project would definitely make available modern tools to the UK Transmission Network Operator that would potentially enable the development of new tools for the assessment of the transmission network stability margins and management of system congestion.*
> *In view of the above, I fully endorse the VISOR project".*

Supporting Organisation: Réseau de transport d'électricité (RTE)
Contact: N. Lemaitre - National Control Centre, Deputy Director (July 23, 2013)

> *"**RTE**, with several years experience on Wide Area Measurement system and inter-area oscillations studies believes your project will benefit electricity network innovation. This is why I am writing to express my full support.*
> *As a component of the future Smart Grids, RTE considers that the Wide Area Measurement systems belong to the new technologies that are to be investigated and developed. As a matter of fact, RTE is currently renewing its set of dedicated measurement devices"*

Supporting Organisation: École Polytechnique de Bruxelles (Brussels School of Engineering)
Contact: Prof. Jean-Claude Maun (July 16, 2013)

> *"Due to my experience in similar areas [to VISOR] (Development of PMUs, WAMS applications, Smart City Blocks project, FP7 EU Project "TWENTIES", WP5 NETFLEX etc), I am ready to support Scottish Power to review the specifications, Project Delivery Programme and Knowledge Disseminations"*
>
> ** TWENTIES = **T**ransmission system operation with large penetration of **W**ind and other renewable **E**lectricity sources in **N**etworks by means of innovative **T**ools and **I**ntegrated **E**nergy **S**olutions*

Supporting Organisation: European Network of Transmission System Operators for Electricity (ENTSO-E)
Contact: Konstantin Staschus, Secretary-General (July 23, 2013)

> *"We hereby confirm our support for the 'VISOR' proposal initiated by a consortium of the Scottish Power and its partners. The project is in line with R&D activities defined in the cluster 2 of the* ***ENTSO-E*** *R&D Roadmap 2013-2022.*
>
> *The VISOR proposal is to set up a system to share phasor measurement data between the grid operators in the Great Britain. The infrastructure will also be developed to monitor sub-synchronous oscillations, which requires some extension from standard wide area monitoring systems. The proposal has a longer-term aim to move towards comprehensive wide area control and monitoring for the future grid, with control strategy for existing and future HVDC links in mind.*
>
> *ENTSO-E highly welcomes consortium to work with grid operators. We are pleased that Scottish Power Transmission Ltd, National Grid Electricity Transmission Ltd and Scottish Hydro Electricity Transmission Ltd are in the consortium.*
>
> *ENTSO-E would welcome the lessons learned to be shared across Europe. We are therefore very interested to learn about the new approaches applied, the experiences and the results made by the consortium"*

Supporting Organisation: Electric Power Research Institute (EPRI)
Contact: Mark F. McGranaghan, Vice President, Power Delivery & Utilization (August 7, 2013)

> *"The Electric Power Research Institute, Inc. ("EPRI") is pleased to offer this Letter of Support for Scottish Power Energy Networks' ("Scottish Power") proposal in response to Ofgem's Electricity Network Innovation Competition ("NIC"). EPRI supports the goals of the NIC scheme with the conviction that accelerating the deployment of new technology and analytics is of great importance.*
>
> *The timing of this opportunity is excellent as increasing amounts of renewable wind energy come online in the UK network changing both the generation pattern and predictability.*
>
> *EPRI, as an independent, nonprofit center for public interest, energy and environmental research, is directionally supportive of the research described in Scottish Power's proposal. We share Scottish Power's interest in applying Wide Area Monitoring (WAM) applications as a means to a Smart Grid enabler, as they provide a new dimension to the way power systems are observed, based on vector measurements or Phase Measurement Units (PMU).*
>
> *EPRI and Scottish Power have worked collaboratively on energy research for three years. In addition EPRI and Scottish Power continue to expand our collaboration by identifying joint research of mutual interest, as well as working with academic centres of excellence within the UK.*
>
> *We applaud the work that Scottish Power is doing to support the electric power industry...... EPRI looks forward to collaborating with the Scottish Power team in exploring this effort for the benefit of our members and society at large".*

Supporting Organisation: RenewableUK
Contact: Zoltan Zavody, Head of Grid (July 30, 2013)

> *"RenewableUK, representing the wind industry across the UK, has been asked for a letter of support. We are supportive of all innovation proposals that help facilitate the accommodation of renewable energy on the system. We are therefore supportive of this proposal and, if it is successful, we will engage our members and help promote awareness of the project across the industry".*

Supporting Organisation: Scottish Renewables
Contact: Catherine Birkbeck, Senior Policy Manager (July 26, 2013)

> *"We are pleased to provide this letter of support for the VIsualisation of Real Time System Dynamics with Enhanced MonitORing (VISOR) project proposed by Scottish Power.*
>
> *This project proposes development and deployment of a Wide Area Monitoring (WAM) system based on Phase Measurement Units (PMU) as a means of optimising existing infrastructure and alleviating constraint limits on flows between England and Scotland, particularly across Boundary 6.*
>
> *A successful trial will help to confirm the business case for a wider roll-out of the application"*

Appendix A11: Base Case Value Derivation

Value Proposition

The value of the VISOR project to Scottish Power Transmission as a transmission network owner comes from two key areas:

- Avoided investment cost through provision of incremental capacity
- Risk mitigation of unstable system oscillations

There are additional value streams from the VISOR method to the GB consumer in the form of reduction in constraint costs, however this value is not directly captured by the transmission network owner and is either through the balancing system costs, or intangibles such as security of supply – i.e. black-out avoidance. These are not sought to be quantified at this stage other than providing an indicative order of magnitude.

Avoided Investment Cost

The VISOR method provides the means to create incremental capacity on the existing system through the ability to reduce the existing safety margins through reduction of uncertainty and better understanding of the underlying transient stability limits.

The value of this to the transmission network owner is to contrast this against their other alternatives for creating the same incremental capacity using conventional reinforcement methods. The following table (Table 1) shows the cost of provision of incremental capacity across the B6 boundary compared to the VISOR scheme. This demonstrates that the VISOR scheme is very cost effective relative to the major reinforcements, and has an avoided cost value of **£45m for every 100MW** of capacity released. The higher value is used as the opportunities for the lower-cost series compensation and reconductoring options on the B6 boundary have been exhausted[1].

B6 Scheme	Capital Cost	B6 Increment	£m/MW	£m/50MW (VISOR Equiv)
Series Compensation	£160m	+1100 MW	0.145	£7.25m
Western HVDC link	£1000m	+2250 MW	0.444	£22.2m
VISOR	£8m	> +50MW	0.160	£8.0m

Table 1: Avoided Investment Cost

Having the VISOR in place (**and on time**) would give the TO the opportunity to delay Eastern HVDC by 1 one or 2 years, which in turn is advantageous option to the consumer.

The following figure (Figure 1) shows the increasing boundary capability of the B6 boundary and the associated reinforcements required to achieve this, as well as the technical and economic requirements for that capacity. It clearly shows a number of significant upgrades required, but also that although post-2016 the technical System Security and Quality of Supply Standard (SQSS) requirement for capacity will be maintained, it remains below the economic requirement, thereby suggesting a continual value to the GB consumer of further cost effective incremental capacity such as that which can be delivered through VISOR. Therefore, while the level of incremental capacity available from VISOR will not resolve the overall requirement for capacity, it does provide significant value to the GB consumer in terms of avoided or deferred cost for otherwise required investment.

Additionally B6 investment schemes only improve B6 boundary, whereas VISOR can be applied to any boundary, specifically those that will arise due to B6 mitigations (potentially B5 and B7).

[1] ENSG 'Our Electricity Transmission Network: A Vision for 2020' (Feb 2012)
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48274/4263-ensgFull.pdf

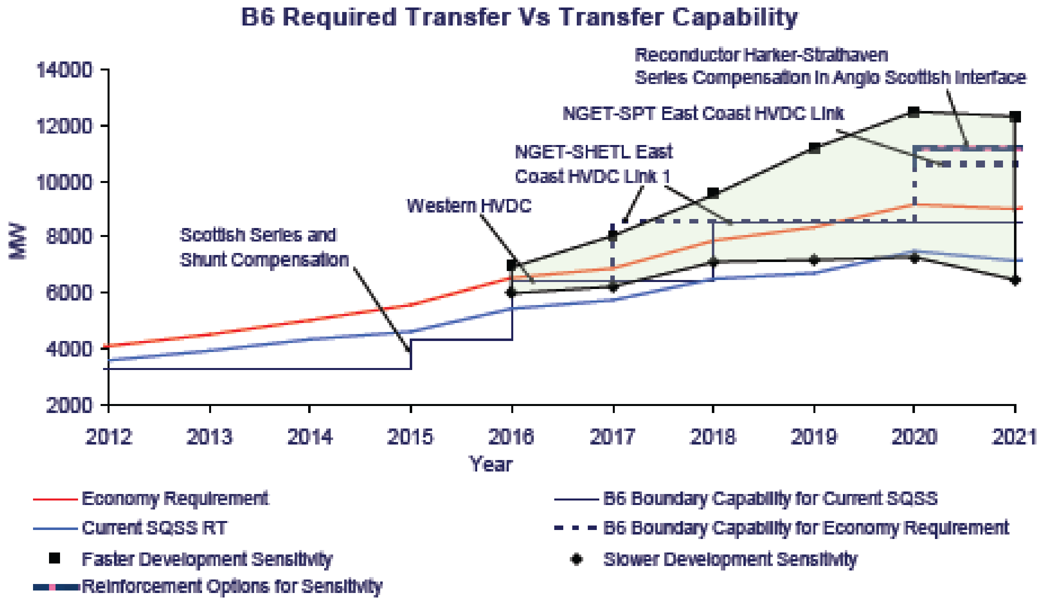

Figure 1 Extract from ENSG Update Report on B6 Boundary (Feb 2012)

Risk Mitigation

Risk mitigation is difficult to explicitly quantify as unforeseen unstable oscillatory events are classified at this stage as low-probability, high-impact events. An unstable oscillatory event that occurs without prior knowledge and in the absence of monitoring can result, at the low-cost end, in generation trips and boundary flow limitations, through to, at the mid-range of major equipment damage, in the form of major generator repairs. At the high-cost end, it could cause system separation and black-outs.

A system wide blackout for the GB at system peak demand would most likely to take up to three days to recover from. This may even be optimistic in the event of equipment damage and depending on the root-cause. Based on the recent work (July 2013) done to establish the value of lost load for GB consumers by London Economics for Ofgem and DECC, this would have an economic impact to GB in the order of **£30bn**. This is based on a peak demand of 50GW, 50% load-factor, 3 day duration, and the weighted average VoLL of £16,940/MWh[2].

It has been demonstrated in the Australian transmission system that some of their poorly damped modes can be explicitly managed via boundary flow constraints, but in other cases it requires installation of physical equipment to provide the damping. The use of monitoring, oscillation detection, and a combination of response schemes, allows them to manage this unstable condition without risk of black-out. The alternative is to invest in further network reinforcement, or provision of damping systems such as STATCOMs (Static Compensators) or SVCs (Static VAR Compensator) with Power Oscillation Damping (POD) controllers. However cost efficient placement and effective deployment requires good knowledge of the interacting equipment, frequencies, and other characteristics of the oscillation. This underpins the second of the two methods of the VISOR project.

[2] The Value of Lost Load (VoLL) for Electricity in Great Britain, London Economics, July 2013, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/224028/value_lost_load_electricty_gb.pdf

Appendix A12: Equipment Technical Specification

The VISOR system comprises the equipment shown in Figure 1, with grey background denoting existing equipment that is not funded under the project. The new equipment includes:

- Additional PMUs
- Sub-Synchronous Oscillation (SSO) monitoring devices
- Computing platforms for the two new WAMS servers (physical servers or VMs)

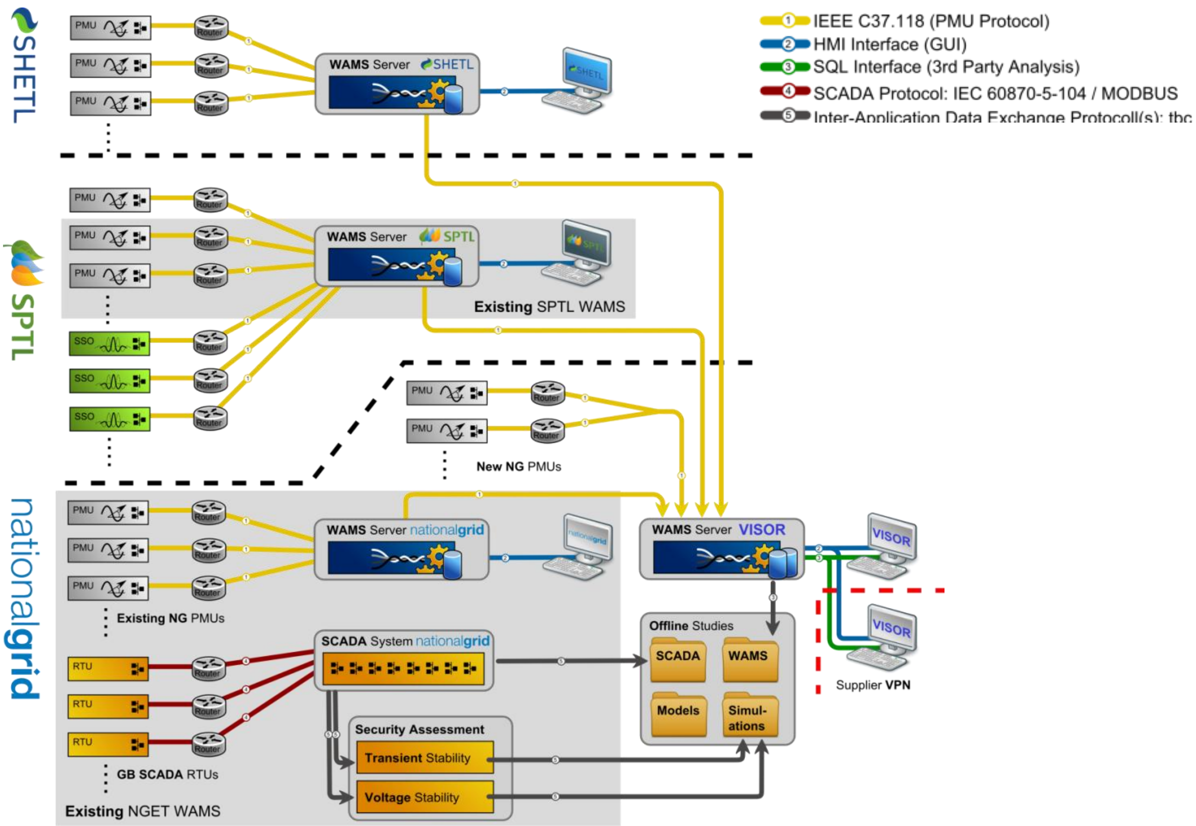

Figure 1 Network of VISOR equipment

In addition to the new equipment for the VISOR infrastructure, there is a requirement for instrumentation for the test laboratory. The test laboratory equipment is required for:

- Testing of PMU and SSO monitoring devices
- Testing of end-to-end applications

Recommended Server Specification

Hardware or Virtual	**Basic WAMS** (i.e. SHETL)	**Advanced WAMS** (i.e. VISOR)
Model (equiv./better) **CPU** (equiv./better) **RAM**	Dell R320/R520 1 x Intel Xeon E5-2440 16 GB	Dell R520/720 2 x Intel Xeon E5-2670 32 GB
Disks: OS & Applications WAMS Data	RAID 1 – 0.5 TB effective RAID V – 3-12 TB effective	RAID 1 – 0.5 TB effective RAID V – 5-30 TB effective
Other:	Hot-swap disks, fans and redundant power supply	

Functional Specification for Phasor Measurement Units

Conformance to IEEE C37.118 (2005) standard for synchrophasors

- Conformance to communication protocol is required
- Conformance to signal performance requirements is preferred

Conformance to IEEE C37.118-1(2011) and IEEE C37.118-2(2011) is an advantage

Independent qualification of static dynamic response of the unit is required, and test results should be provided. These tests should confirm at least that:

- Response time to a step change is within 60 msec
- Phase delay is within 10 degrees for <2Hz oscillations
- At nominal values, Total Vector Error (as defined in C37.118) should be within at least 1% and preferably within 0.5%
- Aliased components should be attenuated by 20dB

The PMU should be capable of streaming the sampled measurements in accordance with the IEEE standard above via an Ethernet RJ45 port. Communication options should be UDP and TCP/IP. Serial communication of phasor measurement, or external conversion from serial to ethernet, is not acceptable.

The units should be supplied with equipment for GPS synchronisation.

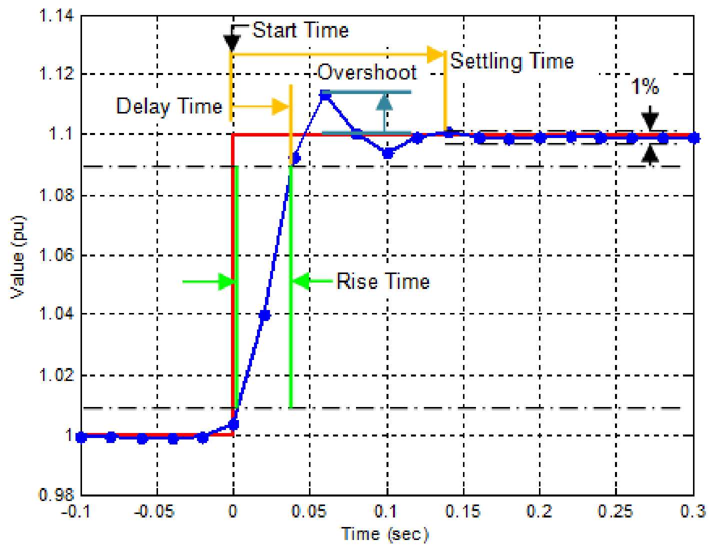

Figure 2 Example of Test of PMU Dynamic Response to Step Input

Functional Specification for Sub-Synchronous Oscillation Measurement Units

There are two options for Sub-Synchronous Oscillation measurement units providing continuous oscillation monitoring.

1. Sub-Synchronous Oscillation Monitoring applied within the measurement unit
2. RMS Values made available continuously at 200Hz or higher, i.e. quarter-cycle

If a local SSO monitoring process is carried out, a detailed technical explanation of the algorithm used is required, and Supplier agreement that a similar process may be applied at the central location to waveform records brought in from other sources, in order to ensure a consistent wide-area view using conventional disturbance recorders.

If streaming RMS values, the Supplier should prove that frequency components in the range 4-45Hz are accurately represented with a flat frequency spectrum and without attenuation (less than 3dB), and that aliased components are attenuated by >20dB.

In addition to the direct SSO monitoring or streamed RMS outputs, the unit should provide access to waveform data in COMTRADE format, sampled at least at 128 samples/cycle. Facility to trigger a waveform capture remotely, and to set up a regular snapshot (e.g. every minute) are required, to align with other disturbance recordings.

Discontinuous SSO monitoring uses existing disturbance recorders, and therefore does not require new equipment.

Laboratory Test Facilities

The test facilities include hardware and communications testing:

- High precision GPS time-stamped signal playback of waveform data
- Two sets of playback data to represent geographically distinct locations, for example at two ends of a line
- Facilities to test several different models of PMU simultaneously

Other facilities required are:

- Simulation of realistic communications network packet drop, network delay, outage and restoration, high network traffic, reduced bandwidth.
- Simulated PMU playback taking file-based phasor data and playing it into the WAMS infrastructure for application testing.
- Data latency testing throughout measurement system
- Power system dynamic simulation to create realistic scenarios and test cases for WAMS and SSO systems and applications

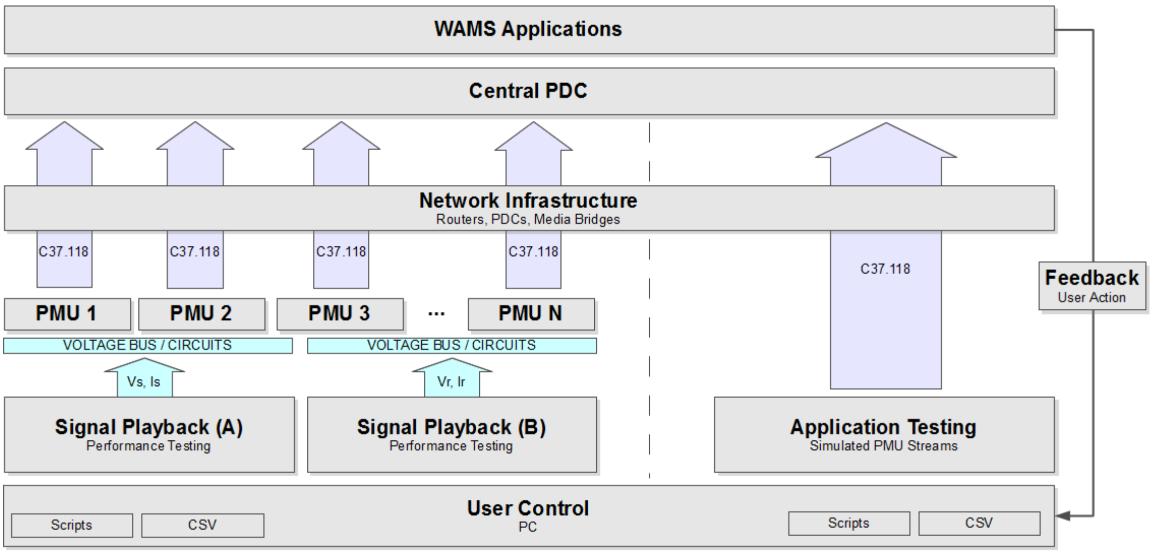

Figure 3 Network of VISOR equipment

Appendix A15: Literature Survey

This is a literature survey on the technical field for the proposed VISOR project synchrophasor technologies. The goal of this survey is to identify the current state-of-the-art of these technologies and gaps, noting the technology readiness that can be assumed in the domain.

Constraint and security management have been claimed in a general sense in synchrophasor literature, but specific use cases and benefits are not widely reported, suggesting that there are not yet many cases where constraint relief has actually been applied in practice. There are cases of constraint management for oscillations reported, and some evidence of line thermal monitoring for dynamic line rating.

Oscillation Management

Oscillation management has been carried out for a long time using estimation of the mode frequency and damping. This approach was used in the National Grid control room for many years, originally for constraint relief and more recently for security monitoring. The approach has been used in Australia for around a decade.

The innovation in the VISOR project is to do with source location methods to identify the contributions to oscillations, rather than identification of the oscillations and damping. There is literature on identifying sources of oscillations that the VISOR project will draw on, and an early commercial implementation of a source location method, however some further development is needed to address operational and commercial needs. The proposed approach has been used in a consulting process with a case study reported in the IEEE PES General Meeting paper, and another case study from Australia was reported at the Alstom EMS Users North American Users Group, 2013.

- IEEE Task Force Report TP 462: "Identification of Electromechanical Modes in Power Systems", 2012
  Discusses oscillation identification using discrete disturbances and continuous ambient noise perturbation, chiefly using synchrophasor measurement as the data source. Quotes multiple respondents surveyed reporting practical use or intended use of oscillation identification methods.
- Control Centre Applications of Integrated WAMS-based Dynamics Monitoring and Energy Management Systems, D. H. Wilson, K. Hay, R. F. B. MacLaren, D. J. Hawkins, A. Dunn, A. J. Middleton, A. Carter, W. Hung, CIGRE, Paris, August 2008
  Describes the history of use of oscillation monitoring in the GB system.
- Discrete Control for Transient Stability and Oscillations: Applications and Case Studies, D. H. Wilson, N. Al-Ashwal, H. Halldorsson, S. Boroczky, IEEE PES General Meeting, Vancouver, Canada, July 2013
  Discusses oscillation detection as part of constraint and security monitoring in Australia, and a case study of an event in Iceland where the proposed source location method was used as an offline investigation method.
- Classification of Mode Damping and Amplitude in Power Systems using Synchrophasor Measurements and Classification Trees: McNabb P.J. et al. IEEE Special Publication on Synchrophasor Applications, 2013.
  Describes sensitivity of dynamic behaviour to changes in network state.

- Alstom eTerraphasorpoint product brochure, quotes "Mode Power Path (MPP) to show the path of network power oscillations, identifying regions or plants contributing to the mode."

Defining Constraints as Angle Difference

Angle differences are recognised as being a stress measure in the grid, however no literature was found to show that angle differences are yet used operationally in constraint definition. One project to manage angle different constraints relating to wind farm output introduces the concept that synchrophasor data can be used in defining network capability.

Another project is a special protection approach for a transmission corridor. While these projects use angle stress, neither relates the angle difference to a corridor with the characteristics of the B6 boundary, and neither has a constraint level used in the control-room. It should be noted that there are many wide-area monitoring platforms available from commercial vendors (e.g. ABB, Schweitzer Engineering Labs Inc, Alstom, Siemens) that include visualisation of angle differences, however the key VISOR innovations are in the business process to use this value as a constraint, and to present the information in real-time in an appropriate way to take action.

- PMU-Based Angle Constraint Active Management on 33kV Distribution Network, Wang, D. Wilson, D. Venkata, S. Murphy. G, CIRED, Stockholm, 2013.
  Discusses a pilot project to use angle measurements for addressing 33kV network thermal, voltage and reverse power constraints, not transmission-level transient stability as in the B6 boundary.
- "Using Synchronized Phasor Angle Difference for Wide-Area Protection and Control", Enrique Martínez, Nicolás Juárez, Armando Guzmán, Greg Zweigle, Jean León
  Describes application of angle difference to operating special protection in a Mexican corridor.
- "A cutset area concept for phasor monitoring", Dobson I., Parashar M.
  Describes an approach to deriving a representative angle difference that defines the stress in a corridor.

Hybrid SE incorporating PMU data

The use of PMU data in state estimation is widely covered in literature and methods are well established. There are two basic approaches: (1) the Hybrid SE approach of incorporating phasor measurements in existing SCADA-based SE, and (2) the Linear SE approach, which uses only phasor measurements and no SCADA measurements for a much faster solution, expected to be more accurate, but requiring full observability.

Several major Energy Management System (EMS) vendors, including Alstom, ABB, Siemens and GE appear to have the capability to include PMU measurements in the EMS State Estimator solution.

There is generally a lack of literature demonstrating a practical business case identifying additional capacity released or greater robustness due to the addition of synchrophasors. This may be due to the fact that large-scale deployment of PMUs in North America is recent and there has been a focus on completing the WAMS infrastructure and not yet an extensive test case for Hybrid SE.

- Ross, *Synchrophasor's Application in State Estimation*, PhD Clemson University, 2008: Results show very little improvement to conventional SE; voltage magnitude 0-0.25% better; voltage phase angle max improvement 1.4% (at 118 bus system, 1.6% av. error using conventional SE, 0.47% with PMU at every 10th bus, 0.21% with PMU at every bus)
- Various papers point out the disadvantages of conventional SE:
    - SCADA only updates every 4-10 seconds, no dynamics captured
    - Asynchronous measurement due to communications delay
    - No voltage angle measurements
- Cai, *Wide Area Monitoring, Protection and Control in the Future Great Britain Power System*, PhD University of Manchester, 2012: This thesis funded by National Grid, Scottish Power and SSE thinks that the quality of the estimation can be "significantly improved".
- NERC, *Real-Time Application of Synchrophasors for Improving Reliability*, NERC 2010, p 10: "California ISO, BPA, AEP and Tennessee Valley Authority are working to incorporate real-time phasor data into their state estimation tools to get more accurate and higher sampling rate than their SCADA system can provide." No reporting of successful results to date.
- Power System Corporation Limited (POSOCO), *Invitation for Bids*, 2012: Defines a requirement for a hybrid state estimator, thus anticipating that it can be delivered commercially. The qualification on the business case, and the level of implementation challenge is not described.
- Avial-Rosales, Lisa Beard, *Recent Experience with a Hybrid SCADA/PMU On-line State Estimator*, 2009: Six-month trial period of a hybrid state estimator.

Appendix A16: Glossary of Technical Terms

This section provides explanations of technical terms used in this document; they are presented in alphabetical order.

Electricity Networks Strategy Group (ENSG): is a high level forum which brings together key stakeholders in electricity networks that work together to support government in meeting the long-term energy challenges of tackling climate change and ensuring secure, clean and affordable energy.

Energy Management Systems (EMS): This is a system of software tools which control, monitor and optimise electric utility grids.

Independent System Operator (ISO): Independent, regulated entity that is responsible for ensuring the efficient use and reliable operation of the transmission grid and, in some cases, generation facilities.

National Electricity Transmission System Operator (NETSO): The entity that operates the transmission of electrical power from generation plants over the electrical grid to regional or local distribution networks.

Pan-European Grid Advanced Simulation and State Estimation (PEGASE): PEGASE is a four-year R&D project funded by the 7th Framework Program of the European Union. It is implemented by a consortium composed of 22 Partners which includes Transmission System Operators (TSOs), expert companies and leading research centres in power system analysis and applied mathematics.

Phasor Measurement Unit (PMU): A PMU is a device which monitors AC voltage and/or current signals from the electrical system, producing GPS time-synchronised magnitude and angle measurements, or "Synchrophasors"

Power Networks Demonstration Centre (PNDC): The Power Networks Demonstration Centre is a venture between the University of Strathclyde, Scottish Enterprise, the Scottish Funding Council, Scottish Power and Scottish and Southern Energy aimed at accelerating the adoption of novel research and technologies into the electricity industry.

Rate of Change of Frequency (ROCOF): Rate of Change of Frequency depends on size of the change in balance between supply and demand, Energy stored and Natural response to frequency and control action taken in response to frequency

Remedial Action Scheme (RAS): See Special Protection Systems (SPS)

Special Protection Scheme (SPS): An automatic protection system designed to detect abnormal or predetermined system conditions, and take corrective actions other than and/or in addition to the isolation of faulted components to maintain system reliability. Such action may include changes in demand, generation (MW and MVar), or system configuration to maintain system stability, acceptable voltage, or power flows. An SPS does not include (a) under-frequency or under-voltage load shedding or (b) fault conditions that must be isolated or (c) out-of-step relaying (not designed as an integral part of an SPS). Also called **Remedial Action Scheme.**

Static VAR Compensators (SVC): SVCs provide fast-acting reactive power on high-voltage electricity transmission networks

Sub-synchronous Resonance (SSR): Sub-synchronous Resonance is a power system condition where the electric network exchanges energy with a turbine generator at one or more of the natural frequencies of the combined system below the synchronous frequency of the system **i.e. sub-synchronous Oscillations (SSO).**

Supervisory Control And Data Acquisition (SCADA*)* is a type of control system that monitor and control industrial processes.

System Operator and Transmission Owner Code (STC): The STC defines the high-level relationship between National Grid as National Electricity Transmission System Operator (NETSO) and Transmission Owners. It is supported by a number of procedures (SOTO Code Procedures or STCPs) that set out in greater detail the roles, responsibilities, obligations and rights etc of the NETSO and the TOs.

Transmission Owner (TO): A Transmission Owner is the entity that owns and maintains transmission facilities.

Wide Area Monitoring (WAM): Wide Area Monitoring (WAM) is a key SMART Grid enabler as it provides a new dimension to the way power systems are observed, based on vector measurements or Phasor Measurement Units (PMU).

Wide Area Monitoring, Protection, and Control (WAMPAC): Advanced applications in wide area monitoring, protection and control (WAMPAC) systems offer a cost-effective solution to improve system planning, operation, maintenance, and energy trading. Synchronized measurement technology and applications are an important element and enabler of WAMPAC.