Boston Spa Energy Efficiency Trial

Literature Review

February 2021

Contents

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0.1 Document history

Version	Status	Issue Date	Authors
1	First Issue	09 February 2021	Francis Shillitoe, Mark Callum

0.2 Document review

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Mark Callum	Technical Lead	9 February 2021
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0.3 Document sign-off

Name	Responsibility	Date
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1 Introduction

Boston Spa Energy Efficiency Trial (BEET) will use smart meter data in (near) real-time to dynamically optimise the HV and LV network voltage. It is anticipated that this will decrease energy consumption for customers, and will therefore save customers money and reduce carbon emissions. The savings for customers from energy efficiency are expected to far outweigh any capital and operational expenditure, given that the majority of the investment required is already covered by the ED1 smart grid enablers programme and the national smart meter rollout. The project will also explore interoperability issues where the DNO might, in parallel, be offering services to the transmission system at the "other end" of the network such as Customer Load Active System Services (CLASS) and how voltage optimisation of the power network can be part of a whole energy system approach including supporting whole-system energy optimisation.

This innovation project is split into three phases (at a high level):

Phase 1 (voltage optimisation studies) concluded in December 2020, and has provided the justification for commencing the phase 2 dynamic voltage optimisation trial. When a static target voltage is employed, as is current practice, it is necessary to keep the network voltage high, in order to cater for the large voltage drops that can occur under peak demand and abnormal network (N-1) operating conditions. The BEET-algorithm can maintain the primary target voltage at a high value under these conditions but reduce it for the majority of the time when demand is not at its peak and the system is running in the intact state.

Phase 2 (dynamic voltage optimisation trial) will utilise a platform developed for this project (the BEET-Box), to analyse smart meter voltage data in the trial network to optimise the voltage every half hour (enabled by the smart grid enablers investment). This phase will run from May 2021 to May 2023.

Phase 3 (exploration of DSO Services) will trial DSO service provision, such as those classified as Customer Load Active System Services (CLASS). The purpose of this phase is to not just trial the technical feasibility of DSO services, but to do so in the context of the voltage optimisation service and conflict management, to determine the optimal approach that should be taken within the industry. This phase will run in parallel with the last four months of Phase 2, and continue for a further four months beyond Phase 2

This Literature Review has been conducted during the Phase 1 period and looks primarily at Conservation Voltage Reduction (CVR) trials and technologies. The Literature Review focuses on previous innovation projects which have explored similar themes and pulls out the main learnings and outcomes.

A long list of learning materials was pulled together, which is shown in chapter 2, and which were briefly assessed, and those which were thought to be the most relevant went into a short list, chapter 3, which were examined more thoroughly.

2 Long List

- **SPEN – Flexible Network for a Low Carbon Future:** This project investigated the passive application of voltage optimisation (at the primary substation) as a method of reducing peak demand and to facilitate higher volumes of embedded generation. The conclusion of this report at a high level confirmed a 1:1 relationship between voltage and demand/consumption, and ultimately supported NPg's 11kV primary target voltage reduction programme, and the customer benefits of the programme.
- **National Grid – DNO Investigation into Voltage Interaction and Dependency Expectation (DIVIDE):** This innovation project sought to determine the relationship between voltage reduction and reduction in power demand from the context of demand control via voltage control when required as part of the ESO's network balancing tool-kit as defined in Grid Code Operational Code 6 (OC6). The project explores the concept of 'ZIP' coefficients to describe the three main load types; constant impedance (Z), constant current (I), constant power (P).
- **EATL - Strategic Technology Programme 5 (STP5):** Numerous devices/appliances were tested by use of a 'variac' and energy meters, that could be used for a bottom-up analysis of the voltage-demand relationships on our network.
- **SSEPD - LV Network Modelling and Analysis:** This project looked at creating an LV modelling environment to integrate the half hourly smart metering data with LV power analysis tools. It also conducted various load flow scenarios of LCTs within the new LV modelling environment. In conclusion the project proved the concept that the integration between existing data input sources and new modelling tools is functionally possible at least at LV for a small representative network.
- **ENWL - LV Network Modelling:** This project looked at understanding the LV network performance , using LV monitoring data to develop detailed LV models to understand actual system capacity & potential system constraint solutions, and to improve load estimates & forecasting tools across HV/LV. In conclusion the project created a methodology to improve the LV system modelling based on substation monitoring data.
- **WPD – LV Network Templates:** This project was setup to produce LV network templates that were representative of UK networks, that could then be used across the industry. Whilst the project did not result in templates that were adopted within the industry, the key learning from the project was the relationship between voltage and consumption. This cause and effect relationship between voltage and consumption was analysed and confirmed by statisticians from Bath University. The project outputs triggered the initiation of the ENA Working Group setup to review if the statutory voltage limits should be relaxed to a low limit of 207 V.
- **WPD - Voltage Reduction Analysis:** This project followed on from LV Network Templates. Bath University were commissioned to analyse the effects of substation primary target voltages being lowered from 11.4kV to 11.3kV. This showed a reduction in real power demand (kW) and consumption (kWh), reduction in reactive power demand in the network, and a reduction in maximum demand. It showed that the overall number of voltage excursions outside ESQCR limits reduced, with the number of excursions outside the upper statutory limit significantly decreasing with a conversely smaller increase in the number of excursions below the lower statutory limit.
- **ENWL – Customer Load Active System Services (CLASS):** This project explored the use of voltage reduction (at HV and LV) as a way of providing balancing services (reactive power, frequency response and fast reserve) to the ESO. Primary Firm Frequency Response (FFR) was provided by off-

loading a primary transformer within 10 seconds, whilst Secondary FFR was provided by reducing the primary target voltage by 5%. Fast Reserve used the same method as Secondary FFR. A significant volume of customer engagement was undertaken to conclude that customers did not notice a difference when the voltage was lowered. The project also reviewed the use of primary transformer tap-stager as a method of providing reactive power services.

- **ENWL – Smart Street:** This project is superficially similar to 'BEET' in that alongside the application of voltage/network management devices (voltage monitors, distribution OLTC transformers, LV capacitors and HV capacitors used for voltage management; controllable LV circuit breakers and link-Box switches used for LV automation, i.e. switching); the voltage was reduced to provide the benefit of reduced demand. A significant volume of customer engagement was undertaken to conclude that customers did not notice a difference when the voltage was lowered. A key point is, that unlike the BEET proposals which utilises minimal investment alongside smart meters to provide voltage reduction benefits; Smart Street was dependent on significant network investments to provide customer benefit. A comparative assessment between BEET and Smart Street shall be reviewed as part of the Closedown Report for BEET.
- **Voltage Optimisation (Powerstar):** Powerstar are one of the UK's leading voltage optimisation companies, who manufacture and supply their own voltage optimisers (i.e. transformers) for industrial, commercial and domestic premises. There are multiple case studies and benefit calculations on Powestar's website.
- **NPg Smart Network Design Methodologies (SNDM):** This project concluded in March 2020 and there are several relevant work-streams; smart meter data analytics, novel analysis techniques at LV, and multi-voltage level modelling. A key conclusion was the importance of modelling the LV and HV networks together, rather than independently. Prior to commencing Phase 1 of BEET we planned to model the BEET trial area using combined 11kV and LV models. However, we were unable to do this due to data quality problems in the LV networks models in eAM Spatial.
- **NPg Autodesign:** The core output of this project (the Autodesign tool, and associated LV budget estimation tool) was released in January 2020. Autodesign represents a step change in LV design capability; with network information automatically uploaded from eAM Spatial records, and application of loading parameters (using the method detailed in EREC ACE 49 rather than the ADMD method), to provide voltage drop information for the entire network. Prior to commencing Phase 1 of BEET we planned to use the LV voltage drop calculations produced as an output from Autodesign however, we were unable to do this due to the LV network data problems in eAM Spatial. Whilst the current iteration of Autodesign can assist in producing budget estimates for new LV customers wanting to connect to the network, there were significant gaps preventing the production of comprehensive sets of LV voltage drop data.
- **NPg Customer-Led Network Revolution:** The CLNR L217 report provided updated domestic ADMD values to better reflect today's customer energy usage and behaviour from the existing values which were developed from ACE 49 and 105 in the 1980s. This report also details the newly developed ADMD values for low carbon technologies like solar PV, heat pumps and electric vehicles. These learnings have been fed into the update of EREC P5 – Methods to determine demand characteristics for LV underground networks which are designed for new housing developments. CLNR also drove a change in voltage policy whereby HV and LV voltage drops would be considered together.

- **NPg Smart Data** (Sheffield PhD): This project looked to see how the smart metering data potentially with substation monitoring can assist in design and management of LV networks. It examined the issues of missing data, accuracy of data and how these affect aggregation.

3 Short List

This section provides a review of literature associated with:

- ENW Customer Load Active System Services (CLASS);
- ENW Smart Street;
- SPEN – Flexible Networks for a Low Carbon Future;
- WPD – Voltage Reduction Analysis;
- Powerstar.

3.1 Electricity North West – Customer Load Active System Services (CLASS)

Electricity North West – Customer Load Active System Services (CLASS)	
Background	• An LCN Fund Tier 2 project which ran from 2013 to 2015 with a budget of £8.1m. • The project was initiated due to the increasing power flows associated with decarbonisation (and the corresponding uptake of electric vehicles and heat pumps) reducing the free capacity at substations. It was noted that the need to reinforce may eventually be offset by generation, storage and/or flexibility. Before this more flexible consumption arises, it was identified that that DNOs should find other techniques (in the short term) to better manage peak demand with existing assets (i.e. without the need for expensive reinforcement). Further to this peak demand problem, the changing generation mix (with decreasing system inertia) will erode the system (frequency) stability. Subsequently, it was identified that there will be a need for more system balancing, and thus DNOs should seek to offer these services, which are critical as DNOs transition to DSOs. • CLASS seeks to demonstrate how it is possible to unlock network capacity deferring the need for reinforcement, and also explore the opportunity of providing alternative frequency and reactive power services to the market by using innovative techniques at substations. • The core concept of the project hinges on the concept of conservation voltage reduction (CVR) for real power / frequency services, and the use of tap staggering of transformers for reactive power / voltage services.
Objectives	The objectives of the CLASS Project were to test the following hypotheses: 1. The CLASS Method creates a demand response and reactive absorption capability through the application of innovative voltage regulation techniques 2. Customers within the CLASS trial areas will not see/observe/notice an impact on their power quality when these innovative techniques are applied 3. The CLASS Method will show that a small change in voltage can deliver a very meaningful demand response, thereby engaging all customers in demand response 4. The CLASS Method will defer network reinforcement and save carbon, by the application of demand decrement at the time of system peak 5. The CLASS Method uses existing assets with no detriment to their asset health.
Methodology	The project consisted of 4 trials carried out over a 12-month period across 60 primary substations. Note that significant effort was made to ensure that the 60 primaries in the trial were representative of the wider ENW network. **<u>Trial 1: investigate the voltage/demand relationship</u>** for normal (i.e. several percent) increments of system voltage at primary substations across the year. • At primary substations, the BAU transducers were used for MW/Mvar/V/I/f data (generally accuracy to +/- 1 volt/amp), however the use of a high data rate (generally 1 second) RS485 connection, channelled via a Nortec (3G/4G) Envoy provided data for use by University of Manchester (available on iHost). This was far better than the typical 30 minute averages and/or 5-10% dead-band applied for the existing SCADA system.

	- The load modelling of 15 primaries, (out of a total of 60 in the trial) were conducted, crossing different profile classes (i.e. different percentages of the 8 'Elexon' profile classes). Rather than simply relying on the typical 2 to 20 tap changes that happen each day, both parallel primary transformers were (forced) tapped by one tap position which changed the voltage by approximately 1.5%. The new tap position was held for 15 minutes to capture any recovery phase of the demand. This forcing of tap position was important as during the relatively flat low demand overnight, and flat higher demand during the day, the transformers would not typically tap. To enable production of voltage/demand matrices for the full day and year, this data is essential. - Half-hourly demand matrices (for each substation) were developed by University of Manchester, which can then be used for future frequency response services (to determine the amount of response available for a given settlement period). This voltage/demand matrix was a key output that was then used as an enabler for Trial 3. **Trial 2**: **investigate demand response for peak load reduction** in order to prevent or defer network reinforcement. - Voltage reductions of 3% (demand reduction 'DR' half) and 5% (DR full) were applied at peak load times. The signal to invoke the service was sent to the ASC (see Trial 3 for further information on the ASC). **Trial 3: investigate demand response during frequency events** to support the ESO. - This was done by either i) opening one of a pair of primary Tx (primary frequency response, i.e. fast), or ii) dropping the tap positions of the primary transformers (secondary frequency response, i.e. slow). - A device referred to as the Autonomous Substation Controller (ASC), was a core building block to enable this trial. The ASC functions developed in this Project were: - Local coordination and prioritisation functions; - Switch management; - Reactive power management; - Local voltage management; and - Frequency management. *Note: The ASC is not required for BEET, as NPg is installing modern RTUs, which can be configured with programmable logic.* - The CLASS system overview is shown in the figure below, which clearly shows that the ASC acted as an interface between the RTU, the AVC (which were of a modern type during the trial), and the circuit breaker tripping scheme (for primary frequency response).

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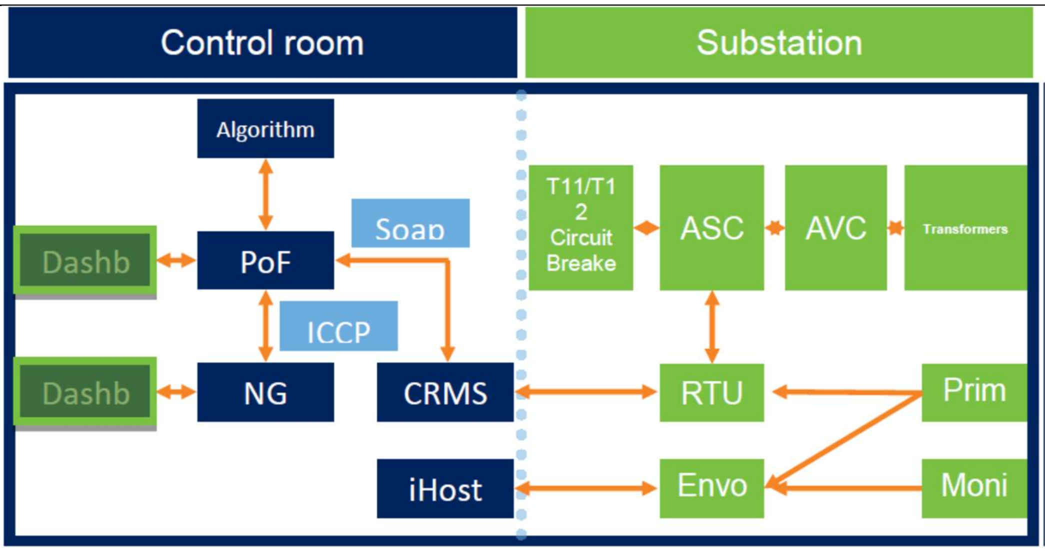

Figure 1. CLASS system overview (*source: Fig 3.6 of CLASS Closedown*).

The CLASS dashboard (the software controller for demand response, was developed in the 'Power on Fusion' (PoF), which also utilised the predictive yields based on voltage changes and measured loads could be produced for each of the CLASS functions, using a look-up table of load parameters (produced during Trial 1). Note that the ICCP link (for inter-control room communication; i.e. between the ESO and ENW) is not needed for BEET and is not reviewed further
The CLASS frequency response services are split into two as follows:

Primary Frequency Response: designed to operate within 0.5 seconds and sustain for 30 minutes, uses the principle that opening one of a pair of (in-service) primary transformers will result in the remaining in service transformer load doubling, and therefore (the voltage drop across the transformer increase), resulting in the voltage on the HV bar reducing. This is only suitable for double-transformer primaries, and was trialled at 10 primaries by CLASS. The operation of a transformer trip was triggered when frequency fell below 49.7 Hz. The ASC also 1) calculates the likely Vdrop, and if >12% it blocks operation, and 2) confirms both transformers are in service before tripping.
Secondary Frequency response: designed to operate within 30 seconds, and sustain for 30 minutes, uses the principle that reducing the target voltage by 5%, will result in the AVC instructing the tap changers to adjust the tap positions of the transformers, and thus reduce the HV bar voltage. CLASS instructed the service for frequency below 49.8 Hz.
Note: the ESO requirement for primary and secondary frequency response start/sustain times (valid January 2021) are 10sec/20sec and 30sec/30min respectively. It is also noted that NGESO regularly review the services required and the technical requirements for these services.

<u>Trial 4: investigate the viability of tap-staggering</u> technique for provision of reactive power services to the ESO and DNO. Note: this is not discussed further in this literature review as it is not directly relevant for BEET.

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<td>Learnings and</td>
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The results of the CLASS trials have produced a mathematical quantification of

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outcomes relevant to BEET	the relationship between voltage and demand which supports the hypothesis. • The trials have shown that DNOs could provide ancillary services for demand reduction during frequency events and reactive power absorption to reduce high voltage on the NG transmission system during minimum load periods. • The CLASS methodology will cause increased tap change switching and shock loading of transformers when providing frequency response. The studies carried out by the University of Manchester and University of Liverpool have indicated a negligible impact on asset health. • Robust customer research has demonstrated that the use of voltage reduction techniques does not cause any detriment to customers' perception of quality of supply (95% confidence, based on statistical analysis). • The carbon impact of the deferment of traditional network reinforcement has been identified through modelling, along with the carbon benefits of the CLASS service to the frequency and reactive power markets. • The results have shown that a 1% voltage reduction at a primary substation produces a seasonal average real power reduction of between 1.3% and 1.36% • The speed of response for the CLASS stage 2 frequency function is dependent on the type of transformer tap changer, with times of operation between 20 seconds and two minutes (largely dependent on age and type of tap changer). • A significant amount of effort was applied to gaining customer input into how to best communicate with the wider customer base in the CLASS trial area. A customer leaflet was produced, and should be used as the basis for any communications undertaken as part of BEET. • Indoor Super TAPP/Micro TAPP (modern) AVC relays – were considered most appropriate. All NPg sites will be using modern equivalent AVCs (including the SuperTAPP SG). • To make sure that customers did not experience any voltages outside of statutory limits the normal primary monitoring equipment was replaced by more accurate measurement equipment and extra monitoring was fitted on the LV and HV systems. This is (generally) not considered necessary for BEET, as instead, smart meter voltage accuracy is to be confirmed, and an allowance made for customers who could be subjected to the lowest voltages, being accounted for in the algorithm where smart meters are not located. **The load modelling and voltage/demand matrix is summarised in further detail below, as this is particularly relevant to BEET.** • A static load model was found to be the most appropriate load model for CLASS (as opposed to a dynamic model) measurement data as it captures the prolonged sustained response of the load following a voltage disturbance which was of interest in the CLASS Project. These load models analysed the relationship of both real power (P) and reactive power (Q), defined by the formulae below: $P = P_0\left(\frac{V}{V_0}\right)^{K_p}, \; Q = Q_0\left(\frac{V}{V_0}\right)^{K_q}$ • Explained in simple terms; the power exponents (Kp and Kq for real and reactive power, respectively), refer to the amount of change in the power quantity for every 1% of voltage change. For example, a Kp value of +1.2 would represent that for every 1% increase in voltage, the real power demand would

	increase by 1.2%. These factors can also be referred to as the CVR factors.

- From the analysis undertaken, the load model parameter values were summarised as follows
    - For domestic substations, the average value of real power exponent for a weekday is about 1.3 and reactive power exponent is about 6.06
    - For mainly industrial and commercial substations, the average value of real power exponent for a weekday is close to 1.48 and reactive power exponent is close to 5.58
    - For mixed-type substations, average value of real power exponent for a weekday is about 1.22, and reactive power exponent is about 5.9.
- The key takeaway for BEET being that a real power exponent of at least 1.2 can be assumed, and a reactive power exponent of 5.5 can be assumed. This will be analysed as part of BEET, via i) the values calculated with the SuperTAPP following tap changer operation, and ii) through the statistical analysis of demand data.
- For further information on the seasonal and daily power exponent values, the figure below are an invaluable reference.

Kp	Mainly domestic			Mainly non-domestic			Mixed			All subs
	Min	Max	AV	Min	Max	AV	Min	Max	AV	AV
Winter	0.87	1.93	1.33	0.86	1.85	1.47	0.7	1.91	1.23	1.34
Spring	0.83	1.86	1.32	1.02	1.80	1.39	0.8	1.68	1.20	1.3
Summer	0.72	2.11	1.25	1.02	1.97	1.52	0.7	1.58	1.20	1.32
Autumn	0.67	1.91	1.31	0.95	1.98	1.53	0.71	1.8	1.23	1.36

Figure 2. Kp, Real power exponent values (source: figure 4.1 of CLASS Closedown)

Kq	Mainly domestic			Mainly non-domestic			Mixed			All subs
	Min	Max	AV	Min	Max	AV	Min	Max	AV	AV
Winter	3.98	7.98	5.96	3.79	6.86	5.62	4.36	6.93	5.92	5.83
Spring	4.58	8.05	6.14	4.3	6.75	5.56	3.82	7.52	5.82	5.84
Summer	3.25	7.62	5.98	3.96	7.26	5.65	4.52	6.95	5.75	5.79
Autumn	4.41	8.06	6.16	2.41	6.79	5.49	4.26	7.58	6.1	5.92

Figure 3. Kq, Reactive power exponent values (source: figure 4.2 of CLASS Closedown)

- ENW identified that if the CLASS approach is adopted across the whole of GB there is potential to unlock demand response of:
    - 700MW (summer minimum) to 2GW (winter maximum) for a 3% voltage reduction
    - 1.2GW (summer minimum) to 3.3GW (winter maximum) for a 5% voltage reduction.

Conclusions

- The relationship between voltage and real power was confirmed during CLASS. A simple assumption for BEET is that the CVR factor for real power is c1.2, whilst for reactive power is c5.5. The positive CVR factor for real power is crucial to BEET, which then provides network losses benefit as it is above 1; in addition to the reactive power CVR factor of c5.5 reducing the network losses.
- There was no statistically significant impact on the customers' perceived

	quality of supply. Note that the impact of CLASS was not just the prolonged voltage reduction, but also the rapid voltage step change associated with providing frequency response. Given that neither of these effects were perceived to result in detriment to the customer, it is reasonable to assume that the application of BEET will not cause any detriment. Ahead of application of voltage optimisation, NPG customer services shall be appraised of the trial, and any complaints made during the course of the trial shall be captured by the BEET project team.
	• RIIO ED1 smart grid enablers will result in new AVCs, RTUs and primary comms being available at all primary substations (which are also a pre-requisite for BEET). These smart grid enablers provide the capability to provide CLASS services, with the notable exceptions being (particularly for an future roll-out):
	    o Power on Fusion (PoF) dashboard for implementing CLASS services.
	    o Voltage/demand matrices are required to quantify the level of response available. To implement CLASS, these matrices will be required for each site, and should feed into the balancing services bids, and the real-time dashboard (NMS) for implementing CLASS. This is worth reviewing as part of Phase 3 of BEET.
	    o Enhanced monitoring data will be required to confirm the response at a more granular level than achievable b existing SCADA monitoring.
	    o Communications with ESO; either email or API. It is noted that an ICCP link was used by ENW during CLASS, however NGESO are reducing barriers to entry, and it is likely that more rudimentary communications will suffice.
	• The application of CLASS utilised the same principles as BEET. It is therefore critical to understand the interaction between offering year-round CVR benefit (as proposed by BEET) and sporadic demand reduction for the purpose of deferring network investment and providing frequency response (as proven by CLASS). This is the focus of phase 3 of BEET.

3.2 Electricity North West – Smart Street

Electricity North West – Smart Street	
Background	An LCN Fund Tier 2 project which ran from Jan 2014 to Dec 2017 with a budget of £11.5m. Smart Street was trialled at six primary substations and 38 associated distribution substations serving 67,000 customers in Manchester, Wigan, Wigton and Egremont. Smart Street used real time optimisation software to simultaneously manage HV and low voltage (LV) network assets to respond to customers' changing power demand. Voltage management on HV networks was used to reduce network losses while conservation voltage reduction (CVR) on the LV networks reduced energy demand. Capacitor banks on the HV networks were used to help manage network losses by adjusting the network's power factor. On the LV networks, a mix of capacitor banks and controlled meshing of circuits (using LV switching devices in place of fuses and links) were integrated to flatten the voltage profile and improve energy efficiency. The meshing of LV networks was also released additional network capacity.
Objectives	• Demonstrate reduced energy consumption by Conservation Voltage Reduction. • Demonstrate by optimising the network configuration and by controlling the network voltage distribution that network losses can be reduced, and that customers can benefit from energy savings. • Demonstrate that customers do not perceive changes in their electricity supply and that there will be no adverse effects on customers' internal installations or appliances. • Provide a full demonstration of a fully centralised LV network management and automation system. • To demonstrate that Smart Street techniques are faster to deploy than traditional network reinforcement.
Methodology	• The project was split into the following workstreams: **Research workstream** • Carry out HV and LV voltage and configuration optimisation studies. • Study the design and operation of interconnected LV networks. • Carry out a cost benefit analysis. • Carry out a carbon Impact assessment. • Determine the impact on customers' electrical installations. • Produce an optimisation implementation study. **Customer Engagement** • Convening an Engaged Customer Panel to target awareness of the trial in the community. • Elicit customer feedback on any perceived effects on the electricity supply during the trial. • Training of ENW's customer contact centre and directing any potential customer enquires/complaints to the Smart Street team. **Technology** • Deployment of LV automation products (controllable circuit breakers to replace fuses at secondary substations, and controller switches to replace links in underground link boxes on the LV network). These were connected to

<table>
<tr><td></td><td>the central control system.
Deployment of LV capacitors.
Deployment of new distribution (secondary) substation transformers with on-load tap changers.
Real time control via a portfolio of LV network solutions.
Deployment of a centralised control system (Siemens Spectrum Power 5, SP5) using off the shelf components.
Synchronisation of SP5 with existing customer room management system.
Deployment of end point monitors on radial LV circuits.
Deployment of RTUs and implementation of new and existing protocols to link systems together.
Trials
LV voltage control using secondary OLTC, LV capacitors at substations, and LV capacitors on feeders, and combinations of these.
Compare benefits of LV circuits run radial and meshed.
Voltage control at primary substation, capacitors on HV circuits and combinations of the two.
Compare benefits of HV circuits run radial and meshed.
Losses reduction and energy reduction using SP5 to perform control actions to optimise on user-defined functions such as: minimise voltage violations, minimise power losses, minimise customer active power consumption etc.
Control system trials were carried out in open-loop mode prior to closed loop mode. In open loop mode all settings/switching orders calculated are not automatically executed but available for review in the user interface.
Learning and Dissemination
Dedicated website and social media channels.
Publicly available project reports.
Advertorials in the E&T magazine.
Internal company dissemination with monthly team briefing packs and company newsletters.
Webinars and IET TV events.
Knowledge sharing events and participation at LCNI.
Raw monitoring data available to public on Smart Street website.
Ofgem project progress reports.</td></tr>
<tr><td>Learnings and outcomes applicable to BEET</td><td>Economics
The benefits of minimising LV energy consumption and HV loss reduction were quantified. A reduction in energy consumption of up to 10% could be expected on LV networks coupled with a reduction in HV losses of up to 15%.
Reduction in energy consumption provides an undoubted benefit for customers, but can affect the businesses of DNOs and other stakeholders who rely on energy related charges.
The Smart Street approach can lead to annual economic savings of up to £70 per customer.
Voltage control and CVR
The use of OLTCs can increase the firm capacity of distribution networks by</td></tr>
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	alleviating voltage issues. • Smart Street reduced the primary substation voltage by 1 – 4 % using the primary OLTC, and a further voltage reduction was provided by the LV de-energised tap changers (DETCs) and on-load tap changers, giving a total voltage reduction on the customer side of 5 – 8%. This led to an energy reduction of 5 – 8%, resulting in an average CVR factor of approximately 1. **Quality of Supply** • Following customer engagement there was no reports of any power quality or voltage issues relating to the implementation of the Smart Street techniques. • There would be no adverse impacts on customer installations. **Network Studies** • For network studies, models of HV and LV networks were developed in Open DSS, which can solve load flows in unbalanced networks, can represent changes over time and can model embedded generation. Domestic load profiles were taken from the CREST tool developed by Loughborough University. Non-domestic customer profiles were taken from Elexon data. Solar PV and EV charging were modelled stochastically. **Operation** • The BEET-Box should be trialled in an open loop mode first to reduce the risk of unintended control actions being actioned, prior to being run in closed loop mode. • The BEET-Box will initially be set to run in half-hour cycles to align with frequency of smart meter HH measurements. This also aligns to cycle time of Smart Street control system. • Smart Street ran combinations of trials scheduled over an eight-week period, which also incorporated 'trial-off' periods to provide baseline data. This is not currently being considered by BEET but could prove useful as the project will not have baseline data from the halted static voltage optimisation trial. • There were problems with the SP5 software sending erroneous set points, which required changes to base parameters during the trial. The BEET-Box will need active monitoring and it needs to be possible to carry out parameter changes or firmware upgrades during the trial. These need recording, and trial results need to take account of changes to the BEET-Box. • We need to brief our customer contact centre so that they are aware of the trial and be able to handle any customer enquires/complaints within the trial area appropriately. **Customer Engagement** • Customers tend to focus primarily on the personal risks and financial benefits to themselves. BEET needs to focus on these elements when targeting customers to take up smart meters. • The most effective way of communicating with customers on trial circuits is through leaflets. The Smart Street Engaged Customer Panel helped to provide essential feedback on the leaflets which included, who ENW were, what Smart Street is, what is happening and how it will affect the customer.
Conclusions	The BEET method will be different to Smart Street because it will use voltage measurements from smart meters as the input method to the control algorithm. BEET

	will not require investment in new primary equipment on the HV or LV networks, which formed the greatest percentage of the Smart Street project budget. For Smart Street to be scaled up would require a large financial investment in new primary equipment on the networks where it would be deployed, whereas BEET would only require scaling of IT and data handling systems, which would be significantly lower cost. Smart Street has proven the CVR hypotheses and has demonstrated that voltage reduction can be implemented without effecting customers' quality of supply. This provides that evidence that voltages can be lowered and CVR implemented on distribution networks, and therefore the BEET project should focus on the technology implementation.

3.3 Scottish Power Electricity Networks – Flexible Networks for a Low Carbon Future

<table>
<tr><th colspan="2">Scottish Power Electricity Networks – Flexible Networks for a Low Carbon Future</th></tr>
<tr><td>Background</td><td>An LCN Fund Tier 2 project which ran from Jan 2012 to Dec 2014 with a budget of £6,362m. Its aims were to increase capacity in a faster way than traditional methods to cater for a transition to a low carbon economy with increasing dependence on electricity for heating and transport.</td></tr>
<tr><td>Objectives</td><td>• To provide enhanced monitoring and analysis to determine existing network performance.
• To deploy novel technology to improve network operation, including flexible control and dynamic rating.</td></tr>
<tr><td>Methodology</td><td>• Techniques trialled on three networks: st Andrews, Whitchurch and Wrexham (Ruabon)
• Enhanced network monitoring
• Enhanced primary transformer thermal rating
• 33kV Overheadline RTTR system
• Flexible network control
• Integration of voltage regulators
• Energy efficiency
• Voltage optimisation</td></tr>
<tr><td>Learnings and outcomes relevant to BEET</td><td>These learnings and outcomes focus primarily on the voltage optimisation part of the project:
• In the absence of local knowledge, a 1% demand reduction per 1% voltage reduction is a reasonable estimate. This is broadly consistent with the learning from the National Grid (Operation Juniper) tests.
• Reductions in demand tend to be larger over the short term than the long term.
• The reduction achieved will depend on the types of load present, and therefore:
i) can vary between different parts of the distribution network,
ii) can vary between different seasons, and different times of day
iii) can vary according to the ambient temperature.
• Reactive power demand will generally be reduced by a larger factor than active power demand.
• A network voltage reduction does not seem to reduce the network current in the longer term, therefore network copper losses are not reduced by reducing the network nominal volts.
• The main barriers to permanent voltage reduction is that due to voltage dropping below statutory limits at the ends of feeders during high demand feeders, and maintain voltage above statutory limits for HV connected customers.
• The main constraint to embedded PV generation uptake is the increased voltage towards the end of the feeder rather than asset thermal limits. The voltage can exceed statutory limits when high PV uptake is present e.g. due to socio-economic driven clustering.
• A number of customers whose supply voltage is in the lower range of the voltage limits band are likely to be affected whenever changes are made to nominal network operating parameters – and this needs to be understood and managed.
• One of the key learning points was that network voltage control strategy should</td></tr>
</table>

	not simply be about setting a new lower voltage set point, and that additional flexibility (such as the need to apply seasonal settings) may be necessary. Furthermore, this leads to the requirement for additional network monitoring (including smart meters) as well as being able to remotely set voltage control relays at primary substations. This is the key objective of the BEET project. • SPEN should model network loads on a constant current basis. This is what we did during the Phase 1 BEET studies. • Evaluating the precise relationship between voltage reduction and demand reduction when experiments are carried out at a substation level can be difficult to ascertain to uncertainty in demand over time. Careful consideration needs to be given to the methodology used for any voltage reduction / demand reduction trials. • Secondary substation monitoring equipment was trialled. A data characterisation system was developed to identify emerging patterns of data issue resulting from faults in the monitor or data communication issues. Data transmission through mobile data networks is not 100% reliable and allowances need to be made to manage this. A data cleansing algorithm was developed to reduce the impact of outliers and zero values such as those due to load transfer characterisation on network loading behaviour. • The early engagement of control room staff was crucial for later buy-in of changes to network operations policy. Changes to operational practice are best implemented through policy rather than through additional network management tools.
Conclusions	The project provides ample evidence for the benefits of CVR and provides useful insight for carrying out trials at a substation level to determine the correlation between voltage reduction and demand reduction. A detailed technical note summarising voltage reduction experiments conducted in the UK and internationally available here: https://www.spenergynetworks.co.uk/userfiles/file/Technical_Note_on_Modelling_of_Load_45.pdf A detailed report on a voltage reduction experiment carried out at Ruabon primary substation in 2015 is available here: https://www.spenergynetworks.co.uk/userfiles/file/Analysis_of_2015_Voltage_Reduction_Experiment_at_Ruabon_46.pdf The voltage optimisation methodology and learning report is available here: https://www.spenergynetworks.co.uk/userfiles/file/Voltage_Optimisation_Methodology_and_Learning_Report.pdf

3.4 Voltage Reduction Analysis

Western Power Distribution – Voltage Reduction Analysis	
Background	This was a follow on project from WPD's Low Voltage Network Templates (LVNT) project. The VRA project looked to quantify the reaction of consumption, maximum demand and voltage profiles on real monitored networks following the reduction in AVC settings in South Wales from 11.4kV (±200V) to 11.3kV (±165V).
Objectives	To analyse the effect of voltage reduction on power, through the use of statistical techniques. Bath University were sub-contracted to carry out the analysis work.
Methodology	The analysis used data collected from LVNT monitoring equipment from 2014 and 2015. Substations monitored voltage, current, real power delivered and reactive power delivered at 10 minute averages. These covered a range of primary substations in South Wales. Feeder end monitors measured only voltage at the same time intervals. At 31/12/2015, measurements were available from 753 substations and 2810 voltage monitors, although the number of substations available and suitable for analysis varied for different months and years. Voltages at some substations couldn't be changed for practical reasons, and these ended up forming a control group. The demand analysis sought to determine whether there were any discernible changes in both average and maximum demands associated with the 11kV AVC settings changes. In order to ensure that demands were comparable between years, they were adjusted for weather. Sense checking was also performed on the data to ensure that large external factors, such as the loss/gain of customers on a substation did not affect results.
Learnings and outcomes relevant to BEET	• Methods for determining the efficacy of CVR taking into account factors such as weather were developed; • Interesting statistical methods are described for analysing CVR. These methods could be useful for BEET, and should be reviewed during Phase 2. • The shift in target voltage from 11.4kV to 11.3kV has a noticeable impact on voltage excursions, reducing the overall number. Whilst the number of under voltage excursions increase, the number of over voltages decreased by significantly more. The changes in number of over and under voltage ESQCR excursions needs to be a metric captured during the BEET trial. • The 0.88% voltage reduction in voltage settings resulted in an average consumption drop of 1.16%. There were network benefits to be found in the reduction of maximum demand (by 1.14%), helping to release network capacity. The effect of voltage reduction on demand is seasonal. There is also a significant reduction in reactive power consumed by networks. • The project concluded that the implementation of voltage reduction via 11kV AVC schemes is very broad brush, and will require DNOs to manually tap distribution transformers at network extremities (requiring outages), but these can be highly targeted and if well co-ordinated can lead to further reductions. • The AVC deadband was changed from ±200V to ±165V when the target voltages were changed from 11.4kV to 11.3kV. The BEET project studies needs to determine what deadbands should be used for different target voltages during the trial.
Conclusions	The benefits of CVR were proven. The number of voltage excursions outside ESQCR limits should be measured during the BEET trial to see if BEET reduces thus number compared to the use of a static target voltage. The VRA report and full Bath University study report will need to be thoroughly reviewed prior to developing a statistical method for quantifying the effectiveness of the BEET trial to ensure the project builds on the learning.

3.5 Powerstar

Powerstar are one of the UK's leading voltage optimisation companies, who manufacture and supply their own voltage optimisers (i.e. transformers) for industrial, commercial and domestic premises. There are over 100 case studies on their website explaining how customers have saved energy by way of voltage reduction after installation of a voltage optimiser. Some of these case studies provide specific data regarding the voltage reduction implemented and the resultant energy saving. The table below has been derived from these case studies. The CVR factor can be seen to be between 0.4 and 2.6 with a mean of 1.5. These figures should be treated as on the optimistic side for the influence of voltage reduction alone, as in some cases the Powerstar equipment would also be reducing harmonics, evening phase unbalance and improving the power factor which would also contribute to excessive energy consumption. It should also be noted that the case studies are not in domestic settings. CVR factors for domestic dwellings could differ due to differing load types. However, the principle of CVR is demonstrated here.

Another point of interest is that in the case studies the equipment is set with a voltage set point of about 220V (4% below the 230V nominal).

Case Study	Voltage Reduction [%]	Annual Energy Consumption Saving [%]	CVR factor [%]
Ammann Group, textile manufacturer	6.8	17.7	2.6
Atlas Insurance, Malta	8.7	13.4	1.5
Flexiform Business Furniture, production line	7.8	11.3	1.4
TEAM Precision Pipe Assemblies	7.8	8.0	1.0
Manhattan Hotel, Pretoria	8.0	20.7	2.6
Quorn Foods, Billingham, Site 1	11.9	5.1	0.4
Quorn Foods, Billingham, Site 2	11.9	10.2	0.9
RENOLIT Cramlington, Site 1	6.5	11.7	1.8
RENOLIT Cramlington, Site 2	5.4	6.2	1.1
Tadcaster Community Swimming Pool	9.8	16.5	1.7
Queizar SL	7.0	8.9	1.3
Tees Active, Billingham Forum	6.5	8.8	1.3
Tees Active, Splash Stockton	8.7	10.2	1.2
Tees Active, Thornaby Pavilion	9.8	11.5	1.2
Bristol and Clifton Golf Club	4.3	5.0	1.2
Continetal Cars, South Africa	10.9	23.6	2.2
Calzaturificio Europa, Italy	6.5	12.0	1.8
Chesterfelt Group, roofing manufacturer	5.0	9.9	2.0
ISG Totty, Bradford	8.7	18.0	2.1
Vassiliko Cement Works, Cyprus, Raw mill air compressors	8.9	9.7	1.1
Vassiliko Cement Works, Cyprus, Kiln pre-heater elevator	3.2	6.0	1.9

Max CVR factor	2.6
Min CVR factor	0.4
Mean CVR factor	1.5

Table 1 – Conservation Voltage Reduction factors calculated from Powerstar case studies

4 Conclusions

The Literature Review has found that:

- Conservation Voltage Reduction is a proven concept with CVR factors ranging from 0.4 to 2.6 depending upon the types of load present, and therefore i) can vary between different parts of the distribution network; ii) can vary between different seasons, and different times of day; iii) can vary according to the ambient temperature. In the absence of local knowledge, a CVR factor of 1 between voltage and consumption reduction is a reasonable estimate;
- CVR can be implemented without detriment to customers' perception of quality of supply;
- Previous innovation projects have relied on significant investments in primary equipment at 11kV and LV to provide CVR including voltage monitors, distribution OLTC transformers, LV capacitors and HV capacitors;
- The BEET concept is a significantly lower cost method of providing CVR as it uses existing primary equipment and voltage measurements from smart meters that are being rolled out as part of the national smart metering programme.