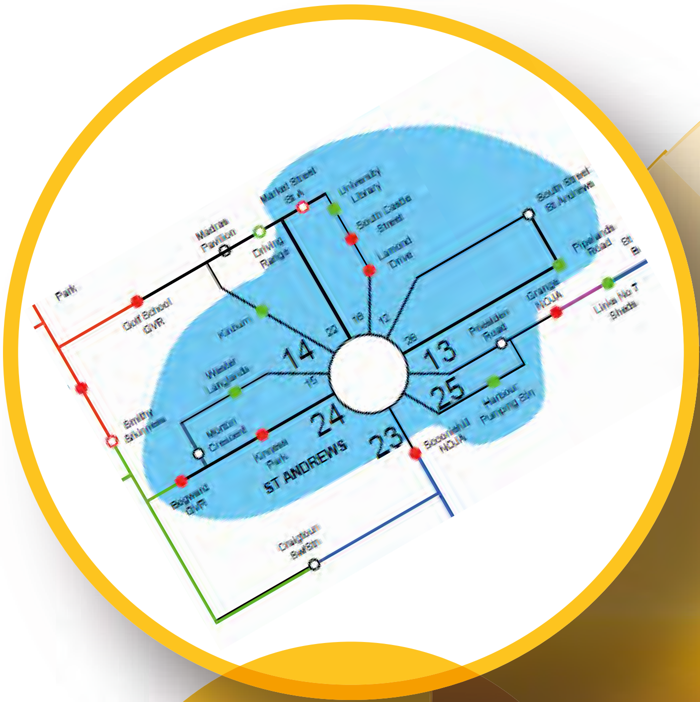
SP ENERGY NETWORKS

Flexible Networks for a Low Carbon Future



Case Study

Management of Network Capacity

St Andrews Trial Area

August 2015

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1 Executive Summary

This document summarises the work undertaken in the St Andrews trial area as part of the Flexible Networks project. The background reasons for this area being selected are explained. The overall objective was to achieve an increase in headroom of 20%. The initial make-up of the 20% as envisaged at the commencement of the project is summarised. The secondary substation monitoring that was installed to support the headroom increase is outlined, and each of the techniques trialled is discussed: - Flexible Network Control; Dynamic Rating; Voltage Optimisation; and Energy Efficiency. The results achieved from each method are outlined confirming that the overall objective of a 20% increase in headroom has been achieved.

2 Background

Growing load requests in St Andrews are a significant area of concern in East Fife along with the lack of capacity available in the 33kV distribution circuits at the Cupar Grid supply point. This is driving the need to consider additional Primary level reinforcement in the area. St Andrews is predominantly a University and Tourism load centre, with many sensitive customers at certain times in the year. At present the key demand growth drivers are due the expansion of the town and general load increase although there has been contact from some of the major consumers around energy efficiency and low carbon technology measures. In addition, one developer has also shown interest in connecting a 12MW wind farm onto the 11kV network which would add another dimension of complexity to the management of this network's capacity.

The level of 11kV interconnection is poor for St Andrews Primary and it is considered a largely "isolated" load centre. An additional primary substation was planned for late within the DPCR5 period, however this would be challenging to deliver due to the lack of land availability within the town, limited access to roads for laying the additional cables, and difficult way-leaves for new overhead lines due to the land use around the town.

The lowest cost traditional method would involve reinforcement works including the installation of two new 33/11kV transformers, new 11kV switchgear, 17km of 33 kV overhead line and extensive cable works to reconfigure the 11kV network

The Flexible Networks project seeks to investigate how extra capacity can be obtained from the existing HV networks through the use, in a coordinated way, of a number of innovative engineering solutions. The central objective of the project is to release network headroom, and thereby defer traditional investment, using a variety of technical tools. The core objective is to improve the flexibility with which the 11kV network can be operated to enhance the existing network capacity, and to provide useful increments of network capacity on a rapid and reasonable cost basis.

Due to the urgent nature of reinforcement within St Andrews and the challenges this would present, SPEN proposed this as an ideal site to undertake a project of this nature. As well as delivering benefits to the network in St Andrews the project has delivered valuable learning that will be applied to other reinforcement projects within ED1.

3 Our Initial Proposal

We set a target for this project to create headroom of up to 20% at St Andrews primary substation. This will defer further network investment for at least ten years, and potentially longer, unless significant load growth materialises beyond that which is currently foreseeable.

The justification for 20% being achievable was based on the following build-up:

Flexible network control: 9% of peak load can be redistributed on the network at appropriate times

Dynamic rating: 7% increase in capacity following site specific assessments

Voltage optimisation: 2% reduction in demand by reducing voltage where appropriate

Energy Efficiency: 2% reduction by reducing overall demand

Our approach was to develop a number of work packages, focussed on the interventions above, together with Network Monitoring which facilitates the other work packages. These are discussed briefly below.

Monitoring

Traditionally, Secondary substations in the UK distribution networks have very basic maximum demand meters that do not provide any information on the timing, duration, or frequency of the peak demand. As these require manual reading, the data is gathered infrequently and because of this has limited use for network planning. As network planning and reinforcement decisions require a good characterisation of the network and the connected demands and profiles, a lack of good quality data means that conservative assumptions must be made to safeguard the network and customers.

Part of the innovation in this project, has been to develop a metering programme led by the network planning and operational needs, taking due consideration of the relatively low cost margins required by Secondary distribution networks. To this end secondary substation monitors have been installed throughout the St Andrews urban area. Additionally next generation automation equipment is being trialled as part of the project which allows analogue data to be recovered from 11kV network devices such as RMU's and NOJA's.

Dynamic Ratings

Present industry best-practice revolves around the use of fixed equipment ratings based on conservative seasonal conditions. Improved thermal management of network assets using accurately modelled ratings can help to release additional network capacity.

Flexible Network Control

Incremental capacity can be created on the secondary (11kV) network by using of flexible open points to link neighbouring groups with different demand profiles. This project is developing flexible network control to provide the capability to dynamically transfer load between primary substations.

Rural networks, or isolated urban networks, are often complex and difficult to reinforce due to long feeder lengths. These networks are also the ones that may be early adopters of low carbon technologies such as heat-pumps and renewable generation due to their location and economic drivers from off-gas grid heating, or fewer planning restrictions. Often the network P2/6 capacity limitation is due to the back-up capacity in the event of a network problem (N-1), rather than the normal intact network. These long 11kV network feeders tend to be voltage constrained rather than thermally constrained, and so the use of series voltage regulators, or in some circumstances reactive power compensation, can create useful levels of an incremental capacity in a comparatively rapid and low-cost manner.

Voltage Optimisation

It was considered that voltage reduction at a primary substation level may result in a beneficial reduction of peak load on the distribution network.

Energy Efficiency

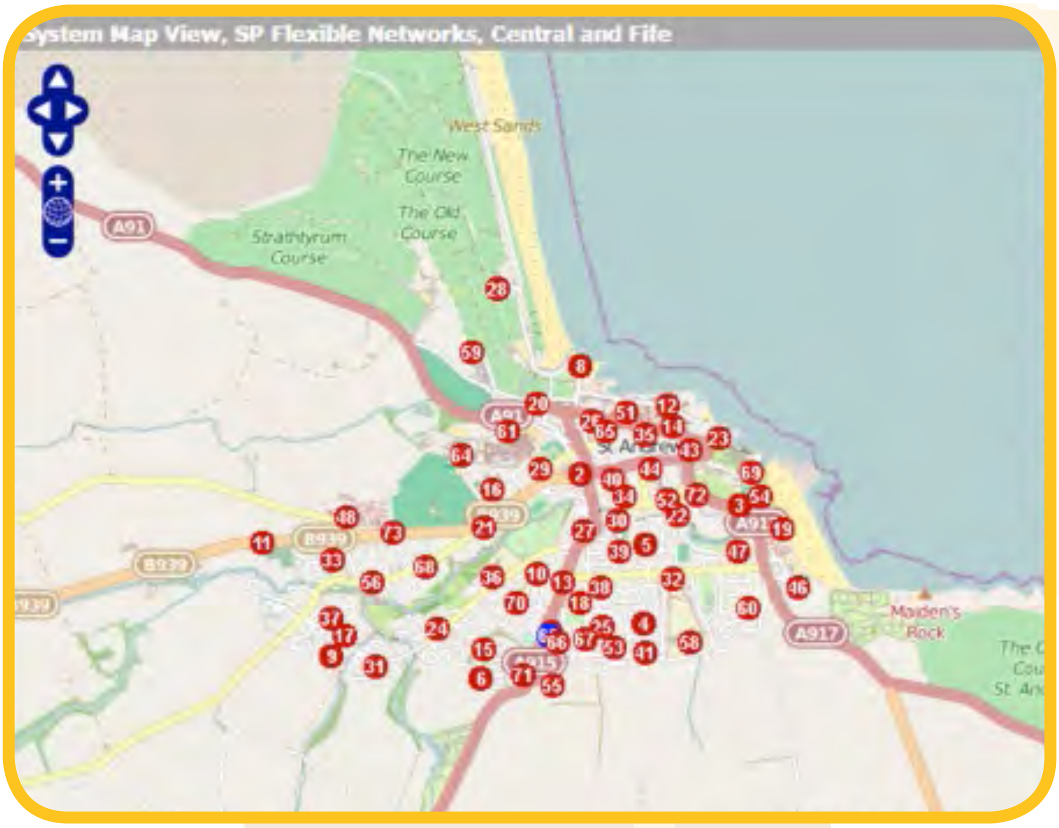
There is an opportunity to achieve increases in capacity headroom on the distribution network by working with customers and energy suppliers to identify and implement appropriate energy efficiency measures that can reduce power demand as well as energy demands, i.e. voltage regulators, reactive compensation and low energy appliances. The campaign was targeted on specific areas served by stressed network assets rather than a blanket approach, and specifically focused on reducing electrical power demand at the larger customers; provided this also results in an overall neutral or better reduction in energy demand for the customer. Energy efficiency surveys were structured to identify potential demand reductions that could be achieved, provide advice and support to customers, and where consented, share this information with Energy Suppliers to see if they could assist.

4 The work carried out

The process undertaken to develop the solution for St Andrews is described below. Again, the headings below refer to the Work Packages that are most relevant to the St Andrews site.

Enhanced Network Monitoring

Substation monitors have been installed at 4 primary substations and 66 secondary substations in the St Andrews area.



Monitoring specifications for Flexible Networks are as follows.

Table 1 Primary and Secondary Substations

Variable	Resolution
RMS phase voltage	1 min snapshot
RMS phase current	10 min snapshot
Supply Frequency	10 min snapshot
Power factor (each phase), per measured current	10 min snapshot
Real, reactive and apparent power (per measured current)	10 min average values
THD (per measured phase voltage)	Last 10 min period value

Measurements are logged in a remote Nortech iHost server. The data is available to view over a web interface and for download by SPEN and our project partners for more detailed analysis.

Dynamic Rating

The project has trialled the enhanced thermal rating of primary transformers and real time thermal rating of 33kV overhead lines. It is the enhanced rating of primary transformers that is particularly relevant to St Andrews at present.

Through a competitive tender exercise, DNV GL (formerly DNV KEMA) were engaged to undertake a study of 8 primary transformers in the trial areas to assess their capability for enhanced rating. Part of the criteria used in the selection of DNV GL was their extensive previous experience in the area of real time thermal rating of different assets. In the St Andrews area, the transformers at Cupar primary and St Andrews primary were considered.

DNV GL assessed the condition of each transformer and estimated its remaining life. The following activities were performed:

- collection and analysis of the available information on transformer characteristics, historic loading, and historic through fault history
- detailed visual inspection
- thermo-graphic inspection
- online partial discharge measurement
- oil analysis (dissolved gasses, quality, corrosiveness, furanic compounds)
- estimation of the remaining life on the basis of:
  - furanic compounds in the oil
  - loading-guide calculation

The results of this assessment are documented in DNV GL 'Final Condition Assessment' report. The report concluded that the estimated remaining life of the St Andrews primary transformers is over 25 years and they are suitable for careful enhanced loading.

In the subsequent stage of their study DNV GL developed a thermal model for the transformers and created future load patterns, based on actual load patterns to simulate and verify a safe increase in loading.

The results of this modelling are documented in the DNV GL report 'Prospects of Applying RTTR to Distribution Transformers'.

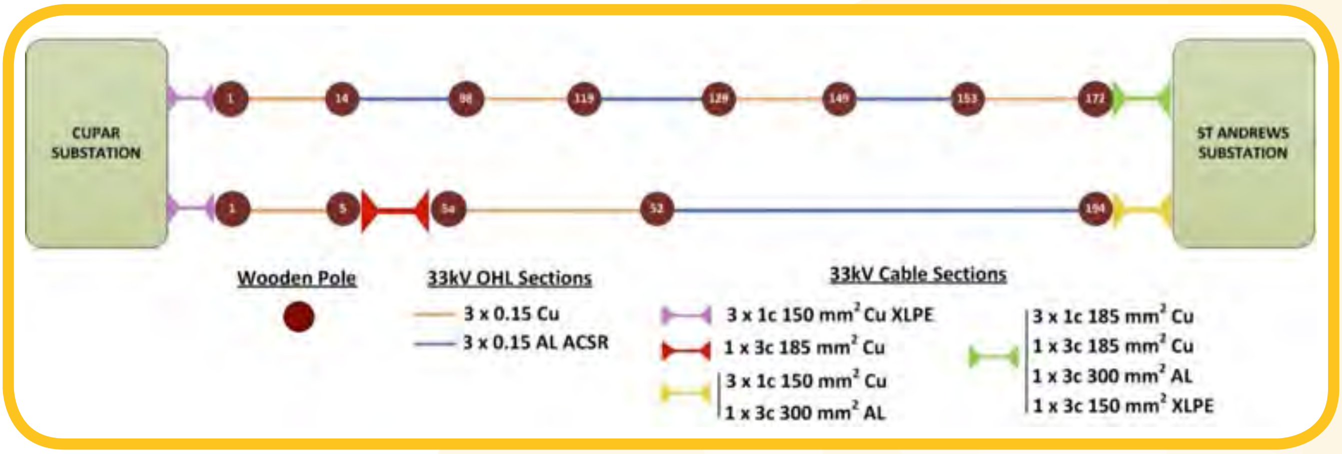
The study concluded that peak loadings can be increased above nameplate rating by 30% while maintaining an expected technical lifetime of 40 years.

Dynamic Rating [continued]

A study of the other associated assets considered

- The 33kV cabling and OHL in the circuits supplying the transformers

The makeup of the circuits are shown below. The ratings have been checked against the ratings in the SPEN Equipment Ratings document ESDD 02 007. The lowest ratings are associated with certain cable sections which have a winter cyclic rating of 24MVA.



- The 11kV transformer tails
  Transformer tails are 2x500mmCu (or imperial equivalent).
- The 11kV switchboard
  The incoming circuit breakers are Hawkgas 12 rated at 1250A with 1200A CT's.

  This study concluded that capacity of associated assets effectively limit the peak loading on the transformers to 24MVA, equivalent to a 14% uplift on peak loading. The LTDS will be amended to include the new firm capacity.

The calculation of the transformers enhanced rating requires their typical load profile to be taken into account. This profile could change in the future due to the impact of changing loads arising from, for example, low carbon technology or new connections. The Flexible Networks project has developed a tool which allows designers to calculate the enhanced rating of primary transformers, knowing the characteristics of the transformers, the ambient temperature, and their load profile. This enables the enhanced rating of the transformers to be recalculated should there be a significant change in the load profile in future.

In order to maximise the potential of the transformers to achieve their theoretical remaining life it was considered necessary to refurbish the transformers including the installation of new cooler banks. Although this work is not required to achieve the additional capacity it is necessary to provide assurance that the enhanced capacity can be maintained over their remaining life.

Flexible Network Control

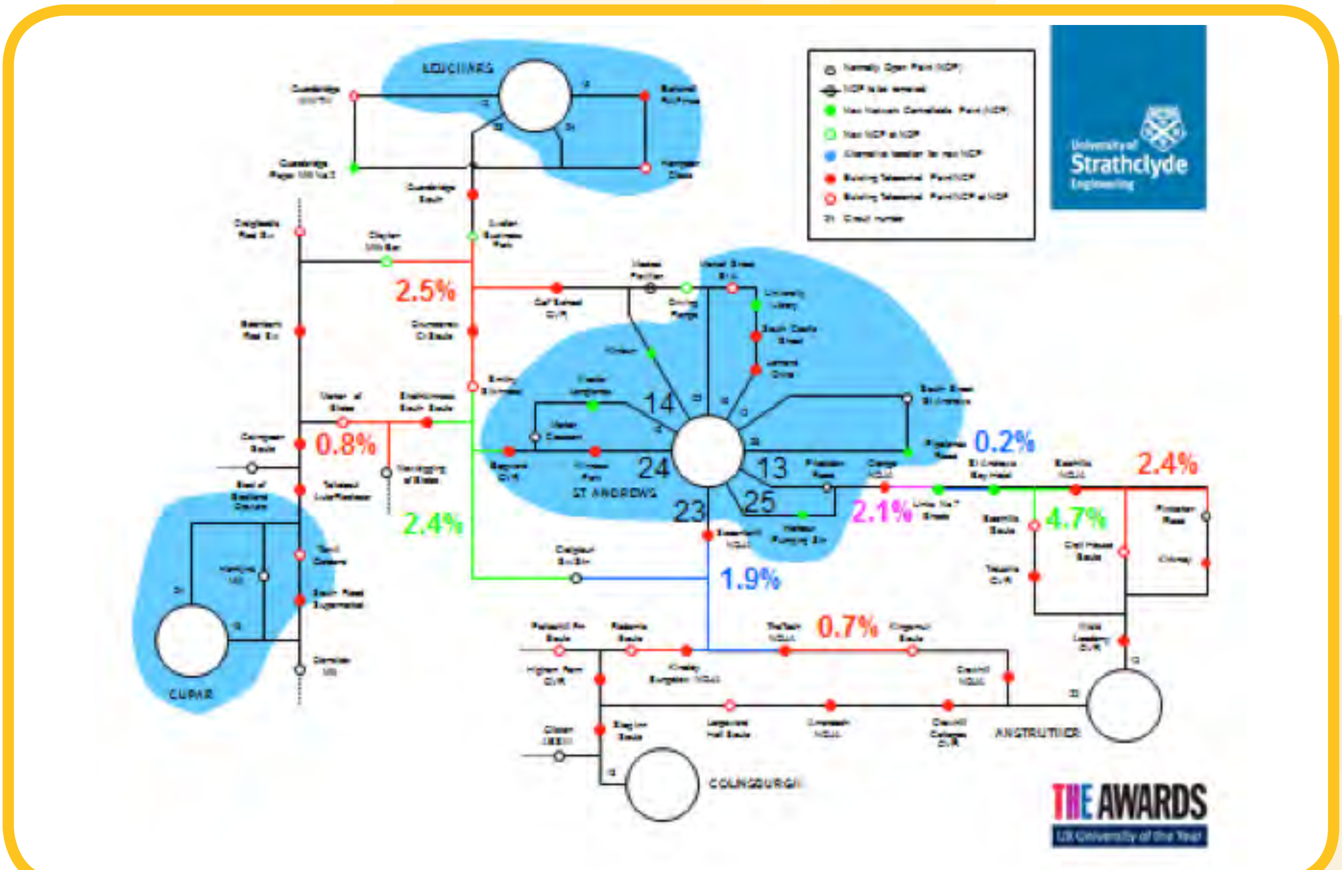
The 11kV secondary network in the St Andrews area is equipped with a number of Network Controllable Points (NCP) which facilitate remote control of the network and the ability to bring back status signals to the central SCADA system. Communication is by VHF radio which does not have sufficient bandwidth to bring back analogue load data from these points. As part of the project we have installed a number of next generation NCP points at ground mounted secondary substations and pole mounted controllable points. These new NCP points are equipped with UHF radios that have sufficient bandwidth to bring back analogue data. We are developing and trialling algorithms to run on the central PowerOn SCADA system to initiate switching sequences including the switching of load between primary substations.

University of Strathclyde (UoS) assisted by TNEI have undertaken a modelling exercise to evaluate the available thermal headroom at St Andrews primary substation, and at adjacent primary substations. Data from the secondary substation monitoring installed as part of the project was used in the modelling together with primary substation data from the existing PI historian, meter data for HV customers, and NOJA data from manual downloads. Opportunities to increase the headroom at St Andrews by permanent, seasonal or dynamic network reconfiguration to transfer load onto adjacent primary substations were identified and analysed.

The analysis considered the effect of load transfer on the maximum demands at the adjacent primary substations to ensure that these would not be moved into LI 4 or LI 5 load index positions.

As part of 11kV reconfiguration, an automatic voltage regulator (AVR) is required to overcome an out of statutory voltage condition on St Andrews circuit 25 (13), under load transfer conditions from Anstruther circuit 12. The installation of the AVR is covered in detail in the Methodology and Learning Report for Work Package 2.4.

The initial report prepared by UoS identified a number of options for progressively shifting load from St Andrews to adjacent primary substations by moving normally open points (NOP's) as illustrated in the slide below.



Flexible Network Control [continued]

The following combination of options were selected for consideration at a workshop involving representatives from Asset Strategy and Control Room: -

1) St Andrews Circuit 25 (Circuit 13) - Move NOP from Crail Soule to Grange NOJA
9.4% Headroom uplift

2) St Andrews Circuit 23 - Move NOP from Kingsmuir Soule to Scooniehill NOJA
2.6% Headroom uplift

3) St Andrews Circuit 24 - Move NOP from Morton of Blebo to Bogward GVR
2.4% Headroom uplift

4) St Andrews Circuit 14 - Move NOP from Avalon Bus. Park to Golf School GVR
2.5% Headroom uplift

These options were selected because they avoid moving any customers currently served from an underground circuit onto an overhead circuit. The potential resulting total headroom increase is 16.9%. These proposals were discussed at the workshop. The Control Room commented that it is undesirable to move NOP's from Soules to NOJA's or GVR's. It was requested that any opportunities to benefit from differing load profiles at adjacent primaries should be maximised. The issue of CI/CML implications was discussed and it was concluded that the movement of the NOP on a circuit is not a major consideration in comparison with other factors such as automation to provide restoration within 3 minutes.

Following the workshop the reconfiguration options were reviewed and further analysis undertaken by UoS.

The resulting proposals following review were as follows: -

1) St Andrews Circuit 25 - (Circuit 13) Move NOP from Crail Soule to Links No.7 Shed
7.0% Headroom uplift

2) St Andrews Circuit 24 - Move NOP from Morton of Blebo to Bogward GVR and Strathkinness South Soule
2.4% Headroom uplift

3) St Andrews Circuit 14 - Move NOP from Avalon Bus. Park to Golf School GVR
2.3% Headroom uplift

These reconfigurations result in an overall headroom uplift at St Andrews primary of 11.7% without moving Anstruther primary into an LI 4 or LI 5 position.

However there is a preference to minimise load transfer onto Anstruther which is itself a heavily loaded primary. Therefore it is proposed to limit the extent of the transfer in 1) above to Boarhills NOJA giving a headroom uplift at St Andrews of approximately 2.5%. The overall resulting headroom increase at St Andrews is 7.2%.

Whilst this does increase the peak load on Anstruther by approximately 500kVA, analysis of the Anstruther transformer using the TNEI enhanced rating tool developed as part of the project confirms that the firm rating of this primary can be increased by 1MVA to 11MVA. Therefore the proposed load transfer does not cause any reduction in available capacity.

Flexible Network Control [continued]

As part of the analysis, the effect of an N-2 event at St Andrews Primary has been considered. It has been concluded that P2/6 compliance can be achieved provided that the adjacent primary substations are intact.

The results of the analysis also determined that network reconfiguration at Guardbridge Switching Station is necessary to put the feeder towards Avalon Business Park onto Leuchars Feeder 23. The NOP is moved to Avalon Business Park.

Further improvements to the 11kV network were identified as follows: -

1) A new Soule switch adjacent to Clayton Milk Bar (as the Milk Bar switchgear can't be automated and replacement is uneconomic).

2) A new NOJA near to Avalon Business Park to protect the overhead lines under the revised feeding arrangement from Leuchars.

3) Replacement of the Crail House Soule with a NOJA.

Voltage Optimisation

Through the findings of this project and other related projects we have concluded that voltage reduction only provides minimal benefits to the network in terms of load reduction. Therefore this intervention was not considered part of the solution for St Andrews.

Energy Efficiency

To investigate the opportunity for increasing network flexibility via energy efficiency we considered it important to engage with key stakeholders to better understand their current, and future, energy needs, demand profiles, energy use characteristics; as well as stakeholder's attitudes and priorities regarding energy efficiency, distributed generation, investment and funding. This engagement was undertaken by BRE in 4 phases.

- Phase 1: Initial stakeholder identification and engagement: Research each specific network / geographical area and identify key stakeholders via desk based review. Contact all stakeholders to enter into follow up discussions to gauge interest and discuss next steps, where relevant. Prioritise future stakeholder activity to parties offering the most promising opportunities, those with high cost effectiveness, highly replicable and/or those which enable maximum project learning.
- Phase 2: Conduct one to one meeting with key stakeholders:
- Phase 3: Targeted site surveys at selected stakeholders: Following completion of the above, this phase included undertaking a number of technical surveys at the sites of engaged stakeholders.
- Phase 4: Develop an appropriate delivery mechanism for implementation: Following completion of the above, this phase included considering appropriate delivery mechanism and procurement routes for realising the energy efficiency interventions identified during the earlier phase. This would be formulated depending on the quantity and mix of engaged stakeholders, their building types, energy efficiency opportunities available and the stakeholder's attitudes to energy efficiency investment.

By working through the phases above in the St Andrews area attention became focussed on a small number of significant energy users in the education, hospitality and leisure sectors.

Energy Efficiency [continued]

Potential interventions were identified at a number of sites and prioritised for implementation with the assistance of a financial contribution from the project.

Interventions capable of reducing peak load by approximately 100kW were progressed with one stakeholder in education sector which is approximately equivalent to 0.5% of the peak load on St Andrews primary substation. It was not possible to implement these interventions within the timescale of the project.

Through liaison with the same large customer in the education sector we were able to identify a number of sole use secondary substations where we were able to alter the voltage tap setting to reduce the output voltage. The effect of these changes on peak load and energy consumption are currently being assessed.

5 Comparison with Original Objectives

The table below shows a comparison of the released capacity that was originally envisaged for each technique compared to the results actually obtained.

Technique	Target	Actual
Dynamic Rating	7%	14%
Flexible Network Control	9%	6%
Energy Efficiency	2%	<1%
Voltage Optimisation	2%	—
Total	20%	20%

It can be seen that the initial overall target of 20% has been achieved; however the way this target has been achieved is different from what was originally envisaged.

We have learnt through the implementation in the St Andrews trial area: -

- Enhanced Rating of primary transformers can be an important technique in achieving incremental capacity increase, subject to the limiting capacity of associated assets.
- Flexible Network Control has the capability to make best use of network capacity in a geographical area.
- 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.
- Voltage reduction at primary substation level is unlikely to be a useful technique for reducing peak demand.

6 Business Case

Business as Usual Baseline

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. 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.

Trial Project Costs and Rollout (Method) Costs

The following method costs are taken from the cost benefit analysis (CBA) included in the close down documentation:-

Technique	Trial Project Cost (£k)	Rollout (Method) Cost (£k)
Monitoring	596.8	306.7
Transformer dynamic rating	215.5	30.2
OHL dynamic rating	315.3	0.0
Flexible network control	507.3	188.0
Voltage regulator	286.0	122.2
Energy Efficiency	84.3	0.0
Other Activities (Analysis, project management & dissemination etc.).	429.0	0.0
Total	2,434.3	647.1

Net benefits

Our calculations indicate a future method cost for a similar site would be approximately £647k. Compared to the Base Case costs of £6,200k this represents a net benefit of £5,553k.

It should be recognised that this solution is only providing an incremental solution and additional substation reinforcement may still be required at some point in the future. 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 would therefore avoid the cost of constructing assets that were only required for a short period of time and then become stranded.