Customer Voltage & Power Quality Limits ‘Changing Standards’

An Innovation Funding Incentive Project

Closedown Report

August 2015

CONTENTS

VERSION HISTORY

Version	Date	Author	Status	Comments
1	July 2015	T Kennelly	Version 1	
2	July 2015	D Pearmain	Version 2	Incorporating feedback from Steve Cox
3	July 2015	M Brainch	Version 3	Additional content incorporated
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GLOSSARY

Abbreviation	Term
BaU	Business as usual
CLASS	Customer Load Active System Services
DNO	Distribution network operator
DUoS	Distribution use of system
ECP	Engaged customer panel
EHP	Electric heat pumps
ENWL	Electricity North West Limited
EV	Electric vehicle
GSP	Grid Supply Point
HV	High voltage
I&C	Industrial & commercial
IFI	Innovation Funding Incentive
LCN Fund	Low Carbon Networks Fund
LCT	Low carbon technology
LV	Low voltage
MPAN	Meter point administration number
NIA	Network Innovation Allowance
PSR	Priority services register
PV	Photovoltaics
THD	Total harmonic distortion
WPD	Western Power Distribution

1 EXECUTIVE SUMMARY

This document and the analysis therein is the culmination of a 12-month customer engagement exercise involving consultation with 1,796 customers from across Electricity North West's distribution region.

The Changing Standards project explored customers' attitudes towards power quality at measured values. The aim of the research was to determine if customers are sensitive to the provision of an electricity supply at or near to statutory limits.

This report sets out the main findings from a sample of customers confirmed to have received voltages exceeding existing power limits and a baseline sample of customers supplied consistently within the current standards.

During the course of this research, voltage measurements from over 7,000 low voltage (LV) networks were collated and provide the first comprehensive assessment of the voltage profile across a range of LV feeders on Electricity North West's distribution network.

This project was funded by Ofgem's Innovation Funding Incentive (IFI) scheme, which was replaced in April 2015 with the Network Innovation Allowance (NIA). The schemes encourage DNOs to invest in smaller, technical, commercial or operational projects, which have the potential to improve network operation and maintenance and deliver financial benefits to the licensee and its customers.

1.1 Background

DNOs are currently required to supply electricity to customers within two mandatory operating standards relating to voltage and total harmonic distortion (THD)[1]. Where customer supplies exceed the mandated limits, re-attaining compliance can be very costly. These issues may increase with greater adoption of low carbon technologies (LCTs) such as electric heat pumps (EHP), electric vehicles (EV) and micro-generation.

If existing UK standards are maintained, the challenges associated with sustaining voltage within these limits could cost DNOs and their customers many millions of pounds in traditional network reinforcement to meet the projected increase in demand and generation. If these standards could be relaxed, even by a relatively small amount, significant savings could be made in expenditure on the network infrastructure required to maintain compliance.

The standards have existed for many years and have their origins based on the requirements of appliance technologies from the 1960s. Changing Standards focuses on customer perception of supply quality and does not examine any element of risk to any type of electrical/electronic equipment associated with an extension of the standards. It is of note that appliances/equipment designed for the UK market are now generally manufactured to conform to European voltage specifications and will overwhelmingly operate well beyond the limits of the GB standards.

Empirical evidence shows that short duration or lower level excursions outside these standards do not cause any noticeable effects for customers or indeed detract from satisfaction levels. Nor is there any evidence of a correlation with customer complaints. Electricity North West is not aware of any published research that has sought to measure customers' sensitivity to voltage and harmonic distortion, either within or beyond the current standards.

This project focuses on exceedance of voltage limits rather than fluctuation within the standards and therefore investigation around flicker was excluded from this research.

[1] Refer to Appendix 1.1 Fundamental Drivers of Voltage Limits

1.2 Objectives

Electricity North West sought to test the following hypotheses:

- Customers will not notice a decline in service standards if the permissible ranges for voltage and harmonic distortion are widened;
- If customers do notice, their perception of power quality and overall satisfaction are not adversely affected.

The Changing Standards research addressed these hypotheses by measuring customer satisfaction:

- When supplied with electricity at an average voltage level that conforms to the existing statutory range;
- When these limits are exceeded.

Electricity North West conducted this research in parallel with its Second Tier LCN Fund Customer Load Active System Services (CLASS) project, which used voltage regulation techniques to manage peak demand within existing standards. The CLASS project incorporated a statistically robust customer survey to test the extent to which the Method was discernible and/or acceptable to customers. The results of CLASS customer engagement serve as an indicative benchmark for the Changing Standards research. The detailed method and findings of the CLASS customer survey can be found on the project website.

1.3 Methodology

To establish if an extension of the present standards would be discernible to customers and empirically define the points at which sensitivity or detriment to service is observed, it was necessary for Electricity North West to:

- Collate the largest possible sample of LV network data;
- Engage with a sufficiently robust and representative group of customers from across a range of monitored networks.

The customer survey from which this report is derived was jointly designed by Electricity North West and its specialist market research provider, Impact Research. The research methodology and sampling approach was externally validated by an independent peer reviewer, Professor Alan Wilson of the University of Strathclyde Business School.

The Changing Standards research incorporated the following four key elements:

- Identification of areas of the LV network where voltage and/or THD limits had been, or were suspected to have been, exceeded;
- Development of a suitable customer survey instrument;
- Engagement with 1,796 customers across summer and winter seasons involving:
    - A quantitative survey of customers very occasionally subject to voltage and/or THD levels outside existing statutory limits;
    - A quantitative survey of customers where standards had not/were not expected to be exceeded, to act as a benchmark control group;
- Analysis of results to understand public perceptions of supply quality and customer satisfaction, where electricity provision falls outside statutory requirements.

Voltage and THD measurements were plotted on a power quality matrix, with the highest and lowest measurements segmented into specific data points. This matrix highlighted the duration of time that each voltage value was recorded over the monitoring period. This data influenced the selection of the survey population and ensured that the satisfaction measures accurately represented the view of customers exposed to voltage/THD at a specific value for a statistically significant period of time. The majority of surveys in the ‘exceedance sample’ were completed by customers who had experienced voltages outside the standard for over 5% of the monitoring period; this ensured customer perception was accurately measured on such networks.

1.4 Key findings

1.4.1 Customers known to have experienced voltages exceeding present limits are no more likely to claim they have noticed an effect than the general population

Customers who reported an effect/change in power quality or in the operation of appliances or lighting were no more likely to have experienced an exceedance than the reference population, indicating a weak relationship between detection and actual voltage excursions.

Customers on monitored circuits during the winter period were more likely to say they noticed an effect/change in their electricity supply, appliances or lighting (26%) compared to the summer period (19%) and the CLASS benchmark population (21%). Higher perceptions of changes/effects occurring during the winter period are correlated with the increased use of electrical appliances and equipment (specifically lighting) compared to the summer period, thus increasing the likelihood of customers noticing such effects should they occur.

1.4.2 When exceedances occur, there is no discernible impact on customer satisfaction

Satisfaction was generally high amongst the customers surveyed, even though the samples were deliberately skewed to areas where there had been an actual or suspected exceedance of operating limits.

Figure 1.1 demonstrates customer satisfaction levels (on a 1-10 rating scale where one is completely unsatisfied and ten is very satisfied), among segments included in the summer and winter seasons. Relative to the control group, there were no significant differences in the level of satisfaction observed in the summer among customers subjected to exceedance of the standard or any other segment.

At an aggregate level, overall customer satisfaction was lower in the winter compared to the summer, indicating greater sensitivity to power quality at times of increased demand.

However, there was no evidence to suggest that exposure to voltages outside the standard detracted from customers’ satisfaction of the service received, with comparable scores in winter and summer. The inclusion of a sample of customers exposed to a power cut during the winter season demonstrated that supply interruptions are a much stronger indicator of dissatisfaction than voltage.

Figure 1.1: Satisfaction levels amongst customer segments by season

Customer satisfaction	Summer	Winter
Control group[2]	9.2	9.0
Power cut[3]	*Not included*	8.5
PV[4]	9.2	*Not included*
Voltage enquiries[5]	9.4	8.7
Confirmed exceedance [6]	9.1	9.2
THD	NA	9.5

Figure 1.2 indicates that when satisfaction ratings given by customers supplied consistently within limits are compared to those where an excursion was confirmed, there are no statistically significant differences, irrespective of the magnitude of the exceedance.

Figure 1.2: Satisfaction levels amongst customers matched to an exceedance of voltage limits

Average voltage level	Change in standard	Summer	Winter
278v or more	10% or more	9.2	9.0
253v to 278v	Up to 10% over	9.3	9.3
216v to 253v	Within existing standard	9.4	8.9
194v to 216v	Up to 10% under	9.2	8.7
194v or less	10% or less	9.3	9.3

1.5 Conclusions

The research supports the hypothesis that customers are generally insensitive to supply voltage. The scale of LV network reinforcement, associated with the adoption of LCTs and driven by voltage compliance, is expected to become increasingly significant. A proportion of these costs could be avoided by allowing wider voltage operating limits; as the research shows little linkage with customer satisfaction.

The Changing Standards findings challenge the statutory requirement for absolute compliance to existing limits. Based on the evidence of this research, it can be concluded that UK adoption of the wider EU voltage parameters of 230V +/- 10% would most likely be indiscernible to customers.

Evidence from this extensive customer engagement project has established that customers exhibit little sensitivity when exposed to varying degrees of voltage exceedance. The findings show no significant or directional relationship between customer satisfaction and voltage exceeding the existing standards either by magnitude or duration.

[2] A sample where no voltage readings outside of the statutory range were recorded during the reporting period.
[3] A sample of customers on electricity circuits subject to faults (either a single or multiple supply interruptions).
[4] A sample of customers on feeders with a high penetration of PV.
[5] A sample of customers from networks with a reported voltage enquiry, some of which are confirmed as being subject to an exceedance and others confirmed to be within limits.
[6] A targeted sample representing “actual” not “suspected” voltage exceedances.

Changing Standards has identified that customers experiencing an unplanned supply interruption in the 12 months preceding the survey were significantly more likely to express dissatisfaction with their service than those customers exposed to minor exceedance of voltage limits, particularly if they had found it necessary to make contact with the DNO about the fault.

This comprehensive research builds on the earlier work by Western Power Distribution[7] (WPD). It suggests that an opportunity exists for an extension of present voltage limits and indicates that this can be achieved without customers' noticing or experiencing any detriment to service. Electricity North West proposes that extending the existing operating limits will better utilise low voltage networks, allowing the DNO to host increased photovoltaic (PV) penetrations and installations of EHP or EV on different types of LV network.

The benefits of extending power quality limits are derived from the avoidance of reinforcement costs arising from compliance with existing, restrictive parameters. A change in standards would allow DNOs to more effectively manage the transition to a low carbon economy and support environmental improvement through facilitating the adoption of LCTs at lower cost to customers and reduced distribution use of system (DUoS) costs from the deferral or avoidance of traditional network reinforcement.

The results herein and recommendations are based on a robust methodology which has been independently verified by peer review as robust in assessing customer perception against comparative technical voltage data. Other broader factors may need addressing by the electricity industry to support this recommendation, including technical considerations around the voltage tolerance of electrical and electronic apparatus designed for the UK market and the limits of older equipment presently connected to UK networks.

[7] Based on the learning outcomes from the Second Tier LCN Fund project LV Network Template for a Low Carbon Future.

2 METHODOLOGY

This section of the report provides supplementary information regarding the customer engagement methodology utilised to test the hypothesis referred to in section 1.2.

2.1 Customer engagement

To establish if an extension of the existing standards would be indiscernible to customers and empirically define the limits at which sensitivity or detriment to service is observed, it was necessary for Electricity North West to collate the largest possible sample of LV network data and engage with a sufficiently robust and representative group of customers from across a range of typical and monitored networks.

This section summarises the project activities and methodology adopted by Electricity North West and its project partner, Impact Research.

2.2 The customer surveys

The Changing Standards research ran concurrently with the CLASS customer surveys. This presented two distinct advantages:

- The CLASS surveys were used to establish perception of power quality amongst customers supplied consistently well within limits during normal operating conditions, providing a benchmark population;
- The CLASS survey instrument was used as a basis for developing the Changing Standards survey and this alignment allowed direct comparison of results.

The questionnaire was designed to measure if:

- Customers typically experience any adverse effects or changes in their electricity supply provision, or the functioning of electrical appliances/equipment or lighting;
- Customers are satisfied with the service they receive ie if the status quo is acceptable.

All of the customer surveys were conducted by telephone utilising customer data provided by Electricity North West and lasted approximately 20 minutes. The survey methodology was cost-effective and efficient given the geographical diversity of the targeted survey population. A financial incentive of £10.00 was offered to survey participants and paid in the form of an electronic retail voucher, cheque or charity donation.

A statistically robust sample of 1,796 customer surveys were conducted, 1,001 of which took place in summer 2014 and the remaining 795 were completed during winter 2014/15. The survey population was comprised of customers confirmed to have been exposed to voltage exceeding the standard and a control group, consistently supplied well within the limits. The aggregate survey population was recruited to be representative of the demographic profile of domestic and industrial and commercial (I&C) customers served by a range of Electricity North West's urban and rural networks with typical LV assets and configuration.

Detailed quantitative analysis was subsequently conducted, which compared actual voltage and THD measurements with the observational feedback from customers and their perception of the service provided. The analysis also aimed to distinguish if factors other than voltage exceedance, such as supply interruptions, might influence customer satisfaction.

The results, which are provided in section 3, were weighted by age, gender, social class and geographic area. A weight is a value assigned to each customer interviewed which indicates the statistical significance of each participant eg if a customer has a weight of two, then their answers will have twice the influence in the dataset. This recognised data analysis practice enabled the statistics calculated to be more reflective of the population they represent.

One of the challenges of this research was that only a proportion of Electricity North West's customers would reside or operate businesses in areas where LV voltage and harmonic standards are exceeded. Therefore, Changing Standards actively sought to identify monitored networks where minor exceedances had occurred and deliberately recruited customers on these feeders to participate in the survey.

The Changing Standards project team conducted a meticulous exercise to ensure that customers' meter point administration numbers (MPANs) were matched as reliably as possible to the respective feeder and consequently, the customers recruited to take part in the survey accurately aligned to network monitoring data.

Feedback from customers on CLASS trial circuits had indicated that dissatisfaction with service is primarily driven by exposure to supply interruptions. To understand if factors other than changes outside voltage standards were influential in driving dissatisfaction, a sample of customers who had experienced both voltage exceedance and supply interruption/s in the 12 months preceding the survey were interviewed. A control group of customers, supplied well within power quality limits, but who had experienced at least one supply interruption preceding the survey, were also interviewed.

2.3 Peer review of the customer survey instrument

A peer review of the customer survey instrument was conducted by Professor Ken Willis, Meritus Professor of Environmental Economics at Newcastle University.

The purpose of the peer review was to determine the suitability of the questionnaire proposed by Impact Research to provide robust quantitative research on customer sensitivity to voltage supply in areas where it exceeds or falls below the statutory guidelines. The peer review was required to ensure that high standards of quality, performance and credibility were achieved.

The conclusions of the peer review were summarised as follows:

- The questionnaires compiled by Impact Research for the IFI Changing Standards project follow good practice and are comprehensive in their coverage of the issues associated with customers who experience low or high voltages;
- The questionnaires are commendable and will permit an assessment of whether voltages changes are perceived by customers, and which types of electrical equipment customers perceive to be affected.

2.4 Use of network data to direct the customer surveys and support the analysis

The adopted methodology was designed to obtain data from the maximum number of accurately monitored networks at LV feeder level; match the network data to serviced customers and complete a sufficient number of surveys from which a robust evaluation of customer sensitivity could be gauged.

The four main steps followed are outlined below:

- Analyse historical network data to maximise the records available to Changing Standards and assess the general voltage profile across Electricity North West's LV network;
- Obtain recently recorded network data from
  - Monitors installed for routine BaU operational activities and to support LCN Fund projects
  - Monitors specifically installed on targeted networks of interest
  - Identify and survey customers on these networks;
- Obtain network data derived from recent voltage enquiry investigations. Identify and interview suitable customers on these networks;

- Conduct a substantive data analysis exercise, comparing actual power quality measurements with quantitative customer data, to empirically gauge customer sensitivity and satisfaction with service at a range of voltage values within and exceeding existing statutory limits.

A more comprehensive account of each of these steps is provided in appendix 4.

2.5 Network monitoring equipment

Technical data collated during Changing Standards was sourced from a range of different network monitors. Appendix 5 outlines the key features of the various monitoring instruments. It outlines why these instruments were utilised and gives details of how the equipment was deployed. Detailed specifications for the various instruments are also provided in the appendices and are published on the manufacturers' respective websites.

Careful consideration was given to the following criteria to ensure robust network data was captured to test the hypotheses listed in section 1.2:

- Appropriate sampling intervals for the network monitors
- Development of appropriate 'exception reports' (appendix 6), to assess a large volume of data derived for the following instruments:
    - Nortech Envoy/GridKey Monitoring Control Unit (MCU)
    - PSL PQube power quality monitor (PQM)
    - Kelvatek Bidoyng smart fuse
    - Acksen Electrocorder voltage monitor

Details on the procedures adopted for network data capture are provided in appendix 6.

2.6 What was outside of the scope of the research?

The study did not examine any element of risk to any type of electrical/electronic equipment, on the basis that modern equipment will generally operate well beyond the voltage limits defined in the UK and European standards.

Flicker can be caused by a range of factors and is most commonly observed in lighting. This project focused on exceedance of voltage limits rather than fluctuation within the standards and therefore flicker was excluded from this investigation.

A thorough discussion of these topics is included in appendix 4.

3 ANALYSES AND RESULTS

This section of the report summarises the key findings from the analysis of the customer survey and critically focuses on establishing if customers are sensitive to minor changes outside existing voltage and THD standards. It also aims to empirically determine a revised range which is acceptable to the UK public, based on customer consultation.

The key findings in this section draw on analysis of customer perception data, collected through the administration of a customer survey instrument (referenced in appendix 3) and the cross-referencing of perception data with actual voltage and THD measurements.

3.1 Customer perception measurement

Network data confirmed that some customers had been exposed to relatively significant exceedances beyond the limits of the BS EN 50160 standard. However, most modern electrical appliances are manufactured to operate across a much wider voltage and THD range. Therefore the implication is that exceedance of the current standards is unlikely to affect appliances in a way that is discernible to customers.

The Changing Standards survey instrument was designed to measure any observable impact on customers' power quality including:

- Impact on specific appliances (particularly older equipment with a lower voltage tolerance);
- Observations of equipment working quicker/slower, or less effectively than usual;
- Effect on lighting around flicker, dimming or brightness.

To provide a measurement of the status quo, survey questions were carefully phrased to understand customers' current perceptions of their power quality. When prompting customers to consider whether they had noticed any changes in the performance of their appliances, they were asked to think about the current situation relative to the previous three months.

3.2 Actual voltage and THD measurements

Actual voltage and THD measurements from end-to-end data sets, obtained from monitored LV feeders at both transformer busbars and mid/end end points, were plotted on a power quality matrix. This data was analysed by segmenting the highest and lowest measurements into specific data points.

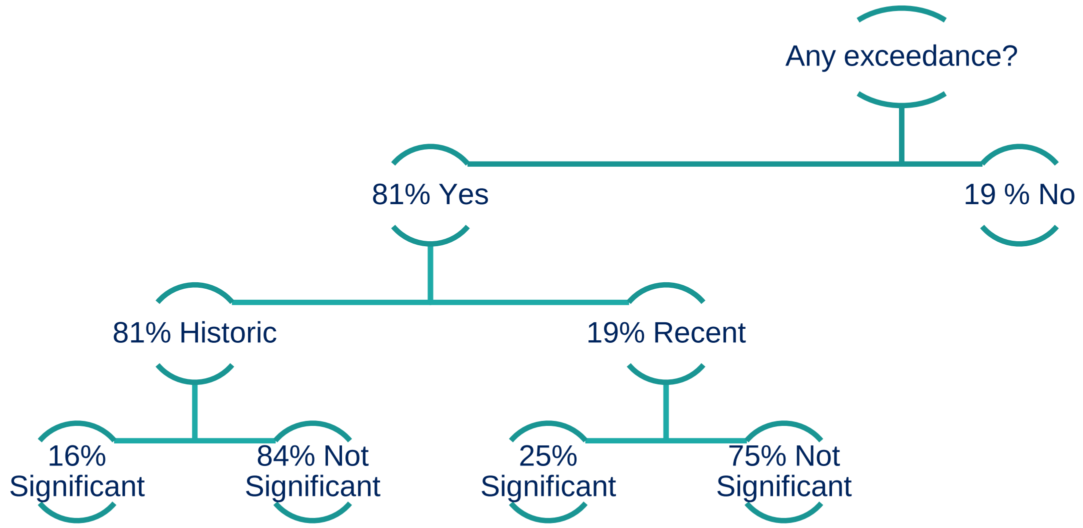
It is important to note that the basis on which customers were selected to participate in the survey was more sophisticated than simply observing the highest and lowest recorded voltage. Complete CSV data files, showing voltage profiles at a granular level, were available for each monitored site. This data was considered when selecting the survey population, to ensure the satisfaction matrix accurately represented the view of customers exposed to voltage/THD at a specific value for a statistically significant period of time. An exceedance of the standard for 5% of the monitoring period, or over, was regarded as significant. The majority of customer surveys in this sample were conducted with respondents exposed to exceedances classified as significant, to ensure customer perception was representative of the voltage profile on these networks.

3.3 Matching survey participants to actual voltage and THD measurements

Figure 3.1 demonstrates that a large proportion of the network measurements collated during Changing Standards indicated some degree of minor exceedance. Around 20% of these fell into the significant category.

Figure 3.1: Voltage measurements

7,082 network measurements analysed



- In the summer season a total of 2,867 voltage readings from multiple monitoring instruments were obtained and 59% of survey participants were accurately matched to these network measurements, providing a robust sample size with which to test the hypotheses;
- In the winter season a total of 4,215 voltage readings were collected, representing a significant increase in data relative to the summer. In addition to having a greater volume of voltage data, 85% of survey participants were accurately matched, providing a much larger sample of customers with which to conduct statistical analysis;
- Technical data collated as part of this project provided little evidence to suggest that LV networks in Electricity North West's distribution region are currently at risk of breaching the permissible 5% planning tolerance for background harmonics. In the summer season 264 THD readings were acquired followed by 223 in the winter, none of which were outside the standard. This research considered around 4,000 THD measurements in total; this analysis revealed only minor exceedances at 12 distribution substations, with the highest reading being only fractionally over 5%.
- In summary the largest possible sample of LV network data was collected across the summer and winter phases of the research and successfully matched to a significant proportion of customer surveys, enabling a statistically robust analysis of customers' sensitivity to changes outside present voltage and THD standards.

3.4 Are voltage exceedances discernible to customers?

The customer survey was designed to test if customers supplied a) consistently within statutory voltage limits and b) subject to occasional exceedances, experienced problems with their electricity supply or the functioning of electrical appliances/equipment or lighting.

The analysis of customer perception data indicates that in both seasons, only 7% of respondents reported an effect/change in power quality. This increased when respondents were prompted to think specifically about lighting. This resulted in approximately 20% of participants in summer and 26% in winter claiming to have noticed an effect. In the CLASS baseline survey (in areas where customers' supply voltage remained well within the statutory operating range), 21% of participants answering the same question claimed to have noticed an effect.

The higher observations of effects during the winter period were correlated with the increased use of electrical equipment (specifically lighting) compared to the summer period. The lighting effect most commonly observed by the customers claiming to have noticed a change was flickering (78% of the 26% reporting an effect), significantly more so than during the summer (53% of 20%).

Figure 3.2 illustrates that customers who observed a change in overall power quality or the operation of equipment/lighting are only marginally more likely to have experienced a recent or significant excursion. This analysis of customer perception data cross-referenced with associated voltage and THD measurements indicates a weak relationship between detection and actual voltage exceedance.

Figure 3.2: Customers matched to actual voltage/THD readings

Proportion of customers	Total survey sample	Customers who noticed an effect
Recent – Customers confirmed to have experienced an exceedance in the winter period	38%	41%
Significant – Customers known to have experienced an exceedance of voltage limits for 5% or more of the monitoring period	31%	35%

3.5 If discernible, are exceedances of voltage standards acceptable to customers?

The customer survey included pertinent questions to decipher if customers were satisfied with the service they receive and if the status quo is acceptable.

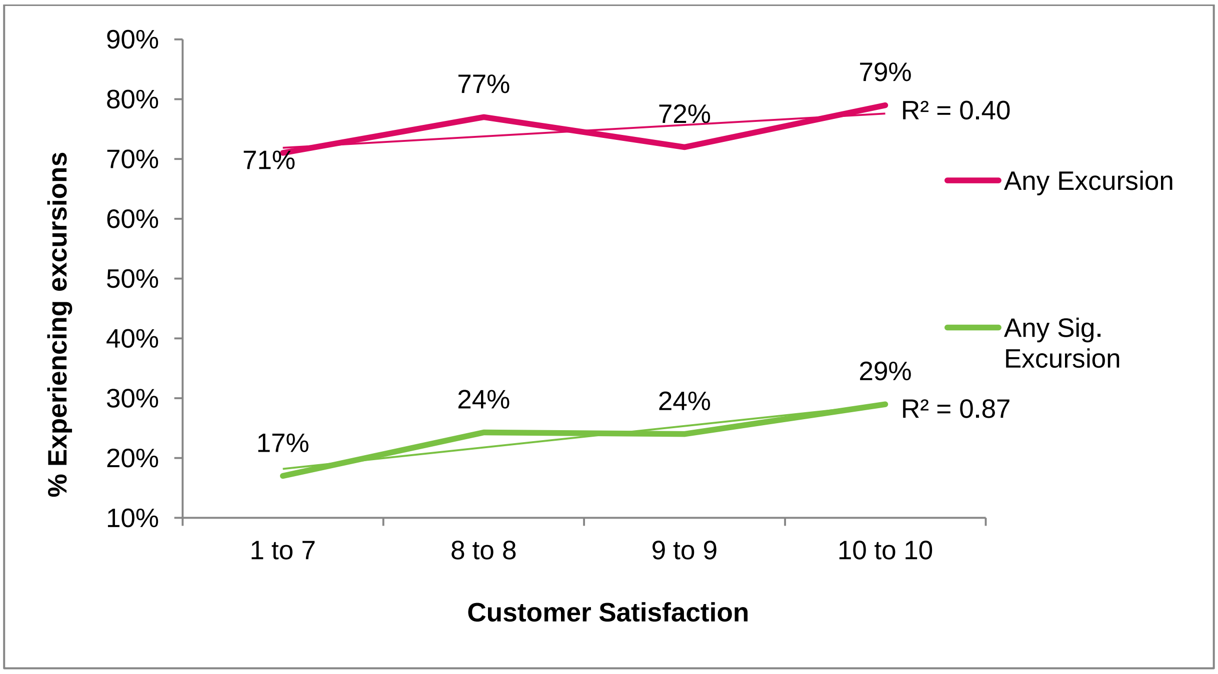
Notably, satisfaction was very high among the targeted sample of customers surveyed, despite this population being skewed to areas where there had been an exceedance of the voltage limits. Approximately 90% of these customers reported satisfaction ratings between eight and ten (ten representing complete satisfaction and one being completely dissatisfied). The CLASS baseline customer satisfaction level, carried out before any voltage management techniques were applied, was comparable at 89%.

Interestingly, 88% of customers confirmed to have been supplied consistently well within limits (control sample), were satisfied with service. This was marginally less than the 91% expressing satisfaction in the exceedance sample. More notably, customers in the control sample, who claimed to have noticed an effect in appliances/lighting, exhibited significantly less satisfaction with service (68%) than those who had been exposed to a minor exceedance, and had observed an effect, 85% of whom reported the highest satisfaction scores.

Such a high level of satisfaction within the population exposed to voltage exceedance and contradicting results from customers supplied well within limits implies a very weak correlation between voltage and customer satisfaction.

In addition to general analysis of customer perceptions, more in-depth analysis was conducted which matched perception data to actual voltage and/or THD readings. Figure 3.3 demonstrates that a statistically significant proportion of satisfied customers actually experienced some degree of exceedance. This suggests further evidence of a weak relationship between voltage and the degree to which customers are satisfied with their power quality.

Figure 3.3: Customer satisfaction levels plotted amongst participants known to have been subject to any exceedance and/or a significant exceedance



Further analysis grouped customers into one of five different segments, depending on the magnitude of the voltage exceedance they had been subjected to.

Figure 3.4 demonstrates that when the satisfaction ratings given by customers supplied within limits are compared to those on networks where exceedances occurred, there are no statistically significant differences, irrespective of the extent of the exceedance.

Figure 3.4: Mean satisfaction levels amongst customer matched to voltage excursions

Average voltage level	Change in standard	Summer	Winter
278V or more	10% or more	9.2	9.0
253V to 278V	Up to 10% over	9.3	9.3
216V to 253V	Within existing standard	9.4	8.9
194V to 216V	Up to 10% under	9.2	8.7
194V or less	10% or less	9.3	9.3

The equivalent analysis was applied to all variables within the scope of the survey:

- The type of customer (domestic or I&C);
- The season in which the customer was surveyed/voltage readings were obtained;
- Customers who experienced a supply interruption in the previous 12 months that:
    - Did or did not make contact with the DNO as a result;
- Customers who claimed to have noticed an effect that:
    - Did or did not have this claim verified by actual voltage/THD readings.

There was no statistically significant evidence that demonstrated a strong correlation between exceedance of the statutory voltage range and a decline in customer satisfaction.

The only exception was a slight increase in sensitivity amongst LV connected I&C customers in the exceedance sample, who also claimed to have noticed an effect. However, these were very few in number and, based on their feedback, were far more likely to have experienced a fault than the average customer. As such, it is not possible to separate the driver of dissatisfaction from the impact of supply interruptions and a voltage effect.

3.6 Determinants of variances in levels of customer satisfaction

Key learnings from Electricity North West's Capacity to Customers (C_2C) project with regards to customer influences on power quality perception included:

- Customers are likely to be aware of the frequency and duration of supply interruptions/faults. This intrinsically means that the incidence of supply interruptions has a greater and more negative weighting on perception of power quality;
- The perception of power quality is likely to vary in rural and urban regions. Customers in areas such as Cumbria, where fault rates are typically higher, appear to have a greater tolerance to supply interruptions and different expectations than customers from more densely populated urban regions.

The Changing Standards customer research findings mirror those from CLASS and C_2C, confirming the impact of power cuts and that a resultant contact with the DNO seems to be a much stronger indicator of dissatisfaction than exceedance of operating voltage limits.

Analysis of customer feedback obtained during the Changing Standards project has quantified the likelihood of contact being made with the DNO as a direct result of experiencing either an effect/change in supply, appliances or lighting (20%) or supply interruptions (43%). Both short and lengthier supply interruptions are significantly more likely to prompt contact than exceedance of voltage limits, being more obvious to customers. The effect of a supply interruption may also be discernible to customers who are away from the property at the time of the incident, because of inconvenience associated with re-setting alarms, time switches and digital displays etc.

3.7 Peer review of the customer survey results

A peer review of the customer survey results was undertaken by Professor Alan Wilson of the University of Strathclyde Business School.

A summary of the peer review is included below:

- The research shows that around 26% of participants in winter and 20% in summer claimed to notice changes in overall power quality or appliances, with the majority of effects being specific to lighting. From the data, there is little evidence to suggest that minor voltage exceedance directly impacts on satisfaction. However, the impact of supply interruptions seems to be a much stronger indicator of dissatisfaction than voltage;
- It should be noted that satisfaction was generally high in the targeted samples even though the survey population was skewed to areas of actual and suspected incidences of voltage exceedance;
- Technical data confirms that customers who noticed an effect were more likely to have experienced a recent exceedance; however, no significant or directional relationship between customer satisfaction and voltage excursions was found;
- The research does not identify the limits at which sensitivity is observed and therefore cannot identify the most appropriate power quality limits;
- A robust methodology was employed and data was obtained by rigorous means. An independent peer review of the research methodology, approach and findings has concluded that customers exhibit little sensitivity to minor exceedance of power quality limits beyond the current standards.

4 PROJECT CHALLENGES AND RISKS

This section of the report seeks to disseminate the lessons learned from the project. It highlights specific risks and explains how Electricity North West overcame these challenges to ensure the validity of the results and demonstrate how the learning could be applied to other innovation projects.

The primary challenges were around site selection, the choice of appropriate network monitors and the development of new reports to interrogate large volumes of network data from multiple devices.

4.1 Speculative monitoring

Electricity North West recognised that extensive speculative monitoring represented a risk, as networks confirmed to have exceeded voltage limits might require further investigation and potential costly remediation. Networks identified as having been subject to an exceedance during this research were assessed on a case-by-case basis and the appropriate remedial measures undertaken.

4.2 Choice, availability and constraints of network monitors

Electricity North West's stock of various LV network monitors is generally fully utilised for active fault management, specifically in the case of transient faults which are particularly disruptive to customers.

Funds for Changing Standards to procure new monitoring instruments were limited. Existing available devices, used in previous LCN Fund projects, required upgrading to deliver the required outputs of the project. This involved returning instruments to the manufacturer. Costs and turnaround timescales associated with upgrading equipment (Bidoyngs) and the delivery of new apparatus (Electrocorders) threatened the timely implementation of the initial phase of targeted network monitoring during summer 2014. The availability of suitable network monitors, and the budget and appropriate timescales to procure new instruments, should be a primary consideration in any research of this type. This should factor more critically in the initial scoping of future similar projects.

4.3 Availability of network data

The availability of network data was constrained by three key issues encountered during the preparatory stage of customer engagement:

- Technical issues were encountered during the development of new firmware to enhance the capture of network performance data from Nortech Envoys which consequently delayed the upgrade. This constraint significantly impeded the identification of networks potentially exposed to exceedance of planning limits for harmonic distortion until late into the delivery phase of the project;
- Development of new technology (namely the WEEZAP and the LYNX) associated with Electricity North West's current Second Tier LCN Fund project Smart Street unavoidably impacted upon Kelvatek's ability to deliver an exception report, allowing interrogation of Bidoyng data until autumn 2014. This impeded identification and subsequent recruitment of survey participants from some samples;
- Work undertaken to confirm the accuracy of the Bidoyngs identified that large and erroneous THD values (>6%) were attributable to a poor connection at the neutral busbar. This was valuable learning for Electricity North West and Kelvatek. The situation had no detrimental effect except on 'distance to fault' reporting. Bidoyng measurements from over 2,000 installations were analysed during Changing Standards and this issue affected only 100 (5%). All false results were excluded from the research.

To counteract these issues, a flexible approach was adopted to recruiting survey participants, as technical data became available. As such, there was no significant slippage in the overall delivery of the project.

4.4 Site selection

Electricity North West estimates that less than 2% of households in its region might occasionally receive voltages that are slightly lower than 216V or marginally higher than 253V for very short durations. There are likely to be a small number of LV networks in remote rural communities that are very occasionally subject to voltages under 216V, for short periods during winter peak demand. Because of the absence of street lighting or other serviced street furniture it was not possible to effectively monitor these feeders, within the scope, budget and time constraints of this project. However, in the absence of voltage complaints from customers on these networks, we can reasonably assume that those residing or operating businesses in these areas are generally satisfied with the status quo.

5 SUMMARY OF KEY FINDINGS

This section of the report summarises the key messages from the analyses carried out to address the customer hypotheses:

- Customers will not notice a decline in service standards if the permissible ranges for voltage are widened;
- If customers do notice, their perception of power quality and overall satisfaction are unlikely to be adversely affected.

The research was undertaken in two phases in summer 2014 and winter 2014/15, during which time approximately 1,800 customers were consulted and over 7,000 LV networks measurements interrogated. This research provides the first comprehensive assessment of the voltage profile across a representative range of LV feeders on Electricity North West's distribution network.

Evidence from extensive customer consultation undertaken during Changing Standards has established that customers exhibit little sensitivity when exposed to a minor exceedance of voltage limits. The findings also establish thaqt there is no significant or directional relationship between customer satisfaction and voltage exceedance by either modest limit or duration.

These findings are supported by CLASS customer engagement. Voltage reduction techniques deployed at 60 primary substations during the CLASS trials affected 17% of Electricity North West's network, representing 485,000 customers. These techniques were designed to maintain supply within statutory limits, substantiated by HV and LV monitoring, which identified only one CLASS LV end point measuring under 216Vat the remote end of the main.

In light of the Changing Standards research, it must be assumed that during times of peak demand and voltage reduction techniques there were likely to be other networks exposed to similar levels of exceedance. Despite this, Electricity North West did not receive any power quality complaints that were directly linked to CLASS and satisfaction amongst customers on CLASS trial circuits was overwhelmingly positive, notably increasing during the trial period from the initial baseline benchmarking survey. The initial CLASS customer survey summary report is available on the project website. The full closedown report was published in September 2015.

The Changing Standards research set out specifically to identify networks that might occasionally exceed limits. While the project has confirmed the existence of these networks, it suggests that voltages are generally well maintained within the present statutory limits. This supports the findings of Electricity North West's Low Voltage Network Solutions project and WPD's LV Network Templates, which involved more substantial analysis of feeder-end voltages.

Based on the voltage THD data collated during Changing Standards, there is little evidence to suggest that LV networks are currently at risk of breaching the permissible 5% planning tolerance for background harmonics. Harmonic distortion is anticipated to increase with greater penetration of LCTs however, from the network data obtained during this project, it is not possible to empirically define if an extension to THD planning and compatibility limits would be acceptable to customers.

Changing Standards research identified that customers' experience of a planned or unplanned supply interruption in the 12 months preceding the survey were far more likely to express dissatisfaction with service than those customers exposed to minor voltage exceedance by magnitude or duration, particularly in the case of customers who had found it necessary to make contact with the DNO about a fault.

Given these findings, Electricity North West supports WPD in suggesting that an opportunity exists for an extension of the limits and this can be achieved without customers noticing or experiencing any detriment to service. Given the diversity of impacts on LV networks resulting from the adoption of LCTs, the existing standards are considered too restrictive and warrant greater flexibility. Changing Standards challenges the statutory requirement for absolute compliance to present limits and based on the evidence presented, proposes the UK's adoption of the wider EU voltage parameters of 230V +/- 10% (EN 60038 - 2011), representing a modest extension to the standards.

Electricity North West proposes that extending the present limits will better utilise low voltage networks, allowing the DNO to host increased PV penetrations and installations of EHP or EV on different types of LV network.

The benefits of extending power quality limits are derived from the avoidance of unnecessary maintenance and reinforcement costs driven by LV voltage compliance with existing, restrictive parameters. Relaxing the standard would allow DNOs to more effectively manage the transition to a low carbon economy and support environmental improvement through facilitating the adoption of LCTs at lower cost to customers and reduced DUOS costs from deferral or avoidance of traditional network reinforcement.

This recommendation is based on the perception of a statistically robust sample of domestic and I&C customers served by typical LV distribution networks, assets and configuration. The research was deliberately skewed towards customers supplied at, or around the extremes of, mandatory operating standards, for very short periods. It is therefore not strictly representative of most of Electricity North West's customers, fed from networks with normal voltage characteristics.

Other wider factors may need addressing by the electricity industry to support this recommendation, including technical considerations around the voltage tolerance of electrical and electronic apparatus designed for the UK market and the limits of older equipment presently connected to UK networks.

6 NEXT STEPS

These findings will be presented to the Energy Network Association ENFG task group, which reports to DECC and Ofgem on investigations from all DNOs, National Grid and appliance manufacturers on the effect of adopting the wider EU LV voltage limits. It is anticipated that these findings will support the argument for further research activity around:

- ESQCR technical compliance and clarity of the current ESQCR regulations and guidance notes in respect of voltage limits, which are presently considered too restrictive;
- The viability, risks and advantages of extending the present UK 230V +10/-6% limits to, and potentially beyond the European voltage levels (EN 60038 - 2011), which allow a greater LV band of 230V +/-10%.

The Changing Standards research was run in parallel with Electricity North West's Second Tier CLASS project, which deployed voltage changing techniques and critically had a robust customer trial element embedded within the methodology.

The CLASS closedown report was published in September 2015 and early findings of both Changing Standards and CLASS provide customer evidence to suggest that a modest reduction may be possible in certain networks without any detriment to service, supporting WPD's proposal to extend current limits based on the output of its LCN Fund LV Templates project.

7 APPENDICES

APPENDIX 1: FUNDAMENTAL DRIVERS OF VOLTAGE LIMITS

1.1 Voltage control – statutory & licence conditions

For many years the United Kingdom operated a standardised supply voltage of 240V ±/-6% (415V for three-phase). The historical basis for present statutory limits was the removal of the perceived barrier to trade between European countries in 1994, when the European Commission (EC) determined that the standard UK mains voltage of 240V should be 'harmonised' at 230V with the European standard of 220V. The EU regulations were modified in 2010 to 230V (nominal) +/-10% (between 207 and 253V).

Electricity North West is considered typical of the UK distribution industry, having generally carried out little physical alteration to the network to actively reduce the nominal supply voltage from 240V to 230V. On the whole, the supply voltage remains at around 240V open circuit at the terminals of the local distribution transformers.

1.2 The Electricity Act 1989 (as amended by the Utilities Act 2000)

The Act sets out the legal framework and license conditions for electricity distribution in the UK. Specifically, it gives force to the Electricity Safety, Quality and Continuity Regulations **(**ESQCR) 2002 and in section 9 (27) declares the supply characteristic for electricity supply and the permitted variations.

1.3 Electricity Safety, Quality and Continuity Regulations (ESQCR)

The voltage defined in respect of a supply to a LV customer in ESQCR is 230V/400V nominal +10%/-6% at the supply terminals. The maximum permitted supply voltage is 253V and the minimum is 216.2V (single phase). All UK DNOs are currently bound to comply with this regulation.

1.4 The Distribution Code

Each distributor license holder is required to hold, maintain and comply with the GB Distribution Code. This covers all material and technical requirements in respect of the connections to, and the operation and use of the distribution systems of the distribution network operators.

1.5 Engineering Recommendations

Voltage, THD and flicker limits are referenced in BS EN 50160:2010 / G5/4-1 / ENA ETR 122 / BS EN 61000-4-30 which set out the methodology for measuring and testing supply voltage quality. BS EN 50160 defines the category of the monitoring device and the testing period of a ten-minute average root mean square (RMS) measured over seven consecutive days. It dictates that the parameters of the supply voltage shall be within the range of +10/-6% during 95% of the test period and the mean value shall be between 90% and 110% of the nominal voltage during this period.

Engineering Recommendations however are overridden by the statutory instrument, ESQCR which defines absolute values. Therefore any deviation from the Regulation in either magnitude or duration implies a breach of the statute.

APPENDIX 2: CUSTOMER ENGAGEMENT

2.1 Customer surveys

- The Changing Standards research ran concurrently with CLASS surveys, which were conducted to test the hypothesis that customers would not observe any discernible impact associated with voltage control and frequency response trials. Electricity North West was therefore able to extend the Changing Standards control sample, using survey data obtained from customers in the CLASS trial areas, representative of the wider GB network. The CLASS surveys were used to establish customer perception of present service levels and provided a benchmark population.

2.2 Survey instrument

It was recognised that the quality of the Changing Standards survey instrument would be pivotal in achieving reliable evidence of customer sensitivity to changes in electricity provision. The survey instrument therefore needed to be clear, the terminology easily understood and simple to answer, and the key metrics suitable for testing the project hypotheses. It was also important that the questionnaire was administered within a timeframe of approximately 20 minutes or less, to avoid the task being too onerous for customers.

To ensure that the questionnaire was sufficiently robust, the CLASS survey instrument was used as a basis for developing the Changing Standards questionnaire. The CLASS instrument had been guided and refined by an engaged customer panel (ECP) and was subsequently peer reviewed before being piloted and eventually rolled out, to maximise its learning outcomes. Changing Standards capitalised on the CLASS questionnaire, developing the instrument to measure if:

- Customers supplied a) consistently within statutory voltage limits and b) subject to occasional exceedances, experienced problems with their electricity supply or the functioning of electrical appliances/equipment or lighting;
- Customers were satisfied with the service they received and if the status quo is acceptable.

The Changing Standards domestic and I&C survey instrument are provided in appendix 3.

2.3 Customer survey protocol

Customer data was made available to our market research partner, Impact Research. After first analysing network data to identify customers who had experienced a minor exceedance of the voltage standards, they then conducted a telephone matching exercise, which enabled them to approach customers to participate in the survey.

The majority of surveys were conducted by phone. However, some difficulties were encountered in obtaining published telephone numbers from customers on certain networks of interest and in these circumstances supplementary face to face interviews were conducted to boost survey numbers. A financial incentive of £10 was offered to survey participants, payable by cheque, e-voucher or charitable donation.

A statistically robust sample of 1,794 customer surveys were conducted, 1,001 took place in summer 2014 with the remaining 793 completed over the winter of 2014/15. This sample was considered sufficient to empirically determine a correlation between actual network data and perceived quality of service. The survey population was comprised of customers exposed to short exceedances of the voltage standard and control groups, representative of a wide domestic and I&C customer demographic. The sample was also representative of customers from a range of Electricity North West's urban and rural networks with typical LV assets and configuration. Customer data collected during Changing Standards was designed to maximise learning associated with the impact of any seasonal variation on customer perception. This was achieved by conducting the surveys during the hottest and coldest months when observations of power quality problems were most likely.

Detailed quantitative analysis was subsequently conducted, which compared actual voltage and THD measurements, recorded over a reasonable period of time, with the feedback from customers supplied within the measured profile. The analysis aimed to distinguish if factors other than supply quality might influence customer satisfaction with service. The results, which are provided in section 3, were weighted by age, gender, social class and geographic area to ensure they were sufficiently representative of the general population.

2.4 Identifying the customer survey population

The main challenge in this research was that only a proportion of Electricity North West's customers would reside or operate businesses in areas where voltage or harmonic distortion standards are exceeded. Therefore, Changing Standards actively sought to identify monitored LV networks where an exceedance had occurred and deliberately recruited survey participants from customers likely to have been exposed to the worst voltages.

Section 4 describes the process followed to identify and monitor networks of interest. It also outlines the procedure adopted to obtain data from monitors previously and recently deployed on LV networks which had been, or were still being utilised to investigate voltage enquiries, to manage faults or to gather data to support other LCN Fund projects.

All pertinent LV network data was collated and utilised to identify and recruit a suitable customer survey population. Customers participating in the survey, who were confirmed to have been exposed to exceedances, had generally experienced a notable exceedance by either duration or magnitude. The project team adopted a 5% exceedance rule, in line with the BS EN 50160 standard, as the basis for its selection criteria wherever possible. This document denotes this as a 'significant' exceedance.

2.5 Control survey population

The CLASS survey results were utilised to provide a benchmark. However, it was recognised that the main challenge in using this data was that only a small and random proportion of these survey participants were expected to be from areas where voltage or harmonic distortion standards might have been exceeded. As such, an additional control group of customers confirmed, by network monitoring, to have been supplied well within tolerance were recruited to take part in both summer and winter Changing Standards surveys. The control sample provided a baseline to gauge general customer satisfaction with service across the spectrum of compliant electricity provision. This sample would also highlight any seasonal variation in results within the normal voltage range.

2.6 Customers affected by supply interruptions

Advanced statistical analysis of feedback from customers on CLASS trial circuits indicated that dissatisfaction with service is primarily driven by experience of supply interruptions. To understand if factors other than experience of voltage at and around the extreme limits were influential in driving dissatisfaction, a sample of customers who had experienced both voltage exceedances and supply interruptions in the 12 months preceding the survey were interviewed. A control group of customers, supplied consistently within average power quality limits, but who had experienced at least one supply interruption preceding the survey were also interviewed.

2.7 Data accuracy

The Changing Standards project team recognised that a fundamental requirement in selecting suitable survey participants was rooted in accurately matching customer data to corresponding LV network measurements.

Electricity North West controls its operations with the aid of a robust network management system allowing accurate HV and LV connectivity modelling. It maintains associated systems for customer allocation to networks, the most significant of which are:

- CRMS (normal running) – for network connectivity;

- DADS/ECOES – for customer data;
- LVFI/Strumap input – for allocating LV customers to network;
- HV address reference file – for allocating LV customers to network.

Electricity North West acknowledges that the allocation of customer Meter Point Administration Numbers (MPAN) to the distribution network at LV feeder level is occasionally subject to areas of uncertainty. MPANs are matched to LV features in the Participatory Geographical Information Systems (GIS) system by proximity. There are a number of situations where this operation can be inaccurate.

LV features are assigned to respective feeder on the LV transformer panel by the Strumap system. This depends on the recorded data for the LV open points where double-ended and teed LV circuits are present. Occasionally, GIS numbering of LV ways (feeder) might not accurately correspond with LV asset numbering. Due to the flexibility of network configuration and the associated maintenance of LV records, anomalies of this nature are thought to be common amongst other DNO licence holders.

Electricity North West implements a number of rules to make the best assumptions in areas of uncertainty. The Changing Standards project team conducted a detailed exercise to ensure that customer MPANs were matched as reliably as possible to the respective LV feeder and consequently, the customers recruited to take part in the survey accurately aligned to network monitoring data.

Customer information was captured by running various reports from the DUOS and Associated Distributions System (DADs) and the customer Address Management System (AMS) maintained by Electricity North West.

Due to time and financial constraints, it was not possible to monitor an appropriate mid or end point of all LV feeders where exceedances over 253V were observed at the busbar. Therefore, where high voltage was recorded at the head of the feeder, only those customers nearest to the distribution substation were selected to participate in the survey. Recruitment therefore involved a desk top study of individual feeders in GIS, which included measurement of feeder length from the substation to property.

APPENDIX 3: THE CHANGING STANDARDS DOMESTIC AND I&C SURVEY INSTRUMENT

308 Domestic IFI Questionnaire (Winte

308 I&C IFI Questionnaire (Winte

APPENDIX 4: USE OF TECHNICAL DATA TO STRUCTURE THE RESEARCH

4.1 Historical data analysis (no customer survey)

In parallel with targeted network monitoring (appendix 4.2.1) Changing Standards examined historic voltage measurements, captured largely as an unintended consequence of routine fault management activities. This information provided a baseline measure of compliance with operating standards across Electricity North West's LV networks. By augmenting this data, Electricity North West has been able to indicatively evaluate the instance of exceedance outside existing standards. These levels are set to increase with increased penetration of low carbon technologies.

Historical network data was classified as measurements recorded 12 months prior to the research. Customers exposed to exceedances of an historic nature were not generally surveyed, as the reliability of customer feedback based on experience of past electricity provision was considered questionable. Exceptions were made where a confirmed voltage exceedance required reinforcement works, which took several months to complete. In these circumstances surveys were appropriate, as the customers interviewed remained at continued risk of exceedances during the timescales pertinent to this research.

4.2 Data from recent network monitoring

LV network data collated during Changing Standard came from a number of sources. Power quality measurements were obtained from equipment specifically installed as part of the project and other data was collected as a consequence of BaU activities.

Data from networks confirmed by routine BaU investigations, to have been subject to exceedances and awaiting imminent compliance driven reinforcement were obtained Likewise, details of networks where remediation had very recently been completed (no longer than twelve months preceding this research) were also collated.

Recent power quality measurements were obtained from monitoring devices installed on LV networks as part of other LCN funded projects, namely C_2C, CLASS and LV Network Solutions. These instruments had generally been installed on LV circuits, representative of those across the wider GB network, in terms of asset, configuration and customer type. However, a percentage of these had been specifically deployed on 'networks of interest', known to have a high penetration of LCTs and were thus pertinent to this research.

4.2.1 Targeted network monitoring (suspected of occasional exceedance in voltage standards)

Research key to this project was the identification of previously unmonitored LV networks, where Electricity North West had a suspicion that voltage and/or THD standards might occasionally be exceeded for short periods. A rigorous exercise, considering a number of factors led to the identification of around 120 LV feeders considered at greatest risk of breaching standards in the summer season, because of a high penetration of embedded generation. An equivalent number of feeders were targeted to monitor the voltage profile of demand customers in the winter. A more detailed explanation of the selection criteria is provided in appendices 4.3 and 4.4.

4.2.2 Targeted network monitoring protocol

Having considered the learning outcomes from WPD's Second Tier Low Voltage Network Templates project, it was considered impractical to install monitoring equipment in customers' premises, which would require prior consultation. This was anticipated to be both costly and time consuming to administer; was not anticipated to achieve significant 'buy-in' and when access was agreed, gave no guarantee that the service would be suitable to monitor. The process of installing monitoring equipment in properties might also have exposed customers to short duration interruptions and risk sensitisation to potential power quality issues.

The deployment of network monitors (Bidoyng smart fuses and Electrocorder loggers – refer to appendices 5.3/5.4) on targeted networks in the summer and winter seasons was achieved by a well managed installation schedule. The installations were programmed to take place during the hottest and coldest months when embedded generation and demand on local networks was expected to present the greatest risk of voltage and THD exceeding present limits.

Given that the busbar would only act as a proxy if sufficient knowledge of the feeders already existed, monitors were installed to concurrently measure voltage along the length of the targeted feeders. Bidoyngs were installed at the feeder head and an Electrocorder was simultaneously connected at a suitable mid or end point on the corresponding main.

Monitoring at feeder level during the summer was conducted as near to the highest penetration of photovoltaic (PV) systems as possible. This was achieved by installing the Electrocorder at the terminal of a suitable street lighting service, on the same phase (where practical) as that with the greatest cluster of PV connections, where voltage was expected to be the highest. Similarly, an Electrocorder was installed at the remote end of the main during the winter monitoring phase, where the voltage drop was likely to be the greatest.

The project team proactively consulted local authorities, responsible for district lighting, prior to commencing the installation programme. Electrocorders were installed only after local authority consent had been granted. In the interests of safety, the loggers were appropriately labelled with a caution notice, identifying the devices as belonging to Electricity North West, on the off-chance that local authority personnel had cause to access the service during the monitoring period.

Approximately 30 targeted LV networks were monitored simultaneously for around 30 days after which, the results were downloaded for analysis before all devices were relocated to the next tranche.

4.3 Summer season (targeted site selection methodology – criteria and challenges)

The site selection strategy sought to identify networks exceeding 253V and THD over the 5% planning limit.

Government feed-in-tariff (FIT) incentives have encouraged the uptake of various forms of distributed generation, connected to LV networks. Electricity North West, in common with other DNOs, has witnessed the installation of significant numbers of residential photovoltaic (PV) systems on certain networks, particularly in social housing stock where notable clusters are reported.

Electricity North West has previously monitored a number of LV feeders with a high penetration of embedded generation under the Low Voltage Network Solutions project. However, further evaluation of the effect of PV clusters on the voltage profile of LV feeders was intrinsic to the targeted monitoring phase of Changing Standards during the summer of 2014, in particular the effect on customers.

Electricity North West maintains a distributed generation (DG) database which contains details of generation connected to its network. These records are the most comprehensive indication of the level and nature of embedded generation on the LV network. However, it is recognised that DNOs ability to identify the true penetration of PV and thus potential voltage issues on individual LV networks is compromised by the failure of some installers to provide the appropriate notification, as required under Engineering Recommendation G83/1.

DNOs are currently only able to access feed-in tariffs data from Ofgem by local authority area, the granularity of which was insufficient to identify relevant customers for surveying.

Significant discrepancies exist in the local authority data and that held by Electricity North West.

The DG database, being the most accurate source of data available, was utilised to map PV clusters. These LV networks were predicted to be those most likely to exceed the upper voltage limit of 253V during maximum export over the summer, when solar activity was strongest. These networks also warranted investigation to understand the effect of harmonic voltage distortion, generated by multiple PV systems.

A data control exercise was conducted to accurately match reported PV installations with customer MPANs and these were linked to the feeding transformer. PV clusters were then plotted at individual feeder level and 128 LV mains, found to contain the highest penetration of PV, were subsequently monitored between June and September 2014.

To measure the voltage profile across the length of the feeder, monitoring devices were installed concurrently at the feeder head at the busbar and at a strategic mid-point on the associated LV main, in the vicinity of the greatest cluster. This strategy captured the voltage range across the measured length of the feeder. Where practicable, monitoring at the cluster point was carried out on the phase with the greatest proliferation of connected PV. However, monitoring at phase level was not always possible because of restrictions associated with connecting the loggers at suitable street lighting terminals (refer to appendix 4.4)

4.3.1 Total harmonic distortion (THD)

Electricity North West routinely conducts strategic planning studies to investigate background harmonic levels, in response to certain connection applications. However to date, it has not sought to actively conduct an extensive monitoring programme to assess voltage THD at LV level. There are numerous published research papers which point to PV export having a significant effect on the harmonic profile of LV networks and this view is supported in Electricity North West's Voltage Management on Low Voltage Busbars project and WPD's Assessment of Solar Panel Implications.

Distributed generation is by no means the only source of harmonic distortion. Non-linear loads from electronic power sources likely to cause disturbance include, amongst others, I&C variable speed drives; motors, welding equipment; uninterruptible power supply (UPS) systems and switch mode power supplies. Nevertheless, networks with a high penetration of PV installations were those where breaches in standards might predictably be observed because of the correlation between PV power output and emitted harmonics, particularly transient harmonics, when the export is ramping up.

The targeted networks were monitored for approximately 30 days and details of the monitoring equipment deployed can be found in appendix 5.

4.4 Winter season (targeted site selection methodology)

The site selection strategy deployed sought to identify networks breaching the lower voltage limit of 216V.

Selecting LV networks, where customers might theoretically experience occasional voltage under 216V presented a far greater challenge than identification of the summer targets focused on breaches of the upper limit. Electricity North West operates a robust planning and capital investment programme to maintain a robust and resilient network. Rigorous procedures are embedded to highlight any exceedance of power quality limits and address/resolve customer led voltage enquiries promptly, appropriately and as they arise.

These procedures ensure Electricity North West conforms to its licence conditions and maintains a network compliant with statutory obligations. Therefore, areas that historically might have been exposed to excursions at the lower end of the standard, due to augmented local demand and diverse patterns of seasonal load have progressively been eliminated from the network by traditional reinforcement techniques.

Planning engineers were able to highlight a limited number of networks under investigation or in the process or compliance driven reinforcement works. The Changing Standards project team considered the network data obtained as a result of these investigations and organised monitoring on feeders where technical data was unavailable. Customers supplied by these networks were recruited to take part in the survey, to gauge sensitivity to voltage where exceedances were confirmed.

For the reasons outlined above, it was challenging to identify networks, at LV feeder level, that might occasionally experience voltage under the lower limit of 216V. It was however, recognised that minor exceedances were likely on certain feeders and customers served by these networks might very well be subject to these conditions, for very short periods, without noticing or having any cause for concern.

Normalisation and lower expectations of power quality was considered more likely amongst customers in remote rural areas where voltage depression/sags, flicker and dimming lights might to be an accepted norm during winter peak on application of seasonal heating load. Properties in some rural farming communities were thought more likely to be occasionally exposed and accustomed to these conditions, particularly when milking equipment and motors without soft start technologies are operational.

To identify areas of the network where voltage limits might be exceeded, the project team examined a suite of data:

This exercise considered the distribution transformer size, type and rating along with the half hourly maximum demand indicator (MDI) recorded at the transformer. Electricity North West has developed and maintains a ‘distribution transformer loading report’ and MDI records are collected and uploaded into this database as part of routine BaU maintenance activities. The report calculates load allocation (LA) based on a number of factors, including customer numbers connected to the transformer, and uses algorithms which assume normal HV and LV network configuration.

The LA report contributes to a range of asset condition management tools, which were considered during Changing Standards to identify ‘networks of interest’. High MDI readings were carefully considered during the selection process as these can be erroneously influenced by a number of network conditions. The selection criterion therefore included only transformers with consistently high MDI/LA profiles, recorded over several years and sites with obvious spurious readings were discounted.

After selecting networks served by the smallest transformers with the highest demand indicators, feeding a high ratio of customers; the penetration of customers at LV feeder level was considered.

Customer type and the load profiles of domestic and I&C customers fed on these networks was taken into consideration in conjunction with a detailed examination of LV schematics from the Geographical Information System (GIS), to ascertain the rating, length, impedance and connectivity of LV cables and identify specific feeders ends where the indicative voltage drop from the transformer was likely to be most significant.

The distance of the secondary transformer from the primary substation was also considered and this suite of data formed the basis on which LV feeders were selected for monitoring over winter, on the assumption that customers at the end of these mains were most likely to experience the worst and most significant seasonal voltage drop.

4.4.1 Off gas networks

It was possible to predict, with relative accuracy, a high demand profile at specific times on networks with no access to a mains gas supply, where households are reliant on electricity for heating and cooking.

Customer MPAN data held by Electricity North West was utilised to map clusters of domestic and commercial customers with dual rate meters. This MPAN data was supplemented by information from the Centre for Sustainable Energy, which has published a complete list of postcodes in GB not connected to the mains gas grid.

Dual rate meter clusters associated with apartment blocks, serviced by rising mains, were excluded as breaches were unlikely to be observed. These networks are generally 'over designed' with highly rated cables to sufficiently meet the demand of multiple 'all electric' dwellings. Connection of monitoring equipment was also considered problematic, often requiring key holder access to the riser.

Having identified 'off gas' clusters, local authorities were consulted to identify properties in their respective regions, which relied on off peak electric storage radiators, as their main source of heating.

A typical three-bedroom house might be heated by six storage heaters, typically rated at between 1kW and 3.5kW. Each unit will operate at full capacity when the meter switches to off peak mode and the same demand profile might simultaneously be expected from multiple dwellings on the feeder.

On the basis of the above information, a random sample of LV feeders meeting the following criteria were selected and monitored:

A) supplied via small and highly loaded transformers; B), serving a dense population of dual rate metered customers, predominantly using night storage radiators as the primary heating source. This monitoring programme was designed to coincide with the coldest winter temperatures and anticipated greatest load.

Despite the stringent site selection criteria used to identify networks most vulnerable to contravention of voltage standards, Electricity North West failed to observe significant excursions at the end of these feeders. This has been attributed to the positive contribution of the radio teleswitch (RTS) introduced in the UK in the early 80s. The RTS allows electricity suppliers to remotely switch large numbers of electricity meters between different tariffs and better controls the gradual switching over to off peak demand, to level out the demand curve.

4.4.2 Highly loaded pole mounted transformers (PMT)

Long rural overhead circuits fed by small PMTs, particularly heavily loaded networks supporting commercial operations, are those where customers at the remote end of the radial, are most likely to experience the greatest drop in voltage.

A detailed exercise, outlined above, was conducted to identify networks of this type and considered transformer rating, customer numbers, load allocation and LV schematic data to determine conductor sizes and length.

A number of PMT fed networks, suspected to be at potential risk of minor exceedances, were identified. However, the absence of street lighting furniture at, or near to, the remote end of these feeders, prevented monitoring, without alerting customers to the activity. Because of restrictions in installing LV end point monitors on the rural networks thought most likely to be at risk of minor exceedances, many were discounted. The targeted winter feeders were therefore predominantly fed from highly loaded ground mounted transformers (GMT) with the smallest kVA ratings.

4.4.3 Electric heat pump and electric vehicles

The uptake of domestic EHP installations and EVs, which are expected to significantly influence the demand curve of local networks, remains relatively small within Electricity North West's distribution region at the present time. The limited number of networks with clusters of these LCTs are suitably designed and not currently regarded as presenting a risk of breaching standards.

As such, these networks were not targeted under the Changing Standards project. However, Electricity North West is conducting further research around the impact of domestic heat pump installations in partnership with the Japanese New Energy Development Organisation (NEDO).

The penetration of EHPs and EVs is expected to increase incrementally and the University of Manchester has analysed data collected under LV Network Solutions to build models to demonstrate potential uptake levels of LCTs that might be accepted on LV networks, without breaching thermal or voltage limits.

4.4.4 Diverse patterns of high demand

Electricity North West’s distribution area covers the densely populated conurbation of Manchester and Salford. This region is home to a large orthodox Jewish community, centred around Higher Broughton, Kersal, Prestwich and Sedgley Park. A small and random sample of networks serving this community was monitored during the winter season. These networks were considered on the basis of historical fault data, which has demonstrated a pattern of electrical diversity specific to this particular community. This suggests that some customers, at the remote end of certain feeders, might occasionally experience minor load related voltage exceedance, for very short periods on Fridays, linked to preparations for the Shabbat.

4.5 Customer voltage enquiries

The analysis of network data resulting from voltage enquiries was significant to Changing Standards in understanding the network conditions and voltage range driving dissatisfaction with the service provided. This research primarily focussed on customer and network data generated from voltage enquiries received in the 12 months preceding the customer survey.

Many of the voltage related enquiries received by Electricity North West are not the result of customers noticing a supply problem, but are reported as a consequence of tests carried out by meter operators, electricians and boiler engineers during routine domestic maintenance activities. Electricity North West records voltage enquiries on both a ‘customer contact’ and a fault management system. These records provided a key source of customer data, which was matched to technical monitoring data to establish the conditions and voltage range experienced by customers, which prompts these reports.

Electricity North West routinely conducts a series of safety tests, in response to a voltage enquiry. This involves checking all connections and taking voltage and earth loop impendence measurements at the service termination, along with a general visual inspection.

If these tests and/or the conditions described by the customer suggest an existing or developing problem, then a voltage and current meter is installed to continuously record supply voltage and current over several days.

The instruments most commonly used by Electricity North West during this initial phase of monitoring are a range of portable single and three phase voltage and current meters (Electrocorders – appendix 5.4).

Customers are notified about the outcome of the investigation and where voltage limits are confirmed to have been exceeded, are furnished with details of any proposed remediation. The service is generally retested at the cut out terminals, following remedial works.

Analysis was conducted to segment confirmed exceedances from investigations were supply voltage was found to be consistently well within the limits.

The strategy for surveying customers on networks where voltage enquiries had been investigated was carefully considered. The strategy deployed generally avoided direct engagement with those customers who had contacted Electricity North West about voltage and were therefore sensitised to actual or perceived power quality problems. This approach militated against resurrecting complaints and negatively distorting results, particularly where customers had attributed damage or financial loss to a genuine or perceived power quality issue.

To more accurately benchmark customer perception/sensitivity to power quality, at recorded values, it was considered more appropriate to conduct surveys with customers residing or operating businesses in the immediate vicinity of the property from where the enquiry was generated.

It was critical for Changing Standards to accurately match survey participants with actual voltage measurements. Therefore, only customers from properties fed off the same LV feeder, in the immediate vicinity of the property where the voltage investigation had taken place, and ideally on the same phase, were recruited to take part in the survey; being exposed to the same or a very similar voltage profile.

Customer MPAN and GIS data were analysed to identify these customers and only those most recently and most significantly exposed to voltage exceedances by limit and duration were interviewed about their perception of power quality.

A control group of customers, confirmed to have been supplied well within limits during investigations resulting from voltage enquiries, were also surveyed to provide a comparison baseline sample.

4.6 Considerations outside the project scope

4.6.1 Impact – customers' equipment

The Changing Standards project focused on understanding customer perception across a range of voltage profiles and sought to define revised power quality limits likely to be acceptable to the public. It did not examine any element of risk to any type of electrical/electronic equipment associated with an extension of the standards, on the basis that appliances/equipment designed for the UK market are now manufactured to conform to European voltage specifications and will overwhelmingly operate well beyond the limits of the European standards.

4.6.2 Flicker

The power quality limits for flicker are referenced in ENA Engineering Recommendation G5/4-1 and BS EN 61000-4-3. Investigations around conformity to flicker were not considered as part of Changing Standards. Flicker is a characteristic of a notable voltage fluctuation which increases with the amplitude of the fluctuation and is most commonly observed in lighting. Flicker might equally be a symptom of harmonic disturbance; a fault on the customer's private installation or a public network fault. The normal operation of network protection equipment or HV switching process may also be interpreted by customers as flicker.

Reports of flicker are most commonly received in the form of voltage enquiries and Electricity North West responds to these following an embedded process (appendix 4.5). This initially involves a preliminary investigation, generally followed by the installation of a category B monitor, to measure supply voltage over the period of several days. If the results indicate a problem with flicker, requiring further investigation a 'Category A' instrument is subsequently installed, typically a Dranetz PowerXplorer PX5 power quality analyser (appendix 5.5), to accurately record the degree and conformity to the standard. This project focused on exceedance of voltage limits rather than fluctuation within the standards and therefore flicker was excluded from this investigation.

APPENDIX 5: MONITORING INSTRUMENTS

Instruments other than those referenced in this appendix are routinely used by Electricity North West to monitor LV networks. These may be installed during planning and strategy investigations associated with new connections and traditional reinforcement works and also to locate and manage network faults. However, voltage data from instruments not listed below was discounted largely because it was not considered sufficiently accurate, at granular level, on which to base customer research.

For the purpose of Changing Standards current values and those of active and reactive power obtained from monitoring instruments was not considered.

5.1 GridKey MCU / Nortech Envoy (substation / mid-point / end point monitors)

Electricity North West deployed Nortech and GridKey monitoring equipment on 200 distribution substations (28 pole mounted and 172 ground mounted), under the First Tier LCN Fund LV Network Solutions project, which included over 1,000 LV feeders. An additional 200 monitors were subsequently installed along 100 associated feeders at strategic mid-points and end-points.

Data obtained from both Nortech and GridKey units was utilised during the Changing Standards research. This equipment was developed by two different suppliers: the Envoy DNP3 from Nortech and GridKey manufactured the monitoring control unit (MCU). Both of these devices meet the requirements of accuracy Class 1 of the active energy metering standard IEC 62053-21 and Class 2 of the reactive energy metering standard IEC 62053-23.

Electricity North West did not conduct further calibration or accuracy testing of the monitoring equipment as part of LV Network Solutions or Changing Standards. However, more information relevant to Electricity North West's assessment of these instruments is available here. Further details about specification, accuracy and compliance are available from both manufacturers on the Nortech and Gridkey websites.

These monitors continuously capture power quality data, which is stored and available on a 'real time' basis through the iHost server, supplied by Nortech. Monitoring data continues to be collected and made available to the business to support further innovation projects and performance evaluation of networks with LCT clusters.

A further 54 Gridkey MCUs were deployed under CLASS at strategic locations on LV networks (10 at the distribution substation and 44 on the remote end of LV feeders). A 'Distribution Network Information System' Dinis study identified secondary substations with the greatest HV voltage drop, relative to the primary substations in the CLASS trial areas. Conductor size and length was considered in identifying appropriate feeder ends on which to install monitoring equipment. This data was particularly relevant to Changing Standards as it was assumed that customers most likely to experience the greatest drop in voltage were those at the end of the longest LV feeders, fed from distribution substations identified as having the most significant HV voltage drop.

GridKey units originally indicated only power THD and the Nortech units provided current THD. Current and power THD are only indicative of the underlying issue of the total harmonic distortion of voltage. The capability of the Nortech Envoy was therefore extended under Changing Standards to capture voltage THD (up to the 30^{th} harmonic) by downloading additional firmware and additional processing of the data recorded.

GridKey confirmed that voltage THD could be collected with more significant modifications to the MCU. However, the cost and time constraints associated with this upgrade was prohibitive under Changing Standards and would have compromised project delivery timescales.

5.2 PSL PQube power quality monitor (PQM) – substation monitor

Electricity North West installed 77 PQube PQMs in secondary substations at LV, as part of its monitoring strategy during the Second Tier LCN Fund project, C_2C. Individual phase RMS currents and voltage sampling rates were set at one minute. THD (as defined in IEEE Std 519 [12]) per-phase are displayed up to the 50^{th} order. The full specification of this Class A device (IEC 61000-4-30) is available at here. A proportion of the C_2C circuits are comprised of predominantly industrial and commercial customers. Any observation of harmonic distortion, associated with non-linear loads on these circuits was critical to Changing Standards.

PQube PQMs were retained on the C_2C networks during the course of the Changing Standards project. Whilst these instruments accurately record THD and interharmonics up to the 63rd it was not considered appropriate to redeploy them on targeted Changing Standards networks because of the requirement to maintain data collection during the C_2C closedown phase. The cost of redeployment and specifically data collection was also prohibitive to this project, as these devices are not supported by telemetry and retrieval of stored data involves manually collecting SD cards from individual PQMs before uploading into the iHost server. This issue is documented as a leaning outcome of C_2C.

5.3 Bidoyng – smart fuse (substation monitor)

The Bidoyng smart fuse is a single-shot auto-recloser, the development of which was initiated by Electricity North West, in partnership with the manufacturer, Kelvatek under the IFI funded Fuse Restorer project in 2006. The device was designed for, and is most commonly used as a fault management tool, which assists in the location and removal of intermittent faults from the LV network.

The device is installed at the distribution substation and fits into existing LV fuse positions using two LV fuses in parallel. The primary fuse carries the load current until a fault causes it to operate. After a programmed delay, the secondary fuse is switched on and the network re-energised without the need for customer interruptions.

Bidoyngs record network performance data, including voltage and current along with voltage THD up to the 25^{th} harmonic. The remote interface provides ‘real time’ data from Kelvatek's server. Specification details can be found at here.

Electricity North West has also used Bidoyngs for long term LV network monitoring linked to two innovation projects in Stockport. Further information about the recent Power Saver Challenge (PSC) project in the Heaton area of Stockport, aimed at changing domestic patterns of consumption to improve the sustainability of substations is available at Power Saver Challenge | Electricity North West. To support Changing Standards the sampling period of these monitors was changed from 30 to ten minute cycles, to conform to harmonic monitoring requirements of G5/4-1.

All network data collected from Bidoyngs installed under fault conditions was retrieved and analysed as part of the Changing Standards project.

Changing Standards also utilised 99 Bidoyngs and the associated interface gateways to monitor substation voltage and harmonics on targeted networks in summer of 2014 and during winter 2014/15. One set of Bidoyngs (three units – one per phase) were installed at the busbar allowing approximately 30 targeted LV networks to be monitored simultaneously, for approximately 30 days. A suitable mid or end point of an associated feeder was concurrently monitored by Electrocorder loggers, before all devices were relocated to other networks of interest.

5.4 Electrocorder – mid and end point monitor

Singe and three phase Electrocorders data loggers, manufactured by Acksen Ltd are the monitoring instruments most commonly used by Electricity North West during the initial phase of a voltage enquiry investigation (appendix 4.5)

These portable voltage and current meters record events of one cycle duration. The instruments are connected easily to the customers' service at the cut out terminal or can be fitted directly onto the LV bars at the distribution substation. These category B instruments conform to recording standard BS EN 50160.

Single phase Electrocorders were found to be the most practical means of recording voltage at strategic mid and end points on targeted LV feeders, which were identified by Changing Standards as being potentially at risk of occasionally exceeding mandated limits.

To avoid unnecessary detrimental customer impact, as outlined in appendix 4.2.2 the most practical and secure location to monitor LV feeders was deemed to be at street lighting service cut out terminals. However, traditional Electrocorder leads and connections were too bulky to fit inside the restricted switch gear cavity of many street lighting columns. Acksen were able to modify the connections for single phase EC-1V and EC-2VA loggers, to facilitate their installation into the majority of street lamps. Forty new loggers were procured for Changing Standards and these units were also weatherproofed, in light of the intended point of connection and potential exposure to the elements.

EC-1V and EC-2VA loggers normally record over the period of seven days in line with BS EN 50160 guidance. For the purpose of this project, the manufacturer default settings were changed to provide 30 days monitoring data (six minute RMS). A detailed specification of the loggers is available here.

5.5 Dranetz PowerXplorer PX5

Electricity North West utilises Dranetz PowerXplorer PX5 power quality analysers, conforming to IEC 61000-4-30 specification 'Class A', when ten-minute average RMS voltage measurements of greater accuracy than possible from Electrocorders is required. Dranetz are connected directly to the cut out terminals and accurately record flicker, sags, swells and THD up to the 50th harmonic. See further details.

Electricity North West manages the majority of its voltage enquiries without the need to install this instrument and therefore only a limited amount of data from these devices was available to Changing Standards.

APPENDIX 6: NETWORK DATA CAPTURE

6.1 Network monitors – sampling intervals

For performance evaluation of the network the mean root-mean-square (RMS) value of ten minute sampling intervals or similar was adopted for devices installed as part of this project, to avoid the underestimation of voltage impacts and compliance with the ten-minute sampling timeframe specified in BS EN 50160.

Whilst there was no significant benefit to this research in adopting shorter sampling intervals most equipment providing technical data was programmed to record at shorter intervals. If further scrutiny of this data is required, sampling intervals can be adapted accordingly.

LV networks monitors considered during this research were installed for differing periods of time, ranging from seven days to many months, and therefore the duration of any recorded exceedance of the standard varied accordingly. For consistency the rule of 95% conformity was assumed to define a significant excursion, based on the BS EN 50160 standard, irrespective of the actual monitoring period.

6.2 Power quality exception reports from network monitors

A fundamental requirement of Changing Standards was to develop a process for handling a significant amount of network performance data, from multiple devices. This was critical in efficiently mapping the voltage profile of individual networks by voltage range and duration, at specific values.

LV network performance data, recorded by various monitoring devices, has traditionally been scrutinised on an individual basis to meet the requirements of BaU planning and operational activities. Recorded data from these various instruments has traditionally been saved and retained in a number of separate repositories. Prior to Changing Standards, Electricity North West had no practicable means of collectively reviewing large batches of data from the multiple instruments utilised during this project.

The project team developed a suite of exception reports, specific to individual devices, which were able to highlight LV networks where power quality limits had been exceeded. These reports were designed to provide the detail of any exceedance at a granular level, specifying the duration of the excursion at specific voltage and THD values. This information was critical in selecting suitable customers to participate in the survey.

A summary of the respective reports are listed below:

6.2.1 Nortech Envoy / GridKey MCU report

Telemetry supports ‘real time’ analysis of recorded data from the Nortech Envoys and GridKey MCUs on continually monitored networks, via the iHost server. A set of standard reports was developed under Low Carbon Network Solutions to highlight unusual LV monitoring performance data. Enhanced power quality exception reports were developed from iHost under Changing Standards, which have been incorporated into a range of tools now used to support BaU activities.

6.2.2 Bidoyng smart fuse report

The project team has worked with Kelvatek to develop and implement a report from its server which provides performance data from all Bidoyng smart fuses on the network and highlights where power quality limits are exceeded. Work is ongoing to fully automate the report which will deliver ‘real time’ data to support the Fault Service Centre (FSC), a Kelvatek and Electricity North West partnership, actively managing LV transient fault detection.

The report is also expected to provide outputs from newly developed devices, manufactured by Kelvatek and installed on Electricity North West’s LV network under Smart Street namely the Weezap & Lynx controllable switching devices.

6.2.3 Acksen Electrosoft report

Portable Electrocorder meters are routinely used to record voltage and current at customers' service termination points and at secondary substations, often in response to voltage enquiries. Analysis of the recorded data from these instruments has traditionally involved the examination of individual raw data files. This level of scrutiny is demanded when analysing technical data in response to a voltage enquiry but unrealistic for the purpose of Changing Standards. This called for a practical and speedy assessment tool, to capture voltage data from the several hundred individual data files examined during the lifetime of this project.

Technical support was procured from Acksen Ltd who developed a batch exception report, specifically for this project, utilising existing Electrosoft software. This report allows multiple raw data files to be opened and voltage data to be extracted at a granular level, which can be downloaded in comma-separated value (CSV) format.