electricity north west
Bringing energy to your door

Customer Load Active System Services

Second Tier LCN Fund Project Closedown Report
30 September 2015

VERSION HISTORY

Version	Date	Author	Status	Comments
1	30/09/2015	Kieran Bailey	Completed	

CONTENTS

1 PROJECT BACKGROUND

As Great Britain (GB) moves to a low carbon future, electricity demand and the level of renewable and low carbon distributed generation is currently expected to increase. This decarbonisation pathway will introduce a number of key challenges for the operators of GB electricity networks with the potential to necessitate expensive capital investments. These challenges include:

- An expected increase in the demand for electricity could progressively erode existing network capacity margin at grid and primary substations. When responding to such changes, a distribution network operator (DNO) needs to assess at each step along the pathway if the increase is permanent and warrants immediate intervention or will be eventually offset by distributed generation so that network reinforcement can be avoided or delayed. In order to operate networks safely in the interim without potentially expensive interventions, a new technique is required to enable short-term rapid rises in peak demand to be adequately managed and met using existing assets.
- Unacceptably high voltages that could occur on networks during periods when high distributed generation output coincides with low local demand. A low cost and quickly deployed alternative to traditional expensive asset solutions used to mitigate these excessive voltages is needed.
- An increasing probability that the available generation within a network may exceed the demand or network capacity, leading to unacceptable network conditions and the need to constrain the generation output. This constraint acts to decrease the efficiency of the generation and hence drive up costs to customers. A new technique is required that minimises the constraint of renewable sources such as wind and solar.
- A changing generation mix with increased amounts of low inertia intermittent generation connected to the system along with large nuclear generating units. As a consequence there will be an increased need to access system reserves to maintain overall system stability to help avoid cascade tripping events. Owing to the high financial and carbon cost of conventional spinning reserve, fast acting and flexible demand management for frequency, and system balancing is expected to become an increasingly important part of future system operation. This is of particular benefit for local power balancing within a DNO network, and also offers potential advantages for future distributed system operator (DSO) network management.

Electricity North West's Low Carbon Networks (LCN) Fund Project, CLASS (Customer Load Active System Services), seeks to demonstrate how it is possible to unlock network capacity, deferring the need for major capital reinforcement investment and explores opportunities to provide alternative frequency and enhanced reactive power (RP) services to the market by the implementation of innovative, low cost, voltage regulation technologies.

1.1 Background to CLASS trial methodology

The CLASS Project demonstrates how the implementation of new and innovative technologies applied to existing network assets has the potential to defer traditional reinforcement by reducing peak demands and offers alternatives to the existing ancillary market services.

The Project consisted of four trials, carried out over a 12-month period, developed to robustly challenge the hypotheses of the voltage/demand relationship and demonstrate how voltage management techniques can provide demand response (DR) capabilities.

Trial 1: investigated the voltage/demand relationship for normal increments and decrements of system voltage at primary substations across an annual period. The outcome from this trial is a half-hourly voltage/demand relationship matrix, developed by The University of Manchester (UoM), with the purpose of providing an understanding so that voltage control can be used to manage demand.

Trial 2: investigated demand response for peak load reduction in order to prevent or defer network reinforcement.

Trial 3: investigated demand response during frequency events to support the NETSO. This was done by opening one of a pair of primary transformer circuit breakers or by changing on-load tap positions of primary transformers.

Trial 4: investigated the viability of the tap staggering technique for the provision of reactive power services (ie regulation for high voltages) to the national electricity transmission system operator NETSO and DNO.

2 EXECUTIVE SUMMARY

The CLASS Project has successfully delivered an ambitious programme of work over a two-year period. The Project has produced significant learning for DNOs, academics and the global industry in understanding the voltage/demand relationship and how the use of innovative voltage management technologies can be utilised to provide demand response for the benefit of GB.

The Project trialled the application of innovative voltage management technologies to provide demand response to reduce peak network demand, and to provide a new mechanism for frequency and voltage control to National Grid (NG). The results from the Project have provided new learning regarding customer load types, behaviour and the method by which new technologies can be integrated to provide demand response, as well as the potential for further commercial agreements to provide frequency response services and reactive power services for NG.

CLASS has shown that there is potential to unlock up to 3.3GW of demand response, the equivalent to two combined cycle gas turbine (CCGT) power stations and up to 2GVAr of reactive power absorption at distribution level across the whole of GB. The results have shown that there are possibilities to enter the frequency and enhanced reactive power markets, proving an alternative, low cost, carbon saving and flexible solution to NG for ancillary services when compared to the existing costly and carbon intensive methods.

2.1 Project scope and objectives

The objectives of the CLASS Project were to test the following hypothesis:

- The CLASS Method creates a demand response and reactive absorption capability through the application of innovative voltage regulation techniques
- Customers within the CLASS trial areas will not see/observe/notice an impact on their power quality when these innovative techniques are applied
- 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
- The CLASS Method will defer network reinforcement and save carbon, by the application of demand decrement at the time of system peak
- The CLASS Method uses existing assets with no detriment to their asset health.

2.2 Project outcomes

Throughout the duration of the Project a number of outcomes have been generated.

Figure 2.1: Project outcomes

Output	Description
Load characteristics	Methodology to characterise substation load, based on customer type using the Common Distribution Charging Methodology and Elexon load profiles
Voltage controlled demand capabilities	The Project has shown that the use of innovative voltage control techniques can provide a demand response and the Solution can be deployed by all DNOs GB-wide
Monitored data	Full year's data from all trial substations
Voltage/demand relationship	The results of the CLASS trials have produced a mathematical quantification of the relationship between voltage and demand which supports the hypothesis
Voltage/demand matrix	From the results of the trial data the University of Manchester have constructed a demand/voltage matrix which will become part of the planning engineer's tool kit
Voltage control technology	The retrofitting of new technology onto old technology has been deployed successfully
ICCP link between Electricity North West and NG control centres	The ICCP link has provided NG with enhanced visibility of Electricity North West demand data and the first ever opportunity for NG to switch on a DNO's network
Regulatory impact	Assessment of the methodology and trial results have demonstrated that no changes are required to regulatory standards, namely SQSS, DCODE, GCODE
Ancillary services market	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

Asset health	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
Customer engagement	Robust customer research has demonstrated that the use of voltage reduction techniques does not cause any detriment to customers' perception of quality of supply
Carbon impact	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

2.3 Objectives met

All Project Successful Delivery Reward Criteria's (SDRC's) have been met even though this has been an ambitious and challenging Project. The following objectives were met or proven:

- Explore the voltage/demand relationship and develop a voltage/demand matrix that mathematically quantifies the relationship
- Prove that the technology required to implement the CLASS methodology can be integrated into existing systems to provide a range of demand change capabilities and voltage management services that offer savings to customers without compromising quality of supply
- Demonstrate that the proposed voltage regulation techniques do not cause any deterioration of asset health
- Demonstrate that CLASS is low cost, highly transferable and can be readily implemented by DNOs across GB.

2.4 Objectives not met

None.

2.5 Key outputs and main learning

Through the implementation of CLASS technology, the Project has successfully demonstrated the voltage/demand relationship for dynamic voltage changes across the Electricity North West network.

Implementation of technology

The technology deployed has successfully demonstrated that it is possible to provide a demand response to reduce demand at peak times. In so doing, this will defer major capital spend and in some cases remove the need for system reinforcement where load growth uncertainties lie. Demand response will provide both financial and carbon benefits.

The Project demonstrated that a voltage/demand response exists. Using the CLASS trial data, the University of Manchester (UoM) has developed mathematical voltage/demand relationship matrices for characteristic load types, enabling the real-time estimation of a load's response to be calculated for a desired voltage change and to estimate the level of reactive power absorption available.

The fundamental methodology behind CLASS is to change system voltage levels, achieved by the operation of either transformer on-load tap changers (OLTCs) or the offloading of a transformer if two transformers are running in parallel. Results from trials and associated test data have shown that the increase in the number of tap change operations and transformer outages have negligible impact on asset health.

CLASS has demonstrated automatic delivery of the following critical demand response services: demand reduction/boost, voltage control, and demand reduction at time of system peak. Notably, CLASS is delivered by a combination of local automatic action and central despatch as described below.

Voltage controllers

Dynamic voltage control has been made possible by the integration of an autonomous substation controller (ASC), developed by Siemens and located at each primary substation in the trial area. The ASC interfaces with the substation's existing automatic voltage controller (AVC). The underlying functionality of the AVC remains unchanged but it responds to control tap change operation when prompted to do by the ASC.

Dashboard

The dashboard, the software controller for demand response, was developed in the PowerOn Fusion (PoF) network management system which was integrated with the existing Electricity North West network management system (NMS). The dashboard enables the user to select/control a set of pre-defined functions as well as provide real-time real and reactive power demand response.

A similar dashboard has been developed in the National Grid (NG) NMS to interact with the PoF dashboard.

ICCP link

Inter-control centre protocol (ICCP) is a standard real-time data exchange protocol which provides a mechanism for real-time data exchange between utility control centres. The control centres may have different network management systems provided by different vendors; therefore ICCP provides provision for a standard means of exchanging data between the systems.

ICCP links have been used previously by NG and other DNOs for the exchange of data only. The CLASS Project is the first to use an ICCP with NG to provide control functionality.

Monitoring equipment

New monitoring equipment, providing sampling rates advised by the University of Manchester, was deployed at all 60 primary substations in the trial area and at tactical points on the distribution network. This high accuracy, high resolution monitoring was used to record all trial data.

CLASS trials & Data evaluation

The trials were developed to gain a full understanding of all the functions and their responses at different times of day and on different days of the year.

Load model

The academic research carried out by the University of Manchester, using the real-time data, has shown that a time dependent static load model, rather than the more complex dynamic model, can be used to estimate load response to changes in the voltage at primary busbars.

The trial results have shown that demand response changes both seasonally and daily. From the data observed during the trials the University of Manchester has been able to produce a set of indicative voltage/demand matrices that mathematically quantify the relationship between voltage and demand, allowing the estimation of the demand response for different load compositions:

- Mainly domestic
- Mainly industrial/commercial
- Mixed.

Voltage/demand response

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%

Similarly, a 1% voltage reduction at a primary substation produces an average seasonal reactive power reduction of between 5.54% and 5.83%.

Peak demand reduction

Measurement-based models

The quantification of the overall peak demand reduction for the whole Electricity North West network applying the lowest seasonal average real power demand response of 1.3% for a 1% change in voltage is estimated to be:

- 57MW (summer minimum) to 163MW (winter maximum) for a 3% voltage reduction
- 94MW (summer minimum) to 271MW (winter maximum) for a 5% voltage reduction.

On the same basis, if the CLASS approach is adopted across the whole of GB there is potential to unlock a 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.

Literature-based studies

Studies were undertaken to determine the level of demand response that could be unlocked. The results identified the following levels of potential demand response for the maximum allowable voltage step:

- Electricity North West area: 65MW to 235MW
- GB: 1.2GW to 3.3GW.

Demand response for frequency response

During the trial periods there were system events when the network frequency fell to 49.7Hz causing automatic operation of the CLASS stage 1 frequency function. Demand reduction was provided by tripping one of the primary transformer low voltage circuit breakers in less than 500ms. The stage 2 frequency functionality, designed to provide demand reduction by reducing LV voltage by transformer tapping, was observed to be completed within two minutes. 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.

The trials have demonstrated that the CLASS methodology can be used to offer balancing services to NG: fast reserve (FR), frequency control management demand (FCDM) and firm frequency response (FRF), using automatic relay operation for a non-dynamic response.

Reactive power absorption to manage high voltage on transmission system

The CLASS trials have demonstrated that reactive power absorption by transformer tap staggering can provide significant benefits to NG. The results of the trials, when applying a six tap stagger, have shown levels of reactive power absorption when applied to the whole Electricity North West distribution network as follows:

- Summer 133MVAr to 152MVAr
- Winter 131MVAr to 167MVAr.

If the CLASS reactive power absorption technique was applied across the whole of GB there is potential to absorb:

- Summer 1.47GVAr to 1.67GVAr
- Winter 1.44GVAr to 1.83GVAr

Asset health

Health parameters of transformers and tap changers involved in the trial network were monitored to understand if the CLASS methodology caused any noticeable changes to asset health. The results of the trials, based on a pessimistic level of frequency response and reactive power absorption operations for NG, have shown a negligible impact on asset health. Tap changer maintenance is based on an operation level or set time period and the increased level of tapping would generally not cause an operation level maintenance.

Carbon benefits

The range of plausible carbon impacts of the different elements of the CLASS services is wide. There are very small asset impacts from the autonomous substation controllers required to deliver the CLASS services, while the potential benefits in the demand response operations category are over a thousand times greater.

The following general conclusions are drawn on the carbon impact of the three CLASS services:

- CLASS peak demand reduction (PDR) has the potential to defer substantial amounts of network reinforcement but not eliminate the requirement entirely
- The asset carbon impact is outweighed in every category by operations. Strictly it is not comparable in the case of PDR as the benefit of CLASS is a deferral rather than outright prevention of reinforcement
- The carbon potential benefits from DR and RP are significant and of comparable magnitude
- The total benefit to the NETSO from the combined DR and RP ancillary services could be as much as 116,000 tCO_2e per annum.

SQSS and code review

A review of the National Electricity System Security and Quality of Supply Standard, SQSS, and other relevant standards and codes was undertaken to determine if changes were required for the CLASS methodology to be employed. Following the results from the CLASS trials it was concluded that no changes were necessary, however, significant learning was identified.

Customer impact

The Project has demonstrated that the CLASS technique was technically and commercially possible as well as acceptable to customers in trial areas. Robust customer engagement work has demonstrated that the CLASS Method is not noticed by customers. During the course of the seasonal monitoring surveys the proportion of customers who claimed to have noticed a change in their power quality was lower than the level observed in the baseline survey, conducted before the trials began. Notably, there were no statistically significant variations in the proportion of customers who observed a change to their power quality in any of the customer segments consulted, demonstrating that CLASS was indiscernible to all types of customers.

Detailed analysis identified that the proportion of customers who noticed a change to their power quality which might conceivably have been directly associated with the CLASS Method was negligible at just 3%. Such low level perceptions of power quality changes were consistent across all of the monitoring seasons.

The level of overall satisfaction with service/supply quality amongst the survey population was either maintained or improved during the CLASS trials. Furthermore there were no enquiries or complaints about power quality from any customers in the trial areas during the testing regime that could be directly attributed to the CLASS Method.

Detailed analysis of the CLASS customer surveys, and the absence of any related customer complaints during the trials, indicate that Electricity North West can be confident that the implementation of the CLASS Method across its distribution region would have no detriment to perceived power quality. In addition, any change would be indiscernible to customers. These findings support the transferability of the Method and suggest it can be applied across the wider GB network without customer impact.

3 DETAILS OF THE WORK CARRIED OUT

In order to fully explore the benefits associated with the CLASS Project the learning outcomes were segmented into four key knowledge areas:

- Customer engagement and feedback
- Technology implementation and effectiveness
- CLASS trials
- Data evaluation.

For each of these areas CLASS has been implemented and trialled to satisfy the learning objectives of that area of research.

3.1 Customer engagement and feedback

Communicating with customers in the trial area

To investigate the impact and provide confidence that customers did not perceive any degradation of power quality while the new technologies were trialled, extensive customer engagement was essential to demonstrate acceptance of the Method. To embed on-going customer engagement an engaged customer panel (ECP) was convened. Initially the ECP formulated the most effective method of communicating CLASS to customers in the trial areas and to optimise the customer survey instrument. The hypothesis that the application of CLASS is indiscernible to customers would be demonstrated by customer acceptance of the Method, derived from feedback obtained throughout the trials. To achieve these objectives, four phases of meetings were scheduled with the ECP, which was split into three separate focus groups. These meetings occurred between October 2013 and January 2014 and examined three key questions:

- Do customers understand the CLASS concept?
- Which key components of CLASS need to be communicated to customers and how?
- How can the learning from the ECP be utilised effectively to design and implement a customer survey to test the CLASS hypothesis?

Project Partner Impact Research recruited panellists who reflected Electricity North West's domestic and Industrial and Commercial (I&C) customer base with quotas set on demographic information and business size and sector respectively.

In each phase of research, three 90-minute ECP discussions were administered:

- Group one: Carlisle, domestic customers
- Group two: Manchester, domestic customers
- Group three: Manchester, I&C customers.

The outcome of the work was an endorsed customer leaflet that explained the Problem, the CLASS Solution and the likely effect of the Method on customers. It also explained how those customers on trial circuits could register to participate in the customer surveys and provided relevant contact details. The detailed Method and findings can be found in the ECP report.

Monitoring the effects of the CLASS trials on customers

To demonstrate customers' acceptance and perceptions around the effects of CLASS, an extensive programme of research was undertaken to examine two key objectives:

- To determine the effect of CLASS, if any, on trial customers who participated in the customer survey during the trial tests
- To determine the effect of CLASS, if any, on the control group of customers who participated in the customer survey during of the trial tests.

In April 2014, a total of 696 customers (496 domestic and 200 I&C) were recruited from trial circuits for the baseline survey before the trials started to act as a benchmark. Customers were recruited:

- Through website registrations, generated in response to a leaflet distributed to all customers served by trial circuits
- By telephone, utilising customer data provided by Electricity North West.

696 baseline surveys were completed via face-to-face and telephone interviews. The baseline survey results acted as a benchmark for any potential changes to power quality observed or perceived by customers in the monitoring surveys, conducted during the trial phase of the Project. The 20-minute survey included questions about household demographics and composition, appliance ownership and the customer's existing perception of power quality.

Four subsequent seasonal surveys (summer 2014 to spring 2015) monitored the effects of the trials by focussing on customers' perceptions of power quality in the seven days preceding the survey. The same five-minute questionnaire was used in each of the four seasonal monitoring surveys and was conducted via a telephone interview. The monitoring surveys were designed using a test and control method to identify genuine changes in customers' perceptions of power quality.

To validate the results, the proportion of test and control surveys was balanced by customer type and trial type. To further explore the impact of customer sensitisation (placebo effect), half of the test and control samples received advanced notification of a test (by text message) and half did not.

A total of 1357 monitoring interviews were completed during the trial phase of the Project. This sample size was deemed statistically robust and all analysis was significance tested at the 95% confidence level. The volume of surveys completed allowed for robust analysis by season, trial type and customer type, and test and control groups.

Any enquiries that could perceivably be linked to the CLASS trials were monitored and investigated.

Both the research methodology and the analysis were externally critiqued by an independent peer reviewer, Professor Ken Willis. A peer review of the methodology can be found in the CLASS Peer review of the survey methodology. The findings of the survey can be found here. A peer review of the survey findings can be found here.

All customers in the trial area were able to contact Electricity North West through normal communication channels regarding any power quality concerns, regardless of their participation in the customer surveys. Before the CLASS trials began, a robust process was embedded to ensure that any customer feedback outside of the surveys, that might potentially be attributable to the CLASS Method, was captured and promptly addressed. This procedure utilised existing business as usual (BAU) processes and involved the registration of all potential CLASS related enquires/complaints on Electricity North West's customer contact management system. This automatically generated a prompt for investigative action from the CLASS Project team.

To ensure that all internal stakeholders were fully informed and able to link any potential CLASS related enquiries, the trial schedule was verified on a weekly basis and an extract was issued electronically to all members of the customer contact centre (CCC), construction and maintenance services (CMS) team and other internal stakeholders, in advance of that week's testing regime. As a further safeguard, the fault management system was updated with details of the testing regime and individual tests were electronically displayed on the date scheduled. CCC personnel could therefore easily identify and merge any potential CLASS associated quality of supply (QoS) issues with the appropriate CLASS test. As a final safeguard, the control engineer initiating planned tests contacted the CCC and CMS immediately before and shortly after each test during the initial few months of the trials and following every unscheduled 'frequency response' command from National Grid.

All potential CLASS related enquiries were handled on an individual basis and in consultation with the customer. Each involved a thorough investigation, initially scrutinising network data in iHost, a web-based service used to collect, distribute and share data. This enabled the Project team to understand the overall supply voltage experienced by the customer, the voltage range recorded during the CLASS testing periods and the levels recorded during the period corresponding to the customer's observation of the Problem. A total of 11 enquiries from customers on trial circuits warranted investigation, being initially deemed as potentially CLASS related. Of these, none were found to be attributable to the CLASS Method.

3.2 Technology implementation and effectiveness

Equipment was installed at 60 sites for operation of the trials. The following sections explain how the trial sites were selected and the equipment installed.

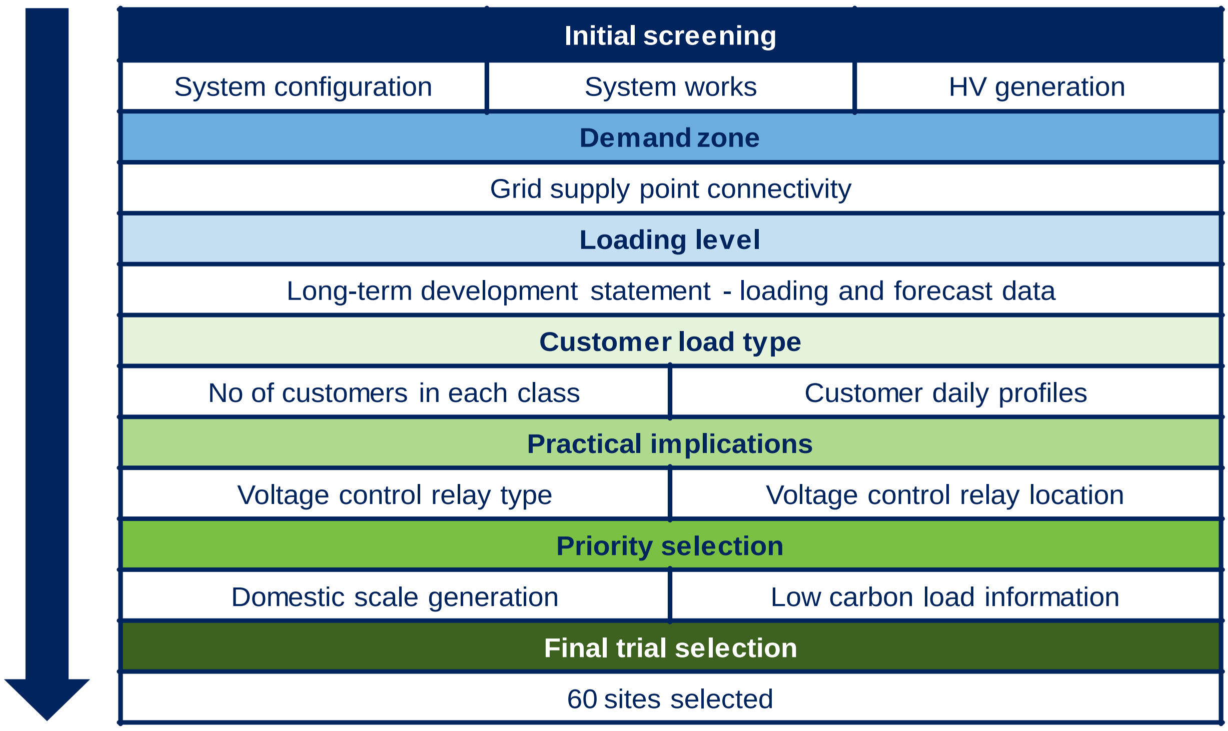
Trial selection methodology

The trial circuit selection methodology was developed to ensure that the selection of trial sites covered the Electricity North West geographic area and a true representative range of customer types, allowing extrapolation (for scaling purposes) to reflect the whole of the GB distribution network. The steps in developing the methodology are shown in figure 3.1 below.

Initial screening

The initial screening was applied to the total population of approximately 350 primary substations on the Electricity North West network to avoid locations where the system configuration or system operation could affect the implementation of the trial or the trial results.

Figure 3.1: CLASS trial selection methodology



Demand zone

Electricity North West's distribution system covers a wide range of areas: from scarcely populated regions in Cumbria to urban areas within and surrounding cities, for example Manchester, with high concentrations of commercial, industrial and domestic customers. It was considered important that the selected primaries reflected the whole Electricity North West region, and hence all customer types, to maximise the learning outcomes of the trials and ensure the transferability to other GB distribution networks. Consequently, the methodology included consideration of all grid supply points (GSP), ensuring selection of at least one primary substation supplied downstream of each GSP.

Loading level

An objective of the CLASS trial was to investigate the use of demand response initiated through active voltage management technologies to defer network reinforcement. Consequently, primary substations with the highest loadings were selected for the trial. The loading values for 10% of the primary substations were found to be greater than, or equal to, 85% of firm capacity and the loading values for 45% of primaries were found to be greater than, or equal to, 75% of firm capacity.

Customer load type

Customer load types were considered as part of the trial selection methodology to ensure that learning was obtained on how the demand of different customer groups responds to the CLASS techniques.

To characterise customer load types the 'peak load sharing' methodology, as described in the final submission, was implemented.

Peak load sharing methodology

The peak load sharing methodology was developed to characterise load types at each primary substation based on the individual profile class to ensure a mix of customer types were included in the trial selection. Each customer connected to the distribution network is characterised by a profile class. Electricity North West maintains a record of the numbers of customers connected to each primary by profile classes, as shown in Figure 3.2 below.

Figure 3.2: Profile class

Profile Class	Description
Profile class 1	Domestic unrestricted customers
Profile class 2	Domestic Economy 7 customers
Profile class 3	Non-domestic unrestricted customers
Profile class 4	Non-domestic Economy 7 customers
Profile class 5	Non-domestic maximum demand customers with peak load factor less than 20%
Profile class 6	Non-domestic maximum demand customers with peak load factor between 20% - 30%
Profile class 7	Non-domestic maximum demand customers with peak load factor between 30% - 40%
Profile class 8	Non-domestic maximum demand customers with peak load factor in excess of 40%

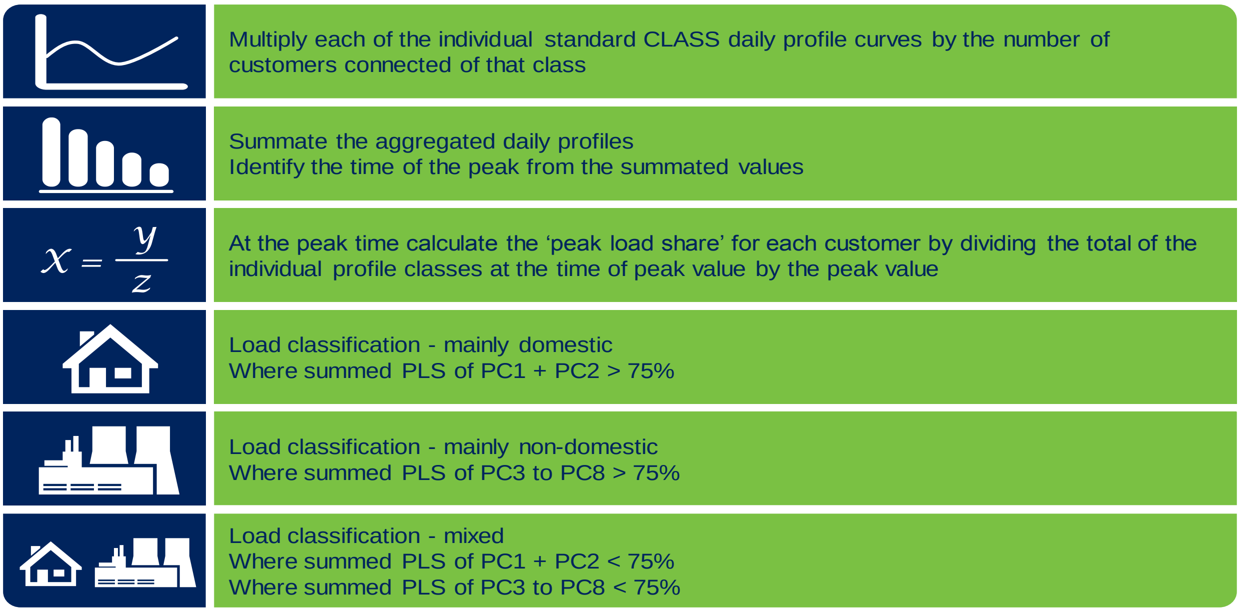
For the purposes of the peak load sharing methodology the above classes were reclassified based on the common distribution charging methodology (CDCM) tariffs as shown in figure 3.3 below.

Figure 3.3: CDCM tariff daily profiles assumed to correspond to each profile class

Profile class	Assumed corresponding CDCM tariff daily profile
PC1	Domestic unrestricted
PC2	Domestic two-rate
PC3	Small non-domestic unrestricted
PC4	50% small non-domestic off-peak/50% small non-domestic two rate
PC5 to PC8	LV medium non-domestic

For each of the above profile classes in figure 3.3, a standard winter weekday daily profile was generated based on an arbitrary winter day, using actual metering data provided for each profile class for every half hour period. These individual profile class load profiles were then used as the basis of the peak load sharing methodology. To determine the peak load share for each primary substation the procedure shown in figure 3.4 was followed:

Figure 3.4: Peak load share methodology



The aggregate daily profile was not expected to replicate the actual daily profile of the primary demand. It is rather an approximation for the sole purpose of identifying the percentage of the peak demand consumed by customers in each profile class. The primary's daily peak demand and its time of occurrence were identified using the aggregate profile.

Practical implications

Modifications to the existing wiring of primary transformer automatic voltage control (AVC) relays were required to accommodate the control functionality necessary for the CLASS trials.

As part of the site selection it was necessary to classify the different types of AVC based on risk, taking account of the age, capabilities of the existing AVC, availability of wiring diagrams, location of tap changer (indoor or outdoor) and time required to carry out the modifications.

The definitions of the categories assigned to the AVC installation at each primary are given below.

Figure 3.5: AVC installation categories

Category	Description
Category A	Indoor Super TAPP/Micro TAPP (modern) AVC relays
Category B	Indoor Brush Star (legacy) AVC Relays or mixed Super TAPP/Micro TAPP with AVE/Brush Star (legacy) AVC relays
Category C	Outdoor Super TAPP/Micro TAPP (modern) AVC relays
Category D	Indoor AVE/Brush Star AVC (legacy) relays
Category E	Outdoor AVE/Brush Star (legacy) AVC relays
Category X	Uncertain AVC relay type and/or relay location

Category A primaries were considered in the selection due to them being indoor modern relays and thus presenting least project risk. Category B and D primaries were also considered within the selection since the additional risk of the legacy relays was judged to be acceptable. However, sites with modern relays were chosen in preference where possible.

Primaries categorised as C and E were not considered for selection in large numbers due to the aforementioned issues with outdoor installations. However, one primary (Longsight) in Category E was included in the selection to enable assessment of the installation of the autonomous substation controller (ASC) at a site with an existing outdoor AVC scheme.

Priority selection

Low carbon technologies

Load composition could change as low carbon technologies (LCTs) become more prevalent. The CLASS Project recognises this evolution and so the trial selection needed to include sites with loads best reflecting the future load composition.

It was difficult to obtain specific data regarding plans for connections of developments making extensive use of low carbon technologies, eg vehicle charging locations and heat pumps. As a broad and wide-ranging set of primary substations have been selected for the trials, these are likely to cover areas where connection of LCTs is most likely. In particular, the selected sites include urban areas where electric charging is most probable, as well as suburban areas where new apartments or commercial buildings using heat pump technology are likely to be developed.

Embedded small scale generation

Low carbon initiatives are resulting in increasing numbers of domestic scale generators, particularly photovoltaic panels, being connected to the electrical distribution system. It was important that the CLASS trials investigated the effect that these have on the applicability of the CLASS methods.

In the Electricity North West network, the average capacity of small scale embedded generator connections corresponds to approximately 1.6% of the maximum demand at each primary. An assessment was carried out to confirm that the ratings of low voltage connected small scale generators at each of the primaries included in the selection are near to the overall average. Within the selection of 60 primaries, 17 have above average low voltage connected small scale generation. There are three primaries with above 4% small scale embedded generation.

Final selection

Following the above methodology 60 sites were selected for the trials across the Electricity North West network, capturing approximately 350 000 customers of which approximately 95% were domestic and 5% were commercial customers.

For further detail refer to the Trial substation selection methodology report.

CLASS system installation

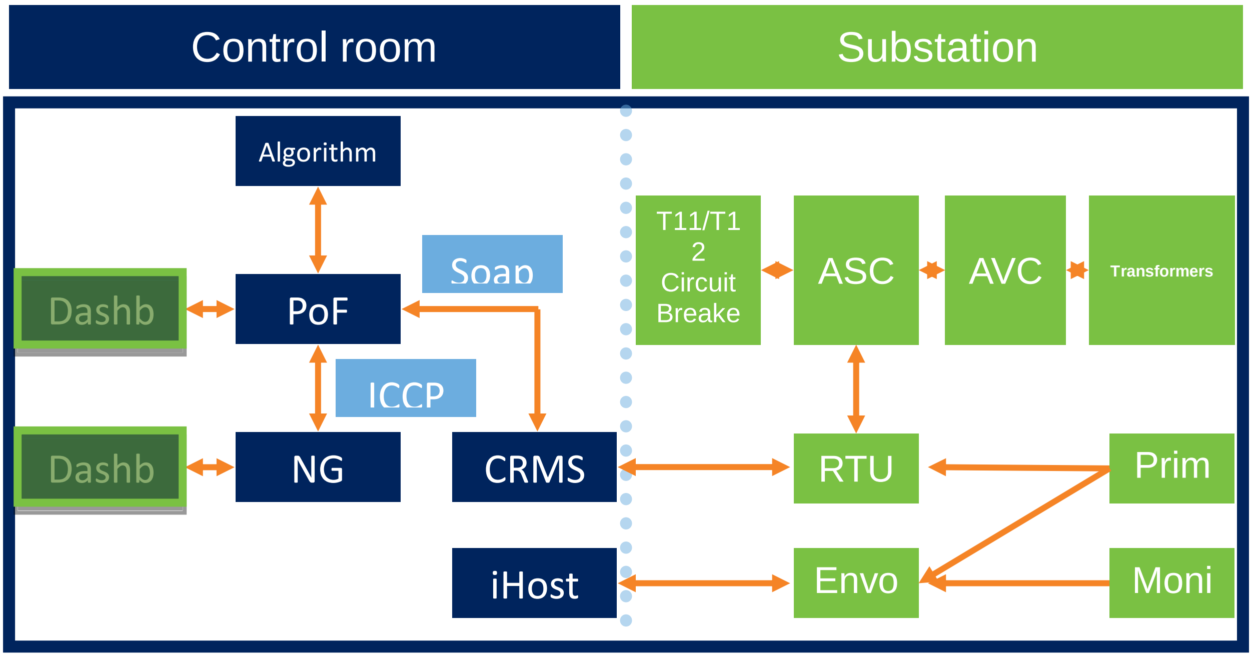
System overview

The CLASS Project installed a device called an autonomous substation controller (ASC) at 60 primary substations. This device linked to the control room management systems and the on-site automatic voltage control (AVC) relay. The AVC relay is a business as usual device which monitors voltage and operates the transformer on-load tap changers to maintain voltages within statutory limits. The ASC is the on-site intelligence of the CLASS system which, once activated or enabled from the NMS dashboard, via the remote terminal unit (RTU), makes decisions on what commands to send to the AVC. On a limited number of sites (ten) the ASC was also able to issue commands to trip one of the primary transformers circuit breaker to reduce demand very quickly, while keeping all customers supplied. Reducing voltage due to the increase in impedance as one of the pair of parallel transformers was taken out of service. The ASC is linked to the National Grid (NG) NMS via an ICCP link which enables CLASS functions to be enabled and activated by NG.

Figure 3.6 below illustrates the CLASS system make-up.

The changes in voltage and demand were measured by the primary monitors and sent via a standard resolution communications link, via the RTU, to the control room and planning tools. The CLASS data was sent by a high resolution 3G (Envoy) communications link to a website (iHost) where information is stored by the second and to a resolution of one volt and one amp. 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.

Figure 3.6: CLASS system overview



Autonomous substation controller development (ASC)

The ASC functions developed in this Project were:

- Local coordination and prioritisation functions
- Switch management
- Reactive power management
- Local voltage management
- Frequency management.

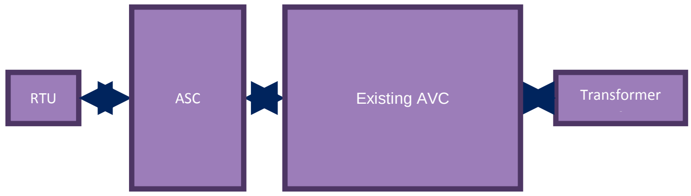
The ASC communicates with the telecontrol RTU (SCADA outstation) to perform the above functions via operation of 11/6.6kV circuit breakers and on-load primary transformer tap changers to affect voltage changes.

Installation types

To enable the maximum amount of learning during the trial period the 60 selected sites were split into different installation types, specifically sites with existing MicroTAPP relays, sites requiring the installation of a new MicroTAPP relay, sites where an Argus relay was installed to interface with existing relays and sites where relays facilitating frequency response were installed.

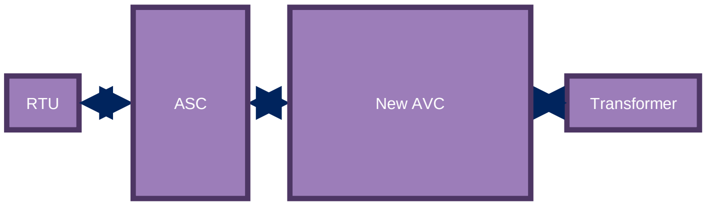
Existing MicroTAPP

This substation type already had the required MicroTAPP relay so only the Siemens ASC needed to be fitted. The primary frequency response function (below 49.7Hz) which trips one of the two transformer circuit breakers in service at the selected primary is not available on this type.



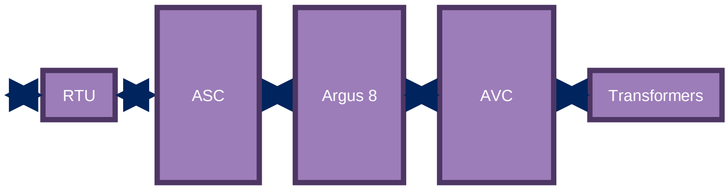
New MicroTAPP

This substation type had a legacy AVC which was changed to a MicroTAPP relay in order for it to communicate with the ASC. The primary frequency response function is not available on this type.



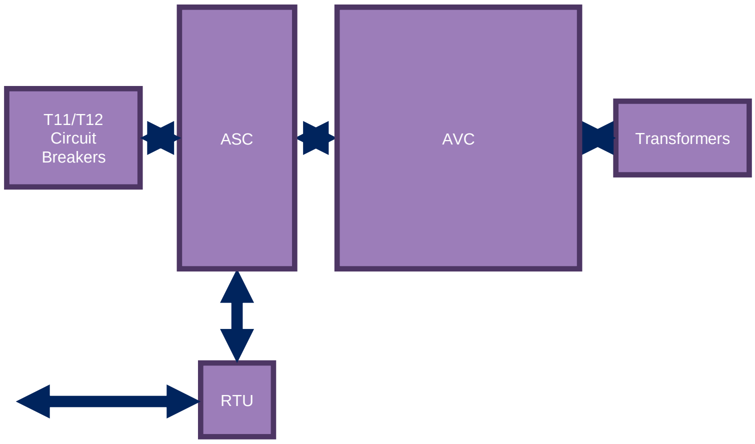
Argus 8

This type uses an Argus 8 relay which acts as an interface between the ASC and a non MicroTAPP legacy AVC relay in order to test if the legacy AVC relays have to be changed to MicroTAPPs for the CLASS functions to work.



Primary frequency response sites

There are ten substations of this type providing primary frequency response when the system frequency falls below 49.7Hz. These sites may have MicroTAPP or legacy AVC schemes with Argus 8 interface relays fitted.



Inter-control centre protocol link (ICCP)

The ICCP is a standard real-time data exchange protocol which provides a mechanism for real-time data exchange between utility control centres. The control centres may have different network management systems provided by different vendors; therefore ICCP provides a standard means of exchanging data between the systems.

ICCP links have been used previously by NG and other DNOs for the exchange of data only. The CLASS Project is the first to use an ICCP with NG to provide control functionality. The ICCP link built between NG and Electricity North West proved that commands as well as data could be sent in a reliable and timely manner between the two system operators.

Dashboard

The CLASS dashboard, the software controller for demand response, was developed in the Poweron Fusion (PoF) network management system which was integrated with the existing Electricity North West network management system. The CLASS dashboard is a graphical universal interface (GUI) that enables the user to select/control a set of pre-defined functions as well as initiate real-time real and reactive power demand response.

The dashboard developed showed how a NMS commonly used in GB DNOs could be configured to display and control the CLASS functions at a large number of primary sites, and how these could be grouped at a grid supply point (GSP), regional and whole company level. It also demonstrated how 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.

A similar dashboard was developed in the NG NMS to interact with the PoF dashboard via an ICCP link.

Monitoring equipment

New monitoring equipment, providing sampling rates advised by the University of Manchester, was deployed at all 60 primary substations in the trial area and at tactical points on the distribution network. This high accuracy, high resolution equipment was used to record all trial data which was publicly available on the Nortech iHost platform.

Data arising from the additional monitoring installed on the primary substation sites was used by the Project's academic partner to examine the voltage/demand relationships. The additional monitors (CLASS MW/MVAr/volts/ampere/frequency transducers) were identical to those purchased for business as usual, except for the addition of an RS485 high data rate output. This RS485 output was channelled via a Nortec Envoy storage and 3G converter unit to a cloud computing iHost website. The improvement in data quantity and resolution was highly significant as values to the second/volt/ampere etc were obtained compared to half hour averages for existing planning tools and dead bands in the 5-10% range for existing SCADA systems.

3.3 CLASS trials

The objectives of the CLASS trials were to explore and understand the voltage/demand relationship and in doing so demonstrate that the CLASS Solution can be applied to reduce peak network demands and provide a new mechanism for frequency management and voltage control to support the transmission system operator at GB level. As well as being able to test the voltage/demand hypotheses the trials needed to show that the CLASS Method and Solution did not cause any asset health issues or affect customer quality of supply.

Extensive tests were planned for the period of April 2014 to end of March 2015 to robustly evaluate the application of the CLASS principles and deliver results and learning that is transferable to all GB DNOs.

The four CLASS trials are summarised in table 3.7 below.

Figure 3.7: Summary of CLASS trials

Reference	Description	Objective	Technique	Trial period	Customer survey requirement
T1	Load modelling	Establish voltage/demand relationship	Raise and lower tap positions	Across entire annual cycle	No
T2	Peak demand reduction	Demand response for peak reduction	Lower tap position	Peak demand	Yes
T3a	Stage 1 frequency response	Response to reduce demand when system frequency falls	Switch out transformer	Anytime	Yes
T3b	Stage 2 frequency response		Lower tap position	Anytime	Yes
T4	Reactive power absorption	Reduce high volts on transmission network	Stagger tap position	Minimum demand	No

Trial 1: Load modelling

The load modelling trials were developed to find the most appropriate load model, producing a voltage/demand matrix that mathematically quantifies the relationship for every half hour across an annual cycle for different types of connected load.

The trials were conducted at 15 sites out of the total of 60 sites included in the trial; one from each of the 15 major grid supply point regions within Electricity North West's operating area. Of these 15 sites, five sites were selected for each of the load characteristic types:

- Large industrial and commercial – primaries where the demand at time of peak demand is largely supplying industrial and commercial load types (ie profile classes 3 to 8)
- Largely domestic – primaries where the demand at time of peak demand is largely supplying domestic loads (ie profile classes 1 and 2)

- Mixed – primaries where there is roughly equal share of domestic and non-domestic loads at times of peak demand.

Approach to determining the T1 test schedule

To understand the voltage/demand relationship, tests were conducted across a 12-month period to fully quantify the demand response for every half hour. To determine the test schedule, load profiles for each trial 1 site were evaluated to identify a representative set of times to carry out tests. Annual and daily load profiles for each primary typically showed a level of similarity in terms of profile shape and demand value over for example a season or a 24-hour period. For example figure 3.8 below shows the 2012/13 daily maximum and minimum demand values for Dickinson Street primary. By examining the average maximum value, the annual load profile can be split into two discrete seasons, April to November and December to March.

The annual profile for this particular primary also highlights a cycle of high and low days throughout the year. Figure 3.9 shows the daily load profile for an example number of high days in season 2. The similarity in terms of profile shape and demand values means it can be assumed that all high days across season 2 depending upon the time of day will exhibit the same demand response for a change in voltage. This therefore allows the number of tests that need to be carried out to quantify the demand/voltage relationship to be reduced to a number of representative periods.

Figure 3.8: Daily min/max values at Dickinson primary substation

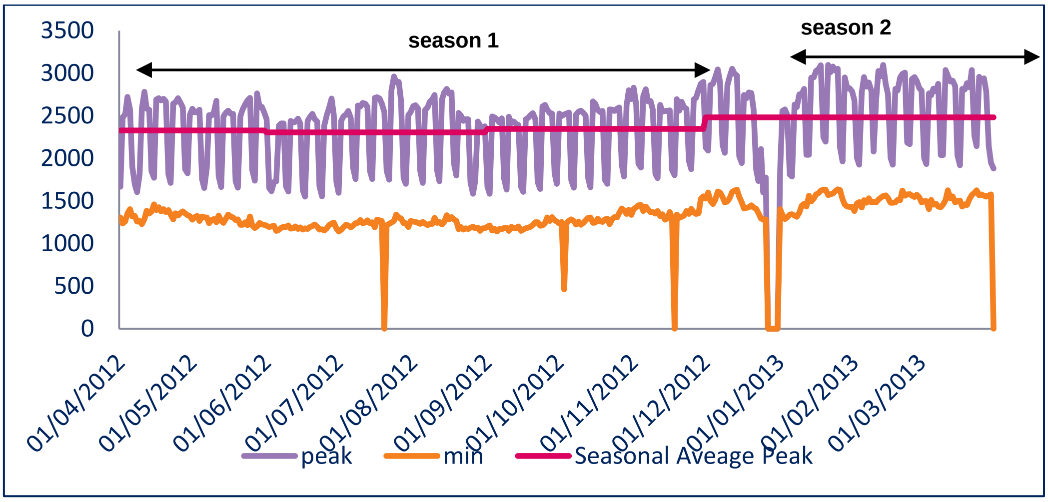
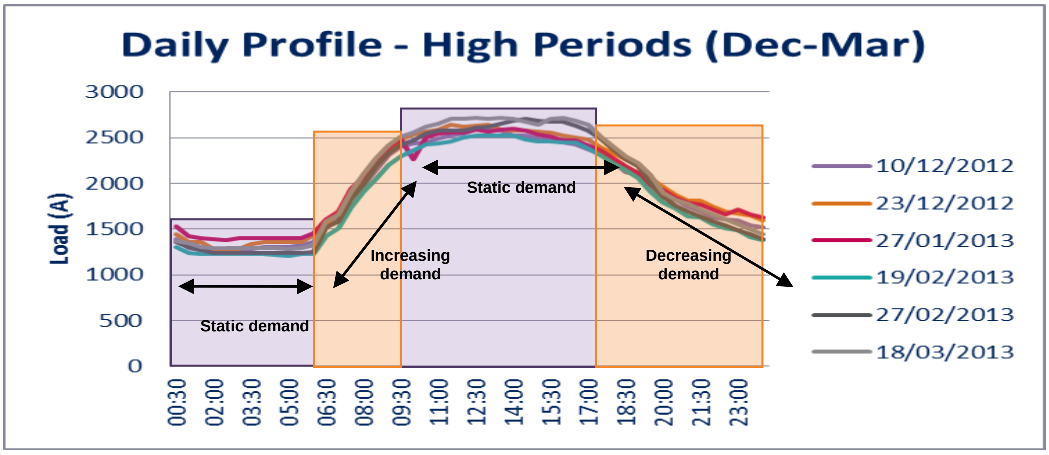


Figure 3.9: Daily load profile for an example number of high days in season 2



The daily profile can be further separated into periods of changing and static demand. These periods occur at similar times for a high day in season 2 and therefore the demand response for a high day in season 2 can be quantified by testing in each of these four discrete periods.

A test schedule for each primary in trial 1 was developed by following this same level of analysis and inspection to determine representative periods to test across the annual cycle.

T1 trial method

As part of normal system operation, the tap position of a primary substation transformer may change position between two and 20 times a day with each operation changing the secondary voltage by approximately 1.5% and both transformers in parallel tapping together. This normal tapping operation could have provided sufficient data for the purposes of trial 1 to fully quantify the response for every half hour. However, specific tests were carried out at each primary substation at static, increase and decrease load periods, as discussed in the previous section of this report, throughout the 12-month trial period. During this test period, both parallel primary transformers were 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.

Trial 2: Peak demand reduction

This trial sought to demonstrate that at peak load when voltage reductions of up to 5% are applied at a primary substation the demand at that substation is reduced and customers do not observe any adverse effects on their electricity supply. In addition to this, the technology required to deliver the Method on a business as usual basis was tested.

T2 trial method

Voltage reductions of 3% and 5% were applied at peak load times to determine if a specific level of voltage reduction at peak demand caused perceptible effects on a customer's electricity supply.

The voltage reductions were carried out via the CLASS dashboard by activating the respective demand reduction function:

- DRF (half):demand reduction function (half) – 3% voltage reduction is instructed
- DRF (full): demand reduction function (full) - 5% voltage reduction instructed

The DRF signal is sent to the ASC which changes the target voltage of both parallel transformers via the tap change relay. The transformers tap down two positions for a 3% voltage reduction and three positions for a 5% voltage reduction.

In addition to the manual operation of voltage reduction an automatic function was trialled, designed to carry out voltage reduction based on a pre-set MW capacity value for the site. When the ASC detects that the load is approaching this level it automatically initiates the tap changer to start reducing the 11kV or 6.6kV voltage. This automatic reduction capability was enabled at each primary substation via the CLASS dashboard using the network reinforcement deferral (NRD) function.

Trial 3: Frequency response by demand management

The objective of trial 3 was to test that the installed CLASS technology and existing network assets can deliver a frequency response services within the existing market operational timescales of two seconds to two minutes and ascertain whether customers observe any adverse effects.

T3 trial method

T3a CLASS primary frequency response: The paired arrangement of primary transformers has been utilised to deliver this service, by disconnection of one transformer resulting in an immediate voltage reduction and corresponding demand response. The primary frequency response was designed to operate within 0.5 seconds of an event, sustainable for 30 minutes.

This function was enabled at 10 primary substations in the trial via the CLASS dashboard using the automatic primary frequency response (APFR) function. The ASC has a frequency relay which automatically trips one of the pair of transformers circuit breakers upon detecting a frequency of 49.7Hz. Before the ASC trips a circuit breaker, it calculates the likely voltage drop. If the voltage drop is calculated to be greater than 12% the ASC blocks the trip signal. The ASC also confirms that both transformers are in service before activating the trip.

T3b CLASS secondary frequency: By tapping down primary transformers resulting in an output voltage reduction and corresponding demand response. The secondary frequency response was designed to operate within 30 seconds of an event, sustainable for 30 minutes.

This function is enabled at each primary substation in the trial via the CLASS dashboard using the automatic secondary frequency response (ASFR) function. When the ASC frequency relay detects a frequency of 49.8Hz it automatically sends a signal to the tap relay to tap down the output voltage by 5%. This function was designed to operate within two minutes with a voltage reduction of up to 5%, sustainable for 30 minutes. Voltage will be reduced to a minimum of 0.94pu.

The secondary frequency response was also tested when instructed directly by NG via the ICCP link.

Trial 4: Reactive power absorption

The objective of trial 4 was to test that the installed CLASS technology and existing network assets can deliver three levels of reactive power absorption using the tap staggering technique.

T4 trial method

The trial 4 tests were carried out using the ASC and the inbuilt tap stagger functionality of MicroTAPP relay activated by the CLASS dashboard and a manual tap stagger using the existing NMS and associated assets ie existing control functionality.

A further test was also undertaken to test the communication and control technology required to remotely request these services by NG. The function was activated via the ICCP link.

This service is most likely to be required during low load periods and as such the tests were conducted at times when peak demand had passed.

ASC initiated tests

The inbuilt functionality was designed to provide three selectable levels of reactive power absorption corresponding to one, two and three tap staggers. It was found that a greater level of tap stagger would be required which was not possible via the MicroTAPP relay.

Manual tap staggering

In order to evaluate and quantify the reactive power absorption capabilities a series of manual stagger tests were carried out to provide an enhanced data set for analysis. Tap stagger tests were carried out at all CLASS sites fed from Stalybridge GSP and South Manchester.

During the CLASS trial period a further test was requested by the University of Manchester to carry out analysis for tap stagger capability, validating the off line modelling and capability studies. A single test was carried out at Dickinson Street primary substation and measurements were taken at Bloom Street, the feeding BSP, on both 132/33kV grid transformers to capture the MW and MVAr changes immediately after two, four and six tap staggers were applied at Dickinson Street primary substation.

3.4 Data evaluation

Demand profiling study

The CLASS load modelling research developed accurate load model structures and corresponding parameter sets in the form of a voltage/demand relationship matrix for three different load compositions existing in the network.

- Mainly domestic
- Mainly non-domestic
- Mixed.

Each primary substation load type was defined using the peak load sharing methodology described in section 3.3.

Load models were initially developed for a representative set of 15 monitored substations but later extended to the full 60 CLASS sites. The monitored data from these sites was used to develop accurate load models and associated voltage/demand matrices for use in the CLASS dashboard which were then extended to non-monitored sites of similar load profiles. For each of the CLASS sites a full 365 day, 24-hour (48*half hour) matrix was developed.

Actual load responses following initiated voltage disturbances were measured and analysed for the development of suitable load models and for the estimation of load model parameters. This measurement-based load modelling approach captures the stochastic nature of the variation in load.

Tools and techniques, including software codes and programmes were developed for data processing, filtering and load modelling.

Load model selection

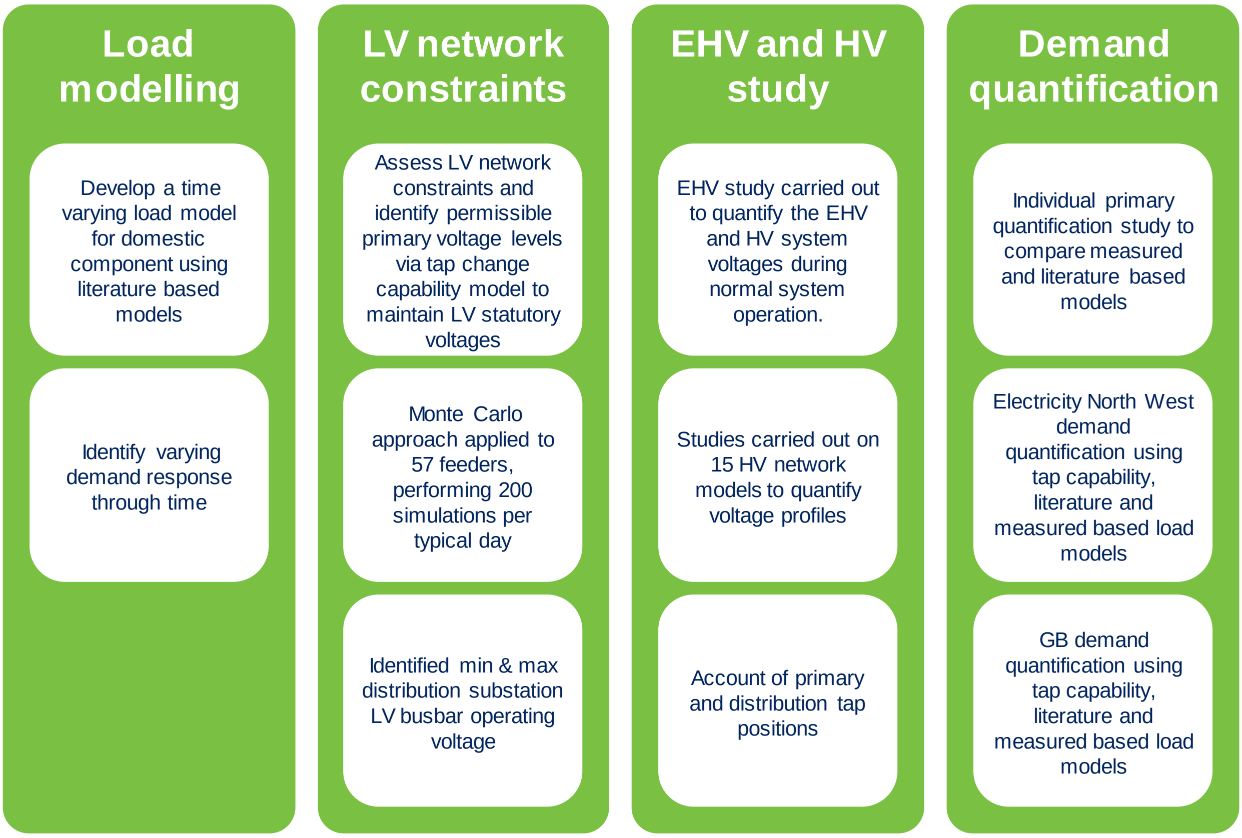
A review of the different types of load models was undertaken to determine the most appropriate model to be used for CLASS. Simplicity and general acceptability was considered in determining the most suitable model. Load models are categorised into two basic groups – static and dynamic. A static load model describes the steady state relationship. A dynamic load model includes the response of changing load behaviour with time. An assessment was made of a number of models to determine the most suitable and applicable for load modelling.

Simulation-based capability studies for quantification of demand response

The aim of this work was to provide a mathematical description of the half-hour demand response unlocked by reducing voltages through on-load tap changer actions at primary substations, using off line system modelling. The quantification was carried out per primary substation, per grid supply point, for the Electricity North West area and for the whole of GB considering four typical days of the year. The methodology developed caters for the constraints imposed by customers in real LV networks as well as features of real high voltage (HV) and extra high voltage (EHV) networks. This, in turn, allows the extent to which the voltage can be changed (ie voltage capability) without affecting customers or violating any network limitation to be quantified in a realistic manner. In addition, load models (ie the relationship between voltage and demand) given in the literature as well as on monitoring data were adopted and compared. By quantifying the demand response for every primary substation in the Electricity North West area the contribution across the whole of Electricity North West was then quantified.

Finally, by considering number of dwellings, domestic load profiles, load models and historical demand data the demand response for the whole of GB was quantified.

The following methodology was developed to quantify demand response:



Literature-based capability studies for quantification of reactive power absorption

Studies were carried out to assess the Electricity North West reactive power absorption capability through the use of the transformer tap staggering technique and to validate the estimated results with site trial data. The operation of parallel transformers (33kV to 11 or 6.6kV) with staggered taps can provide a means of absorbing reactive power. The aggregated reactive power absorption could be used to mitigate the high voltage issues in the transmission network during periods of low demand. The studies required the development and conversion of network models as well as load modelling profiling.

The following methodology was developed to quantify the reactive power absorption across the Electricity North West area and the GB areas.

Network modelling and conversion

- Two representative models selected for simulation studies South Manchester GSP and Stalybridge GSP. Full 132kV to 11/6.6kV network modelled
- Developed a process to convert Electricity North West master IPSA+ files into open DSS for studies.
- Time series load flow studies carried out using open DSS model

Load profiling and conversion

- Time varying load models developed for each primary substation using annual load profile and monitored data
- Developed methodology to convert each single static single exponential load model into a ZIP model

Quantification of reactive power absorption

- Studies investigated the reactive power absorption capability of Stalybridge GSP for one day, in each season.
- Reactive power absorption capabilities of the overall Electricity North West network and the entire GB network was be estimated
- Validation of simulation studies with trial data. Monitored data, as observed by NG during the trials was also used in validation process

Asset health

Studies were undertaken to analyse, monitor and predict the health conditions of transformers and tap changers in the Electricity North West HV network when providing CLASS Methods. The degradation or failure mechanisms associated with the new operational mode were studied through simulation and experiments in order to identify the necessary change of the maintenance/service regimes. An overall asset health assessment was based on the historic asset database trend, data mining techniques, expert knowledge and new experimental and simulation findings.

The following activities were carried out to understand the impact on asset health:

Monitoring

- Analysis of Electricity North West transformer database carried out to identify three sites for trials
- Thermal and acoustic equipment installed at three trial sites

Analysis

- Thermal modelling was carried out to assess the thermal effect due to higher currents flowing through the transformer and tap changer during the trials
- Tap changer contact erosion effects caused by additional current, lower power factor or due to the increased number of making and breaking of tap positions.
- Assessment of load duty factors
- Oil monitoring to detect change in condition and chemical species

Asset health Index

- To understand any impact, and to demonstrate that the health of the assets were not compromised, a review of the asset health index calculation was required to develop a new formula for calculating tap changer operability and load duty factors when considering tap staggering.

SQSS and Code Review

A review of the National Electricity System Security of Supply Standard, SQSS, was undertaken to assess whether there was any need to propose changes as a result of the findings from the CLASS Project. It also explored other relevant standards and codes, which may be influenced where CLASS learning can be employed in their application. This included the Grid Code, in particular section OC6, and 'Engineering Recommendation P2/6 Security of Supply',

Two workshops were held and a recommendation paper was produced.

Carbon assessment

The CLASS Solution unlocks capacity with a lower requirement for additional assets than traditional reinforcement. It was also proposed that by releasing capacity quicker due to fewer requirements for planning and groundworks, that the CLASS Solution facilitates emissions savings from other low carbon technologies such as heat pumps and renewable electricity generation. In addition to the deferment of network asset replacement, CLASS also sought to quantify the potential cost and carbon savings due to providing frequency and reactive power services to NG. This is an alternative market mechanism to the high merit carbon intensive generation which is traditionally called upon during frequency perturbations and to the reactive power compensation equipment for reducing high transmission voltages during high generation, low load periods.

The carbon impact assessment work, delivered by the Tyndall Centre for Climate Change Research, University of Manchester, sought to test the hypothesis *'The CLASS Method will defer network reinforcement and save carbon, by the application of demand decrement at the time of system peak.* Modelling and assessment of the potential carbon reduction capability associated with the CLASS Method was undertaken to evaluate this hypothesis.

At the start of the Project the Tyndall Centre reviewed the pilot carbon impact methodology included in the Full Submission, to update as appropriate to incorporate more recent carbon benchmarks, best practice in carbon assessment and scenarios for the rate of decarbonisation in the UK.

Firstly the Tyndall Centre examined the academic literature on the environmental impact of electricity networks. There is little existing literature on distribution networks directly but insights can be drawn from studies of transmission systems. The review highlighted that, as the CLASS Method has multiple consequences in terms of assets for operation of the distribution and transmission network, and facilitation of new connections, it is important to consider each aspect independently across the Electricity North West network. Also the importance of grid decarbonisation in the relative balance between impacts embodied in assets and those arising from losses is seen in a number of papers, with the compounding issue of marginal grid emissions factor also noted. This suggested that a scenario or sensitivity exercise would be important.

4 THE OUTCOMES OF THE PROJECT

The main outcomes from each work stream of the CLASS Project are detailed below

4.1 Customer engagement and feedback

Communicating with customers in the trial area

The ECP described in section 3.1 helped formulate effective communication plans and provide relevant and clear information to customers on trial circuits. This section summarises the findings from the ECP feedback which was designed to address three key questions:

- Do customers understand the CLASS concept?
- Which key components of CLASS need to be communicated to customers and how?
- How can the learning from the ECP be used effectively to design and implement a customer survey to test the CLASS hypothesis?

Do customers understand the CLASS concept?

The research found that with appropriate education customers generally understood the CLASS concept.

A direct learning from the Capacity to Customers (C_2C) project was the poor customer awareness of Electricity North West as a company, and a lack of understanding about the role of a DNO in the electricity sector. This finding was reinforced during the CLASS ECP. Therefore as part of any education, Electricity North West's role and its delineation with suppliers should be clarified in any customer communications.

A number of communication materials were shared with customers in order to optimise their understanding of CLASS. The CLASS video and the use of a kettle analogy (demonstrating how a 2% change in voltage would affect the time taken to boil a kettle by eight seconds) were effective in explaining a relatively complicated concept in a succinct and understandable way.

Which key components of CLASS need to be communicated to customers and how should they be communicated?

The key components of the Project that needed to be communicated included: a summary of the Problem and the Solution, the likely effect of the Method on customers, and how customers could help evaluate the success of CLASS by participating in the surveys.

Customers had an appetite for quite detailed information about the CLASS Solution. This included trial dates and duration, whether the tests would be intermittent and how their household/property and power quality might be affected. A further significant and direct benefit to communicate was the associated financial saving of the CLASS technologies compared to traditional reinforcement.

Customers felt that including advisory information outlining 'what to do in the event of a power cut' detracted from the positive message that no changes were anticipated in power quality as a result of the trials.

The ECP agreed that social media should not be utilised in isolation as a means of engaging with customers, due to constraints surrounding content and audience reach. The preferred approach was a customer leaflet, distributed to all customers on trial circuits.

The final customer leaflet, optimised over the course of two ECP meetings, clearly summarised the Problem, the Solution and the likely effect of the Method on customers. It also explained how customers on trial circuits could register to participate in the surveys. The leaflet contained an informative FAQ section which addressed the specific requirements and questions raised by the ECP in relation to the trials and provided contact information for Electricity North West. The leaflet was sent to all 485,000 customers on trial circuits in February 2014, before the start of the trials.

How can the learning from the ECP be utilised effectively to design and implement a customer survey to test the CLASS hypothesis?

The survey instrument was appraised by the ECP as clear and easy to understand with only minor changes suggested to the wording of some questions and their placement in the questionnaire. The ECP helped to clarify the explanation of unknown terminology and influenced the expansion of the list of common electrical appliances included in the survey.

The customer survey FAQ was considered to be a useful document to aid the recruitment of survey participants.

The ECP proposed that the maximum financial incentive of £150, available for taking part in the quantitative surveys should be referenced from the outset of the recruitment phase due to it being a highly motivating reason for participation. Beyond monetary incentives, the ECP also indicated a genuine interest in the CLASS Project and a desire to be kept informed about the progress of the trials.

A comprehensive summary of the framework and key findings from the research can be found in the ECP report.

Monitoring the effects of the CLASS trials on customers

Prior to the CLASS testing regime during the baseline surveys, 21% of customers at an aggregate level reported having recently noticed a change to their power quality. This fell significantly to an average of 15% over the course of the seasonal monitoring surveys. If the CLASS Method had been discernible to customers, the proportion noticing a change to their power quality would have increased during the monitoring waves. The statistically significant decrease strongly supports the CLASS hypothesis.

Further analysis was conducted amongst the 15% of customers who perceived a change in any aspect of their power quality during the monitoring surveys. A process of elimination was used to determine if the change could be directly attributable to the CLASS trials. The observations of customers who were interviewed as part of the control group were eliminated as they were not exposed to CLASS tests. Additionally, adverse effects were discounted amongst participants confirmed not to have been at the property when a test took place or where the effect did not coincide with the time of a test. This significantly reduced the proportion of customers who may have conceivably noticed an effect potentially associated with the CLASS Method to 3%. Such a low level of perceived changes in power quality was consistent across the monitoring seasons, and supported the hypothesis that customers found the trials largely indiscernible.

Overall satisfaction amongst the survey population was relatively high with 90% of customers scoring Electricity North West eight or more for their service (one representing the poorest score and ten the highest satisfaction rating). Scores were equally high amongst those customers who perceived a change in power quality during the trials (that may or may not have been due to CLASS). The relevance of this finding is that even when customers perceived a change in power quality, overall satisfaction with their supply was unaffected. These findings indicate that Electricity North West can be confident that implementation of the CLASS Method across its distribution region would have no detriment to power quality and would be indiscernible to customers. These findings support the transferability of CLASS and suggest that it could be applied across the wider GB network without any customer impact.

Customer enquiries outside of the customer survey

In parallel to the customer surveys, a robust framework was embedded to ensure that all enquiries and complaints received by Electricity North West, via its traditional reporting mechanisms, were monitored to highlight any power quality issues that might potentially be related to CLASS activities. During the live trial period a total of 11 power quality related complaints that may have been associated with the CLASS trials were received. These were thoroughly investigated to establish if there was a relationship with the trials. In each case, the issue was proven to be unrelated to the CLASS Method and attributable to either a local network fault or a problem with the customer's own installation, equipment or load.

A detailed summary of the customer research framework and results can be found in the Customer survey report and a peer review of the survey findings and methodology are available on the Project website.

4.2 Technology implementation and effectiveness

CLASS site selection

A detailed list of the primary substations selected for the CLASS trial based on the selection criteria above can be found in Trial substation selection methodology document. In brief:

- A total of 65 primaries were initially selected including five on a reserve list as a contingency to cover any unknown on-site practicality issues
- At least two primaries were included from each of the grid supply point groups
- All primaries selected were loaded to more than 75% of the firm capacity
- 17 primaries were included with a load index of five, ie the present or forecast loading is expected to exceed 100% of the primary firm capacity.

The primaries selected for the CLASS trial were judged to be representative of the range of primaries within the total Electricity North West circuit population.

CLASS system installation

The CLASS system was installed at 60 primary substations. All substations were monitored for voltage and demand and end point LV/HV monitoring was installed. Functions were successfully enabled/activated from the ENW dashboard and the NG dashboard via the ICCP link. The level of functionality depended on which of the four types of installation were fitted.

4.3 CLASS trials

The trials schedules were executed as planned, providing:

- Data for the University of Manchester and Liverpool to test the Project hypotheses
- Data to develop a robust voltage/demand matrix
- Customer learning though quantitative analysis
- Useful feedback and lessons learnt by testing the capability of new technology.

All trial data was uploaded to the web via iHost. Although the data was primarily for use by academic partners, it was also available for stakeholders upon request.

4.4 Data evaluation

Load modelling and voltage/demand matrix

A static load model was found to be the most appropriate load model for CLASS (load) measurement data as it captures the prolonged sustained response of the load following a voltage disturbance which is of interest in the CLASS Project.

$$P = P_0\left(\frac{V}{V_0}\right)^{K_p}, \quad Q = Q_0\left(\frac{V}{V_0}\right)^{K_q}$$

The above static exponential load model is proposed, where K_p and K_q represent the voltage exponents of real and reactive power. A static exponential load model is chosen for load modelling at all substations due to its simplicity and clear coherence in defining demand-voltage matrix.

The results demonstrated that a rise or fall in voltage produces a change in demand that changes diurnally and with the type of load. The Method has proven the hypothesis that innovative voltage regulation techniques can be implemented to provide voltage/demand response without impacting the quality of supply to customers.

It was found that the load model parameters describing weekday load behaviour are more consistent, ie less variable. The weekdays and weekend parameters are influenced by both the changing load-mix of the substations and by changes in the consumption pattern at weekends and even though the overall load mix may remain the same.

Estimated load model parameter values can be 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.

Figures 4.1 and 4.2 below show the minimum, maximum and average voltage exponents for both real, Kp, and reactive, Kq, power for four seasons for the three load characteristics. The exponent identifies the percentage demand response for 1% voltage change; ie for a load having a real power exponent Kp of 1.6, a 3% voltage change could generate a demand boost or reduction of approximately 4.92%.

Figure 4.1: Kp, Real power exponent values

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 4.2: Kq, Reactive power exponent values

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

Using the developed load model and an average exponent value Kp of 1.3 there is potential to unlock significant demand within the Electricity North West network and across GB. The values below show the potential demand response for Electricity North West:

- 57MW (summer minimum) to 163MW (winter maximum) for a 3% voltage reduction
- 94MW (summer minimum) to 271MW (winter maximum) for a 5% voltage reduction.

Consequently, if the CLASS approach is adopted across the whole of GB there is potential to unlock a 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.

For each of the 15 sites involved in trial 1 (five of each load type) a full 365 day, 24-hour matrix was produced. These matrices were then used as a representative set to reflect the three load types identified in the trial selection criteria: mainly domestic, mainly non-domestic and mixed. Each primary substation load within the Electricity North West network was characterised in the initial phase of the Project using the peak load sharing (PLS) methodology.

An appropriate voltage/demand matrix is applied to each primary substation within the CLASS dashboard to enable a real-time estimation of the demand response at primary and group level.

For further details of trial 1 showing the full methodology and results, refer to the Load profiling modelling study final report.

Quantification of PDR by simulation

The voltage/demand matrices developed from trial 1 tests were used as a company representative set, applied to each primary substation of corresponding load type within the Electricity North West network, to estimate the aggregate demand response across the Electricity North West network and GB.

To validate the demand response results using the absolute measured voltage/demand data above, system modelling studies were carried out to compare the measurement-based load models with literature-based models. For quantification it was necessary to develop the literature load model which could be applied to each of the primary substations in the Electricity North West network to determine the demand response across the Electricity North West network and the whole of GB.

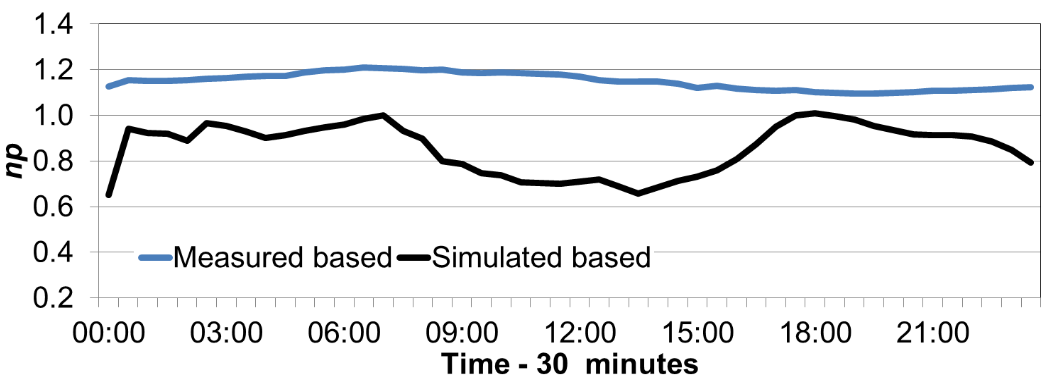
The simulation methodology for total demand response quantification used a bottom-up approach, maintaining LV voltages at the most remote points compliant with ESQCR and BSEN60150. The LV voltage level was then used to determine the tap capability at each primary substation throughout each half hour period of the day, referred to tap capability scenario. The use of a 'tap capability' method determines the theoretical voltage reduction available at any half hour period.

Comparison between measurement-based and literature-based load models

The literature-based load model was designed to provide a reliable description of the voltage/demand relationship of mainly domestic primary substations. Due to the lack of industrial and commercial load data it was not possible to validate mainly non-domestic and mixed type load models and therefore the non-domestic component of the demand was assumed non-responsive. Consequently, a comparison between the literature- and measurement-based load models for residential primary substations was the main focus.

Mainly domestic load model

Figure 4.3: Representative load model for mainly domestic primary substations – winter



- Figure 4.3 shows the real power exponent, np, for every half hour over a 24-hour period
- As the literature model accounts for the known domestic proportion of load (using PC1 and PC2) it is not expected that the literature or measured load models would be identical. What can be seen from the above is that the literature model underestimates the demand response for most of the day except at peak time, when the demand is predominantly domestic
- The most significant difference between both models occurs during the late morning and early afternoon. This difference is due to the non-domestic proportion of load which is considered non-responsive.

Mainly non-domestic and mixed load model

Representative load modes were developed for mixed and mainly non-residential primary substations. In these cases the agreement between the two models is much lower, as would be expected, as the neglected non-residential demand represents a dominant component. Indeed, as shown below in figures 4.4 and 4.5, the representative literature-based load model is not able to properly represent the demand responsiveness, especially in the case of mainly non-domestic substations where the difference is significant at all times.

Figure 4.4: Representative load model for mainly non-domestic primary substations – winter

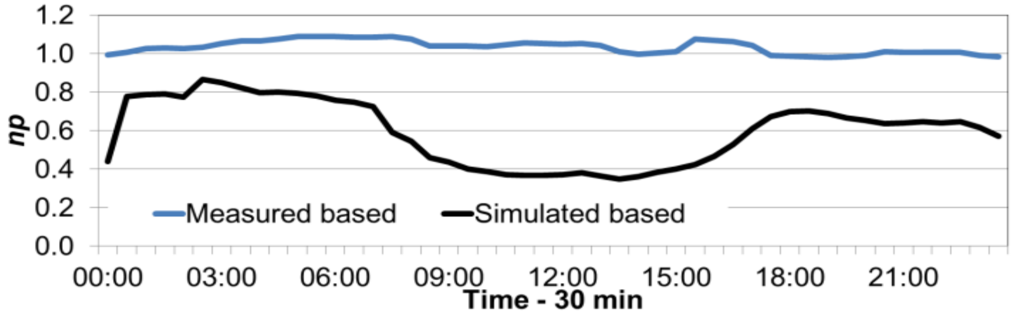
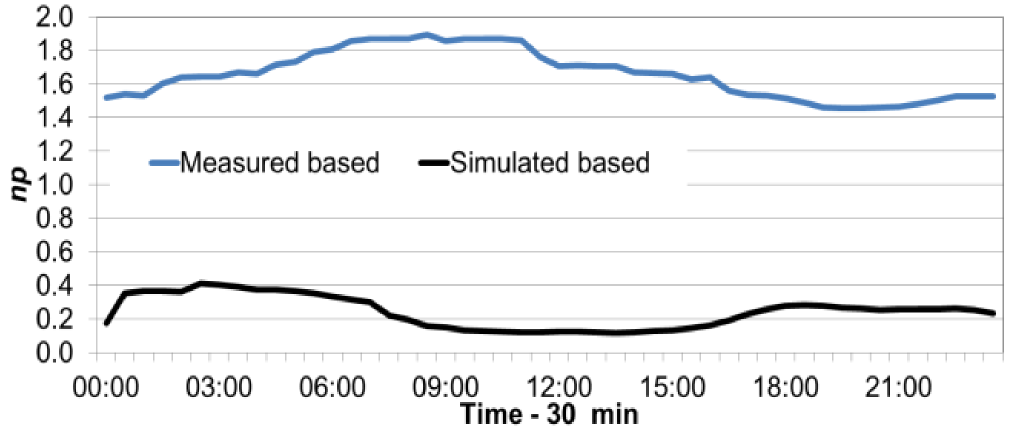


Figure 4.5: Representative load model for mixed primary substations – winter



Figures 4.4 and 4.5 above show the real power exponent, np, for each half hour over a 24-hour period.

Analysis of the load models has shown that the validation process is accurate when considering domestic type loads. There is little correlation in the exponent values in any given day between the measurement and literature-based models except for winter peak time when load is predominantly non-domestic.

Tap change capability scenarios

Using the bottom-up approach model described above, the level of voltage reduction available on the LV side of the primary transformers was calculated for any half hour period in the day in terms of tap capability, while maintaining LV voltage levels within statutory limits.

Figure 4.6: Tap capability scenarios – all seasons day

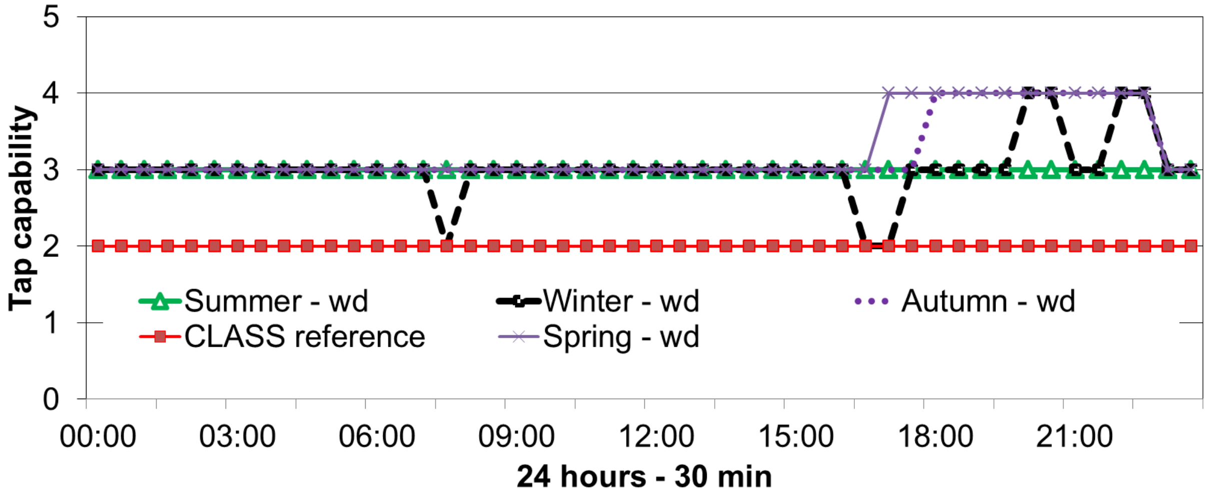


Figure 4.6 above shows the generalised tap capability at a primary substation across all seasons. Power flow studies were performed to quantify the extent to which the voltage at the primary substation could be reduced, ie the voltage capability. The potential voltage fluctuations at the primary side of the substation were also catered for by carrying out a simplified analysis using one EHV network model.

During all seasons a two tap step reduction (ie around 2.86 %) can be introduced at primary substations. In summer a three tap step reduction is possible due to the limit imposed by the OLTC headroom. In spring and autumn peak times a four tap step reduction (ie 5.43 %) is possible.

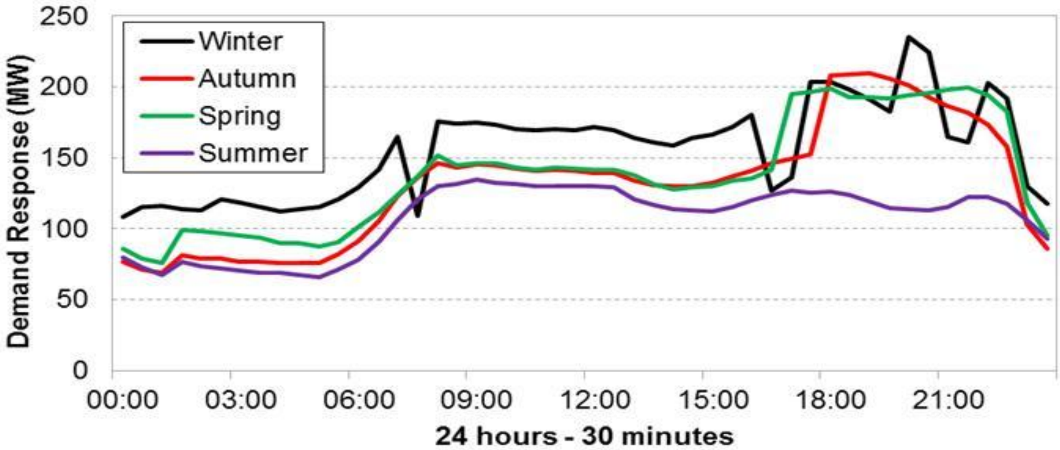
Indeed, trial 2 confirmed that 3% and 5% voltage reduction at peak time at all 60 primary substations resulted without any noticeable impact to customers. Furthermore no voltage violations were recorded that could be attributed to the CLASS trials. This is not in contrast with the literature outcomes where at peak time in winter only 1.43% is achievable. Indeed this represents a very conservative figure (called 'conservative scenario') based on three HV networks only. In addition, the LV network constraints analysis flags a customer as 'non-compliant' even in those cases where its supply voltage violates the statutory limits for a fraction of volts and for a few instants only. However, in these cases, customers' appliances are rarely negatively affected as they are designed to work properly with a wide voltage range.

Electricity North West demand response

The demand response in the Electricity North West area using the measurement-based models and the tap capability model was found to be a minimum of 65MW during the summer and 235MW in the winter. Figure 4.7 shows the variation in demand response across all four seasons. The maximum demand response in winter occurs at around 8pm. However, at winter and autumn peak time the demand response was found to be approximately 200MW.

Using the measurement-based model, the results have shown a voltage reduction of 5% could yield up to a 6.5% demand reduction and therefore defer the capital replacement of primary transformers up to three years, depending on the rate of load growth.

Figure 4.7: Aggregated demand response: Electricity North West area – all seasons using measurement-based load models and tap capability model



The aggregated Electricity North West area demand response was quantified by reviewing the response for three load models:

- Literature-based time varying domestic model only
- Measurement-based time varying model.
- Enhanced literature-based model (domestic model + a non-time varying real power exponent value of 1.3 to represent non-domestic load).

The literature-based load model for each substation considered only the proportion of domestic customers whereas the measurement-based model accounts for the total load response. Figures 4.8 and 4.9 below show the expected difference between the two models for a typical winter and summer day.

Figure 4.8: Winter day demand response: Electricity North West area literature and measurement-based model with tap capability

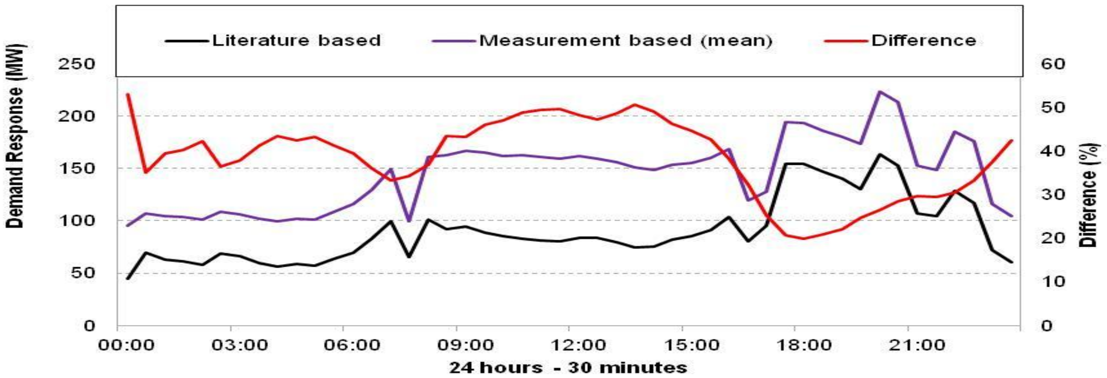
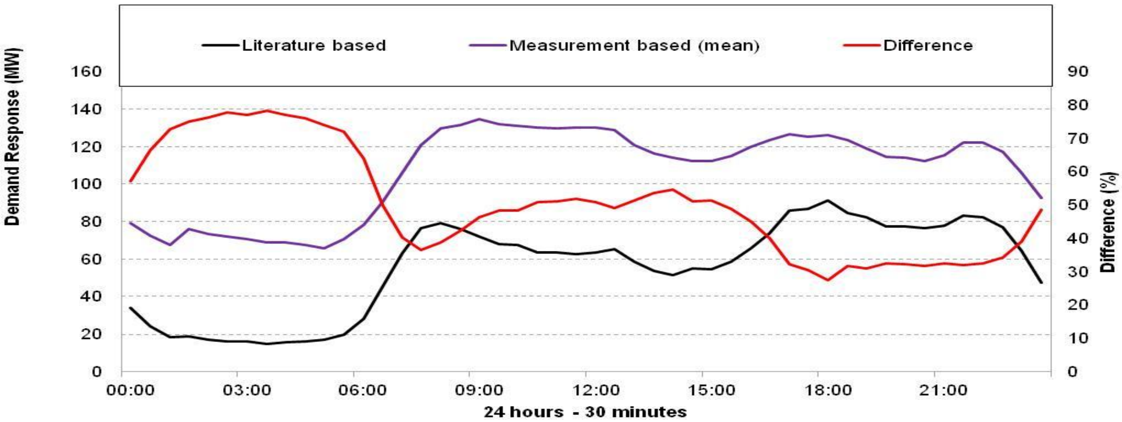
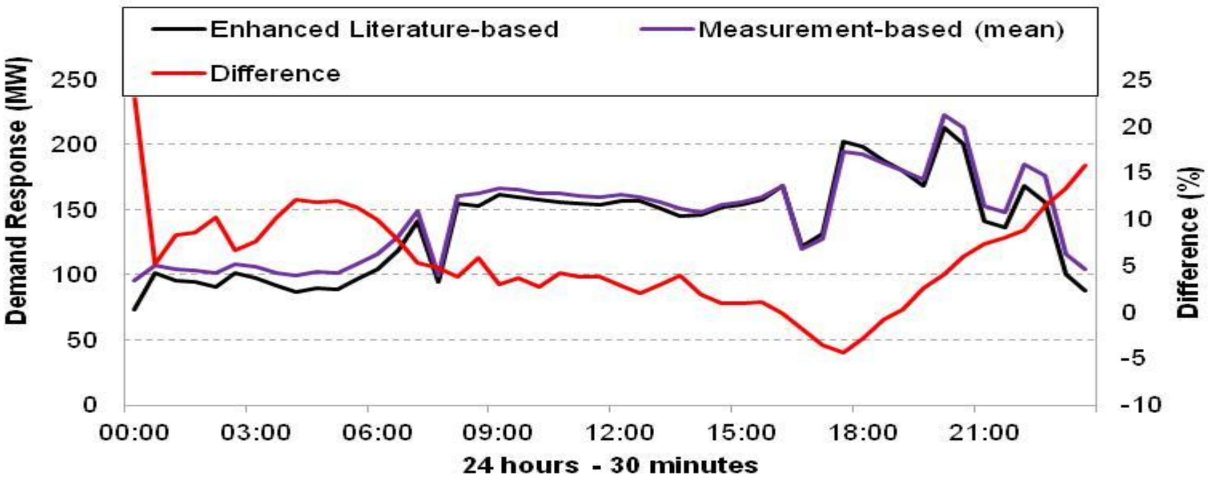


Figure 4.9: Summer day demand response: Electricity North West area literature- and measurement-based model with tap capability



As such, to provide an accurate quantification of demand response, an enhanced literature model was developed using the literature-based model for domestic load and a non-time varying real power exponent value of 1.3 to represent the non-residential component. Figure 4.10 shows the demand response, comparing the enhanced literature model with the measurement-based model. The models show very similar values confirming the suitability of the literature-based domestic model.

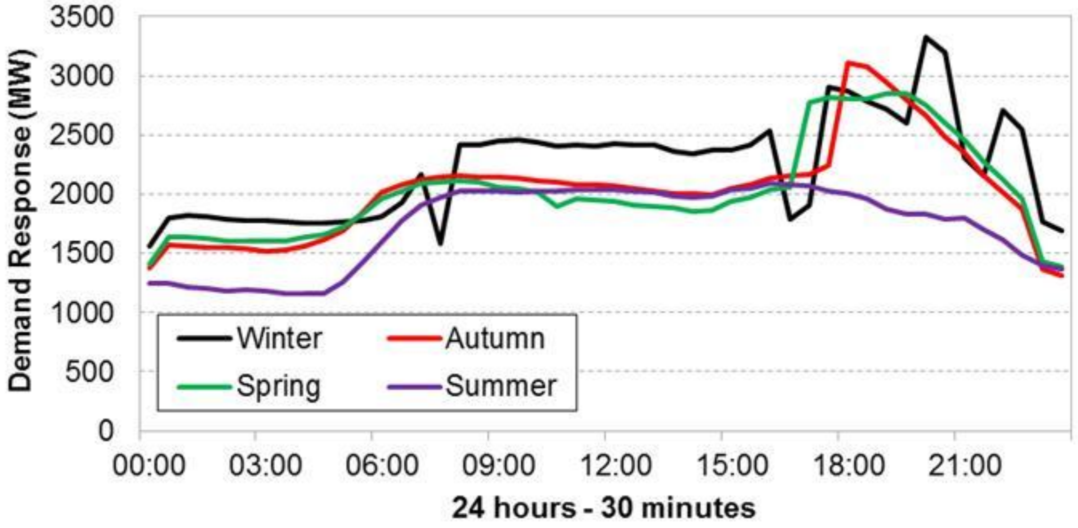
Figure 4.10: Winter day demand response: Electricity North West area enhanced literature and measurement-based model with tap capability



Quantification of GB demand response

The demand response across the whole of GB using an enhanced literature-based model and an optimistic tap capability model was found to be a minimum of 1.1GW during the summer and 3.3GW in the winter. Figure 4.11 shows the variation in demand response across all four seasons. The maximum demand response in winter occurs at around 8pm. However, at winter peak time the demand response was found to be approximately 2.8GW.

Figure 4.11: Estimated demand response for whole of GB – all seasons enhanced literature load model with tap capability



The significance of the potential demand response that CLASS may provide is demonstrated by a nationwide quantification. The quantification used a different methodology than that used solely for the Electricity North West network, due to the lack of information available for other DNOs' primary substation load.

The GB demand response was quantified by identifying the following:

- Number of dwellings in the UK
- Domestic customer proportion in the UK
- Average demand profile per single dwelling in the UK
- UK demand.

The aggregated GB demand response was quantified using an enhanced literature load model, where the non-domestic load was modelled with an exponent value of 1.3.

For further details of the quantification of demand response, showing the full methodology and results, refer to the Offline demand response capability assessment final report.

Frequency response by demand management

The results from the trials have shown that the CLASS Solution could provide a demand response for frequency response. Stage 1 and stage 2 automatic frequency response functions were tested a number of times both automatically and manually from the CLASS dashboard. Analysis of the results shows the following response times:

- Stage 1: Demand response in <500ms
- Stage 2: Demand response between 20 seconds to 120 seconds.

The results show that a stage 1 response is almost instantaneous whereas a stage 2 response is dependent on the age and type of tap changer. The faster, more modern tap changer relays performed very quickly but the few older schemes took almost 120 seconds to complete operations.

The results of the frequency response tests and automatic operation following a frequency excursion show that the CLASS Solution could provide a demand response within the existing frequency market timeframes.

Reactive power absorption

The CLASS trials demonstrated that reactive power absorption by transformer tap staggering can provide significant benefits to NG. Figures 4.12 and 4.13 show the level of reactive power absorption when applying a two to ten tap stagger.

Figure 4.12: Reactive power absorption across Electricity North West network

Season	2 tap stagger (MVAR)		4 tap stagger (MVAR)		6 tap stagger (MVAR)		8 tap stagger (MVAR)		10 tap stagger (MVAR)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Spring	14.6	17.7	58.9	69.8	129.4	156.1	179	267.9	189.4	358.3
Summer	15.	17.4	59.7	68.1	133.8	151.8	188.6	244.3	196.5	303.7
Autumn	14.9	18.7	59.2	71.9	132.1	159.3	177.5	270.1	177.5	356.2
Winter	15.6	19.5	61.6	75.3	131.2	167	184.1	275.1	215.4	359.4

If the CLASS reactive power absorption was applied across the whole of GB there is potential for levels of absorptions as shown in table 4.13:

Figure 4.13: Reactive power absorption across GB

Season	2 tap stagger (GVAR)		4 tap stagger (GVAR)		6 tap stagger (GVAR)		8 tap stagger (GVAR)		10 tap stagger (MVAR)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Spring	0.16	0.19	0.65	0.77	1.42	1.72	1.97	2.95	2.08	3.94
Summer	0.17	0.19	0.66	0.75	1.47	1.67	2.07	2.69	2.16	3.34
Autumn	0.16	0.21	0.65	0.79	1.45	1.75	1.95	2.97	1.95	3.92
Winter	0.17	0.21	0.68	0.83	1.44	1.84	2.03	3.03	2.37	3.95

From the results it can be seen that the demand level impacts the level of reactive power absorption through the use of the tap stagger technique. In general, the network has higher reactive power absorption capability when demand is high.

In summer the normal operating tap position at primary transformers is one or two taps lower than in winter. As such, when carrying out symmetrical tap staggering, it is unlikely that any more than a six tap stagger will be available.

Simulations were carried out for tap staggers two to ten, however in reality, due to the nominal tap operating position and potential voltage rise or drop for the loss of a transformer, a six tap stagger is likely the limit of availability due to voltage regulation.

With this level of reactive power absorption there is potential to provide reactive power services to NG. This service could be used to defer the need to replace existing assets or potentially remove the need for new installations. The tap staggering method offers a flexible, dynamic, cost-effective and low carbon solution to the existing techniques used to absorb reactive power.

For further details of the quantification of reactive power absorption, showing the full methodology and results, refer to the Reactive power absorption capability assessment final report.

Asset health

From the health point of view, the impact of CLASS techniques on the transformer main tank is minimal and is limited to a small number of transformers with high peak loads when implementing the transformer tripping CLASS technique. This can be attributed to the following two reasons: 1) the design philosophy of most primary substation transformers allows short-term overloading, with both the cooler and protection system preventing the transformer from experiencing excessively high temperatures; 2) the existing low load levels allow the transformers room (in terms of thermal capacity) for implementing CLASS techniques. In spite of this, when implementing CLASS techniques, the safe operation of the network cannot be neglected due to potential transformer alarms and trips which occur because of possible hot-spot temperature violations during transformer tripping.

External temperature changes were insensitive to CLASS operations. Those temperature rises were small. This implies that no significant heating of the bulk oil is happening within the timescale of the tests although there might well be localised hot spots.

The acoustic signature for the transformers for pre-, during- and post-tap changer operation did not show any significant changes for non-CLASS and CLASS operations. This implies that mechanically there were negligible effects on the mechanism. For further details refer to the Asset health final report.

Results for SQSS

A review of the National Electricity System Security and Quality of Supply Standard, SQSS, and other relevant standards and codes, was undertaken to determine if the CLASS methodology required changes in their application. Following the results from CLASS trials it was concluded that no changes were required. However, significant learning was identified through the trials and this improved understanding can inform other processes and considerations, including the following:

- Inform the assessments that NG use when checking that voltage step changes are within the limits quoted in the SQSS. In particular, the CLASS outputs will inform NG's in-house guidance documents on modelling load response
- Improve the quality of modelling and forecasting
- Enable a more informed fundamental system review in the longer term, for example considering definition of peak demand or acceptable operational voltage ranges
- Possible relaxation of the voltage limits in ESQCR Regulation 27 would enable a more widespread application of the CLASS voltage reduction technique to provide demand response
- CLASS findings will provide NG with improved understanding of the demand reduction that will be achieved by voltage changes instructed under OC6
- Uncertainty with regard to applying predicted CLASS benefits in security of supply assessments because P2/6 does not explicitly allow for reductions in demand as a response to operational actions
- Value in improving the accuracy of investment planning modelling and operational planning modelling, and in determining the effectiveness of applying voltage reduction instructions during power system operational emergencies. An accurate understanding of the demand voltage relationship is also important when modelling networks that are constrained by voltage stability.

For further details refer to the SQSS and code review.

Carbon impact

The range of plausible carbon impacts is quite substantial between the different elements of the CLASS services. There are very small asset impacts from the autonomous substation controllers required to deliver the CLASS services, while the potential benefits in the demand response operations category are over a thousand times greater.

The following general conclusions are drawn on the carbon impact of the three CLASS services:

- CLASS PDR has the potential to defer substantial amounts of network reinforcement but not eliminate the requirement entirely
- The asset carbon impact is outweighed in every category by operations. Strictly it is not comparable in the case of PDR as the benefit of CLASS is a deferral rather than outright prevention of reinforcement
- The total benefit to the NETSO from the combined demand response and reactive power ancillary services could be as much as 116,000 tCO_2e per annum.

For further details refer to the Carbon impact assessment final report.

5 PERFORMANCE COMPARED TO THE ORIGINAL PROJECT AIMS, OBJECTIVES AND SDRC

Successful delivery reward criteria

Title	Criterion	Required evidence	Actual evidence
Technology build workstream	1. Design regulation scheme for substation voltage controllers by December 2013 2. Select sites for installing voltage controllers and monitoring equipment by June 2013 3. All hardware including substation controllers, and monitoring equipment	1. Publish the design of the regulation scheme for substation voltage controllers by February 2014 2. Publish the site selection report including the methodology by August 2013 3a. Network monitoring equipment installed and commissioned by March 2014	Voltage regulation scheme Trial substation selection methodology Monitoring location selection

Title	Criterion	Required evidence	Actual evidence
	communications infrastructure installed and commissioned by March 2014 4. Design, build, test and commission ICCP link between Electricity North West's and NG's control centres by March 2014	3c. Publish the commissioning reports by April 2014 3d. Technology go-live by April 2014 4a. ICCP installed and commissioned by March 2014 4b. Publish the ICCP commissioning reports by April 2014	Commissioning report ICCP report
Trials workstream	1. Trial area selected by June 2013 2. Trials and test regime design completed by December 2013 3. Live trials commence in April 2014 4. Tested the capability of the voltage control system for all trial scenarios by May 2015 5. Transfer trials data every quarter with all trials data transferred to The University of Manchester by June 2015	1. Publish on CLASS website map of trial area by September 2013 2. Publish on CLASS website trials and test regime report in January 2014 3. Baseline customer survey initiated in April 2014 4. Publish on CLASS website an initial capability report for all the trial scenarios by September 2014 5. Evidence of test trial data transferred by July 2014	Trial area map and postcode search Trial design and test schedule Capability report Regular emails sent to UoM with completed test schedules
Customer engagement	1. Create the customer engagement plan and data privacy statement by July 2013 2. Produce customer marketing/campaign materials by January 2014 3. Deliver the customer survey pilot workshop by March 2014 4. Control group and trial area customers identified and first communication pamphlets distributed in February 2014, subsequent forms of communication will be delivered as per Project Plan 5. Customer surveys completed by June 2015	1. Send for approval the customer engagement plan and data privacy statement to Ofgem by July 2013 2. Publish on CLASS website customer marketing/campaign materials by September 2013 3. First customer workshops held by October 2013; workshops completed by December 2013 4. Publish on CLASS website control group and trial area customer communication by January 2014 5. Customer surveys completed, with an initial summary report published by June 2015	Customer engagement plan Data privacy statement Customer leaflet Customer survey summary report
Research workstream	1. Deliver the network modelling reports by September 2015 2. Deliver the voltage profile modelling reports by September 2015 3. Deliver the asset health study report by September 2015 4. Deliver customer survey report by September 2015 5. Develop change proposals for NETS SQSS by June 2015	1. Publish on CLASS website interim and final network modelling and analysis reports by January 2015 and September 2015 respectively 2. Publish on CLASS website Interim and final profile modelling study by January 2015 and September 2015 respectively 3. Publish on CLASS website interim and final asset health study report by January 2015 and September 2015 respectively 4. Publish on CLASS website customer survey report by September 2015	Load profiling modelling study interim report Load profiling modelling study final report Offline demand response and reactive power capability interim report Offline demand response capability assessment final report

Title	Criterion	Required evidence	Actual evidence
		5. Publish on CLASS website NETS SQSS change proposal report by June 2015	Reactive power absorption capability assessment final report Asset health interim report Asset health final report Carbon impact assessment final report Customer survey report SQSS and code review
Learning and dissemination workstream	1. Produce first video podcast of the series by September 2013 with the remaining to follow as per Project Plan 2. Develop and launch the CLASS Project website and social media forums by September 2013 3. First annual LCNI conference attended and first webinar and learning event held by April 2014, with others to follow as per Project Plan 4. Raw monitoring data is initially made available on demand by September 2014, and updated per season	1. Publish on CLASS website first video podcast by September 2013 2. CLASS website and social media forums is live by September 2013 3. Active participation at annual LCNI conference, and first webinar and learning event held by April 2014 with others to follow as per Project Plan 4. Raw monitoring data is downloadable from CLASS website by September 2014	Podcasts and webinars Website Learning event 1st webinar 2nd webinar 3rd webinar Website (available until end October)
Closedown and long-term monitoring study	1. Produce a closedown report and initiate a long-term monitoring study with NG	1. Provide confirmation from NG that the long-term monitoring study has been initiated	Appendix C: Long-term monitoring study

CLASS hypotheses

CLASS Method creates a demand response and reactive absorption capability through the application of innovative voltage regulation techniques.

The CLASS Method showed that by operating existing primary transformer circuit breakers and on-load tap changers in a coordinated and novel way, a meaningful and significant demand response and reactive power absorption capability can be obtained.

Customers within the CLASS trial areas will not see/observe/notice an impact on the power quality when these innovative techniques are applied.

It was proven that customers did not notice any detrimental change in power quality during the trial periods.

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.

The CLASS trials have shown that a 5% change in voltage yields a typical real power demand change of between 4% and 8%. The variance is due to the mix of customer types, seasonal and daily variation.

The CLASS Method will defer network reinforcement and save carbon, by the application of demand decrement at the time of system peak.

CLASS has shown that using a 5% reduction in voltage will on average produce a 6% reduction in demand during a winter peak demand period. Based on DECC load growth scenarios this would defer primary transformer asset replacement by up to three years.

The CLASS Method uses existing assets with no detriment to their asset health.

Before and after the CLASS trials, samples of primary transformer main tank and on-load tap changer oil were taken. Analysis by the UoM and the UoL showed there was no detriment to their asset health.

In addition to validating the hypotheses a number of other key learning outputs were concluded:

A methodology has been developed to allow the Solution to be deployed across GB.

The CLASS Project sought to make the methodology used to be as universally applicable to GB DNOs as possible. This was done by using existing technology used by other DNOs and off-the-shelf market products.

Understanding of the changing relationship between voltage and demand.

CLASS sought to use modern transducers and data transfer systems to measure the voltage/demand relationship very accurately. Daily and seasonal changes in the relationship were observed.

Confirmation that the techniques do not compromise a DNO's existing demand control obligations.

As part of the Project the existing demand control obligations (OC6 of Grid Code and NETS SQSS) rules and procedures were reviewed with regards to any changes they may be needed to accommodate the introduction of CLASS techniques. The review concluded that no changes were required.

High peak demands can be reduced by CLASS to defer network investment.

The CLASS Project showed that by applying a voltage reduction as peak load levels approach, a reduction in demand can be achieved. This reduction could defer or prevent the need for network reinforcement.

Voltage control can be provided by DNOs for TSO at times of low load.

The tap staggering technique on pairs of primary transformers created reactive power demand which could assist TSOs in reducing their voltage at times of low load.

CLASS can help in preventing excess generation conditions occurring at times of low load.

The voltage boost function was shown to increase the amount of load on the system. This increase in load could be used at a time when the amount of generation exceeds the load prior to a CLASS voltage boost being applied.

CLASS can intervene in response and reserve markets to reduce customer costs.

Two of the CLASS functions were developed to assist NG in system frequency stability. For a very fast response to low system frequency events (< one second) one of a pair of primary transformer circuit breakers was opened when system frequency fell to 49.7Hz. In order to respond to a system frequency event at 49.8Hz, an automatic voltage reduction of 5% was applied (<30 seconds).

5.1 Customer engagement and feedback

Communicating with customers in the trial area

This activity was successful in establishing an ECP consisting of three groups of ten customers, with the objective of exploring the most effective method of communicating CLASS to customers. The feedback obtained was used to help design a customer leaflet which was sent to 485,000 households and businesses on the CLASS trial circuits. The leafleting campaign generated expressions of interest from over 3,500 individuals who registered for the customer survey. The ECP was also influential in guiding the development of the survey instrument, ensuring it was sufficiently robust; easy to understand and administer; provided a framework to maximise the learning outcome; and detect any customer impact that could potentially be attributed to the CLASS Method.

Monitoring the effects of the CLASS trials on customers

This activity was successful in repeatedly engaging with 496 domestic and 200 I&C customers on the CLASS trial circuits. These customers participated in extensive research which explored whether the CLASS Method was indiscernible to customers. This hypothesis was proven via a two stage approach: a baseline survey which provided a benchmark for power supply quality before the start of the trials; and a series of monitoring surveys across all trial seasons to monitor any changes in customers' perception. This research element of the customer engagement approach was successful as it provided sufficient evidence, based on a large sample of 1357 monitoring surveys, that the CLASS Method had no adverse effect on customers' perceptions of power quality. The research conducted was sufficiently robust to further prove the validity of the hypothesis across a broad range of analysis groups, for example by trial type, customer type, test and control groups, and by season.

5.2 Technology implementation and effectiveness

The CLASS bid sought to prove the voltage/demand relationship hypothesis and by using existing primary substation assets in a novel way how this relationship could be exploited to change network demand and thus deliver carbon reduction and financial savings for GB customers.

The use of existing assets such as primary tap changers and associated 11/6.6kV circuit breakers via the Electricity North West/NG dashboards, ICCP link, legacy SCADA system, ASC and modern AVC schemes was proven to be a cost-effective and relatively simple method of achieving controlled voltage changes and thus demand (to varying levels).

The bid specified that a regulation scheme for substation voltage controllers would be designed by December 2013; this was achieved. The bid also specified that the CLASS sites would be selected for installing voltage controllers and monitoring equipment by June 2013; and that the CLASS hardware (including substation controllers and monitoring equipment communications infrastructure) would be installed and commissioned by March 2014; this was achieved. The CLASS bid stated that the Project would design, build, test and commission an ICCP link between Electricity North West's and NG's control centres by March 2014; this was achieved.

For further detail of how this was implemented, refer to the voltage regulation report and commissioning report.

5.3 CLASS trials

The CLASS trials test schedule was developed to rigorously test the hypotheses of the Project. The trials sought to prove the voltage/demand relationship and the ability to provide additional services to NG in terms of frequency response and reactive power absorption. In addition to the above, the trials needed to demonstrate that the methodology did not cause any impact on customer quality of supply or asset health.

The test schedule was followed throughout the Project, however, due to unforeseen network faults, there were occasions when the test schedules had to be revised. Where a test was not undertaken, a revised plan was provided, ensuring the volume of tests was maintained. Over the time of the Project the actual number of tests carried out exceeded the initial plan due to the refinement of the technology, providing flexibility to test groups or areas rather than at single sites.

The test regime and trials provided the University of Manchester and University of Liverpool with sufficient data to carry out a comprehensive assessment of the CLASS techniques.

5.4 Data evaluation

The CLASS Project was developed to show how innovative, low cost voltage management techniques could be installed with existing network assets to provide a demand response. At the heart of CLASS was the natural relationship between voltage and demand. The CLASS trials, developed with the University of Manchester, were designed to test the voltage/demand relationship and demonstrate through post-test analysis, the relationship and potential demand response. In addition to the demand response, other tests were carried out to assess further benefits such as demand response for frequency response and voltage control to support NG by the absorption of reactive power.

Following assessment of the trial data the following benefits have been found:

- The voltage/demand response is not linear. A 1% voltage change could result in an average MW demand response between 1.3% to 1.36%
- During the trials every primary substation in the trial area was subjected to a series of 3% and 5% voltage reduction tests for a period of time ranging from 30 minutes up to 180 minutes. During this period no voltage complaints were received and furthermore no voltage excursions outside of statutory limits were recorded
- The ability to reduce network voltage at times of peak load provides the ability to defer asset replacement for a period of time. If a 5% network reduction was applied across Electricity North West this could potentially unlock 270MW
- If a 5% network reduction was applied across GB, based on a winter MD of 52GW, the CLASS technique could unlock 3.3GW of demand
- Although it is clear that the CLASS Method will defer network reinforcement, it is very difficult to predict the exact time period due to load growth uncertainties. It is estimated that CLASS could defer an assessment replacement scheme by up to three years

- The CLASS technique can provide NG with a demand response for frequency reserve services. The results from the trials have shown that demand response can be achieved in less than 0.5 seconds
- The trials for reactive power absorption indicated a significant benefit. It is estimated that across the Electricity North West network a maximum of 167MVAr could be absorbed during winter peak periods and 133MVAr during the summer minimum. It is estimated that in GB a maximum of 1.84GVAr could be absorbed during winter peak periods and 1.67VAr during summer. These results indicate there is an opportunity to provide NG with reactive power services
- The total carbon impact benefit to NG from the combined demand response and reactive power ancillary services could be as much as 116,000 tCO2e per annum.

6 REQUIRED MODIFICATIONS TO THE PLANNED APPROACH DURING THE COURSE OF THE PROJECT

6.1 Customer engagement and feedback

Communicating with customers in the trial area

No changes were required to the planned approach.

Monitoring the effects of the CLASS trials on customers

The customer workstream anticipated unforeseen challenges associated with the delivery of a complex customer research activity, in conjunction with the CLASS trial schedules. Therefore a flexible approach was adopted to make appropriate adjustments to customer engagement activities, if required. Several small changes were made during the course of the Project. The reasons for and subsequent course of action are outlined below.

Compensating for planned tests that did not occur as scheduled

On occasion, factors outside the control of Electricity North West prevented a planned test from taking place as scheduled. The customer survey programme was flexible enough to be amended during the trial period to ensure that a sufficient 50:50 balance of test and control interviews, representative of each test and sub-group, was maintained to robustly test the hypothesis.

Expansion of test window to improve the likelihood of successful testing within planned timings

The monitoring surveys were designed to identify genuine changes to customers' perceptions of supply quality. Therefore, a robust test and control survey methodology was adopted to validate the findings, as it was recognised that survey customers questioned about power quality had a heightened sensitivity to changes and this might potentially elicit false reporting.

A key feature of the customer surveys was to record whether participants had been at their properties at the time of the test and therefore in a position to accurately comment on any observed effects. On the rare occasion that a test had taken place on the planned day but outside of the scheduled test window, the interview data was retrospectively allocated to the control sample, as it was not possible to accurately confirm if the participant was present during the test. This had the potential to upset the balance of test and control interviews in favour of the control sample.

Widening the planned testing window to an hour either side of the original schedule provided Electricity North West with a greater degree of flexibility within which to conduct the tests and increased the number of surveys classified as test interviews. Customers were subsequently asked if they were present during the extended testing time band. This approach improved the successful completion of test surveys over the winter and spring seasons.

6.2 Technology implementation and effectiveness

The bid described the various types of CLASS primary sites and included an option of a modified legacy AVC scheme. In the bid it was proposed that such an option would use interface relays to communicate to the ASC and influence the actions of the legacy scheme to produce the CLASS functions and hence its effects. The number of such schemes was at that stage put at zero. However, it was felt that the limitations and cost comparison of such a scheme would need benchmarking against the MicroTAPP schemes. As such eight sites were implemented using such a scheme and were defined as type 4.

The type 4 sites used the Argus 8 relays as a substitute for the MicroTAPP functionality. However, this did not involve the tap stagger function (TSF), as most of the type 4 legacy schemes were master/follower or circulating current schemes; these would have required major redesign and rewiring to prevent out-of-step/lock-out situations arising in tap stagger mode especially where tap position information was not readily available from a second set of tap position indication (TPI) resistors on each transformer. In order to commission the new Argus 8 AVC interface scheme, the input voltage of each AVC scheme was modified at each of the Argus 8 interposing VT tap positions. A load current transducer was fitted in series with the transformer LDC CT to provide transformer load information to the ASC. This transformer load information was required for a number of the CLASS functions; in particular automatic demand reduction function-network reinforcement deferral (ADRF-NRD) and APFR required it to work effectively.

The cost of producing the Argus 8 type 4 solution was about half the cost of the average type 2 MicroTAPP retrofit site. The only serious limitation of the type 4 schemes compared to the MicroTAPP (type 1, 2, 3A) sites was the lack of a tap stagger function. All other CLASS functions were achieved including the very fast frequency response tripping sites (type 3B) at Romiley and Longsight.

The bid document left open the possibility of using the existing SCADA system to pass the CLASS monitoring data through. This option was explored and subsequently discounted due to the lack of data link speed from existing RTU (SCADA outstations at primary substations) to the central control system. The data was taken from the new CLASS transducers associated with the primary transformers and channelled through a RS485 high speed link to a Nortec Envoy unit which in turn broadcast it via 3G to an iHost website. The transducers at many legacy primaries required an upgrade but were almost identical to those installed for new business as usual sites; however the CLASS transducers were fitted with an RS485 output option.

6.3 CLASS trials

The CLASS trial schedules were initially developed on a site-by-site basis to capture data as necessary for each trial.

The trial 2 (voltage reduction) tests were developed to cover each of the ‘time variation’ windows for every day for 14 primary substations. The schedule was planned to carry out tests at single sites, some during one time period and other sites at different periods in the day. To increase the volume of tests and therefore data, the test plan was revised to carry out trial 2 tests at all 60 sites in the trial areas and to activate the test on a group basis rather than on an individual site basis. This also had the advantage over the single site-by-site strategy when there were planned or unplanned outages.

Following the installation and commissioning of the voltage regulation equipment, it was found that the tap stagger functionality could not provide the reactive power absorption levels required. A revised set of manual tests were carried out to account for this and ensure that the University of Manchester had sufficient data to quantify the reactive power absorption capabilities.

The planned test methodology was not inappropriate but improvements were made to overcome technical limitations, planned or planned network outages, simplification and best use of control room resource and time. The modified approach provided more tests and therefore more results to support the hypotheses.

6.4 Data evaluation

No change to approach.

7 SIGNIFICANT VARIANCE IN EXPECTED COSTS

£000s Cost Category	Total Forecast	Budget	Variance	Variance	Reasons for >10% variance
Labour	**1,913**	**1,948**	**35**	2%	
Data management	43	32	(11)	-35%	Additional work to improve support for response to customer calls
Data routing configuration	60	99	39	39%	Efficiencies identified that reduced required works
Installation and configuration of dashboard hardware and software	74	83	10	11%	
Monitoring equipment	240	236	(4)	-2%	
Project management	1,027	1,035	8	1%	
Purchase and installation of substation controllers	120	99	(20)	-21%	Additional work identified
Publicity and dissemination	20	20	0	0%	
SOAP Interface to PoF	142	156	14	9%	
Voltage controllers interface	188	188	(0)	0%	
Equipment	**934**	**1,141**	**208**	18%	Efficiencies identified
Purchase and installation of substation controllers	591	657	66	10%	
RTU installation	18	172	154	90%	Scale of RTU installation work was found to be lower than planned
Monitoring equipment	326	313	(13)	-4%	
Contractors	**3,533**	**3,644**	**112**	3%	
Purchase and installation of substation controllers	1,006	1,125	119	11%	
Installation and configuration of ICCP	33	27	(5)	-20%	Minor additional work identified
Customer survey	244	219	(25)	-11%	Additional work identified to confirm robustness of survey results
Development of change proposals	41	60	18	31%	Efficiencies as full change proposal not required
Carbon impact assessment	34	41	7	17%	
Research - technical	923	886	(38)	-4%	
Project management	895	912	17	2%	
Design of voltage regulation scheme	357	375	19	5%	
IT	**235**	**287**	**52**	18%	
Installation and configuration of dashboard hardware and software	63	122	59	48%	Efficiencies found during install and configuration
Installation and configuration of ICCP	172	165	(7)	-4%	Minor additional work identified

£000s Cost Category	Total Forecast	Budget	Variance	Variance	Reasons for >10% variance
Payments to users	**86**	**141**	**55**	39%	
Incentive to attract customers to complete surveys	86	141	55	39%	Efficiencies identified
Contingency	**220**	**595**	**375**	63%	
Installation and configuration of ICCP	22	147	125	85%	Additional work item by partner
Purchase and installation of monitoring equipment	46	124	78	63%	Additional grid key (LV monitoring) device costs
Incentive to attract customers to complete surveys	0	33	33	100%	
Purchase and installation of substation controllers	152	156	5	3%	Additional unplanned work (Argus 8) identified at
Installation and configuration of dashboard hardware and software	0	78	78	100%	
Research - technical	0	56	56	100%	
Other	**293**	**341**	**47**	14%	
Publicity and dissemination	194	194	0	0%	
Accommodation	99	146	47	32%	Electricity North West efficiencies found
	7,214	**8,098**	**884**	11%	

8 UPDATED BUSINESS CASE AND LESSONS LEARNT FOR THE METHOD

Customer benefits

With the assistance of the Tyndall Centre and The University of Manchester, Electricity North West has undertaken initial modelling work on the potential benefits of the CLASS Project. The modelling is based on an assessment of the range of network reinforcements required at substations when demand exceeds capacity. This modelling work details the type, financial cost, carbon cost and time to complete reinforcement. Additional modelling has been undertaken by the Tyndall Centre to understand the carbon savings available by providing demand response and reactive power absorption capabilities to NETSO. Details of this can be found in the Carbon impact assessment final report.

Financial benefits

The principal benefit of the CLASS Solution is that it provides a quickly implemented Method to defer reinforcement through the application of voltage decrement techniques at times of peak loading to reduce peak demand. In the short to medium term (within DPCR5 and RIIO-ED1), extending the time to reinforce creates the opportunity to consider alternative infrastructure investment decisions, including customer demand response programs. In the longer term (ie RIIO-ED2 and beyond), the application of this technique allows for the optimal scheduling of resources to manage the expected significant infrastructure development program from the connection of low carbon technologies.

When the CLASS Method is applied across all primary substations in the Project, Electricity North West could gain up to 12.8MVA of network capacity, and defer the reinforcement of five primary substations with an associated expenditure of £2.8 million for up to three years. The CLASS Method can be implemented at one primary substation 57 times faster and 12 times cheaper than traditional reinforcement. It takes one week to retrofit into a primary substation at a cost of £44 000 compared with the typical average time to reinforce a primary substation of 57 weeks at a cost of £560 000.

These are the minimum benefits available by reducing the voltage by 1.5% (ie one tap position) at the primary substation. If the voltage is reduced by 5% Electricity North West could gain up to 250MW of network capacity, and defer the reinforcement of 28 primary substations with an associated cost of £15.9 million for up to three years. When applied at GB scale, it is possible to gain up to 3.1GW of network capacity (the equivalent of 135 new primary substations), and defer £78 million in reinforcement costs.

The Grid Code obliges a DNO to provide a demand response to NETSO for the management of frequency, delivered by the 3% or 6% voltage reduction at DNO substations; but this is generally called upon when other generation and demand management options such as STOR have been exhausted. There is no base case for the commercial provision of demand response for frequency reserve or reactive power for voltage control from a DNO to NETSO. This is because the current regulatory model disincentivises such activities. The feasibility study and the scoping studies, developed by The University of Manchester and Tyndall Centre in preparation of the CLASS Full Submission, highlighted that the potential revenues from the provision of these network services to NETSO could be in the region of £25 000 000 per annum, if the CLASS Solution was applied GB-wide, these revenues would flow directly to DNO customers through reduced bills (from lower DUoS charges).

Carbon benefits

In the CLASS Project the deferment of 14 primary substations under the highest load growth will defer carbon of 2602 tCO2eq and potentially reduce network losses delivering a carbon saving. Rolling out across Electricity North West, CLASS would defer 6122 tCO2eq; while GB-wide, the carbon deferred is 67344 tCO2eq. The actual reduction in losses from applying the peak reduction technique will be assessed within CLASS. The Innovation Funding Incentive (IFI) report highlights the subsequent 'Scope of Work' reinforcing the potential financial and carbon benefits derived in providing demand response for frequency reserve and reactive power for voltage control. In the CLASS Project, it has been shown that it is possible to support the wider GB system through the provision of demand response and reactive power absorption to NETSO, as well as the carbon savings derived. To understand the potential carbon savings available by adopting CLASS initially, The Tyndall Centre considered the existing operators in the frequency reserve/control and reactive power markets and assumed that these would be displaced by the CLASS Solution.

Demand response: The CLASS trials used the inherent functionality of the voltage controllers to sense under-frequency events and initiate a voltage decrement by either switching out one of a pair of primary transformers or lowering the current tap position of each primary transformer. CLASS quantified the demand response that can be provided at all times of year, while maintaining the quality of supply to customers and the health of existing assets. Using the fast reserve (FR) and the firm frequency reserve (FFR) markets as a proxy for understanding the current carbon intensity of frequency control services the Tyndall Centre has shown that there are significant opportunities available for carbon savings by displacing current providers. The current market participants in FR and FFR have a carbon footprint of between 415 to 926 gCO2eq per kWh. The CLASS trials determined that the demand response could displace up to 698 tCO2eq per annum from 365 applications ie one hour per day. As the CLASS Method is scaled up, the potential carbon saving for Electricity North West are up to 2 280 tCO2eq per annum or 5215 tCO2eq over RIIO-ED1; and at GB level up to 57366 tCO2eq per annum or 458928 tCO2eq over RIIO-ED1.

Reactive power: NG procures reactive power to manage the energy flows across the transmission network. This is secured through various market mechanisms or through the operation of compensation equipment eg static VAr compensators (SVCs) and mechanically switched capacitors (MSCs). NG monitors the real power and reactive power flows across its network and at grid supply points, the boundary with DNOs. The reactive power requirements change significantly over each day and on a seasonal basis. Where there is a requirement for additional reactive support that the reactive market cannot provide, NG will install reactive compensation equipment. The CLASS trials applied the 'tap stagger' technique to reduce the power factor of the primary substations by generating circulating current around the pair of primary substation transformers, thereby increasing reactive power demand on higher voltage networks. CLASS quantified the reactive power absorption capability that can be created, while maintaining the quality of supply to customers and the health of existing assets. Using the installation of a statcom as a proxy for understanding the carbon intensity of the traditional solution for managing transmission system voltage, The Tyndall Centre reported that there are significant carbon savings in the application of the `tap stagger' technique for the provisioning of reactive power. If the technique was applied at all 60 primary substations for 600 hours per annum (ie five hours per night for 120 days) the CLASS Solution could provide up to 129 MVAr or reactive power absorption, totalling 78GVArh per annum, and saving up to 3 336 tCO2eq per annum. As the CLASS Method is scaled up the carbon saving for Electricity North West are 6 188 tCO2eq per annum or 45 903 tCO2eq over RIIO ED1; and T GB level, 63 840 tCO2eq per annum 510 721 tCO2eq over RIIO ED1.

Non-quantified benefits

While the CLASS Method demonstrates significant potential financial and carbon saving benefits there are also a number of non-quantifiable benefits that should be noted. The first of these is how the Solution will inform discussions in the RIIO-ED1 mid-term review.

A key aspect of RIIO-ED1 is innovation and how customers will benefit from this. The CLASS Project demonstrates innovation in the novel use of dynamic voltage regulation techniques to drive the greater utilisation of existing assets. CLASS, like the Capacity to Customers project, follows the strategy of generating additional value for customers and stakeholders from the greater use of existing assets.

Another key consideration for RIIO-ED1 and beyond is the delivery of network services with long-term value for money for existing and future consumers. Learning from CLASS has demonstrated that the innovative use of dynamic voltage regulation for demand response paves the way for better value for money delivery of ancillary services. The Project has confirmed the Solution can play a role in the delivery of a secure and sustainable energy sector, reducing the carbon intensity of the provision of current balancing services.

An updated and enriched understanding of voltage/demand characteristics will enhance power system modelling at distribution and transmission levels when determining reinforcement timing (immediate post-fault voltage depressions) and to assess voltage instability risk that can jeopardise power system security on a large scale.

Additional benefits are anticipated through the availability of an enhanced operational interface (the ICCP link included in CLASS) between Electricity North West and NETSO. This interface could provide additional future benefits, as more embedded generation is installed on Electricity North West's network which would otherwise be ‘invisible' to NETSO.

The development of the CLASS network monitoring equipment will form the basis of a long-term monitoring study. The data collected will help track the change in the voltage/demand relationship over time with the penetration of customers' low carbon technologies.

The fast application of CLASS could be valuable in bridging the operational time gap before other solutions come into effect, eg enabling forms of DR via aggregators or the effect of price signals from the time of use pricing via smart metering.

9 LESSONS LEARNT FOR FUTURE INNOVATION PROJECTS

9.1 Customer engagement and feedback

Communicating with customers in the trial area

Engaged customer panel: In common with learning from previous ECPs, the CLASS ECP demonstrated that customers have little or no awareness of Electricity North West as a company, and little understanding of the role of a DNO in the energy sector or how the DNO’s role differs from that of a supplier. Customers generally have little concept of decarbonisation, the possible increasing demand for electricity and the need to potentially expand the electricity network. Participants needed educating about these matters before the concept of CLASS could be introduced. Utilising learning from previous ECPs, the CLASS ECP demonstrated again that the most effective way of communicating this information is through a simple question and answer factsheet, video material and a concept board. These stimulus materials effectively explained how CLASS could address the Problem and how customers in the CLASS trial areas might be affected. To maintain interest and credibility customers must also be reassured about the reliability of their supply. A key learning outcome was that most customers needed educating about the role of DNOs and why projects such as CLASS are necessary to meet future electricity demand. Only when this had been established could awareness material on the Project be effectively presented. When forming an ECP, sufficient resources, time and materials should be allocated to initially educate customers about the electricity sector and the challenges it faces.

An ECP is an effective forum for testing survey instruments: An ECP is not a conventional method for piloting a customer survey instrument. However the technique proved to be an effective way of optimising the survey before it was utilised on a much larger scale to test the CLASS customer hypothesis. The conversational nature of customer focus groups allowed participants to share their understanding and any sensitivity about the questions and their responses with each other. It also encouraged discussion around possible improvements to the questionnaire, for example changing the wording or the order of some questions and refining the responses in others. The ECP was also very influential in the formulation of a customer survey registration FAQ, designed to assist in recruiting customers to take part in the survey. This document answered common questions, including but not limited to, the frequency, duration, subject matter and incentivisation of surveys.

Piloting the survey instrument with the ECP provided valuable learning and is recommended for future innovation projects where applicable.

It is advisable to obtain participants’ consent for the use of audio/visual soundbites in dissemination activities: Video sound bites of ECP members commenting on their experience of participating in the forum were recorded. These videos were an engaging means of demonstrating the outcomes and intrinsic value of the ECP and were used at CLASS dissemination events. It is standard practice in the market research industry for ECP sessions to be recorded and participants are informed of this practice beforehand. However, participation in the video requires the explicit permission of participants for their audio/visual data to be used for specific dissemination purposes.

In future innovation projects, interviews of this nature could be scheduled to take place at the focus group venue following the final ECP meeting. Planning for this and acquiring participants' consent as part of the recruitment process would be the most cost-effective and efficient means of obtaining the videos.

Monitoring the effects of the CLASS trials on customers

A customer leaflet is an effective means of raising awareness and encouraging registrations in the customer survey: The CLASS customer leaflet encouraged prospective participants to register their interest in taking part in the surveys. The leaflet included a call-to-action, '*help us to help you by getting involved with our customer surveys*', and advertised the offer of a cash reward. Over 3,000 customers pre-registered online via the website or by calling or texting the customer contact centre (CCC) after the leaflet was distributed. This response exceeded expectations, generating a considerably higher level of customer interest than anticipated, which was far greater than the numbers needed for the baseline survey. The positive response was undoubtedly influenced by the reference to a cash reward for taking part in the survey. Whilst extremely positive, the response had the effect of increasing the time and resources involved in administration. The most significant of these are as follows:

- The CCC had been briefed in advance and was prepared to deal with enquiries generated from the leaflet. However, the leaflet arrived at most customers' homes on a Saturday and the CCC was unprepared for the volume of calls received over the weekend when resource levels are lower. In future it would be sensible for leaflets to arrive mid-week, when staffing levels are best suited to meet potential increases in telephone traffic
- To encourage pre-registration, only a limited amount of data was requested from customers to ensure the process was quick and simple. A telephone-based screening process was designed to subsequently determine a customer's suitability. In light of the excellent response to the customer leaflet, collecting more information at the registration stage would have helped the selection process
- Customers registering their interest in the survey expected to be automatically selected to take part. However, only a proportion of customers who registered to take part were required. Due to unprecedented interest, the registration page on the website was closed much earlier than anticipated and Electricity North West subsequently issued a sensitively worded 'rejection' letter/email to those who were unsuccessful.

Future engagement materials will be designed to avoid setting an expectation that customers will be automatically selected to take part in surveys. Clearer information will also be provided to set expectations regarding the likely timescales involved in customers receiving confirmation of being accepted as a participant. To refine the registration process and avoid unnecessary administration, future communications strategies are likely to inform customers that they will only receive further communication if successful.

It is essential to recruit sufficient numbers of customers into the survey panel to allow for natural attrition and provide reliable and robust data: The CLASS survey panel needed to be large enough to generate 1,400 monitoring surveys over the course of the four seasons of the trial. It was anticipated that participants would take part in a maximum of four surveys each. As a large base of 696 customers were recruited, not all were required to take part in a survey during each season. This number proved sufficient to make allowances for those customers who were unavailable to take part in a survey when contacted, and allowed for natural attrition over the course of the trial. Notably, only one customer withdrew from the survey. The low attrition rate was likely to have been influenced by appropriate incentivisation (method and value) and the effective communication strategy which was maintained throughout the trial period by the issue of regular newsletters and website updates.

A choice of methods is required for issuing incentive payments: The customer incentive for completing surveys was originally restricted to Bankers' Automated Clearing Services (BACS) transfer payments, which needed customer bank account and sort code numbers. Many customers had concerns about divulging their bank account details, which led some participants to question the authenticity of both the research company and the survey. A cheque payment was therefore offered as an alternative to a BACS transfer which allayed customer concerns and only required a name and address for payment. This change significantly impacted the time and administration costs associated with the issue of payments.

This is significant learning and should be considered in any future projects where customer incentives are required. Reluctance to divulge personal bank details, particularly in a climate where fraud and identity theft are prevalent, means that BACS payments may not be acceptable to all survey participants, particularly vulnerable customers. Therefore project timings and budget should account for alternative methods of payment.

It is advisable to mitigate against tests not proceeding as planned: On occasion circumstances beyond the control of the Project team, including network faults, resulted in some deviations from the original test schedule during autumn and winter. This affected customer survey activity during the period. Test windows were extended to ensure the requisite number of tests and associated customer surveys were completed. This flexible strategy was valuable learning and should be adopted when undertaking future tests of this nature.

9.2 Technology implementation and effectiveness

The commissioning procedures for the ASC, MicroTAPP, Argus 8 and tripping sites were agreed between the Electricity North West technology build lead engineer and all the external protection engineers at the first site of each type. By creating a procedure which changed very little after the commissioning of the initial site of each type and preventing any misunderstandings, this approach ensured a consistent approach.

As a result of the lessons learnt during the CLASS Project all future projects have ’all-partner kick-off’ meetings to ensure that all parties have a clear understanding of the objectives, approach and their responsibilities during the Project.

The Project demonstrated that business as usual transducers, already in place, are fit for purpose for innovation data gathering. However, the communications links in the majority of primary substations do not have the capacity to transfer the quantities of data that may be required. As such it has been shown that mobile communications systems combined with a capacity to store the data in the mobile communications unit allows for the quantities of data to be transferred, even when the mobile link is unavailable for periods.

The CLASS technologies were very effective in all areas except for the amount of tap stagger that the ASC could request from the MicroTAPP relays. The ASC attempted to create a tap stagger between the two primary transformers by requesting a circulating current target to be activated in each of the two MicroTAPP relays. This circulating current target provided a maximum tap stagger of up to three taps apart. The size of tap stagger required to give the magnitudes of reactive power absorption useful to National Grid would be in the range of six to eight taps apart range at each primary substation. It was not practicable to change the MicroTAPP circulating current limit maximum value during the Project. It was also notable that the MicroTAPP could not control the tap changer from a direct command from the ASC.

9.3 CLASS trials

The CLASS trials were carried out over a representative set of substations, covering all types of load types: rural, urban, semi-urban, domestic, industrial and commercial, and across all major grid supply points. Although this approach provided sufficient data to prove the hypothesis, improvements could have been made with regards to the reactive power absorption tests. These tests were quantitative, based on the results from simultaneous tests at all CLASS sites within the same GSP. The main test was carried out at Stalybridge GSP, which included seven CLASS sites. As Stalybridge feeds 28 primary substations a methodology was devised by the University of Manchester to quantify the potential reactive power absorption at Stalybridge using simulation and then across the whole of Electricity North West. In this instance it would have been beneficial to have carried out tap staggering at all primary substations within a GSP. This would have required additional monitoring equipment to be installed and control equipment to enable manual operation via the existing SCADA.

9.4 Data evaluation

The CLASS Project allowed for the automatic collection of trial data via an iHost server, allowing external parties to readily access data. This proved most successful for the UoM as data was available for analysis and processing immediately following the trials. In previous projects internet connectivity was not provided, meaning data had to be downloaded manually from each site. The use of an iHost server for automatic data collection provided a cost and time benefit.

10 PROJECT REPLICATION

The following sections identify the data requirements, including software and literature resources, to replicate each area of the Project.

10.1 Customer engagement and feedback

Communicating with customers in the trial areas

The physical components required to replicate this activity are listed below:

- Database of customers in the trial area
- Recruitment screener
- Recruitment quotas
- Discussion guide
- Stimulus materials
  - Show cards explaining the role of a DNO and industry structure, a problem statement, list of possible solutions to the Problem and an analogy of the Solution
  - Communication materials (audio and/or visual as appropriate) eg video and leaflet
  - Customer survey instrument and FAQ
- Focus group venue
- Transcripts and audio recordings.

The knowledge required to replicate the outcome of this activity is as follows:

- Knowledge of trial area
- Knowledge of customer profile in the trial area
- Knowledge of various methods of recruiting customers for ECP
- Knowledge of qualitative research methods required to produce the physical components listed above for recruitment, design, moderation, analysis and reporting
- Knowledge of quantitative research methods required to produce the survey instrument and FAQs.

The anticipated business as usual costs are in the region of:

- Conducting an ECP (30 customers taking part in four phases of focus groups across two different locations) – £50k
- Incentivisation – £11k
- Designing a leaflet – £350
- Printing and mailing a leaflet to 485,000 customers – £140k.

Monitoring the effects of the CLASS trials on customers

The physical components required to replicate this activity are listed below:

- Customer video
- Customer leaflet
- Customer survey FAQ document
- Recruitment questionnaire (domestic and I&C customer versions)
- Recruitment quotas
- Online registration page
- Baseline questionnaire (domestic and I&C customer versions)
- Monitoring questionnaire (domestic and I&C customer versions)
- Interviewer briefing instructions
- Letter of survey endorsement (part of interviewer briefing pack)
- Database of customers in trial area
- Texting platform to communicate with participants.

The knowledge required to replicate the outcome of this activity is as follows:

- Knowledge of trial area
- Knowledge of customer profile in the trial area
- Knowledge of methods used to enhance the accuracy of customer contact data
- Knowledge of various methods of recruiting and maintaining sufficient participants for survey and managing the exit strategy upon closedown of the survey
- Knowledge of market research methodology and execution, including, but not limited to, survey design and statistical analysis
- Knowledge of IT systems to produce the physical components above for recruitment, design, analysis and reporting.

The anticipated business as usual costs are in the region of:

- Producing a video – £12k
- Customer survey – £150k

- Incentivisation – £74k.

10.2 Technology implementation and effectiveness

The CLASS Project used existing BAU assets with a relatively small quantity of new technology to control those assets in order to provide the CLASS functions and effects. The primary transformer and its associated 11/6.6kV circuit breaker were the main BAU assets in the CLASS Project. Existing SCADA systems with additional point-to-point wiring were required to command and receive status information from the Siemens ASC which in turn controlled and monitored the MicroTAPP AVC relays or the Argus 8 relays and associated load current monitors via a fibre optic link. The CLASS system on the 60 primary substations sites was controlled by a GE power-on-fusion (PoF) server with a ‘dashboard’ displaying sites loads/voltages/status information and predictive yields. The GE PoF server talked to the Electricity North West SCADA/network management system (NMS) which in turn sent status information/analogues and received commands from NG XA21 NMS via an ICCP link.

10.3 CLASS trials

The knowledge required to replicate the outcome of this activity is as follows:

- System data and configuration
- Load data – long-term development statement
- Customer daily profiles
- Customer profile – number of customers in each profile class
- Plant data records
- Levels of embedded generation
- Details of all planned load and generation activity at each primary substation during trial period
- Outage plan for all primary substations.

10.4 Data evaluation

CLASS Project WP1 software and data requirements

Software components

Name	License	Role
MS Excel	Commercial	Trial data extraction; pre-processing raw load data
MATLAB R2015a	Commercial	Data extraction, filtering, load model parameter estimation, developing seasonal/daily 24-hour (48 x half hour) voltage/demand matrix

Data requirements

- Field measurement data (voltage, active and reactive power) of 60 Electricity North West primary substations over one year, with a sampling rate of 1Hz
- Site trial data and time schedule for trial 1 (ie load modelling trial periods)
- Substation classification based on the type of consumers, ie domestic, mixed-type and industrial substations classification.

References

[1] Electricity North West, CLASS trial design and associated test schedule, 2014.
[2] K. N. Hasan and J. V. Milanovic, Interim Profile Modelling Study, The University of Manchester and Electricity North West Limited, UK, 2015.
[3] K. N. Hasan, J. V. Milanović, P. Turner, and V. Turnham, *A step-by-step data processing guideline for load model development based on field measurements*, in IEEE PowerTech Conference,, Eindhoven, The Netherlands, 2015.
[4] K. N. Hasan and J. V. Milanović, *Practical aspects of developing load models at distribution network buses based on field measurements*, in CIRED International Conference and Exhibition on Electricity Distribution, Lyon, France, 2015.
[5] Alstom. (2015). iSTAT i500 High Performance Multifunction Transducer.
[6] CIGRE_WG_C4.605, *Modelling and aggregation of loads in flexible power networks*, Jovica V. Milanović, (Convenor), Julija Matevosiyan, Anish Gaikwad, Alberto Borghetti, Saša Ž. Djokić, Zhao Yang Dong, Andrew Halley, Lidija M. Korunović, Sergio Martinez Villanueva, Jin Ma, Pouyan Pourbeik, Fernanda Resende, Stefan Sterpu, Fortunato Villella, Koji Yamashita, Odin Auer, Karim Karoui, Dimitry Kosterev, Shu Kwan Leung, Dumisani Mtolo, Samila Mat Zali, Adam Collin, Yizheng Xu, ISBN: 978-2-85873-261-6, 2014.
[7] L. M. Korunovic, D. P. Stojanovic, and J. V. Milanovic, *Identification of static load characteristics based on measurements in medium-voltage distribution networks,"* IET Gen, Trans and Distr, vol. 2, pp. 227-234, 2008.
[8] EPRI, Measurement-based load modelling, 2006.
[9] D. P. Stojanović, L. M. Korunović, and J. V. Milanović, *Dynamic load modelling based on measurements in medium voltage distribution networks*, Electric Power Systems Research, vol. 78, pp. 228-238, 2008.
[10] I. R. Navarro, *Dynamic Load Models for Power Systems*, PhD Thesis, Lund University, Sweden, 2002.
[11] D. J. Hill, *Non-linear dynamic load models with recovery for voltage stability studies*, IEEE Trans on Power Systems, vol. 8, pp. 166-176, 1993.
[12] J. V. Milanovic, K. Yamashita, S. Martinez Villanueva, S. Z. Djokic, and L. M. Korunovic, *International industry practice on power system load modelling*, IEEE Transactions on Power Systems, vol. 28, pp. 3038-3046, 2013.

[13] P. Kundur, *Power System Stability and Control*, McGraw-Hill, New York, 1994.

CLASS Project WP2 – software and data requirements

Software components

Name	License	Role
IPSA 2.4.2	Commercial	Simulation for the Electricity North West EHV network; initial studies of load flow, *Q* absorption by tap stagger and *P* reduction by voltage reduction
OpenDSS	Free, open source	Simulation for the selected sub-networks; studies of load flow, *Q* absorption and *P* reduction capability studies over 24 hours in a day and in four seasons Voltage studies in the EHV network Voltage capability studies in HV networks Network constraints assessment in LV networks
MATLAB R2015a	Commercial	Network conversion from IPSA to OpenDSS; establishment of OpenDSS modelling scripts, load profiles and load models; tap stagger and tap changing control algorithm; site trial data processing Data post processing Drive OpenDSS for LV network constraints assessment and HV voltage capability studies
Excel	Commercial	Translate DiNIS export files of the HV network models into OpenDSS scripts Demand response quantification at regional and national level. Produce residential load profile (CREST tool)

- Data requirements
- Circuit data (as IPSA files) of Electricity North West EHV network
- 24-hour (48 x half hour) load demand data over a year based on site measurements at primary substations
- 24-hour (48 x half hour) voltage/demand matrices over a year, which describe the relationships between voltages and demands at primary substations
- Site trial results during the trial 4 (ie tap staggering trial) periods
- Full computer-based models of a representative set of low voltage (LV) networks including type of consumers
- Full computer-based models of a representative set of high voltage (HV) networks including number and type of consumers per LV substation as well as monitoring data at the primary substation
- Full computer-based models of an extra high voltage (EHV) network (from GSP to primary substations) including number and type of customers per primary substation
- Recent Elexon's annual half-hourly profiles per type of customer as well as the total number of customers per type for the corresponding DNO
- Total number of customers per type and peak demand per primary substation for the corresponding DNO.

References

[1] K. Harker, *Power System Commissioning and Maintenance Practice*, IEE Power Series 24, The Institution of Electrical Engineers, London, 1998, pp. 129-132.
[2] L. Chen, H. Li, V. Turnham, and S. Brooke, *Distribution network supports for reactive power management in transmission systems*, IEEE PES Innovative Smart Grid Technologies (ISGT) European, Istanbul, Oct. 2014.
[3] C. M. Hird, H. Leite, N. Jenkins, and H. Li, *Network voltage controller for distributed generation*, *IEE Proceedings of Generation, Transmission and Distribution*, vol. 151, no. 2, pp. 150-156, Mar. 2004.
[4] L. Ochoa, *Tier 2 CLASS proposal: methodology for the selection of primary substations*, Technical report, the University of Manchester, 2012.
[5] Electricity North West, "*Low Carbon Networks Fund submission from Electricity North West – CLASS*,
[6] R. C. Dugan and T. E. McDermott, *An open source platform for collaborating on smart grid research*, in *Power and Energy Society General Meeting, 2011 IEEE*, 2011, pp. 1-7.
[7] OpenDSS
[8] ELEXON, *Load Profiles and their use in Electricity Settlement*, 2015.
[9] Microsoft Excel.
[10] MATLAB R2015a.
[11] I. Richardson, M. Thomson, D. Infield, and C. Clifford, *Domestic electricity use: A high-resolution energy demand model*, Energy and Buildings, vol. 42, pp. 1878-1887, Oct. 2010.
[12] CREST tool.

CLASS Project WP3 software and data requirements

Main tank assessment

Software components

Name	License	Role
MATLAB R2014a	Commercial	Analysis of load data Analysis of oil data Thermal modelling of power transformers Calculation of health indexes

Data requirements

- Trial design and associated test schedule
- Transformer nameplate data, including: power rating, voltage, impedance, cooling mode, year of manufacture, manufacturer, etc.
- Transformer historical oil data
- Transformer temperature rise test results (if possible)
- Ambient temperature data
- Online monitoring load data during trial periods
- Transformer yearly load profiles (minute-based or half-hour-based)
- Health index database for transformer assets.

References

[1] M. J. Heathcote, *The J & P Transformer Book*, 13th ed. Oxford: Elsevier, 2007.
[2] M. A. Kayes, *Code of Practice 382 Transformer Ratings*, Electricity North West Limited, Manchester, p. 39, 2009.
[3] D. Feng, *Life Expectancy Investigation of Transmission Power Transformers*, University of Manchester, 2013.
[4] Dave Hughes, T. Pears, J. Peacock, and M. Coffin, *Condition Based Risk Management with Electricity North West Ltd*. Capenhurst, Chester, 2009.
[5] Electricity North West Ltd, *CLASS trial design and associated test schedule*, 2014.

Tap changer assessment

Software components

Name	License	Role
Operational software for acoustic unit	UoL	Operation of the sensor units (including power quality, temperature and acoustics) Communication protocols with IHost and restart protocols Data processing and storage Preliminary analysis of data Take the acoustic data to extract information Short/medium/long-term trend analysis Detecting tap changer acoustic signatures Optical signature analysis of oil samples Visualisation of the processed outputs
Data processing software	UoL	
MATLAB R2014a	Commercial	

Hardware components

Name	License	Role
Acoustic monitoring unit	UoL	Supports opto-electronic acoustic sensor Provides signal conditioning Data storage Supports ENVOY communications unit (ENVOY from Nortech) Processes the data Support temperature sensors
Power quality unit	Commercial	Records V, I, P and Q
Oil monitoring unit	UoL	Optical source to interrogate the oil sample Detection system to capture the optical signal passing through the oil Software to process the captured optical signal

Data requirements

- Trial design and associated test schedule
- Confirmation of tests performed and at which site
- Tap changer type and approximately age
- Oil samples from tap changers under test
- Oil samples from tap changers with known tap operations for calibration.

References

[1] [G. R. Jones, A. G. Deakin and J. W Spencer. *Chromatic Monitoring of Complex Conditions*. 2008. ISBN 978 1 58488 988 5. CRC Press.

[2] H. M. Looe et al. Cigre paper in *Towards an Integrated and Interconnected Transmission Power Grid; Challenges and Opportunities*. AORC-CIGRE Technical meeting 2015 Malaysia.

[3] Dave Hughes, T. Pears, J. Peacock, and M. Coffin, *Condition Based Risk Management with Electricity North West Ltd*. Capenhurst,Chester, 2009.

[4] Electricity North West Ltd, *CLASS trial design and associated test schedule*, 2014.

Carbon impact assessment

The following list contains the necessary information to replicate this activity:

- SimaPro software
- Database of asset embodied carbon
- Reinforcement and power flow simulation delivering the following time series outputs:
    - Assets required (line km, numbers of transformers in four size classes)
    - Losses attributed to network (MWh)
    - Losses attributed to DG (MWh)
    - Capacity released (MW)
- Scenarios of grid carbon intensity through relevant period.

References

[1] EcoInvent Database v2.2 - *Ecoinvent Centre (2010) Ecoinvent Database Version 2.2*, Swiss Centre for Life Cycle Inventories Switzerland.

[2] Electricity North West (2008) *Carbon Footprint of ENW Limited*, Emissions factors updated 2011.

[3] Hammond and Jones (2011*) Inventory of Carbon and Energy (ICE) v2.0,* University of Bath.

[4] Jones, C. I. and M. C. McManus (2008). *Life Cycle Energy and Carbon Assessment of 11 kV Electricity Overhead Lines and Underground Power Cables, A Report for Western Power Distribution (WPD).* Bath, Sustainable Energy Research Team (SERT), University of Bath.

[5] Jones, C. I. and M. C. McManus (2010). *Life Cycle Assessment of 11 Kv Electrical Overhead Lines and Underground Cables.* Journal of Cleaner Production 18(14): 1464-1477.

[6] ICE (2011) CESMM3 *Civil Engineering Standard Method of Measurement Carbon and Price Book*, Institution of Civil Engineers ISBN 978-0-7277-4137-0.

[7] Turconi, R., C. G. Simonsen, I. P. Byriel and T. Astrup (2014). *Life Cycle Assessment of the Danish Electricity Distribution Network.* International Journal of Life Cycle Assessment 19(1): 100-108.

Economic modelling

The following list contains the necessary information to replicate this activity:

- MathWorks Matlab for coding all the relevant algorithms
- MathWorks MatPower to simulate the networks.

Knowledge required to replicate the outcome:

- Understanding power system economics and network modelling
- Knowledge of investment assessment under uncertainty; particularly on optimisation tools and
- models applicable to investments in engineering systems (metaheuristics and recursive functions in this work)
- Experience in developing algorithms in programming language
- Detailed economic data and technical models of the distribution networks, and the different infrastructure required for upgrading the lines and substations
- Demand growth scenarios
- Information and knowledge of existing distribution network upgrade practices (eg P2/6 engineering recommendations) and regulatory framework to assess asset build at the distribution level (eg Ofgem’s CBA framework).

11 PLANNED IMPLEMENTATION

The CLASS Project used existing off-the-shelf products to which configuration changes and some new designs of AVC schemes (Argus 8) were made. As such there are no technical hurdles to prevent the full rollout of CLASS in any GB DNO. In addition automatic CLASS commands from NG to DNOs via the ICCP link have been proven in addition to the analogues of previous DNO projects. If all GB primary substation sites were to offer the tripping of primary transformer 11/6.6kV circuit breakers to reduce GB system demand during frequency events then agreement on an auto-reclose philosophy would be required across GB DNOs and NG. It is likely that such a philosophy would use a factor which prevented all sites from auto-reclosing at the same time to prevent ‘shocking’ the system with additional demand. One strategy may be a stochastic approach to auto-reclosure by using load ie lightest loaded substations first to reclose and the heaviest last. An alternative philosophy would be to use a probabilistic approach to auto-reclosure timing thereby randomising system re-loading over a predetermined maximum and minimum period.

12 LEARNING DISSEMINATION

This closedown report is a key element of the dissemination approach to ensure sharing of Project learning.

The report has been structured around four key learning activities in order to facilitate easy access to specific content from a variety of different stakeholders:

- Customer engagement and feedback
- Technology implementation and effectiveness
- CLASS trials
- Data evaluation.

A peer review of the closedown report was completed by Northern Powergrid. Suggested improvements and recommendations that will enable other DNO's to understand and implement CLASS were received and adjustments to the closedown report made.

In addition a summary of the Project outcomes and lessons learned have been presented at the following events: CLASS knowledge dissemination event, April 2014; CLASS webinars, June 2013, June 2014 and March 2015; LCNI conferences 2013 and 2014; CLASS workshop, July 2015; and CLASS closedown event September 2015.

Electricity North West conducted a consultation with other DNOs at the CLASS workshop regarding preferred methods to receive learning. Electricity North West will offer bespoke one-to-one knowledge dissemination sessions with each DNO and Ofgem. All knowledge dissemination material has been published on the Project website and key stakeholders made aware of the material and how to access it.

13 KEY PROJECT LEARNING DOCUMENTS

Project progress reports and key learning documents are listed below. A more extensive range of Project-related key documentation can be found on the Project website.

13.1 Project progress reports

Title	Date	Website Link
Project Progress Report No 1	16 June 2013	Project progress report 1
Project Progress Report No 2	19 December 2013	Project progress report 2
Project Progress Report No 3	23 June 2014	Project progress report 3
Project Progress Report No 4	22 December 2014	Project progress report 4
Project Progress Report No 5	21 June 2015	Project progress report 5

13.2 Key learning documents

Title	Date	Summary	Website Link
Monitoring location selection	Aug 2013	Describes and applies a robust methodology for identifying the locations where monitoring equipment for the CLASS trials were installed	Monitoring location selection
Trial substation selection methodology	Aug 2013	The methodology for the selection of primary substations for the CLASS trial and the outcomes from its application	Trial substation selection methodology
Design approach to trials and associated test schedules	Jan 2014	Agreed design methodology and subsequent test schedule for each CLASS trial	Design approach to trials and associated test schedules
Voltage regulation scheme	Feb 2014	Functional specifications and voltage regulation scheme for the autonomous substation controller	Voltage regulation scheme
Engaged customer panel report	Mar 2014	Summary of the key findings from the engaged customer panel	ECP summary report
Commissioning report	Apr 2014	Describes the methodology for the commissioning of the MicroTAPP relays and the autonomous substation controller	Commissioning report
ICCP report	April 2014	Describes the methodology for the commissioning of the ICCP link	ICCP report
Capability report for trial scenarios	Sep 2014	Proves the ability of CLASS to address challenges from current patterns and increases in demand	Capability report for trial scenarios
University of Manchester interim and final reports WP1	Jan 2015	Study of demand profiles through modelling and validation using high-resolution field measurement data	Load profiling modelling interim report Load profiling modelling study final report
University of Manchester interim and final reports WP2	Jan 2015	This study uses the estimated load models based on literature review and models the capability of primary substations to deliver demand response and reactive power absorption capability	Offline demand response and reactive power capability interim report Offline demand response capability assessment final report Reactive power absorption capability assessment final report
University of Manchester interim and final reports WP3	Jan 2015	A study of the possible impact of CLASS techniques on the health conditions of transformer main tanks and tap changers	Asset health interim report Asset health final report
Carbon impact report		An overview of the carbon impact assessment approach and findings of the CLASS Method	Carbon impact assessment final report
CLASS SQSS and code review	Jun 2015	A review of the National Electricity System Security and Quality of Supply Standard, SQSS, undertaken to assess whether there is a need to propose changes as a result of the findings from the CLASS Project	CLASS SQSS and code review
CLASS dashboard	July 2015	Explanation of the functionality of the CLASS dashboard	CLASS dashboard
Customer survey	July 2015	Learning from a strategic piece of	Customer survey report

report		market research undertaken to test the hypothesis that the CLASS Method is indiscernible to customers on trial circuits. The report includes a comprehensive account of the survey methodology, key findings and Project learning	

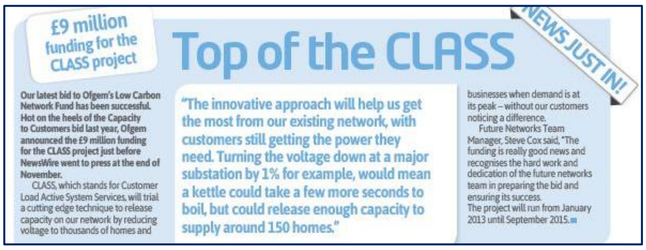
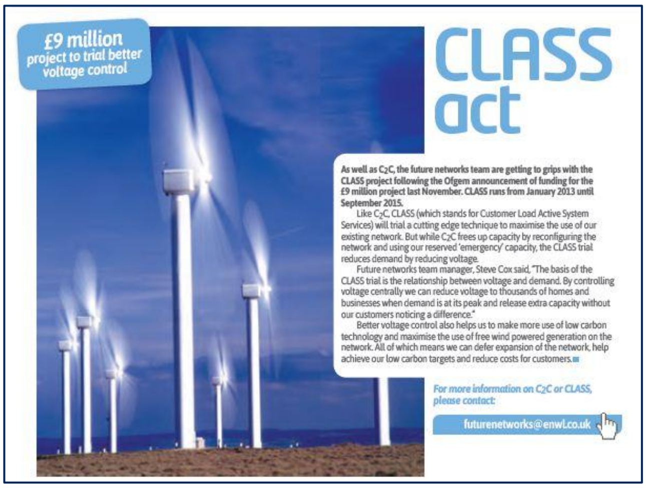
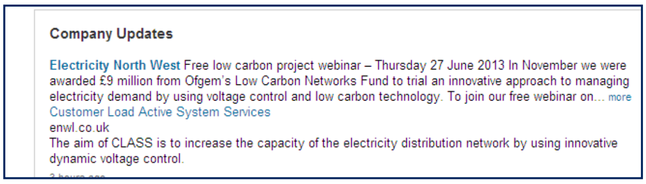
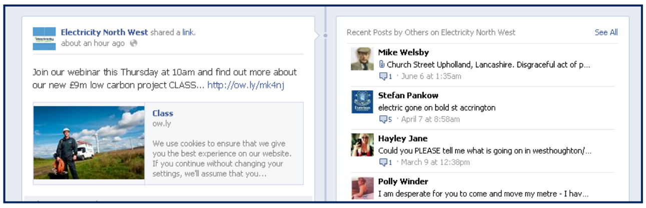
14 CONTACT DETAILS

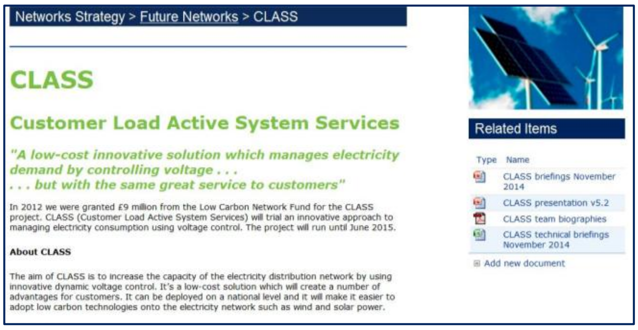
Paul Turner
Delivery Manager
Electricity North West
Technology House
Lissadel Street
Salford
M6 6AP

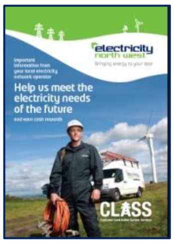
T: 0843 311 3936
Email: futurenetworks@enwl.co.uk

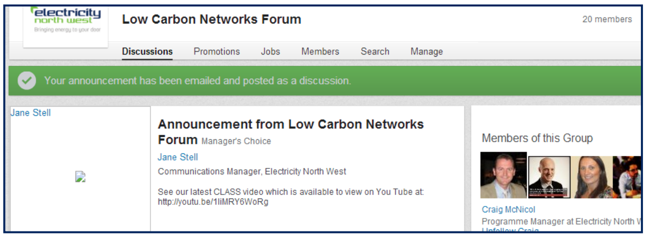
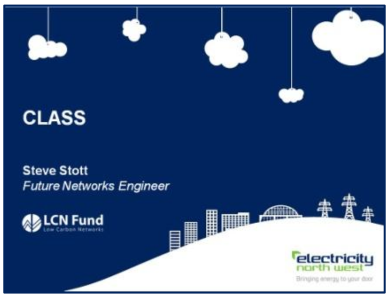
15 APPENDICES

APPENDIX A: LEARNING AND DISSEMINATION ACTIVITIES

Date	Activity	Audience	Evidence
Nov 2012	Twitter announcement on LCN funding	All interested stakeholders	
Nov 2012	First Project video on You Tube	All interested stakeholders	CLASS introduction video
Dec 2012	Story on announcement of funding in internal magazine, NewsWire	Employees	
Mar 2013	Overview of innovation projects in internal magazine, NewsWire	Employees	
June 2013	Twitter announcement on first webinar	Industry and regulatory stakeholders	
June 2013	Linked In announcement on first webinar	Industry and regulatory stakeholders	
June 2013	Facebook announcement on first webinar	Industry and regulatory stakeholders	
June 2013	First webinar	Industry and regulatory stakeholders	First webinar recording
June 2013	First webinar slide presentation	Industry and regulatory stakeholders	Webinar presentation slides

Date	Activity	Audience	Evidence
June 2013	Interim Project website	All interested stakeholders	Website homepage
June 2013	Project team biographies on website	All interested stakeholders	Project team biographies
June 2013	Project partners info on website	All interested stakeholders	Project partners
July 2013	Project page on The Volt company intranet	All internal stakeholder	
Aug 2013	Publish draft marketing and communications materials on website	All interested stakeholders	Trial survey page
Sep 2013	Main Project website live	All interested stakeholders	Project website
Oct 2013	Tweet about website launch	All interested stakeholders	
Oct 2013	First industry newsletter	All interested stakeholders	First newsletter
Oct 2013	First engaged customer panel (ECP)	Domestic and I&C customers	Project introduction ECP stimulus board
Nov 2013	Second ECP	Domestic and I&C customers	
Nov 2013	LCNI conference	Industry and regulatory stakeholders	LCNI conference slides
Dec 2013	Third ECP	Domestic and I&C customers	
Jan 2014	Fourth ECP	Domestic and I&C customers	Baseline domestic customer survey Baseline I&C customer survey Monitoring domestic customer survey Monitoring I&C customer survey
Jan 2014	Project trials survey page published on website	Domestic and I&C customers	Trials survey page
Jan 2014	Supplier liaison letter	Top ten suppliers	Letter

Date	Activity	Audience	Evidence
Feb 2014	Knowledge sharing event promoted on LinkedIn	All interested stakeholders	**Announcement from Low Carbon Networks Forum** Jane Stell Communications Manager, Electricity North West We will be holding a knowledge sharing event on 30 April 2014 for our CLASS project (Customer Load Active System Services) at the Manchester Museum of Science and Industry. Funded by the Low Carbon Networks Fund, CLASS is a trialling new ... Like • Comment • Unfollow • 3 months ago
Feb 2014	Mailing to 485,000 customers on trial circuits to provide overview of Project	Customers on trial circuits	 Customer leaflet
Feb 2014	Interview following customer mailing on Radio Lancashire	All interested stakeholders	ElectricityNW News @ElecNW_News · Feb 28 Earlier Simon Brooke discussed our innovative CLASS project on @BBCLancashire and how you can get involved ow.ly/u5L55
Mar 2014	Interview following customer mailing on Radio 4's You and Yours	All interested stakeholders	
April 2014	First knowledge sharing event	All interested external stakeholders	Knowledge sharing event slides
April 2014	Knowledge sharing event promoted on Twitter	All interested external stakeholders	ElectricityNW News @ElecNW_News · Apr 30 We've enjoyed speaking to our stakeholders today @voiceofmosi about our low carbon CLASS project  View more photos and videos
April 2014	Project video	All interested stakeholders	Project video
May 2014	First customer update	Survey participants and other customers	Trial customer updates
May 2014	Second webinar promoted on LinkedIn	Any interested stakeholders	**Announcement from Low Carbon Networks Forum - CLASS webinar** Jane Stell in Low Carbon Networks Forum Our second learning and dissemination webinar will be held at 11.00am – 11.40am, Friday 27 June 2014. We will cover two subjects: 1. Overview of voltage regulation technologies presented by Dr Vincent Thornley, solutions manager at Siemens, a CLASS project partner. 2. The CLASS approach to the customer baseline surveys, presented by Dr David Pearmain, director of advanced methods at Impact Research, also a CLASS partner. To find out more about the webinar and how to register, please visit www.enwl.co.uk/class/news-views/events-

Date	Activity	Audience	Evidence
May 2014	Second webinar promoted on Facebook and Twitter	Any interested stakeholders	
June 2014	Second webinar	All interested external stakeholders	Webinar slide presentation
June 2014	Podcast from the second webinar	All interested external stakeholders	Webinar recording
June 2014	Podcast from second webinar promoted via LinkedIn	All interested external stakeholders	
Aug 2014	Second customer update	Survey participants and other customers	Trial customer updates
Oct 2014	Annual LCNI conference	Industry stakeholders	LCNI conference slides
Nov 2014	Informal employee briefings on progress of trials	Employees	
Nov 2014	Third customer update	Survey participants and other customers	Trial customer updates
Nov 2014	Second industry newsletter	All interested stakeholders	Second newsletter

Date	Activity	Audience	Evidence
Nov 2014	Update on Project progress in internal magazine, Newswire	Employees	CLASS **Our £9 million Customer Load Active System Services (CLASS) project is trialling a range of innovative techniques to manage electricity consumption by controlling voltages on the network – without customers noticing a difference.** Early in spring 2014, we achieved a major milestone with the successful go live of the CLASS solution. This is a suite of inter-connected technologies installed across our network, in our control room and in National Grid's control room. Project manager Herb Castillo said, 'Designing, developing and commissioning the technology has been one of the biggest challenges for the project to date – but what we learn will help with any future rollout of CLASS.' The technology installation is a major part of the project but we also need to understand if CLASS has any effect on our customers. So now that CLASS is live, we've started our trials and customer surveys to ensure that the technologies are working as planned and to see if customers notice any difference to their electricity supply. The first season of CLASS trials started in May and finished in August 2014. The good news is that customers haven't noticed any changes in the quality of their supply so far.' Herb added, 'The fact that the initial surveys are showing that customers haven't noticed any adverse effects on their quality of supply is great news for CLASS. But we won't have the full picture until September 2015 when all the trials and surveys have been completed.' The findings from the customer surveys and analysis being carried out by the University of Manchester, will determine if CLASS has been successful, and whether it can be rolled out across our network and by other DNOs.
Feb 2015	Fourth customer update	Survey participants and other customers	Trial customer updates
Mar 2015	Third webinar	All interested stakeholders	Third webinar recording
Mar 2015	Third webinar	All interested stakeholders	Webinar slides
April 2015	CLASS webinar promoted on Linked In	All interested stakeholders	Low Carbon Networks Forum ✓ Member electricity north west Bringing energy to your door Electricity North West CLASS webinar Last month we held our third webinar on our low carbon CLASS project. In this webinar we discuss the interface with National Grid and the live trials and events we have
May 2015	CLASS trial completion promoted in internal ebulletin	Employees	Trials show project is a CLASS act  Trials for our £9 million CLASS project are now complete. The project set out to trial a range of innovative techniques to manage electricity consumption by controlling voltages on the network – and prove that our customers wouldn't notice a difference. Since the project went live in spring 2014 we have completed four sets of trials and over 1300 customer surveys. By carrying out these trials and surveys, our aim was to show that CLASS has no adverse effects on our customers' electricity supply and that using these techniques will enable us to make maximum use of our existing network. This will reduce carbon emissions and help reduce costs to customers. The findings from the trials and surveys have successfully proved that CLASS does not affect customers' perception of their electricity service and, subject to analysis of additional data, could be rolled out to electricity networks nationwide. Innovation Delivery Manager Paul Turner said, "Before the trials could start we had to install a range of equipment in our control room and in 60 primary substations serving 485,000 of our customers in the North West. I'd like to thank all teams involved in the installation of the CLASS equipment and completion of the trials for helping us to deliver this great result." You can find out more about CLASS and our other low carbon projects at www.enwl.co.uk/thefuture.
May 2015	Fifth customer update	Survey participants and other customers	Trial customer updates

Date	Activity	Audience	Evidence
May 2015	CLASS trial completion promoted on Yammer	Employees	PT Follow paul turner May 29 at 10:45am We have now completed our trials as part of the £9 million low carbon CLASS project. Over the past year we have carried out four sets of trials and 1300 customer surveys which aimed to show that we could reduce demand on the network by reducing voltage. The surveys have proved that customers did not notice a difference to their electricity supply during the trials which means that CLASS has been successful and could be rolled out to other DNOs. Before the trials started we installed equipment at 60 primary substations serving 485,000 of our customers. Many thanks to all the teams who helped with the installation of the CLASS equipment and completion of the trials for helping us to deliver this great result. Find out more about CLASS and our other low carbon projects at www.enwl.co.uk/thefuture. « collapse The Future - ENWL's plans for future network investment www.enwl.co.uk Part of our role as network operator is to plan for the future. We invest money from customers' bills right back into region's electricity networ... Unlike · Reply · Share · More You, Mike Kay, Ged Flanagan and 3 others like this.
Jul 2015	Workshop	Industry and regulatory stakeholders	Workshop slides
Jul 2015	High level results on website	All interested stakeholders	Project update July 2015
Aug 2015	Closedown event on Linked In	Industry stakeholders	Jane Stell Communications Manager, Electricity North West CLASS closedown event - 9 September 2015 Next month we are holding our final dissemination event for our low carbon project CLASS at the BMA in London. CLASS has been trialling innovative techniques to control voltage, to reduce demand and maximise the use of existing electricity network capacity. Our results show that CLASS could save the need for a new power station. Find out more and register for the event: https://www.eventbrite.co.uk/e/class-closedown-event-registration-17762907334 less Comment (0) · Like (0) · Unfollow 20 seconds ago
Aug 2015	Closedown event on Twitter	All stakeholders	ElectricityNorthWest @ElecNW_News · Aug 25 To discover the key findings from our low carbon project CLASS come along to our free event next month eventbrite.co.uk/e/class-closed... #thefuture View summary
Sep 2015	Closedown event	Industry stakeholders	Event slides
Sep 2015	Closedown event on Linked In	Industry stakeholders	Jane Stell Our CLASS closedown event on 9 September received great feedback from delegates and was well attended by our industry stakeholders. You can see the slides from the day on our website at: http://www.enwl.co.uk/class/about-class/key-documents less Like (0) · Delete 1 second ago
Sep 2015	Closedown event on Twitter	Industry stakeholders	ElectricityNorthWest @ElecNW_News · 4 hrs Find out more about our closedown event for #lowcarbon project CLASS in #London yesterday enwl.co.uk/class/about-cl... 

Date	Activity	Audience	Evidence
Sep 2015	Closedown event on Yammer	All employees	Jane Stell Wednesday at 10:24am from iPhone A great turn out for our CLASS project closedown event in London today. Here's Steve Cox introducing the day.  Like · Reply · Share · More Steve Cox 15 hours ago Great performance by the team today - we received some great feedback from ofgem and DECC attendees as well as from the other DNOs. A £10m R&D project that will help transform the UK grid system but it wouldnt have happened without the team who delivered it. Thankyou to everyone across the business for all your help and especially the futures team very proud of you all :) Unlike · Reply · Share · More You and Phil McFarlane like this Jane Stell 20 seconds ago You can see the slides from the event on our website at: http://www.enwl.co.uk/class/about-class/key-documents
Sep 2015	Closedown event on Twitter	All stakeholders	Electricity North West We held a very successful closedown event for our low carbon project CLASS in London yesterday and got some great feedback from industry stakeholders. To find out more about what we discussed, you can read through our event slides here...https://... more  Organic Targeted to: All Followers 5,337 impressions · 48 clicks · 10 interactions · 1.09% engagement Sponsor update Like (9) · Comment · Pin to top · 5 days ago

APPENDIX B: GLOSSARY OF TERMS

ASC	Autonomous substation controller
CB	Circuit breaker
CCC	Customer contact centre
CCGT	Combine cycle gas turbine
COMA	Customer operational and maintenance agreement
DCODE	Distribution code
DG	Distributed generation
DNO	Distribution network operator
DR	Demand response
DUoS	Distribution use of system
ECP	Engaged customer panel
FFR	Firm frequency response
FR	Frequency response
GB	Great Britain
GCODE	Grid code
I&C	Industrial and commercial
ICCP	Inter control centre communication protocol
MSC	Mechanical switched capacitor
NETSO	National electricity transmission system operator
NG	National Grid, UK electricity transmission system operator
NMS	Network management system
PDR	Peak demand reduction
PoF	Power On Fusion, general electric network management system
QoS	Quality of supply
RIIO	Revenue = Incentives + Innovation + Outputs
RP	Reactive power
RTU	Remote terminal unit
SQSS	System security and quality of supply standard
SVC	Static var compensator
TSO	Transmission system operator
UoL	University of Liverpool
UoM	University of Manchester

APPENDIX C: LONG-TERM MONITORING STUDY

Proposal

Summary

Project sponsor: Electricity North West Ltd (ENWL)
Project owner: Paul Turner
Project title: Post-CLASS long-term monitoring study
Project duration: 10 Years
Commencement date: December 2015

Introduction

The Customer Lead Active System Service (CLASS) Project, funded by the Low Carbon Networks Fund and Project partners, successfully delivered the Project over a two-year period, completed in September 2015. The Project provided an understanding between the voltage/demand relationship and how the use of innovative voltage management techniques can be utilised to provide demand response.

The CLASS Project consisted of the installation of new low cost innovative voltage management techniques to provide new demand response to reduce peak network demand and provide a new mechanism for frequency and voltage control to National Grid.

A Successful Delivery Reward Criteria (SDRC) of the CLASS Project was to continue a ten year long-term study of the data and analysis post the Project closedown to continue to validate the results of the Project.

Technical background

New monitoring equipment, providing sampling rates advised by the University of Manchester, was deployed at all 60 primary substations in the trial area. This high accuracy, high resolution equipment was used to record all trial data which was publicly available on the Nortech iHost platform.

Data arising from the additional monitoring installed on the primary substation sites was used by the academic partner to examine the voltage/demand relationships. The additional monitors (CLASS MW/MVAr/Volts/Ampere/frequency transducers) were identical to those purchased for business as usual except for the addition of an RS485 high data rate output. This RS485 output was channelled via a Nortec Envoy storage and 3G converter unit to a cloud computing iHost website. The improvement in data quantity and resolution was highly significant as values to the second/volt/ampere etc were obtained compared to half-hour averages for existing planning tools and dead bands in the 5-10% range for existing SCADA systems.

As the CLASS Project is now complete it was not cost-effective to keep the data transfer and iHost website active.

Project aim and scope

The aim of this Project is to complete a ten-year long data collection and analysis which will complete the final SDRC of the CLASS Project.

As the data transfer system and website is no longer active the proposal is for Electricity North West to monitor six primary substation sites which are representative of its geographic area/customer base. The data will be collected every two years from the secure digital card in the Envoy communication units that have been installed at these sites under the CLASS Project. The collected data will then be analysed to validate the coefficients developed in the CLASS trials and the results passed to National Grid. This process will carry on for ten years continuing to validate the results of the CLASS Project and provide valuable data to National Grid as well as being able to provide a long-term monitoring study on the changing demand response of networks. All costs for this proposal will be carried by Electricity North West.

The six substation sites identified for this long-term study are shown below in table 1 which is a representative geographic and customer base mix of Electricity North West's region.

Table 1: Six representative primary substations

Domestic	Industrial & Commercial	Mixed
Longsight	Trafford Park North	Hyde
Chassen Road	Kingsway	Dickinson Street

Testing plan

The data collected from the six sites identified in table 1 will show the normal tapping cycle of the network. It is also proposed that the week prior to the collection of data, both primary transformers should be tapped up/down by one tap as per table 2 test plan shown below to continue to validate the voltage/demand hypotheses and results.

Each test should last for 30 minutes.

Table 2: Test plan

Time	Midweek		Weekend	
	No. of tap up tests	No. of tap down tests	No. of tap up tests	No. of tap down tests
00:00 to 06:00	1	3	1	2
06:00 to 09:00	1	3	1	2
09:00 to 18:00	1	3	1	2
18:00 to 00:00	1	3	1	2

There will be no customer engagement to provide confidence that customers still continue to perceive no degradation of power quality, as extensive customer engagement was completed in the CLASS trials to demonstrate acceptance of the Method.

Key milestones and deliverable

The following activities and their descriptions are the acceptance milestones and deliverables of the Project.

The deliverables would be defined as follows:

	Deliverables	Delivery date
1	Collect the data from the six primary substation sites	December 2017
2	Analyse the collected data and pass results to NG	April 2018
3	Collect the data from the six primary substation sites	December 2019
4	Analyse the collected data and pass results to NG	April 2020
5	Collect the data from the six primary substation sites	December 2021
6	Analyse the collected data and pass results to NG	April 2022
7	Collect the data from the six primary substation sites	December 2023
8	Analyse the collected data and pass results to NG	April 2024
9	Collect the data from the six primary substation sites	December 2025
10	Analyse the collected data and pass results to NG	April 2026
11	Long-term monitoring study on the changing demand response of networks	September 2026

If at any stage the data collected and analysis shows any significant deviation away from the coefficients and demand/voltage matrix, this will be investigated in more detail.