electricity north west
Bringing energy to your door

First Tier Portfolio Reward

1 March 2017

1 Executive Summary

Welcome to our First Tier Portfolio Reward submission document which summarises the projects undertaken by Electricity North West and our partners during the DPCR5 period. We have outlined the technological, commercial and customer service innovations delivered through our work during this period but more importantly, **how these have delivered real benefits to both customers of Electricity North West and across Great Britain (GB)**.

The First Tier of the Low Carbon Networks Fund (LCN Fund) formed an important funding mechanism allowing early stage projects to be developed by ourselves and our partners. Without this funding many of the projects discussed below would not have been possible and we believe Ofgem should be commended for their foresight in establishing the First Tier mechanism.

As you will read, much of our work has already progressed into business as usual (BAU) in Electricity North West and other GB distribution network operators (DNOs). Our work has also led to significant Second Tier and Network Innovation Competition (NIC) projects and has captured interest from across Europe and wider international audiences.

The key focus of our portfolio is to **maximise the use of the assets customers have already paid for and to deliver real solutions to the real problems faced by customers**. Customers remain at the centre of our innovation strategy and the projects described below form a critical foundation for our future work to meet their needs.

While it is important to recognise the service and financial benefits to customers, there are other significant benefits arising from this work: new academic understanding, new manufacturing technologies and new commercial opportunities leading to jobs and economic growth. These factors have helped energise the electricity sector supply chain with manufacturers investing significant sums in project participation and technology development. Without this supply chain support, meeting the decarbonisation challenge would be much harder. We would like to recognise and thank all of our academic, consultancy and manufacturing partners for their support.

The focus of our First Tier projects was on the operation and management of the low voltage (LV) networks under normal system performance and under fault conditions. **Our exceptional project results** have led to technology solutions being **successfully transferred into BAU for Electricity North West and other GB DNOs**.

One example of how our portfolio has delivered real benefits to GB customers is the development of a suite of fault management tools which have delivered **significant improvements in LV network performance.** These tools and associated business processes have fully transitioned into our BAU LV transient fault management protocol and importantly have been widely adopted by GB DNOs.

Our portfolio has taken significant steps towards dynamic management of LV networks. The techniques from this are now being used in full scale field trials as part of our Second Tier project Smart Street. We developed a low cost Smart Joint to enable mid-point feeder monitoring which has been used subsequently in many other innovation projects and which are likely to play a significant role in the facilitation of our 'connect and manage' policy for low carbon technologies (LCTs). Another exceptional outcome from this work is the finding that the **LV network can accommodate greater numbers of LCTs than had previously been assumed.**

Using learning from a First Tier project we have deployed a central control system to manage fault level using adaptive protection, fault current limiters and a new commercial technique under our Second Tier project, Respond.

Exceptional dissemination activities include our website with its dedicated First Tier platform, academic published papers, internal and external presentations, and 'How to' training videos. **Our efforts have been recognised and we have won several innovation awards.**

In the remainder of this document we provide details of our six First Tier projects, explain why we undertook each project, how it benefitted customers and how the learning has been used going forward. We believe that Electricity North West has invested customers' money wisely under the First Tier and **achieved demonstrable value for money from this investment**. We would highlight our Well Justified Business Plan and Innovation Strategy documents which quantify these in more detail for the RIIO-ED1 and ED2 periods.

2 Description of Portfolio

2.1 Introduction

Our First Tier Portfolio Reward application describes how we have used innovation to improve the service we offer to all our customers by gaining a better understanding of the LV network and the issues faced by DNOs from the transition to a low carbon economy.

Between 2010 and 2015 we successfully completed six First Tier innovation projects. This application is focused on the exceptional benefits that we have already provided to both our customers and those of other DNOs as a direct result of these First Tier projects. The application also focuses on the benefits gained from these projects in laying the foundations for some of our Second Tier LCN Fund and NIC projects.

Our First Tier projects broadly fall into two categories: 'standalone' projects and 'forerunner' projects. Standalone projects are focused on answering specific questions, for example: what is the potential of the Smart Fuse as a fault management tool to deliver improvements in LV supply performance?

Forerunner projects provide a basis for learning towards broader innovation challenges. These projects facilitated, accelerated and de-risked our Second Tier projects. Examples include Low Voltage Integrated Automation (LoVIA) and Fault Current Active Management (FCAM) which were forerunner projects for the Second Tier projects Smart Street (funded as *eta*) and Respond (funded as FLARE) respectively.

Our stakeholders tell us that reliability of supply and affordability are their main priorities for their electricity supply. This will be even more important as reliance on electricity increases with the take-up of LCTs such as photo voltaic (PV) generation, electric vehicles (EV) and electric heat pumps (HP). As the vast majority of our 2.4 million customers are supplied from our LV network, it was important to give consideration to the future operation of this particular area of our network and its assets. Hence our First Tier Portfolio was focused on gaining a greater understanding of the historically passive LV network, and in trialling and deploying innovative equipment to better manage its capacity and reliability.

Before the start of the price control DPCR5 period, we brought together key stakeholders from across the North West, such as the North West Development Agency and the University of Manchester, to help us develop and launch our smart grid vision. The start of DPCR5 in April 2010 signalled the first step in our smart grid journey supported by the existing Innovation Funding Incentive (IFI) and the newly introduced LCN Fund.

2.2 Innovation strategy and First Tier projects

Our smart grid vision is a core part of our overall innovation strategy to manage the long-term challenges of our operator 'trilemma': managing our ageing assets; managing the effects of changing energy use; while meeting the increasing expectations of our customers (Figure 2.1). Innovation is key to resolving these challenges and is therefore central to our business plan.

Figure 2.1: Operator trilemma

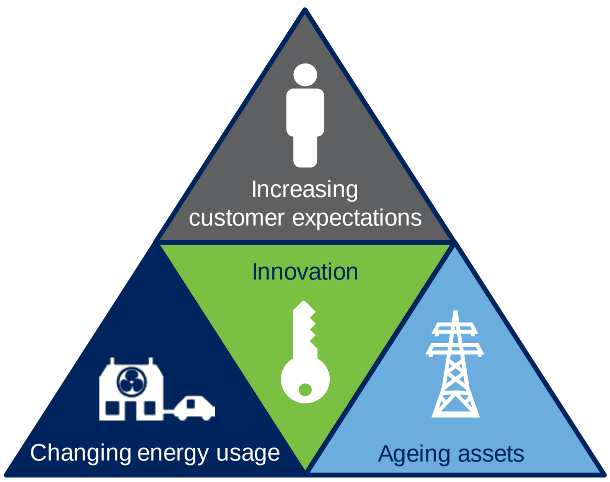
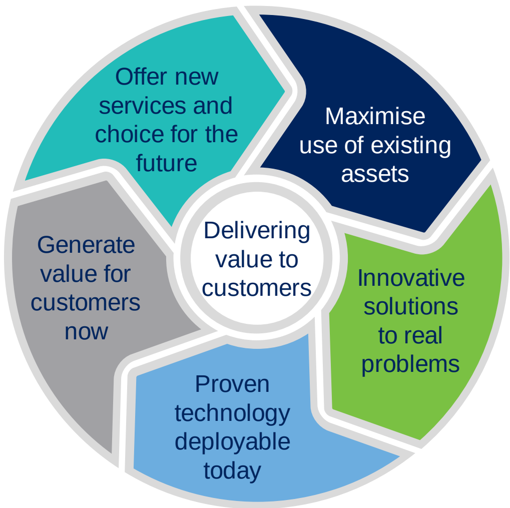


Figure 2.2 Innovation strategy



Our innovation strategy (Figure 2.2) focuses on delivering value to our customers by maximising the use of our existing assets and ensuring that we develop innovative solutions to real problems. Our business plan ensures we focus on the projects which are likely to deliver real value to customers in the near to medium term. This focus has enabled our First Tier Portfolio to demonstrate exceptional performance.

Through our First Tier projects, we have demonstrated that new thinking enabled by technology can transform electricity networks and bring significant benefits to all GB customers. We have trialled new equipment, developed new software algorithms, trialled new commercial models and linked these together through improved communications infrastructure. This has provided us with visibility of our LV networks, and enabled remote management and optimisation. Our projects have consistently focused on our customers' needs and we have involved them throughout our work.

2.3 Strategic partnerships and transfer to business as usual (BAU)

The success of our First Tier Portfolio was aided by the strategic relationships we have developed with our world class partners such as the University of Manchester, Kelvatek, Siemens, ABB and others. Many of these partners have developed technology that has enabled us to deliver exceptional project results and successfully transfer innovative solutions into BAU for Electricity North West and other DNOs across GB. In some cases, First Tier project technology, business processes, procedures and specifications are enabling a larger Second Tier or NIC project with wider benefits.

2.4 Our First Tier Portfolio

Our First Tier innovation portfolio demonstrates how distribution networks can help reduce bills for customers by using reliable and proven technology and assets in a novel way. This improves the network's efficiency and increases security and continuity of supply, while reducing the financial and carbon costs incurred by traditional reinforcement solutions.

The six projects that make up our exceptional First Tier Portfolio are summarised in Figure 2.4 and are considered individually in more detail in the following chapters. The main driver for the projects is the acceleration of the development of a low carbon energy network. The portfolio has contributed to the reform of electricity networks by developing and testing low cost solutions and new voltage regulation regimes which facilitate the faster connection of increasing amounts of low carbon technologies. It is important to recognise that supply reliability, while important now, will be even more important in the future as customers become increasingly reliant on electricity as their main source of energy.

The focus of our First Tier projects was the operation and the management of the LV networks both under normal system performance and under fault conditions. The projects considered power flow, thermal capacity, voltage management, harmonics, network control, network visibility, transient fault management and fault level management.

We undertook a detailed review of likely network issues that needed to be explored and set out our innovation portfolio to address them. The network issues are listed against the First Tier projects in Figure 2.3 and discussed in greater detail below.

Figure 2.3: Innovation portfolio addressing network issues

Network issue	LVNS	LoVIA	FCAM	Smart Fuse	Voltage Management	LVPaC
Voltage	✓	✓			✓	✓
Thermal	✓					✓
Transient faults				✓		✓
Network control		✓		✓	✓	✓
Visibility	✓	✓		✓	✓	✓
Power flows	✓					✓
Fault level			✓			
Harmonics	✓			✓	✓	✓

Voltage: At any particular point on the distribution network, increases in demand will result in lower voltages, while an increase in generation will result in higher voltages. As the uptake of LCTs (both demand and generation) increases, different voltage profiles will occur across the LV network at different times of the day/year. The management of these varying profiles can be problematic and requires new solutions.

Thermal: Rising demand leads to an increase in current on the network which in turn increases the operating temperature of our assets. All assets have an assigned rating related to operating temperature which, if exceeded, will result in premature ageing and, in some cases, early replacement. Large levels of simultaneous load pick-up, such as when an estate with HPs is restored following a power outage, can result in operation of LV fuses.

One of the exceptional outcomes of our portfolio from our research into voltage and thermal issues has been the finding that the LV network can accommodate greater numbers of LCTs than had previously been assumed. As a result, our planning policy has been modified to adopt a connect and manage approach for the connection of clusters of small-scale embedded generation such as PV systems, with appropriate network monitoring. This research area has not only reduced the need for costly reinforcement associated with residential PV adoption, but has also greatly simplified and speeded up the associated connection processes for our customers.

Transient faults: A transient fault is a fault which causes a network fuse to operate but then re-heals without any manual intervention. A transient fault can eventually develop into a permanent fault but before this can cause a great deal of inconvenience to customers. Another demonstration of how our portfolio has delivered real benefits to GB customers is the development of a suite of fault management tools which have successfully delivered significant improvements in LV network performance. These tools and the associated business processes have fully transitioned into Electricity North West's BAU LV transient fault management protocol and have been widely adopted by GB DNOs.

Network control: Historically DNOs did not have remote control of the low voltage network as it was previously a passive system. Our work has shown that active management of LV and high voltage (HV) networks offers great savings and improved reliability for customers while allowing increasing levels of distributed generation and LCT demand to be connected. The real challenge with adopting active management and network meshing was safety. Our portfolio has successfully solved this historic problem delivering new devices using advanced protection algorithms and a communications platform. Our First Tier Portfolio has taken significant steps towards dynamic management of LV networks. This work not only solves these problems but allows significant cost reductions for customers now and in the future. These techniques are now being used in full scale field trials as part of the Second Tier project Smart Street.

Visibility: Historically, visibility of the LV network was not required due to its passive nature. Our portfolio focused on gaining new understanding of the actual characteristics of LV networks through extensive data monitoring and ongoing analysis which has provided previously unavailable visibility of the LV network and its demand. This allows more accurate modelling, planning, control and operation of the LV network and reduces costs for customers.

Power flows: The increased use of LCTs is expected to significantly alter the power flows traditionally seen on the LV network. The monitoring deployed as part of our portfolio gives increased visibility of these power flows and the issues caused. The communications we have developed, combined with the smart devices being trialled in Smart Street, allow network configuration to be changed to manage the variation in power flows.

Fault level: Fault level is defined as the potential maximum current that will flow when a short circuit occurs. Our portfolio investigated a range of techniques which can be used to manage fault levels on the GB distribution network. We have used the learning to deploy a central control system to manage fault level, using adaptive protection, fault current limiters and a new commercial technique under our Second Tier project, Respond.

Harmonics: Harmonics are higher frequency voltages or currents which create a ripple on the power supplied to devices. If the ripple is significant it can cause customers' appliances to mal-operate. As LCTs proliferate, harmonics may get worse and hence it is important to devise efficient solutions to these problems so customers can freely adopt LCTs without any inconvenience. We have trialled active filters to manage and reduce the level of harmonics on the network. The trial was successful and filters are now part of our BAU solution for harmonic issues.

Figure 2.4: Summary of Electricity North West's First Tier Portfolio

First Tier Project	Project summary	First Tier funding £k*	Licensee compulsory contribution £k*	Other contributions £k*	Link to closedown report
The 'Bidoyng' Smart Fuse	This project deployed Smart Fuses (previously developed under the IFI Fuse Restorer project) to mitigate the impact of LV transient faults on customers by reducing restoration times to less than three minutes.	£348,602	£38,734	£0	Smart Fuse webpage
Fault Current Active Management (FCAM)	This project investigated innovative techniques to manage the breaking capacity and through fault withstand of existing protection assets, as an alternative to traditional operating methods. It included an independent risk assessment of the use of existing and new assets for fault current management.	£234,846	£26,094	£0	FCAM webpage
Voltage Management (on Low Voltage Busbars)	This project explored the potential to use alternative technical solutions for controlling voltage on LV networks, to help manage increased load and generation by installing: power quality filters, Power Perfectors, distribution transformers with on-load tap changers (OLTCs) and LV capacitors. The University of Manchester used the findings to identify and assess the benefits of deploying the various technologies on the network.	£636,398	£70,711	£0	Voltage Management webpage
Low Voltage Integrated Automation (LoVIA)	This project developed and trialled an integrated solution and novel application of automated voltage control on LV networks by combining existing and new equipment including: LV monitoring at the mid and end-points of feeders, distribution transformers with OLTCs and substation controllers. The control solution delivered regulation of network voltages based on local and remote real time measurements.	£692,565	£76,952	£0	LoVIA webpage
LV Protection and Communications (LVPaC)	This project developed and tested the enhanced protection and communication functionality to be applied to the Kelvatek load management devices, WEEZAP and LYNX. This enhanced functionality will allow greater control on the LV network, facilitate the low cost adoption of LCTs and further permit a more appropriate response for a range of faults as network loads change.	£411,865	£45,763	£0	LVPaC webpage
Low Voltage Network Solutions (LVNS)	This project installed monitoring equipment on the LV network; the data from this was analysed and combined with network modelling by the University of Manchester to provide a better understanding of the available capacity on LV networks to accommodate LCTs. Project findings have helped to: develop policies on what and when to monitor on LV networks; improve processes for LV monitoring and data collection; better understand how LV monitoring and network models can support other innovation trials; and assess future implications for LV planning, operations and connections policy.	£1,511,739	£167,971	£0	LVNS webpage

**nominal prices*

The Bidoyng Smart Fuse

This project deployed smart fuses across the network (previously developed under an IFI project) to reduce the restoration time for low voltage transient faults to less than three minutes, which previously required a site visit.

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Benefits

- Allows wide-scale deployment
- Reduction in CMLs
- Improved customer service
- Improved LV network visibility
- Easily adopted by other DNOs

Previous project	Fuse Restorer IFI Project	Follow on project	Fault Support Centre IFI Project Start: **Jan 2014** End: **March 2015**

Project partners

KELVATEK

Durham University

BUSINESS AS USUAL

www.enwl.co.uk/tier1

3 Smart Fuse

3.1 Background

When a fault occurs on an underground low voltage circuit, one or more LV fuses operate at the distribution substation and disconnect customers on the faulty circuit from the network. The first response is to replace the fuse protecting the circuit; for 50% of faults, supplies are restored with no further fault activity. This type of fault is referred to as a 'transient' fault. The Smart Fuse automatically performs this fuse restoration action within the first few minutes of the fault occurring. This significantly improves customer service and avoids protracted supply interruptions.

Following the successful outcome of the Fuse Restorer project, the Smart Fuse First Tier LCN Fund project was launched in December 2010. The purpose of this project was to carry out a wide scale trial of the Smart Fuse, assess its potential as a fault management tool and deliver improvements in LV supply performance. The ultimate aim was to move the Smart Fuse through design, development and deployment to BAU, and provide real data to further develop the original financial cost and benefit projections.

In order to develop the justification for the project, we analysed low voltage transient fault data from 2006-07. Figure 3.1 shows the number of repeated fuse operations and the impact on customer interruptions (CIs) and customer minutes lost (CMLs).

Figure 3.1 Analysis of repeat fuse operations (sample one to four operations)

No. of fuse operations	No. of transient faults	CML	CI
1	1,665	6,196,584	40,574
2	635	2,553,842	17,400
3	329	1,117,709	8,666
4	204	871,631	6,243

Description of the Smart Fuse technology

The Smart Fuse (named as the Bidoyng by Kelvatek) is a single shot automatic reclosing device that carries two standard 'J-Type' fuses in parallel. This device is used to replace a standard single fuse holder at an LV distribution substation and fits into existing LV fuse positions, creating a robust single-shot auto-recloser. The primary fuse carries the load current until a fault causes it to operate. Then, after a user-programmed delay, the secondary fuse is switched in to reclose and re-energise the network, without customer interruptions. The Bidoyng Smart Fuse uses telemetry to provide the real time status of installed units and sends automatic notification of primary and secondary fuse operation to nominated contacts.

The Bidoyng Smart Fuse carries a range of high specification voltage and current recording sensors which can be used to detect the presence of the fault activity (before the fuse operation). This means that the replacement of faulty underground cable and joint sections can be planned in advance of the full short circuit in an effort to reduce unplanned disruption to our customers.

3.2 Outcome

The First Tier Smart Fuse project successfully delivered all of its key objectives. The Smart Fuse has successfully demonstrated the positive impact of the innovation incentives available to DNOs. We used the initial IFI funding to de-risk the development and field testing of a prototype low voltage auto-reclosing device then utilised the First Tier funding mechanism to conduct extensive performance testing and final performance requirement definition. With support from Ofgem's incentive schemes, we have transitioned a simple concept, through all phases of research, development and trial cycle into BAU, to meet a real customer need.

To fully exploit the opportunity provided by Smart Fuses to reduce response and restoration times, we developed the Fault Support Centre (FSC) in collaboration with Kelvatek. This is a dedicated 24-hour support centre hosted at Kelvatek's headquarters in Belfast which actively monitors transient faults. The FSC gathers data from the Smart Fuses installed on the LV network which is then analysed to identify where to use 'fault sniffers' (devices that smell gases generated from cable faults). This enables us to detect and repair faults before they become permanent and prevent customer interruptions. The FSC benefits around 50,000 of our customers and saves £2 million a year in CIs, CMLs and guaranteed standards payments.

The routine deployment of Smart Fuses has revolutionised LV fault management and the customer experience by significantly reducing the incidence of multiple interruptions historically associated with faults of this nature.

This solution has been adopted into the BAU method by which all LV transient faults are managed. The techniques and technology have now been adopted by all GB DNOs and are therefore directly benefitting all GB customers.

The section below identifies the key learning relevant to the reward criteria.

Carbon plan	
Key learning relevant to reward criteria	**Associated project details**
Transient fault management and use of technology to reduce carbon emissions associated with management of LV networks. Domestic PV could be connected without the need for investment in additional LV infrastructure**.**	For individual transient faults the Bidoyng Smart Fuse provides an almost instantaneous reconnection, which substantially reduces the duration of supply interruptions. Telemetry provides the real time status of installed units. This visibility enhances fault management capabilities, allowing planned visits to be scheduled for the replacement of a primary fuse. It also flags that customers are off supply, before they make contact, if the secondary fuse has operated. This information allows us to manage LV network faults in a manner that was not previously possible. This has resulted in the reduction of unplanned work in this area and more efficient planned work to isolate and repair faults. This new practice has led to a direct and demonstrable reduction in operating carbon. The monitoring element of this project, conducted by Durham University, has statistically proven that connecting domestic PV generation has no noticeable effect on the low voltage side of a standard distribution transformer. This provides a high level of confidence that DNOs can continue to allow the connection of domestic PV without the need for investment in additional LV infrastructure, thereby removing a perceived barrier to the connection of renewable energy.

Network capacity release	
Key learning relevant to reward criteria	**Associated project details**
Capacity can be released for domestic PV without the need for investment in additional LV infrastructure**.**	The monitoring element of this project has statistically proven that connecting domestic PV generation has no noticeable effect on the low voltage side of a standard distribution transformer. Along with the learning from LVNS the Smart Fuse monitoring has led to the implementation of our connect and manage policy.

Financial benefits	
Key learning relevant to reward criteria	**Associated project details**
Smart Fuse can be used to reduce CIs and CMLs. Smart Fuse can be used for 'time-shifting' of fault repairs and reduce repair cost.	The Smart Fuse project has helped to significantly reduce the impact of LV underground transient faults by substantially cutting the number of CIs and CMLs for faults of this type. In 2016 the Smart Fuse delivered an estimated CI savings of £498k, CML savings of £783k and annual fault restoration savings of £576k. This results in a total annual savings of £1,857k. Using the Smart Fuse with the FSC also enables us to exploit potential 'time shifting' of fault repairs from out of hours into normal working hours. This increases the availability of repair teams by reducing sleep time, which is cost efficient and improves service to customers.

Rollout across the DNO's system and across GB	
Key learning relevant to reward criteria	**Associated project details**
Smart Fuse has been deployed in other DNOs across GB allowing more customers to benefit from the technology	Following our lead, the Smart Fuse has been adopted by all other GB DNOs and is therefore delivering real improvements in service for all GB customers. We have 766 Smart Fuses installed on our network with other DNOs adopting this approach. In 2015-16 UK Power Networks deployed 601 devices and Northern Powergrid deployed 1011. Kelvatek has informed us that "All the GB DNOs are using Bidoyng. There are nearly 10,000 Bidoyngs in operation across GB, with the sale of several more thousand projected this year." Knowledge from this project has been disseminated via a number of platforms, examples of which include our website, conferences, social media, press releases, internal communication and reports, documents and training material.

Other benefits	
Key learning relevant to reward criteria	**Associated project details**
The Smart Fuse project has improved safe working practices	The Smart Fuse has improved our way of working regarding safety. The traditional method of live fuse changing may generate sparks and potential arcing risks to the operator. The Smart Fuse can be safely inserted in the 'dead' position and subsequently closed to the 'live' position by means of a handheld remote control device. This is operated at the substation but at a safe distance from the LV board, thus improving safety for our field teams.

Portfolio management	
Key learning relevant to reward criteria	**Associated project details**
The Smart Fuse project has demonstrated that one solution can integrate with other innovation initiatives	Electricity North West is making a significant investment in a replacement network management system (NMS) which offers advanced distribution network management functionality. We have collaborated with Kelvatek to ensure existing Smart Fuse communication technologies integrate with the new NMS applications, to ensure that we exploit and integrate all system functionality into BAU.

Fault Current Active Management (FCAM)

This project investigated the innovative use of existing protection assets as an alternative to traditional methods and included an independent risk assessment of the use of existing and new assets for fault current management.

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Benefits

- Faster LCT uptake
- Improved management of existing assets
- Reinforcement deferral
- Active network management
- Improves fault level management

Where next?

RESPOND

Timescales

Start:
Jan 2016

End:
Oct 2018

Project partners

SIEMENS
ABS Consulting
ABB
EPS

www.enwl.co.uk/tier1

4 Fault Current Active Management (FCAM)

4.1 Background

Historically DNO networks were designed to cater for unidirectional power flow, predicable fault current paths and predictable fault current levels. With the increasing levels of distributed generation (mostly from renewable low carbon technologies) connected to the DNO network, the system has become much more complicated, particularly for power flows and fault current levels. Generators provide an additional infeed to the network under fault conditions which leads to much larger fault currents than previously seen. This results in more areas of the network running close to or possibly beyond the designed fault current levels.

Traditional methods to overcome this problem would be to change the switchgear for that of a higher rating which increases either the cost of a connection for a generator or the DNO's reinforcement spend. Alternative methods to control fault current level are vital for DNOs to ensure that generators (mostly renewables) can be connected in a timely and cost effective manner while ensuring that the network does not become overstressed under fault conditions leading to possible asset failure.

Description of the FCAM technologies

The techniques investigated in this project are aimed at managing the breaking capacity and through fault withstand of the equipment on the network. Fault making capacity can be effectively managed through existing network operating protocols. This project identified two techniques which can be used to address the problem, namely: I_S-limiters and adaptive protection.

I_S-limiters

The I_S-limiter, manufactured by ABB, combines an extremely fast-acting switch (which can conduct a high-rated current but has a low switching capacity) and a fuse with a high breaking capacity mounted in parallel. By dividing the two functions of the switching device into two paths (ie conducting the operating current and limiting the current when a short-circuit occurs), the I_S-limiter can conduct a high operating current and limit the short circuit current before the first current peak.

The current flowing through the I_S-limiter is monitored by an electronic measuring and tripping device. In order to determine during the first rise of the short-circuit current and whether tripping of the I_S-limiter is necessary, the instantaneous current and the rate of rise of the current across the I_S-limiter are constantly measured and evaluated. If the set-point for the instantaneous current and the rate of rise of current are reached or exceeded at the same time, the I_S-limiter trips. When the I_S-limiter trips it sends a signal to the associated circuit breaker to open all three phases.

Adaptive protection

Adaptive protection is the application of alternative protection relay operating times and can be used to manage breaking capacity. These operating times can be changed in real time, based on signals from local sensors or a central control system (such as a network management system), to alter how the protection scheme operates.

Use of adaptive protection will lead to longer clearance times ie 1s rather than 0.5s but will effectively mitigate the risk associated with breaking high fault current. Owing to these increased clearance times, before deployment of this technique, it is necessary to understand the through fault withstand capability of existing switchgear and the sequence of protection needed to manage breaking capacity. The project investigated the withstand capability through testing and protection sequencing through simulation.

Figure 4.1: Normal protection operation

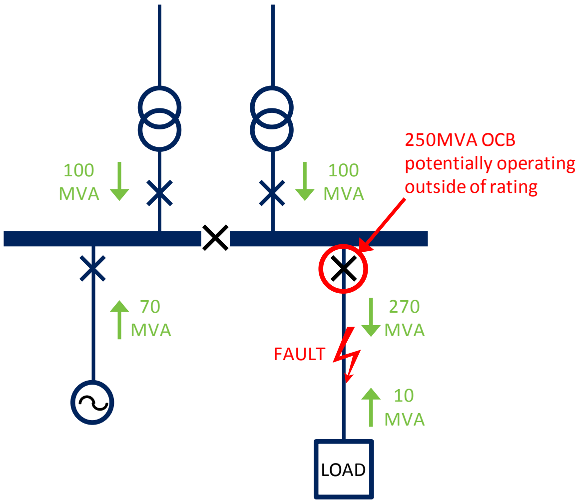
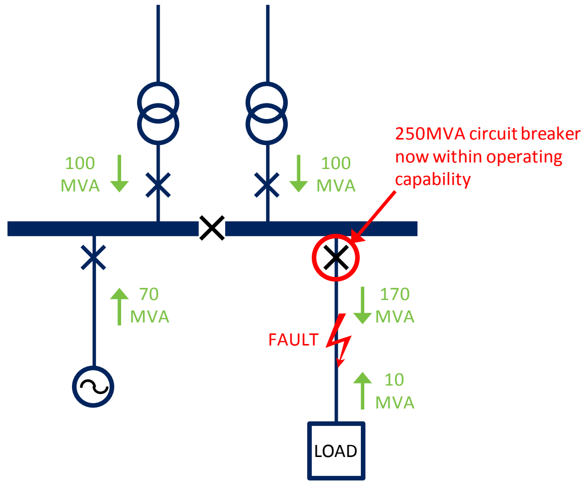


Figure 4.2: Adaptive protection operation

- Transformer circuit breaker operates first; then
- HV circuit breaker opens second



4.2 Outcome

The Fault Current Active Management (FCAM) project investigated the suitability of a range of techniques to manage fault level on the electricity network. This investigation included research, testing and simulation using independent consultants, manufacturers and universities. This work resulted in a suite of solutions which use new applications of existing commercially available technology to address fault level issues, which will directly reduce future costs for customers.

Carbon plan	
Key learning relevant to reward criteria	**Associated project details**
I_S-limiters and adaptive protection could be used to withstand breaking capacities and allow increased levels of distributed generation (mostly from low carbon technologies)	The project has successfully shown through a combination of research and simulation that I_S-limiters and adaptive protection can be used either separately or in combination to provide lower cost and reliable fault level management. The investigation into the safety case for use of I_S-limiters showed a relatively low risk for deployment but Electricity North West recognises that further work is required on the risk assessment ahead of business as usual use.

Network capacity release	
Key learning relevant to reward criteria	**Associated project details**
Studies and simulations have shown that commercially available technologies could be used to implement low cost solutions to release network capacity.	I_S-limiters can be used for managing through fault and breaking capacity issues but previous industry work revealed risks associated with the operation of the devices. FCAM reviewed the previous work and updated it with the latest ‘in service’ information. The work carried out by EPS UK, demonstrated that distribution switchgear is capable of carrying more fault current than the declared rating albeit for a much shorter time. Having this extra fault capacity will allow the use of adaptive protection with slightly longer clearance times without any adverse effect on the distribution switchgear. The Siemens investigation shows that adaptive protection can be implemented in a number of ways which vary in complexity and cost. For adaptive protection to be successful, at least one of the relays on site would need to be a modern numerical relay with the ability to be remotely switched between different protective settings.

Financial benefits	
Key learning relevant to reward criteria	**Associated project details**
Using I_S-limiters and adaptive protection can avoid the need to change the switchgear for that of a higher rating.	The project has successfully shown how low cost innovative use of existing technology (I_S-limiters and adaptive protection) can provide effective fault level management and avoid the need for equipment replacement and network reinforcement. A cost effective method to manage through fault withstand and breaking capacity is adaptive protection. Testing was successfully conducted and confirmed that the longer clearance times associated with adaptive protection did not cause any undue damage to other equipment on the network. An extension to the network adaptive protection is the disconnection of a customer's electrical equipment. The work carried out by the University of Manchester demonstrates that it is possible to disconnect an electrical equipment to provide fault level response but the protection requirements are significant. In the Respond project we are investigating the practical and commercial aspects of this form of adaptive protection, known as the Fault Current Limiting service (FCL Service).

Rollout across the DNO's system and across GB	
Key learning relevant to reward criteria	**Associated project details**
The project developed a solution that could be widely adopted across DNO networks.	The report produced by Siemens contains the appropriate information to allow DNOs to deploy adaptive protection using their existing infrastructure and design process. The methodologies in this report are not confined to Siemens relays and can be readily applied to any manufacturer's equipment. The ABB I_S-limiter is a mature product available on the open market. Using the safety case information generated by ABS Consulting will allow DNOs to decide if they wish to deploy this device on their own network. The project is considered readily replicable as it is a novel application of existing technologies freely available to all DNOs.

Portfolio management	
Key learning relevant to reward criteria	**Associated project details**
The project builds on and provides learning from/to other projects.	Other First Tier projects looking at the problem of fault level mitigation are: 33kV superconducting fault current limiter (NPG) and implementation of an active fault level management scheme (WPD). This has reinforced the need to carry out further investigations. FCAM has informed Respond about the viability of the techniques to be implemented. All of the techniques learned in this project will be deployed in the Respond project which will produce the detailed design, installation, protection setting and operational policies to alleviate fault level constraints. Respond will deploy a central control system to manage fault level, using adaptive protection, I_S-limiters and a new commercial technique.

Voltage Management on Low Voltage Busbars

This project explored the potential to use alternative technical solutions for controlling voltage on LV networks, to help manage increased load and generation by installing power quality filters, Power Perfectors, distribution transformers with on load tap changers and LV capacitors. The findings were used by the University of Manchester to model the effects of deploying this technology on our future LV network and will help us identify and assess the benefits of deploying the technology on the network.

Safety & Environment | Network Resilience | **Capacity** | **Efficiency** | Customer Service | Commercial Evolution

Benefits

- Faster LCT uptake
- Creates capacity
- Reinforcement deferral
- Improves voltages
- Easily deployable

Where next?

SMART STREET

Timescales

Start: **Jan 2014**

End: **Apr 2018**

Project partners

power Perfector (energy saving like no other) · ABB · MANCHESTER 1824 The University of Manchester · MR

www.enwl.co.uk/tier1

5 Voltage Management on LV Busbars

5.1 Background

The decarbonisation of energy production, transport and heating is expected to result in significant increases in electricity demand. As the demand on the network increases, the likelihood of supply voltages falling below acceptable thresholds becomes increasingly likely. In addition, the expected increase in domestic forms of generation such as PV, is likely to give rise to supply voltages exceeding acceptable thresholds during periods of low demand and high generation. It is expected that fluctuations in supply voltages will need to be addressed if appropriate voltage quality is to be maintained and reinforcement avoided. This project concentrated on developing innovative and economic alternatives to traditional network reinforcement which typically accompanies voltage problems on LV networks.

5.2 Description of the solution offered by Voltage Management

The project deployed a range of voltage management technologies and techniques across a number of distribution substations. We assessed these technologies in terms of their ability to effectively regulate line voltage in real time. In addition to voltage management, we also assessed the ability of compensating devices to correct for poor power factor. The project sought to develop understanding of the potential for these alternative techniques to address issues of voltage regulation on LV networks, in response to increases in low carbon loads and generation. This would then inform the development of our operating practices.

5.3 Outcome

As part of the Voltage Management project we successfully deployed the following voltage management technologies/techniques across a number of sites on our LV network:

Voltage regulation

- Two distribution transformers with on-load tap changers (OLTC)
- Two voltage optimisers (PowerPerfector Plus)

Reactive compensation

- Eight LV capacitors

Voltage quality

- Two active harmonic filters

The technologies were purchased with basic specifications which were further developed during the build, installation and commissioning phases and were installed in parallel with existing equipment to ensure a speedy changeover in the unlikely event of a failure. We developed and introduced a new set of operational procedures for these devices.

In parallel with the installation of the equipment the University of Manchester conducted modelling work on all the technologies installed as well as some not installed to assess their effectiveness at managing voltage.

The university developed sophisticated, validated network models to allow simulations to be performed. These simulations allowed us to explore a number of scenarios not possible during the trials including the effects of increasing the amount of connected PV and future load patterns.

Electrical models of all the devices deployed were developed and the monitoring data was used to verify that the models were correct. Importantly the manufacturers of the various devices supported the university in the production of these models. The university also used standard models of other voltage control devices not being deployed as part of this project (eg battery energy storage).

The remaining network capacity was calculated by running the voltage profile under different load conditions and then implementing voltage controls, such that the maximum capacity is a scenario in which the end of feeder voltage is just above the lower statutory limit. Figure 5.1 compares several different options of the voltage control equipment for one of the trial networks. This shows that the network capacity of Dunton Green substation can be increased by up to 88% depending on the voltage control option deployed.

Comparing two trial networks shows that installing capacitors or storage at Edge Green (Figure 5.2) is not as effective as Dunton Green due to different network conditions and line impedances. This project demonstrated the importance of understanding existing network conditions when choosing the appropriate voltage control devices. A distribution transformer with an OLTC option was found to be a more effective method of increasing network capability than capacitors or storage.

Figure 5.1: Dunton Green network capacities with various voltage control devices

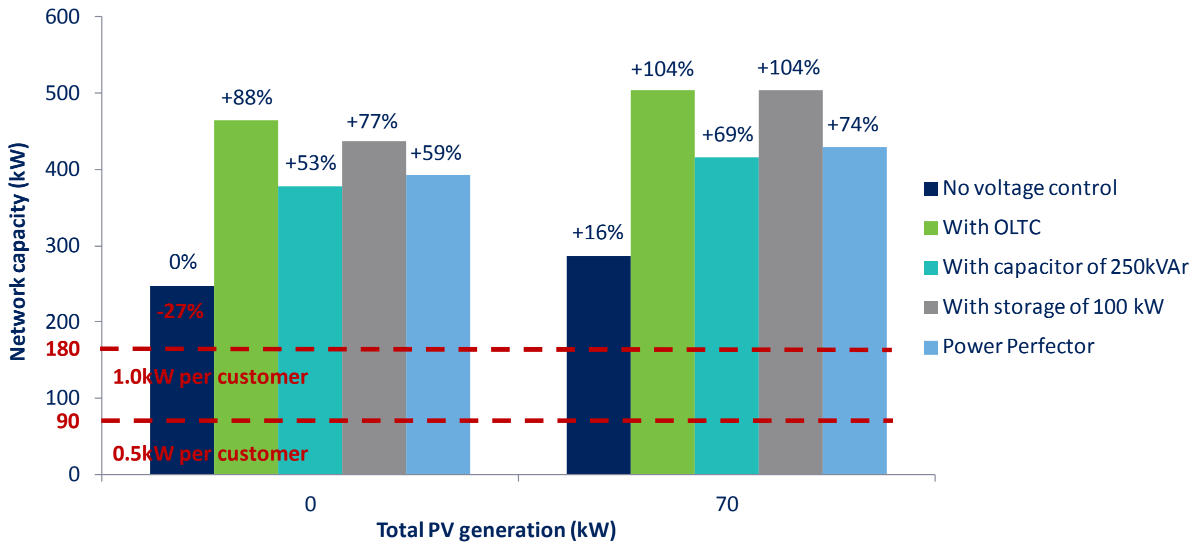
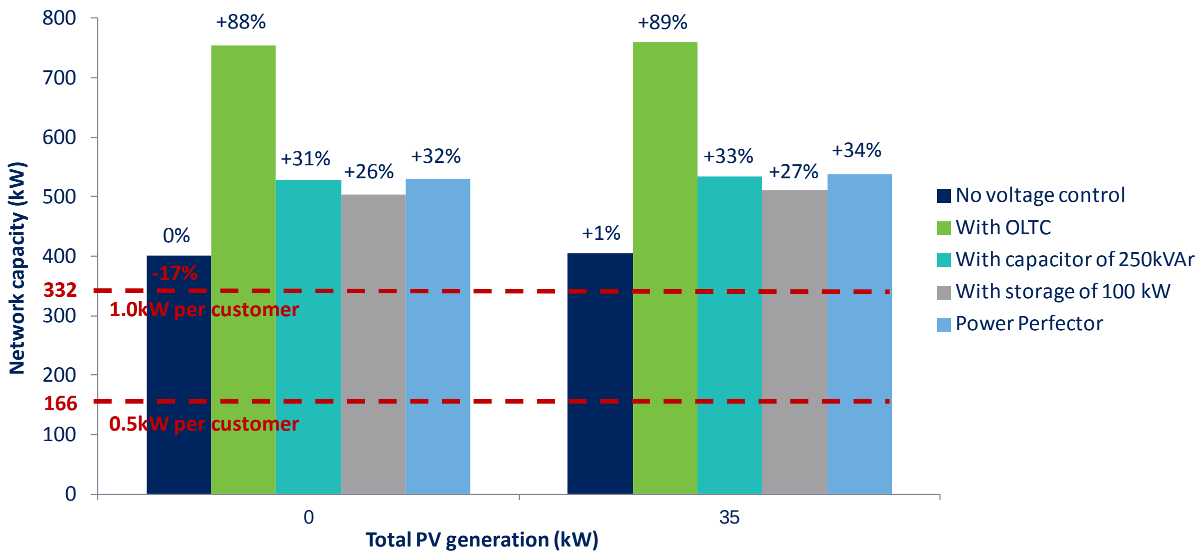


Figure 5.2: Edge Green network capacities with various voltage control devices



Carbon plan	
Key learning relevant to reward criteria	**Associated project details**
The project demonstrated techniques that could be used to effectively manage LV network voltage and facilitate connection of LCTs (renewable generation).	This project has successfully shown that through the use of techniques such as distribution transformers with an OLTC and LV capacitors, voltages can be effectively managed on the LV system to support the connection of increasing numbers of LCTs. The active filters were successfully trialled and can be used in future to reduce the level of harmonics on the LV network as and when an issue arises.

Network capacity release	
Key learning relevant to reward criteria	**Associated project details**
The project has experimented with different control approaches that could be used to control power quality and make LV network capacity available to (low carbon) loads.	The project has demonstrated that a coordinated approach to voltage control on the LV network may provide a more effective means of voltage management than the use of locally controlled devices but that both approaches offer benefits. The trials and research analysis has shown that significant capacity can be released by actively managing the voltages at distribution substations.

Financial benefits	
Key learning relevant to reward criteria	**Associated project details**
The project demonstrated that by actively managing network voltages, we can accommodate LCTs without the need for reinforcement.	The trialling of voltage management techniques in this project has shown that by actively managing voltages on the LV network, we can create both additional headroom and legroom capacity. When there is a capacity constraint caused by LCT uptake, the techniques in this project could be applied as a low cost alternative to traditional reinforcement.

Rollout across the DNO's system and across GB	
Key learning relevant to reward criteria	**Associated project details**
The project is contributing to other projects for wide scale deployment.	Wide scale deployment of the techniques and associated control systems is being trialled as part of the Second Tier project, Smart Street. We have produced and made publically available: detailed operational procedures for all devices, settings for the tap changer control relay and a specification for the LV capacitors.

Portfolio management	
Key learning relevant to reward criteria	**Associated project details**
The learning from this project is being used and integrated in other projects.	The monitoring equipment developed and installed under our LV Network Solutions First Tier project was used to support the trials and to assess the effectiveness of the equipment to manage voltages. Various trials were performed with the support of both technology suppliers and the University of Manchester to investigate the full operational range of all the devices and to record the associated network effects. The successful conclusions of this project have led us to take LV voltage control a stage further through the Low Voltage Integrated Automation (LoVIA) First Tier project. As part of Smart Street we have installed five transformers with OLTCs and 84 LV capacitors to provide voltage control as well as optimisation software linked to the NMS to control the devices.

Low Voltage Integrated Automation (LoVIA)

This project developed and trialled an integrated solution and novel application of automated voltage control of LV networks by combining existing and new equipment such as LV monitoring at mid end points of feeders, distribution transformers with on load tap changers and substation controllers. The control solution delivered regulation of network voltages based on both local and remote real time measurements.

Safety & Environment | Network Resilience | Capacity | Efficiency | Customer Service | Commercial Evolution

Benefits

- Faster LCT uptake
- Reinforcement deferral
- Improved LV network visibility
- Improved voltages
- First steps to LV network control

Where next?

SMART STREET

Timescales

Start: Jan 2014

End: Apr 2018

Project partners

GRIDKEY – UNLOCKING THE SMART GRID

Smart solutions. Strong relationships.

MANCHESTER 1824 – The University of Manchester

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6 Low Voltage Integrated Automation (LoVIA)

6.1 Background

The adoption of LCTs, at scale, can be shown to introduce significant challenges for DNOs in relation to the control of network voltages. Network analysis shows that the presence of LCTs, at scale, will result in varied voltage profiles. These varied profiles are expected to require the coordinated use of a number of different active voltage control devices. Such devices will include, but are not limited to, on-load distribution transformers and in-line voltage regulators. These devices will form an integrated voltage control platform where their action is appropriately coordinated. LoVIA demonstrated the applicability of this platform.

Description of the solution offered by LoVIA

This project developed and trialled an integrated solution and novel application of automated voltage control of LV distribution networks. The project integrated existing and new equipment such as LV monitoring at mid/end-points of feeders, distribution transformers with OLTCs and substation controllers. The integrated control solution delivered regulation of network voltages based on local and remote real-time measurements. This allowed improved control of voltage profiles and facilitated the co-ordination of voltage regulating devices.

An algorithm developed by University of Manchester (UoM) was deployed at two substations. This algorithm, which can be run at set time intervals, used the local substation and remote feeder end voltage measurements to decide if the tapchanger set-point needed to change to keep the voltages within statutory limits. UoM developed models for the two substations and associated networks to carry out a series of simulations to assess if voltage control in this form could offer advantages as the demand and generation mix changes in the future. The performance of the LoVIA control algorithm was examined by comparing it with alternative control strategies that could be used in LV networks. These alternative voltage control strategies are:

- **Off-load tap changer**: the off-load tap changer is set to tap position 4, ie, +2.5% to cope with PV systems
- **Constant set-point control (CSC)**: the voltage set-point is kept at a fixed value of 1.04pu throughout the year
- **Time-based control (TC)**: The voltage set-point is changed according to the time of the day. During minimum demand a set-point voltage of 1.03pu is used whereas during peak this value is set to 1.05pu.

Figure 6.1 shows that when there is an off-load tap changer, customers experience voltage issues from 30% of PV penetration. However, when the on-load tap changer is installed, irrespective of the control strategy, it is only after 50% of PV penetration that customers might experience voltage problems.

Figure 6.1: Customers with voltage problems – comparison (annual average)

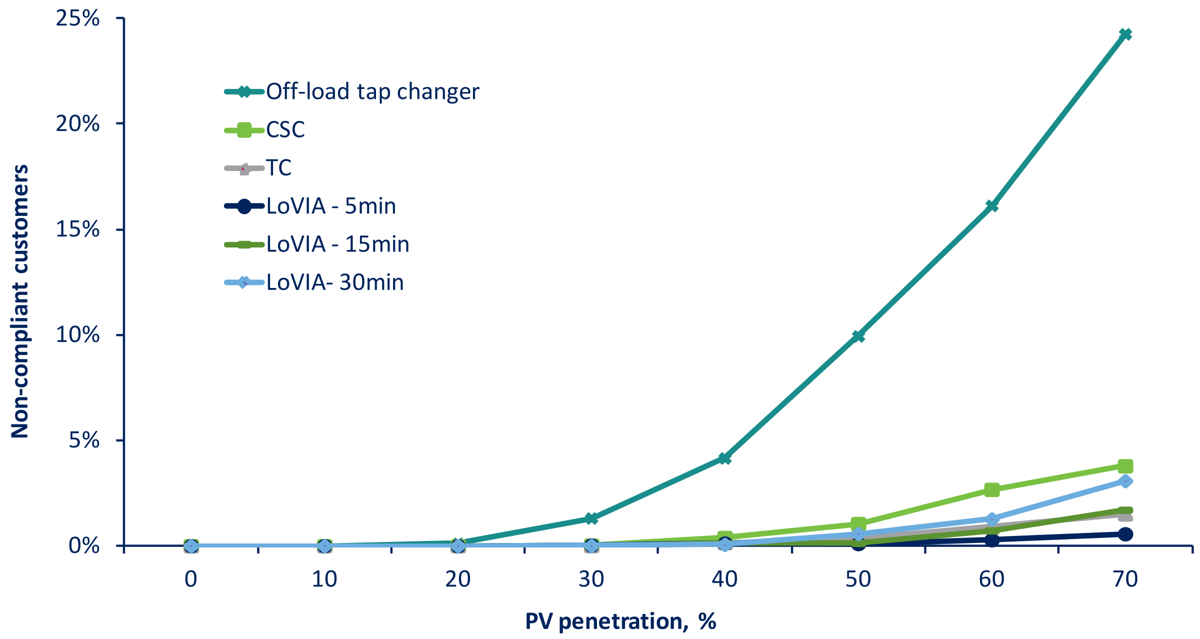
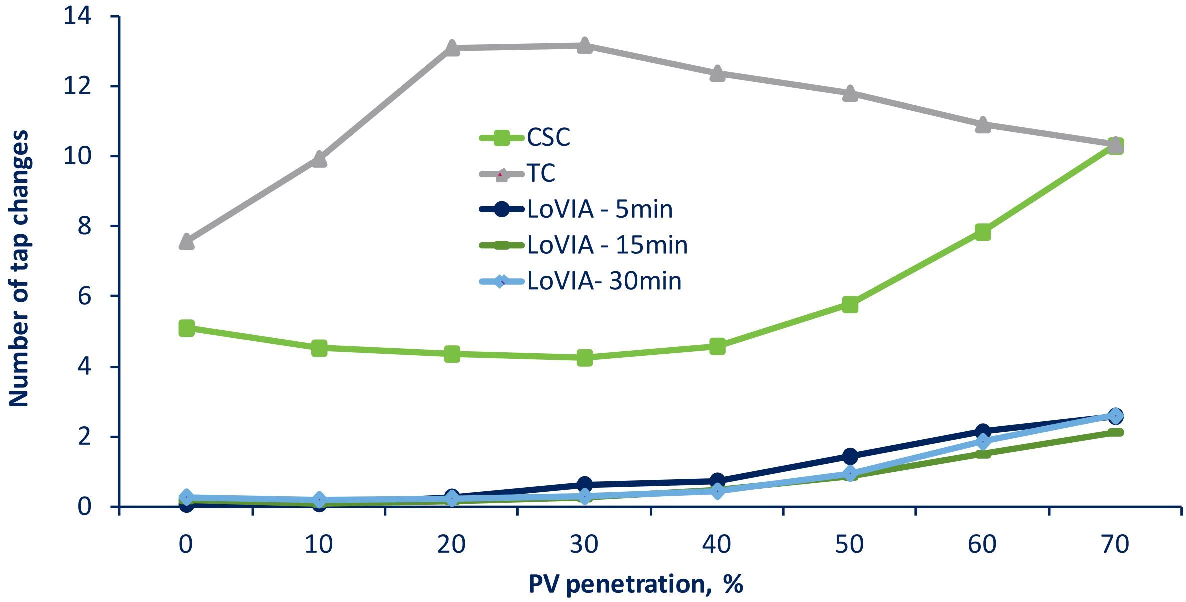


Figure 6.2 shows that although the time-based control (TC) strategy results in a better mitigation of voltage issues than constant set-point (CSC) and is comparable with the LoVIA control, this at the expense of more tap operations. Overall, the LoVIA 30-minute control strategy results in a much better mitigation of voltage issues than TC and CSC, and with only a fifth of the tap operations.

Figure 6.2: Daily average number of tap changes – comparison (annual average)



6.2 Outcome

The project successfully developed an algorithm to provide voltage control based on remote measurements. This algorithm was successfully deployed in two distribution substations which already had transformers with on load tapchangers installed. The algorithm was encoded into a CG Automation Systems UK Ltd (CG) remote terminal unit which provided the interface to the tap change control relay and the central control room.

The voltages required to drive the algorithm were measured by a GridKey monitoring unit connected to the LV cables via a smart joint which was developed in the First Tier project, Low Voltage Network Solutions.

The project also investigated various methods of communications between the devices. Following this investigation we decided to use GPRS as it proved the most reliable method.

The University of Manchester developed models for the two substations and associated networks. These models were used to carry out a series of simulations to assess the advantages of LoVIA as the demand and generation mix changes in the future.

Carbon plan	
Key learning relevant to reward criteria	**Associated project details**
The project demonstrated that coordinated voltage control systems could be used to support the connection of LCTs.	This project has successfully shown that an integrated and coordinated voltage control system can be deployed at distribution substations to provide more refined management of voltages on the LV systems to support the connection of increasing numbers of LCTs.

Network capacity release	
Key learning relevant to reward criteria	**Associated project details**
The project demonstrated that actively managing voltages can release capacity which could be used by renewable energy resources.	It was concluded that LoVIA is the best control strategy of the three investigated. However, for networks without remote monitoring, CSC and TC can still deliver benefits. DNOs can choose the most suitable control strategy depending on the characteristics of their networks and the focus of the operation, eg targeting voltage compliance or fewer tap operations. In common with other First Tier projects, LoVIA has demonstrated that actively managing voltages can release capacity which can be used for the connection of LCTs.

Financial benefits	
Key learning relevant to reward criteria	**Associated project details**
The project found an optimum cycle to manage voltage issues and reduce tap changer maintenance requirements.	The project has shown the functionality of existing technologies such as an LV monitoring system and an OLTC can be enhanced by the addition of a substation controller equipped with a control algorithm. The frequency of the control cycle has an effect on the quality of voltage delivered to the customer but this can be at the expense of tapchanger operation; ie the more frequent the control cycle, the more tap changes per day, which can lead to increased maintenance requirements. There appears to be an optimum cycle of around 30 minutes which minimises the voltage issues and tapchanger operation.

Rollout across the DNO's system and across GB	
Key learning relevant to reward criteria	**Associated project details**
The algorithm is available to other DNOs and can be implemented in other substations.	As part of this project the University of Manchester has made available the logic for the algorithm in the closedown report. This algorithm can be implemented in other manufacturers' substation controllers. We have presented this project at two Low Carbon Networks & Innovation (LCNI) annual conferences.

Other benefits	
Key learning relevant to reward criteria	**Associated project details**
Additional learning: GPRS cellular communication was considered the lowest risk and therefore was the preferred technology.	Although this project was not intended to solve communication issues, secure and reliable communication networks are required to link the various elements of the system together so that devices can exchange information and the system operate successfully. For the project, GPRS cellular communications was considered the lowest risk and therefore was the preferred technology.

Portfolio management	
Key learning relevant to reward criteria	**Associated project details**
The project enhanced existing learning from other projects and provided learning for other projects.	Under the First Tier LCN Fund projects, Voltage Management and LVNS, we had already deployed two distribution transformers with OLTCs, automatic voltage control equipment, substation monitoring and cable monitoring. LoVIA enhanced this existing equipment by deploying CG Automation Systems (CG) remote terminal units (RTUs) at the distribution stations to provide an interface to the tap change control relay and the central control room. The successful conclusions from this project have been integrated into our network as part of the Second Tier project, Smart Street, which deploys a centralised voltage control system operating on a 30 minute cycle. As part of Smart Street, we have installed five transformers with OLTCs and 84 LV capacitors to provide voltage control and optimisation software, linked to the NMS, to control the devices. We have also installed 498 WEEZAPs, 126 LYNX and 49 end-point monitors to provide voltage measurements for the control system. [A WEEZAP is a retrofit LV vacuum circuit breaker with control, protection and monitoring. It responds to transient faults in a similar way to the Smart Fuse with the added functionality that we can reclose the device. A LYNX allows us to trial meshing and unmeshing of networks.]

LV Protection and Communications (LV PAC)

This project involved the development of sophisticated LV protection algorithms to cater for faults in both radial and meshed configurations as well as coping with the changing loads associated with LCTs. The project also developed improved links to allow us to communicate directly with the WEEZAP devices and modify the protection remotely.

Safety & Environment | Network Resilience | Capacity | Efficiency | Customer Service | Commercial Evolution

Benefits

- Allows wide-scale deployment
- LV network control
- Improved LV network visibility
- Improve customer service
- Easily adopted by other DNOs

Previous project	WEEZAP IFI Project	Follow on project	SMART STREET Start: **Jan 2014** End: **Apr 2018**

Project partners

KELVATEK

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7 Low Voltage Protection and Communications (LVPaC)

7.1 Background

The introduction of LCTs such as PV has meant that LV networks have become more active with frequent changes in power flow. In order to meet the government's targets for carbon reduction, our customers will install more LCTs including HPs and EVs. As these new demand and generation technologies are connected to the network in greater penetrations, future load profiles and power flows will be dramatically different than those of today.

To meet these challenges economically DNOs will need to move to active network management techniques including network meshing. To safely achieve the significant savings offered by these techniques we will require more complicated protection techniques than those delivered by the standard BS88 fuses used in today's radial networks.

We anticipate a significant increase in meshed networks in the future to efficiently allow the connection of additional LCT loads. This will require a more complex level of protection which may include distance protection. With this additional load comes the issue of cold load pickup following an HV fault. The result of all the demand coming back on at once may result in overloaded assets. With existing fuse protection, this could result in a fuse blowing and customers experiencing a longer loss of supply.

7.2 Description of the solution offered by LVPaC

The project enabled Electricity North West and Kelvatek to successfully develop new communication and protection functionality which can be applied to the LV network. The new protection algorithms developed under LVPaC will provide protection for faults in both radial and meshed configurations as well as coping with the changing loads associated with LCTs. The project has successfully demonstrated enhanced protection functionality which can be applied to the WEEZAP devices. This enhanced functionality can provide greater protection for low level faults at the end of longer feeders and can protect against cold load pickup following a prolonged outage.

Kelvatek utilised data from field measurements together with knowledge about how protection operates at other voltage levels to develop the protection functionalities. These new algorithms were tested via simulation and field testing either on the Kelvatek test network or the Electricity North West distribution network.

The project successfully implemented DNP3 communications between the Kelvatek WEEZAP or LYNX devices and our control room management system. This communications link provides integration of the LV technologies within the supervisory control and data acquisition (SCADA) system. This facilitates the remote control of these devices along with the transfer of status and measurement data from the device to Kelvatek's server for analysis. This functionality was tested on our test NMS.

In collaboration with Electricity North West, Kelvatek had already developed an LV circuit breaker, which can be opened and closed remotely. This device may be used in the meshing of networks to support increasing demand and generation. The device was fitted with protection which replicates the BS88 fuse curves. This project developed the protection characteristics further to cater for the networks of the future. The project developed the devices to include:

- Mimic IEC fuse curves to provide better discrimination with HV devices
- Cold load pickup protection
- Fault protection during cold load pickup
- Three phases operating in ganged mode
- Additional protection to those parts of the network beyond the reach of the fuse
- Directional protection from meshed networks
- Communications protocols to establish the most appropriate for LV networks
- Communications to allow all parameters to be changed remotely as well as provide remote operation of the devices.

7.3 Outcome

The project has been instrumental in the adoption of LVPaC technologies into BAU for network monitoring and fault response. As with the Smart Fuse project, these devices are delivering positive and tangible benefits in reducing the impact of transient faults, which directly correlates to a measurable reduction in operating carbon to attend site. Capacity release opportunities resulting directly from LVPaC are being demonstrated in Smart Street. This solution is less carbon intensive than traditional approaches and is predicted to deliver an asset carbon saving of up to 93%.

LVPaC successfully delivered new communication and protection functionality which has enabled the WEEZAP and LYNX load management devices to be used in Smart Street. This project will release capacity by actively controlling voltages. The Smart Street solution is transferable to 64% of our network and 72% of GB networks, releasing capacity up to 2,985MW for Electricity North West and 39,630MW for GB.

Other benefits and additional learning were identified in this project regarding the operation of the devices and their interaction with our systems. These included:

Remote setting of trips to lockout

Initially, once the device had tripped to lockout a local reset was required. As a direct result of this project, we have made modifications which allow this to be carried out remotely from the central system using DNP3 controls and a reset command. When work is carried out on the LV network any device can be placed in the local mode to avoid remote operations occurring.

Gateway boot up time

Following a loss of power, the gateway can take up to 60 seconds to boot up and restore communications. Electricity North West has an automatic restoration programme to restore customers following a HV fault. This 60 second period can create confusion for the programme and add significantly to customer restoration times. To resolve this issue, Kelvatek has developed a battery backup for the gateway. This functionality enhancement was developed in LVPaC.

The devices used within LVPaC were developed under an IFI project. This First Tier project developed enhanced functionality for the devices which are now being used in the Second Tier project, Smart Street.

Project information has been published on the LVPaC web page and has been made available at each LCNI conference. The protection functionality developed under this project was fundamental to Smart Street, which is disseminating the associated learning through events, webinars and conferences.

Carbon plan	
Key learning relevant to reward criteria	**Associated project details**
Protection algorithms developed in this project are helping to connect new LCTs to the system.	The new protection algorithms developed under LVPaC will provide protection for faults in both radial and meshed configurations as well as coping with the changing loads associated with LCTs.
Devices are delivering tangible benefits in reducing the impact of transient faults and carbon emissions associated with them.	The devices developed in this project are delivering positive and tangible benefits in reducing the impact of transient faults, which directly correlates to a measurable reduction in operating carbon to attend site. This solution is predicted to deliver an asset carbon saving of up to 93%.

Network capacity release	
Key learning relevant to reward criteria	**Associated project details**
The learning from this project will be used in the Smart Street project, which is expected to release network capacity by actively controlling voltages.	The devices developed in this project benefit from independent operation. It was recognised that to deliver greater benefit, there was a need to develop communications, allowing remote control and enhanced protection, in order to facilitate their coordinated operation, and to cover radial and meshed configurations. Capacity release opportunities resulting directly from LVPaC will be demonstrated in Smart Street.

Financial benefits	
Key learning relevant to reward criteria	**Associated project details**
The project is facilitating low cost adoption of LCTs.	The enhanced functionality developed during this project will allow greater control on the LV network thus facilitating the low cost adoption of LCTs. It will further permit a more appropriate response for a range of faults as the network loads change.

Rollout across the DNO's system and across GB	
Key learning relevant to reward criteria	**Associated project details**
The protection algorithms and communication platform are available and applicable to all DNO networks. The Smart Street project, which derives learning from this project is transferable to 72% of GB networks.	The project successfully delivered a number of advanced protection algorithms and a communications platform for the Kelvatek devices. These algorithms are now available on the WEEZAP and LYNX platform used by all GB DNO networks. The learning from this project is also being used in the Smart Street project, which is transferable to 64% of the Electricity North West and 72% of GB networks, potentially releasing capacity up to 2,985MW for Electricity North West and 39,630MW for GB.

Other benefits	
Key learning relevant to reward criteria	**Associated project details**
The project developed protection functionality that provides protection against cold load pickup and low level faults at the end of long feeders.	The project has successfully demonstrated enhanced protection functionality which can be applied to the WEEZAP devices. This enhanced functionality can protect against cold load pickup following a prolonged outage. (Cold load pickup occurs when a cluster of heat pumps are re-energised following a prolonged supply interruption.) The enhanced functionality also offers protection against low level faults at the end of long LV feeders which are currently undetectable by fuses. This could greatly improve safety on the network.

Portfolio management	
Key learning relevant to reward criteria	**Associated project details**
The project derives learning from an IFI project and will contribute to the Second Tier LCN Fund Smart Street project.	The devices used within LVPaC were developed under an IFI project. The communications and protection developed as part of this project are being deployed as part of the Second Tier project, Smart Street. Further measurements captured as part of Smart Street will allow continued development and improvement of the protection algorithms.

Low Voltage Network Solutions (LVNS)

This project installed monitoring equipment on the LV network and the data was analysed by the University of Manchester to provide better understanding of what capacity is available on the network to accommodate LCTs. The findings from this project helped us to develop policies to monitor and manage our network in the future.

Safety & Environment | Network Resilience | Capacity | Efficiency | Customer Service | Commercial Evolution

Benefits

- First wide scale monitoring of LV networks
- First model of real LV networks
- Creates capacity
- Faster LCT uptake
- Defined specification for future LV monitoring

Previous project	Load Allocation IFI Project	Follow on project	SMART STREET
			Start: **Jan 2014** End: **Apr 2018**

Project partners

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8 Low Voltage Network Solutions (LVNS)

8.1 Background

Low voltage distribution networks in GB were created on a fit-and-forget basis, assuming that customer demands and diversity would not significantly change. There is no routine real-time monitoring of LV networks. However, as we look forward to future scenarios, where customers increasingly adopt LCTs, historic assumptions about customer behaviour may no longer be valid. Therefore, DNOs now need a better understanding and visibility of the performance of their LV networks and how that could change in the future, as customer behaviour evolves. Consequently, DNOs need to explore potential responses.

8.2 Description of the solution offered by LVNS

LV Network Solutions (LVNS) was a three-year project which aimed to:

- Trial and develop procedures to install low voltage (LV) monitoring without customer interruptions on 200 low voltage networks
- Increase understanding of current low voltage network performance
- For the monitored network, work with the University of Manchester to allow them to develop detailed electrical models to assess hosting capacity and potential network solutions under increasing penetrations of low carbon technologies (LCTs), and
- Improve existing estimates of load, and develop a tool to estimate future loads and capacity headroom across the whole LV and HV networks.

8.3 Outcome

Across the network, the project validated and improved our existing estimates of network loading and provided us with a tool to assess future capacity headroom in different scenarios.

The project produced specifications and detailed procedures for installation of LV monitoring without customer interruptions at substations. Pre-installation survey and careful attention in planning and commissioning the data collection are crucial to a smooth deployment. The Code of Practice, specification and jointing procedures are published by this project to facilitate replication by others.

As a result of the learning outcomes of LVNS, we have been able to successfully implement a streamlined approach to the connection of domestic scale PV systems to the LV network. The solution is being actively used across our region. We have established a business process supported by internal policy that provides for continued monitoring of LV networks in response to PV penetration levels. Specific actions are triggered when PV volumes are exceeded and follow up actions are performed as appropriate.

The University of Manchester built LV network models from our GIS records, with the network configurations validated by the monitoring data and made the first ever detailed assessment of the performance of the Electricity North West LV network. This evaluation covered issues such as transformer utilisation, substation busbar voltages, the voltage unbalance factor across phases, power factor, neutral currents and indicative values of total harmonic distortion.

For a sample of underground networks, they assessed voltage and thermal constraints to identify the capacity of the LV feeders to accept low carbon technologies (LCTs) such as solar PV, electric vehicles and heat pumps and made recommendations about what to monitor in future. This project has validated our connect and monitor/manage approach to PV which avoids delaying customers wishing to connect clusters of PV systems to our network.

The project also developed a specification and techniques for installation of feeder mid-point and end-point monitoring without customer interruptions, including developing a Smart Joint (Figure 8.1) to allow voltage and current to be monitored at a cable mid-point. This low cost technique has been taken forward in a separate installation programme supporting a number of other innovation and performance evaluation projects, in total delivering 200 additional monitors along 100 selected underground feeders from the monitored substations – 100 mid and 100 end-points.

The project developed a live installation approach – using Rogowski current coils and novel voltage connections enabling deployment of monitors without causing customer interruptions. A further development was made by GridKey in the form of a 'Smart Plug'. When inserting the Gridhounds current sensors (Rogowski coils) into a Smart Joint, it is possible for the jointer to install them reversed so they read negative current. Therefore GridKey developed a plug which switched the polarity and could be inserted in the roadside cabinet after the installation has been done (and the joint buried).

Figure 8.1: LV Smart Joint

LVNS used monitoring data to review, validate and improve the baseline load estimates produced by load allocation. The project also used the load allocation as a baseline to create a future capacity headroom model, to estimate thermal and voltage overloads in future scenarios of LCT uptake. This was used in the early stages of our preparation for the RIIO-ED1 Well Justified Business Plan and continues to be used to understand the scale of future interventions for load reasons on the secondary networks.

Carbon plan	
Key learning relevant to reward criteria	**Associated project details**
The project validated Electricity North West's approach to connect and monitor PV installations. The project found that for many feeders, no intervention is expected due to LCT uptake.	This project has validated our approach to connect and monitor/manage PV; this avoids delaying customers wishing to connect clusters of PV systems to our electricity network. The results of the university's multi-feeder what-if scenario analysis emphasised that although there was significant variation in the penetration of LCTs that different feeders could accept before voltage or thermal issues occur, there would be a significant number with no identified thermal or voltage issues, even at high levels of LCT penetration. For many feeders, no intervention would ever be expected to be required due to LCT uptake. The combination of these findings from the modelling and monitoring data supports our approach to move to connect and manage approach to PV clusters, in which monitoring is the first intervention to identify impacts as and when they arise, rather than proceeding directly to reinforce or use a voltage management technique. This avoids delaying connection and increasing costs to customers by performing network studies and then intervening before allowing a connection.

Network capacity release	
Key learning relevant to reward criteria	**Associated project details**
The project provided a tool to assess future capacity headroom.	The project developed our approach on how to monitor our LV networks at substations and along feeders, without customer interruptions. We applied this across 200 distribution substations to increase our understanding and visibility of how LV networks with differing characteristics perform. The project validated and improved our existing estimates of network loading. It also provided a tool to assess future capacity headroom in different scenarios.

Financial benefits	
Key learning relevant to reward criteria	**Associated project details**
The project delivered a method to reduce waiting times associated with PV connection and removed the need for expensive connection studies.	The solution delivers benefits to customers by avoiding the waiting times associated with the connection of PV systems to the LV network. We have also been able to avoid expensive and resource-intensive network connection studies, thus reducing internal costs and freeing up resource to concentrate on other parts of our connection services. In 2015-16 this solution delivered an estimated cost savings of £185k over the equivalent traditional solution cost.

Rollout across the DNO's system and across GB	
Key learning relevant to reward criteria	**Associated project details**
The technology developed in this project is available for deployment with other DNOs and industry stakeholders.	Based on the product development work conducted in collaboration with Electricity North West for the LVNS project, Gridkey entered and won the 2012 UK Energy Innovation award for the 'Best Smart Grid Technology'. This provided high-profile publicity about the trial and the benefits of the monitoring approach that we developed with Gridkey in this project. LVNS was featured in University of Manchester publications. The project learning was disseminated and is available on the LVNS webpage. In addition details of the project were presented at the LCNI annual conferences in 2011, 2012, 2013 and 2014. Regular project updates have featured in our internal magazine 'Newswire'.

Other benefits	
Key learning relevant to reward criteria	**Associated project details**
Additional learning: Harmonic distortion issues identified in association with PV.	In terms of the indicative THD assessment, the performance evaluation identified higher values of total harmonic distortion of current as being a problem associated with PV. The particular issue of current THD is being investigated further with a more robust assessment of total harmonic distortion of voltage.

Portfolio management	
Key learning relevant to reward criteria	**Associated project details**
The project has directly contributed to a number of other innovation projects.	The project has built the foundations for future deployment of LV monitoring – making significant contributions to the questions of how and when to monitor in the context of increased LCT uptake. As such, this project has directly contributed to a number of other low carbon and innovation projects at Electricity North West such as Voltage Management on Low Voltage Busbars, Low Voltage Integrated Automation, Customer Voltage & Power Quality Limits, and monitoring of heat pump installations in partnership with the Japanese New Energy Development Organisation (NEDO).

9 Portfolio Compliance

9.1 A1: Aspects of the Carbon Plan that have been facilitated

The Carbon Plan, published by the UK Government in 2011, describes the importance of moving to a low-carbon economy and sets out how the legally binding targets for the reduction of greenhouse gas emissions will be achieved. The challenges faced by electricity network operators such as Electricity North West as a result of the Carbon Plan and the UK's ongoing decarbonisation of electricity generation, heat and transport are greater than that faced by previous generations. Finding affordable solutions is important not just for our customers but for the environment and the sustainability of our business.

Below we consider the network issues addressed by our project portfolio with respect to the Carbon Plan and with evidence of the portfolio delivery.

Voltage

Relevance to the Carbon Plan: As the uptake of LCTs (both demand and generation) increases, very different voltage profiles will be experienced across the LV network at different times of the day/year and the management of these profiles can be problematic.

Projects and description of network solutions – LVNS, LoVIA, Voltage Management, LVPaC and data from the Smart Fuse project. A toolbox of techniques and demonstrations to manage voltage has been developed. One or more technologies may be required to manage the voltages. For example:

- Integrated and coordinated voltage control system for distribution substations
- Distribution transformers with on load tap changer and voltage control strategies
- Voltage optimisers
- Capacitors
- Active filters
- Enhanced protection functionality
- Network models to explore LCT scenarios.

Aspects of the Carbon Plan that have been facilitated: We have implemented a connect and manage policy which allows the connection of LCTs without significant network studies and cost. We will then monitor the LCT penetration and decide when to apply network monitoring to assess if we need to carry out any reinforcement. The outcome of these projects has provided our planning team with more solutions to new connections, thus speeding up the time to connect LCTs and avoiding network reinforcement.

Thermal

Relevance to the Carbon Plan: Rising demands means an increase in current on the network which in turn increases the operating temperature of our assets. All assets have an assigned rating related to their operating temperatures which if exceeded will cause premature aging, damage or early asset replacement. Large levels of cold load pick up, such as when an estate with HPs has power restored following a prolonged outage, can result in the operation of LV fuses removing supplies to customers.

Projects and description of network solutions: LVNS, LVPaC and LVNS developed network models to explore LCT scenarios and assess the capacity of networks to take up LCTs. The sophisticated protection algorithms developed in LVPaC cater for the 'cold load pick up problem' by modifying the protection curves.

Aspects of the Carbon Plan that have been facilitated: Our connect and manage policy as described above has been implemented. Ways to manage thermal constraints are being further explored in our Network Innovation Competition project, Celsius. We have deployed a number of devices with the cold load pickup algorithm which are enabled on our distribution network.

Transient faults

Relevance to the Carbon Plan: Improved management of transient faults could reduce CIs and CMLs and reduce carbon emissions associated with operation and maintenance activities.

Projects and description of network solutions: Smart Fuse, LVPaC. For individual transient faults, the Bidoyng Smart Fuse provides an almost instantaneous reconnection, substantially reducing the duration of supply interruptions. Analysis of network data (as recorded by the Smart Fuse) has provided a new way to identify LV transient faults. Telemetry provides the real-time status of installed units enhancing fault management capabilities, flagging if customers are off supply and allowing scheduled planned visits. The protection algorithms in the LVPaC project are helping to connect new LCTs to the system and reducing the impact of transient faults and carbon emissions.

Aspects of the Carbon Plan that have been facilitated: We have reduced unplanned work and have improved the efficiency of planned work to isolate and repair faults. The new practices (Smart Fuse and protection algorithms) and the associated Fault Support Centre have led to a direct and demonstrable reduction in operating carbon by minimising site visits.

Network control

Relevance to the Carbon Plan: Historically DNOs did not have the ability to control the low voltage network. As the network has become more active due to the adoption of LCTs, their control has become more critical and this creates the need to consider new control methods.

Projects and description of network solutions: LoVIA, Smart Fuse, Voltage Management, LVPaC. Voltage Management demonstrated the need for coordinated voltage control on LV networks. This was considered further in LoVIA, which developed a control algorithm to actively manage network voltage. Wide scale deployment of the techniques and the associated control systems is been trialled in our Smart Street project. The Smart Fuse project's data has provided new ways to identify LV transient faults and can be used for 'time-shifting' of fault repairs and reduces repair cost. LVPaC has demonstrated enhanced protection functionality to allow greater control of the LV networks and developed communications for the WEEZAP which were also applied to a LYNX device by the manufacturer. This has led to the meshing and un-meshing network trial in Smart Street.

Aspects of the Carbon Plan that have been facilitated – We have helped develop the Fault Support Centre to continuously monitor the activity of installed Smart Fuses and respond appropriately. This has led to a direct and demonstrable reduction in operating carbon when attending site. Coordinated voltage and protection control techniques facilitate the connection of LCTs and permit an efficient response for a range of faults as network loads change.

Visibility

Relevance to the Carbon Plan: With the addition of LCTs, it is important to have accurate modelling, planning, control and operation of the LV network for which network visibility is an enabler.

Projects and description of network solutions: The projects in our portfolio have all required monitoring and have successfully demonstrated a range of techniques enhancing our visibility of the LV networks.

Aspects of the Carbon Plan that have been facilitated: Better visibility of the LV network allows more accurate modelling, planning, control and operation in respect of the connection of LCTs to minimise traditional reinforcement.

Power flows

Relevance to the Carbon Plan: The increased use of LCTs will significantly change traditional power flows on the LV network. Network re-configuration and protection techniques need to become more sophisticated to manage the operation of LV networks due to the frequent changes in power flow.

Projects and description of network solutions: LVPaC. We have developed new protection algorithms and communications.

Aspects of the Carbon Plan that have been facilitated: New protection techniques improve customer experience in respect of the connection of LCTs. The learning is being used in the Second Tier Smart Street project which allows the network configuration to be changed to manage the variation in power flow.

Fault level

Relevance to the Carbon Plan: Increasing levels of distributed generation has resulted in larger fault currents than previously seen. This has resulted in some areas of our network running close to designed fault rating.

Projects and description of network solutions: FCAM. This project demonstrated that the use of I_S-limiters and adaptive protection will prevent the need to change switchgear and other equipment. The FCAM project investigated commercially available technologies to provide a low cost solution to release network capacity. This solution could be widely deployed across all DNOs.

Aspects of the Carbon Plan that have been facilitated: These technologies will allow connection of LCTs without the need for reinforcement and this is being deployed in the Second Tier Respond project where a central control system to manage fault level is being developed.

Harmonics

Relevance to the Carbon Plan: LCTs are expected to increase harmonics on the networks, which must be managed to prevent malfunctioning of the DNO's and customers' equipment.

Projects and description of network solutions: LVNS, Smart Fuse, Voltage Management. The LVNS project identified high current harmonic distortion associated with PV connections and the Smart Fuse project gathered data to support the analysis of low voltage network performance. Voltage Management trialled active filters which can be used in future as and when a harmonic issue arises to reduce the level of harmonics on the network.

Aspects of the Carbon Plan that have been facilitated: Various projects in our portfolio have gathered data about harmonics and suggested ways to manage them. Learning obtained will be used to better manage a network with high levels of LCTs.

Other network issues – fault location

During the Smart Fuse project it was recognised that the data collected by the device could be used to predict fault location prior to fuse operation. This was further investigated under an IFI project resulting in the formation of the Fault Support Centre (FSC) and the proactive management of LV faults. Following the development of these techniques this approach has been widely adopted by other DNOs.

9.2 A2: Releasing network capacity

The portfolio was developed to give increased visibility of our existing LV network and allow us to investigate solutions to release network capacity for the future. We are continuing to trial a number of these solutions in Second Tier projects. As a result of this portfolio and our Second Tier portfolio, we will be able to amend our planning policies and provide a suite of solutions to solve various constraints. To date, we have not seen the increases in demand and generation to cause the constraints and warrant the need to apply the solutions. However the learning we have gained will enable us to act swiftly if LCT clusters have a detrimental effect on the network and will result in improved network reliability to encourage adoption of LCTs.

Voltage Management Project: The Voltage Management on Low Voltage Busbars project investigated a range of voltage management technologies and techniques in terms of their ability to increase network capacity while maintaining voltage level within statutory limits. Several case studies were carried out using simulation models of six substations and associated networks. This allowed the network capacity for each to be assessed and compared, when using different voltage management techniques with increasing levels of connected PV. At some substations it was shown that the network capacity can be increased by up to 88% depending on the voltage control option deployed. The project demonstrated the importance of understanding existing network conditions when choosing the appropriate voltage control devices. A distribution transformer with an OLTC option was found to be a more effective method of increasing network capability than capacitors or storage. LoVIA enhanced the findings of the Voltage Management project to better control voltages.

Smart Fuse/Low Voltage Network Solutions (LVNS): Although the scope of the Smart Fuse and LVNS projects was not intended to investigate the release of network capacity, their findings provided far greater visibility of the low voltage network than had previously been possible. This visibility allowed us to conclude that our LV network is more robust than had previously been envisaged and could cope with the connection of more PV. This led to the introduction of our LV connect and manage policy. Figure 9.1 shows the number of PV installations that were notified to Electricity North West and the equivalent network capacity that was released in the period between 2010 and 2016 which is over 26MW in total.

Figure 9.1: PV installations and equivalent network capacity 2010 –2016

	FY2010/11	FY2011/12	FY2012/13	FY2013/14	FY2014/15	FY2015/16
No of PV installations notified to Electricity North West	892	7,514	9,184	3,689	4,630	6,695
20% are in clusters greater than 20	178	1,503	1,837	738	926	1,339
Network capacity released (kW) (assuming 4kW per installation)	**714**	**6,011**	**7,347**	**2,951**	**3,704**	**5,356**

LVPaC: provided communication and protection enhancements to the WEEZAP. This enhanced functionality allowed the controllable, configurable, retrofit vacuum switching device to be deployed as part of the Second Tier project, Smart Street. The use of this device will contribute to capacity released as part of LV network meshing.

Smart Street: predicted benefits relate to Voltage Management using the learning from LoVIA and LVPaC. Figure 9.2 shows base case cost and capacity release, derived from Appendix G2 of the Second Tier Smart Street project submission document. This project trialled technology developed in various First Tier projects across a range of 40 substations. It was assumed that 50% of reinforcement was demand-led and 50% was generation-led and that the released capacity is the same for both methods.

Figure 9.2: Smart Street capacity release and cost summary

	Smart Street technology		Traditional reinforcement	
	Cost (£m)	Capacity release (MW)	Cost (£m)	Capacity release (MW)
Generation	[redacted]	[redacted]	[redacted]	[redacted]
Demand	[redacted]	[redacted]	[redacted]	[redacted]
Total	[redacted]	[redacted]	[redacted]	[redacted]

Research revealed that this technique can be applied to 64% of LV cables in the Electricity North West area which equates to 52,137 cables. Assuming that there are four eligible LV cables at each substation we estimate that we can apply the technique to 13,034 substations. The capacity released is estimated to be 229kW at each substation. If technology was installed to cover all eligible LV feeders the total capacity release is estimated to be 2,985MW which equates to 370,000tCO2e.

FCAM: As a forerunner to the Second Tier project, Respond, FCAM assessed the feasibility of new techniques (I_S-limiters and adaptive protection) to control fault level, which are now being deployed in Respond. In FCAM, these techniques were assessed in a series of desktop exercises, simulations and tests to understand their capabilities. Figure 9.3 shows the estimates of capacity release that is expected on the high voltage network through the implementation of these technologies.

Figure 9.3: Expected capacity release on high voltage network level (MVA)

Method	2020	2030	2050
Adaptive Protection (AP)	1,117	2,604	5,796
Fault Current Limiting Service (FCL Service)	1,117	2,604	5,796
I_S-limiter (IS)	1,117	2,604	5,796

9.3 A3: Delivering financial benefits

The financial numbers for our First Tier projects and relevant Second Tier projects are discussed in the following section.

Smart Fuse: The financial model was based on actual activity levels and costs for FY11/12 vs. the cost and levels for future years. There was an initial capital cost of [redacted] to purchase the Bidoyngs and it is assumed they are replaced on a 10-year cycle. Savings have been based on reductions in CIs and CMLs and visits to site for fuse replacement. The predicted years are based on the past four years' average savings. It has been assumed that the level of faults on the network remains constant. The savings also include the estimates of annual fault restoration savings. The annual benefits for DPCR5 are shown in Figure 9.4 below. The figures for the years until 2015 have been adjusted using the RPI to show 2016/17 prices. The table also includes rollout until 2050. The NPV for the rollout of Smart Fuses for the period between 2012 and 2050 is estimated to be [redacted]. This uses a discount rate of 3.5% for the first 30 years and a discount rate of 3% for the remaining years.

Figure 9.4: Smart fuse financial model

Financial Year	2013	2014	2015	2016	2017	2018-2020	2021-2030	2031-2040	2041-2050
Cost of purchasing Bidoyngs (£k)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Annual CI savings (£k)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Annual CML saving (£k)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Annual fault restoration savings	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Net Cash Flows (£k)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]			
Annual RPI* (%)	[redacted]	[redacted]	[redacted]						
Net Cash Flows (£k) 2016/17 prices	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]			
Cumulative Savings 16/17 prices	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		

**Source:* Office of National Statistics

Note: The projections in the column 2018-20 are cumulative numbers for a three-year period and projects in columns 2021-30, 2031-40 and 2041-50 are cumulative numbers for a 10-year period.

LVNS: In order to estimate the benefits from this project, a financial model has been developed based on the actual levels of PV installed on the LV network from FY12/13 to FY15/16, followed by predictions. A summary of the model is given in Figure 9.5. We have estimated the number of PVs that are in clusters greater than 20 and less than 20 and the planning cost for the two clusters separately.

For schemes with more than 20 PV installations, a system reinforcement cost is estimated. We then determine the CI and CML costs that would be associated with outages that would have to be taken for the assumed reinforcements. We then computed the total cost of the traditional solution, which is the sum of the planning cost, reinforcement cost and CI/CML costs.

Considering the cost associated with the LVNS solution we use the same assumptions as above except for the fact that by using LVNS the planning engineer would take three hours rather than 12 hours as assumed in the traditional approach. We have estimated an LVNS solution equipment cost of [redacted] per site.

It is likely that at some point, the continuous monitoring of substations would highlight places where we would need to carry out reinforcement. We have assumed that after 2020, even after implementing the LVNS solution, 5% of the traditional reinforcements would be required and 10% of the traditional reinforcement would be required after 2030.

Finally, we compute the total cost savings by subtracting the cost of traditional solution and the cost of using LVNS. The cumulative cost savings (in 2016/17 prices) to present day is [redacted] (shown in Figure 9.5). The net present value for the solution to 2023 is [redacted].

Figure 9.5: LVNS cost benefit analysis

	2012 /13	2013 /14	2014 /15	2015 /16	2017 /20	2021 /30	2031 /40	2041 /50
No. of PV installations notified	9,184	3,689	4,630	6,695	5,973	14,168	14,875	20,990
Total traditional planning cost (£k)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Traditional reinforcement cost (£k)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Traditional CI and CML cost (£k)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total traditional cost (£k)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
LVNS planning cost (£k)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
LVNS equipment cost (£k)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
LVNS reinforcement cost (£k)						[redacted]	[redacted]	[redacted]
Total LVNS cost (£k)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Cost savings (£k)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Cumulative cost savings (£k)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Note: The projections in the column 2017-20 are cumulative numbers for a three-year period and projects in columns 2021-30, 2031-40 and 2041-50 are for cumulative numbers for a 10-year period.

Respond: Predicted benefits relate to FCAM – The financial benefits have been estimated with the following assumptions: each method is used for 100% of solutions (no mix in methods), benefits are assumed to be constant. For the FCL service the minimum cost is the protection retrofit to enable the service and the maximum value is the base case reinforcement cost. These benefits are detailed in Figure 9.6. The actual future benefit will depend on the mix of solutions required as the take up of LCTs increases.

Figure 9.6: FCAM benefit summary

Method	Method Cost £m	Base Case Cost £m	Benefit		
			2020 £m	2030 £m	2050 £m
Adaptive Protection (AP)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Fault Current Limiting service (FCL)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
I_S-limiter (I_S)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Smart Street: Predicted benefits relate to Voltage Management, LoVIA and LVPaC. Figure 9.7 shows the net financial benefit is [redacted] which equates to [redacted] per substation intervention. Research revealed that this technique can be applied to 64% of LV cables in the Electricity North West area which equates to 52,137 cables. Assuming that there are four eligible LV cables at each substation we estimate that we can apply the technique to 13,034 substations. Therefore the total benefit is estimated to be in the order of £740m if technology was installed to cover all eligible LV feeders.

Figure 9.7: Smart Street benefits summary

	Smart Street cost (£m)	Traditional cost (£m)	Net benefit (£m)
Generation	[redacted]	[redacted]	[redacted]
Demand	[redacted]	[redacted]	[redacted]
Total	[redacted]	[redacted]	[redacted]

Intellectual property

This portfolio has been conducted based on the default intellectual property rights arrangements for LCN Fund projects, whereby supporting knowledge transfer is a key aim of the fund. Potential IP generation is discussed with project partners at the outset of the project. Our approach recognised that taking the default approach to IP enabled wide knowledge transfer for the benefit of all GB electricity customers. There have been some specific instances where we negotiated discounts for successfully developed products in order to deliver the best return on investment for customers.

We worked closely with our project partners, Kelvatek, by facilitating the development and testing of the Bidoyng on our LV network which led to its ultimate rollout across the industry. Consequently, we were able to obtain additional benefits for our customers by securing commercially advantageous rates in the purchase cost of the devices for use on our network.

9.4 A4: Rollout across the DNO's system and across GB

Current use of portfolio

Figure 9.8 shows all the equipment installed on our network as a result of the First Tier Portfolio. This also includes the projects which have been transferred into the relevant Second Tier projects. The majority of the portfolio has not yet been adopted into BAU because the network is not currently subject to the constraints anticipated when demand and generation becomes more unpredictable. However, lessons learned and the developments in innovative solutions generated from this portfolio provide the solid foundations for a suite of tailored options that will allow Electricity North West and other DNOs to make the transition to smart networks, as and when problems begin to arise.

Devices that have been developed and enhanced as part of this portfolio, for example, WEEZAPs and Bidoyngs are now routinely used by Electricity North West in BAU and have been adopted by other DNOs for day-to-day network and fault management activities.

Figure 9.8: Numbers of smart equipment installations on our network

Equipment installed	LVNS	Smart Street	Voltage Manage ment	LoVIA	Smart Fuse	Respond	BAU/ Other Projects
LV substation monitoring	229						
End point monitoring	84	49					45
Mid point monitoring	88						
Transformers with OLTC		5	2				
Power Perfector			2				
LV capacitors		84	8				
PQ filters			2				
RTUs				2			
Tap change relays (AVC relay)			2				
WEEZAP		498					43
LYNX		126					
Bidoyng					200		983
I_S-limiter						2	
Relays for adaptive protection						5	

Smart Fuse: The manufacturer Kelvatek has informed us that "There are nearly 10,000 Bidoyngs currently in operation across all the DNOs, with the sale of several more thousand projected this year. All the GB DNOs are using Bidoyngs".

Future use of portfolio

Using the methodology developed in our recently completed Network Innovation Allowance (NIA) project, Demand Scenarios with Electric Heat and Commercial Capacity Scenarios, we have developed best-view peak load scenarios to 2030. Beyond 2030 to predict the demand growth we use trends consistent with the average of the National Grid Future Energy Scenarios.

Based on those assumptions, we anticipate the aggregated peak demand growth on our network in our 'best-view scenario' for BSPs and LV as illustrated in Figure 9.9. This suggests the need to accommodate around 31% additional LV peak demand (700 MW) across the network by 2050.

Figure 9.9: Peak winter load growth in best-view scenario

Year	Aggregated load of BSPs (kW)	Aggregated load growth (%)	Estimated aggregated load on LV network assets	Distribution transformer upgrades required by load growth from future capacity headroom
2016	4,427		4,955	
2020	4,543	2.6	5,084	142 (FY2023)
2030	4,927	11	5,515	413 (FY2031)
2040	5,344	21	5,981	
2050	5,797	31	6,486	1,897 (FY2051)

Even in the best view, for some LV assets actual demand growth will be lower than 31% and much higher for others eg due to clustering of LCTs and changes in customer numbers and mix per asset. For identification of the typical scale of future thermal overloads on our LV network in Figure 9.9, we used our future capacity headroom (FCH) model to capture the impact of the load scenario. This suggests 2,452 transformer changes due to load growth by 2050 in the best view. The FCH model was originally developed under LVNS, and has since been updated under NIA for continued use in business planning.

The numbers above are intended to give a sense of the scale of future intervention. Demand growth and the scale of intervention would be higher in a scenario that meets carbon reduction targets on time.

The most cost-effective intervention – traditional or otherwise – will depend on the scale of demand increase expected for a specific site. Electricity North West currently uses a 'real options' CBA model to decide between traditional reinforcement and demand response solutions for the grid and primary networks. This model is being further developed to include other solutions from our innovation portfolio and will determine the most cost effective approach to managing constraints on all our networks.

Alternative solutions

There are a number of LCN Fund projects which focused on the LV network. These were mainly aimed at improving the visibility to the DNO. Many of the projects focused on monitoring the impact of PV, due to the large volume of installations in recent years and in particular, the effect of clustered installations. The LVNS project not only monitored these networks, but also carried out modelling work, to better understand the robustness of the network to PV, in addition to HP and EV.

We investigated solutions to voltage issues caused by LCTs, such as transformers with an OLTC, capacitors and storage. In order to understand how storage can be compared to the other voltage control solutions, we modelled its use but we did not physically trial it, on the basis that there were many other LCN Fund projects trialling this technology. We expect to harness the transferred learning from other DNOs' projects, should we deploy storage techniques into BAU going forwards.

When we began to scope FCAM, we were aware of a fault level management project registered by Western Power Distribution (WPD). The WPD project was also a forerunner to their Second Tier project, FlexDGrid, which was investigating a number of fault level mitigation techniques. We decided to investigate alternative solutions to inform our Second Tier project, Respond. However, the Respond project delivery team are working with WPD to ensure that our learning is complementary and will result in a larger suite of transferable solutions that DNOs can select in different circumstances.

Similar projects

LVNS has been used purely to understand and validate the connect and manage approach to distributed generation. The Smart Fuse project looks at the development and application of Bidoyngs. FCAM informed the subsequent Respond project and Smart Street was developed from the combined learning derived from LoVIA, LVPaC and Voltage Management. The financial numbers detailed in section A3 are project specific and are not counted twice.

Exceptional knowledge dissemination

Electricity North West has captured a wealth of knowledge from delivering this portfolio of innovation projects which is of significant interest and benefit to various stakeholder groups, including other DNOs, our customers, various industry groups, political and regulatory bodies, academic institutions, innovators, partners and suppliers.

Exceptional effort has gone into disseminating the learning and benefits derived from the First Tier Portfolio. For example the Bidoyng Smart Fuse project has been effectively publicised via multiple communication channels. This has been instrumental in the positive uptake by other DNOs and the benefits derived from this project are now being felt by customers across GB.

We have taken a structured approach to dissemination and at all times keep an open door policy to anyone wishing to discuss our projects.

Exceptional dissemination activities that have taken place include:

- Electricity North West website – dedicated First Tier platform
- Published academic papers
- Presentations (internal and external eg academic institutions, industry conferences, Electricity North West internal events)
- How to videos which have led to a new method of delivering training.

Our efforts have been recognised across the industry and we have won the following awards:

- 2012 energy innovation award for the best smart grid technology for Gridkey's work on LVNS
- 2013 Energy Innovation Centre award for 'Best Innovation contributing to Customer Quality and Reliability of Supply' for Kelvatek's work on the Bidoyng

- 2013 IET awards ‘highly commended’ recognition and associated certificate for the ‘measurement in action’ category.

9.5 A5: Other benefits

While delivering this portfolio Electricity North West has developed exciting new learning detailed below.

Smart Fuse: The Smart Fuse project led to the development of the Fault Support Centre (FSC). The tangible, measurable benefits of this development in transient fault management are being demonstrated, beyond our borders, as other DNOs adopt the services of the dedicated 24-hour support centre, hosted at Kelvatek’s headquarters in Belfast. The FSC responds to all Smart Fuse operations, allowing us to make real time decisions about how to react. This ensures swift supply restoration and the efficient use of resources. The centre also uses advanced analytics to direct field teams to the optimum locations for fault repair, preventing multiple disconnections that have historically been associated with LV transient faults. This has significantly reduced CIs and CMLs and has led to improved network reliability standards, greater visibility of the characteristics of specific LV networks and ultimately raised levels of customer service. The FSC has resulted in savings in excess of two million pounds per annum.

LVNS: The LVNS project initially set out to measure voltages along the feeder using street lights, etc. It was recognised that load measurements along the feeder would improve the accuracy of the university models and this resulted in the development of a Smart Joint. This is a cable joint that contains current transformers (CTs) for current measurement, in addition to a voltage measurement point. The cables from the CTs and voltage measurement are ducted from the joint to a small roadside cabinet, which contains a data collection unit. The rollout of Smart Joints was funded using a BAU capital scheme. We have utilised Smart Joints subsequently in many other innovation projects and they are likely to play a significant role in the facilitation of the connect and manage policy for LCTs.

FCAM: FCAM led to a series of testing on secondary network switchgear to assess actual fault level capability. This proved conclusively that we could modify the fault level ratings of some equipment. We have now registered a follow up NIA project (Investigations of Switchgear Ratings) to examine a larger range of switchgear types and the possibility of assigning new ratings. The NIA project estimates benefits of one to ten million pounds.

LoVIA: As part of the LoVIA project we looked at various techniques for communication between the end of the feeders and the substation. One approach considered was power line carrier; however, this was only effective on short cables. As networks grew longer and more complicated it became increasingly difficult to transmit data accurately. While this method was discounted, the investigation provided valuable learning in demonstrating that accurate data transfer was best achieved via the mobile data 3G network. This influenced the communication platforms used to communicate network data in subsequent innovation projects, specifically Smart Street.

9.6 A6: Portfolio management

All our innovative solutions are designed, implemented and monitored through a set process. Over the years, we have identified an innovation lifecycle that is most effective in delivering benefits to our customers. As illustrated in Figure 9.10 this starts from idea generation, alignment of ideas to our innovation strategy, scoping of the project, seeking partners, delivering innovation, identifying key learning, disseminating learning to other DNOs and bringing innovation to business as usual.

Figure 9.10: Innovation lifecycle

To ensure we have a balanced portfolio of projects and are thus using our innovation resources to achieve the best overall outcomes for our customers, we have identified a number of key innovation themes which relate to these challenges and to our business plan. These themes are illustrated in Figure 9.11. Each of our projects is designed to support one or more of these themes.

Figure 9.11: Innovation themes

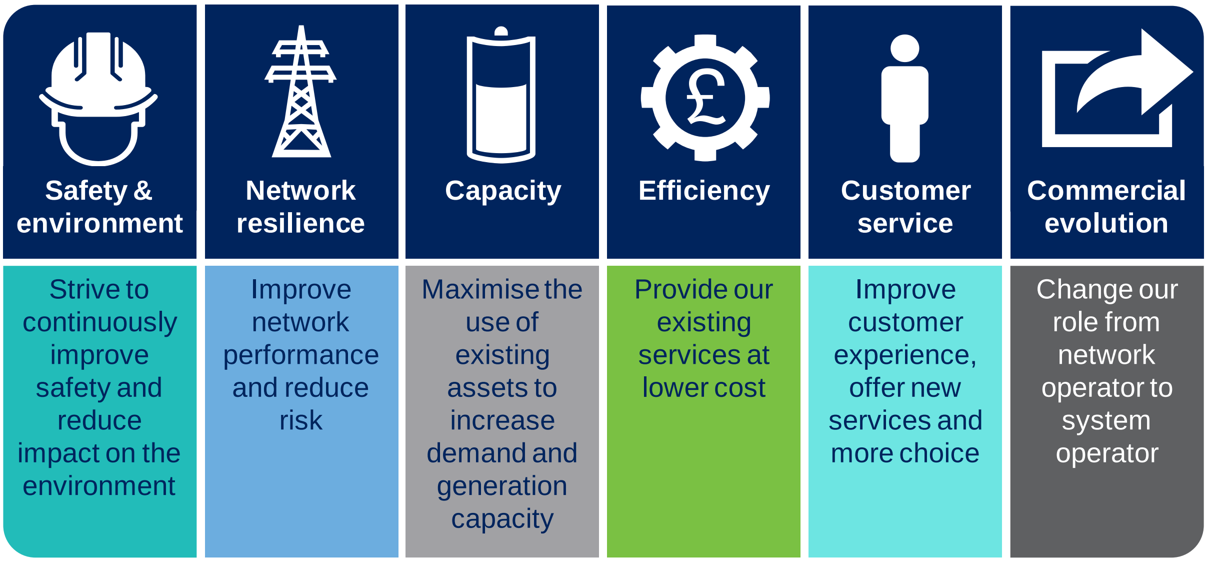
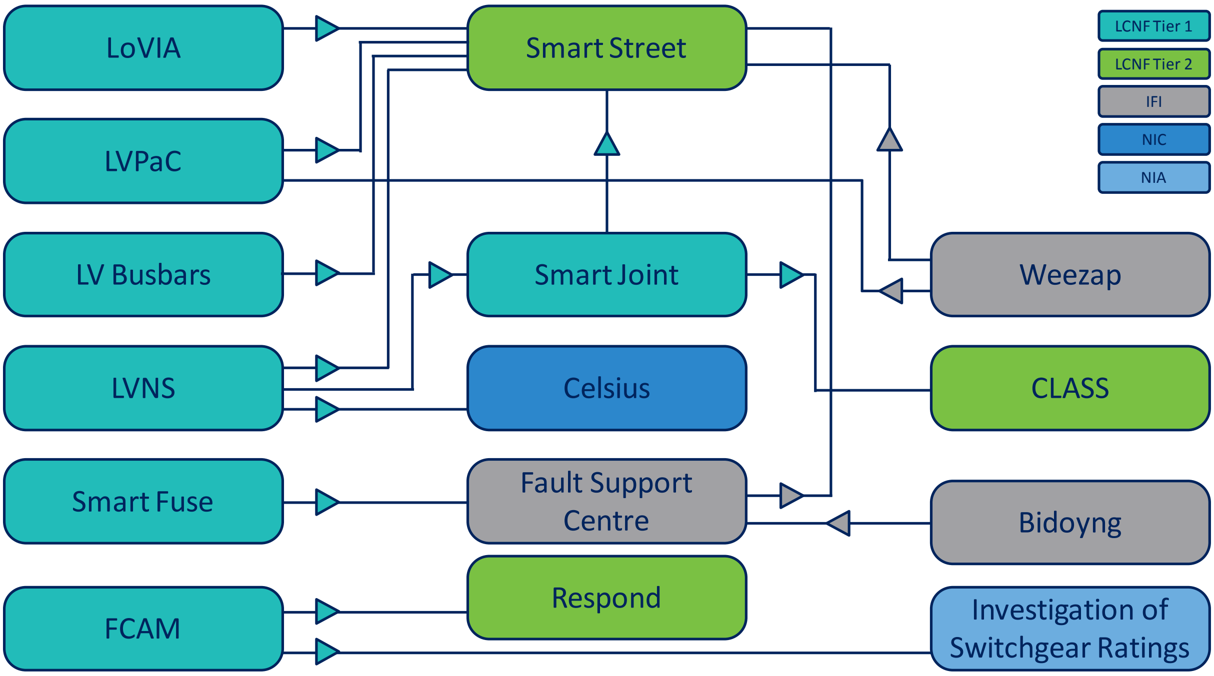


Figure 9.12 illustrates how the learning outcome of the First Tier project has facilitated (or is facilitating) larger projects within the wider portfolio of the LCN Fund.

Figure 9.12: First Tier Portfolio facilitating other innovation projects



Our LV networks are comparable to LV networks across GB. Hence the equipment, policies and procedures we have developed, trialled and implemented, are applicable to all DNOs.

9.7 Reward criterion B

We are not submitting any evidence in respect of this reward criterion.

9.8 Reward criterion C:

9.9 C1: Demonstrate where the portfolio has delivered more learning than was expected

We recognise that not all projects deliver more learning than expected; however the following projects from the portfolio have provided more learning than was expected and have benefited all GB customers.

LoVIA

LoVIA fully delivered on the criteria outlined below, the only modification being the type of RTU deployed at the distribution substation.

Successful criteria – LoVIA registration document

- Demonstrate appropriate integration and communication between low voltage monitoring systems and a distribution substation controller (ie RTU)
- Show how LoVIA can be used to control the actions of an OLTC distribution transformer to control voltage
- Show through both field trial and simulation that coordinated voltage control will help network operators manage voltages following adoption of LCTs.

More learning

The data collected in this project was used by the University of Manchester. The UoM work showed that there is a disadvantage to using multiple capacitors on the same LV network as the voltage boosts can add together which results in voltage outside limits at the busbars. The voltage rise resulting from deploying multiple capacitors on the LV network was quantified as part of the project. The results are summarised in Figure 9.13.

Figure 9.13: Rise in voltage (volts) with capacitors connected.

	Feeder with Capacitor Connected			Busbar	Feeder 1 End Point	Feeder 2 End Point	Feeder 3 End Point	Feeder 4 End Point	Feeder 5 End Point	Feeder 6 End Point
	4	5	6							
One capacitor	Yes			3.9	3.9	3.9	3.9	8.4	3.9	3.9
		Yes		3.9	3.9	3.9	3.9	3.9	7.2	3.9
			Yes	3.9	3.9	3.9	3.9	3.9	3.9	7.1
Two capacitors	Yes	Yes		7.9	7.8	7.8	7.8	12.4	11.2	7.8
	Yes		Yes	7.8	7.8	7.8	7.8	12.4	7.8	11.1
		Yes	Yes	7.9	7.8	7.9	7.8	7.8	11.2	11.1
Three capacitors	Yes	Yes	Yes	12.0	11.9	12.0	11.9	16.6	15.3	15.3

The learning here has shown that if more than one capacitor is connected a voltage rise of between 8V and 16V can be observed at various points on the LV network which can lead to issues with high volts. This learning along with that gained in Smart Street will be incorporated into future planning policy to ensure capacitors are deployed in an appropriate manner so as not to create other network issues.

LoVIA investigated the use of power line carriers which was unsuccessful. Although this project was not intended to solve communication issues, secure and reliable communication networks were required to link the various elements of the system together. It was identified in the project that GPRS cellular communication was the lowest risk mode of communication and was the preferred technology.

9.10 FCAM

FCAM successfully delivered the criteria set out below with a few modifications. At the onset of the project, expectations were that small site trials of one or more of the techniques would be performed with the aim of validating the simulations and informing practical considerations of wide scale deployment.

The initial reports received from the partners regarding the various techniques were very encouraging and we decided it was appropriate to expand the trials to form a wider scale deployment as part of a larger Second Tier LCN Fund project. The requirements of this project were thus limited to concentrate solely on simulation and risk assessment, and to inform the design of the trials in the larger Second Tier project. Respond will use a centralised software system to calculate the fault level and send instruction to enable or disable the different techniques.

Successful criteria – FCAM registration document

- Installation of fault current monitors
- Delivery of an independent risk assessment for techniques for fault current management
- Successful simulations of the new techniques
- Production of design criteria for the new techniques to control fault current level.

More learning

The learning achieved from the testing of the secondary switchgear enabled us to undertake a NIA project to test a wider range of equipment. All techniques learned in this project will be deployed in the Respond project, which is expected to produce detailed design, installation, protection setting and operational policies to alleviate fault level constraints.

9.11 Voltage Management

The Voltage Management project fully delivered on the criteria outlined below with the following modifications. An extension to the project was required due to the issue with lead times. As there was a delay in the installation of some of the technologies and the associated monitoring, the data could not be supplied to the university. This in turn had a knock-on effect on the validation of the models and subsequent scenario simulations.

The number of devices deployed and number of independent sites used differed from the project registration. The combination of devices added to the learning and allowed demonstration of feeder control in conjunction with substation control.

Successful criteria – Voltage Management registration document

- Establish learning on a range of alternative techniques for management of voltages on low voltage networks
- Deployment of new technology on the network for improved voltage regulation and measurement of the effect on voltage profiles in response to changes in demand
- Production of standard designs/applications for installation of alternative voltage management techniques
- Measurement of voltage profiles and their behaviour in relation to changes in load over the load cycle and comparison with reference networks
- Improved efficiency (ie reduction in networks losses and optimised real power distributions) on low voltage networks via improved power factor
- Improved power quality through a reduction in voltage perturbations.

More learning

The project has shown that more than one technology may be required to manage the voltages on LV feeders associated with a distribution substation. Feeders which contain more generation than demand may require a different control approach than those without generation. The issue becomes more complicated when one substation contains some feeders with significant generation and others with significant new non-diverse low carbon loads such as EVs and HPs. In these cases a capacitor could be installed to control the individual demand biased feeders while a transformer with an OLTC manages the rest of the substation which is generation biased.

9.12 LVPaC

LVPaC successfully delivered the criteria outlined below. There were no modifications to the scope or outputs of the project and all aims were achieved. During the course of this project we initiated a BAU project to implement DNP3 communications to our distribution substations. This BAU project was then able to offer efficiencies to LVPaC by including the majority of the IT element scoped as part of the First Tier spend. As a result the IT element of this project was de-scoped and these elements transferred to the BAU project.

Successful criteria – LVPaC registration document

- The project will deliver the method to calculate the settings to be applied to the different network configurations
- The project will deliver a communications system to allow these to be altered remotely.

More learning

Successful delivery of the communication was rolled out to other products in the Kelvatek portfolio. The project successfully delivered a number of advanced protection algorithms and a communications platform for the Kelvatek devices. These algorithms are now available on the WEEZAP and LYNX platforms and are applicable to all GB DNO networks.

9.13 LVNS

LVNS fully delivered on the criteria set out below, the only significant change in method being in the selection of networks to be monitored/identification of representative networks. In terms of additional benefits, the initial 25 feeder deployment of mid-point/end-point monitoring was transferred into a larger capital scheme for performance evaluation of 100 feeders (200 monitors).

The analysis of voltage and harmonics in LVNS was also further extended and provided baseline data for our IFI project 'Customer Voltage & Power Quality Limits' which reviewed a combination of quantitative network data and qualitative customer data, to understand if and when deviations cause any noticeable effects for customers. Within LVNS, the GridKey units indicated 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. THD had not been part of the core specified requirements of the LVNS project, but analysis of the THD results laid the groundwork for the capability of some of the monitoring installed in the LVNS project to be extended to voltage THD for further analysis.

Successful criteria – LVNS registration document

- Identification of a statistically meaningful sample of representative LV networks
- Establish a database of network demand and voltage profiled time series data across the selected networks including full network connectivity with MPANS
- Construct an LV/HV capacity model utilising newly obtained data and other existing data
- Establish requirements of the minimum LV instrumentation requirements needed to support future network operation, the preferred technology types and their methods of installation
- Develop options for future operating practice and control methods to help address future network requirements and the effectiveness of alternative technologies
- Validate results of other LCN Fund projects such as the WPD Second Tier low voltage template project.

More learning

During the project it was recognised that load measurement along the feeder would improve the accuracy of the university models and this resulted in the development of a smart joint. We have utilised smart joints subsequently in many other innovation projects.

9.14 Smart Fuse

The Smart Fuse project met all of its original objectives and outperformed against the original aims. There were no modifications to the scope or delivery of the project from the information provided at time of registration.

Successful criteria – Smart Fuse registration document

The specific project deliverables are:

- 65 substations with 200 Smart Fuse units installed
- Demonstration of advantages of the technology: auto-reclosing, load profiling etc
- Data to be collated and analysed and recommendations made from the data analysis
- Determining the topology of feeders on which to install Smart Fuses for maximum benefit
- Demonstration of the potential for improvements in power quality
- Demonstration of resilience improvements in vulnerable network areas (eg Consac cables areas)
- Assessment of the rules driving the intelligence and automation to determine the optimum settings
- Allow assessment of benefits of wide scale deployment of the Smart Fuse
- Capability to monitor voltage and reverse power flow caused by DG
- Determine if network reinforcement is necessary.

More learning

Information was taken from the project to feed into the development of the Fault Support Centre (FSC). This is a dedicated 24-hour support centre hosted at Kelvatek's headquarters in Belfast which actively monitors transient faults. The FSC gathers data from the Smart Fuses installed on the LV network which is then analysed to identify where to use 'fault sniffers' (devices that smell gases generated from cable faults). This enables us to detect and repair faults before they become permanent and prevent customer interruptions. The FSC benefits around 50,000 of our customers and saves £2 million a year in CIs, CMLs and guaranteed standards payments.

9.15 C2: Additional learning as a result of exceptional effort of the DNO

LVNS was a three-year project which developed procedures to install LV monitoring on 200 LV circuits without customer interruptions; and increased our understanding of current low voltage network performance. During this project, we also developed a specification and techniques for installation of feeder mid-point and end-point monitoring without customer interruptions. This included developing a Smart Joint to allow voltage and current to be monitored at a cable mid-point. This low cost technique has been taken forward in a separate installation programme supporting a number of other innovation and performance evaluation projects. In total we have delivered 200 additional monitors along 100 selected underground feeders from the monitored substations – 100 mid-points and 100 end-points.

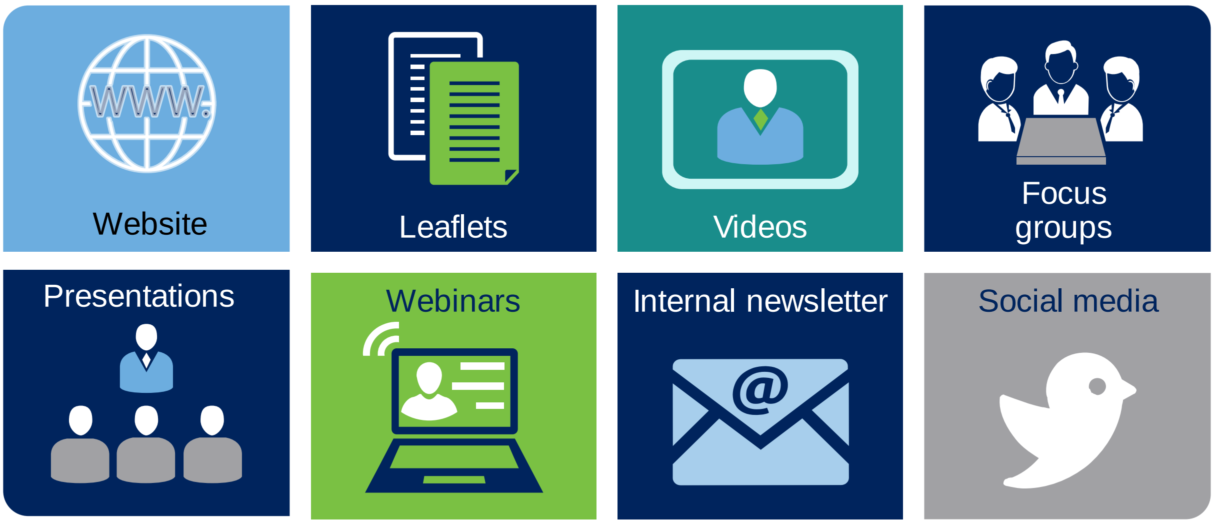
9.16 C3: Exceptional capture and dissemination of learning in a way that maximises value for all customers

Electricity North West is committed to exceptional capture and dissemination of learning through a variety of methods to suit a range of audiences. A number of audiences have been identified as key stakeholders for learning derived from our innovation projects. These consist of various industry groups and include but are not limited to Ofgem, Department of Energy and Climate Change (DECC) now Department for Business, Energy & Industrial Strategy (BIS), wider government agencies, GB DNOs, the Energy Network Association (ENA), academic institutions, Association of Electricity Producers (AEP), Citizens Advice and Smart Energy Demand Coalition (SEDC). Data collected from our projects is currently used by students and researchers in universities to develop a better understanding of electricity networks.

Other local groups are consulted, as appropriate to the projects, including local planning authorities, local enterprise partnerships, councillors, business leaders, chambers of commerce, charitable organisations and various policy makers.

We also disseminate learning internally with a focus on the new business processes and policies required for BAU adoption. Dissemination activities from all our projects reflect the diverse needs and interests of the type of audience and project as illustrated in Figure 9.14.

Figure 9.14: Dissemination channels used for First Tier projects



We have worked with universities on many of our projects in the portfolio and the students involved publish and present papers on our behalf in internal publications and at associated conferences. The First Tier Portfolio has produced a lot of monitoring data, which we make available either directly on our website or on request.

Our overriding principles are to maintain an open and transparent approach, ensure that information is easily accessible and that our dissemination methods match the needs of our stakeholders. This will maximise the learning gained by other parties to the benefit of all GB customers.

We take a proactive approach in knowledge dissemination throughout the development and delivery of our innovation projects, sharing learning at the annual Low Carbon Networks and Innovation (LCNI) conference and at many other industry events. Further knowledge transfer is delivered through our industry engagement at the ENA and the many working groups that comprise their technical and commercial portfolio.

To ensure our stakeholders receive a balanced view of our learning, our project partners, suppliers and sometimes trial customers participate in our dissemination events. We attend supplier trade conferences to explain our work and regularly hold briefings with local companies on particular techniques or technologies. Our website is the repository for sharing the learning derived from our projects.

As well as holding events, learning is shared through technology transfer. A good example of this is the product development of Bidoyngs which are now widely used in other DNOs as fault management devices.

Examples of further dissemination activities on a project by project basis are provided below.

LVNS: In order to disseminate information about this project, we produced four journal papers and 18 conference papers. To facilitate replication we have produced and are making publicly available the following documents:

- A code of practice for the installation of the monitoring equipment
- Jointing procedures and associated drawings for specific LV cable types and overhead lines
- An information-seeking (tender) specification for substation monitoring
- A formal specification for the mid/end-point monitoring equipment
- Distribution substation survey form (planning phase).

Towards the end of the LVNS project, two detailed bilateral workshops were held to enable sharing of learning in relation to WPD's LV Network Templates project and EA Technology's Transform model. After the closedown of the LVNS and Voltage Management projects, these were jointly presented at an academic event led by the University of Manchester on 3 October 2014 and at the 2014 Low Carbon Networks Fund conference.

LoVIA: In relation to this project, we produced two journal papers and five conference papers.

As a direct outcome of this project we have produced and made publicly available:

- The algorithm used to adjust the set-point, and
- A communications architecture for the LoVIA system.

Voltage Management: In relation to this project, we produced two journal/conference papers.

As a direct outcome of this project we have produced and made publicly available:

- Detailed operational procedures for all devices
- Settings for the tap change control relay (TAPCON 230)
- A specification for the LV capacitors.

Smart Fuse: To disseminate key learning from this project, we produced two journal/conference papers.

LVPaC: All of the protection algorithms and communications protocols developed as part of LVPaC will be commercially available on the WEEZAP and LYNX platforms. Any combination of the algorithms can be used to meet the individual DNO's requirements.

FCAM: Based on the learning obtained in this project, a report was developed by Siemens which contains the appropriate information to allow DNOs to deploy adaptive protection using their existing infrastructure and design processes. The methodologies in the report are not confined to Siemens relays and can be readily applied to any manufacturer's equipment.

The ABB I_S-limiter is a mature product available on the open market. Using the information from ABS Consulting will allow DNOs to decide if they wish to deploy this device on their own network.

The project is considered readily replicable as it is a novel application of existing technologies freely available to all DNOs.