Electricity North West LV Interconnection Study Workshop

Institution of Engineering & Technology
Savoy Place
London

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Introduction

Along with many other Distribution Network Operators, Electricity North West (ENW) is experiencing an increase in the amount of connection applications being received for low carbon technology and distributed generation, which is being driven by the UK government's commitment to reduce carbon emissions by 2050.

These new technologies tend to be connected in clusters, which has a dramatic effect on the electricity distribution network. Whilst the requirements of electric vehicles and heat pumps is likely to cause the network voltage to fall below statutory limits, new generation from photovoltaics, which is exported to the network, will have the opposite effect and increase voltage levels. This change in energy flow has the potential to drive up network reinforcement costs and produce additional network losses, especially at peak times.

To assist network operators with this challenge the electricity regulator, Ofgem, established the Low Carbon Networks (LCN) Fund to support research projects that help all network operators understand how they can provide a secure and economic electricity supply as Britain moves towards this low carbon economy.

One such research initiative funded by Ofgem is the ENW Smart Street, a four-year £11.5 million project to trial active optimisation of the low voltage (LV) network and which has been running from January 2014 and is due to conclude in April 2018.

The Smart Street project

The project involves a series of live trials at six primary substations and 38 related distribution substations to test the effectiveness of new controllable switching device technology. The trials, which have already been conducted across urban and rural networks, involved approximately 67,000 customers and were run in conjunction with a number of partners:

(a) **Kelvatek** – supplied the WEEZAP and LYNX switching devices and provided technical support and training.
(b) **Siemens** – responsible for the supply, installation and configuration of the Smart Street optimisation hardware and software.
(c) **Impact Research** – customer engagement and survey activities.
(d) **TNEI** – responsible for the Smart Street network design and managing the consultation process.
(e) **The University of Manchester** – delivery of three studies and the provision of support during the trials.
(f) **Queens University Belfast** – delivery of two studies and the provision of support during the trials.
(g) **Tyndall Centre** – support of the carbon impact assessment work and the provision of learning and dissemination support.

Consultation

Following a four-week consultation to determine whether the rollout of this technology across a distribution network would have an adverse impact on the customers connected to the system, the IET hosted a workshop at its Savoy Place headquarters to discuss the trials and conclusions from the consultation.

LV interconnection study workshop

The workshop, a free IET event, was attended by representatives from various industry-related disciplines. The workshop was also streamed live, which attracted 96 live views and 166 subsequent plays of the recording at the time of writing.

The study workshop panel consisted of:

Mr Ben Ingham – ENW Innovation Project Manager
Mr Daniel Gheorghe – TNEI Consultant
Mr Mark Coles – IET Head of Technical Regulations
Mr Trevor Pickard – IET Facilitator

Trial Overview – Mr Ben Ingham

The workshop opened with Ben Ingham delivering an informative and well-balanced overview of the Smart Street trial, which also included some of the finer detail behind the technical requirements and challenges.

The aim of the trial, which was conducted across both urban and rural networks, was to:

(a) stabilise the voltage profile across the length of the LV feeders;
(b) quantify the benefits of conservation voltage reduction (CVR) at the distribution level;
(c) validate the ability of the Siemens Spectrum algorithm to regulate the network and confirm if it was safe to be left operating on the network in conjunction with the day-to-day operational requirements;
(d) identify any power quality issues that could affect customers; and
(e) ultimately, to provide ENW with a hardware matrix that could be used to install appropriate equipment on the different circuits types within the ENW region.

Mr Ingham explained that, historically, networks have no automatic voltage regulation and that the increase in low carbon technologies being added to the networks can cause drift in the voltage range, which will affect the efficiency of the network and the operation of customers' electrical appliances. Mr Ingham went on to say that the reliability of the existing network is a 'fix on fail' arrangement and repairs are only executed when the company is notified of a failure, normally by a customer.

The design parameters of low voltage feeders normally specify a volt drop of 7 % across the feeder. This prompted a question from the audience on what the actual figure was on the trial networks and Mr Ingham confirmed that the trial, surprisingly, showed that on the circuits chosen there was very little voltage reduction across the feeders.

Mr Ingham explained that the trial involves the installation of a central network management system, the interconnection of circuits and the fitting of transformer ‘on load tap-changers’ (OLTC), capacitors to give a voltage boost, WEEZAPs (LV vacuum circuit breakers) at the LV distribution board, and LYNX automatic switching devices fitted to link boxes.

This setup allows constant monitoring of the network so that transient faults are dealt with immediately and gives ENW repair teams a precise location for any non-transient faults.

It was made clear that if this trial moves to a ‘business as usual’ scenario it would interconnect with other previous innovation projects such as the CLASS (system voltage control at the primary voltage) and ‘Capacity to Customers’ (C_2C) which rewards contracted customers for being flexible and reduce their demand for electricity. This in turn can help network management by releasing capacity where and when it is needed.

The outcomes from the trial to date are:

(a) 23 months of real data to validate the networks that have been produced by The University of Manchester and Queens University Belfast to simulate the effects on the networks.

(b) The predicted CVR factor analysis shows that for every voltage reduction of 1 %, there is a 1 % reduction in demand.

Mr Ingham was asked if any specific assets that might affect voltage, such as batteries, were installed on the network as part of the trial. Mr Ingham informed that the circuits were selected to overlap with another project, currently in progress, that was installing heat pumps in social housing but no other assets were installed with the knowledge that there was already LCT on the network.

The final analysis of all of the data being collected during the trial is due in February 2018 and this will be used to establish whether Smart Street is a viable option compared to conventional reinforcement of the network.

In summing up Mr Ingham outlined the expected benefits of Smart Street:

(a) Optimisation of the LV network
(b) First example of a centrally controlled/managed LV network
(c) Lowers energy bills
(d) Provides a more reliable supply
(e) Allows a faster connection of LCTs

Mr Ingham then took further questions from the floor.

Q. What interaction had there been with the customers affected by the trial?

A. He explained that engaging with customers and understanding whether customers were affected by the trials was crucial to the viability of the Smart Street solution. All affected customers were contacted at the start of the trial by letter and the ENW website, leaflet circulation, social media and customer engagement panels were used regularly to communicate information about Smart Street.

The customer engagement panels held during the trials were also used to collect qualitative information from customers. The aim being to test if customers observed any changes in their electricity supply. The majority of feedback received seemed to indicate that customers related power quality to the number of supply interruptions they experienced rather than actual quality and voltage and the major concerns centred around the LV capacitor street furniture. This interaction led to the LV capacitor street furniture design being revised to prevent them being used for unauthorised access to adjacent private property and as a congregating point for juveniles.

Q. Were there many interventions initiated by the Siemens Spectrum Software?

A. Mr Ingham explained that the recorded voltages showed that on average the automation had operated 2-3 times a day meshing circuits, changing taps and closing capacitors to support the network.

Mr Ingham gave an explanation on the method of achieving the balanced network and that the Siemens Spectrum 5 system ‘state estimator’ fed data every 30 minutes into an optimisation algorithm to select the most efficient way of running the network.

Q. Could more detail be given regarding the connection of the capacitors?

A. Mr Ingham confirmed that the capacitors do not have G59 relays fitted but have an under-voltage relay that would operate when a loss of mains voltage was identified. The LV capacitors were subject to ‘staged’ operation whereas the HV capacitors located at the primary substations were not and they were either ‘in or out’

Q. Was it possible to control the 3 phases independently?

A. A design decision was made not to have individual phase control and that the three individual phase measurements were taken and averaged to create a single phase. It was explained that although there is an existing imbalance on the LV network, which was confirmed by the received readings and although it was working on an averaged value, the system had not created any imbalance and all three phases were within statutory limits at all times.

Q. Would there be benefits of an independent controlled 3-phase network?

A. Mr Ingham thought that there were benefits but he was not sure if the technology was available at the present time but he believes in the future, we may see independent phase by phase optimisation.

Without any further questions being posed by the audience, Mr Ingham was thanked for his presentation and Mr Gheorghe asked to give an overview of the involvement of TNEI in the Smart Street project and the Power Quality Analysis undertaken.

Power Quality Analysis – Mr Daniel Gheorghe

In order to run a series of power flows and fault level studies TNEI used input data provided by The University of Manchester for the 33 and 11 kV networks; standard aggregated data from ENW for the LV network; load profiles from a day of peak demand in December; historic photovoltaic generation data and CHP and wind as a constant connection.

During the power quality study, the following metrics were used – voltage profile; voltage step change, in case of switching events; voltage unbalance; fault level studies; HV and LV power flows and the impact of LV interconnection and meshing.

Mr Gheorghe outlined the methodology used in the studies and explained that the studies were automated as the data was 1-minute profiled. A first ‘rough’ 15 minutes analysis was carried out to identify the elements that were most overloaded (busbars and circuits) and then a full 1-minute simulation for the entire cycle. This initial analysis was necessary because of the amount of data (100 Gb) that would have to be processed if all elements were analysed.

The voltage studies looked at both the HV and LV network with minimum and maximum voltage levels (-6 %+10 %); voltage unbalance; instances of frequency and increases in voltage imbalance.

For the load flow studies, the power flow was analysed through the distribution transformer in places where the LV networks were contained in the model; current flow through the HV and LV circuits and for the fault level studies the study looked at the HV and LV busbars.

It was felt by TNEI that some of the assumptions made were conservative but they believe they achieved a good level of accuracy on how the network would behave if the Siemens Spectrum equipment was installed.

In the trial area where the studies were carried out, it was found that the voltage profiles were within statutory limits; voltage unbalance was never more than 2 %; voltage step change was less than 3 % although there were isolated cases where the tripping of larger capacitors could result in voltage step changes higher than 3 % but it was felt that this only occurred in situations where capacitors and OLTC keep the voltage to an artificial level.

Fault levels did increase but they were within the switchgear ratings.

Mr Gheorghe went on to give examples of the analysis which showed voltage profiles stay within statutory limits and that the voltage unbalance analysis showed that the interconnection improved the unbalance.

A question from the audience asked Mr Gheorghe if any calculations were undertaken on transformer losses. It was explained that losses were not considered by TNEI as they were predominantly dealing with power quality and the losses aspect was being undertaken as a separate piece of work by Queens University Belfast.

It was asked whether the trial had compared results with actual measurements and were there any problems with load allocation for interconnected areas. Some results have been compared with actual measurements and they showed similarities – the differences were in the loading of each phase.

When the LV meshing took place did the interconnection take place between distribution two substations or where they just LV feeders from the same HV circuit?

If they were fed from the same 11 kV feeder it would not be expected to see a big difference in voltage but if interconnecting two distribution substations from different primary substations that would be a different scenario.

It was confirmed by Mr Ingham that all interconnections were on the same HV circuit.

Was there any co-ordination between transformer voltages?

Transformers in the trial were standard fixed tap nominal voltage of 433 V no load with one OLTC per trial area so there is no real ability to coordinate both ends if disconnection did occur.

Consumer Installations – Mark Coles

Mr Coles gave a brief outline of his role within the IET and his involvement with BS 7671 the IET Wiring Regulations.

He described the normal method of protection against electric shock in a dwelling, automatic disconnection of supply (ADS), which requires basic protection (insulation of live parts) and fault protection (earthing, bonding and operation of a protective device).

Mr Coles went on to explain the theory of earth fault loop impedance and the path of the fault current in the case of an earth fault on a customer's appliance. In order for faults on electrical installations to be removed by ADS in the required time, maximum values of earth fault loop impedance are given in BS 7671.

Mr Coles' concern was that if the installation of the Smart Street equipment on the ENW network were to raise the value of earth fault loop impedance, faults may not disconnect in the required time which could lead to dangerous voltages appearing across simultaneously-accessible-parts or the overheating of conductors which could lead to the failure of insulation and/or fire.

He then posed the following question to the Smart Street team "does the installation of Smart Street equipment affect the values of earth fault loop impedance (Z_e), as seen from the terminals of a consumer's low voltage electrical installation"?

Mr Ingham responded that this was not something that was studied specifically as part of the trial but confirmed that the majority of the equipment installed on the network would not affect the impedance of the network up to the consumer's terminals.

The only exception is when automatic interconnection between circuits takes place; which will have the effect of lowering the overall impedance which in turn will reduce the time required to clear the fault.

Mr Coles then went on to describe the requirement of BS 7671 relating to items of electrical equipment, such as consumer units and circuit-breakers, which are normally rated at 16 kA to deal with the expected prospective fault current (I_{pf}). Knowledge of I_{pf} is required throughout a low voltage electrical circuit by the installation designer so that the correctly rated equipment can be selected.

Mr Coles said that although 16 kA is rarely seen at the customer's terminals, this figure is often quoted by network operators to electrical contractors.

Mr Coles asked the panel “does the installation of the Smart Street equipment affect the values of prospective fault current, as seen from the terminals of a consumer’s low voltage electrical installation”?

Mr Ingham’s response was that the installation of the Smart Street equipment does have an effect on the values of prospective fault current. The TNEI studies show that the meshing of the circuits with interconnection lowers the impedance and so increases the prospective fault current however the starting values experienced were very low compared to the quoted figure of 16 kA. The highest percentage increase in prospective fault current experienced during the trial was 42 % but the value started at 1.3 kA to 2.4 kA which is a large percentage increase but does not impact on the design level of 16 kA.

It was acknowledged that the trials have identified that customers appear to be mainly interested in supply interruptions and would not either understand or be aware of the implications of an increase in prospective fault current. Also if an increase did take them above the 16 kA figure, how would they be informed?

Mr Ingham advised that the customer’s installation was not within their sphere of control but if the trial moved to ‘business as usual’ ENW would publicise the changes and would have to notify customers that these changes may have an impact on their installation and may necessitate a review of their installations.

An audience member raised the issue of prospective fault current in London where figures of 25 kA were quoted and the rating of rewireable fuses were 2-3 kA. Mr Coles highlighted the fact that BS 7671 is a framework and whatever equipment is chosen must be suitable for the application in which they are to be applied. So, although rewireable fuses are still permitted they must be suitable for the application and that includes prospective fault current.

Mr Ingham was asked if any issues had arisen from increased prospective fault current being experienced with street furniture (street lighting, bus stop information equipment, etc.) as this normally sits in close proximity to main low voltage distribution cables. Mr Ingham confirmed that there had been no reported problems.

Mr Gheorghe stated that large percentage increases in fault levels identified in the analysis only occurred where there were multiple interconnections and it is unlikely that the Spectrum 5 would connect multiple connections on the live network. The analysis showed that the median fault level in most of the networks modelled was in the region of 6-7 kVA and moving towards 9-10 kVA when the interconnections take place.

Open Forum

The presentations from the three panel members were followed by an open forum with questions from the audience being put to the panel.

Q. Will the application process for low carbon technology connections be amended if Smart Street was available in that area?

A. Ben Ingham – Smart Street is based on retrofit technology that allows ENW to adapt to connection demands more quickly than would be the case if this increase in connections makes network reinforcement necessary. Therefore, by using Smart Street reinforcement can be delayed and the existing network retained for longer periods of time.

Often ENW are not informed when a PV connection is installed in a domestic situation; with only 33% of installations being notified to the company. Many of the voltage complaints received are due to PV installations raising the system voltage.

Q. Will Smart Street data be able to be used to reduce the time required for ENW to carry out a network study for a generation connection?

A. Ben Ingham – Smart Street is LV technology and connections on the LV network are usually for domestic installations. The schemes that require network studies are usually large-scale schemes that require connection to the HV network and will not be impacted by Smart Street.

Q. Within the USA there are schemes where the supply companies can ask customers to switch off specific pieces of equipment to reduce demand; will Smart Street be able to do this?

A. Ben Ingham – Even with the completion of the smart meter roll out, there will not be the detailed information available for individual properties to control individual pieces of equipment. The load information is aggregated over 10 properties so the detail is not available for individual pieces of equipment. At the HV level part of the C_2C project (automated and interconnected HV network) large customers have a managed connection agreement where they agree to 'shed load' in the event of a fault to enable EMW to control demand if there is a need to reconfigure the network. In the future this control may be necessary as the distribution network changes.

Comment from the audience.

A scheme initiated by EA and another DNO designed a system (My Electric Avenue) where 220 electric vehicles could be charged at night on a reduced tariff rather than during the day. This resulted in only 8 % of the network needing reinforcement. Once people had adapted to charging their vehicles at night at reduced rate rather than a higher tariff during the day they were happy with the arrangement. It was found that no one in the trial used more than 50 % of the battery capacity during the day and they were then able to charge it up during the night which could help the DNOs with putting power back into the grid.

A. Geraldine Paterson ENW – this is one of a number of innovation projects and all of the DNOs learn from each other from these projects. The issue at the moment is that the tariff structures are all 'time of use' and changing tariffs will be the only way to encourage people to change their habits. There are domestic appliance smart technologies available but they are expensive compared to standard appliances and consumers are reluctant to purchase.

There are other innovation projects that are seeking customer feedback on how keen the customer would be in DNOs gathering data on their energy consumption if this could result in optimising the energy usage.

Q. With the UK Government's aim of moving everyone onto electric vehicles and the requirement for rapid charging for public transport vehicles, will the Smart Street technology be sufficient to meet these increased energy demands?

A. Ben Ingham – The idea of Smart Street is that as the clusters of LCT demand appear the demand can be dealt with in the short term whilst a review of the reinforcement needs are reviewed. In some cases, Smart Street could be a permanent solution and some of the hardware could be retained for fault response and LV monitoring. Smart Street is seen as a means of dealing with the demand in a controlled manner.

Q. What type of assessment tools have been developed for triggering when Smart Street technology is deployed?

A. Ben Ingham – At the moment nothing has been determined. The final analysis of data from the trial is due in February 2018 and all of the data will be used to determine how Smart Street will be deployed in the most effective way.

Q. Has any analysis been carried out with regard to asset health and have there been any problems with capacitor switching and the voltages induced on the interrupters plus any issues with losses associated with supplying the capacitors with VArs?

A. Ben Ingham – No issues identified with asset health but there were early problems with the noise that the capacitors put onto the network made. The capacitor switching did cause a problem with the integration that the WEEZAPS were using to obtain the current readings but that has now been refined and the issue resolved.

The main concern has been with the network studies for the installation of the HV capacitors and the issue of breaking the capacitive current through the circuit breakers. At the primary level there was not an issue but the local level it was necessary to install a controlling unit at the capacitor. In the event of an HV fault the primary circuit breaker would operate to clear the fault and then a local breaker would open on 'no volts' so that when the circuit was re-energised as part of the fault repair the capacitor would be off the system.

Q. Have there been any issues such as 'ringing' with the distribution transformers by the addition of large amounts of capacitance?

A. Ben Ingham – There have been no noise complaints – the worst-case scenario has been with the 200 kVAr capacitors installed at the distribution substation for voltage control and all 3 stages were switched in with staff on site as part of the commissioning process and there has been no additional noise such as 'ringing'.

Q. In the Cumbrian network has there been any interaction with the static compensation from the wind farm devices?

A. Ben Ingham – The majority of the wind farm installations in Cumbria are generally large commercial operations that tend to be connected at 33 kV or occasionally 11 kV and the Smart Street circuits in the Lakes do not have generation connections so this may be something that has to be considered when Smart Street is rolled out as 'business as usual'.

Q. What training have the ENW operational staff been given to ensure when an incident does occur they are not having to contact the project team for advice?

A. Ben Ingham – The WEEZAPs are used in 'business as usual' and all staff are familiar with their operation and all staff have been briefed on the use of the LYNX. The biggest change was a requirement to brief control engineers on the LV managed network. Each area has an overall control which in the case of a fault or planned work taking place; the Spectrum system would be frozen to prevent any changes being made to the network during that period. A change to a code of practice was made and a briefing note circulated that gave responsibility to the LV authorised persons to provide isolation as required. Training was given in isolation of the HV and LV capacitors.

Q. How quickly can faults be located?

A. Ben Ingham – There have been 6 HV faults with the Smart Street system being paused the fault repaired and the system reconnected. One of the benefits of the WEEZAP technology is the ability to feed data to a fault detection algorithm that can identify fluctuations in the supply and detect that a fault is imminent and give a fairly precise fault location. This enables a repair team to be despatched to identify a fault before an interruption occurs.

Q. Has it reduced Customer Minutes Lost?

A. Ben Ingham – When an LV fault occurs the normal identification process involves customers giving a post code, the relevant substation being identified and a fault repair team being dispatched to carry out a fault location and repair. Smart Street has the ability to identify the substation, the circuit and phase and so reduce repair time.

Q. Has meshing the circuits created an increase in the number of customers that could be subjected to a fault?

A. Ben Ingham – Smart Street and meshing does increase the number of customers at risk of fault but Spectrum has the ability to only mesh when it benefits the system. While it is meshed and a fault occurs the WEEZAPS at both ends trip and the LYNX will operate on no volts. This splits the network and both WEEZAPs will reclose after 30 seconds with the healthy circuit staying connected. If there is a permanent fault on the other circuit the WEEZAP will follow a 5 shot reclose cycle before locking out. This means that customers subject to a transient fault are connected in 30 seconds and permanent faults are located with a precise location.

Q. As the distance to fault algorithm is impedance based, did changes have to be made due to the changing state of the connection of the capacitors?

A. Ben Ingham – Yes it does and the company responsible for the devices are making revisions.

Q. With the capital and installation cost of capacitors do you believe that the analysis will show a cost benefit for the project?

A. Ben Ingham – One of the findings identified so far is that as feeder volt drop is not 7 % as anticipated and as such the capacitors may not be as beneficial as first thought. The outcome from the trial may be that LV capa`citors are not installed.

Q. Could you please expand on the site selection process and did you have monitoring equipment already installed on the chosen sites?

A. Ben Ingham – Trial networks were chosen to be installed on sites that had been used previously for the CLASS project and the LV networks were chosen to represent the various networks within ENW hence the geographic spread. All of the monitoring equipment was installed for the project.

Planning approval requirements had to be considered and the space available to physically accept the HV capacitors.

Q. Do you think that the future proposed change in voltage tolerances to +/- 10 % will impact on the future of Smart Street? Would not changing the nominal set point on the secondary transformer to a lower voltage be more beneficial?

A. Ben Ingham – It would be better to reduce the voltage to 220 V. The customer engagement panels have identified that there have been no reports of undervoltage even though the voltages have been at 227-230 V. The OLTC have an ability to reduce or increase voltage depending on network requirements and this may be an option going forward.

Mr Ingham went on to explain that the OLTC transformers were new units, the WEEZAPs were fitted to newer type LV boards, the LYNX equipment was installed into existing LV link boxes and the capacitors are installed in street furniture. The WEEZAPs can be fitted to older type open frame LV boards.

T R Pickard

18th December 2017