SP ENERGY NETWORKS

# Flexible Networks for a Low Carbon Future


## Case Study

### Management of Network Capacity

### Whitchurch Trial Area

June 2015

# Contents

# 1 Background

Whitchurch is facing an increasing demand. Several enquiries have been made recently regarding the connection of additional demand in this area of network over the next 3 years. Based on this and historical underlying load growth, it is expected that load will increase over the next 5 years to a level that triggers a significant local network reinforcement. This will have a cascade effect on the rest of the network which will require higher voltage levels to also be reinforced.

The existing 33kV network around Whitchurch is run interconnected as a single group and fed from three 132/33kV grid transformers at Whitchurch, Oswestry and Marchwiel. The 33kV group is a mixture of some industrial and mostly domestic customers. During outages in the Whitchurch area, elements of the network can be loaded up to 99% of their rating which means that this network is on the limit of P2/6 compliance - hence the desire to seek cost effective incremental capacity. Network monitoring shows that demand is increasing and based on customer engagement there is every likelihood that this will continue.

Due to the length of the feeders the wider network is broadly voltage constrained, which also makes it an ideal site for exploring the benefit of coordinated dynamic network control. This type of network situation is typical of GB networks and is a comparable test case to load growth due to low carbon technology.

# 2 Our Initial Proposal

We set a target for this project to create headroom of up to 20% at the Whitchurch network. 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 as an enabler to facilitate 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 Whitchurch 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 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 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 secondary 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; 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.

# 3 The work carried out

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

## 3.1 Enhanced Network Monitoring

Substation monitors have been installed at 3 primary substations and 47 secondary substations in the Whitchurch 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.

## 3.2 Dynamic Rating

The project has trialled the enhanced thermal rating of primary transformers. It is the enhanced rating of primary transformers that is particularly relevant to Whitchurch 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 Whitchurch area, the transformers at Liverpool Rd primary, Yockings Gate primary and Whitchurch Grid 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

## 3.2 Dynamic Rating [continued]

The results of this assessment are documented in DNV GL 'Final Condition Assessment' report. The report concluded that the estimated remaining life of all the primary transformers assessed 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.

A study of the other associated assets considered

- The 11kV transformer tails

  Transformer tails are 300mmCu (or imperial equivalent).

- The 11kV switchboard
- The incoming circuit breakers are rated at 630A.

This study concluded that capacity of associated assets effectively limit the peak loading on the transformers to 11MVA, equivalent to a 10% 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.

The starting point for the dynamic rating benefit assessment was the intact capacity of the Whitchurch group is listed in the LTDS as 22.5MVA, (3x7.5MVA). The theoretical maximum group capacity is listed in the LTDS as 20MVA and is based on a single transformer outage with all three transformers having a cyclic rating of 10MVA. This theoretical maximum would only be achieved if the demand in the network were perfectly balanced. The network was modelled with demands from iHost on 07/11/2013 17.30 (highest demand of an average winter day). This loading was then scaled to meet the group maximum demand listed in the LTDS. The sum of the individual substation peaks is virtually identical to the group peak. The network was assessed under N-1 conditions, reconfigured and demand uniformly grown across network until a thermal (transformer or circuit) or voltage limitation was identified. Under the loss of a transformer, reconfiguration was considered to be by opening the feeder breakers and resupplying the feeder from its remote end. In general feeders are resupplied by other transformers within the group. The exceptions are four feeders out of Whitchurch - assumed that these would be resupplied by their remote ends (Ellesmere, Overton, Wrenbury Frith, Newhall). The St Ivel feeder out of Yockings Gate was not resupplied from Prees – rather it was assumed that this would be resupplied through the Yockings Gate busbars, or from Liverpool Road.

## 3.2 Dynamic Rating [continued]

For all three outage conditions studied, by enhancing the rating of the transformer by 10% released significant amounts of capacity.

For outage of the Liverpool Road transformer, the first limitation identified was a thermal overload on an HV feeder near the Girls High School. Although some demand on this feeder could be moved by operating the tele-controlled switching points to move the normally open point from Bargates to Green End Arcade. The loading on the Whitchurch transformer would increase to its maximum continuous ONAF rating of 10MVA. For the purposes of this analysis, this is considered to be the existing limitation of the group.

Enhancing the thermal rating of the Whitchurch transformer was able to release approximately 10% of existing firm capacity as it enables the above reconfiguration which alleviates the HV feeder constraint. The next constraint was the enhanced thermal rating of the Whitchurch transformer. Firm capacity was considered to increase from 17.34MVA to 19.11MVA (10.2%)

For outages of either of the Whitchurch or Yockings Gate transformers, the HV feeder network was not found to limit the capacity. The first limitation was the cyclic rating of other transformers in the group. Under N-1 of the Whitchurch transformer, some feeders were supplied by remote ends (Ellesmere, Overton, Wrenbury Frith, Newhall). Consequently the group demand is lower under these conditions and this is therefore not expected to be the limiting contingency for the group.

Results also indicated that under N-1 conditions, loading on Yockings Gate could be managed so that it doesn't exceed 10MVA (and therefore does not require enhanced rating).

The table below shows the analysis results for the N-1 loading conditions and the increased capacity to the group from using an enhanced thermal rating.

| Network demand scaling factor | Study Condition | | Equivalent group loading under Intact | N-1 flow through transformers | Whitchurch 33/11 7.5/10MVA 10 / 10 11 / 11 | Liverpool Road 33/11 7.5MVA 7.5 / 10 8.25 / 11 | Yockings Gate 33/11 7.5MVA 7.5 / 10 8.25 / 11 | Transformer Type<br>Existing Rating (Intact/N-1)<br>Enhanced Rating (Intact/N-1) |
|---|---|---|---|---|---|---|---|---|
| 1.000 | Intact | Unscaled BASECASE demand | 14.700 | - | 6.969 | 4.465 | 3.266 | |
| 1.180 | N-1 LIV RD | Existing - limited by feeder thermal issues | 17.346 | 17.72 | 8.669 | - | 9.046 | Thermal overload on HV feeder near Girls High School |
| 1.300 | N-1 LIV RD | Transformer ratings enhanced by 10% | 19.110 | 19.64 | 11.01 | - | 8.634 | Limitation is Whitchurch transformer |
| | | **Capacity release through Transformer enhanced rating** | **1.764** | **10.2%** | | | | |
| 1.290 | N-1 YOCK | Existing | 18.963 | 19.37 | 10.04 | 9.332 | - | Limitation is Whitchurch transformer |
| 1.410 | N-1 YOCK | Transformer ratings enhanced by 10% | 20.727 | 21.29 | 11.05 | 10.246 | - | Limitation is still Whitchurch transformer |
| | | **Capacity release through Transformer enhanced rating** | **1.764** | **9.3%** | | | | |
| 1.660 | N-1 WHIT | Existing | 24.402 | 17.38 | - | 10.024 | 7.352 | Limitation is Liverpool Rd transformer |
| 1.815 | N-1 WHIT | Transformer ratings enhanced by 10% | 26.681 | 19.12 | - | 11.022 | 8.095 | Limitation is still Liverpool Rd transformer |
| | | **Capacity release through Transformer enhanced rating** | **2.279** | **9.3%** | (Under N-1 configuration some feeders are supplied by remote ends, consequently group demand had to be increased more before issues were identified. This level of group demand would be expected to be limited under intact conditions) | | | |

## 3.3 Flexible Network Control

The 11kV secondary network in the Whitchurch 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.

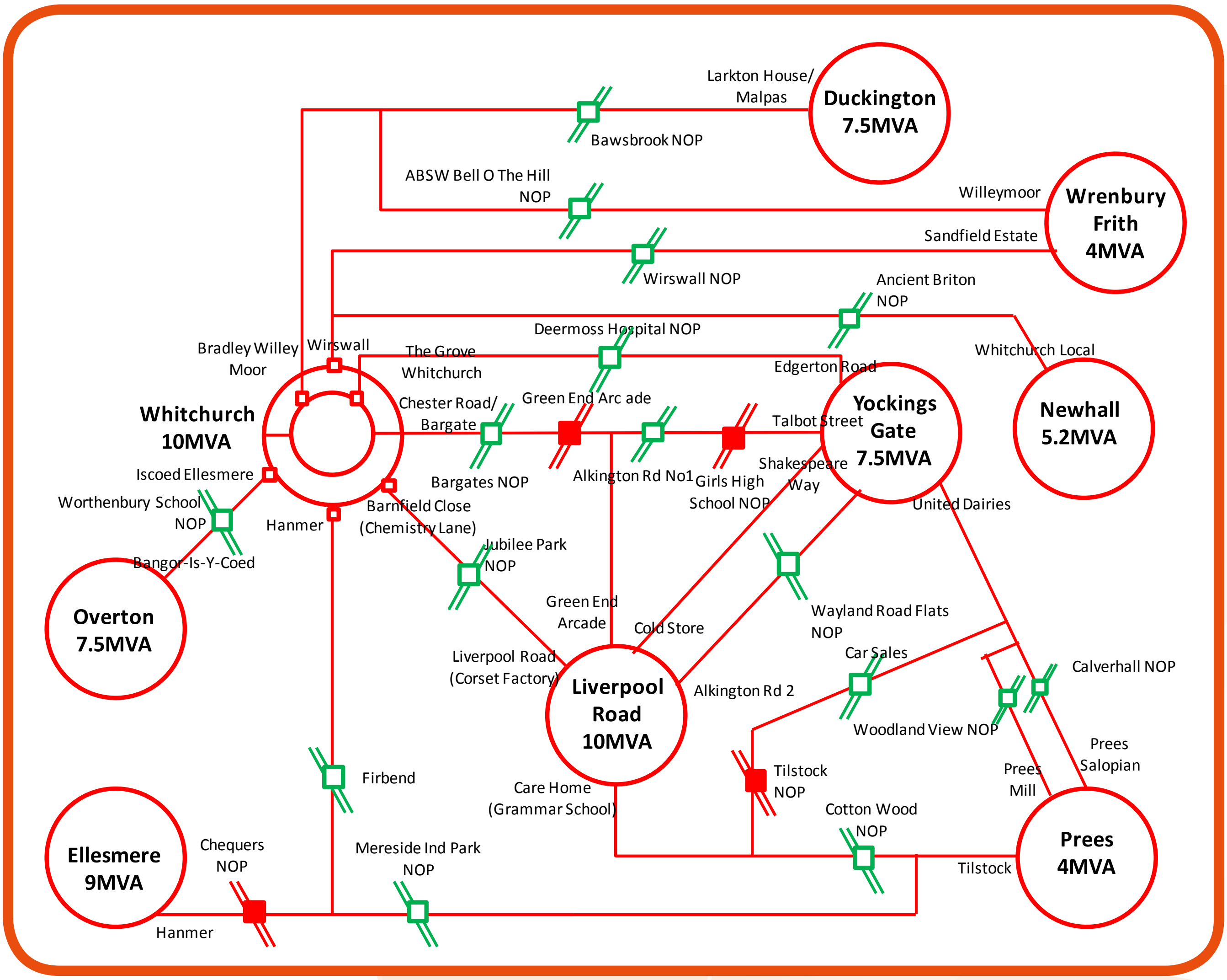
TNEI have undertaken a modelling exercise to evaluate the available thermal headroom at Whitchurch primary substation, and at adjacent primary substations. Data from the secondary substation monitoring installed as part of the project was used in the modelling together with primary substation data from the existing PI historian, meter data for HV customers, and NOJA data from manual downloads. Opportunities to increase the headroom at Whitchurch 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.

Initially it was anticipated that as part of 11kV reconfiguration, an automatic voltage regulator (AVR) would be required to overcome any out of statutory voltage condition on extended feeder(s) under load transfer conditions. Following the analysis work using the new monitoring data it was identified that the alternative network configurations did not create any requirement for voltage correction with a voltage regulator.

## 3.3 Flexible Network Control [continued]

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




| Loading condition | Yockings Gate | Liverpool Road | Whitchurch | Total |
|---|---|---|---|---|
| Current configuration (MVA) | 6.06 | 7.64 | 8.03 | 14.44 |
| Benchmark Headroom (%) | 19.2% | -1.9% | 19.7% | 27.8% |
| Proposed new configuration (MVA) | 5.75 | 6.4 | 6.41 | 12.81 |
| New Headroom (%) | 23.2% | 14.7% | 35.9% | 36.0% |
| Improvement (MVA) | 0.31 | 1.24 | 1.62 | 1.63 |
| Improvement (%) | 4% | 16% | 20% | 11% |

## 3.3 Flexible Network Control [continued]

It was noted that while the circuit could be reconfigured for capacity gain in the Whitchurch sites, that we had to be mindful of the customer numbers and feeder lengths that were being re-fed from alternative substations. This is due to the feeders have been optimised to minimise the numbers of customer Interruptions (CI's) and customer minutes lost (CML's) under circuit fault situations and of the effects moving the normal open points using the automation scheme. The CI's & CML's were minimised as much as possible by the selection of the new open/automation points and recognition was made of the support that the extra tele-controllable switching point could make in fault outage restoration activities.

The reconfigurations had the potential to create a headroom uplift at Whitchurch primary of up to 15.9%. However one of the changes of this network configuration would have been to move the normal split point from ABSW Bell O the Hill to the Whitchurch switchboard circuit breaker. This running arrangement would have been an unacceptable risk of additional CI/CMLs for an overhead line fault on that circuit from Wrenbury with all the customer on it, therefore this feeding arrangement would only be applied under specific circumstances of N-1 of the Whitchurch area primaries and a peak loading condition. By omitting this load transfer from the overall capacity headroom gain, the improvement percentage figure reduces to 11%.

Also until the additional capacity is actually required within the Whitchurch substation sites, some of the normal open points will remain configured for CI/CML optimised performance.

## 3.4 Voltage Optimisation

Through the findings of this project and other related projects we have concluded that voltage reduction does not provide significant benefits to the network in terms of load reduction and can introduce issues when applying flexible network control. Therefore this intervention was not deployed as part of the solution for Whitchurch.

## 3.5 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 in to 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.

## 3.5 Energy Efficiency [continued]

By working through the phases above in the Whitchurch area attention became focussed on a small number of significant energy users in the industrial, commercial and local authority sectors.

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

The energy efficiency measures in the Whitchurch area identified to the customers were not suitable for contribution from the project given their size and cost against the budget available. The nature of the energy efficiency measures identified whilst benefitting the user in kWh reduction did not provide any considerable capacity gain to the network. However the customers that engaged with BRE on the surveys and energy use analysis did take from the engagement the understanding of how to improve their energy use and ideas that they could incorporate into their business plans for future years.

# 4 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.

| Intervention | Target | Achieved |
|---|---|---|
| Dynamic Rating | 7% | 10% |
| Flexible Network Control | 9% | 11% |
| Energy Efficiency & | 2% | — |
| Voltage Optimisation | 2% | — |
| Total | 20% | 21% |

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 Whitchurch 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 overall 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 has limited benefit as a useful technique for reducing network loading.

# 5 Business Case

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. This would take approximately 2 years to complete and would be around £3.1m.

## 5.1 Trial Project Costs and Rollout (Method) Costs

The following 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 | 427 | 306 |
| Transformer dynamic rating | 162 | 45 |
| Flexible network control | 273 | 188 |
| Voltage regulator | Not required | — |
| Energy Efficiency | 84 | 73 |
| Other project activities | 509 | — |
| **Total** | **1455** | **612** |

## 5.2 Net benefits

In comparison to the original submission business case; *at Whitchurch, the lowest cost traditional methods would involve reinforcement works and the construction of a greenfield 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. This would take approximately 2 years to complete and would be budgeted at £3.1m.*

Our figures indicate a future roll-out cost for a similar site using these interventions would be approximately £612k. Compared to the Base Case costs of £3.1M, this represents a net benefit of £2.5M.

It should be recognised that this solution is only providing an incremental solution for a demand increase of up to 20% and additional substation reinforcement may still be required at some point in the future. However should future load not increase beyond the 20% additional headroom provided by these techniques or overall demand decrease due to energy efficiency, then these approaches will have saved the significant costs of the traditional reinforcement works.

## 5.3 Supporting information documents

This business case study for the Whitchurch network area is supported by a series of more detailed reports, as identified below:

1. Dynamic Thermal rating Methodology and Learning report
2. Cost benefit analysis – Dynamic Thermal Rating (Primary Transformers)
3. Flexible Network Control Methodology and Learning report
4. Cost benefit analysis – Flexible Network Control
5. Whitchurch Load Automation Feasibility Assessment
6. Detailed Network Monitoring Methodology and Learning report