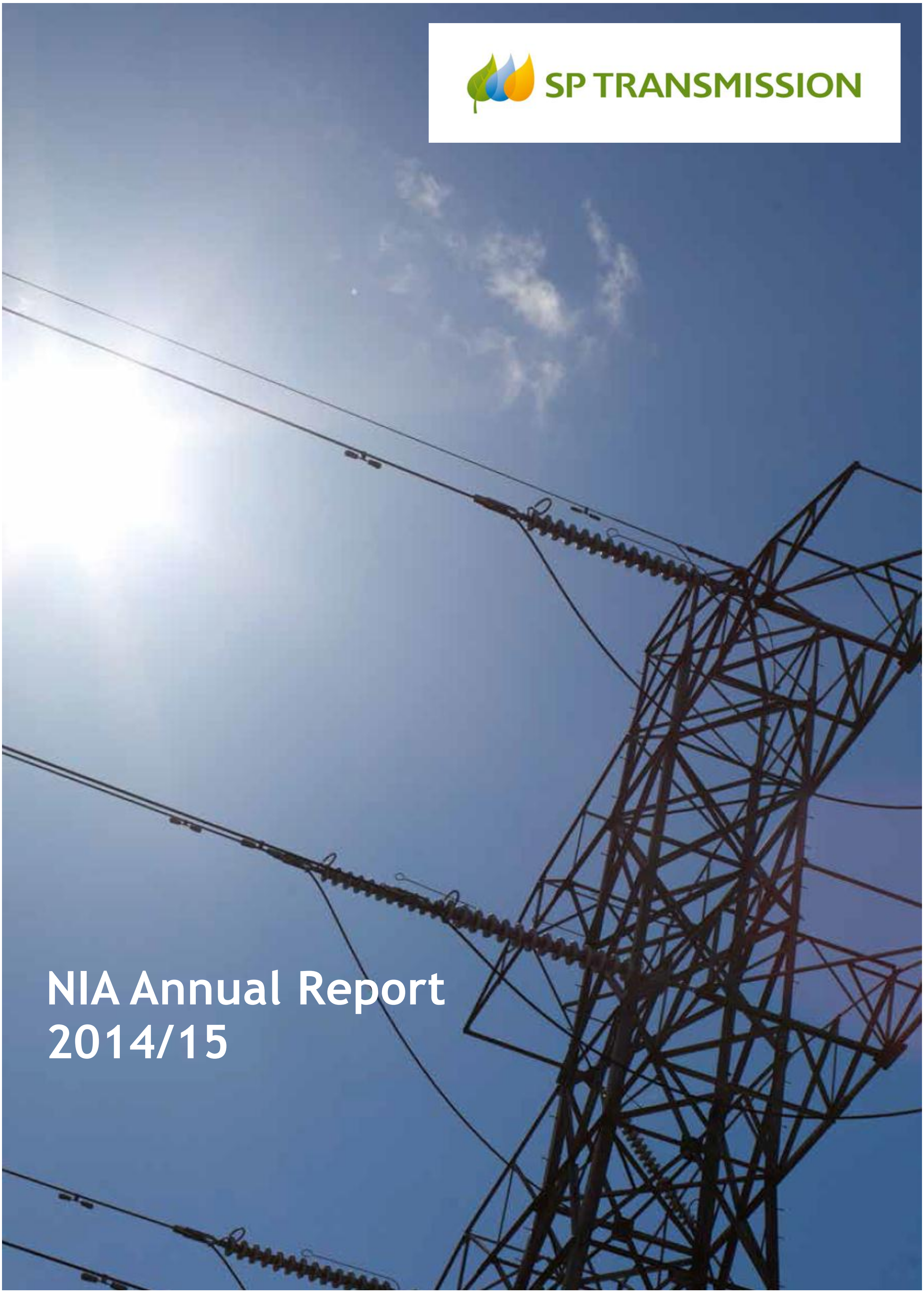
SP TRANSMISSION



NIA Annual Report 2014/15

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Foreword

SP Energy Networks (SPEN) is committed to delivering the Transmission Grid of the future through our licensed business SP Transmission (SPT).

This is our second Network Innovation Allowance (NIA) Annual Transmission Report and is an overview of on-going Transmission related projects being undertaken and those initiated during the regulatory year 2014/2015.

SPEN is developing three Network Innovation Competition (NIC) proposals for 2015, two of which have capitalised on the learning and outputs from the following NIA projects which are detailed in this report:

NIA Inputs	NIC Output
NIA SPT 1303 IEC 61850 Integration of Substation Protection and Control **NIA SPT 1502** Distributed Photonic Grid Instrumentation **NIA SPT 1503** Protection Settings to Cater for the Evolving Transmission Network	Future Intelligent Transmission Network SubStation FITNESS Proposal
NIA SPT 1306 HVDC Cable Conditioning Monitoring Project **NIA SPT 1501** Medium Voltage DC (MVDC)	Angle DC Proposal

Similarly, our Smart Transmission Zone NIA project enabled our supporting partner role in National Grid's Effective Frequency Control Capability (EFCC) project that was awarded NIC funding in 2014.

We will continue to seek opportunities to develop NIA projects into NIC submissions or use them to support and inform such submissions. In addition, NIA project selection will continue to be influenced by current and future transmission challenges such as the growth of renewables, thermal generation decline and subsequent reduction in system inertia and potential protection setting implications. As a RIIO focused business, we will embrace innovation with the clear purpose to deliver benefits.

Our innovation focus remains firmly centred on our customers and stakeholders, who shape both our Transmission Innovation Strategy and innovation project portfolio that could help toward the successful delivery of RIIO-T1.

Colin F. Taylor

Colin Taylor

Director of Engineering Services

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Executive Summary

Our second Network Innovation Allowance (NIA) Annual Transmission Report has been compiled in accordance with Ofgem's Electricity Network Innovation Allowance Governance Document which sets out the regulation, governance and administration of the Electricity NIA. This second NIA Annual Statement presents an overview of the projects we have initialised during the regulatory year 2014/2015 and an update on those projects reported during 2013/2014 which are still active.

The progress of each project aligns with the five innovation objectives set out in our Transmission Innovation Statement:

- Innovation meeting the needs of stakeholders;
- Innovation opportunities are identified in a timely manner, which will benefit these stakeholders;
- Innovation is managed in an efficient and proactive manner;
- A balanced portfolio of innovation is pursed which includes commercial, process and technology innovation; and
- The outcome of innovation activity is adopted by the wider business to ensure that customers benefit at the earliest opportunity whilst minimising the risk to the integrity of the network.

Our NIA innovation project portfolio will continue to be shaped by on-going stakeholder engagement, both internal and external, with a view to maintaining a balanced portfolio that will address not just the near/medium term transmission issues, during the current price control period (RIIO-T1), but also those anticipated as longer term requirements (beyond 2021).

In addition to funding smaller projects, we will be utilising NIA funding to prepare the following three projects for the Network Innovation Competition (NIC) submission in July 2015:

1. Future Intelligent Transmission NEtwork SubStation (FITNESS) Project: An integrated digital substation design with IEC61850 compliance

2. Evolution Project: To create and demonstrate elements of Distribution System Operator (DSO)

3. Angle-DC Project: To provide a step change demonstration by converting existing assets to DC operation

We will continue our strong commitments in innovation and to ensure that our innovation at SPT is:

- Meaningful, tangible and adaptable for business;
- Is carried out in an efficient, coordinated and collaborative manner; and
- Represents value for money for customers in the long term.

In addition, we will aim to maximise knowledge transfer with other licensees and facilitate useful outcomes into Business as Usual at the earliest opportunity.

1 Introduction

SP Transmission has obligations to meet the Special Condition 3H (The Network Innovation Allowance) of the Electricity Transmission Licence, which was introduced as one of the key innovation proposals for the RIIO-T1 (Revenue = Incentives + Innovation + Outputs, 2013-2021) model for price control. The purpose of the NIA is to encourage Network Licensees to innovate to address issues associated with the development of their networks.

NIA is to provide a consistent level of funding to Network Licensees to allow them to carry out smaller innovative projects for two purposes:

- To fund smaller projects which meet the criteria set out in this Governance Document; and
- To fund the preparation of submissions to the Network Innovation Competition (NIC) which meet the criteria set out in the NIC Governance Document.

From that point of view, NIA plays an important and integrated role in uplifting the technology readiness levels (TRL), preparing for flagship demonstrations at national level and knowledge sharing.

It is acknowledged that the transmission network will experience unprecedented change in response to realising the low carbon ambitions for the UK. In order to meet the associated challenges innovative techniques, technologies and processes will be required to develop the transmission network. This is recognised by the fact that Innovation is a key element of the new RIIO - T1 model for price controls with the introduction of the NIA.

This report presents SPT's NIA activities during the second year of its introduction, summarises progress made against objectives and highlights areas of significant new learning.

Developments in our transmission network over recent years have fundamentally been driven by an ongoing process of stakeholder engagement. SPT has identified a number of key themes as a result of our ongoing stakeholder engagement which are the principal drivers behind our innovation strategy.

Following a comprehensive stakeholder mapping activity, which formed part of our Transmission Innovation Strategy published in 2011, the key outputs from subsequent stakeholder engagement to date have been:

- Communicating with stakeholders to understand their needs and expectations more effectively;
- The connection of customers (demand and generation) onto the network to deliver sustainable low carbon energy through fair, clear and accessible processes;
- Maintain security of supplies and maximise long term value for end-users through improved network availability and reliability processes; and
- Minimise the environmental impact of our operations.

SPT recognise that consideration needs to be given to not only the RIIO-T1 period and stakeholder's immediate needs, but also how we address the longer term issues which the transmission network may face. This is being addressed through a balanced portfolio of innovation projects where we are considering some of the longer term issues which may involve technology and techniques at a lower technology readiness level as well as immediate challenges to be faced over the next decade. This consideration is detailed within the report along with details of how our NIA activities link to SPT's innovation strategy.

2 Progress Summary

During the reporting year 1st April 14 to 31st March 15 SP Transmission registered the following three NIA projects:

NIA SPT 1501	Medium Voltage DC (MVDC)
NIA SPT 1502	Distributed Photonic Grid Instrumentation
NIA SPT 1503	Protection Settings to Cater for the Evolving Transmission Network

The following sections provide a short overview of each active NIA project and summarises the progress that SPT has made on them. Further details on SP Energy Networks Innovation activities can be found on SPEN's website (http://www.spenergynetworks.co.uk/pages/innovation.asp) and on the ENA Learning Portal (http://www.smarternetworks.org). Key learning associated with these projects is summarised in Section 4.

2.1 NIA SPT 1301 Electrical Power Research Institute (EPRI) Programme Engagement

EPRI's Grid Operations research programme delivers value using the shared experiences and understanding of its utility and independent system operator (ISO) members in conjunction with the expertise of EPRI's staff and network of top-level contractors.

The programme collects network experiences and learning at international level, conducts research projects that lead to prototype methods and tools that can be utilised by system operators, and supports members in their research needs. EPRI also engages with external industry standards, regulatory, and research efforts to ensure that the EPRI research programme is taking advantage of broader industry efforts and advancing the state of the art technologies.

This research programme also strives to provide members near-term, mid-term, and long-term value. For example, the 2013 Grid Operations research programme will finalise the development of prototype tools for supporting identification and mitigation of potential voltage stability concerns and deliver prototype tools and guidelines for identifying the optimal black start capability needed to restore the system after an outage during a time when many systems are re-evaluating black start/restoration plans given the evolving generation mix. At the same time, EPRI will continue development/evaluations of advanced data processing, computing technologies, and solution algorithms to improve the performance of all operational analytics and decision making. The outcome of this research programme will allow transmission licensees to capitalise on the latest technology advancement and lead to a more effective network development and operation. This project will facilitate the awareness and application of new technologies on the transmission network and benefit both customers and stakeholders by accelerating cost effective renewable generation connections.

A key objective is for SP Transmission engineers to continue to engage fully with the EPRI research programme and apply relevant outcomes to business activities and innovation projects.

2.1.1 NIA SPT 1301 Project Progress

Our programme engagement was initiated from January 2013, and will continue through to the end of 2015.

In order to help realise the aforementioned objective three dedicated meetings between SPT internal stakeholders and EPRI project engineers were arranged to ensure that the knowledge generated from the engagement programme could be fully appreciated. In addition, EPRI arranged a HVDC project workshop at Wokingham to present their study results. SPT has also been actively involved in the scope definition and staged reporting via teleconference. EPRI has also provided support relating to other SPT research initiatives beyond the scope of this project. Consequently, these projects are considered to be on track to realise business benefits.

2.2 NIA SPT 1302 Enhanced Weather Modelling for Dynamic Line Ratings

Dynamic Line Rating (DLR) schemes have the potential to release significant network headroom on circuits supplying renewable generation that can be controlled by Active Network Management (ANM) schemes. Whilst the same DLR uplifts are present on the network's main interconnector circuits, the headroom cannot be as readily exploited as there is less correlation between the required power transfer capacity and the ambient conditions under which significant uplifts can be achieved; nor is there a single controllable load to be coupled with an ANM scheme to avoid excursions on the network. As a result of this, the exploitation of DLRs on the main interconnector circuits will be reliant on Control Engineers to manage the network loads and keep them in line with the available DLR uplift. However, to effectively do this without risking excursions on the network the Control Engineers will need to have confidence that the DLR will be available for a prolonged period of time, and this depends on accurate forecasting of dynamic ratings. At present the main focus of DLR schemes developed has been on the generation of an instantaneous value as opposed to a forecasted value several hours into the future.

This project makes use of an advanced spatial/temporal model developed within the Electronic and Electrical Engineering Department at Strathclyde University, and supported by SPT, over the last five years. In the enhancement of the methods for forecasting of dynamic ratings, Strathclyde University will use the available weather data from existing meteorological stations and hourly meteorological data from other sites across the UK to which Strathclyde University has access. The forecasting will be applied to the estimation of wind speed and directions in the vicinity of key overhead line spans for the purpose of calculating dynamic overhead line ratings. The model will also be applied to air temperature forecasting as it is the combination of wind speed and air temperature that determines overhead line cooling and subsequent maximum current carrying capacity.

The success criteria is the application of spatial interpolation techniques to determine forecasts at regular intervals along an overhead line and the use of wind speed, wind direction and air temperature forecasting to determine local overhead line cooling rates.

Other success criteria will be the provision of an estimate of uncertainty associated with the forecast so that the system operator can make appropriate judgements with respect to management of risk and the necessity for preventive actions.

2.2.1 NIA SPT 1302 Project Progress

This project has been registered as a joint project by National Grid, and therefore they will provide a progress summary in their NIA Annual Report 14/15 consequently; no project progress has been included in this report. However, we, as an active partner of the project, will outline our New Learning for this project under Section 4.

2.3 NIA SPT 1303 IEC 61850 Integration of Substation Protection and Control - Test Facility

The IEC 61850 standard is intended to provide a standardised framework for the implementation of communication-based Substation Automation Systems (SAS). The principal benefits of employing the IEC 61850 approach are to achieve:

- Reduced engineering through re-usable designs
- Reduced time and cost for assembly and wiring
- Reduced site wiring and installation
- Increased off-line testing resulting in faster commissioning and reduced outage durations

Early experiences of attempting to engineer an IEC61850 compliant multi-vendor substation using the various files and software tools from each vendor led to unsatisfactory conclusions:

- It was difficult to achieve interoperability between devices from different vendors as each vendor has implemented the IEC 61850 standard according to its own designs. No two vendors implement the same functions to the same extent.
- The engineering process was complex and time consuming. It required extensive work to create the Intelligent Engineering Device (IED) configuration files and an expert knowledge of the underlying format of IEC 61850 configurations.

To further our knowledge experience and understanding of a GB compliant IEC 61850 process and related compliant IED’s, we intend to create an IEC 61850 test facility in Cambuslang that would not only create a "station bus" simulation substation but also allow the pilot of the new IEC 60870-101 communication protocol to our Operational Control Centre (OCC). This facility would provide the following benefits:

- Allow the testing of multiple IEC 61850 IED's from different vendors, remote terminal units (RTU’s) and fault recorders for compatibility and operational adequacy.
- Enable the risk free trial of the new IEC 60870-5-101 communication protocol and its support tools (the replacement of the existing Mk2A protocol).
- Allow the testing and programming of IED's before installation reducing outage time and streamlining work on site.
- Future proofing: if the IEC 61850 standard ever changes/progresses, this centre will be able to prove compatibility with future versions.
- Reduced support costs as SPEN would provide first line support for this system (i.e. reduced costly third party support).

The main project objectives area as follows:

- Prove the interoperability of all the IEDs and their performance in the SAS architecture proposed by SP Transmission.

- Prove communication between the test facility and the OCC using IEC 60870-5-101 (create a substation “Cambuslang”) and prove all required functionality from the OCC (including support tools).
- Thoroughly test compatibility of any new IED to be installed onto the network.
- Understand and document any issues faced and resolved from the above activities.
- Share all knowledge gained.

2.3.1 NIA SPT 1303 Project Progress

This Project started in April, 2013 and was scheduled to last two years. We are now in the final stages of delivery.

Progress against our objectives for the project to date is as follows:

- Multi-vendor IED interoperability has been proven and we are currently evaluating the performance in the SAS architecture.
- Remote communications for the test substation at Cambuslang have been established and we are in the process of establishing communications with the OCC.
- We are presently evaluating IEDs
- As we encounter issues we have recorded what they are and how we resolved them.
- It is planned to roll out training which will address knowledge and skills.
- IEC61850 is where protection and SCADA meet. It is therefore an area where training of both disciplines is imperative.

We are on schedule to address the issues highlighted in the previous section and realise the principle benefits of using an IEC 61850 approach.

We have a 132kV protection project planned which will implement IEC61850. The Cambuslang test build is being used to evaluate the scheme logic and settings.

2.4 NIA SPT 1304 Smart Transmission Zone

There is an increasing quantity of onshore and offshore wind generation and as a result the power flows across the transmission system are becoming increasing variable and unpredictable. In time this will compromise the security of the network as control engineers will lose the ability to ensure the system is operating economically.

In addition as the system becomes more complex previous security systems, such as inter-trip systems which are designed to automatically trip generation or carry out automatic system reconfiguration, will require redesign to optimise operational responses. The system modelling effort required to manage special protection systems will increase and the duration and opportunity to engage special protection systems may reduce significantly.

The determination of the power system ‘state’ pre and post fault is a key requirement in determining the post fault control action. The connection of generation to transmission boundary circuits leads to a very complex set of variables since the amount of generation to be tripped to restore security/stability will vary with the fault point, pre-fault transfers, generation background, parallel HVDC flows and other pre-fault network contingencies.

This proposal included a generic feasibility study that would identify the performance requirements and functionality of a Smart Zone control system detailing technology limitation i.e. state measurement, system modelling and communications etc. The benefits of employing Phase Measurement Units (PMUs) in the determination of network states to inform post fault control would also be evaluated.

The objectives set for the work were as follows:

- Carry out a generic feasibility study on the performance requirements and functionality of a Smart Zone control system.
- Increase security and stability of the transmission system.
- Understand the performance and how reliable the IT communication system is along with any changes which may be necessary to withstand the future needs of the system.

By exploring various smart control technologies, including the information from PMUs, this project will provide valuable information and guidance regarding the future applications in our NIC VISOR project.

2.4.1 NIA SPT 1304 Project Progress

The project considers the potential to use response-driven stability intertripping as illustrated in Figure 1, rather than the current event-based (line-end-opening) intertripping. Phasor measurement provides key dynamic information to enable response-based action. There is a trade-off between speed of response and proportionality. An event-based response can be initiated faster, and for the worst-case faults (i.e. 3-phase short-circuit at a large generator) will be the most effective, however in most conditions it would over-trip, thereby introducing a risk of cascading failure in complex events. Response-based action, although somewhat slower, will be sensitive to the actual system response, and in many cases will not need to trigger. The completed study has identified a preferred approach to be event-triggered, but allow a response-trigger mechanism to supplement the action if needed. The response-driven mechanism can be permanently armed, as it will only trigger as angles are separating, and forms a defence against more complex phenomena that may not be covered in the event-driven design.

This project has fulfilled all the original expectations.

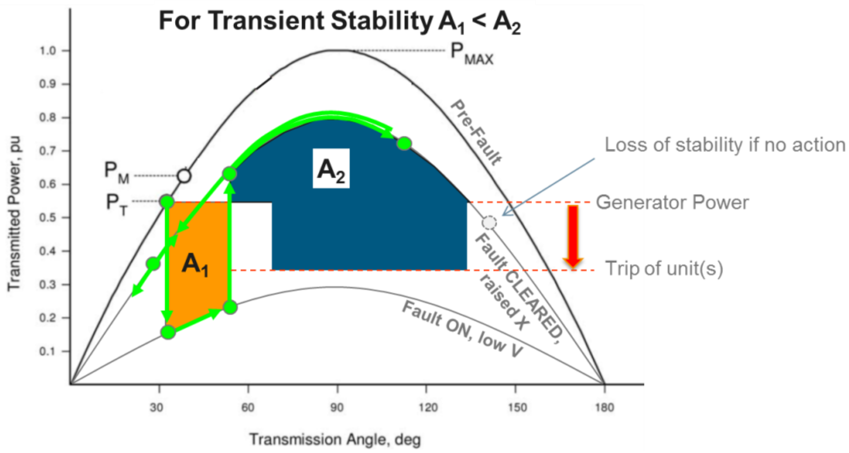


Figure 1 Basic Transient Stability Problem With Generation Shedding

The outcomes of the project contribute to various new innovation proposals including Smart Transmission Zone (control aspect); Wide Area Protection and Control under Horizon 2020.

2.5 NIA SPT 1305 Nanocomp

Transmission network operators are currently planning development of the next generation of high efficiency and reliable HVDC transmission systems to connect large offshore windfarms to load centres and provide network reinforcement. The operational voltage stresses for these HVDC systems are, however, extreme and difficult to control. Establishment of higher performance and more reliable insulation material solutions, which are still affordable, is one of the major challenges that the electricity transmission industry faces.

Successful insulation technology demonstration and its subsequent implementation is seen as vital to supporting timely expansion of renewable generation and its integration in the UK power grid.

In laboratory R&D, nanocomposite electrical insulation materials have been shown to significantly out-perform conventional micro composite insulating materials but results have been inconsistent and scaling to manufacturing processes has been problematic.

The planned work includes mastering the different facets of nanophase processing of cost effective materials for repeatable and scale independent manufacturing of preproduction materials for optioneering and optimisation as well as for demonstrator HVDC components that test scalability. The development will use state of the art processing and measurement methods to establish design and processing rules and to support the design of components with highly optimised electrical and physical properties that can withstand the multi-stress environments found in HVDC systems.

The design and processing rules will then be trialled by manufacturing a demonstration component and undertaking suitable electrical and mechanical testing of the component.

The work will assess whether nanocomposites can be dispersed in polymeric insulation material in a reproducible fashion and whether a new improved insulation material can be created and used to construct full size products such as bushings. The project will evaluate the potential of the new material to offer the reduction in size of insulation, which in turn could represent significant cost savings for the industry.

The availability of proven advanced insulating materials integrated in HVDC but also in HVAC equipment (GIS plants for instance) is expected to reduce the size and improve the reliability of the insulation associated with HVDC converter systems and associated HVAC systems in the UK. This should yield significant financial savings for UK customers especially for offshore applications (for instance more compact GIS plant for pollution prone coastal grid connection areas for offshore renewables) but would also be substantial for onshore systems. In general terms, the project is targeting the reduction in size and improvement in the reliability of the insulation systems associated with such converter stations that include both DC and AC equipment. This should result in a reduction in life-time cost.

2.5.1 NIA SPT 1305 Project Progress

This project has been registered as a joint project by Scottish and Southern Energy, and therefore they will provide a progress summary in their NIA Annual Report 14/15 consequently; no project progress has been included in this report. However, we, as an active partner of the project, will outline our New Learning for this project under Section 4.

2.6 NIA SPT 1306 HVDC Cable Conditioning Monitoring Project

In response to the 'market need' for improved maintenance information, HVPD Ltd is developing an integrated high voltage network management system (OLPD-HVDC) that will address the emerging industry demand for the 'holistic' condition monitoring of HVDC cable networks. The system will provide early warning of faults and therefore allow direct preventative maintenance to help improve operating efficiency through the use of 'holistic' condition monitoring technology solutions and a corresponding, robust condition based management approach to managing these assets. The monitoring technology will be able to indicate insulation defects along with cable faults ahead of failure to allow for preventative maintenance interventions. This will prevent the need for unplanned outages and downtime which as a result improves the security of supply and reduces operation and maintenance costs.

The objective of the work is as follows:

- Improve accuracy and detail of information available on the condition of the HVDC networks.
- Increase ability to carry out preventative maintenance.
- Reduce the number of cable and insulation failures and as a result the outages and downtime.
- Allow more accurate determination of where the faults in the cables have occurred and thus reduce costs of repairs.

2.6.1 NIA SPT 1306 Project Progress

Field trials of the Beta system are on-going in line with the project programme and a report on these trials is in preparation.

Figure 2 HVDC OLPD Alpha Monitor System In Cable Ageing Laboratory

During Phase 1 the Alpha system was designed and built and laboratory testing was undertaken at HVPD, with complimentary work completed at the University of Strathclyde. Trials of the Alpha system took place at the Alstom Cable Aging Facility, Figure 2, and field trials were carried out on the Moyle Interconnector-Auchencrosh.

The project is now in Phase 2. To meet milestone 4 the HVDC Beta Prototype specification including both system software and hardware requirements was made in follow up to the results from field trials of the HVDC Alpha system and in-house development work. The Beta system included changes to: (i) the system design, (ii) PD data capture hardware comprising synchronous acquisition of 6x input channels with the possibility of extension using a multiplexer, (iii) the PD data acquisition routine optimised for PD under HVDC stress, (iv) analysis software for HVDC PD testing, (v) the central control PC for combining data from all acquisition modules and (vi) transient and harmonics monitoring using alternative analogue data interfacing card and a power quality (PQ) module. The Beta system has been designed and built. Tests have been carried out in line with the system acceptance criteria and a programme of laboratory testing of the Beta system.

Complimentary laboratory work is being undertaken at the University of Strathclyde. This has included investigation of the behaviour of PD in HVDC cables and other associated phenomenon related to the measurement of PD. Early work looked at PD pulse attenuation modelling in HVDC cables and analysis of HVDC Partial Discharge Pulse Sequence Data to evaluate the severity of the PD activity on test samples. This includes the testing of two 33 kV XLPE cable samples with manufactured defects and generic test objects under DC voltages to measure potential Partial Discharge (PD) emission. Significant PD activities have been detected from both these cable samples. Glasgow Caledonian University have investigated HVDC Partial Discharge Characteristics under switched voltage input and will begin an initial investigation of the influence of Voltage Source Converter (VSC) ripple on PD characteristics.

2.7 NIA SPT 1307 MVDC

Today's power systems use alternating current (AC) for transmission of electrical energy but historically the first grids were based on direct current (DC). As a result of considerable technical progress in the field of high-power semiconductor devices and cable technology, high-voltage point-to-point direct current (HVDC) transmission has been incorporated into grid networks.

Due to the high cost of HVDC power electronics (which is likely to continue in the foreseeable future), the physical demonstration, testing and development using high voltage levels can be prohibitive. Lower voltage level research and testing could, in certain instances, help understand the technology at higher voltages, by extrapolating the results based on the modular concept of the HVDC equipment.

This type of research and testing facility provides additional societal benefits such as the facilitation of more competition in the DC suppliers sector, de-risk the manufacturing constraints and help SME companies to develop technologies in this space. Such a facility could also support the development of supply chain companies.

The scope of the project is to understand what MVDC research and development initiatives are being conducted worldwide and to understand from an industrial perspective, the future direction of MVDC in the electricity transmission and distribution systems.

2.7.1 NIA SPT 1307 Project Progress

The outcome of the project led to a comprehensive study commissioned by Scottish Enterprise regarding the wider benefits of the technology to Scotland.

SP Energy Networks is also actively exploring potential areas to deploy/pilot this technology.

2.8 NIA SPT 1308 Synthetic Inertia

There is concern over the future stability of power systems as they incorporate reducing amounts of conventional synchronous machines and increasing quantities of wind farms. As a result there is an increased interest in the provision of synthetic inertia from wind power plants to introduce more stability to the system.

There are two main situations where the stability of the system could be improved by synthetic inertia:

- Firstly, during a major loss of generation or interconnection capacity.
- Secondly, during a short-circuit fault on the system. In this case the fault results in an acceleration, usually limited by the inertia of a rotating plant, due to the reduced active power demand on generators in the vicinity of the fault.

The conventional thermal generation assets can provide strong system inertia due to their long and heavy shafts to hold the system frequency. Operation of wind generation on the power system, on the other hand, will be linked with the network via power electronic device which decouple the generation from the network frequency. Hence the high level of penetration of wind generation in a transmission network will impact on the first swing stability of conventional synchronous machines following a network short circuit fault. However, the timescales for response to allow effective action to be taken in time to affect the first swing stability are challenging, with detection of a fault event within 10/20 ms, followed by initiation of response from the wind capacity within 60-80ms.

In the two cases outlined in the section above, synthetic inertia could improve the system as follows:

- In the first case an inertial response from a converter-interfaced energy source, in the form of a temporarily increased real power contribution would be desirable following the detection of a significant drop in the system frequency and/or increase in the rate of change of frequency.
- In the second case some form of response from windfarms (either through reducing/ceasing to supply power, or ideally, even by absorbing power from the accelerating system) is desirable.

In addition, careful modelling of the power system, turbines, inverters and their control, could provide a good guide as to what can be expected from the wind plant, but the more difficult engineering challenge is the provision of a robust and reliably fast fault detection system.

The objectives of the work are as follows:

- Investigate the potential contribution of windfarms to the GB system inertia focusing on the first-order inertial behaviour (i.e. first swing stability of conventional synchronous machines)
- Assess windfarms' potential contribution to frequency stability
- Detailed modelling of wind turbines (mechanical, power electronics and control systems) to examine the implications on the turbines themselves when providing synthetic inertia

2.8.1 NIA SPT 1308 Project Progress

The project carried out systematic reviews regarding:

1) Existing control strategy on wind turbines;

2) Existing Grid Requirement; and

3) Operational experience on industrial software on the GB transmission network.

It has been agreed that the control of a turbine should be treated as one element within control of power electronics, including TCSC, HVDC and Statcom.

The project met the original success criteria on turbine and system modelling and fulfilled the majority of the original expectation.

2.9 NIA SPT 1309 Low Frequency Electricity Transmission Technology Evaluation

This project will be a comprehensive and objective appraisal of the concept of Low Frequency Alternating Current (LFAC) transmission as an alternative to High Voltage Direct Current (HVDC) transmission.

High Voltage Alternating Current (HVAC) cabling is the current standard being used for offshore power transmission; however, as distances offshore increase the charging reactive power associated with the cable can prohibit its use. This project will assess the implications of reducing the operating frequency (e.g. in the range of 0.5 to 5Hz, or 1/3 of the nominal frequency) in order to reduce the charging reactive power and increase transmission capability, such that HVAC could, potentially, be used in far offshore applications. However, the reduction of the frequency would have an adverse impact on the size/weight of the power plants. Hence the size implication for the associated low frequency transformers will require to be addressed. In addition, the assessment will consider the following:

- Quantification of the benefits and the limitations of the LFAC concept, giving a comparative evaluation against favoured voltage sources converter (VSC) HVDC technology. Differences in converters, cables and circuit breakers are to be evaluated based on their predicted stresses during operation.

- Operations (control and protection) of the LFAC transmission concept, under different windfarm scenarios and transients, satisfying all the grid code requirements.

- Criteria under which LFAC transmission would be a more attractive design option, with respect to variables such as transmission distance and voltage level.

2.9.1 NIA SPT 1309 Project Progress

A collaboration agreement was signed with Warwick University under which LFAC modelling and simulation work for an offshore windfarm connection under different windfarm scenarios and transients has been completed. A comparative evaluation of LFAC versus conventional HVAC and HVDC has also been undertaken with particular emphasis on estimating the impact on transformer size/weight. A publication has been made summarising the main outputs of the analysis.

Following the encouraging results from the aforementioned study another piece of work was commissioned in December 2014. This work is ongoing and is expected to conclude in July 2015. All mechanisms and resources have been put in place to undertake a comprehensive analysis of the market use of LFAC technologies as well as the identification of the major component/technical barriers by engaging with key stakeholders. Finally a potential application in the transmission business is being simulated and a comparison with HVDC will be made to determine the need for a future demonstration project.

2.10 NIA SPT 1310 Shunt Reactor Switching Innovation Study

This innovative research project to investigate whether standard switchgear can be used to switch shunt reactors, or whether specialised switchgear or switchgear of a higher rating is required. If it is found that higher rated switchgear is necessary, it will be determined if a more economical solution would be to modify standard switchgear by means of shunt capacitors, surge arrestors or snubber circuits.

The similar technical principle will be similar between distribution (33kV or 11kV) as the transmission connected shunt reactor (at 132kV).

The work for this study has been broken down into a set of discrete tasks divided into two study phases as listed below.

Phase 1

- Literature survey into shunt reactor switching
- Liaise with manufacturers and SPT Asset Management to define factory test data currently available
- Investigate current SPEN systems, simulate various items of equipment, designs and connections
- Investigate practical mitigation techniques

Phase 2

- Measure shunt reactor characteristics
- Practical testing of a vacuum circuit breaker and reactor combination

The project will develop guidelines for reactor switching transient recovery voltage (TRV) simulations at 33kV (and other voltages) and make recommendations for circuit breaker rating and mitigation options for inclusion in a company policy document.

If the outcomes are useful, there could be the possibility of extending the project to cover higher voltages and series reactors.

2.10.1 NIA SPT 1310 Project Progress

A literature review of shunt reactor switching techniques from around the world established a lack of evidence of a fit for purpose circuit breaker specification reflecting operational experience.

Switching studies were undertaken to assess transient overvoltages that may be experienced at 33kV. Where circuit breaker transient recovery voltage exceeded set limits a set of mitigation solutions were explored to determine the most effective means of control.

2.11 NIA SPT 1311 Transformer Research Consortium

This project was started in April 2013 and is scheduled to last four and a half years. This research project being undertaken by the University of Manchester builds on initial work undertaken assessing ester based alternatives to conventional insulating oil and seeks to enhance understanding of transformer health and the key variables that can lead to premature failure. The research focuses on ageing indicators, partial discharge diagnostic, dissolved gas and thermal analysis.

While this project is being undertaken at laboratory scale consideration is being given to system application issues. The outcome of this project is expected to inform asset management policies with the aim of optimising operational and capital expenditure.

It is believed that the work packages will provide outcomes that can realistically be deployed in short to medium term timescales that will allow SPEN asset managers to benefit from new test methods and data collection techniques that will directly contribute towards the transformer asset decision making. This development of transformer specifications that include online monitoring and condition data collection techniques that reduce maintenance costs and provide more accurate condition assessment information.

2.11.1 NIA SPT 1311 Project Progress

This project has been registered as a joint project by National Grid (NIA_NGET0088), and therefore they will provide a progress summary in their NIA Annual Report 14/15 consequently; no project progress has been included in this report. However, we, as an active partner of the project, will outline our New Learning for this project under Section 4.

2.12 NIA SPT 1501 Medium Voltage DC (MVDC)

Increased levels of distributed renewable generation have contributed to a growing need for radical reinforcement solutions in areas of the network which are stretched to capacity. The distribution network is facing both thermal and voltage limits and significant reinforcement is required to accommodate the demand and generation growth anticipated. It would be expected, from the initial desktop studies, that converting an existing 33kV circuit to DC operation can increase the thermal capacity, as well as resolving voltage issues and limiting fault level.

This project will gather the evidence required to support a strong business case, which may lead to the first ever DC operation of an existing AC distribution network circuit in the UK. As part of this project review, consideration was also given to potential transmission applications.

2.12.1 NIA SPT 1501 Project Progress

The detailed network studies to determine the suitability of MVDC as a reinforcement solution have been completed. Both a distribution and a transmission case have been analysed. Following the outcome of the studies a fit-for-purpose functional specification has been developed to meet the requirements of the system in the proposed areas.

The cost-benefit analysis is being undertaken and will include all main capex and opex elements, including the impact of losses and unavailability.

2.13 NIA SPT 1502 Distributed Photonic Grid Instrumentation

Synaptec Ltd is developing a unique technology which allows any standard telecommunication fibre to be utilised to measure a broad range of electrical and environmental parameters. These include voltage, current, vibration, temperature (ambient or surface), strain, and pressure, with only a single fibre needed to acquire all measurements (potentially 100 discrete sensors per fibre).

Synaptec Ltd was awarded Best University Technology at the 2014 UK Energy Innovation Awards and was a finalist at both the IET Innovation Awards and the Converge Challenge in the same year.

This innovation provides geographically-distributed measurements of current, voltage, vibration and temperature at a single interrogation point enabling faster, more selective protection and enhanced monitoring of network conditions. The project will demonstrate multisensor operation integrated with existing CT secondary circuits. The technology has potential to drastically reduce network operators' costs by eliminating conventional infrastructure expenditure associated with instrumentation for monitoring, control and protection.

2.13.1 NIA SPT 1502 Project Progress

The design and simulation of the distributed electrical sensing system is now underway, and the sub-contractor carrying out process development and device assembly have been engaged by Synaptec.

The project is presently on track to complete the sensor design, package design, and assembly process design, and initiate assembly of the prototype sensors by the relevant milestone points. This initial 4.5-month phase will focus on the design and simulation of voltage and current sensors using optical fibre. A second 4.5-month phase will focus on construction of the sensors and basic testing to ensure compliance with key elements of the relevant IEC standards.

2.14 NIA SPT 1503 Protection Settings to Cater for the Evolving Transmission Network

The UK transmission system (in particular Scotland) is experiencing significant changes with the introduction of large amounts of wind energy and distributed generation against a background of fossil-fuelled synchronous generation decommissioning. The associated anticipated reduction in system inertia could lead to significant reductions in fault levels and variations in post-fault system behaviour. There is consequently a risk that traditionally applied protection schemes and settings based on well understood and modelled system behaviour may no longer be valid.

In order to guard against protection mal-operation, protection system performance analysis is required under different future network scenarios. The adequacy and suitability of existing protection methods, settings and polices must be assessed against future network requirements.

A new process, assisted by a protection setting and performance validation tool, is required to fully check protection settings and performance against radically changing system behaviour in the short, medium and longer term.

The objectives of this project are to:

- Carry out a comprehensive review of existing techniques and tools
- Selection of those considered most suitable for the intended application
- Assess suitability of tools through actual validation exercise using network and protection data
- Identification of a route forward to adapt the method and tools for business as usual application

2.14.1 NIA SPT 1503 Project Progress

This project will formally kick-off later in May 2015, so the initial progress so far has been concerned with evaluation of suitable tools and techniques that can automatically analyse the protection settings. The learning that will arise from the initial work, in terms of tools that will be suitable for the next stage of the project and a proposed approach to systematically analyse the settings for transmission protection under future scenarios, will be reported during Q3 of 2015.

3 NIA Activities Linked to SPT Innovation Strategy

It is recognised that innovation cannot be a prescribed by rigid process but must stimulate creativity and new ideas. However, to ensure good governance, SPT has applied an over-arching framework to ensure that it is managed efficiently and delivers the benefits without constraining creativity.

The five innovation objectives within SPT are:

1. Innovation meeting the needs of stakeholders;
2. Innovation opportunities are identified in a timely manner, which will benefit these stakeholders;
3. Innovation is managed in an efficient and proactive manner;
4. A balanced portfolio of innovation is pursed which includes commercial, process and technology innovation. Our activity has a relevant focus on developments at different technology and commercial readiness levels to which balances radical with incremental innovation; and
5. The outcome of innovation activity is adopted by the wider business to ensure that customers benefit at the earliest opportunity whilst minimising the risk to the integrity of the network.

Figure 3 outlines the general R&D management structure within SPT.

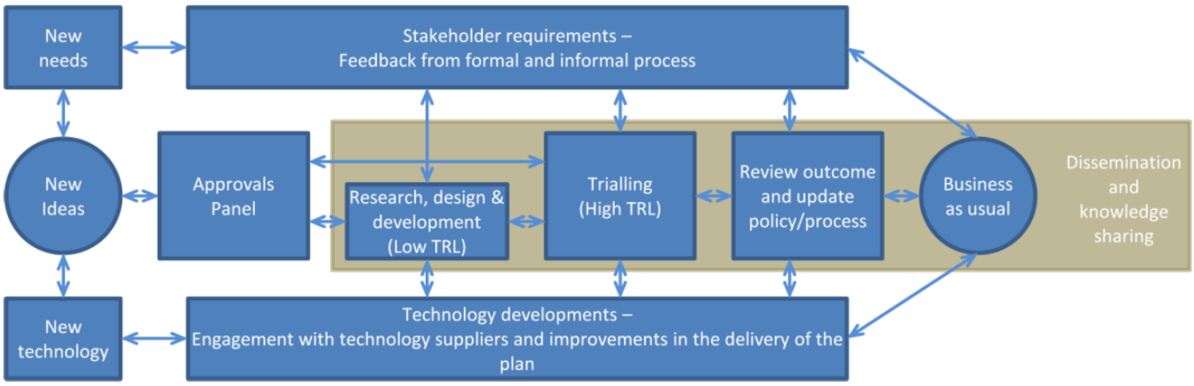


Figure 3 SPT Innovation Management Procedure

As part of our long term innovation strategy, stakeholder engagement will be central to ensuring that our innovation plans are meeting customer's expectations. The involvement of stakeholders is also a vital source of ideas for innovation – particularly the academic community, equipment suppliers and other network operators (DNOs and TOs).

Figure 4 illustrates the NIA development process at SPT.

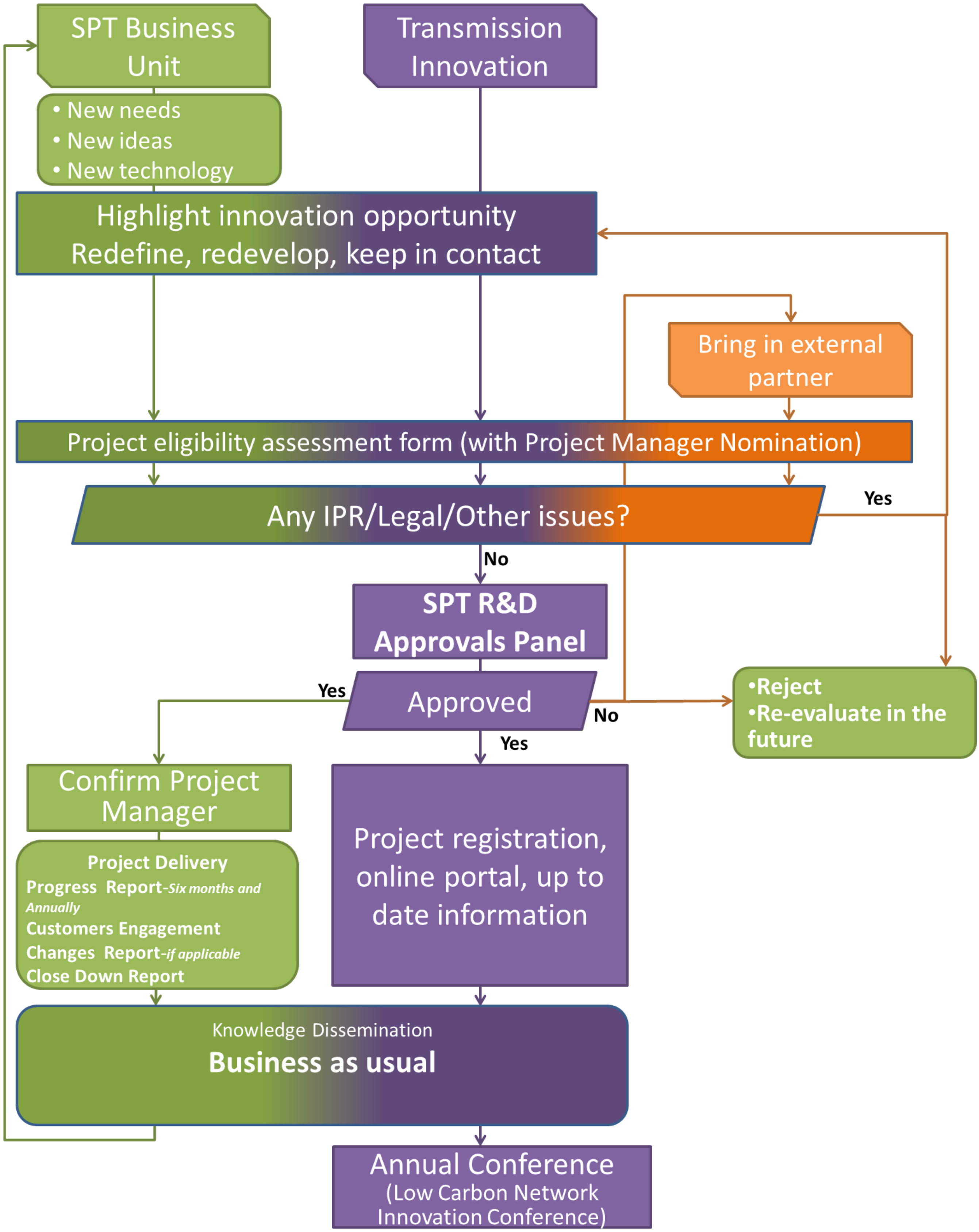


Figure 4 SPT NIA Development Process

Our approach to innovation development is summarised in figure 5 below which contains five steps:

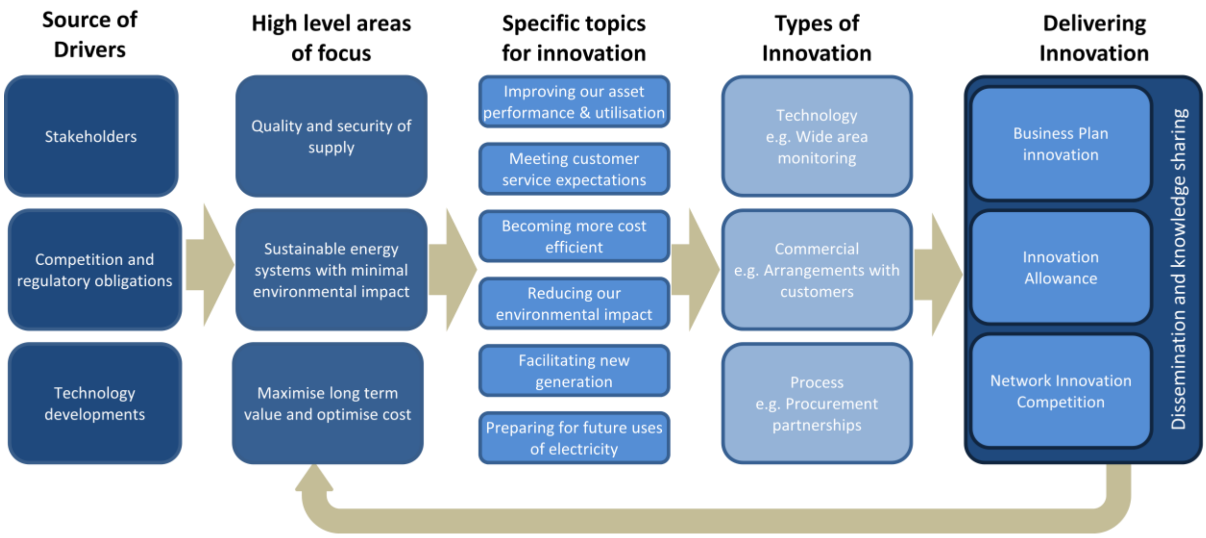


Figure 5 SPT Approach to Innovation Development

In order to realise our future network vision we have identified the following five dimensions that require to be addressed:

1. **Visibility:** The combination of monitoring devices, computing process and communications infrastructure provides an effective means to present the real time information for wide area monitoring. This visibility can cover almost all the aspects regarding transmission network performance, ranging from steady state thermal limitation of critical boundaries to sub-synchronous oscillation behaviour in the local area. This visibility provides a new dimension and reference for system operation and protection.

2. **Controllability**: The visibility of transmission network at the GB level requires review of some control algorithms which had been designed based on a centralised approach. Smart grid control involves many more controlled elements than in the conventional design, together with greater uncertainty in generation. The increasing complexity requires new approaches to observing, modelling and controlling the interactions between generation, transmission, distribution, and load. How to react to the information available requires a defined and coordinated approach to ensure that the existing supply quality and reliability standards are not compromised, and that customers can realise maximum benefit from the latest technology.

3. **Intelligence:** As a result of the improved visibility and control of the network, active management of generation output around network constraints will improve the time required to connect new demand and generation. Wide area monitoring combined with real time asset ratings, will ensure that maximum capacity is utilised before reinforcement is required. Processing of network data will also inform designers of when reinforcement is required and inform the deployment of appropriate, cost effective, solutions.

4. **Interoperability:** The variety of new technologies deployed on the network will require to be interoperable such that new solutions can be readily integrated, for example through the application of technology standards such as IEC61850. We will work with the wider industry nationally and internationally to develop open-access standards. Reliable and secure communication systems will also be required to transfer data across the network combined with IT systems that can effectively manage the new data that is generated. This will require a significant extension of our communications systems using internal and external services to achieve the necessary coverage.

5. **Commercial Mechanisms:** Our network will be reliant on commercial arrangements with network users as there are close linkages with many of the technology solutions.

To achieve these five dimensions, we consider three different ways in which we invest in the network. These investments can be described as follows:

Enablers: This includes smart-ready asset replacement and other investments which create a robust foundation and enabler for the smart grid applications. These are considered as “no regrets” investments which can be deployed in a top-down manner and are an essential component of the network. Having the enabling technology in place will allow us to flex between different future scenarios. Typical enablers are Remote Terminal Units for SCADA with expansion capability and the installation of additional network monitoring.

Applications: This is the implementation of a solution which has an immediate application to directly address an output within RIIO-T1 such as meeting load growth, facilitating new customer connections or improving quality of service. Where we have proposed a smart application, a cost benefit analysis (CBA) will be undertaken as in most cases a comparison with a traditional solution can be made. Typical applications are real time thermal ratings, intelligent voltage control or active network management.

Future Proofing: Where a positive business case exists, we will identify where additional enabling technologies are considered to be of long term benefit to customers, although not necessarily required in the short term. This category is also regarded as top-down investment as it is required to further enable other applications in the longer term. Future proofing investments are also subject to a CBA to ensure that they are efficient investments for the customer. Typical future proofing includes oversizing conductors for future load requirements and switchgear being pre-wired for sensors and automation.

The variety of new technology and commercial arrangements deployed on the network are vital to meeting the future requirements of our customers in a responsive and cost-effective way. However, it will be through the effective management and stewardship of the existing asset base that we will ensure value for money and that a sustainable network solution is delivered.

3.1.1 SPT NIA Project Mapping with Innovation Strategy

Network Investment			Figure 6 NIA Projects Mapped to SPT Innovation Strategy	Specific Dimension				
Enabler	Application	Future Proofing		Visibility	Controllability	Intelligence	Interoperability	Commercial Mechanism
	✓		NIA 1301: Electrical Power Research Institute (EPRI) Engagement					
	✓		NIA 1302: Enhanced Weather Modelling for Dynamic Line Rating					✓
		✓	NIA 1303: IEC61850 Integration of Substation Protection and Control: Test Facility				✓	
✓			NIA 1304: Smart Transmission Zones			✓		
✓	✓		NIA 1305: Nanocomp		✓			
	✓		NIA 1306: HVDC Cable Conditioning Monitoring Zone	✓		✓		
		✓	NIA 1307: MV-DC and Feasibility Studies		✓		✓	
✓		✓	NIA 1308: TIC (Strathclyde university) Synthetic Inertia	✓	✓			
		✓	NIA 1309: Low Frequency AC Transmission Technology Evaluations		✓			
	✓		NIA 1310: Shunt Reactor Switching Innovation Study		✓			
✓	✓	✓	NIA 1311: Phase 3 Transformer Research Consortium	✓	✓	✓		
✓	✓		NIA 1501: Medium Voltage DC (MVDC)		✓			
	✓		NIA 1502: Distributed Photonic Grid Instrumentation	✓		✓		
✓	✓	✓	NIA 1503: Protection Settings to Cater for the Evolving Transmission Network		✓			

4 Areas of Significant New Learning

The following identifies area of learning on a project by project basis:

NEW LEARNING:

NIA SPT 1301 Electrical Power Research Institute (EPRI)

Scottish Power Transmission participates in collaborative research through EPRI's power system operations research programme. The outcomes and new learning of each research project within the programme for the reporting period are detailed in the Appendix at the end of this report.

EPRI has made all reports and software tools which were deliverables from the projects available to Scottish Power. Several reports and technical updates on the transmission operations work packages that SPT has engaged in have been received and commented on.

SPT has received feedback and support to help inform specific areas of interest including power system protection, system restoration and Scottish Power's VISOR project. The feedback enhanced our existing understanding of the technical nature of those projects and help shape the project to meet industry needs.

NIA SPT 1302 Enhanced Weather Modelling for Dynamic Line Ratings

Please refer to National Grid's NIA Annual Report 14/15 for details of areas of any significant new learning on this collaboration project.

The University of Strathclyde has produced a detailed review of Dynamic Line Rating (DLR) techniques, including a comparison of direct monitoring vs. indirect interface techniques. The University has researched statistical methods to forecast wind speed around overhead lines and have reached conclusions concerning the relative accuracy of different techniques. A paper has been prepared for the IEEE PowerTech Conference titled "Wind Forecasting Using Kriging and Vector Auto-Regressive Models for Dynamic Line Rating Studies". It introduces the methods of spatial interpolation and weather forecasting on wind speed.

NIA SPT 1303 IEC 61850 Integration of Substation Protection and Control - Test Facility

We have now completed the test build and we are currently testing files / settings configurations destined for Windyhill 132kV substation on the test build. The test facility has been used to evaluate and prove the system will operates as expected when it is deployed on the power system, with customers connected.

Considerable effort has been expended configuring IEDs. As setting files will be reused for future projects, features such as delayed auto reclose with reversion had to be built and tested, even though the delayed auto reclose with the reversion feature may not be used on every circuit. It is considered that time spent proving solutions that are relatively future proof (as far as is known) is well spent.

IEC61850 training has taken place however specific training will have to be programmed / planned as IEC61550 is a major departure from our conventional protection systems. We have documented issues and resolutions as and when they arose. Issues have been shared with Iberdrola and IED manufacturers.

NIA SPT 1304 Smart Transmission Zone

The project considers the potential to use response-driven stability intertripping, rather than the current event-based (line-end-opening) intertripping. The preferred approach in this study is for a first stage of response to be event-triggered, but allow a response-trigger mechanism to supplement the action if needed. The response-driven mechanism can be permanently armed, as it will only trigger as angles are separating, and forms a defense against more complex phenomena that may not be covered in the event-driven design.

It is noted that the values of benefits are early-stage indications, based on modelling using simplified models, and taking multiple constraints into account. Noting that after the addition of series compensation, the stability and thermal limits will be at similar levels, various approaches may be required in combination. There may be additional complexity of the wider system response that would make the benefits lower than first appear. Also, further work on other operational scenarios would be useful, noting that the simulation was carried out with high power injection in the North of Scotland and higher loadflow in the East of Scotland. Other potential scenarios would include different balances of North vs Central Scotland generation and East vs West loadflow.

Regarding the technical outcomes of this project, the follow-on options suggested for consideration by SP Transmission and the project team includes:

- An extension of the VISOR project monitoring concept of the power-angle boundary limit representation to auto-curtailment of generation and HVDC modulation is a promising approach, with early indications of 400-1000MW total uplift possible compared with today's practices.
- Include new intertripping capabilities for B6 boundary extension, replacing retiring intertripping generators and extending capability
- Applying set point control to the Western HVDC link
- Applying SVC-POD (Static VAR Compensation – Power Oscillation Damping) control for voltage support to improve B6 capability
- Addressing non-stability constraints

The results of this study suggest that both intertripping and auto-curtailment tend to be more effective towards the north of Scotland. This conclusion should be verified using the detailed model and further simulations, but can be explained by:

- Tripping generation in the North changes loadflow across a large part of Scotland and reduces the angles of several generators, while generation tripping in the South only affects a few generators.
- Generation in the South provides voltage support where it is needed for the B6 corridor during the event, and loss of this generation reduces the corridor capability to resynchronise after the fault.

NIA SPT 1305 NIC Nanocomp

Please refer to Scottish and Southern Energy's NIA Annual Report 14/15 for any details of areas of significant new learning on this collaboration project.

The learning and potential benefits from this research should lead to the future deployment of this new class of nanocomposite materials in HVDC power equipment, potentially leading to reduction in costs due to higher rated, more compact equipment with a smaller footprint for converter stations. Increased network performance and fewer equipment failures due to the enhanced insulation, electrical, mechanical and thermal qualities provided by these new nanocomposite materials.

Learning from the various work packages would indicate that these new materials will find an application in existing HVAC equipment including distribution voltages, with improvements expected in lifetime reliability and potentially in operational management such as in the management of surface trapped charge on GIS barrier insulators for example.

Significant developments in the past year relate to the ability to scale the materials production to industrial level processing enabling the successful manufacture of commercial scale MV bushings and insulators that work with enhanced performance. New functionalised nanofillers have also been produced that have led to a significant increase in the electrical breakdown strength along with ultra-low electrical conductivity and rapid space charge dissipation with extremely low residual charge, well below that of conventional materials. This confirms the high value of these materials in HVDC applications but interestingly the low dielectric loss of these materials combined with the other enhanced properties makes them valuable as replacement materials for HVAC applications.

Environmental and economic impact studies also confirm that these materials confer supply chain benefits and they can be adopted by HV component manufacturers at similar cost to existing materials with no change in the process technologies currently used. An added benefit is that they process easier and more rapidly than existing materials - this is likely to reduce the risks of casting defects and reduced production and rework times. These benefits combined with performance enhancements will improve the overall failure rate of components for both HVDC and HVAC network applications.

NIA SPT 1306 HVDC Cable Conditioning Monitoring Project

Partial discharge measurements have been carried out on insulation and cable samples in the laboratory. This was done to evaluate the occurrence of partial discharge under HVDC which would occur on in-service HVDC cables if there were defects inside of the insulation. The laboratory measurements have also investigated the effect of PD when there is a ripple on HVDC voltage as would be the case in an in-service HVDC system. Knowledge has been gained through these experiments which can be used to evaluate PD measurements in the field.

Continuous monitoring measurements have been made at a cable aging laboratory which has proved the signal detection capabilities of the prototype monitoring system to detect partial discharge signals that were generated by a corona discharge source on the high voltage connections.

As site measurements have been made on an in service HVDC interconnector. This has allowed knowledge to be gained on the noise interferences that can occur and affect condition monitoring measurements.

An updated review on standards and commercially available technology found little new information on commercial PD testing for DC cables; published results remain the same with Haefely and Omicron having laboratory test offerings. A DC test software option is claimed in Techimp literature but no presentation of results was found.

NIA SPT 1307 MVDC

The learning from the project identified significant R&D needs for MVDC technology in the following areas:

- Renewable Energy resource integration;
- Enabler role in DSO due to its transient controllability;
- Distribution network reinforcement to provide a comprehensive support on voltage and power flow; and
- Other industries such as shipping and railway.

With reference to Figure 7 the existing research can be found on either transmission level (>132kV AC system) or low voltage (i.e. households). Due to the continued performance improvement and cost reduction of power electronics, MVDC should be considered and trialled to be part of the tool box for DNOs. This project, when it was initialised, was to identify the need: both commercially and technically and develop the roadmap to deployment towards Business as Usual (BaU).

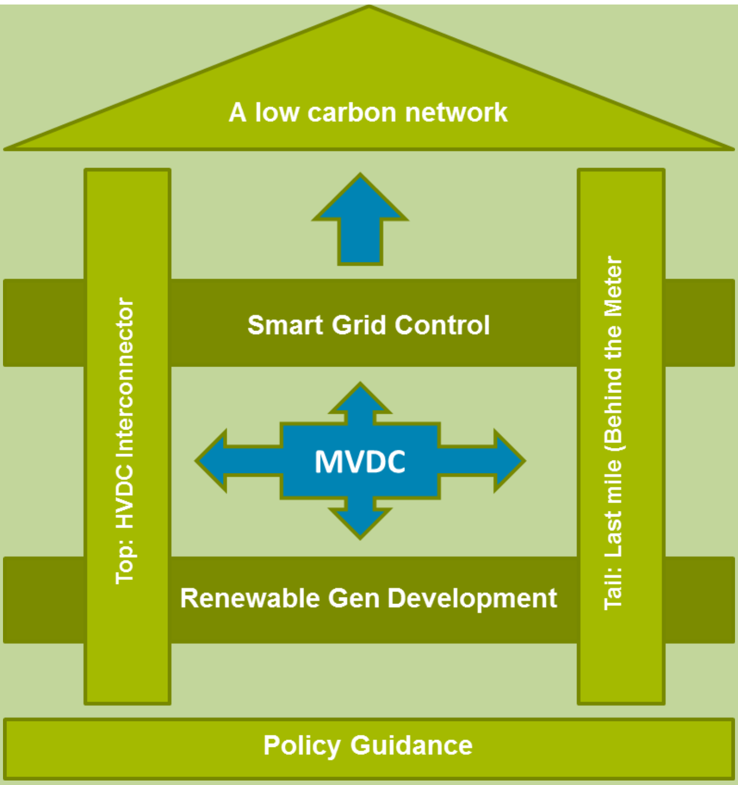


Figure 7

Taking into account the successful NIC application from WPD regarding a 11KV back-back link (equilibrium: http://www.westernpowerinnovation.co.uk/Projects/Network-Equilibrium.aspx), and the associated business need the MVDC project has been consequently shaped but the following findings are still valid:

1. This technology is close to being commercially available and laboratory tests or simulation will have limited contribution to uplifting the TRL;

2. The stakeholders and suppliers are keen to see a trial on the distribution network to provide operational experience and serve as a valid example to provide market and user confidence; and

3. The market potential of this technology can only be realised if the full operational configuration is analysed where locations prohibit the installation of one back-to-back convertor.

NIA SPT 1308 Synthetic Inertia

WTG control has a strong impact on systems boundary limits; such impact is sensitive to the location of replacement generation. The radical change of generation mix in the Scottish transmission network requires sufficient consideration of local inertia support.

From that perspective, Synthetic Inertia should not be treated as one parameter to reflect the whole network, but it should be treated as a signal to represent a local scenario. The study looked into an additional control element to reflect the local system condition as reflected in Figure 8.

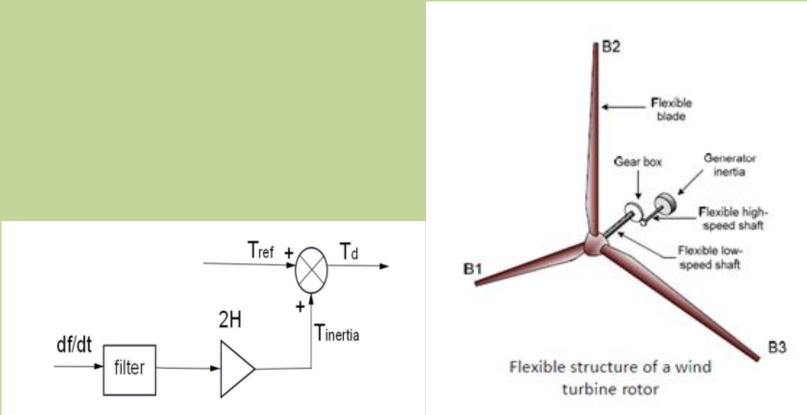
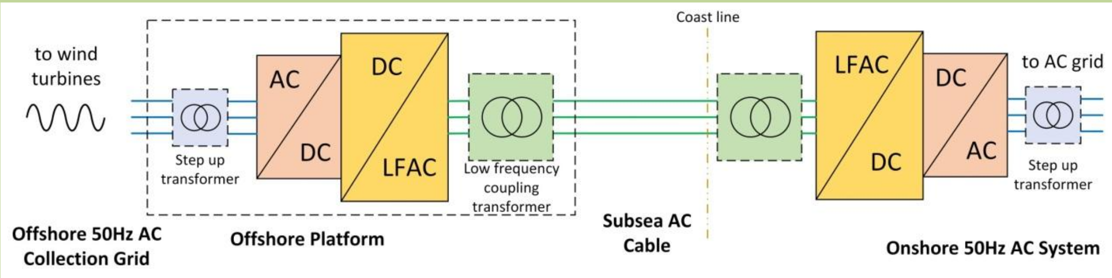


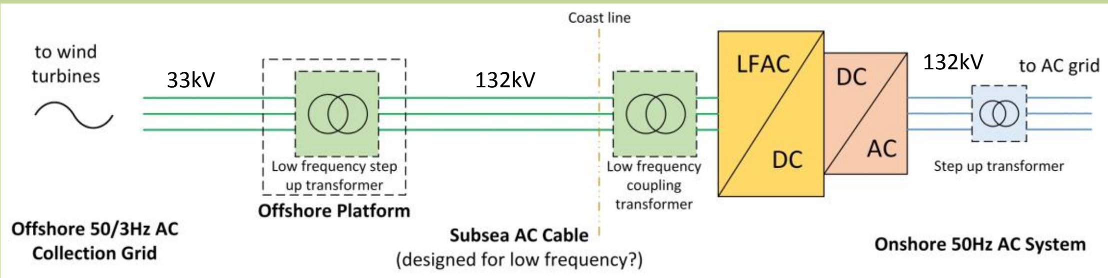
Figure 8 Additional Control Element to Provide Frequency Response

Further studies and simulation need to be developed to take into account the renewable generation (particularly large scale windfarms) and their potential contribution to the regional synthetic inertia.

NIA SPT 1309 Low Frequency Electricity Transmission Technology Evaluation

During the first stage of the project two topologies for the connection of an offshore windfarm were analysed, see below.

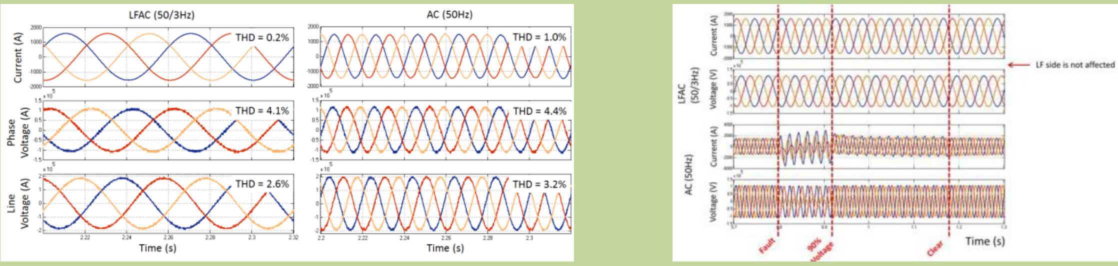




The first option shows a connection that could be applied to any windfarm. Two back-to-back converters are required and low frequency coupling transformers are necessary to remove the zero sequence components.

The second option shows Low Frequency transmission extending as far as the windfarm. In doing this, the need for the windfarm side converter was removed and thus the amount of power electronics deployed offshore is reduced. A low frequency transformer would still be present at the windfarm side. This option proved to be the most suitable LFAC solution.

Simulations were carried out to assess the performance of such system. Both normal operation and fault scenarios were studied.



Simulation results

It was determined that LFAC technology could be a valid option in certain cases. Having demonstrated technical benefits for the offshore industry the challenge addressed by the second stage of the project is to establish whether the benefits can be extrapolated to the onshore transmission industry. This is being complemented with ongoing market research analysis.

NIA SPT 1310 Shunt Reactor Switching Innovation Study

Switching studies were carried out in order to assess the transient overvoltages that may be experienced on the 33kV system SPEN's Smeaton and Neilston substations when switching the circuit breakers (CBs) connecting the 60MVAr shunt reactors.

These studies were carried out under different system conditions and topologies including various lengths of cable and different reactor configurations and capacitances. The purpose of these studies was to assess the transient recovery voltages (TRVs) experienced by the CBs during normal reactor switching (opening) and under three phase and single-phase fault conditions. It was found that in most unmitigated cases investigated, the TRVs experienced by standard ac CBs exceeded the limits set out in IEC Standard 62271-100.

A set of mitigation solutions were then explored to find the most efficient means of controlling the TRVs at the CBs. The solutions explored were snubber circuits, surge arresters, and increased CB ratings. After considering the mitigation strategies and the results of the associated studies, one technical practice considers the use of surge arresters connected across the CB terminals to be the most efficient and cost effective solution to controlling the TRV for a standard 36kV rated CB. The effectiveness of using a 27kV rated surge arrester is demonstrated for what was considered the most onerous conditions established from the series of studies undertaken. However, in the case of the Smeaton 1000MVA transformer, three-phase fault rates of rise exceed the T60 TRV criteria – surge arresters alone can constrain the peak amplitude but not the rate of rise.

Additional mitigation options would have to be used to reduce the RRRV to within the standard T60 envelope for a CB conforming to IEC Standard 62271- 100 for standard 36kV rated CBs unless the CB manufacturer states enhanced capability.

NIA SPT 1311 Transformer Research Consortium

Please refer to National Grid Electricity Transmission's NIA Annual Report 14/15 for any details of areas of significant new learning on this collaboration project.

Within these research activities are new methods for evaluating the condition of a transformers health which will provide SPEN asset managers with more accurate Health Index scores for their transformer fleet. The various work packages are designed to help solve the industry wide problems faced by the electricity network operators and material/equipment manufacturers.

The benefits from the learning will allow the research consortium members to increase their knowledge and understanding of these technical issues, with the intention to directly contribute towards the transformer asset decision making for maintenance, condition monitoring and specifications of new transformers. Learning from this research has already been implemented by SPEN with the installation of fibre optics sensors now standard on all new grid transformer designs and the deployment of online condition monitoring equipment that allows SPEN to manage its assets with greater efficiency and increased reliability.

NIA SPT 1501 Medium Voltage DC (MVDC)

MVDC reinforcement proved to be a cost-effective solution for areas of the network facing a combination of challenges, these include:

- Voltage issues
- Thermal constraints
- High fault levels
- Boundaries between different areas where control of power flow is a problem

Some of these reinforcement challenges can be met using back-to-back MVDC. The added value of converting the circuit for DC operation lies on a more widespread voltage control and enhanced network capacity. Theoretical analysis indicates that the following thermal uplifts in Table 1 can be achieved by converting an AC circuit to DC operation:

Circuit Type	Capacity Increase from AC to DC Operation	
	Base Assumptions	Optimistic Assumptions
Single circuit, triple core	-1%	31%
Single circuit, other	14%	51%
Double circuit	71%	126%

Table 1. Thermal uplift.

NIA SPT 1502 Distributed Photonic Grid Instrumentation

This project has only recently started so the learning arising will be reported in the next annual NIA transmission report.

NIA SPT 1503 Protection Settings to Cater for the Evolving Transmission Network

The learning that will arise from the initial work, in terms of tools and techniques that can automatically analyse the protection settings, that will be suitable for the next stage of the project and a proposed approach to systematically analyse the settings for transmission protection under future scenarios, will be reported during Q3 of 2015.

5 APPENDIX - EPRI Programme Outcomes and Learning

1. P39.011a – Situational Awareness Using Comprehensive Information Visualization of Operating Boundaries (VOB)

The goal of the project and value:

Goal: Develop new visualization methods/tools that improve operator awareness of critical operations limits allowing faster root cause analysis and recommended mitigation.

Value: Increase system reliability by reducing amount of information that the operator must monitor to keep the system within stable operating margins.

Interaction with project: Scottish Power staff have participated in project webcasts and technical meetings.
2014 Outcomes:

Visualization Translation

- Work with vendors to validate XML input format and to verify interoperability of data files for operational tools.
- Useful for designing transfer studies and setting up in Case Studies

Visualization Enhancements

- New features for data flagging, equipment names, and case comparisons
    - Report number: 3002002874
    - Compatible with Powertech Labs DSA Tools

Case Study

- Interim report on Real-Time VSA application
    - Report number: 3002004872
- Work continues in 2015
- Learn from Southern Company and ISO New England how VOB works in practice

Visualization Research

- Results for thermal and voltage boundaries and for operator actions
    - Report Number: 3002002875
- Conduct case studies and integrate into vendor tools

2015 Accomplishments:

- Interface speedup
- Real-Time VSA Case Study preliminary results
- Analysis of operations trends and transmission operational studies using database and filtering

2. P39.011b – Situational Awareness Using Comprehensive Information: Integrating Asset Condition Information into Control Center Operations

Goal
Integration of asset information on key equipment in control centers to support grid operators' decision-making

Outcomes

- Completed a survey and report on the use of asset condition information in the control room. Most critical equipment are transformers and circuit breakers any work should focus on new sensor.
    - Operators usually receive all alarms that are not directly actionable and pass along the information to other staff.
- Completed a survey and report on data and data practices that describes current data available in operations, what information is desired, and its potential business value. Can use survey results for comparison, technologies in wide-spread use, identify industry trends and justify research.
    - New equipment has many more sensors and potential alarm points compared to the past. There is a need to produce better, more concise and directly actionable alarms from all this data or the operator will continue to have to manually funnel the alarms to the right area.
- Control Center Operator Task Force (CCOTF) workshop in August, CCOTF feedback on grid operations projects
- Survey on Utility Data Practices : Technical Update
    - Report Number: 3002002977
- Integration of Equipment Condition Information into Control Center Operations: Survey on Equipment Condition Information for Transmission Operators : Technical Update ID# 3002004614

3. P39.013 (2014 and 2015) – System Restoration Decision Support Tools

Goal: Develop methods and tools to support development and evaluation of restoration plans and to provide real-time decision support during restoration events

Value: Improved restoration plans and strategies. Improved restoration drills and training. Improved blackstart placement and investment decisions.

Outcomes

- **2014 Projects Progress (A Web meeting was held on 10 December, 2014 with Scottish Power to discuss the 2014 progress of P39.013 project.)**

    - Developed System Restoration Navigator (SRN) 3.0, customized for integration with an Operational Training Simulator (OTS)
    - Integrated SRN 3.0 with EPRI OTS (PowerSimulator)
    - Performed optimal black-start capability (OBC) case study on Duke Energy system
    - Value:
        - 1) SRN 3.0 can be used through PowerSimulator to review, practice, experiment with and revise the existing system restoration plans and procedures.
        - 2) SRN 3.0 and API can be used to integrate SRN 3.0 into vendor's OTS.
        - 3) SRN and OBC tools can be utilized through supplemental projects.

- **2015 Projects Goals**

    - Develop a suite of SRN and OBC tools that can be used by restoration planning and operations staff in developing/validating/testing/revising restoration plans, in restoration drills and training and in real-time implementation of restoration plans
    - A new version of the Optimal Blackstart Capability software, OBC 2.0, is being developed.
    - A new version of the System Restoration Navigator, SRN 4.0, is being developed.

- One of the 2015 project tasks include SRN/OTS testing by eligible members such as Scottish Power. EPRI has provided information to Scottish Power about this testing.

4. P39.012A (2014) – Hybrid Voltage Stability Assessment (HVSA)

Goal: Develop hybrid voltage stability assessment (HVSA) strategy/tools that integrate simulation-based and measurement-based VSA techniques
Value: Improved situational awareness >>> Improved reliability; Increased power transfers.

Outcomes
2014 Goals:

- Perform a case study to identify value from integrating Measurement-based Voltage Stability Assessment (MBVSA) into real time operations environment.
- Develop enhanced Measurement-based Voltage Assessment technique.
- Develop Hybrid Voltage Stability Assessment (HVSA) strategy.

2014 Results and Value:

- Case study on ISO-NE system completed.
- A new and enhanced MBVSA technique developed and tested.
- A framework for HVSA strategy developed.
- **Value**: Incorporating MBVSA in real time can help with situational awareness:
  - following an event and before new RTCA results are available; and
  - when multiple outages occur, pushing the system to approach its voltage stability limit

Reference Guide, "Industry Practices and Tools for Voltage/VAR Planning and Management:"

The goal of one-year (2015) project is to identify the variety of voltage and VAR planning and management practices and tools used by transmission planners and operators globally across the industry. By accomplishing this goal, project funders should expect to have a reference guide on industry practices and tools that can help in understanding the applicability and suitability of practices and tools with respect to factors such as reactive power resource availability, reactive power reserves, static versus dynamic reactive resources, criteria used, etc.

- A detailed outline of the reference guide has been prepared. The outline includes feedback from several members.
- The EPRI project team has collected industry material on voltage/VAR planning/management practices.

5. P39.012B (2014) – Day-Ahead 24-Hour Reactive Power Forecasting and Scheduling

Goal: Develop a computational tool/process to produce an optimal 24-hour schedule of reactive power controls and voltage profile across the system

Value: Increase system utilization. Maximize reactive power reserves.

Outcomes

2014 Goals:

- Develop a single, integrated forecasting/scheduling software tool
- Perform case studies to understand tool applicability on realistic systems

2014 Results and Value:

- Developed an integrated software for Forecasting and Scheduling tools
- Completed case studies on Taiwan Power and ERCOT power systems
- **Value**: Scottish Power can use the Forecasting/Scheduling software .

Improved Static Load Modeling from Synchrophasor Data for Real-Time Contingency Analysis and Voltage Stability Assessment Studies:

The ultimate goal of this two-year (2015-16) R&D effort is to develop techniques and tools that can derive static ZIP load model used in real-time contingency analysis and voltage stability assessment studies. By accomplishing this goal, Scottish Power could expect to improve reliability and possibly increase power transfer capability. During 2015, EPRI will aim to accomplish the following: a) a technique to derive static ZIP load model parameters from synchrophasor data; and b) application of the technique on a realistic system. From these 2015 efforts, the project participants are expected to understand the potential impact of improved load model parameters at critical locations within a voltage stability constrained area on maximum power transfer capability.

- A Statement of Work has been prepared to develop a technique to derive ZIP load parameters from synchrophasor data.

6. P39.014 – Application of New Computing Technologies & Solution Methodologies for Power System Operations

Goal: Target benefits to operations engineering tools by applying new computing technologies (hardware, software, processing techniques, etc.).

Outcomes
2014 Specific goals:

(1) Improve computation speed of AC contingency analysis with Graphics Processing Units (GPU)
(2) Use robust techniques developed for power flow and apply them to an AC Optimal Power Flow (OPF) that would be practical to use for developing preventative actions
(3) Alpha tool to test the methods developed and provide hands-on feedback.

2014 Outcomes

- Development and Testing of PFOPT Package for Power Flow:
- Accomplishments: The package is available for download. Engineers can easily install and test the package on their own power flow cases with the supporting documentation.

- Value: EPRI hopes that those that do will provide feedback so that it can be further refined and help move the work forwards so the methods can be incorporated into commercial software tools.
- GPU Applicability to Reduce Computation Time for Power Flow and Contingency Analysis:
- Achieved a maximum speedup of 7.2x for the full Newton-Raphson AC power flow algorithm on the GPU compared to CPU.
- Achieved a maximum speedup of 8.2x for the multiple AC power flows (CA) on one GPU compared to a 4core CPU.
- The limiting factor was found to be the rate at which data can be transferred and not the arithmetic intensity. A reasonable estimate of the potential speedup is to compare the GPU data access rate to the CPU data access rate. For example, on the test system, this ratio was 11x (170 GB/sec / 16 GB/sec).

Value:

- Can compare data access rate of a GPU with CPU available to estimate the potential speedup for performing contingency analysis. EPRI will approach vendors with the results and stress that they used available GPU libraries to make the development easier.
- Methods for a Practical AC Optimal Power Flow in Operations:
- Accomplishments:
- The number of control actions suggested in an AC-OPF can be successfully reduced using a smooth sparsity-inducing penalty function. This penalty also adds convexity to the problem, which is exploited by the solution algorithm for improving numerical stability and robustness.
- Different techniques for handling discrete control actions were tested to try to obtain a better AC-OPF solution. These methods are still a subject of future research, but have shown some benefit over traditional methods.
- Successfully developed a technique for AC-OPF that could be used to develop a small number of high-impact preventative actions to improve reliability and maintaining efficiency. Further testing is required though with more realistic costs.

7. P39.015 – Synchrophasor Applications: Stability Analysis and Prediction Using Synchrophasors

Goal

Develop advanced analytical tools and techniques that can facilitate: a) the assessment and prediction of system stability from synchrophasor data; and b) the development of remedial control actions to address potential instability.

Outcomes

- Oscillations Damping Controller:
    - 2014: Designed a wide area closed-loop controller using synchrophasor data for oscillations damping. Promising results based on simulation studies.
    - 2015: Controller algorithmic improvement and hardware-in-the loop testing.
    - Value: System reliability and performance improvement- synchrophasor application on Wide Area Control

- Rotor Angular Stability Assessment (MLE technique):
    - 2014: PMU placement criteria based on nonlinear observability analysis. Computational efficiency improvement of the algorithm.
    - 2015: Testing the technique in large scale systems and further improve computational efficiency. Software deliverable
    - Value: Online mode: Synchrophasor application for real-time rotor angle stability assessment and control. Potential application as a standalone application or integrated in a synchrophasor applications platform in the control center. Offline mode: PMU placement criteria based on nonlinear dynamic observability analysis

- Synchrophasor Application Library summarizing applications, industry implementations and maturity level (extra deliverable in 2014)
- PMU Emulator. New task in 2015.