Flexible Networks
for a Low Carbon Future

# Flexible Networks Closedown Report Final

December 2015

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# Glossary

| | |
|---|---|
| **BAU** | Business-As-Usual |
| **CI** | Customer Interruptions |
| **CML** | Customer Minutes Lost |
| **DNO** | Distribution Network Operator |
| **GPRS** | General Packet Radio Service |
| **LCT** | Low Carbon Technology |
| **LTDS** | Long Term Development Statement |
| **MDI** | Maximum Demand Indicator |
| **NMS** | Network Management System |
| **PI** | Process Instrumentation – SPEN's Network Monitoring Data Historian System |
| **PNDC** | Power Networks Demonstration Centre |
| **RIIO-ED1** | Electricity Distribution price control for period 01 April 2015 to 31 March 2023 |
| **RTTR** | Real Time Thermal Rating |
| **RTU** | Remote Terminal Unit |
| **SPD** | SP Distribution |
| **SPEN** | SP Energy Networks |
| **SPM** | SP Manweb |

# 1 Project Background

The UK electricity network is forecast to have significant demand growth in future years. This will largely be due to the de-carbonisation of transport and heating, which will be utilising electricity from both centralised and distributed sources of low carbon energy. The distribution network will be required to connect and manage increasing levels of demand from electric vehicles, heat pumps, and general load increase; while at the same time addressing the uptake of renewable and other embedded generation at various voltage levels.

The growth of low carbon technology on the network is likely to be rapid and localised, with limited forward visibility to allow the DNO to plan and implement network upgrades. The rate of change within some parts of the network could exceed the capability of the DNO to respond with traditional solutions.

There are also complexities associated with demand and generation profiles for low carbon technology that have the potential to significantly increase peak network flows and produce substantial voltage rises. This heightens the risk on the network in terms of network integrity, quality of supply and service to the customers, with existing design standards, due to these rapid rates of change.

The distribution network has generally been designed and operated in a conservative manner, this has been deemed the appropriate techno-economic solution in the past to minimise risk and cost. The traditional solution for dealing with increasing load above network constraints has been to install additional capacity on the network; this involves building new substations, overhead lines and laying cables. This can be a time consuming, expensive and energy intensive exercise. For example, obtaining new substation sites and line or cable routes can be difficult due to land access and environmental issues.

Measures are needed that can:

- Determine more accurately the capacity headroom while maintaining licence obligations,
- Allow that headroom to be exploited in a safe, reliable and cost-effective manner, and,
- Provide incremental increases in headroom in a timely and cost-effective manner.

The primary driver is to allow higher levels of low carbon technology to be accommodated without adversely affecting quality of supply, but also allow reinforcements where appropriate to be deferred until greater certainty on the nature of future loads can be gained. This then allows appropriate business decisions on reinforcements to be made without the risk of stranding assets or inefficient network investment.

A number of innovative methods are available to release and increase capacity headroom that are not yet sufficiently technically and/or economically proven. Flexible Networks aimed to provide a 20% increase in network capacity through a number of innovative measures. This will enable more customers to make the transition to new low carbon generation and demand technologies.

# 2 Executive summary

Flexible Networks delivered all six successful delivery reward criteria, providing a robust framework within which to select and deploy one or a number of innovative techniques collaboratively to techno-economically release incremental network headroom.

SPEN was awarded £3.6M in 2011 by Ofgem to carry out Flexible Networks for a Low Carbon Future with the project commencing in January 2012. A further £2.588M was invested by SPEN with some additional contribution (£174k) from project partners.

Three areas of our network with known capacity issues were identified which provide an opportunity to analyse and implement alternative flexible solutions to network reinforcement see Figure 2 1. All three sites have different but representative characteristics and customer demographics, and are similar in that they have near-term constraints due to increasing demand and an uptake of low carbon technology. The rapid nature of these changes both imposes a requirement, but also provides the opportunity to trial solutions that are faster and more cost-effective to implement than traditional reinforcement.

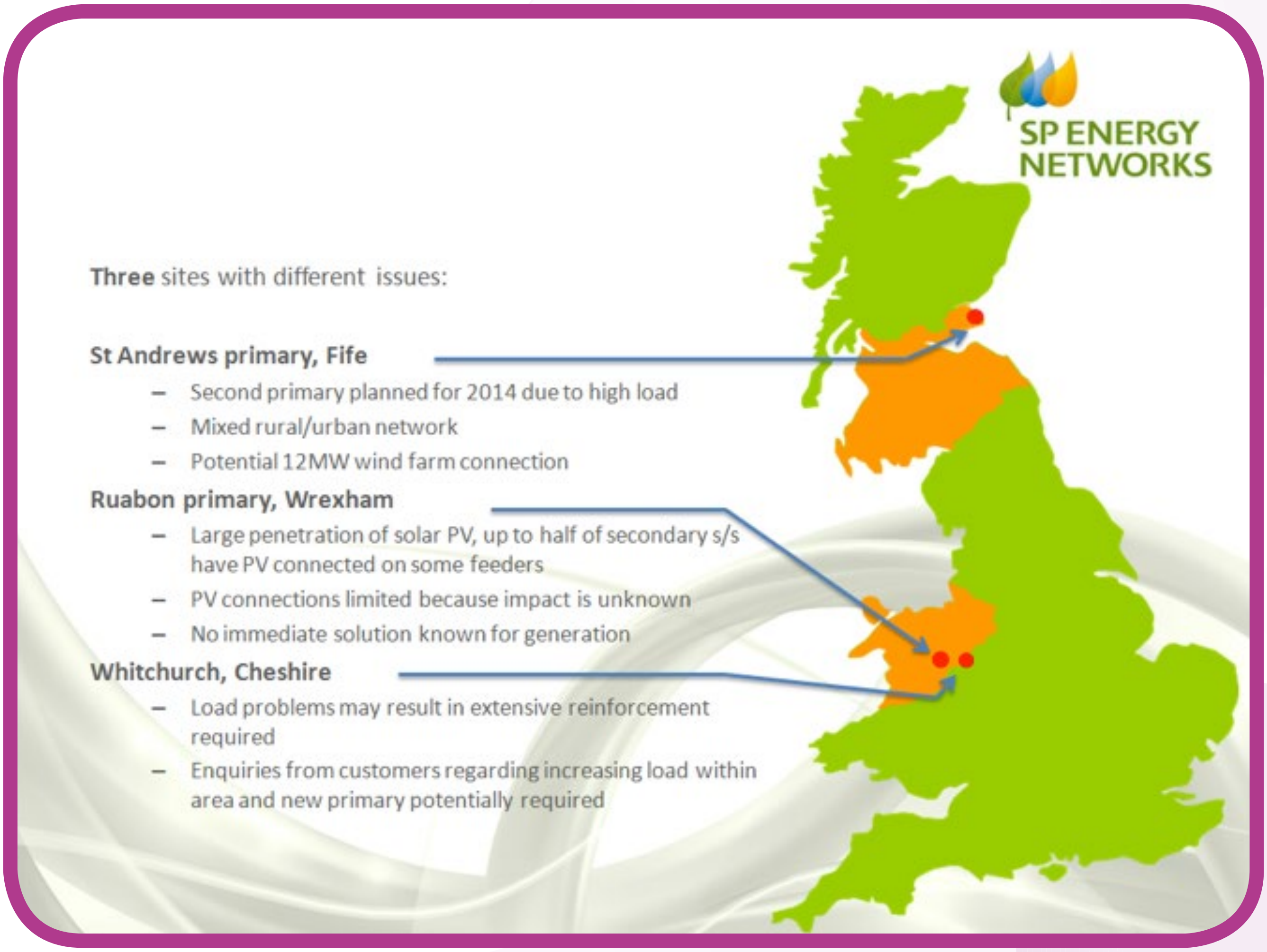



Figure 2-1 Trial Area Location Map

The specific issues facing us in these three locations are mirrored across the UK electricity distribution network, and this project provides generic solutions and recommendations to address these. For the learning to be relevant, representative and robust, it is essential that there is a strong focus on verification of the trials. These were critical factors in the trial site selection process as well as the partnering decisions with Strathclyde University to provide high quality verification and TNEI to provide robust analysis.

## 2.1 Aims and objectives

Flexible Networks for a Low Carbon Future aimed to provide network operators with economic, DNO-led solutions to increase and enhance the capability of the networks. These would be capable of being quickly implemented and help to ensure that the networks do not impede the transition to a low carbon future. Learning outcomes from Flexible Networks would inform intelligent future network change management.

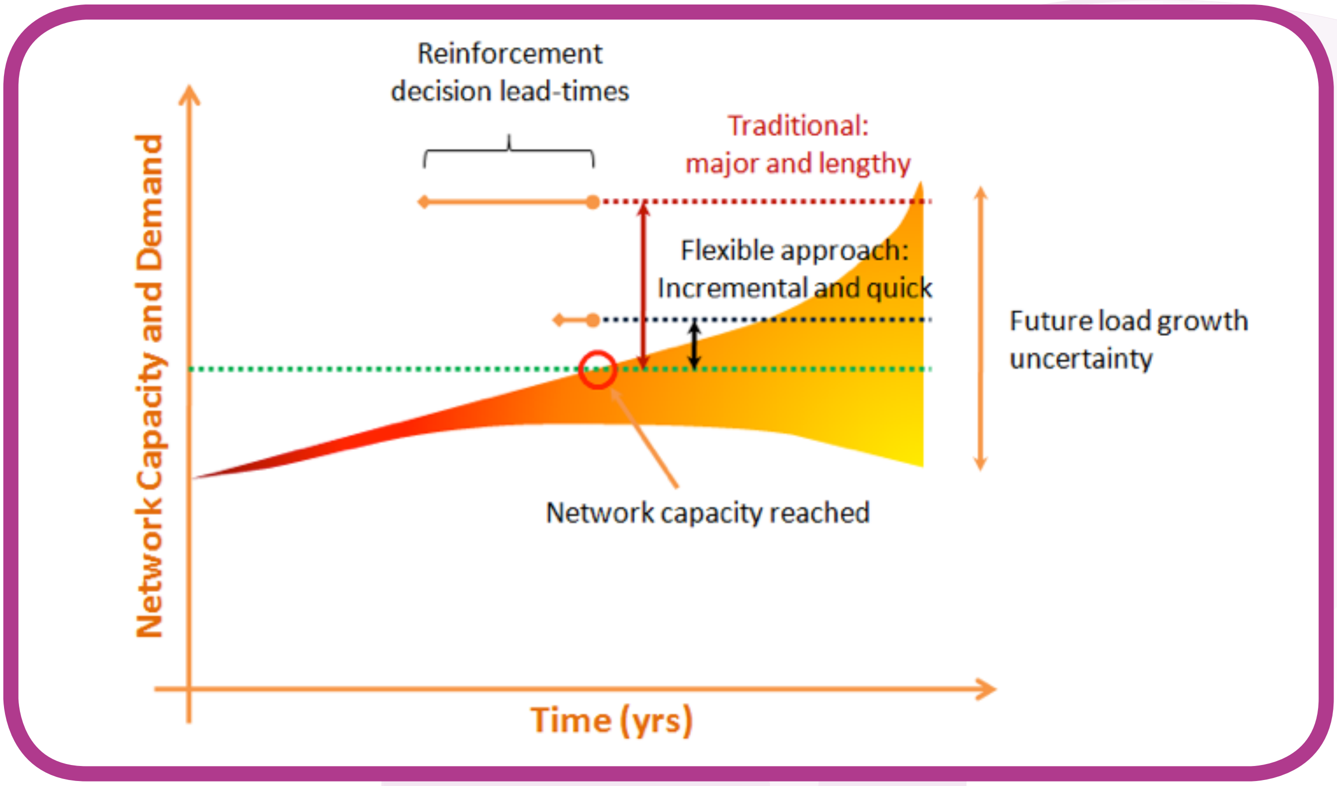



Figure 2-2 Smart grid vs conventional reinforcement: decision lead times, implementation timescales, capacity increase and costs

It is recognised that there are some inherent conflicts between the ideal design, operation and management of a distribution network. A significant advantage to applying a more holistic approach, as developed through Flexible Networks is that it facilitates interaction between business functions, planning, operations and asset management, to optimise the tools and techniques developed.

The objectives of the various activities (work packages) were as follows;

- Develop an enhanced network monitoring methodology and based on this network data, develop and integrate improved DNO planning and operations tools and practices that are optimised for future low carbon networks and use of the innovative techniques being trialled,
- Trial novel technology measures for improved performance of the network such as dynamic thermal ratings of assets, voltage optimisation, and flexible network control,
- Identify the measures by which material improvements in the cost-effectiveness of accommodation of future energy needs can best be demonstrated,
- Develop an investment and future roll-out plan where appropriate cost-benefit exists,
- Disseminate learning to key stakeholders such as customers and other DNOs to ensure sustainable user adoption, through future technical and regulatory policy changes for example.

## 2.2 Scope

The key stages of the project can be summarised as follows:

- Establish a baseline to improve understanding of network and demands,
- Deploy innovative network techniques for improved network operation and control,
- Review of outcomes, quantification of benefits and dissemination of learning.

Establishing a baseline involved the monitoring of the three trial sites to a higher degree of accuracy than is currently undertaken. This process allowed the demand on the network and contribution of generation to be extensively understood.

Monitoring data was used to verify benefits of technology trials as well as develop and validate new analysis methodologies and tools to enhance network planning and operations policy and practice and to facilitate user adoption of technologies trialled.

Innovative techniques trialled for demand constrained networks comprise;

- Improved network analysis techniques
- Enhanced thermal ratings for primary transformers,
- Real time thermal ratings for 33kV overhead lines,
- Flexible network control enhanced with voltage regulators,
- Customer energy efficiency,
- Voltage optimisation.

Innovative techniques that can also be applied to generation constrained networks comprise;

- Improved network analysis techniques
- Real time thermal ratings for 33kV overhead lines,
- Voltage optimisation.

These technologies were trialled at the three network trial sites within the SPEN licence areas, with various demand and generation constraint issues.

### 2.2.1 Project structure

Flexible Networks involved the trialling of 4 separate innovative techniques that were integrated with the overall objective of the project. This enabled a number of smaller, simpler steps to be taken rather than a single large complex step. This approach also minimised the risk that a failure or change in a single step placed the entire project at risk or created knock-on delays. This was supported by an activity focussed on enhanced network monitoring including improved planning and operational tools and an activity focussed on stakeholder engagement (internal and external). The final outcome was an intelligent, flexible approach to network management that enables a Low Carbon Future.

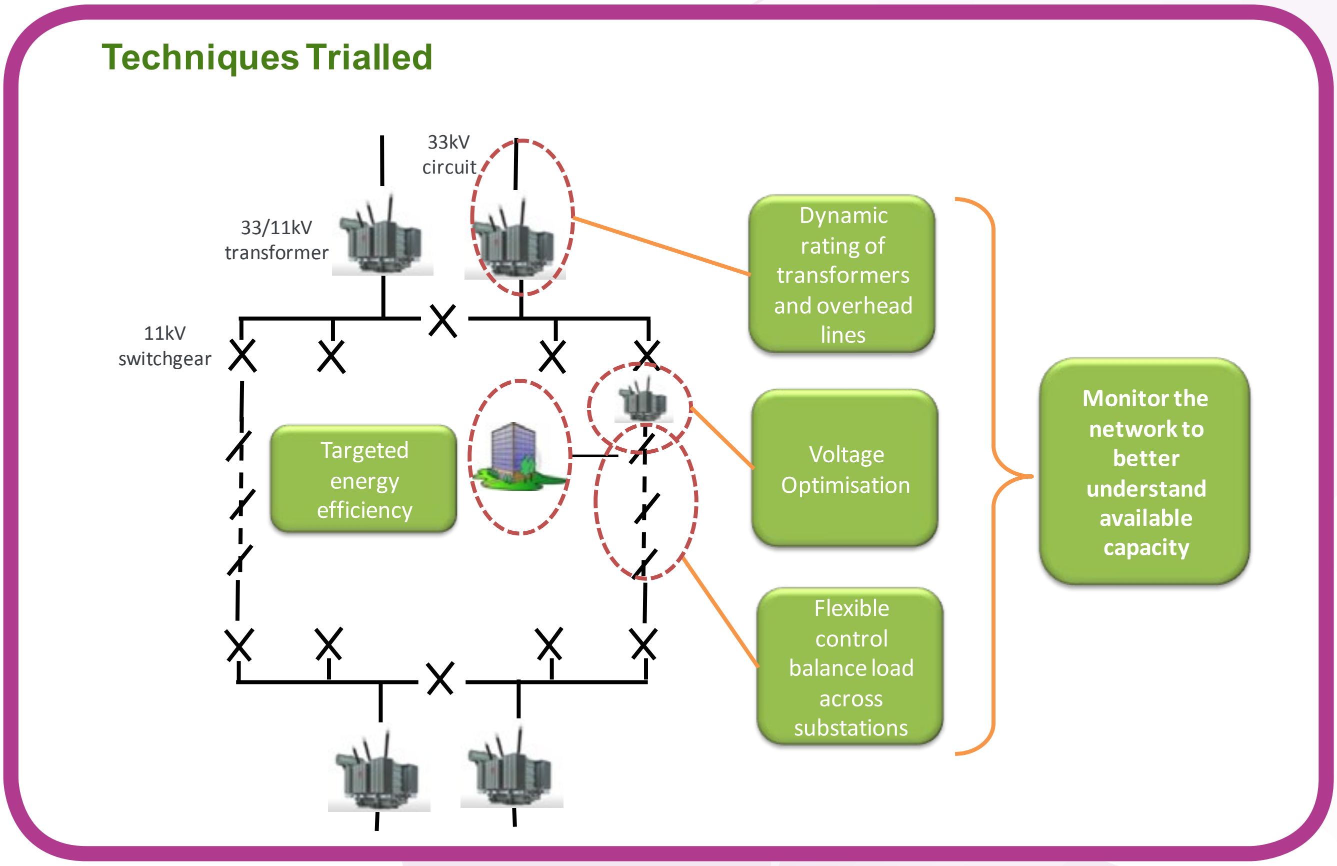



Figure 2 3 Flexible Networks innovative techniques

## 2.3 Key learning outcomes

### 2.3.1 Project

Flexible Networks developed new analysis methodologies and tools that improve knowledge of the distribution network, the ability to identify critical changes and selection of the appropriate techno-economic response.

*Flexible Networks has achieved a 20% increase in capacity for St Andrews and Whitchurch trial sites and facilitated more than 20% additional PV generation onto the Wrexham trial site.*

### 2.3.1 Project [continued]

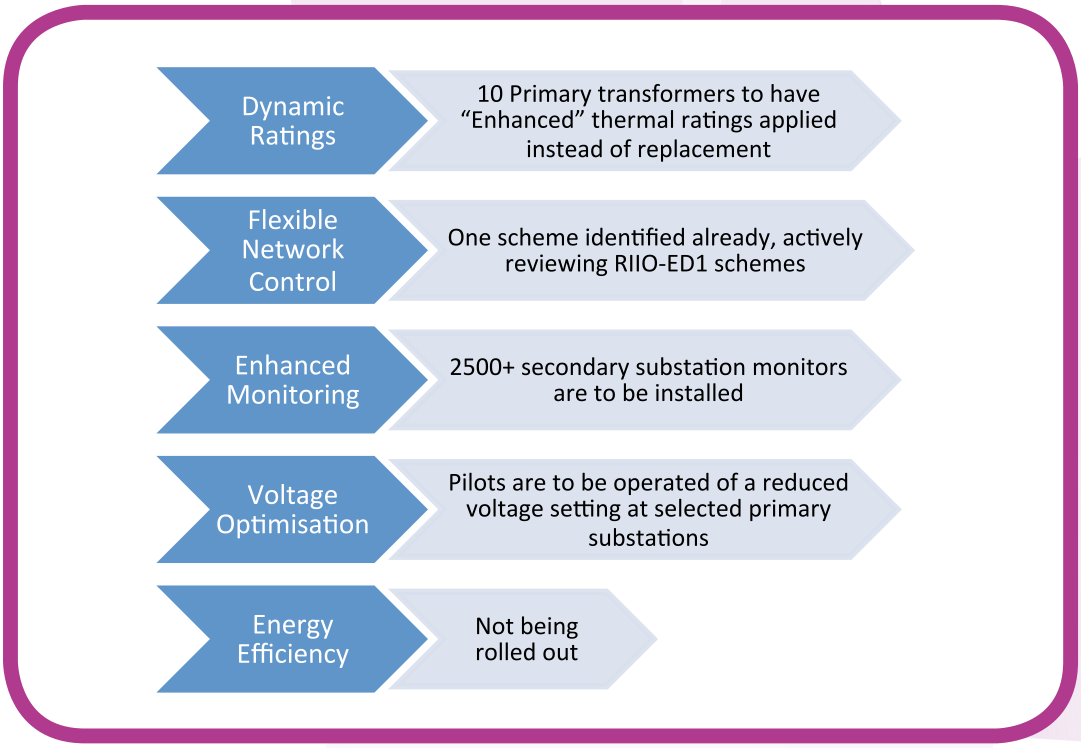
Increased demand can be accommodated on the network through a better understanding of existing and future demand characteristics. It was also found that greater volumes of PV generation can be accommodated on the LV network through improved characterisation of PV generation and customer demand. Voltage optimisation can enable further generation to connect. Depending on voltage profiles during times of peak demand, it may be possible to apply a permanent voltage reduction rather than a seasonal reduction.

The deployment of the innovative techniques was successful, providing capacity headroom gains generally at or above the anticipated levels. The planning methodologies, design specifications, procurement, installation and commissioning approaches developed as part of this are now being adopted by the business. This enabled the successful application at the three network trial sites to defer or avoid costly traditional reinforcement as evidenced with the updated business cases.

*Application of Flexible Networks in a holistic manner to the network enables cost-effective release of incremental capacity headroom – deferring or avoiding costly traditional reinforcement.*

Next generation telecontrol equipment was developed as an enabler of flexible network control and similarly for integration of voltage regulators, a new telecontrol solution was developed.

More widely, learning outcomes from Flexible Networks are rapidly evolving into business as usual, informing changes to network planning and operational policy and practices. There are a number of planned and proposed applications to schemes included in the RIIO-ED1 regulatory period as shown below. There is a great deal of interest in and enthusiasm for the project both internally and within the wider industry.



### 2.3.2 Method

The various innovative techniques provided the following capacity gain benefits based on the three trial networks;.

**Table 2-1 Capacity headroom release for Flexible Networks methods trialled**

| Innovation | Potential capacity headroom release |
|---|---|
| Enhanced network monitoring | 8% on average |
| Enhanced primary transformer thermal rating | 10 -14% |
| 33kV Overhead line RTTR system | Up to 11% |
| Flexible network control | 6 - 11% |
| Integration of voltage regulators | Enabler |
| Energy efficiency | Negligible |
| Voltage optimisation | Demand: 1% for 1% voltage reduction<br>Generation: > 850W per customer for LV networks with embedded PV generation |

In terms of future monitoring strategy on the LV network, recommendations were made to the business for "smart" MDIs to be deployed to secondary substations at key locations across the LV network identified through application of the LCT Network Monitoring Strategy[1]. More detailed monitoring will be specified for critical network locations with high levels of low carbon clustering.

[1] *SPEN, RIIO-ED1 LCT Network Monitoring Strategy, March 2014.*
*http://www.spenergynetworks.co.uk/pages/distribution_business_plan_supporting_annexes.asp*

## 2.4 Performance against successful delivery reward criteria

Flexible Networks delivered at least 20% of additional demand or generation capacity at the three network trial sites, St Andrews, Whitchurch and Ruabon, thus meeting the successful delivery reward criteria.

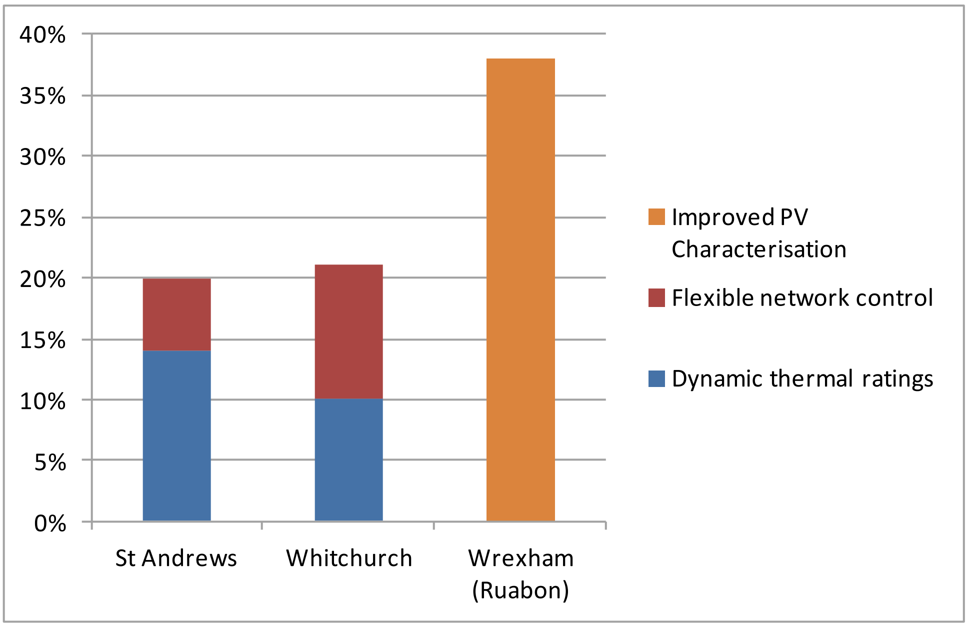



Figure 2 4 Performance against successful delivery reward criteria

The project was delivered to budget and timeline, subject to the change request approved by Ofgem in October 2014.

https://www.ofgem.gov.uk/sites/default/files/docs/2014/10/decision_letter.pdf

Extensive stakeholder engagement was carried out both internally and externally with other DNOs, the wider industry and customers. User adoption for the current regulatory period, levels of interest from other DNOs in the methods trialled and learning outcomes and customer satisfaction are good indications of the success of our stakeholder engagement strategy.

# 3 Details of the work carried out

Please note that further details of each activity can be found in the supporting reports described in Section 13, where reports are cross-referenced to the relevant subsections in Section 3.

## 3.1 Enhanced network monitoring

This trial was to improve knowledge of the distribution network, the ability to detect changes, extrapolate trends and identify the appropriate response. It specifically supported in the identification of suitable applications for the Flexible Network innovative techniques, assessment of potential performance, evaluation of performance and improvement in quantification of the costs and benefits of detailed network monitoring [2, 3].

### 3.1.1 Improved use of primary substation data

*Application of a more probabilistic approach for analysis of monitoring data to enable the appropriate techno-economic response to load growth.*

Primary substation data analysis has conventionally been based on single value maximum and minimum demands and generation extracted from time series data. A more probabilistic approach to data analysis augmented by appropriate analytical tools was explored to provide a much fuller characterisation of network behaviour, sensitivities and trends. This enables a more appropriate techno-economic response to load growth compared to generalised deterministic analysis which is generally more conservative [5].

To achieve this, an enhanced load forecasting tool was developed based on a probabilistic data analysis approach that more accurately forecasts future network group load growth trends, utilising existing primary substation monitoring data. The underlying methodology reduces the impact of outlier values on peak load trends. The performance of the algorithm in reproducing demand forecasts was evaluated against the existing load forecasting approach and actual measured data. The enhanced load forecasting tool is now in common use by SPEN network planners with incorporation of local intelligence on new network connections, as envisaged.

A network risk characterisation tool (based on peak loading duration and frequency) was also developed to provide peak load duration metrics (total duration, number of events etc) for a defined peak load and total duration, to support characterisation of additional network risk for peak loading close to and above firm capacity. This is integrated with the enhanced load forecasting tool.

A review of Engineering Recommendation P2/6 was also carried out including its application by Distribution Network Operators (DNOs) and its interactions with other regulatory initiatives, such as the Interruption Incentive Scheme (IIS) and 'load indices' [6].

### 3.1.2 Improved secondary substation monitoring

*Development of a holistic approach to network information gathering that is optimised for network planning and operations needs.*

The monitoring regime for this project was focussed on understanding the interdependence of the HV and LV network from primary HV substations down the chain to the customer across LV networks via an innovative "cascade" approach.

Monitoring was installed at a total of 184 secondary substations across the three trial areas St Andrews, Wrexham (Ruabon) and Whitchurch. Detailed monitoring was installed at the following primary substations in or adjacent to the trial areas; St Andrews, Cupar, Leuchars, Anstruther, Whitchurch, Liverpool Road, Yockings Gate and Ruabon. Monitoring of voltage was also undertaken at selected LV customer locations [7].

### 3.1.2 Improved secondary substation monitoring [continued]

Two suppliers were trialled for the substation monitoring equipment; Selex-ES UK "Gridkey" units [8] and Embedded Monitoring Systems Ltd using their "Subnet" unit [9]. This approach was adopted to;

- spread the risk of any equipment/component issues that may arise from a single manufacturer,
- explore different solutions for the various applications across the range of sites,
- gain experience from the installation and use of different units,
- to explore how we may derive further network benefit from any additional functionality available that specific devices provided.

The timescales of the load/network behaviour to be captured was considered when specifying the monitoring resolution. A future cost-effective network monitoring strategy was developed based on learning outcomes from use of the monitoring data within Flexible Networks [10]. This was incorporated into the SPEN RIIO-ED1 business plan and was subsequently developed as further learning became available from the project trials and analysis.

A data quality characterisation system was developed to identify emerging patterns of data issues resulting for example from faults in the monitors or data communication issues. This performance "heat-mapping" viewer is incorporated in the online iHost database server [11].

A data cleansing algorithm was also developed to reduce the impact of outliers and zero values such as those due to load transfer on characterisation of the network loading behaviour. This was a trend-based technique to focus on periods of anomalous behaviour, and through the visualisation of historic behaviour and confidence bands, permit the data to be assessed more easily [12].

A Monitoring Good Practice Guide was prepared to collate and disseminate learning from the enhanced network monitoring activity [13].

### 3.1.3 Improved operational tools

*Provide control staff with a practical framework to aid with their decision making processes.*

The challenges and limitations of existing policy and practice for future low carbon technology uptake and integration of the innovations being trialled were identified through several workshops with control room engineers. A key element was investigating aspects that could be impacting on the effective capacity of the network and introducing beneficial changes derived from improved understanding of network behaviour and risk. Recommendations for amendments and additions to network operations policy and code of practice were developed and presented [14]. The early engagement of operational staff was crucial for later buy-in to any recommended changes.

For example, the main constraint to embedded PV generation uptake is the increase in voltage towards the end of the feeder rather than reaching asset thermal limits. The voltage can approach and exceed statutory limits when high PV uptake is present e.g. due to socio-economic driven clustering in the LV network. The management of voltage through control of the primary transformer voltage relay was investigated for the purposes of connecting higher volumes of embedded PV and the consequential implications for voltage policy assessed.

### 3.1.4 Improved planning tools

*New and improved planning tools to understand and predict network behaviour, improve investment decisions and support pipeline management.*

This activity focused initially on gathering information on the dynamic interactions of the various system states over the course of a year of operation from network monitoring, particularly at 11kV and LV. New analysis methodologies and tools were developed that enable evaluation of network suitability and quantification of potential capacity release for the innovations being trialled in Flexible Networks. This included methodologies and tools for trial of different approaches to more accurately assess the impact of phase imbalance and embedded generation on the LV network and voltage optimisation techniques.

The following analysis methodologies/tools were developed:

- *Characterisation of PV at LV:* A model for characterising PV behaviour on network load and voltage profiles and estimating embedded generation connection capacity was developed and validated with detailed network monitoring data and power system modelling. The Wrexham (Ruabon) LV network was used as it has a high uptake of clustered PV generation connected at LV. This informed development of generic "rules-of-thumb" that can be applied when assessing generation connections with limited network monitoring data. Opportunities for voltage optimisation were also explored to facilitate increased PV connections [15].
- *Characterisation of HV and LV imbalance:* A simple methodology was developed and tested to characterise LV phase thermal imbalance from large volumes of monitoring data, focusing on magnitude and persistence of phase imbalance under high loading conditions. A high level search algorithm was developed and applied to identify LV feeders with the most potential for capacity headroom release by phase rebalancing across all three trial sites. A cost-benefit comparison of various phase rebalancing solutions compared to network reinforcement was carried out including consideration of practical challenges. The methodology was also applied to characterise thermal phase imbalance at HV [16].
- *Improved future network modelling:* Techniques to more efficiently and accurately build HV and LV network models were investigated including increased automation and improved business database linkages. Analysis of detailed monitoring data available from secondary substations and LV feeders verified existing network modelling practices and provided recommendations for improvement [17, 18].
- *Data Analytics:* A pilot study was undertaken with IBM as part of Flexible Networks to develop a Distribution Grid Analytics tool. This utilised GIS data, NMS network configuration data, co-ordinates of monitoring locations and monitoring data. The current network topology was then visualised through an overlay on Google Maps and analytic tools implemented to enable identification of thermally overloaded substations, voltages outside of statutory limits, and phase imbalance, from analysis of the monitoring data [19].

### 3.1.4 Improved planning tools [continued]

Planning tools that were developed specifically for technology innovations are covered in more detail in relevant subsections below. These include;

- Enhanced transformer ratings tool
- Flexible network control planning methodology
- Voltage regulator planning methodology

Several workshops were held with SPM and SPD network planners during the process of developing and testing new analysis tools to incorporate feedback from future users. Recommendations for amendments and additions to network planning policy and practice were developed and presented [20].

A number of software models were developed in the power system software IPSA as part of TNEI's partner contribution and verified with measurements from network trials where applicable. These will be free to all IPSA users and comprise asset dynamic thermal ratings, reliability analysis tool, ZIP model, rapid input of network load profiles on a half-hourly or hourly basis, series voltage regulator, PV generation profile templates and a script for conversion of GIS data to IPSA models [21].

## 3.2 Dynamic thermal ratings

*Identify and manage utilisation of additional thermal capacity on 33kV overhead lines and primary transformers.*

### 3.2.1 Overhead line real time thermal rating [RTTR]

The Cupar-St Andrews 33kV overhead lines were selected for trial of a Real time thermal rating (RTTR) system. Four 33kV poles were instrumented with line monitoring based on identified microclimate areas. A GE line monitoring system was also used which includes pole mounted weather stations, solar panels, RTUs and line current/temperature sensors.

A stand-alone PowerOn Fusion server hosted the RTTR calculation engine with communications links to monitoring equipment (both pole-mounted and those in the primary substations). The algorithm included modelling of the geographical and electrical characteristics of the Cupar-St Andrews lines. Data analysis of weather parameters, conductor temperatures and RTTR values was carried out over a 12-month period.

RTTR system output was available through a live web link to the PowerOn dashboard designed specifically for the Cupar-St Andrews circuits. Parsons Brinckerhoff provided technical support and development of RTTR system algorithms. Performance of the RTTR system and underlying conductor temperature algorithm was validated through comparison with measured line temperatures [22, 23].

To improve management of communications or monitoring equipment failure, a graceful degradation algorithm was developed and implemented in the RTTR calculation engine. This reduces the RTTR of the circuit towards the seasonal rating as an increasing number of monitored weather parameters are lost.

### 3.2.2 Transformer enhanced thermal ratings

Enhanced transformer thermal ratings were assessed for all three network trial sites, which include 8 primary transformers [24, 25]. The use of the term "enhanced thermal rating" here refers to a fixed enhanced rating rather than a dynamic rating, which is determined through consideration of transformer specific environmental and loading conditions and verified through monitoring of the transformer duty temperature. This approach of basing the transformer load capability on temperature rather than a definitive manufacturer rating plate figure allows additional capacity to be exploited through existing business-as-usual planning and operational processes, which are designed around fixed transformer ratings.

Transformer capability for enhanced thermal ratings was first assessed by DNV GL using historical loading data and supporting data and documentation [26]. Site surveys were undertaken which included visual and thermal imaging surveys and the use of specialist sensors to measure partial discharge within the live transformer tanks. Transformer oil samples collected during the surveys were analysed. Subject to some cooler refurbishment work required for the St Andrews primary transformers, the suitability of all primary transformers was confirmed.

Thermal modelling was undertaken using the DNV GL dynamic rating system (DRS) to assess possible enhanced thermal ratings of the transformers under a range of future loading scenarios (varying magnitude of peak load and load profile shape) and the implications for transformer asset aging. This included consideration of the capability of connected assets [27].

TNEI and University of Strathclyde jointly developed a software tool to calculate enhanced transformer thermal ratings for integration into the network planning process. This tool was based on the IEC transformer thermal model[2] and calculated an enhanced seasonal rating from measured historical load and ambient temperature profiles, with consideration given to an acceptable rate of transformer aging [28]. An application guide was developed alongside the software tool [29].

Top oil temperature monitors were installed on Liverpool Road and St Andrews primary transformers to enable validation of the IEC transformer thermal model used by DNV GL and TNEI/Strathclyde and derivation of transformer-specific thermal parameters. Manufacturer's heat run test data was not available for these transformers. The monitors provide an indication of transformer winding temperature based on application of a linear scaling factor to the measured top oil temperature, calculated from transformer load. Load transfer was carried out in order to test the primary transformers for a range of loading conditions. This led to some refinement of how the specific thermal characteristics of the Liverpool Road and St Andrews primary transformers were represented in the software tool [30].

*[2]International Electrotechnical Committee, IEC 60076-7:2005 Power Transformers Part 7: Loading guide for oil-immersed power transformers, 2010.*

## 3.3 Flexible network control

*Develop a process for identifying flexible network control opportunities and design and deployment of a system to implement this.*

The use of flexible network control for releasing capacity headroom was evaluated for the St Andrews and Whitchurch trial areas [31,32].

### 3.3.1 Planning methodology

To quantify the potential increase in capacity headroom at the network trial sites through strategic load transfer, a planning methodology was developed [33]. Load profiles for the primary substation and corresponding 11kV feeders were characterised and considered in relation to the load profiles of surrounding primary substations and HV feeders capable of being interconnected on various timescales e.g. average/peak seasonal daily load profiles. This was based on a year's worth of monitoring data from primary substations, 11kV feeders (at primary substations and along circuits) and secondary substations [34, 35].

Transferrable sections of network were identified and modelling was carried out for network reconfigurations under key load conditions to evaluate load flows compared to asset thermal limits and voltage compared to statutory limits. An assessment of the effect on reliability of the various reconfiguration options was also performed.

The location of new network automation points that would help to facilitate release of capacity were also identified followed by comparison to a range of technical engineering criteria to assess feasibility and refine positioning on the circuit [36]. Input was sought from local operational staff to capture local knowledge of the 11kV networks being considered, such as preferred back-feeding routes, the presence and characteristics of generation, and constraints on the operation of the network.

### 3.3.2 Development of field devices

Final network reconfiguration options and underlying drivers due to load seasonality informed the development of logical sequence switching (LSS) logic implemented using the Automation Manager functionality within the NMS.

In order to realise the actions of the LSS logic developed, new generation automation equipment was tested and installed at a number of secondary substations and HV circuit locations in the St Andrews primary network. This was following development of a functional specification, procurement and prototyping activities. Central Communications Units (CCU) with enhanced radio bandwidth was also installed at 5 primary substations (St Andrews, Cupar, Anstruther, Leuchars and Whitchurch) [37].

## 3.4 Integration of voltage regulators

*Develop solution to mitigate voltage drop issues when the network is reconfigured during flexible network control.*

Automatic voltage regulators (AVRs) were identified as an enabling technology for flexible network control to counteract drop in voltage that can occur during load transfer on long 11kV circuits [38, 39].

### 3.4.1 Planning methodology

An AVR was deployed on the St Andrews 11kV network in October 2014 for testing following detailed modelling to identify the most appropriate location. Radio surveys were carried out as required for the telecontrol and temporary additional monitoring and wayleaves obtained.

The AVR was located on an 11kV circuit that has the capability to interconnect to the Anstruther 11kV network and is known to experience voltage issues during backfeeding. Modelling was carried out for a range of network reconfiguration options under key loading conditions and validated with monitoring data pre and post AVR network testing [40, 41].

### 3.4.2 Development of field devices

AVRs are not new technology but have not been used widely in the UK. AVRs were originally designed to provide additional voltage support for very long, but lightly loaded overhead line circuits. However, they are being increasingly considered in relation to generation connections to mitigate voltage rise issues and can also add flexibility to networks whose load is constrained by a combination of voltage and security issues i.e. the capability to support more load is constrained by the ability to back-feed under N-1 conditions whilst complying with ER P2/6. They are not typically integrated with SCADA or the NMS. A generic, standardised pole mounted installation design was developed that can be used for all installation situations (including a full range of possible conductor sizes and spans), for any type and size of regulator up to 200A. AVR performance characterisation and model validation tests were carried out at the PNDC to consider the regulator control system and operating philosophy in more detail [38].

A new telecontrol solution for the AVR was also engineered and will enable the automatic, sequenced control of an AVR thereby allowing them to be used as an enabling technology for flexible network control [38].

An internal working group was established to facilitate integration of the AVR into business-as-usual. With this aim, a number of business documents were created or reviewed and updated including; voltage policy, design guidance, procurement specification, construction documents, commissioning guide, telecontrol guidelines, linesman's manual, maintenance policy, asset data model, field operation instruction, and control room procedures.

## 3.5 Energy efficiency

*Identify cost-effective energy efficiency solutions in collaboration with customers.*

To help identify potential interventions that could reduce (or modify) electricity demand patterns, electricity demand modelling was carried out for the three network trial sites to inform our understanding of electricity use in each area. The BRE models worked on a bottom-up approach with typical loads for each building type derived from national norms or industry accepted methods. A comparison between modelled and measured electricity demand was undertaken to verify the model.

BRE developed a stakeholder engagement methodology and interaction plan [42]. Key customers - predominantly within the Industrial and Commercial (I&C) sector – were then identified and contacted. Opportunities for energy efficiency improvements that create additional network capacity or flexibility were scoped through technical site surveys and meetings with key stakeholders. The objective was to understand current and future energy characteristics and needs as well as stakeholder's attitudes and priorities regarding energy efficiency, distributed generation, investment and funding. The cost effectiveness of the energy efficiency measures was assessed and a report detailing options, costs and benefits was provided to the customer including a list of available grants, incentives and low interest loan schemes.

Several energy suppliers were engaged to use their expertise in targeted site surveys resulting in costed proposals for interventions and estimated energy savings for customers who wished to proceed further.

Intervention scenarios for each of the trial areas were analysed to fully characterise the cost/benefit of introducing the energy efficiency measures to be deployed [43, 44].

## 3.6 Voltage optimisation

*Develop approach to increase network capacity and energy efficiency through improved voltage management.*

Historically, it was assumed in the UK that a 3% reduction in voltage would reduce demand for electricity by 5%. To understand the potential effectiveness of this intervention, a detailed review was carried out on methods of modelling load (considering the changing load mixture) and practical UK and international experience of the response of load to controlled changes in network voltage [45].

A system voltage intervention was also carried out over several weeks in January 2014 and in June 2015 in the Ruabon primary network. This comprised a voltage reduction at the primary substation transformer of 3% consistent with National Grid stage 1 voltage reduction. Measured data at the primary substation and using the extensive secondary substation monitoring system installed as part of the Flexible Networks project was analysed and compared to outcomes of the review of load response to voltage [46, 47, 48]]. LV monitors were installed for the second intervention to capture the effects on voltage at the customer supply points. The effect on HV and LV network currents and voltages was observed.

Detailed modelling of the Ruabon network, which has a high uptake of PV due to a local council initiative on social housing, was undertaken to quantify the increased capacity headroom due to voltage reduction. The model considered actual solar irradiance measurements from Ruabon and was validated with load and voltage profiles measured at secondary substations and voltage measured at a number of LV customers [47, 48].

## 3.7 Verification of experimental design

*Ensure that the experimental or analytical methodology is technically robust, statistically sound and that outcomes are verifiable and reproducible.*

The University of Strathclyde prepared and circulated "Guidelines for Presentation of Flexible Networks Experimental Design" for the project team to facilitate the appropriate design and documentation of experiments (practical and analytical). These experiments included;

- Voltage reduction at primary substations,
- N-1 operation of the network (to verify dynamic rating models),
- Voltage regulator operation,
- Analysis and forecasting of load,
- Characterisation of PV,
- Imbalance assessment,
- Voltage sampling assessment.

An Experimental and Analytical Design Review report was also prepared which documented the University of Strathclyde review of the experimental design of the various trials and analyses carried out for Flexible Networks, to verify that the methodology, results and findings e.g. network benefits, were supported by appropriate experimental and analytical methodology [49].

# 4 Outcomes of the Project

Please note that further details of the learning outcomes from each activity can be found in supporting reports described in Section 13. In addition, further details may be obtained from the project contacts listed in section 14.

## 4.1 Enhanced network monitoring

### 4.1.1 Improved use of primary substation data

The enhanced load forecasting and risk characterisation tool developed provides a more accurate forecast of future network group load growth trends in comparison to existing practice. A more probabilistic approach gives us better knowledge of both existing and future network behaviour, helping to reduce conservatism in peak demand values and forecasts although capacity headroom gains for primary groups are relatively small (in the order of a few percent).

Our analysis also showed that in order to calculate security of supply in a way that is more consistent with actual network risk, it is necessary to carry out the security assessment more fully in the statistical, probabilistic domain [5].

Following a detailed review of ER P2/6 as part of Flexible Networks, learning outcomes were communicated to the ENA working group managing the ongoing review process. These included recommendations on consideration of the different means by which demand might be met, including through use of flexible network interventions such as dynamic or real-time ratings, network reconfiguration and voltage regulation, and means not explored by the Flexible Networks project such as demand side response, and corresponding 'risk'. Also, consistency among standards, conventions and incentives should be improved such that DNO behaviours are driven unambiguously towards their customers' best interests and DNOs can be confident of recovering their reasonably incurred costs [6].

### 4.1.2 Improved secondary substation monitoring

The monitoring regime deployed for Flexible Networks allowed a detailed quantification and validation of benefits for the various technologies trialled. Two monitoring options were also tested that will inform future procurement specifications [7].

Processes were developed to address practical challenges encountered with wide scale monitoring rollout including;

- Site surveys prior to procurement to avoid potentially costly, unforeseen installation issues,
- Online installation and redeployment to other network locations,
- Communication issues due to weak and/or intermittent signal.

A key learning outcome was that data transmission through mobile data networks does not provide 100% data availability and so allowances must be made to manage this to maximise data availability. Implementation of developed algorithms in the data acquisition system ihost to improve identification and handling of data anomalies led to better management of data error and uncertainty.

On a more strategic level, the detailed network monitoring deployed for Flexible Networks informed the future network monitoring strategy that was included in the SPEN RIIO-ED1 Business Plan (RIIO-ED1 LCT Network Monitoring Strategy) and has since been further developed for business rollout [10].

We consider that the cost of measuring, recording, communicating and storing of data for detailed secondary substation monitoring does not provide the level of benefit to justify a wide scale network rollout. We envisage a "smart" MDI monitoring voltage and current on the HV incomers and busbar of the secondary transformer and permanently fitted with a captured-data communication function, providing significantly greater resolution of monitoring data at secondary substation level than is currently available but at lower cost than a more detailed monitoring package.

### 4.1.2 Improved secondary substation monitoring [continued]

This leads to the following future monitoring strategy:

- Install "smart" MDIs in secondary substations at key locations across the LV network identified through application of the LCT Network Monitoring Strategy and as default in all new secondary substations, in place of the traditional conventional MDI.
- Install secondary substation monitors with more detailed functionality e.g. monitoring of all LV distributors and phases at a small volume of selected locations of high LCT clustering and network constraints as identified through application of the LCT Network Monitoring Strategy. These can be relocated as and when an appropriate network solution is deployed.

The more accurate enhanced data information on average gave us the confidence that we had additional capacity available from what was previously understood from the MDI data. The value of the additional capacity over 100 secondary substations with an average capacity of 490kVA was 8% [2]. Note that some secondary substations had additional capacity greater than 8% and other secondary substations had no additional capacity. Also, this was found on a specific group of secondary substations, at another site this figure may be more or less than the average additional capacity figure found to be available in this trial.

### 4.1.3 Improved operational tools

Internal stakeholder engagement activities undertaken with network control engineers led us to the conclusion that changes to operational practice are best implemented through policy, for the integration of network innovations rather than additional network management tools. A key consideration for operational policy and practice was that the likelihood of innovations resulting in extensive additional actions or decisions from the operator should be minimised although the operator should always have the option of taking manual control.

These learning outcomes were incorporated when developing detailed recommendations for improved operational policy and practice for integration of Flexible Networks innovations [14].

### 4.1.4 Improved planning tools

#### 4.1.4.1 Characterisation of PV at LV

Key metrics for characterisation of PV generation are peak solar irradiance and minimum average weekday demand profile. The assumption of a peak PV generation load factor of 90% was found to be appropriate for North Wales/Scotland based on verification of our network model with measured load and voltage data and consideration of detailed irradiance data measured over the summer period.

A generic minimum demand profile was defined and validated for domestic properties, based on residential LV feeder properties in the Ruabon LV network. Minimum daytime demand was found to typically occur during the morning with morning demand generally lower during the week compared to weekends.

Individual LV feeders were found to have a PV hosting capacity of up to 800W per customer and secondary substations up to 430W per customer. This includes consideration of phase imbalance which may be present. Analysis of capacity at Ruabon indicated that an increase in generation capacity headroom of 38% could be achieved [15].

Permanent or seasonal changes to the primary substation voltage set point were analysed as an option to release further generation capacity headroom. Application of a 2% voltage reduction can enable a PV hosting capacity of up to 1300W per customer on feeders and 850W per customer on secondary substations. A generic voltage reduction of 1-2% at the primary substation is now under consideration for inclusion in SPEN voltage policy for networks with high uptake of embedded generation.

#### 4.1.4.2 Characterisation of HV and LV imbalance

Installation of network monitoring at three trial sites within SPENs network found significant imbalance on many low voltage (LV) feeders, currently not visible to network planners. A total of 89 secondary substations with 233 LV feeders were analysed. The HV network in comparison had relatively low levels of phase imbalance [16, 36].

A simple methodology developed for Flexible Networks allowed LV feeders with significant phase imbalance to be rapidly identified from the large volume of measurements and compared with cable thermal ratings. Feeders can then be ranked and prioritised using a high level search algorithm for investigation of phase rebalancing to improve headroom. 9% of LV feeders monitored were identified as suitable for rebalancing, with the potential to release more than 20% capacity headroom and high enough peak load (>100A) to be worthwhile rebalancing. However, the cost of the necessary cable re-jointing would make this an unviable option in the majority of cases. This could change if the cost of re-jointing can be reduced in the future [16].

Based on analysis of a small subset of LV feeders, residential feeders were found to be most balanced likely due to higher volumes of customers and similar load profiles. This is potentially an important finding to better understand phase imbalance implications for the future connection of PV, EV and heat pumps to domestic properties. Feeders with a mixture of residential, industrial and commercial loads and rural feeders were more likely to be unbalanced. Secondary substation MDI data was found to not provide a reliable indication of individual LV feeder phase imbalance [16].

#### 4.1.4.3 Data analytics trial

In common with other DNO's, there is an exponential growth in data being collected across the business. Data is an asset, and analysis of the data has the potential to provide information to improve our cost efficiency, improve our asset management techniques, and facilitate new or improved services to customers. However the area is still largely immature. We carried out a trial of an analytics package, pulling data from different source systems and analysing it to produce visualisations and reports that provide business benefit. We successfully imported the network topology and secondary substation measurement data for 2 of our trial areas into the package which allowed us to use the visualisation and reporting functionality to assess the status of the network.

The trial has generated learning both on the potential power of data analytics to deliver business benefit, and in the difficulties of obtaining data from our existing systems in the correct format [19].

## 4.2 Dynamic thermal ratings

### 4.2.1 Overhead line RTTR

This trial successfully extended a RTTR methodology previously proven on 132kV overhead lines to 33kV overhead lines, enabling an average annual thermal rating uplift of around 11% of the static seasonal thermal ratings [22, 23]. The performance of the monitoring field devices deployed to facilitate this was verified and RTTR values and all other monitored data are now available through a dashboard within the PowerOn Fusion NMS.

Whilst the benefits of an overhead line RTTR system are reported for increased accommodation of generation, it could also be trialled and deployed in future for demand constrained conditions coupled with a demand side management scheme. This would help to maximise available capacity.

The methodology for estimating temperature of overhead line conductors as developed and incorporated into the RTTR algorithm was validated against monitored conductor temperatures at four locations along the Cupar – St Andrews 33kV circuits. A 'graceful degradation' methodology was developed and implemented in the RTTR system to progressively reduce the estimated RTTRs when transmission of real-time monitored weather parameters to the RTTR module is interrupted.

A comparative study between RTTR calculations using one weather station and multi weather stations monitoring micro-climate regions showed that it is important to identify and monitor micro-climate regions along an overhead line where thermal pinch points are more likely. Monitoring at a number of locations also improves the reliability of the system.

Detailed analysis of RTTR values showed that the effect of solar radiation can be significant especially during summer when high solar radiation is experienced. There were occasions when solar radiation and ambient temperature were higher than nominal values given in ER P27, and therefore the RTTRs were actually lower than static rating. If these conditions coincide with sustained high load on the overhead lines it could overheat and damage the assets.

We will continue to progress the system we developed in our trials into a BAU solution to deploy on appropriate projects both for renewable generation connections and to help with network loading issues. Our assessment of the number of weather stations required for dynamic line rating schemes differs from the conclusions reached by other DNO projects such as Northern Power Grid CLNR project. Therefore different cost and asset risk profiles between DNO's could result. We suggest that an ENA working group be set up to agree common requirements for the implementation of dynamic line rating in BAU across DNO's.

### 4.2.2 Transformer enhanced thermal ratings

Comprehensive site surveys and thermal modelling of the primary transformers in the three trial areas concluded that the transformers are suitable for loading above nameplate rating [26]. Analysis of a range of future loading scenarios with consideration of existing and historical loading indicated that peak loads can be increased above nameplate rating by 30% without shortening the technical lifetime of the transformer [27].

As primary transformers spend the majority of their life at loadings well below nameplate rating (in part due to seasonal as well as daily load cycles), transformer aging is not really an issue for implementation of enhanced thermal ratings. Even during infrequent N-1 network contingency conditions, when loading increases significantly (up to double for two transformer groups) the overall aging rate is still relatively low. We identified the transformer hot-spot temperature as the key issue and ensuring that this does not approach critical insulation breakdown temperature taking into consideration uncertainties in forecast ambient temperature and load as well as temperature overshoot effects is the main limit on enhanced thermal ratings.

A RTTR system would allow a higher magnitude of capacity release to be achieved by allowing active management of corresponding risk. However, associated assets in the trial areas such as 33kV circuits, 11kV transformer tails, and 11kV switchboard, effectively limit the increase in capacity available from the transformers to well below the level that would require a closed loop RTTR system to be deployed.

Converting to a network planning context, achieved firm capacity uplifts are provided in Table 4-1 for St Andrews and Whitchurch primary groups [24, 25]. The St Andrews primary group consists of 2 transformers and the Whitchurch primary group consists of 3 transformers. Modelling was carried out to verify the existing firm capacity and the capacity uplift through application of enhanced transformer thermal ratings with consideration of actual transformer and circuit load conditions. The long term development statement (LTDS) will be amended to include the new firm capacity.

**Table 4-1 Firm capacity uplifts through application of enhanced transformer thermal ratings**

| | Firm capacity uplift |
|---|---|
| St Andrews HV group | 14% |
| Whitchurch HV group | 10% |

The IEC thermal model on which the enhanced transformer rating software tool was based was validated through experiments on the Liverpool Road and St Andrews primary transformers. It was found to adequately represent the main aspects of transformer thermal behaviour for the calculation of enhanced and dynamic thermal ratings [30].

Key individual transformer thermal parameters were derived from experimental measurements for use in enhanced transformer ratings calculations. The experiments showed that the example thermal parameters in IEC 60076-7 are conservative in terms of actual transformer behaviour, and that better transformer knowledge has released extra capacity.

## 4.3 Flexible network control

The trial was successful in releasing network headroom at both the Whitchurch (11%) [34] and St Andrews trial sites (6%) [35].

A robust planning methodology was developed and applied to identify feasible load transfer options, potential capacity release and any reliability and protection issues that might limit certain network reconfigurations [33]. The incorporation of input from network control engineers was critical to testing the feasibility of various load transfer options. This is now rolled out to the business for application during RIIO-ED1 [31, 32]. Results also inform switching algorithms to be implemented in the NMS though use of logical sequence switching (LSS).

Next generation telecontrol equipment was developed and successfully deployed in the St Andrews area. This includes creation of a functional specification for wider procurement in future [31]. The ability to retrieve analogue data from pole mounted and ground mounted switches was achieved – something that was not previously possible with the earlier generation of telecontrol equipment. This will benefit customers through both reduced supply interruptions and reduced fault restoration times [37].

## 4.4 Integration of voltage regulators

The use of voltage regulators as enablers for flexible network control was proven through this trial [38, 39]. Testing of the AVR in the St Andrews network demonstrated that the AVR maintained network voltage within statutory limits, allowing the required load transfer to Anstruther primary network.

Detailed device testing at the PNDC provided confidence in the expected behaviour of the AVR under a range of likely and extreme network conditions. This also allowed the validation of a power systems model of the voltage regulator which will be utilised for future network modelling. Network modelling is incorporated into the detailed planning methodology that was developed and verified against network measurements from St Andrews during AVR performance testing [40, 41].

A new telecontrol solution for AVRs was developed and tested that will be adopted as a standard unit for new and existing units [38]. This trial was also successful in progressing 11kV voltage regulators into business-as-usual through the development of a number of facilitating processes and documentation. Whilst this trial focussed on the use of AVRs to facilitate flexible network control, there are additional benefits for application of AVRs to generation connections to reduce the extent of voltage rise. This allows generation projects to connect without the need for network upgrades.

## 4.5 Energy efficiency

The bottom-up modelling approach applied within the project was successfully developed to serve multiple functions, more specifically: to help understand customer / building make-up in each area (to assist in the identification of suitable interventions), to estimate anticipated electricity demands, and to enable a means of modelling the "impact assessment" of various intervention strategies.

The potential interventions offering the most cost-effective opportunities for both reducing operational costs for the customer and offering peak demand reductions were found to include the following technologies:

- Voltage optimisation
- Heating, Ventilation and Air-conditioning (HVAC) controls including variable speed drives
- Lighting
- Lighting controls

This intervention hierarchy provides direction for targeting specific energy efficiency works at stakeholders or specific building types where opportunities have been identified as most likely to exist.

Outcomes from the energy efficiency trial interventions provided some degree of peak load reduction and customer annual energy savings [43, 44]. With a large customer in St Andrews we were able to reduce the voltage at a number of sole use secondary substations, at no cost to the customer and minimal cost to SPEN. Whilst the target for this technique was 2% of the peak demand within the trial sites, the result achieved was negligible. Industrial and commercial energy efficiency presents significant opportunity for peak load reductions however there are a significant number of barriers to ensuring successful engagement to realise the potential in practice within the sector.

If undertaking the project today a different approach would be recommended i.e. to make use of the learning from this project and take advantage of emerging programmes which includes the Energy Saving Opportunity Scheme[3] (ESOS) (a mandatory energy assessment and energy saving identification scheme for large undertakings[4] in the UK that meet the qualification criteria) and DECC's Electricity Demand Reduction (EDR) pilot (a competition providing financial support to organisations that deliver electricity savings at peak times by installing more efficient equipment or increasing the efficiency of selected existing electrical systems.)

A cooperative approach that allowed all those parties that benefit from energy efficiency improvements and peak load reduction to contribute to the initial capital cost of the interventions would be the ideal scenario.

*[3]IThe Energy Savings Opportunity Scheme Regulations 2014 – see http://www.legislation.gov.uk/uksi/2014/1643/contents/made*

*[4]i.e. organisations which employ 250 or more people and which have an annual turnover in excess of 50 million euro (£38,937,777), and an annual balance sheet total in excess of 43 million euro (£33,486,489).*

## 4.6 Voltage optimisation

The international review [45] and our analysis of voltage reduction tests carried out on the Ruabon primary network [46] provided the following outcomes;

- A reduction in voltage will generally result in a reduction in active power demand with this reduction being larger over the short term than in the long term,
- The reduction achieved will depend on the types of load present, and therefore:
  - can vary between different parts of the distribution network,
  - can vary between different seasons, and different times of day,
  - can vary according to the ambient temperature,
- In the absence of local knowledge of experimental results, a reduction of 1% in active power demand in response to a 1% voltage reduction is a reasonable estimate. This is broadly consistent with the learning from the National Grid (Operation Juniper) tests. This reflects a direct energy saving for customers, where a 1% reduction in voltage can typically lead to a 1% reduction in energy consumption.
- A network voltage reduction does not generally seem to reduce the network current in the longer term. Therefore network copper losses (i.e. I2R losses in transformers, cables and overhead lines) are not reduced by reducing the network nominal volts,
- Reactive power demand will generally be reduced by a larger factor than active power demand.

Reduction of nominal network voltage at the primary substation was also found to be a cost-effective method to enable the increased connection of embedded generation [47, 48]. Detailed network modelling validated with measured network data indicated that reduction of network voltage by 2% in the Ruabon network will allow significantly increased volumes of PV to connect at LV – typically 90% more.

However periods of high demand, usually occurring in winter evenings when PV generation will be negligible, could result in the voltage dropping below statutory limits at the ends of feeders. Also, where large commercial/ industrial loads are connected to HV or LV feeders, or customers connected directly to 11kV where there is little or no embedded generation, reducing the voltage set-point at the primary substation could cause voltage to drop below the statutory limit. The impact of voltage reduction on these customers needs to be understood and managed although it does not outweigh the overall benefits to customers of a general voltage reduction. Voltage reduction tests in the Ruabon network in January 2014 and June 2015, encompassing a seasonal range of loads, resulted in no adverse effects on the customers supply.

It may not be sufficient for any new network voltage control strategy to simply be a new (lower) set point voltage. Additional flexibility (such as the ability to apply seasonal settings) may be necessary. This will lead to a requirement for additional network monitoring as well as greater network active management and control, such as remotely settable voltage control relays at primary substations.

The Grid Code requirement to provide voltage reduction as a means to achieve rapid load reduction may need to be reviewed, given that it is less effective than it used to be. An alternative could be for National Grid to procure instantaneous load reduction directly from DNOs (as part of a developing DSO model) as a network ancillary service.

# 5 Performance compared to the original Project aims, objectives and SDRC

The SDRC were developed based on overarching project aims and objectives. Achieving the SDRC is indicative of accomplishment of the wider ambitions of the project. Further details are of performance are provided in Appendix A.

| SDRC | Criteria | Evidence | Status |
|---|---|---|---|
| 5.1<br>Project Budget | The project will be delivered to budget in accordance with the Tier 2 full submission. | The project was delivered at 99% of budget | ✓ |
| 5.2<br>Project Milestone Delivery | Delivery in accordance with timelines and in line with budget, demonstrate effective project management. | The project will be delivered in accordance within the completion date of 30th September 2015. | ✓ |
| 5.3<br>Creation of a Flexible Network - St Andrews | At the end of the project, evidence detailing how a 20% headroom has been achieved will be published along with details of the methodology. | A robust business case paper has been published detailing how a 20% headroom has been achieved, with costs and benefits of the installed Flexible Network solution for Scottish Power to defer or avoid the business as usual reinforcement. | ✓ |
| 5.4<br>Creation of a Flexible Network - Wrexham | Making use of the cascade monitoring to improve knowledge of the network. The improved knowledge will then be used to allow further PV connections with the target to facilitate an additional 20% of PV onto the network. | A robust business case paper has been published detailing the full basis, costs and benefits which facilitates more than an additional 20% of PV to be connected to the network without the need for reinforcement. | ✓ |
| 5.5<br>Creation of a Flexible Network - Whitchurch | At the end of the project, evidence detailing how a 20% headroom has been achieved will be published along with details of the methodology. | A robust business case paper has been published detailing how a 20% headroom has been achieved, with costs and benefits of the installed Flexible Network solution for Scottish Power to defer or avoid the business as usual reinforcement. | ✓ |
| 5.6<br>Engagement, dissemination and adoption | The key aspects of this criterion are to ensure that the project provides high quality and timely engagement and dissemination with the internal and external stakeholders. | Several dissemination events have been held with internal and external stakeholders with post event surveys.<br>A demonstration event and site visit of PNDC for DNO and Ofgem representatives.<br>A formal dissemination event has been held to share the learning and outcomes. A project website has been produced to allow stakeholders to access the project learning details and methodologies. | ✓ |

# 5 Performance compared to the original Project aims, objectives and SDRC [continued]

## 5.1 Verification of benefits

The University of Strathclyde reviewed the experimental design of the various trials and analyses carried out for Flexible Networks, to ensure that the methodology, results and findings e.g. stated network benefits, are supported by appropriate experimental and analytical methodology [49]. In general, it can be said that the experimental and analytical design of the project is such that its results and benefits are likely to be reliable and reproducible within the limits which are claimed for them in the project documentation. This is documented in detail in "Experimental and Analytical Design Review".

# 6 Required modifications to the planned approach during the course of the Project

The solution being developed and the methods being trialled in the project remain consistent with those set out in the full submission, subject to our approved change request extending the project completion date and restructuring the budget to enable the project to deliver its objectives at the required level of quality within the original funding.

Changes to the original planned methodology are detailed below.

## 6.1 Integration of voltage regulators

In the Full Submission, it was stated that as part of Work Package 2.4 Voltage Regulation, 11kV voltage regulation equipment would be installed in each of the 3 trial areas comprising St Andrews, Whitchurch, and Wrexham. Long secondary network feeders tend to be voltage constrained under 'abnormal' network feeding arrangements which can occur under flexible network control. Voltage regulators can be used to address this constraint and therefore facilitate flexible network control.

However detailed analysis and assessment of secondary substation monitoring data available for the Whitchurch and Wrexham networks indicated that this voltage constraint issue did not arise and there was no requirement to install voltage regulators to facilitate flexible network control. This may be due in part to the highly interconnected nature of the legacy Manweb network. Therefore there was no compelling reason or opportunity to deploy voltage regulators at these two sites.

The deployment of a voltage regulator on the St Andrews 11kV network remained valid. At St Andrews, a suitable 11kV circuit was identified which is voltage constrained under particular feeding conditions that are envisaged as part of the flexible network control scenario.

Since voltage regulators are not required to facilitate flexible network control on the Wrexham and Whitchurch networks, this has no effect on the overall project target of creating 20% capacity headroom in each of the trial networks. This led to a cost reduction due to the omission of the two regulator installations, providing benefit to customers.

In order to maximise learning on the voltage regulator during the project, the following activities were taken;

- A voltage regulator was installed in the test network at the Power Network Demonstration Centre (PNDC) which was funded as part of the establishment of the PNDC. This was utilised for Flexible Networks to evaluate the performance of the regulator through a range of test scenarios that wouldn't be possible to carry out on a DNO network.
- A voltage regulator set unrelated to the Flexible Networks project was recently installed for a new generator connection in Ruthin, Wales. Although this is a different application, learning was captured from the design and engineering development in the form of engineering specifications for the procurement, installation and control of voltage regulators. This is available through Flexible Networks for other DNOs to assist in rolling out this technology on their distribution networks.

# 6 Required modifications to the planned approach during the course of the Project [continued]

## 6.2 Energy efficiency

Engagement with Industrial and Commercial customers within the trial area to examine the scope for energy efficiency to reduce electricity consumption proved to be challenging. A smaller number of customers than anticipated were identified to participate in trialling energy reduction measures. This resulted in insufficient participation to realise the target reduction of 2%. However shortfall in any capacity gains through energy efficiency were achieved by other elements of the project.

## 6.3 Procurement

As the project has developed, risks in relation to procurement delays and system development delays materialised. Delays were mitigated where possible however it was necessary to submit a change request for an extension to the completion date for the project. Lessons learnt for future innovation projects are captured in Section 9.

The approved project amount was revised in 2014 during a change request when it became apparent that the total SPEN and LCNF contributions of £6.25M would not be needed. This amount was revised to £5.28M and is set out in the revised project direction letter dated 27 October 2014. The revised budget amount represented a significant return of LCN funding to customers which was identified at that stage in the project. At completion of the project a further small underspend of £67k across the overall project was realised.

Table 7-1 shows the revised approved budget, outturn costs and variance against each cost category. The original submission budget is also shown for reference. It identifies that expenditure was generally in line with the total project budget at 99% spend. Significant variances are explained below.

## 7.1 Labour

Project Management – This was underspent by £73k (16%). This amount included for an overall programme manager for project, establishment of project and generic activities and to advise on regulatory and commercial issues. These elements are difficult to precisely determine at the earlier stages of the project and less man-hours were needed than anticipated which enabled a reduction.

Installation and Maintenance – This was overspent by £11k (28%). The original amount for this labour element was £456k and was reduced to £40k in the change request for several reasons, mainly due to the reduced installation costs of monitor installations and the omission of the voltage regulators in Wrexham and Whitchurch sites. However after it was reduced in the change request, some of the remaining installation work were more difficult and took longer than expected.

## 7.2 Equipment

WP 2.1 Dynamic Rating Equipment (St Andrews) – This was overspent by £113k (126%). The original amount for this element was £155k and was reduced to £90k in the change request because at the time our progress on this work package had identified that our enhanced rating technique was significantly lower cost than a real time control system. When the transformers were condition assessed for enhanced rating duty, the cooling banks at St Andrews primary required improvement which was a significant additional cost.

WP 2.1 Dynamic Rating Equipment (Ruabon) – This was overspent by £5k (98%). The original amount for this element was £70k and was reduced to £5k in the change request for the condition assessment because at the time our progress on this work package had identified that our enhanced rating technique was significantly lower cost than a real time control system. The cost of transformer temperature monitoring was an additional £5k.

## 7.3 Contractors

Legal & procurement – This was overspent by £11k (32%). The original amount for this element was £102k and was reduced to £34k in the change request, because at the time most of the legal matters of collaboration agreements etc. had been concluded. However some extended legal negotiations with landowners over the consents for the voltage regulators required additional legal work.

## 7.4 IT

Software licenses and contractor days – This was underspent by £30k (68%). The purchase/integration of a "dynamic" software package for transformers was not required as originally envisaged.

## 7.5 Payments to users

WP 2.3 Energy Efficiency – This was underspent by £100k (100%). This was for subsidies for energy efficiency equipment as necessary. Despite consultations with numerous customers, none of the identified efficiency measures were carried out and therefore no payments were made from this budget allocation.

## 7.6 Contingency

Whitchurch & Ruabon – The contingency amounts of £21k and £26k specifically for these trial areas was not required.

IT – Of the contingency amount of £14k, only £4k was utilised for data hosting costs.

Payments to Users, Maintenance/Faults and decommissioning – The contingency amount of £8k was not utilised.

11kV Voltage regulators – The contingency amount of £8k was not utilised.

## 7.7 Other

Work at PNDC and other Lab work – This was overspent by £54k (147%). The original amount for this element was £224k and was reduced to £37k in the change request, because at the time the schedule of tests had not been completed and the amount allocated was based on a generic testing example. When the detailed testing programme was compiled this required considerably more work and the revised cost reflected this.

### Table 7-1 Total project costs

| Category | Original Submission budget | Change request Approved budget | Project Outturn Costs | Variation % |
|---|---|---|---|---|
| **Labour** | **2049** | **1,203** | **1,129** | 94% |
| Project managment | 479 | 452 | 379 | 84% |
| Internal stakeholder engagement | 65 | 44 | 44 | 100% |
| Installation and maintenance | 456 | 40 | 51 | 128% |
| Internal engineering days | 1049 | 668 | 655 | 98% |
| **Equipment** | **2007** | **1,815** | **1,948** | 107% |
| WP 1.2 Monitoring Equipment (Whitchurch) | 326 | 284 | 264 | 93% |
| WP 1.2 Monitoring Comms (Whitchurch) | 38 | 40 | 40 | 100% |
| WP 1.2 Monitoring Equipment (St Andrews) | 499 | 551 | 571 | 103% |
| WP 1.2 Monitoring Comms (St Andrews) | 59 | 42 | 42 | 100% |
| WP 1.2 Monitoring Equipment (Ruabon) | 189 | 234 | 227 | 97% |
| WP 1.2 Monitoring Comms (Ruabon) | 22 | 32 | 32 | 100% |
| WP 2.1 Dynamic rating equip. (Whitchurch) | 70 | 15 | 16 | 107% |
| WP 2.1 Dynamic rating equip. (St Andrews) | 155 | 90 | 203 | 226% |
| WP 2.2 Control equip. (St Andrews) | 194 | 334 | 363 | 109% |
| WP 2.1 Dynamic rating equip. (Ruabon) | 70 | 5 | 10 | 198% |
| WP 2.2 Control equip. (Whitchurch) | 146 | 59 | 53 | 90% |
| WP 2.4 11kV Voltage Regulators | 240 | 128 | 128 | 100% |
| **Contractors** | **1105** | **1,533** | **1,556** | 102% |
| TNEI days | 147 | 291 | 297 | 102% |
| Internal Engineering days | 94 | 148 | 145 | 98% |
| University assistance | 318 | 380 | 372 | 98% |
| Other contractors | 474 | 680 | 697 | 103% |
| Legal & Procurement | 102 | 34 | 45 | 132% |
| **IT** | **319** | **319** | **292** | 91% |
| System development / Network control functionality | 125 | 125 | 128 | 103% |
| Software licences and contractor days | 44 | 44 | 14 | 32% |
| IT upgrades and incorporation of equipment technology | 150 | 150 | 149 | 99% |
| **IPR costs** | 0 | 0 | 0 | |
| **Travel and Expenses** | **44** | **22** | **21** | 97% |
| Travel expenses | 44 | 22 | 21 | 97% |
| **Payments to users** | **100** | **100** | - | 0% |
| WP 2.3 Energy efficiency | 100 | 100 | 0 | 0% |
| **Contingency** | **303** | **223** | **152** | 68% |
| Whitchurch | 64 | 21 | 0 | 0% |
| Ruabon | 31 | 26 | 0 | 0% |
| St Andrews | 100 | 84 | 84 | 100% |
| TNEI days | 4 | 4 | 4 | 100% |
| Internal engineering days | 20 | 20 | 20 | 100% |
| Contractors | 34 | 34 | 34 | 100% |
| IT | 14 | 14 | 4 | 33% |
| Legal & Procurement | 5 | 5 | 5 | 100% |
| Payments to users, maintenance, faults and decommissioning | 8 | 8 | 0 | 0% |
| 11kV Voltage Regulators | 24 | 8 | 0 | 0% |
| **Decommissioning** | **45** | **33** | **30** | 90% |
| WP 1.2 decommissioning days (secondary s/stn monitors) | 45 | 33 | 30 | 90% |
| **Other** | **278** | **37** | **91** | 247% |
| Work at PNDC and other lab work | 224 | 37 | 91 | 247% |
| Interuptions | 54 | 0 | 0 | |
| **Totals** | **6,279** | **5,284** | **5,218** | 99% |

# 8 Updated business case and lessons learnt for the method

The business case for application of Flexible Networks to each of the three trial networks was updated from the bid submission based on learning outcomes from the project as well as revision of underlying assumptions. The following details are provided below;

- Future cost for replicating the Flexible Networks solution and net benefits at each of the three trial networks,
- Potential for rollout across the SPD and SPM licence areas and also GB,
- Net benefits at GB scale.

We used the ENA methodology approved by OFGEM for the assessment of NIA projects[5].

## 8.1 St Andrews [50]

At St Andrews, the lowest cost traditional method would involve reinforcement works including two new 33/11kV transformers to be installed, new 11kV switchgear, 17km of 33 kV overhead line and extensive cable works to reconfigure the 11kV network, providing an additional 24MVA capacity. Due to consents matters across the various land owners, experience has shown that this project would take approximately 3 years to implement and is budgeted at a total cost of circa £6,200k. Our analysis indicates a future method cost for a similar site would be approximately £646k and would provide an additional 4.2MVA [50] deferring the need for conventional reinforcement.

## 8.2 Whitchurch [51]

At Whitchurch, the lowest cost traditional methods would involve reinforcement works and the construction of a green-field primary substation. This would include a 33kV switchboard, one 33/11kV transformer, 11kV switchboard and connecting 33kV and 11kV cables interconnected into the existing networks, providing an additional 10MVA of capacity. This would take approximately 2 years to complete and would be budgeted at £3,100k. Our calculations indicate a future method cost for a similar site would be approximately £612k and would provide an additional 3.8MVA [51] deferring the need for conventional reinforcement.

Detailed modelling and analysis of the Whitchurch network group incorporating secondary substation monitoring data available indicated that there was no requirement to install voltage regulators to facilitate flexible network control and achieve the additional capacity headroom required. This has the effect of improving the net benefit to the customer.

## 8.3 Ruabon [52]

At Ruabon, traditional methods would require a number of additional 11kV/LV substations to be installed across the network. It can be particularly difficult to establish these substations in mature housing developments where spare land is generally unavailable. Extensive cable works would also be required to integrate these new substations onto the network. This would take approximately 1-2 years to complete and is budgeted at a minimum of £1,200k. For a site similar to Ruabon, the future method cost including monitoring and voltage optimisation would be approximately £337k to allow typically up to 850W per customer on a secondary substation basis compared to 336W per customer currently [52]. Also, customers with embedded PV generation connections reduce energy usage and receive feed-in tariff payments, receiving a return on their investment over time. Additional societal savings will be achieved by mitigating the cost of carbon that would otherwise need to be funded from fossil fuelled generation.

[5] *https://www.ofgem.gov.uk/publications-and-updates/our-decision-approve-licensees-network-innovation-allowance-project-benefits-guide*

## 8.4 Summary

These solutions provide incremental capacity and it is possible that additional substation reinforcement may still be required at some point in the future. However, in some instances future load may not materialise as expected or overall demand will decrease due to energy efficiency. The ability to provide small capacity increments where required in the network would therefore avoid the cost of constructing assets that were only required for a short period of time and then become stranded.

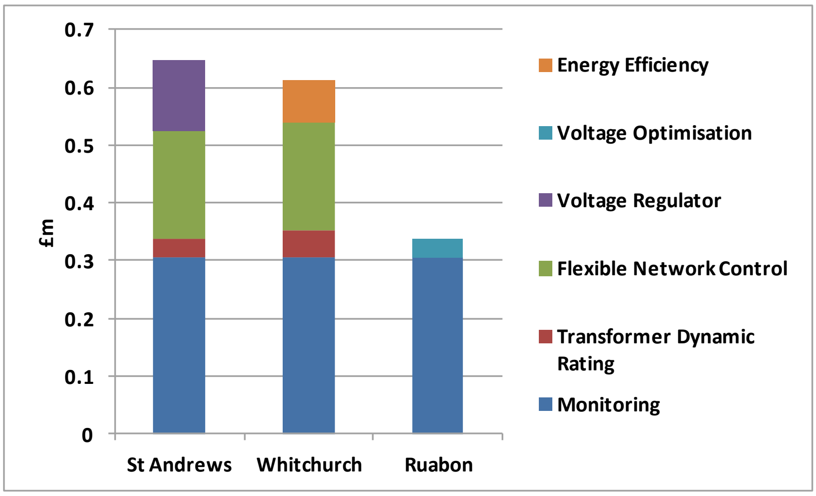



Figure 8-1 Method cost of Flexible Networks technologies at three trial sites

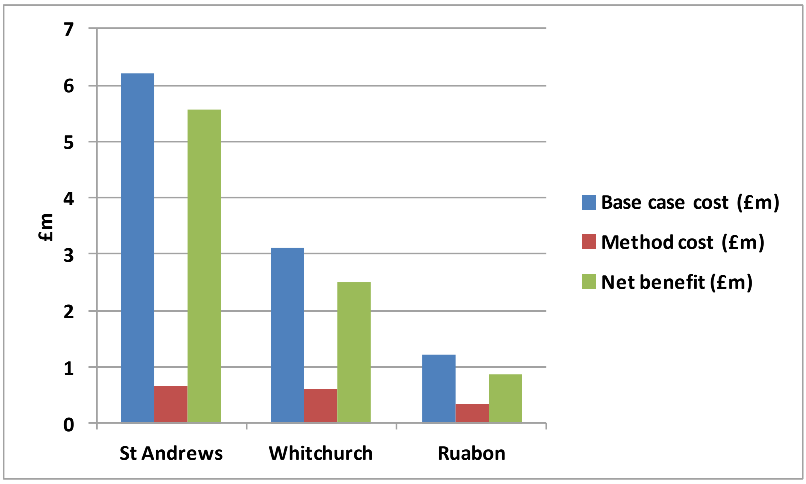



Figure 8-2 Net benefits for application of Flexible Networks at three trial sites

## 8.4 Summary [continued]

A reduction in reinforcement costs of between 70% and 90% was achieved for the three trial sites. The total project cost was £5.2M. Updated analysis indicates that the future method cost for these same three sites will be approximately £1.6M in total. Compared to a base case cost of £10.5M, this provides a net benefit of £8.9M.

Whilst energy efficiency measures were not applied at St Andrews or Ruabon as part of the future method, adequate capacity gain was achieved through other measures to achieve the SDRC.

In the original business case, a net benefit of £8.1M was estimated. As outlined above, greater net benefits amounting to £8.9M were actually obtained.

### 8.4.1 Updated potential for future rollout

Updated analysis of SPEN reinforcement plans for RIIO-ED1 shows that enhanced thermal ratings can be deployed on 10 primary schemes and flexible network control on one scheme to defer traditional reinforcement. This results in approximately £3M of net benefit. We conservatively estimate that benefits will increase to £10M through ED1 for SPEN. By extrapolation a similar conservative benefit for the UK as a whole is £100M.

## 8.5 Lessons learnt for future method

Energy efficiency has not proved to be as beneficial as anticipated, however we believe that it may still have potential, perhaps through a different delivery model.

# 9 Lessons learnt for future innovation projects

## 9.1 Procurement

Detailed below is further learning generated from Flexible Networks that can be applied to future innovation projects to improve outcomes and efficient delivery.

*Procurement of innovative technology or services is likely to take longer than typical procurement timescales.*

In order to procure the equipment required for enhanced network monitoring and the new generation of network control equipment it was necessary to carry out full procurement exercises to ensure correct governance and best value. This is a legal requirement of the Utilities Directive. Due to the complexities associated with procuring innovative technology, procurement typically took three months longer than expected. This is mainly because relatively novel and complex requirements specifications take longer than normal to develop and more time is required for suppliers to respond. This also applies to procurement of specialised contractors.

*One practical measure that can be taken to reduce procurement timescales is to issue technical requirements specifications to suppliers ahead of the full tender documentation to allow suppliers more time to address technical requirements.*

## 9.2 Engineering of new technology

*Additional time is likely to be required to work through engineering issues and obtain equipment approvals for innovative technology.*

An example of the type of issue that needed to be addressed is given below.

*Challenge:* It was determined that new generation network automation equipment will operate over UHF radio channels in order to provide sufficient bandwidth to monitor analogue network data. This equipment also needs to be compatible with legacy automation equipment on the network.

*Solution:* A solution that also incorporated VHF radio communications had to be developed, resulting in additional engineering requirements.

*Lesson Learnt:* Additional time may be required for novel technology to resolve unforeseen engineering issues.

## 9.3 Field devices

*Development of techniques to rapidly identify and resolve issues with large populations of field devices is important.*

A number of unanticipated communications issues were encountered with the secondary substation monitoring throughout the project. In order to manage this, a system of monitoring the operational status of the monitor population and calculating a data capture metric was developed. This enabled more rapid identification of problem monitors, the specific issue and more efficient resolution which is important with a large number of actively managed field devices (at much larger volumes than in the past with a fit-and-forget LV network).

## 9.4 System development

*It is likely to be more cost-effective and lower risk to utilise existing systems where possible than develop new systems and there are also benefits for user adoption.*

Originally, an expert control system was to be developed to run in parallel with the existing SPEN operations system to facilitate flexible network control. However, following a detailed techno-economic evaluation, the business as usual SCADA system was found to be the preferred solution for integration. Key factors influencing this included;

- Much lower technical risk than developing a separate stand-alone expert control system,
- Better facilitates progression of this technology into business as usual,
- This is the most cost efficient approach – using an existing SCADA platform.

## 9.5 External Contractors

Testing at the PNDC centre was on the critical path for the AVR project element. Delays in the opening of the PNDC centre meant that planned AVR activities had to be rearranged to maximise learning. This will be considered in future for involvement of outside contractors and ensuring that there are programme alternatives to move the project forward if external contractors are late in delivery.

# 10 Project Replication

## 10.1 Enhanced network monitoring

The Detailed Monitoring Methodology and Learning Report contains a summary of requirements to replicate the enhanced network monitoring deployed and analysed as part of Flexible Networks [2]. More detailed requirements are provided below.

### 10.1.1 Improved load forecasting and risk characterisation

Details of the methodology developed for improved load forecasting and risk characterisation are given in Work Package 1.1 report [5]. This can be developed in a Microsoft Excel VB interface with automated links to the load database as was done for Flexible Networks.

This report also contains details of algorithms that can be implemented into data processing practice to improve management of data error and uncertainty.

### 10.1.2 Secondary substation monitoring

A monitoring good practice guide [13] and a future monitoring strategy [10] were developed based on the learning outcomes from Flexible Networks. These are publically available to support project replication. In addition, details of monitoring deployment including practical considerations such as site surveys and communications, and detailed lessons learnt are available [7, 8, 9].

### 10.1.3 Improved operational tools

Detailed recommendations for operations policy and practice arising from Flexible Networks are available in a report [14]. This includes recommendations for voltage policy that will enable future voltage reductions to facilitate greater connection of PV volumes at LV and guidelines for adoption of dynamic thermal ratings.

### 10.1.4 Improved planning tools

Full details of the methodology, application to the trial network of Ruabon and the condensed rules-of-thumb for wider application are provided in PV characterisation at LV report [15].

The methodology that was developed and verified for characterising HV and LV imbalance is detailed and available on the project website [16]. The algorithms can be applied in a Microsoft Excel VB environment or similar.

A document was prepared that summarises recommendations for planning policy and practice from all Flexible Networks trials [20]. This provides a useful resource for replication of the various technologies trialled, in a network planning context.

Recommendations for improvements in future network modelling based on analysis of detailed secondary substation monitoring and other analysis carried out as part of Flexible Networks are also available [17, 18].

Details of the data analytics trial undertaken are available [19]. Whilst it is not possible to share the software which is background IP, we have detailed lessons learnt for data extraction across various different systems and visualisations and reports that should benefit the business. These should be of value for other DNOs looking to trial or implement similar systems.

There are a number of IPSA developments for Flexible Networks that are already available in the latest IPSA release (transformer and cable dynamic thermal ratings, reliability analysis, ZIP model, rapid input of network load profiles on a half-hourly or hourly basis) [21]. Remaining developments will be available in the next version due to be released towards the end of 2015.

## 10.2 Dynamic thermal ratings

### 10.2.1 Overhead line RTTR

The RTTR Cupar St Andrews Methodology and Learning Report contains a summary of requirements to replicate overhead line RTTR on 33kV conductors as trialled for Flexible Networks [22]. This trial was carried out using GE PowerOn with a DTR module and thus background IP is protected. However, it should be possible to replicate a similar RTTR system in another NMS based on details of the generic methodology provided.

### 10.2.2 Enhanced transformer rating

The Dynamic Transformer Thermal Ratings Methodology and Learning Report contains a summary of requirements to replicate enhanced primary transformer thermal ratings trialled for Flexible Networks [24].

An "Enhanced transformer rating" software tool was also developed to determine the enhanced rating for a primary transformer based on historic loading profile and site specific ambient temperature [28]. Consideration is given to the ratings of connected assets. This is available to other GB DNOs along with a detailed Application Guide [29]. The methodology for calibration of the IEC60076-7 model based on a primary transformer load test with an electronic winding temperature instrument is also available from the project website [30].

## 10.3 Flexible network control

The Flexible Network Control Methodology and Learning Report contains a summary of requirements to replicate the flexible network control system trialled for Flexible Networks [31]. The methodology that was developed to assess the feasibility of applying flexible network control and the potential benefits is available [33]. The functional design specification that was developed for the next generation telecontrol equipment is provided to enable replication, including block diagrams. Details of the system integration approach and installation and commissioning are also available [37].

## 10.4 Voltage regulator

The Integration of Voltage Regulators Methodology and Learning Report contains a summary of requirements to replicate the integration of voltage regulators on the 11kV network as trialled for Flexible Networks [38]. A number of documented tools and processes are now available that we can share with other DNOs to allow voltage regulators to be modelled, located, installed, commissioned, controlled and maintained. This includes updates to network voltage policy.

## 10.5 Energy efficiency

The Energy Efficiency Methodology and Learning Report contains a summary of requirements to replicate the energy efficiency techniques trialled for Flexible Networks [43]. Also, further details of load modelling and stakeholder engagement techniques are also available [42].

## 10.6 Voltage optimisation

The Voltage Optimisation Methodology and Learning Report contains a summary of requirements to replicate the voltage optimisation techniques trialled for Flexible Networks [47]. A methodology is also provided in PV Characterisation at LV for assessing the potential benefits of voltage optimisation on increasing generation capacity headroom at LV [15].

## 10.7 Method costs

Table 10-1 contains a summary of future rollout costs for each of the innovations trialled and analysed. Further details are provided in the cost-benefit analysis for each innovation [3, 23, 25, 32, 39, 44, 48].

### Table 10-1 Method costs for Flexible Networks innovations

| Innovation | Method cost (capital) (£k) | Method cost (£/kVA) |
|---|---|---|
| Enhanced network monitoring (method cost for approx. 100 secondary substations) | 307 | 78 |
| Enhanced primary transformer thermal rating (based on 2 transformer group) | 30 | 15 |
| 33kV Overhead line RTTR system (based on 4 circuit monitoring locations) | 90 | 45 |
| Flexible network control | 188 | 94 |
| Integration of voltage regulators | 122 | 87 |
| Energy efficiency | 73 | 842 |
| Voltage optimisation | 31 | 107 |

# 11 Planned implementation

Through application of the internal stakeholder engagement strategy, a number of SPEN staff outwith the project supported the project operational delivery aspects and contributed to the development of new tools and techniques. This was found to provide a robust platform to build on when taking the project findings into business as usual. It is intended that members of the Future Networks team will continue to contribute through a 'scheme team' approach, supporting development of individual project plans that include the adoption of flexible networks techniques.

A number of the elements of the project have already been adopted into the ED1 proposals (dynamic thermal rating, flexible network control, voltage regulators). During the period 2015-2023, Flexible Networks techniques and tools will be available to use as an alternative to existing practices for suitable network situations. Activities and learning from the project are already being transferred in to business as usual to become future standard policy.

A tracking regime is now being put in place to measure and record the benefits that the flexible networks techniques deliver for customers during the ED1 period through the reduction in conventional reinforcement.

## 11.1 Enhanced network monitoring

### 11.1.1 Load forecasting and risk characterisation

The load forecasting and risk characterisation tool is already integrated into the existing network planning tool for annual primary network review in SPEN and will be utilised in the upcoming 2015 review [5].

### 11.1.2 Secondary substation monitoring

Early learning outcomes for Flexible Networks were included in development of the SPEN RIIO-ED1 LCN Network Monitoring Strategy. A future monitoring strategy is available that comprises all of the learning from network monitoring in Flexible Networks [10]. This will inform network monitoring strategy and policy going forward.

#### 11.1.2.1 Weather monitoring

Ten weather stations across the SPEN network were included in the RIIO-ED1 business plan.

#### 11.1.2.2 Smarter MDIs

The installation of a "smart" MDI is proposed in place of the traditional maximum demand indicator in all new and replacement LV switchboards and also to areas of the LV network identified through application of the SPEN RIIO-ED1 LCT network monitoring strategy. This will gradually roll out across the entire LV network.

High level functional specifications were developed as part of Flexible Networks for the "smart" MDI. The next step will be to engage with potential manufacturers.

### 11.1.3 Improved operational tools

Through our extensive internal engagement, we found that changes to operational practice are best implemented through policy, for the integration of network innovations. Planned policy changes are specifically addressed for each innovative Flexible Networks technique in the Methodology and Learning Reports as well as more generally in Recommendations on Operational Policy and Practice [14].

### 11.1.4 Improved planning tools

Learning outcomes from the characterisation of PV on the LV network led to recommendations on voltage and PV connection policy and practice changes [15]. These are currently being adopted by the business.

Our data analytics trial in conjunction with IBM has been our first step in data analytics and we believe that the technique is at least 2 years away from business as usual adoption. As a next step we intend to undertake a NIA project which will use analytics to build a 'Network Controllable Points Alarm Processor'. This will be a decision support solution, analysing the increasing volume of data and alarms and will consider the potential benefits of predictive data analytics for fault prediction.

## 11.2 Dynamic thermal ratings

### 11.2.1 Enhanced transformer rating

Beyond the three network trial sites, two primary transformers have now been approved for enhanced transformer thermal ratings. Further to this, it has been proposed to implement enhanced transformer thermal ratings on a further eight primary transformers in the RIIO-ED1 period. This will be rolled out on the basis of learning outcomes detailed in the Methodology & Learning report [24].

### 11.2.2 Overhead line RTTR

Overhead line RTTR will be investigated as an option for increasing capacity on the 132kV 'PK' route in north Wales. We also identified that in order to fully adopt RTTR into business as usual, the following developments are required [22]:

- Integration with the live production NMS
- Establish interface between RTTR system and active network management (ANM) system in future. SPEN have has already trialled an ANM system for controlling generators' outputs, through the "Accelerating Renewable Connections" (ARC) LCN Fund project. SPEN has held a workshop with ARC and RTTR project partners to explore the way forward for integrating RTTR system within ANM system.

Technical manuals and policy documents will be updated to incorporate the application of RTTR in generation connection offers, network planning and operations codes of practice.

## 11.3 Flexible network control

In the ED1 period we will use flexible network control to defer conventional reinforcement where possible. One scheme at Langside in SPD is included in the business plan and we are actively reviewing our reinforcement schemes, to identify other schemes which are suitable for the deployment of flexible network control.

## 11.4 Voltage regulators

An Internal Working Group was set up to get 11kV in-line voltage regulators into business as usual. The group looked at the following separate parts of the business: voltage regulation policy, design guidance, procurement, construction, commissioning, telecontrol, linesman's manual, maintenance policy, asset data model, field operation instructions and control room procedures. Appropriate changes to documentation and processes were suggested [38].

A scheme to resolve a network voltage issue at RAF Shawbury has been instigated in SPM, using the learning from the project's standardisation of the use of voltage regulators.

## 11.5 Energy efficiency

Measures to reduce peak demand through customer energy efficiency will be considered during RIIO-ED1 but in a different form than was trialled for Flexible Networks. The approach taken for Flexible Networks provided significant learning in terms of most cost-effective interventions. Customer engagement was not as successful as hoped however, new legislation and regulations may provide more incentive for customers to consider energy efficiency measures in future.

Energy efficiency forms part of the SPEN 'Smart Buildings' NIA project which we are delivering in collaboration with Glasgow City Council.

## 11.6 Voltage optimisation

The application of permanent voltage reductions (reduced voltage set point) on the 11kV network is currently under consideration within SPEN following dissemination of learning outcomes within the business. This will enable increased volumes of generation to connect at 11kV and/or LV in future. Further detailed consideration of the impact on HV and LV customers particularly during periods of high demand, is first required.

# 12 Learning dissemination

## 12.1 Internal

*Maximise early user adoption to facilitate future rollout.*

The overarching objective for internal stakeholder engagement was to promote staff empowerment and attitude change, and optimise knowledge transfer and learning at all levels.

Workshops were undertaken with staff in 2012 in the early stages of the project to benchmark existing network planning and operations policy and practice. The types of analysis tools that could be developed through Flexible Networks to provide benefits to the business were also discussed.

Throughout the project, as the new tools and techniques were developed and trialled, there were extensive meetings with internal staff across many areas of the business including network planning, operations, policy, procurement, engineering standards, and commissioning. For example, to maximise future user input as functional specifications were defined and user interfaces were developed for new analysis tools, and to discuss analysis tool results and performance.

Meetings also took place between members of the project team, and our Design section to review individual project plans for adoption of flexible networks techniques in the RIIO-ED1 regulatory regime. Each member of the Future Networks team was allocated an area of the business to liaise and share innovation and learning.

Flexible Networks progress was presented at several annual SPEN internal technology conferences which focuses on LCNF and IFI and is attended by up to 100 staff. A follow up survey was completed to gain feedback from the staff. They were encouraged by the level of innovation being undertaken across the electricity supply industry.

Finally, workshops were undertaken in January and March 2015 with participants from our Design and Operations sections respectively to progress the flexible networks techniques into business as usual. A further internal workshop and site visit was held in August 2015 for Engineering Standards, and Planning & Regulation staff to present final learning outcomes from Flexible Networks feedback. Presentations were rated by staff as useful to very useful.

A tracking regime is being put in place to measure and record the benefits that the Flexible Networks techniques deliver for customers during the ED1 period through the reduction in conventional reinforcement.

## 12.2 External

*Provide focussed and timely knowledge dissemination to enable wider adoption by industry and customer awareness and engagement.*

Learning outcomes from Flexible Networks were communicated to a range of target audiences.

### 12.2.1 DNOs and wider industry

#### 12.2.1.1 LCNF/LCNI Conferences

We presented on Flexible Networks elements at 2012, 2013 and 2014 LCNF/LCNI conferences. The LCNI Conference in Liverpool in late November 2015 will be used as an opportunity for further dissemination. In addition to the formal sessions we are planning a series of short 'soapbox' presentations to take place on our stand.

#### 12.2.1.2 Other industry conferences and seminars

Flexible Networks featured in a series of presentations at an IET event on Smart Grids, held in the Manchester Conference Centre in April 2015. The event was well attended by academics, industry stakeholders and other interested parties. Flexible Networks project activities were also presented to the Energy Technology Partnership (ETP) in Dundee, Scotland, where the project learning to date and future adoption plans were discussed. The event was attended by PhD students, energy industry representatives and other academic organisations.

A presentation giving an overview of the project and its benefits was made to the All Energy 2015 conference in Glasgow. The audience comprised wider industry stakeholders including renewable generation developers.

Four technical papers covering various aspects of Flexible Networks were presented at the 2015 CIRED International Conference attended by utilities, manufacturers, academia and consultants.

#### 12.2.1.3 PNDC Stakeholder Dissemination Event

A knowledge dissemination event was held at the PNDC in Cumbernauld on the 10th of October 2013 to give a detailed view of the various work packages with progress and learning to date. Representatives from other DNOs and various other industry stakeholders attended.

#### 12.2.1.4 Peer review

We have engaged another GB DNO to peer review our Flexible Networks Closedown report and associated reports. This will help to facilitate external stakeholder dissemination as well as ensuring a clear and well presented report is delivered.

Also, leveraging on our learning from Flexible Networks, we provided comments to Northern Power Grid on the LCNF Tier 2 Customer Led Network Revolution project close down report.

#### 12.2.1.5 Data exchange

We provided information to a number of other DNOs on learning outcomes from Flexible Networks. This includes providing secondary substation data collected to Western Power Distribution for their LCNF Tier 2 LV Templates project. We have also met with Scottish and Southern Energy, Western Power Distribution and Electricity North West to share learning on monitoring installed for various projects.

We have recently received a request to obtain our Enhanced Thermal Rating software tool.

##### 12.2.1.6 Academia

Several Phd students and undergraduates at the University of Strathclyde were involved in the delivery of aspects of Flexible Networks, some of whom have joined DNOs following graduation.

##### 12.2.1.7 Flexible Networks closedown report

We will take into account responses from other DNOs in finalising the closedown report.

##### 12.2.1.8 Flexible Networks final dissemination event

A final dissemination event is planned for October 2015 to share the learning and outcomes on conclusion of the project.

## 12.3 Customers

For electricity customers, the energy efficiency technique specifically focussed on engagement with a range of customers in order to implement targeted energy efficiency measures. Energy suppliers were also engaged with to investigate opportunities to promote energy efficiency measures with customers and perform detailed site surveys.

### 12.3.1 Borough Councils

A number of meetings were held with Wrexham Borough Council to keep them informed of the project trial and of possible benefits to enable further renewable generation connections.

A meeting was held with Shropshire Business Enterprise in the Whitchurch network area to explain details of Flexible Networks and possible benefits for additional capacity availability, which was welcomed to encourage local economic development.

### 12.3.2 Customers

During the early stages of the project, BRE held a number of meetings with large customers around the trial sites to discuss possible energy efficiency measures including Historic Scotland and St Andrews University.

Also, through our collaboration with BRE we have arranged for BRE Trust (http://www.bretrust.org.uk/) to produce a publication on flexible networks techniques that will make this information available to a wider audience within the building and construction sector.

## 12.4 DNO policy changes

Learning outcomes were used to inform and modify a number of internal policy and guidance documents such as design manuals used by network planners, control room manuals and training, risk management policy and procedures and business process documents. This includes decision making processes such as annual network review, on-going asset management, facilitation of new connections and Ops liaison meetings.

Contributions were made to future engineering technical recommendations, specifically ER P2/6, the current distribution network planning standard (A successor to ER P2/6: existing issues and lessons from "Flexible Networks for a Low Carbon Future")[6].

## 12.5 Transform model governance

SPEN will provide a copy of the Flexible Networks Close Down Report and key project learning documents to EA Technology to support the Transform model governance process. This will ensure that model assumptions are informed by the latest evidence.

# 13 Key Project learning documents

## 13.1 Six-monthly progress reports

Details of six monthly progress reports are provided below.

Low Carbon Network Fund Project Progress Report June 2012

https://www.ofgem.gov.uk/sites/default/files/docs/2012/06/project-progress-report-low-carbon-networks_0.pdf

Low Carbon Network Fund Project Progress Report December 2012

https://www.ofgem.gov.uk/ofgem-publications/46035/spd-flexible-networks-progress-report-dec-2012.pdf

Low Carbon Network Fund Project Progress Report June 2013

https://www.ofgem.gov.uk/ofgem-publications/83234/spenflexiblenetworkssixmonthlyreportjune2013.pdf

Low Carbon Network Fund Project Progress Report December 2013

https://www.ofgem.gov.uk/sites/default/files/docs/2014/02/spd_-_flexible_networks_progress_report_dec_13.pdf

Low Carbon Network Fund Project Progress Report June 2014

https://www.ofgem.gov.uk/ofgem-publications/89330/flexiblenetworksforalowcarbonfuturereportjun2014.pdf

Low Carbon Network Fund Project Progress Report December 2014

https://www.ofgem.gov.uk/ofgem-publications/93447/flexiblenetworksdec2014.pdf

Low Carbon Network Fund Project Progress Report June 2015

https://www.ofgem.gov.uk/sites/default/files/docs/2014/10/decision_letter.pdf

OFGEM decision letter on change request October 2014

## 13.2 Key learning documents

All reports can be accessed (Hyperlink).

| Reference number | Section | Document Title | Publication Date |
|---|---|---|---|
| 1 | | Flexible Networks Closedown Report | September 2015 |
| 2 | 3.1 | Detailed Network Monitoring Methodology and Learning Report | September 2015 |
| 3 | 3.1 | Cost Benefit Analysis – Enhanced Network Monitoring | September 2015 |
| 4 | 3.1 | Network Capacity Headroom Positioning Paper | June 2014 |
| 5 | 3.1.1 | Improved Use of Primary Substation Data | January 2015 |
| 6 | 3.1.1 | A successor to ER P2/6: existing issues and lessons from "Flexible Networks for a Low Carbon Future" | April 2015 |
| 7 | 3.1.2 | Enhanced Substation Monitoring Deployment | September 2015 |
| 8 | 3.1.2 | Installation, setup and removal of GridKey low voltage substation monitoring equipment in secondary substations. | September 2015 |
| 9 | 3.1.2 | Installation, setup and removal of Subnet low voltage substation monitoring equipment in secondary substations | September 2015 |
| 10 | 3.1.2 | Good Practice Guide to Monitoring | August 2015 |
| 11 | 3.1.2 | Monitoring Data Management and iHost System Report | July 2015 |
| 12 | 3.1.2 | Data Error Detection and Correction | August 2015 |
| 13 | 3.1.2 | Future Network Monitoring Strategy | September 2015 |
| 14 | 3.1.3 | Recommendations on Operational Policy and Practice | August 2015 |
| 15 | 3.1.4 | Improved Characterisation of PV Capacity at LV | September 2015 |

## 13.2 Key learning documents [continued]

All reports can be accessed (Hyperlink).

| Reference number | Section | Document Title | Publication Date |
|---|---|---|---|
| 16 | 3.1.4 | HV and LV Phase Imbalance Assessment | September 2015 |
| 17 | 3.1.4 | Future Roadmap for Improvement of HV & LV Network Modelling | September 2015 |
| 18 | 3.1.4 | Technical Note on Investigation of Diversity in Secondary Substation Load | February 2015 |
| 19 | 3.1.4 | Methodology & Learning report Work package 1.2: Data Analytics Trial | September 2015 |
| 20 | 3.1.4 | IPSA Developments | September 2015 |
| 21 | 3.1.4 | Recommendations for Planning Policy and Practice | September 2015 |
| 22 | 3.2.1 | Methodology & Learning Report Work package 2.1: Dynamic thermal rating of assets – Cupar St Andrews RTTR system | August 2015 |
| 23 | 3.2.1 | Cost Benefit Analysis – Dynamic Thermal Rating (33kV Overhead Lines) | September 2015 |
| 24 | 3.2.2 | Methodology & Learning report Work package 2.1: Dynamic thermal rating of assets – Primary Transformers | May 2015 |
| 25 | 3.2.2 | Cost Benefit Analysis – Dynamic Thermal Rating (Primary Transformers) | September 2015 |
| 26 | 3.2.2 | Real Time Thermal Rating System – Phase I Asset Condition Assessment | July 2014 |
| 27 | 3.2.2 | Prospects of applying RTTR to distribution transformers | October 2014 |
| 28 | 3.2.2 | Enhanced Transformer Ratings Tool – A Design and Planning Application Guide | September 2015 |
| 29 | 3.2.2 | Enhanced Transformer Ratings Tool | September 2015 |
| 30 | 3.2.2 | Technical note on calibration of IEC60076-7 model performance based on primary transformer load test | June 2015 |

## 13.2 Key learning documents [continued]

All reports can be accessed (Hyperlink).

| Reference number | Section | Document Title | Publication Date |
|---|---|---|---|
| 31 | 3.3 | Methodology & Learning report Work package 2.2: Flexible Network Control | September 2015 |
| 32 | 3.3 | Cost Benefit Analysis – Flexible Network Control | September 2015 |
| 33 | 3.3.1 | Network Reconfiguration Planning Methodology and Application Guide | July 2015 |
| 34 | 3.3.1 | Whitchurch Load Automation Feasibility Assessment | June 2014 |
| 35 | 3.3.1 | Evaluation of Headroom and Load Transfer Opportunities at St Andrews Primary Substation | August 2015 |
| 36 | 3.3.1 | Report on Assessment of Load Unbalance in HV Feeders | October 2014 |
| 37 | 3.3.2 | Guide to Flexible Network Control | September 2015 |
| 38 | 3.4 | Methodology and Learning Report Work package 2.4: Integration of Voltage Regulators | August 2015 |
| 39 | 3.4 | Cost Benefit Analysis – Voltage Regulators | September 2015 |
| 40 | 3.4.1 | St Andrews Series Voltage Regulator Location Study | July 2014 |
| 41 | 3.4.1 | AVR Planning Methodology | September 2015 |
| 42 | 3.5 | Flexible Networks: Stakeholder Engagement | September 2015 |
| 43 | 3.5 | Methodology & Learning report Work package 2.3: Energy Efficiency | September 2015 |
| 44 | 3.5 | Cost Benefit Analysis – Energy Efficiency | September 2015 |
| 45 | 3.6 | Technical Note on Modelling of Load | January 2015 |

## 13.2 Key learning documents [continued]

All reports can be accessed (Hyperlink).

| Reference number | Section | Document Title | Publication Date |
|---|---|---|---|
| 46 | 3.6 | Analysis of 2015 Voltage Reduction Experiment at Ruabon Primary Substation | September 2015 |
| 47 | 3.6 | Voltage Optimisation Methodology and Learning Report | September 2015 |
| 48 | 3.6 | Cost Benefit Analysis – Voltage Optimisation | September 2015 |
| 49 | 3.7 | Experimental Design and Project Benefit Review | September 2015 |
| 50 | 5.3 | Case Study: Management of Network Capacity St Andrews Trial Area | August 2015 |
| 51 | 5.4 | Case Study: Management of Network Capacity | October 2014 |
| Whitchurch Trial Area | June 2015 | Guide to Flexible Network Control | September 2015 |
| 52 | 5.5 | Flexible Networks Case Study: Ruabon Multiple Domestic PV Connections | September 2015 |

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