Capacity to Customers Second Tier LCN Fund Project Closedown Report

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1. PROJECT BACKGROUND

As GB fulfils its decarbonisation obligations under the Climate Change Act 2008, to cut greenhouse gas emissions by 80% by 2050, the demand on electricity networks is likely to increase significantly. This increase in network demand will be driven primarily through the decarbonisation of heat, transportation and local electricity production rather than by population growth.

This has two direct consequences which will need to be resolved in order to move the UK towards a decarbonised economy. This increased network demand and the resultant direct consequences of high costs and environmental impact using traditional reinforcement methods shall be referred to as the Problem.

1.1 High costs to customers

Meeting growing demand requires additional network capacity and using traditional capital intensive reinforcement techniques would require significant investment. A 2009 Ofgem consultation document estimated that required investment in the GB transmission and distribution network could be as much as £53.4bn between 2009 and 2025. Investment requirements are driven by the current planning and design standard, Engineering Recommendation P2/6 (ER P2/6), which requires, in broad terms, that for every extra 10MW of capacity required, 20MW of infrastructure is needed. Such investment would have to be paid for by customers through higher connection and use of system charges.

1.2 Significant environmental and societal impacts

Addressing the provision of capacity using traditional reinforcement will also have a significant impact on carbon emissions and the wider society. The techniques that traditional reinforcement uses are also very intrusive for local communities and can often involve extensive excavations and disruption. Average reinforcement timescales are in the region of 12-16 weeks for work involving cable upgrades or switchgear and much longer when involving new transformers or more complicated work.

1.3 Background to the Capacity to Customers (C_2C) Trial Method

The traditional asset based approach to the provision of additional demand or generation capacity is unable to facilitate the decarbonisation of energy and transport at an affordable cost and will tend to act as a barrier to successfully achieving carbon reduction targets. The C_2C Method releases capacity through a combination of innovative network management technologies in conjunction with new customer commercial arrangements.

Current EHV and HV networks use redundancy and network interconnection to achieve security of supply standards. Network feeders are interconnected by a normally open point (NOP) which is only utilised in the event of a network fault or planned outage. It is of note that nearly half of circuits do not suffer any faults, and one third experience faults lasting 1 – 2 hours in any five-year period. Under such conditions, closing the NOP allows all customers affected by a fault outage to be re-supplied from the alternative circuit. This means EHV and HV circuits typically operate at only 50 - 60% of their rated capacity. It is this inherent capacity that the C_2C Method seeks to release for use by customers for the connection of new loads and generation.

Specifically the C_2C Method redesigns the network to allow the NOP to be run closed, allowing the whole capacity of the ring to be used by joining the two circuits. To ensure that security of customer supply is maintained and supplies can be restored during fault outages, the C_2C Method has developed and trialled new post-fault demand response contracts which will allow Electricity North West to either reduce consumption or reduce generation depending upon the nature of the post fault constraint being addressed. When a new customer connects to the network they will be offered the option to sign up to a managed contract in exchange for a reduced connection charge (equivalent to the saving of reinforcement costs). These contracts will allow Electricity North West to manage their consumption or generation at the time of a fault and ensure supplies can be restored to all other customers in the event of a fault. It is envisaged that many future customers will opt for part of their demand or generation to be managed in exchange for reduced connection charges.

The C_2C Method is highly transferable across GB and will accelerate a low carbon future by releasing a significant amount of distribution network pre-existing capacity. This capacity can be used to play a significant part in meeting the UK's carbon emission objectives.

This closedown report describes the outcomes and benefits of the C_2C Project, led by Electricity North West Limited, in conjunction with several industrial and academic partners.

2. EXECUTIVE SUMMARY

2.1 Project scope and objectives

The objective of the C_2C Project was to test a combination of enhanced automation technology, non-conventional network operational practices (ie increased network interconnection), and commercial demand side response (DSR) contracts alongside customer acceptance to such changes. These innovations were trialled on defined Trial circuits, representing approximately 10% of Electricity North West's high voltage (HV) system. The Project aimed to prove that the techniques could efficiently release inherent capacity on EHV and HV systems to accommodate future forecast increases in demand and DG, whilst avoiding (or deferring) the cost and environmental impacts that are associated with traditional network reinforcement.

In summary the Project looked to test two different elements:

- The enhanced technology used to enable the C_2C Method
- The customer engagement which facilitates the commercialisation of the Method.

Technology effectiveness

The C_2C Project examined the benefits of an alternative operating model for existing EHV and HV networks which were enhanced with modern network automation functionality. Specifically at HV, the C_2C Method closes the NOP between two adjacent HV circuits to form a closed HV ring which will in general releases the inherent capacity to customers. Existing infrastructure was retrofitted with low cost proven remote control functionality at key locations on the ring. This equipment allowed dynamic reconfiguration of the network in the event of a fault facilitating the rapid re-energisation of customers and minimising the need to activate demand and/or generation side response contracts. This capability not only reduced the incidence of DSR contract use but improved acceptability of the Method for all customers.

The release of latent network capacity through these techniques has been proven to offer significant benefits to both demand and generation customers. The increase in asset utilisation afforded by the use of this technique will also result in an associated increase in the operational complexity of the distribution network. The sophistication of the automation algorithms in a distribution network operators (DNOs) network management system requires a much more rigorous assessment of the effects of DSR connections and a better understanding of the capabilities of these new systems, as well as the acceptability of their use in securing supplies. Specifically the Project examined the benefits of an alternative operational arrangement of the existing HV network infrastructure.

A detailed description of the sequence of events that will occur in the event of a fault outage on any of the relevant network assets can be found in the fault performance white paper.

The effectiveness of the technology was trialled by installing monitoring equipment on the Trial circuits and taking real time data from the network. This allowed Electricity North West to monitor the actual performance and informed a series of network simulations and modelling exercises.

Customer engagement

To realise the capacity benefits that the C_2C Method offers requires that new and/or existing customers be willing to adopt new forms of commercial arrangements. The C_2C Method differs from traditional Demand Side Response techniques in that it allows customers to choose a form of demand and/or generation response which is only called on in the infrequent event of a fault. Demand and/or generation side response can be agreed by new customers at the time of connection or from existing customers agreeing to new commercial arrangements. The customer proposition is specific to the needs of the Industrial or Commercial customer accepting the contract.

In order to successfully trial this new arrangement extensive customer engagement was essential. All Industrial and Commercial (I&C) customers on the selected circuits were contacted directly. A simple explanation of the C_2C Project was also published and circulated to all domestic customers on the Trial circuits. Detailed customer research was carried out on a sample of customers in the Trial area to assist in understanding any relative shift in the overall customer experience and included such aspects as power quality, interruption frequency and duration. New contracts market tested for both new connection customers and for existing customers. These contracts offered significant financial benefits for customers and were much less intrusive than traditional DSR arrangements.

2.2 Project outcomes

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

- *Adaptive network control functionality:* The Trial has successfully developed an advanced network control functionality that is now available to all UK DNOs

- *Demand response commercial templates:* A series of model commercial contracts that can be used by all DNOs to extend the C_2C Method and its benefits to all DNO customers was produced
- *Customer segmentation template:* The Trial produced a customer segmentation template, describing how a DNO's customer base can be segmented and hence better approached for the introduction of demand response contracts
- *New connections process*: The Trial produced a new connections process detailing those technical and commercial steps required to extend C_2C's benefits to future customers
- *Overall customer feedback:* This included feedback from customers participating in all areas of the C_2C Project. Comments on the connections process also the form of response and feedback from customer engagement on planned interruptions and unplanned interruptions
- *Network data*: Detailed analysis of the benefits of the C_2C Method on network capacity, losses and power quality in the form of a full set of network performance data has been produced
- *Modelling/simulation outcomes:* The simulations provided a detailed economic and carbon impact assessment of the benefits of the C_2C Solution
- *New design and planning standard*: The Method represents a fundamental change in the evolution of grids from passive to active operation and Electricity North West in conjunction with PB Power have produced new operating and design standards in the form of an amendment to ETR130 which is a guidance document supporting Engineering Recommendation P2/6. This amendment was adjusted and implemented by all DNOs.

2.3 Objectives met

All SDRC's where met during the project but an extension was required to enable ten new customer contracts to be signed and full learning to be gained. The following objectives were met or proven:

- The C_2C Method will release significant capacity to customers from existing infrastructure
- The C_2C Method will enable improved utilisation of network assets through greater diversity of customers on a closed network ring
- The C_2C Method will reduce like-for-like power losses initially but this benefit will gradually erode as newly released capacity is utilised
- The C_2C Method will improve power quality resulting from stronger electrical networks.
- The C_2C Method will facilitate lower reinforcement costs for customers for the connection of new loads and generation
- The C_2C Method will facilitate a reduction in the carbon costs of network reinforcement
- The C_2C Method will effectively engage customers in a new form of demand and/ or generation side response thereby stimulating the market and promoting the future use of commercial solutions
- Interconnected C_2C operation generally releases more demand capacity than radial C_2C operation
- Use of post-fault demand response in security of supply requirements.

2.4 Objectives not met

None.

2.5 Main learning generated by the Project

The Tier 2 Project has demonstrated that the C_2C technique was technically and commercially possible as well as acceptable to a wide cross section of the I&C customer base. The customer engagement work has shown that there is an appetite in the I&C market for C_2C. Feedback from the I&C research undertaken during the Project shows that many found the C_2C concept appealing and 31% would recommend their organisation to consider opting into a C_2C contract. It was repeatedly expressed by customers that key to forming this judgement was balancing the reward offered against the notional cost as represented by their current demand. The research indicated that contracts will need to be carefully tailored to the needs of individual customers, with a range of customisable contract elements offered to make them as attractive as possible. The research explored various contract elements including: the maximum number of managed interruptions per year; the maximum cumulative interruption duration per year; the payment method; the length of contract; the number of safeguarded days; and various levels of payment. Analysis indicated that an increase in financial reward outweighs all other factors particularly the inconvenience of longer durations. It also proved that increasing the level of payment increases take up by 0.3% for every 1% increase in payment.

When customers were presented with specific examples of contracts, the duration of the contract had the biggest single influence on initial take-up. Choice of the method of payment (Pay-per-usage, fixed annual payment etc) and terms such as safeguarded days also significantly increased take-up rates. While the size of payment was the dominant factor affecting the final decision, these other components were very important in the early phase of negotiations ie without these 'comfort factors' the negotiation would terminate before it reached the price point discussion. Once the negotiation progressed to price, these other factors fell away in importance.

On the Trial circuits where the closed ring C_2C Method was deployed, the change in operating conditions did not adversely affect customer perception of service, interruption frequency or power quality. Indeed, the net change in satisfaction perception either achieves parity with the status quo or a more favourable position for all three key power quality measures: frequency, duration and dips and spikes. This finding is reinforced by the analysis of the 20 fault occurrences during the Trial, which demonstrated that when the network is configured as a closed ring, customer interruptions (CI) increased by 15% and customer minutes lost (CML) are improved by 24% respectively, compared to the radial equivalent. However the initial short duration interruptions (SDIs) are increased by 83%. Despite these changes customer satisfaction is unaffected or marginally improved.

The fault management system architecture and process designed and embedded by Electricity North West was effective in its deployment. Automatic network segregation and fault sectionalising was successfully demonstrated for faults occurring on Trial networks. Evidence of the solution's ability to prioritise and restore multiple managed customers was demonstrated through a detailed testing schedule. The direct real time management of customer loads during the Trial was successfully proven through a suite of automation solutions comprising various types of SCADA and through a range of EHV/HV/LV switches or moulded case circuit breakers (MCCB). These enabled Electricity North West to control either all or part of the customer's load in accordance with the requirements of the managed connection agreement.

Electricity North West has produced commercial templates for post-fault DSR for both demand and generation applicable to existing and new customers. These contracts are proven modifications to existing industry framework contracts and can be adopted by other DNOs. These commercial templates were successfully applied to the 20 participants who signed up during the Trial.

For the ten new connections customers, the total customer contributions for a traditional solution would have been £7.84m versus the contributions required for the C_2C Solution which totalled £0.37m. ie a saving of £7.47m for customers due to savings from the associated reinforcement. The customer types covered both demand and generation managed contracts and ranged in capacity from 500kVA to 10 500kVA.

When procuring post-fault DSR Electricity North West trialled three routes to market namely:

- DNO direct
- Use of an agent or aggregator utilising a finder's fee but using the DNO technology infrastructure and contract forms. Final contracts were bilateral between Electricity North West and the customer
- Via an aggregator using their technology infrastructure and contract forms.

DNO direct engagement was clearly demonstrated as the most effective route to market offering a significantly higher sign-up rate and lower contract cost. In addition, customers valued the strong ongoing relationship with the DNO which reinforced confidence in the Method.

2.6 Main learning derived from the Method

DNOs must innovate to meet the potential for a significant increase in future electrical demand. In meeting this challenge they must find cost-effective and environmentally acceptable solutions. It is also important that future capacity can be delivered without compromising network resilience or the security of supply. Through the course of the Project, Electricity North West has proven the potential scale of technical benefits as well as demonstrating that the Method can be economically and environmentally beneficial to customers and stakeholders.

The studies of actual C_2C Trial circuits have shown that the C_2C Method can release significant capacity for demand and DG. On average, the C_2C Method can achieve an increase in demand capacity of approximately 76%, and a 225% increase in DG, compared with defined base case scenarios. However, the results depend significantly on the individual circuit topologies, the thermal ratings of circuit sections and the exact location of the load or DG. On average, interconnected C_2C operation (with closed HV rings) releases more demand and DG capacity when compared to radial C_2C operation (with radial HV feeders).

A 'holistic' system approach is required when considering the connection of load or generation using the Method; as other technical factors (such as primary transformer ratings) or non-technical factors (such as cost-effectiveness) may affect the maximum capacity which can be released on a particular EHV/HV circuit.

The Project considered the impact of the Method on technical losses on the HV network and demonstrated that losses are normally reduced when the NOP is closed, ie if interconnected C_2C operation is adopted rather than radial C_2C operation. This reduction in losses is offset by the losses caused by the increase in demand/DG driven losses as the level of connected interruptible demand/DG increases. At the maximum levels of demand released by the C_2C Method on average the annual HV network losses are reduced by approximately 1%, as a percentage of demand. This is approximately 0.3

percentage points higher than the equivalent losses assumed from conventional reinforcement of the radial networks. However this must be offset against benefits accrued in the intervening period between introduction of C_2C and the time when the maximum C_2C capacity is reached (which would typically span many years). Extensive analysis of real network data has shown that the C_2C Method is likely to have only a marginal but beneficial impact on power quality. It has also been proven that the Method (even at the most extreme levels demand/DG capacity release) is unlikely to exceed network fault level ratings.

Exploring the various carbon impacts of the C_2C Method through a scenario based approach has revealed a number of features of the Method that may inform future deployment. The net carbon impact is idiosyncratic with respect to the circuit that C_2C may be deployed on. Embodied carbon reductions are observed in the vast majority of scenarios and circuit combinations. In cases where the C_2C Method is not able to meet all the required demand/DG growth over the studied time period, it successfully defers the timing of network reinforcement. Operations impacts arising from change in network losses are sensitive to the existing composition of the network and the operating pattern of the additional demand or generation that is to be connected. As a result the benefits are very wide ranging and must be quantified specifically. Increases in renewable distributed generation tend to reduce operations carbon impact from losses and C_2C is therefore favoured as a method for capacity release. However for the cases studied, the net impact (whether positive or negative), is typically modest at less than -15% of the equivalent traditional solution net carbon impact.

The grid emissions factor assumed for losses is a significant external factor that may alter the net impact. If a low carbon grid is assumed, for instance considering National Grid's UK Future Energy 'Gone Green' scenario, then the scale of impact and hence the possibility for gains is limited. However, if high carbon emissions are maintained, either because of failure to decarbonise the grid as a whole, or because marginal emissions continue to be met by gas power stations, then the benefits are consistently positive.

It has been demonstrated that the C_2C Method can be an attractive means to defer or even avoid costly line reinforcements and substation upgrades. From the economic perspective, both C_2C configurations (radial or interconnected) are a better option than traditional interventions, particularly when demand growth is modest (or uncertain). Both configurations can lead to significant savings from investment avoidance or deferral. From a power losses perspective, the interconnected C_2C configuration is an attractive option, particularly in scenarios where demand is expected to increase significantly. The primary factors that make the C_2C Method beneficial have been clearly identified, namely: reference demand level, substation capacity, DSR availability and capital investment costs. The inclusion of the C_2C Method within a DNO's solution set will assist the DNO in optimising overall costs and will consistently outperform traditional solutions. These conclusions are also valid for connection of DG in the distribution system.

To enable deployment of the Method in a consistent manner without compromising security of supply for customers it was necessary to develop new industry policy to define an appropriate operating risk envelope for the future operational and planning time horizons. Existing planning standards can in many situations specifically preclude the use of smart techniques, such as the C_2C Method. The need for guidance on how DSR should be accounted for within security of supply assessments was recognised within this Project. Following due consultation, changes to the guidance notes for ER P2/6 (ETR130) have been made to accommodate this form of post-fault DSR.

3. DETAILS OF THE WORK CARRIED OUT

In order to fully explore the benefits and learning outcomes associated with the C_2C Solution, the Trials and reporting were segmented into four key knowledge areas:

- Customer engagement and feedback
- Technology implementation and effectiveness
- Commercial framework for demand response services
- Evaluating the benefits of post-fault demand response.

For each of these areas the Method has been implemented and trialled dependent on the learning objectives of that area of research.

3.1 Customer engagement and feedback

The Project hypothesis related to this activity is:

The C_2C Method will effectively engage customers in a new form of demand and/ or generation side response thereby stimulating the market and promoting the future use of commercial solutions to address the Problem.

3.1.1. Engaging and understanding I&C customers

The engagement aimed to show that the Method would stimulate the demand response market and promote the future use of commercial solutions to address the Problem. The Method would be deemed effective if it could be demonstrated that Electricity North West's target customer base of I&C customers were willing and able to provide these services through a contractual arrangement.

The Trial area affected 12% of Electricity North West's customers, of which approximately 1200 are I&C customers. A bespoke mailing containing a leaflet and video were sent to all I&C customers.

To help formulate the new commercial offerings, a segmented database of the 1200 I&C customers was required. The data was gathered and collated from the Electricity North West customer data systems then cleansed and enriched using standard industrial classification codes and/or other publicly available demographic profiling data. This provided a holistic and meaningful view of the Trial area customers.

The subsequent customer research was designed to examine four key questions:

- Is there an appetite in the I&C market for C_2C?
- What is the level of interest by I&C sector?
- How does interest by sector correlate to the size of demand of that sector?
- What contract elements are required to make C_2C as attractive as possible?

Project Partner, Impact Research, an independent market research agency, targeted all I&C customers connected to the Trial circuits. A total of 180 questionnaires were completed by customers from 12 July to 10 August 2012 either through online self completion or by telephone interview. This sample size was deemed statistically robust and all analysis was significance tested at the 95% confidence level. Before completing the questionnaire, respondents reviewed a pack of briefing materials which explained the Project and its objectives. Respondents were those responsible for decision-making for their organisation's electricity supply and required an average of 30 minutes to complete the survey. A detailed summary of the research framework and pilot results can be found in the customer segmentation report.

The research methodology and sampling approach were piloted and externally validated by two independent peer reviewers, Professor Ken Willis and Frontier Economics:

- Customer Segmentation Report Peer Review
- Peer review of monitoring methodology

An additional piece of customer engagement was conducted to provide supporting evidence on the feasibility of commercialising the C_2C Method. This took the form of a customer survey targeted at I&C customers who had either signed or rejected a C_2C managed connection agreement or managed supply construction and installation agreement. The customer research was designed to answer three key questions:

- What are the key motivations for customers signing the C_2C commercial agreement?
- What are the key barriers for customers rejecting the C_2C commercial agreement?
- Are customers who sign the C_2C agreement satisfied with the commercial arrangement after acceptance?

Impact Research completed 15 quantitative interviews with customers who held senior decision-making positions in their respective organisations. A multi-mode approach was taken to administering the customer survey which offered a computer aided telephone interview or an online self-completion survey at their convenience. The question set for both survey modes was the same.

- Post-acceptance fault survey report

3.1.2 Communicating with domestic customers

To embed on-going stakeholder engagement an engaged customer panel (ECP) was formed to explore the extent to which customers understood C_2C, its benefits, any perceived barriers to its success and whether domestic customers needed to be told about it. This panel helped formulate effective communication plans and thereby helped provide relevant and clear information to affected customers.

Impact Research recruited panellists who were representative of Electricity North West's customer base with quotas set on gender, age, social grade and home ownership.

Between July 2012 and February 2013 a three-stage approach was used to gradually develop, test and evaluate communication materials. The sessions were video recorded and viewed by C_2C team observers through a one-way mirror.

In each phase of research, three 90-minute focus group discussions were run:

- *Group 1:* Carlisle, domestic customers

- *Group 2:* Manchester, domestic customers
- *Group 3:* Manchester, I&C customers

The outcome of the work was an endorsed customer leaflet that explained that work was about to be carried out to improve supplies, information on the company's priority services register, advice on what to do in a power cut and C_2C contact and website details. The findings can be found in the ECP report.

3.1.3 Monitoring the effects of demand side response on customers

The change in operating arrangements on the C_2C selected circuits could potentially increase the number of short duration interruptions experienced by all customers; as closing the NOP to form a closed ring will generally double the number of customers affected by a fault. However, importantly, the new operating regime should deliver a shorter interruption to supply than under present operating arrangements. Customer engagement was undertaken throughout the Trial period to understand any impact on the overall customer experience by measuring any effect on the perceived reliability of customers' power quality, interruption frequency and duration.

Two pieces of primary research were undertaken to examine three key questions:

- Where the C_2C Method is deployed and involves meshing the HV network, do customers report any perceived differences in their power quality or supply reliability?
- If any effects are noticed by customers, do they present a barrier to the rollout of the C_2C Method?
- Where detected by customers, do SDIs enhance perception of power quality or supply reliability?

Proactive ongoing monitoring survey

Impact Research carried out detailed customer research with a sample of domestic and I&C customers in the Trial area and a control population outside of the Trial area. This control provided a basis for measuring the relative change in perception amongst customers on C_2C Trial and non-Trial circuits. A series of classification questions were used to ensure that Trial and non-Trial respondents were demographically representative of Electricity North West's customer base and so that direct comparisons could be reliably made between the two groups.

In total, 661 quantitative computer aided telephone interviews lasting around 15 minutes were completed with domestic and I&C customers on C_2C Trial circuits (350) and domestic customers on control groups (311) across three separate phases of research: August 2013, February and August 2014. A sample size of 661 is statistically robust at an aggregated level and all analysis was significance tested at the 95% confidence level which is a market research industry standard. The findings of the survey can be found in the Power quality monitoring report. Peer reviews of the report and methodology can be found in Peer review of power quality monitoring report and Peer review of monitoring methodology.

Reactive post-fault survey

A number of unplanned supply interruptions occurred during the C_2C Project which allowed the C_2C team to prove that the network management systems operated as expected. To seek customer feedback during the Trial, a post-fault quantitative survey was carried out with customers on the Trial circuits who had experienced an unplanned outage of which some were priority service registered or eligible customers.

Every fault that occurs on the Electricity North West distribution network is unique. Surveys were therefore conducted after every fault on a C_2C circuit so that the results reported were representative of the range of faults that occur.

It was also important to contact customers as soon after the interruption as possible to increase their accurate recollection of the fault, particularly with an anticipated increase in SDIs. Therefore, all customer interviews were conducted within a maximum of five days of the fault occurring.

In total, 703 quantitative computer aided telephone interviews, lasting around ten minutes, were completed with domestic (576) and I&C customers (127) following 32 feeder faults. This was a representative sample and the survey length was sufficient to validate that the customer had noticed the fault and to ask key power quality metrics.

The research methodology and sampling approach was piloted and externally critiqued by an independent peer reviewer, Professor Ken Willis. The findings of the survey can be found in the Customer reactive post-fault survey. The peer reviews can be found in Peer review of the post fault survey methodology and Peer review of the post fault survey report.

3.2 Technology implementation and effectiveness

3.2.1 Trial area selection and deployment

To ensure that the Trial delivered results and learning that would be transferable to all UK DNOs the C_2C Method was applied to a representative range of circuits in the Trial area. In conjunction with Project

Partner PB Power, Electricity North West developed a circuit selection methodology for the Full Submission. At the time of producing the Full Submission the initial results of applying the circuit selection methodology to Electricity North West's HV circuits had reduced the circuits from 3 000 to about 400. This methodology needed to be refined and re-applied before the Trial started in order to identify the final 180 HV rings and the 20 HV radial circuits to be included in the Trial. The circuits chosen to form the HV rings were highly reliable (experiencing less than one fault every five years) and representative of over 80% of Electricity North West's circuit population. An additional 20 HV circuits were selected from the high fault rate group and operated radially during the Trial. These circuits were selected to test customers' acceptability for managed contracts across the range of circuit fault rates.

Methodologies were developed to sample different circuit types, voltage levels, customer types and circuit reliabilities. This approach generated learning across a range of network constraints that usually require reinforcement using a traditional approach, against which the C_2C Solution looks to mitigate. The methodology also aimed to capture the proactive and reactive nature of Electricity North West's management of its distribution system and customer connection applications.

The selection of circuits for the C_2C Trial was undertaken in three main stages: initial circuit screening; detailed circuit selection; and circuit simulation for refined circuit selection. To avoid any potential discrimination issues arising during the Trial, all designated circuits were selected and published from the onset.

The initial screening identified circuits with a higher likelihood of attracting C_2C connections during the Trial period. (NB this would not be required for rollout). The initial circuit screening exercise used the following criteria:

- *Circuit loading:* circuits with the highest loading were chosen since they were considered to be the most likely to require reinforcement when making demand connections
- *Connection activity:* circuits with the greatest recent connection activity were chosen since they were believed to be the most likely to attract customer connections during the Trial period.

The detailed suitability of circuits was checked by considering circuit types, the appropriateness of existing equipment for remote control, circuit topology, operation and location. Primary substations with existing hand-charge springs were originally discounted due to the possibility of decreasing customer restoration performance in the event of a fault. This could have artificially limited the possible rollout of C_2C so a decision was taken to select a number of hand-charge spring rings and run them open during the Trial. Circuits with an above average fault history were discounted from the ring selection to prevent an increase in customer fault disturbance. However, to gain an understanding of these circuits 20 were selected to form part of the Trial in a radial configuration.

Finally the operation of the closed ring with additional demand connected was simulated to identify any likely thermal, voltage or fault level issues due to the revised operating regime.

Implementation of the methodology resulted in a final circuit selection for publication in June 2012, alongside the final selection methodology and the Trial variation methodology which was required to manage any risk of customer discrimination.

This exercise was specifically undertaken for the Project. If C_2C was to be transitioned to business as usual (BAU), there would be no requirement to repeat the exercise; as the C_2C option would be considered alongside more conventional reinforcement options whenever an application for a new connection or additional load was received ie the Method will be implemented on a reactive basis as opposed to a pro-active basis.

3.2.2 Development of adaptive network control functionality

Network automation functionality

DNOs have already developed mature technology solutions for network automation using remote control switching devices as part of their strategy to deliver improvements in quality of supply to customers. The extension of this proven low cost technology was utilised in the C_2C Method.

When the Method is applied to a ring network the NOP between two adjacent HV circuits is closed to form a closed HV ring. This NOP is retro-fitted with remote control equipment. The adoption of the novel closed HV ring arrangement can potentially expose a greater number of customers to the risk of loss of supply in the event of a fault when compared to the traditional radial arrangement. This is because the size of the protected zone of network is increased when the NOP is closed. To mitigate against this the additional automation points on the ring networks were deployed to ensure that overall network performance was not comprised by adopting the Method.

The locations for additional remote control functionality on the ring networks were chosen based on an economic and RC installation assessment of the existing network to ensure that overall network reliability and service to customers was not compromised.

Network management system development

Under the Trial Electricity North West developed software tools which allow a network operator to assess and control in real-time the utilisation of DSR to manage constrained networks.

The company has developed and maintains a bespoke in-house control room management system (CRMS). To ensure the transferability of the control functionality required for the Method, GE were selected as a partner (GE provides control room systems to the majority of GB DNOs). The required real-time functionality resulted in the integration of Electricity North West's CRMS with operational applications provided by GE within their existing PowerOn Fusion™ product.

The adoption of the Method as a means of releasing capacity required minor amendments to the existing automation algorithms within the CRMS and the development of linkages to the GE systems.

The automatic restoration sequence (ARS) algorithms within CRMS were enhanced to recognise the HV closed ring network configuration – the requirement to disaggregate into radial networks following a fault and to disconnect managed loads before restoration sequences commence. Also certifying the completion of the automatic sequence switching within three minutes of the fault occurring ensures that affected customers are only likely to experience an SDI. The GE PowerOn Fusion™ product was developed to enable their automation software to offer the Method to other DNOs post-Trial.

The adaptive real time approach used in the C_2C Method requires an improved understanding of the utilisation of a network to maintain security of supply and optimise the use of demand and/ or generation side response agreements. Existing distribution power flow algorithms within GE's PowerOn Fusion™ system were used to estimate demand distributions and loadings at key network points based on known customer data and measured analogue readings. These calculations were configured to run routinely and the results made available within Electricity North West's automation systems for use in the event of a fault outage. These developments were required to augment existing automation routines and control management systems allowing the combined systems to check, as appropriate, for potential violations before automatic or manual switching is undertaken. The presence of managed customer loads on a network required a framework for their administration, control and optimisation purposes. A managed customer database mastered within the GE system was developed to log all managed loads and ensure their inclusion within the automation routines. Software algorithms were also included in the customer database to ensure compliance and optimisation of contract parameters for each managed load.

The interface between the two systems was established using a simple object access protocol (SOAP) with all network analogues and equipment status references being regularly refreshed for inclusion in the power flow analysis. The Trial area network topology and composition was translated into the open standard common information model (CIM) components which formed the basis of the power flow and optimisation models.

Automation of customers' demand

In addition to the central network control functionality and deployment of supplementary remote control at key network locations there was a requirement as part of the C_2C Method to develop a means of controlling managed customers' loads. The planned approach was to control customers' demands by installing automation. As the types of switchgear were not known before the Project started, it was necessary to develop a range of solutions that could be deployed once customers had entered into a managed connection agreement.

After signing up new managed customers to take part in the Trial it was necessary to install and commission solutions to control all or part of their demand. Due to the diverse nature of customer types and network configurations, a range of monitoring and control solutions were developed.

For EHV customers it was generally possible to use existing SCADA systems to monitor and control demand/DG but on two occasions transducers were installed to accurately measure load flows and couple this to an 'auto load reduction scheme'.

In the case of new HV installations a circuit breaker fitted with automation was installed so that load could be disconnected in the event of a loss of a cable or primary transformer. Similarly, existing installations required a retrofit actuator to be installed to either the HV or LV switch controlling the managed demand. An LV switch was developed for occasions where it was not possible to control the customer's supply by using a retrofit actuator.

A remote terminal unit (RTU) was required at each location to provide the communication link to control the actuator. Wherever possible, RTUs were installed in Electricity North West's switchroom rather than the customer's switchroom to minimise the risk of any interference.

3.3 Developing the commercial framework for post-fault demand response services

3.3.1 Commercial templates

To extend the benefits of the C_2C Method to all DNO customers, new commercial templates were required for the provision of post-fault demand side response for new and existing demand and/or generation customers. The development of these new arrangements was facilitated by a substantial customer engagement exercise during the summer of 2012 see section 3.1.1 and 4.1.1.

Having completed this detailed engagement exercise with Trial area I&C customers, the new contracts were brought to market and tested with new connection customers and existing customers. These contracts are intended to offer significant benefits for customers over traditional demand side response formats by being less intrusive and provided at lower cost.

The outcome of the survey was a substantial insight into an I&C customer's appetite for C_2C and is detailed in the customer segmentation report that was published on the Project's website in June 2012. A summary of the survey findings can also be found in section 4.1.

The survey information was a key input to the development of the C_2C commercial templates. In addition the Project's commercial manager held a series of customer focus groups and one-to-one meetings to further explore the potential motives and barriers to participation in the Trial and subsequent acceptance as BAU. This was essential to developing a commercial offering that would be attractive to potential Trial participants.

Given the feedback received, two contract options were considered:

- Refining the existing bi-lateral DSM contract already in place with customers – aggregator suggestion
- Development of a contract variation based on the National Terms of Connection Agreement/ DCUSA customer feedback – simple contract – internal suggestion.

After listening to customers' requirements for a simple contract, option 2 was chosen with a simple set of variations to the National Terms of Connection and DCUSA; as customers were already familiar with them. This approach facilitates ease of transferability to other DNOs.

Finally, to cater for demand and/or generation and new or existing customers, four permutations of contracts were considered. However, it soon became clear that only two types of managed agreement were required covering both demand and generation types, namely:

- Managed connections agreement – new customer
- Managed connections agreement – existing customer

Key features of these agreements are:

- The existing customer agreement had scope to contain contract variables that I&C customers had indicated they would find attractive namely: protected circuits; protected days; maximum number of days per annum where the managed agreement could be implemented; and contract length etc
- The new customer connection agreement could be less flexible and would essentially define network conditions where the customer would accept being managed in all cases.

These agreements were published on the Project's website in December 2012. See Appendix D for table of differences.

3.3.2 Purchase of demand response from new customers

When a new customer connects to the network they are offered the option to sign up to a managed contract in exchange for a reduced connection charge. Under the C_2C Method reinforcement of the network is avoided and therefore the reduction in connection charge is equivalent to the customer funded component of the counterfactual reinforcement costs (less the costs of putting the.C_2C arrangements in place)

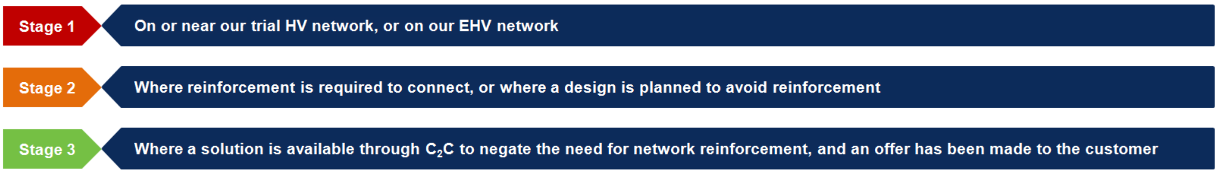
To meet the Project objective of entering into ten managed connection agreements with new connection customers, a process was established to allow the production of a parallel standard quotation (inclusive of reinforcement costs) and a C_2C quotation for generation and load enquiries over 100kVA prior to a personal presentation to the customer. Marketing, customer engagement and customer relations were managed by a small 'in-house' team enhanced by an external contractor to undertake the C_2C scheme design and estimating. A commercial manager was responsible for the managed connection agreement and the managed supply construction and installation agreement. The design, installation and commissioning of the technical solutions for the automation to control customers' loads was managed by the technical manager.

The following details how Electricity North West provided information to a customer allowing them to make an informed decision whether to opt in to the C_2C Project.

An I&C customer seeking a new connection of 100 kVA or above which requires reinforcement received a standard connection offer, in compliance with the Electricity Act, distribution licence and within Electricity (Standards of Performance) Regulations timescales. This connection offer followed the standard design process. In parallel to this the C_2C Project team assessed whether the customer was eligible for a C_2C connection offer.

For HV generation/demand schemes three stages of eligibility were identified, as outlined in Figure 1.

Figure 1: Eligibility criteria defined



A separate team was established to produce and manage the C_2C quotations to minimise the impact on guaranteed standards of performance (GSoP) standards and ensure that the BAU planning workload was not increased.

The first stage involved developing a postcode look-up tool, containing the postcodes of the geographical localities close to the selected C_2C circuits. This standalone tool was used by the clerical teams in the connections business to identify applications potentially eligible for C_2C at stage 1.

The second stage was designed to be a fully automated notification process, based on a simple questionnaire used by the connections planner while completing an engineering report within a new work management tool planned for rollout in the connections business.

Schemes which met the stage 2 criteria were subjected to a further analysis to ascertain if a C_2C solution was feasible. For the stage 3 schemes where a C_2C solution was possible an estimate of the cost of the work required was produced by the C_2C team and a quotation prepared for presentation to the customer.

The team then contacted the customer to arrange to present the C_2C solution. The presentation involved introducing and explaining the C_2C concept and included a section on the historical performance and reliability of the affected C_2C circuit.

This process ran in parallel to the standard connections design process, making both options available to the customer simultaneously, complying with published GSoP requirements.

As all EHV circuits were in scope of the Project and the number of connection applications was historically substantially lower than for HV connections, the intended process was for the EHV planning manager to notify the C_2C team of any eligible opportunities. Again, once an eligible scheme was identified the C_2C Project team presented the proposed C_2C Solution to the applicant with follow-up presentations to the end user.

3.3.3 Existing customer engagement and agreements

As part of the Trial I&C customers in the Trial area were eligible to provide post-fault demand side response in return for payments from Electricity North West. To understand the best method to market for this arrangement and the most appropriate price for the service, Electricity North West worked in conjunction with Project Partners, EnerNOC, Flexitricity and npower. It was the role of Electricity North West and the aggregator Partners to achieve ten managed agreements from existing customers in the Trial area. At the same time the process tested the difference between direct customer contact and a supplier relationship, and informed the price at which existing customers are willing to engage.

Pricing model

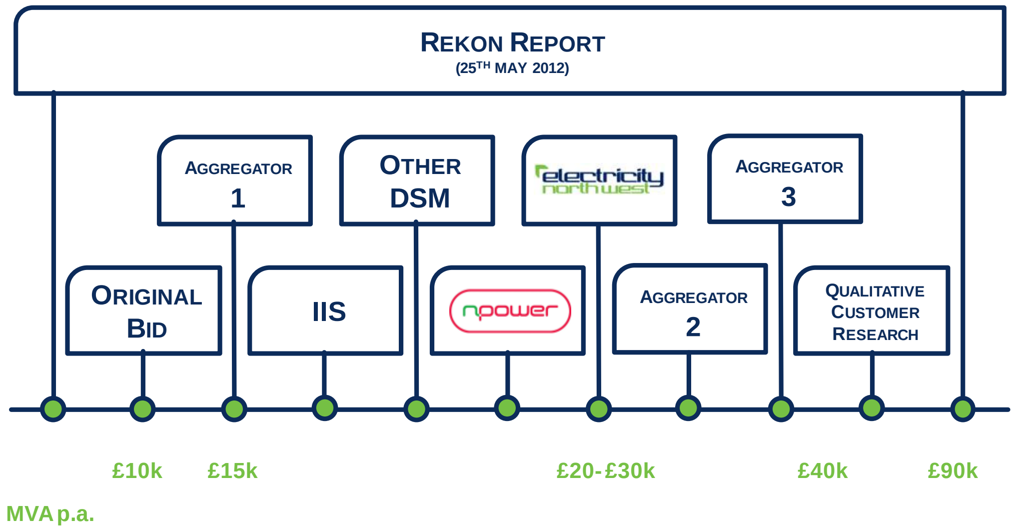
Before engaging with I&C customers on the purchase of post-fault demand response the C_2C team needed to estimate price levels and costs. This included incentive payments to customers for providing post-fault DSR and the fees/costs associated with securing the agreements eg the internal overhead or commission to aggregators or agents.

In November 2012, the C_2C commercial manager held numerous meetings with Project Partners Enernoc, npower and Flexitricity and other suppliers of similar services such as Kiwi Power. Other external expertise included Baringa Redpoint, Frontier Economics and Rekon Report (2012).

From meetings held with aggregators in November and December 2012, it became apparent that there was no common opinion on either the price level for successful customer engagement or commission levels required by the aggregators.

Figure 2 below shows the spread of estimated costs of post-fault DSR. The range extended from £10k to £90k per MVA per annum. In addition, the estimated commission fees also varied significantly.

Figure 2: Price variation



In December 2012, following the assessment of projected commission levels and set-up costs, the C_2C Project team determined that a competitive tender would be the most appropriate method to determine the level of cost for this service. The tender process resulted in a number of innovative proposals. For example the incentivisation model proposed by Kiwi Power, whereby the aggregator receives a higher commission level by outperforming on the cost to sign up customers. This was subsequently built into the awarded contract.

Introducing competition to the market

Engagement with aggregators was required to secure ten existing customer agreements with a budget of £300 000. The original plan was that Flexitricity and Enernoc would carry out this activity supported by npower. However, Enernoc declined to participate in the tender process due to a change in their strategic direction and UK presence.

The tender process was run in January 2013 with the aim of allowing the contract to start on 1 February 2013. The following key performance indicators were built into the contract:

- 1 July 2013 – two customer contracts completed
- 1 October 2013 – an additional four customer contracts completed
- 1 January 2014 – an additional three customer contracts completed
- 1 March 2014 – an additional one customer contracts completed.

Ten contracts were to be sold by the successful bidder on behalf of Electricity North West based on a price model and template contract issued by Electricity North West.

As part of the tender process, companies were asked questions that explored financial aspects ie their proposed costs to purchase the contracts on behalf of Electricity North West and also non-financial aspects such as company background, relevant experience and a description of their proposed method of providing the services. npower scored highest on both financial and non-financial criteria.

The contract was awarded to npower on 1 February 2013, allowing them six months to sign up the first two 'existing' customers and 13 months to sign all ten. To test the alternate routes to market such as direct and via an aggregator, Electricity North West maintained plans to secure agreements with existing customers for these two routes. In the best case, this would have resulted in exceeding the target of ten agreements, or alternatively the plan provided contingency should npower fail to secure ten agreements.

From the analysis undertaken the most likely range of costs was estimated to be £10k-£30k per MVA per annum. Electricity North West decided a contractual 'target cost' of £20k per annum/MVA, at which point npower would be paid between 7.5-10% commission. If npower secured agreements for less, then a higher fee was paid. Conversely if they paid more a lower fee was paid. A cap of £30k per MVA per annum was introduced which represented the maximum that npower could offer. The contract with npower was based on the commission model (see Appendix B) with a mid-point target of £20k/MVA pa. In addition to the commission levels there was a £9250 set up fee and £190 per customer finder's fee.

By entering into a contract for the provision of DSR managed agreements, key performance milestones were agreed, which acted as an additional motivation for npower to complete the task without undue delay. The contract also allowed Electricity North West to purchase DSR directly if a KPI was not achieved.

3.4 Evaluating and enabling the benefits of post-fault demand response

3.4.1 Network performance modelling

Quantifying the technical performance envelope of C_2C Method was essential to understand the long-term potential of the Solution when deployed on typical distribution networks. Specifically analysis of the impact of C_2C operation on available demand capacity, DG capacity, electrical losses, power quality and fault levels was considered. During the course of the C_2C Project Electricity North West in partnership with the University of Strathclyde generated data and developed representative simulation models of the Trial networks to understand the theoretical maximum limits and effects of C_2C operation on the aforementioned criteria. System studies were performed to establish the performance of the network under present and future scenarios. Particular attention was given to quantifying the benefits of interconnected (closed-ring) HV network operation over conventional radial (open-ring) operation.

The detailed studies and findings can be found in the Technical performance report.

Impact of C_2C Method on available demand and generation capacity

A methodology for determining the network demand or generation capacity limits for a defined base case scenario and for C_2C network operation was established. This analysed the results, benefits, and impact that C_2C operation could bring to the HV network in terms of extra capacity released for the connection of new demand/DG. It was important to understand the typical performance of HV circuits without C_2C operation, ie without interruptible load and without closed ring operation, which forms the base case scenario. Hence, the relative performance of C_2C operation – in terms of additional capacity released – was quantified in comparison to this defined base case for a number of scenarios.

The capacity improvement for a selection of Trial area circuits, relative to the defined base case, was determined for both radial C_2C operation and for interconnected C_2C operation, ie the effects of operating the network with a closed ring have been evaluated. Two complementary approaches for determining the capacity range which is released by C_2C operation were used for each circuit: uniform demand growth at existing network locations, and non-uniform 'point' loads at specific circuit locations.

Impact of C_2C Method on network utilisation

The interconnected permutation of the C_2C Method has the potential to increase the diversity of demand connected to a ring circuit, ie the demand profile over time on feeder A may tend to complement – rather than coincide with – the demand on feeder B, yielding further capacity headroom within the ring circuit.

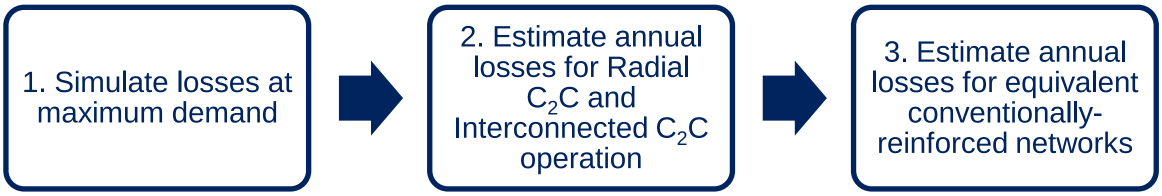
In order to assess the potential to improve the utilisation of existing assets by deploying the C_2C Method, the peak aggregate demand on a selection of Trial circuits was compared to the sum of individual peak demands. It was concluded that a demand diversity factor value of 1 is the worst case, indicating that the individual feeder peak demands tend to coincide. A value of 2 is the theoretical best case, indicating that the feeder peak demand values are similar, but the feeder demands are 'fully' diverse (which is obviously not likely in practice).

Impact of C_2C operation on HV network technical losses

The inclusion of interruptible demand and adoption of new operational configuration in the form of interconnected networks will both have an effect on the losses profile of networks on which they are deployed. Analysis was required to distinguish between the effects of additional demand and interconnected network operation. In addition C_2C operation needed to be compared to conventional reinforcement of HV radial networks, which would normally be required to connect the additional demand and DG connections. Only technical losses resulting from power dissipation in HV network conductors were analysed; transformer fixed losses and non-technical losses (eg from theft or metering inaccuracies) were not taken into consideration.

The methodology for defining the base case firm capacity and the relative capacity improvements associated with radial C_2C and interconnected C_2C configurations is detailed above. All resultant losses analysis relate to the losses incurred up to the maximum demand which can be released by the C_2C Method and is therefore compared up to the 'at limit' scenario at a specific point in the future.

The annual losses for C_2C network operation for the selected C_2C Trial circuits have been evaluated using the following process:



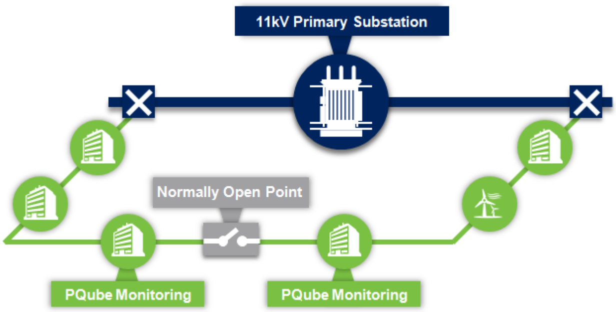
- Simulation of the peak losses for each of the modelled C_2C Trial circuits was conducted. In order to determine the worst case losses for C_2C operation, the lower maximum demand released by either radial or interconnected C_2C operation for each circuit was considered. It was assumed that interruptible demand would grow uniformly at existing locations up to the maximum demand level. Losses were always calculated for system intact conditions
- Estimation of annual losses for radial C_2C and interconnected C_2C operation, using the simulated peak losses and historical demand data
- Estimation of the annual losses in a reinforced radial system supplying the 'maximum C_2C demand'. Ie for a fair comparison with C_2C losses, the system is considered to be reinforced to support at least the same level of demand as C_2C.

Impact of C_2C operation on power quality

The adoption of HV closed rings is expected to improve overall power quality and result in optimal power flows and thus improve overall like-for-like power efficiencies across the relevant networks. The improvement in power quality is a potential additional benefit in enabling future loads and generation types such as wind and PV to connect to the network as these loads tend to degrade overall power quality.

Using power quality monitoring data collected during the Trial, several measured system parameters were compared to ascertain any differences that are apparent as a result of operating in either radial C_2C mode or interconnected C_2C. Therefore, the effects of C_2C operation on power quality have been quantified. The analysis focused on quantifying the effects of interconnected operation (as opposed to radial operation) on RMS voltage, voltage harmonics and flicker. Effects on power quality due to future additional demand or generation accommodated by C_2C operation were not included in the analysis as this is inherent to the type of new demand or generation and at this stage cannot be specified.

'PQube' power quality monitoring devices were installed in 77 secondary substations on 36 C_2C Trial ring circuits, with at least two PQube devices located per ring circuit (ie at least one PQube per radial feeder which are interconnected to form a ring). All PQube devices were connected at LV in a substation relatively close to the NOP. During the C_2C Trial, the NOP for each ring circuit had been periodically opened or closed such that measurements have been made for both radial C_2C and interconnected C_2C modes of operation, with at least seven days of data from each mode of operation, to capture an acceptable range of loading conditions required for analysis.



It was critical to validate the monitoring data so that any conclusions drawn from the measurements were sound and fair. Therefore to analyse the effects, if any, of interconnected operation on power quality, a log of NOP statuses was examined for occurrences of NOP state changes. 'Valid' events were extracted where the state of the NOP was consistent for one week before and one week after the NOP state change.

The data from all valid events were used to numerically analyse the difference between radial C_2C and interconnected C_2C operation. The analysis method involved the following steps:

- Elimination of monitoring locations for NOP state change events where the mean difference in demand between the two weeks to be compared was greater than 5%
- Extraction of the per-phase monitoring data for each valid monitoring location. Each phase was treated independently in the analysis
- Quantification of the extent of the change, if any, for each power quality metric.

3.4.2 Economic and carbon modelling

The Project has informed the development of carbon and economic models which allow a DNO to assess the impacts of the C_2C Solution from a carbon saving and financial planning perspective on its own network.

Carbon impact assessment

The C_2C Solution releases latent interruptible capacity with a lower requirement for assets than traditional reinforcement. It was also proposed that by releasing capacity quicker due to fewer requirements for planning and groundwork's, that the C_2C Solution will facilitate emissions savings from other low carbon technologies such as heat pumps and renewable electricity generation.

The Carbon impact assessment work, delivered by the Tyndall Centre for Climate Change Research, University of Manchester, sought to test the hypothesis *'The C_2C Method will facilitate a reduction in the carbon costs of network reinforcement.'* Modelling and assessment of the potential carbon reduction capability associated with the C_2C Method was undertaken to evaluate this hypothesis.

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

Firstly the Tyndall Centre examined the academic literature on the environmental impact of electricity networks. There is little existing literature on distribution networks directly but insights can be drawn from studies of transmission systems. The review highlighted that, as the C_2C Method has multiple consequences in terms of assets, for operation of the network and facilitation of new connections, it is important to consider each aspect independently across the Electricity North West network. Also the importance of grid decarbonisation in the relative balance between impacts embodied in assets and those arising from losses is seen in a number of papers, with the compounding issue of marginal grid emissions factor also noted. This suggested that a scenario or sensitivity exercise would be important.

High level methodology and rationale

With consideration of the literature review, the work package progressed to look at a suitable methodology for assessment. The starting point was to evaluate the approaches to carbon accounting, specifically considering the concept of life cycle assessment (LCA). A life cycle greenhouse gas (GHG) assessment or carbon impact assessment (CIA) is a restricted type of LCA that considers GHG pollutants as the sole impact category. Consistency in setting study boundaries and the choice of functional unit allows for a fair comparison between multiple ways of delivering comparable goods or services and for this reason the LCA was chosen as the most appropriate means of evaluating the C_2C Method. Typical LCAs are static representations of systems. However, there is a reasonable expectation that the UK energy system will change substantially over the lifespan of the assets involved (DECC 2011). Electricity generation is expected to move from high carbon fossil fuels to low carbon renewable and nuclear sources. A more dynamic approach considering year-on-year changes in the system will therefore have to be used to reasonably assess the consequences of the two alternative approaches to distribution network management. In summary the carbon impact of the C_2C Solution was determined against the traditional means of achieving new network capacity using a project carbon accounting approach with streamlined life cycle assessment (LCA) considering only greenhouse gas emissions.

Work continued by determining the best approach to quantifying the grid emissions factor. However, while a grid average emissions factor is appropriate for reporting emissions associated with consumption of electricity, it is not the best measure for reporting the savings associated with reductions in consumption. A marginal emissions factor, representing the impact of increasing or decreasing demand, should be used to report the impact of changes in consumption due to policies or programmes like the C_2C Method. A 'combined margin' (CM), using a weighted average of the build margin and operating margin is now specified as the default approach for projects that generate lower carbon electricity or reduce consumption. The CM accounts for long-term and short-term effects of the Project implementation. See Carbon impact assessment report.

Study components

Assets: C_2C requires different combinations of conductors, switchgear, transformers and civil works than for traditional reinforcement. The emissions of all GHGs associated with the manufacture of assets deployed in the C_2C Solution and the baseline were accounted for using a partial life cycle assessment. Wherever possible, the geographic origin and fate of the assets used by Electricity North West were specified to enable more accurate identification of impacts from databases. This category of impact is termed 'embodied emissions'.

Operations: The emission of all GHGs arising from the generation of electricity that is subsequently lost in transmission through the Electricity North West network were accounted for. Technical losses were calculated using power flow models, developed in the economic benefit analysis work package, for both the baseline and C_2C network configurations. Given the long life of assets and current changes to UK grid supply driven by energy and climate policy, a dynamic assessment of emissions from losses using a range of defined scenarios for the CM emission factor was used.

Facilitated reductions: The ability to release capacity more quickly with the C_2C Method than with traditional reinforcement will deliver an emissions reduction by enabling the more rapid connection of low carbon technologies (LCTs) such as renewable generation, electric vehicles (EVs) and heat pumps (HPs) at constrained parts of the network. These LCTs are expected to have comparatively lower emissions than traditional 'baseline' means of providing electricity, personal transport and home heating. It was recognised in the pilot study that these putative reductions should be accounted for distinctly due to their short time horizon and substantial uncertainty. Each capacity addition is assumed to be taken up by 30% electric vehicles, 30% renewable generation and 40% background load growth (report).C_2C is assumed to provide capacity four months earlier than traditional reinforcement methods with emissions reductions summed over that period.

Assumptions

Following a fault on a circuit, the C_2C Solution will delay the restoration of interruptible C_2C demand. However, faults are rare and short lived occurrences so any reduction in consumption as a result of the fault is deemed to be negligible.

Emissions were considered over the maximum 45 year lifespan of assets defined by the Ofgem RIIO ED1 cost benefit analysis (CBA) framework. All episodic and continuous sources of emissions were summed over this period. The starting point was taken as the time when a network constraint was reached. It was assumed that all assets complete their life cycle (manufacture, deployment, disposal/recycling) during this period.

It is assumed that the C_2C Solution, in its Trial or wider deployment, does not have other economic impacts or wider effects that alter GHG emissions. For instance, CO_2 emissions arising from the EU power sector are capped by the operation of the EU emissions trading scheme (ETS) up to 2020.

Baseline definition

The network capacity and network reinforcement requirements model has been developed within the scenario based economic benefit analysis work package. The model determines the location of thermal and voltage constraints on the network under predetermined load growth scenarios. It implements Ofgems' RIIO-ED1 framework and determines the least cost sequence of reinforcement required to alleviate the constraint under P2/6 security of supply standard. Where new conductors are required for the reinforcement solution, it has been assumed that all overlays and extensions are 300mm^2 triplex aluminium cable of the shortest length that achieves the new connection. All other associated installation excavation and assets are included with their embodied emissions.

Detailed carbon impact calculation is detailed in section 4.3 'Carbon Impact Assessment Literature Review and Methodology' Report.

Detailed derivation of facilitated emissions reductions due to connection of electric vehicles and renewable generation can be found in sections 4.5.2 and 4.5.3 of the same report.

In summary a carbon impact assessment framework applicable to the deployment of the C_2C Solution at Trial scale and in future scenarios at a range of scales has been developed. Study boundaries have been defined, baselines established and data sources identified.

Economic modelling

The main aim of the C_2C economic benefit analysis work package was to develop a fundamental understanding of the economic rationale to implement C_2C Solutions in existing distribution networks.

Key objectives included:

- Review the adequacy of existing frameworks (developed for the evaluation of investments in distribution network assets) for the assessment of the C_2C Solution
- Based on the outputs of the review, define a preliminary framework that can properly quantify the benefits and costs associated with enhancing network reinforcement practices with the C_2C Solution
- Identify some of the conditions that favour or discourage the use of the C_2C Solution.

In addition to the technical challenges associated with the potential of the C_2C interventions to meet its targets, the economic perspective of the C_2C Solution needs to be fully understood. In this respect, given the context of adopting an operational strategy to substitute for traditional network reinforcements, it was critical to identify a suitable framework that can properly quantify the different economic benefits and costs associated with the C_2C Method. See Economic modelling sensitivity-analysis.

The aim of this area of work was to present (i) the economic assessment of C_2C interventions considering the C_2C Method as an alternative to network reinforcements and (ii) the planning of network expansions considering that optimal investment strategies may be formulated by implementing traditional network reinforcements in combination with C_2C interventions.

The economic assessment of the C_2C Solution must be consistent with existing frameworks for the assessment of other distribution network solutions. Therefore, the C_2C Solution was initially assessed using the CBA framework introduced by Ofgem for the new RIIO-ED1 price control.

Ofgem's CBA framework compares the economic costs associated with proposed network solutions (eg the C_2C Solution) with those of a baseline in a specific scenario, with the objective of identifying the most convenient investments. The baseline comprises least cost network reinforcements triggered whenever demand increases and reaches the firm capacity of the network (the baseline could also be the option to 'do nothing' if no reinforcements are needed). The CBA is set to consider the network investment costs (eg investments in network reinforcements, payments for DSR, costs of automation, and so forth), while it also provides the option to either consider or neglect social costs (eg reductions of CIs and CMLs and losses and emissions reductions, amongst others).

An illustrative study was introduced to exemplify the characteristics of the CBA framework and its adequacy to evaluate the C_2C Solution. See Economic modelling methodology.

The CBA framework only provides a snapshot assessment of the C_2C Solution in a particular scenario, based on potentially sub-optimal investment strategies and assuming perfect information. Therefore it did not provide a realistic assessment of the C_2C Method under practical conditions subject to significant uncertainty (eg multiple potential future scenarios and imperfect forecasts), in which case the DNOs are required to assess a number of investment strategies when searching for the most economically attractive investments. In light of this, the next development step was to automate Ofgem's CBA framework and extend it to address uncertainty. This was achieved by considering best view forecasts based on a rolling horizon, several scenarios for demand growth in combination with a search and optimisation engine to identify optimal deployment strategies and intervention timing with other solutions based on particular criteria. The optimised solutions are from the perspective of either DNO investment costs or DNO investment and social costs (carbon emissions, reliability and network losses) minimisation.

The extended CBA framework was also further developed to assess the value of the C_2C Method subject to new DG connections. However, for this application, a new model for power losses was devised and specific generation profiles for the DG technologies under consideration were included in the CBA framework. In a traditional distribution system without DG, all power losses in the network can be associated to the electricity imported from the grid. However, in a distribution system with DG, a fraction of the power losses would be associated with DG. Considering that power losses attributed to DG may have a different economic value and carbon intensity than those associated with imports from the grid, the CBA must comprise a tool to quantify the power losses attributed to different sources. Accordingly, a methodology based on AC power flows and tracing methods has been included in the proposed CBA framework to quantify losses associated with different sources (eg different DG units, the grid and so forth).

3.4.3 The use of post-fault demand response in security of supply requirements

A key element of the Project was to explore the interaction between DSR services and existing industry policy, more specifically the network planning requirements in ER P2/6.

ER P2/6 stipulates the security of supply to customers based on the aggregation of their demand as it appears on the network. In its simplest form the recommendation sets out the amount of capacity that must be available on the network for specified demand thresholds, so that demand can always be supplied when capacity becomes unavailable due to a fault or a planned outage. For example, for demands greater than 1MW the network capacity is duplicated. As the C_2C Method is using this inherent latent capacity specified as a requirement of ER P2/6 for the connection of new demand, there will be instances following an outage and prior to network switching when customers' unconstrained demand cannot be supported leading to a potential non-compliance under the current framework. For the purposes of the C_2C Trial a derogation from the requirements of P2/6 was granted for all demand groups supplying the Trial circuits. The definition and treatment of DSR in P2/6 security of supply assessment is an important factor in the adoption of DSR as a BAU technique. Unrestricted use could potentially adversely affect security of supply where restrictive treatment may preclude the full economic and technical benefits.

The evaluation of the effects on demand levels due to the operation of responsive loads is not explicitly permitted in ER P2/6. However, DNOs are able to make allowances for individual customers when undertaking customer connections and network reinforcement assessments. Guidance Note 1 of The Distribution Code permits that a customer can elect to receive security at a level lower than a ER P2/6 connection, provided that it does not affect the quality of supply to any other customer in that network.

DSR may be initiated via a variety of methods including and not limited to:

- Energy price signals to consumers

- Incentive payments coupled to response requirements initiated by signals derived from asset events or demand levels.

The latter method is particularly useful to network operators for network balancing, potentially enabling deferment of system reinforcement and better use of existing assets. The potential economic benefits of DSR in meeting the challenge of energy decarbonisation have driven recent work in this area including C_2C.

The remit of this area of work within the Project was to present a recommendation for how DSR could be accommodated within ER P2/6 and its supporting documents in order to realise the benefits of the growing number of novel operational techniques. In addition to this it aimed to provide a consistent and practical approach for the industry to follow when assessing the contribution of DSR to security of supply assessments.

In parallel with the C_2C work, a more structural review of ER P2 has been commissioned by the Distribution Code Review Panel which is intended to reassess the underlying basis of network security assessments. It is envisaged that this more fundamental review will recommend more extensive changes but the panel is unlikely to finalise its recommendations in less than two years.

A broad approach was adopted for the review to ensure that views of the industry were reflected in the conclusions. The methodology employed for the review process consisted: simulation studies; internal Electricity North West workshop; industry consultation; and an industry workshop.

4. THE OUTCOMES OF THE PROJECT

4.1 Customer engagement and feedback

4.1.1. Engaging and understanding I&C customers

This section summarises the findings of the key questions below:

- Is there an appetite in the I&C market for C_2C?
- What is the level of interest by sector?
- How does interest by sector correlate to the size of demand of that sector?
- What contract elements are required to make C_2C as attractive as possible?
- What are the key motivations for customers signing the C_2C commercial agreement?
- What are the key barriers for customers rejecting the C_2C commercial agreement?
- Are customers who sign the C_2C agreement satisfied with the commercial arrangement after acceptance?

Is there an appetite in the I&C market for C_2C?

Feedback from the research described in section 3.1 shows 52% found the C_2C concept appealing and 31% would recommend[1] their organisation consider opting into a C_2C contract. However, this number dropped to 26% when they saw the potential scope of the contracts in more detail (eg the size of the financial reward as presented in the survey). In forming this judgement customers were balancing the reward offered against the notional cost as represented by their current demand. It is believed that this represents the worst case scenario for cost as the interruption of future loads such as EV charging is likely to be less costly than current demand.

What is the level of interest by sector?

For the purposes of the survey I&C customers were split into 14 industry standard market sectors. Manufacturing & processing accounted for 46% of the total survey respondents. The next largest sector accounted for 8%. To preserve the statistical robustness of the data all other sectors were combined and compared with the manufacturing & process sector. The survey showed:

- There is no statistical difference in level of appeal between manufacturing & processing and the ‘other sectors’ with a range of 49-54% finding the concept appealing
- For potential take-up of contracts, the manufacturing & processing sector is 10% less likely to take up a contract both before and after seeing the scope of the contract.

While the manufacturing & process sector appears to be initially more cautious, the findings are not significant enough to require a different sales approach. However, they do indicate that contracts will need to be carefully tailored to each target sector.

[1] Recommend = Those indicating a score of 5 or more on a 7 point scale, where 1 is ‘very likely’ and 7 is ‘not at all likely’

How does interest by sector correlate to the size of demand of that sector?

Amongst the 180 customers surveyed, their maximum import capacity (MIC) value was established and aggregated to understand the total maximum capacity (TMC) of the population surveyed. Manufacturing & processing customers accounted for 54% of the TMC of which 11% were open to having non-essential demand managed and interested in C_2C.

Non-manufacturing & processing customers who where open to having non-essential demand managed and interested in C_2C accounted for 6% of the TMC.

What contract elements are required to make C_2C as attractive as possible?

The research considered: the maximum number of managed interruptions per year; the maximum cumulative interruption duration per year; the payment method; the length of contract; the number of safeguarded days and various levels of payment. Analysis indicated two general patterns:

- An increase in payment level outweighs the inconvenience of longer durations. Varying the level of payment increases take up by 0.3% for every 1% increase in payment
- Payment is less of a compensation if duration of the interruption is longer eg more than an hour.

When customers considered specific examples of contracts, the length of contract had the biggest single influence on take-up. Method of payment ('pay-per-usage') and safeguarded days also significantly increased take-up rates. The size of reward is therefore important during the final decision but other components are critical in progressing negotiations to this point.

What are the key motivations for customers signing the C_2C commercial agreement?

Customers who accepted the C_2C managed connection agreement found the payment methods available, the length of the contract and the financial rewards the most appealing aspects of the agreement. Overall, the financial rewards were cited as the most important single factor in a customer's decision to sign the agreement or not.

What are the key barriers for customers rejecting the C_2C commercial agreement?

The financial rewards and duration of interruptions were considered to be the main barriers to signing the C_2C commercial agreement. The implication of this was that some customers felt that the financial rewards were not sufficient to compensate for the loss of productivity during a fault of up to eight hours.

Are customers who sign the C_2C agreement satisfied with the commercial arrangement after acceptance?

Customers are satisfied with the commercial arrangement after acceptance. No customers who accepted the C_2C managed connection agreement were opposed to extending the contract beyond the 18 months which they have already agreed.

A detailed summary of the research framework and results can be found in the Customer segmentation report.

4.1.2 Communicating with domestic customers

The ECP described in section 3.1.2 helped formulate effective communication plans and provide relevant and clear information to affected customers. During this process it was found that:

- Customers are very focussed on their 'supplier' and the cost of their bill. They expect a safe, continuous supply at a fair price and require reassurance on the reliability of their supply going forward should any changes be proposed
- The relationship between DNO and supplier is still confusing for customers. Communication with customers needs to explain the roles of DNO and suppliers in simple terms to help raise awareness of the service provided by the DNO
- The C_2C concept is too complex for many domestic customers to understand. Information on decarbonisation, the Problem and the C_2C Solution is deemed too technical and unnecessary.
- Customers think it is their right to know about changes to their electricity supply, particularly if the message is positive. The main focus of any communication should make it clear how any changes to customers' supply will benefit them. Beyond this, there is no apparent need to 'sell' the C_2C initiative to domestic customers
- Information should be provided in simple terms and aim to avoid confusion
- Customers want to know what to do in a power cut. This information is considered to be useful and is consistent with the view that the leaflet was a 'public service announcement'.

This ECP resulted in a customer leaflet which was sent to all domestic customers on the Trial circuits before the Trial started. A detailed summary of the framework and key findings can be found in the ECP report.

4.1.3 Monitoring the effects of demand side response on customers

Where the C_2C Method is deployed and involves meshing the HV network, do customers report any perceived differences in their power quality or supply reliability?

The change in operating conditions on C_2C Trial circuits did not adversely affect customer perception. Indeed, the net change in perception either achieves parity with the status quo or a more favourable position for all three key power quality measures: frequency, duration and dips and spikes. This perception is echoed amongst priority service registered customers. The implication of this is that perception of power quality is not adversely affected, even amongst vulnerable customers who could be deemed to be more sensitive to changes in power quality due to an elevated dependency on electricity.

If any effects are noticed by customers, do they present a barrier to the rollout of C_2C?

The analysis suggests that the most discernible aspect of power quality supply for all survey participants is the frequency of faults. The most significant learning is that the C_2C Method improves perception of the occurrence of faults. Findings show that the detection of faults is significantly lower on C_2C Trial circuits compared to control circuits, suggesting that power quality is more favourable using C_2C.

Where detected by customers do SDIs enhance perception of power quality or supply reliability?

Lasting under three minutes, the SDI is significantly more acceptable to customers than interruptions of up to 60 minutes. Under normal fault management procedures, approximately 90% of customers' power supplies are restored in one to three hours. Analysis from this study showed that customers expect power to be restored in a much shorter time period. This implies that any change in operating conditions that increases the proportion of faults that are SDIs, is likely to enhance power quality perception.

A relatively small number of customers claimed to have experienced an SDI. Amongst those that did, the acceptability of the fault duration (asked on a one to ten rating scale) was 27% higher than faults lasting four or more minutes. Full reports on the research can be found in the Customer reactive post-fault report and Customer proactive power quality monitoring report.

4.2 Technology implementation and effectiveness

4.2.1 Trial area selection and deployment

The pre-Trial C_2C circuit selection originally included 180 closed rings and 20 radial circuits. This was modified to 153 closed rings, 27 open rings and 20 radial circuits. A further eight 'spare' circuits were identified which could be brought into the Trial should any problem be identified with the 180 circuits in the initial selection.

The split of the selected circuits compared to the total Electricity North West circuit population based on voltage and circuit indicated an adequate split and representative base of circuits within the selection.

4.2.2 Development of adaptive network control functionality

Network automation functionality

All of the 180 ring networks and 20 radial networks included in the Trial area were successfully enhanced by installing additional remote control devices.

For the closed ring network configuration trialled as part of the Project it was important to ensure that supply restoration following a fault was not adversely impacted for existing customers connected to these networks. The deployment of additional remote control devices at strategic locations was central to this flexible re-supply of customers following a fault.

As a means of comparing the performance of a closed ring, the metrics used in Ofgem's Quality of Service Incentive have been calculated and compared to the respective radial network where the fault occurred. The measures for comparison were: short duration interruptions[2], the number of customers interrupted per 100 customers (CI) and the number of customer minutes lost (CML).

For each of the 20 faults that occurred during the Trial period, the actual fault restoration sequence was captured within the NMS logs giving times and number of customers restored at each operation. In addition to this the theoretical restoration of the equivalent radial network was developed following the normal policy of splitting the network at the midpoint and following with a reclose at the primary substation to gain sectionalised location of the fault. For the purposes of evaluating the customer restoration times on the radial network it was assumed that the additional RC devices installed as part of the Trial would not be available and manual switching would commence at the same time as the first manual intervention as part of the closed ring restoration.

[2] Customers interrupted for less than three minutes. Currently under Ofgems' Interruption Incentive Scheme these interruptions are not incentivised.

All 20 fault occurrences demonstrate that when the network is configured as a closed ring, customer interruptions (CIs) increased by 15% and customer minutes lost (CMLs) are decreased by 24% respectively compared to the radial equivalent. However the initial short duration interruptions (SDI) increased by 83%.

Network management system development

During a system fault on a C_2C circuit that supplies a Trial participant, it was necessary to disconnect part or all of a Trial participant's network. The fault management system architecture and process that Electricity North West successfully designed and embedded is summarised below:

- CRMS (Electricity North West) carries out automated restoration of non-managed customers
- Where required the control engineer implements manual switching
- On completion of manual switching the control engineer requests a PowerOn Fusion (PoF) switching plan for any customers still off supply
- GE PoF provides a switching plan to restore any managed customers off supply.

The complete Network management system required for other DNOs to offer the function will be available in PoF via an option associated with the PowerOn APRS module.

Automation of customers demand

Customer type	Type	Import or export	Total load (kVA)	Managed load (kVA)	Automation Solution
Leisure	Existing	Import	800	800	HV retro-fit actuator
Manufacturing	Existing	Import	150	130	LV RC switch
Retail	Existing	Import	341	160	2 LV RC switches
Manufacturing	Existing	Import	600	600	Replaced customers main switch with LV RC MCCB
Manufacturing	Existing	Import	487	487	Replaced customers main switch with LV RC MCCB
Manufacturing	Existing	Import	185	185	HV retro-fit actuator
Manufacturing	Existing	Import	800	800	HV retro-fit actuator
Utility	Existing	Import	5200	5200	Existing SCADA control
Manufacturing	Existing	Import	1800	1800	HV retro-fit actuator
Manufacturing	Existing	Import	630	630	Flexitricity RTU to control HV switch. RTU interface
Food processing	Additional load	Import	2000	800	HV retro-fit actuator
Manufacturing	Additional load	Import	2000	600	HV retro-fit actuator
Data Centre	New supply	Import	500	500	Replaced customers main switch with LV RC MCCB
Data Centre	New supply	Import	500	500	HV retro-fit actuator
Manufacturing	Additional load	Import	18000	6000	Existing SCADA control with auto load reduction scheme
Manufacturing	New supply	Export	10500	10500	Existing SCADA control with auto load reduction scheme
Manufacturing	Additional load	Export	45000	5000	Existing SCADA control
Manufacturing	Additional load	Export	49900	4900	Existing SCADA control
Retail	Additional load	Import	38000	8000	Existing SCADA control
Transport Infrastructure	New supply	Import	2700	2700	HV retro-fit actuator

An automation solution was installed and commissioned for each of the customers participating in the

Trial. This enabled Electricity North West to control either all or part of the customer's load in accordance with the requirements of the managed connection agreement.

However, for existing customers and those requiring additional load, the provision of new high voltage switchgear was generally not required and therefore Electricity North West developed and tested actuators for approval prior to installation and commissioning. This work was undertaken in conjunction with Long Controls.

Electricity North West's planning policy specifies that loads between 300kVA and 1000kVA are normally supplied via single or ganged ways from a low voltage board and loads between 100kVA and 299kVA are normally supplied directly via an LV cable. Various sizes of motorised LV MCBs were developed in conjunction with contractor IQA and their supplier BEMCO to suit the different supply arrangements. The LV MCBs ranged in size from 400A to 1250A and were either installed in series with the customer's incoming supply or as a replacement for one of the switches on the customer's LV switchboard.

Consideration was given to installing WEEZAP LV VCBs which are generally installed as part of an active network management system. These units simply replace LV fuses so that installation is simple and associated costs are minimal. However, the relatively high capital cost compared to a motorised MCCB outweighed any savings realised at the installation stage.

Automation solutions can be categorised as follows:

- Install an actuator to an existing DNO HV switch to control all of load
- Install an LV motorised MCB in series with customers LV singles to control all of the load
- Install an actuator to a customer-owned HV switch to control all or part of the load
- Change a customer's LV switch for a motorised MCB to control part or all of the load
- Change DNO or customer's HV switchgear for a unit suitable for remote control.

4.3 Developing the commercial framework for post-fault demand response services

4.3.1 Commercial templates

Through customer research and direct engagement Electricity North West has successfully developed a commercial offering and associated contractual framework that is attractive to customers but offers the flexibility and resilience required by a DNO for this form of demand side service. Electricity North West has produced commercial templates for the provision of post-fault DSR for demand and generation and existing and new customers that can be adopted by others as an industry benchmark. These commercial templates have been successfully applied to the 20 participants who signed up during the Trial. A post Trial review based on Electricity North West's and Trial participants' experiences of applying the templates still found them to be the most suitable arrangement. Electricity North West will continue to keep these templates under review and modify them as and when required. Any such modifications will be publicised to all DNOs and made available on the Project website.

4.3.2 Purchase of demand response from new customers

Due to a reduction in demands on the network over the life of the Project there were not as many schemes where network reinforcement was required as originally envisaged. However, despite this setback Electricity North West was still able to sign up ten new customers where a demand response solution was required to manage the increase in demand on the existing network. All of the customers were connected at either HV or EHV and the total customer contributions for the standard solution was £7.84m whereas the contributions required for the C_2C Solution totalled £0.37m. This resulted in savings of £7.47m for the customers being connected due to the avoided associated reinforcement. The customer types covered import and export demand and the managed load ranged in capacity from 500kVA to 10,500kVA. Three of the schemes were for new development while the remainder were for additional load for existing customers.

For connections at HV, both standard and C_2C solutions were designed and fully costed by the team whereas for the EHV C_2C schemes, the costs were often developed as strategic development reinforcement schemes and apportioned as customer contribution for each MVA of demand required. Other EHV schemes required major reinforcements that, even though they were not designed in detail, would have required a significant contribution of the costs from the customer who after evaluating the risks and agreeing to limit the demand decided that the additional security of supply was not required. Consequently, the reinforcement could be deferred along with the associated contributions from Electricity North West.

Customer type	Type	Standard Solution Total Customer Charge (£)	C_2C Solution Total Customer Charge (£NET)	Total Customer Charge Saving (%)	Total demand (KVA)	Managed demand (KVA)
Food processing	Additional load	56799	5782	90	2000	800
Manufacturing	Additional load	21,590	0	100	2000	600
Data Centre	New supply	76646	65996	14	500	500
Data Centre	New supply	73,884	69,140	6	500	500
Manufacturing	Additional load	650,000	67,331	90	18000	6000
Manufacturing	New supply	45,090	34,720	23	10500	10500
Manufacturing	Additional load	1,800,000	6,556	100	45000	5000
Manufacturing	Additional load	1,996,000	3,000	100	49900	4900
Retail	Additional load	3,000,000	38,406	99	38000	8000
Transport Infrastructure	New supply	121,288	81,618	33	2700	2700

During the life of the Project the commercial template that was initially developed evolved to address concerns raised by customers. For instance the situation where two or more customers were connected to the same HV network required a decision for the priority of restoration following a loss of supply. Similarly, the situation where additional network capacity may become available in the future and consequently the customer may be able to take advantage of an unconstrained connection capacity was also considered. See Appendix E for multiple managed customer restoration rules.

4.3.3 Existing customer engagement and agreements

npower secured their first contract in September 2013 with four more in October 2013. Since npower did not meet the KPI in the contract, this allowed Electricity North West to offset some of the ten contracts allocated for npower with contracts that had been secured directly. As a result, all ten existing customer managed agreements were secured within the first six months of the 18-month Trial period. The final mix of agreements purchased were five direct (inclusive of one agreement where the Flexitricity aggregator arrangement was trialled) and five via npower.

Electricity North West has demonstrated that there are three possible routes to market namely:

- DNO direct
- Agent/ aggregator finder's fee using Electricity North West equipment with the contract model being Electricity North West direct with the customer
- Via an aggregator using their system.

The preferred implementation method is direct engagement as it was proven to be both the most cost effective solution and facilitated a strong ongoing customer relationship that builds further confidence in the proposition.

It was learnt that the aggregators had few clients within the Electricity North West area and those that did have a customer presence tended to be focused on a small number of large Demand / generation customers already involved in the ancillary services market. Typically the cost of using an aggregator was ~20% higher than a DNO going direct.

4.4 Evaluating and enabling the benefits of post-fault demand response

4.4.1 Network performance modelling

Evaluation of capacity benefits

The simulation studies of actual C_2C Trial circuits have shown that C_2C operation can release significant demand and DG capacity. On average, C_2C operation can achieve up to approximately a 76% increase in demand and a 225% increase in DG, compared with defined base case scenarios. However, the results depend significantly on the individual circuit topologies, the thermal ratings of circuit sections, and load or DG locations. On average, interconnected C_2C operation (with closed HV rings) releases more demand and DG capacity when compared to radial C_2C operation (with radial HV feeders). Furthermore, a 'holistic' system approach is required when considering the connection of load or generation; other technical factors (such as primary transformer ratings) or non-technical factors (such as cost-effectiveness) may affect the maximum capacity which can be released by a particular HV circuit.

Evaluation of network utilisation benefits

Based on half-hourly feeder current measurement data from the year 2012 the demand diversity factor for each of the 36 modelled ring circuits has been assessed. On average, the demand diversity factor is 1.081, which shows that there is potential for a slight improvement in diversity due to interconnected operation.

Evaluation of losses impact

The technical losses in the HV network arising from C_2C operation have been compared with losses in a reinforced radial system. Losses are generally reduced if the NOP is closed, ie if interconnected C_2C operation is adopted rather than radial C_2C operation. Furthermore, the average reduction in losses due to interconnected C_2C operation diminishes as the level of connected interruptible demand increases. At the maximum levels of demand released by C_2C, C_2C operation leads to annual HV network losses of approximately 1%, as a percentage of demand. This is approximately 0.3 percentage points higher than the equivalent losses assumed from conventional reinforcement of the radial networks, but this must be offset against benefits accrued in the intervening period between introduction of C_2C and the time when the maximum C_2C capacity is reached (which would span years). See technical performance report.

Evaluation of power quality benefits

Power quality measurements from several locations throughout the Electricity North West network and spanning the duration of the C_2C Trial have been analysed to compare the effects of radial C_2C operation and interconnected C_2C operation. Extensive validation of the monitoring data has been performed to ensure that the comparisons are reliable. C_2C operation is likely to have only a marginal but beneficial impact on power quality. This has been confirmed through theoretical analysis of the likely change in voltage total harmonic distortion (THD) resulting from interconnected C_2C operation. In particular, the measurement data indicate that the worst case mean THD measured at LV, approximately 3%, is well within the planning level of 5%.

It has been demonstrated that C_2C operation – even at the most extreme levels of released demand and DG – is unlikely to exceed HV design fault level ratings.

4.4.2 Economic and carbon modelling

Carbon impact assessment

The purpose of this research was to quantify the impact of the C_2C Solution, compare this to traditional reinforcement and understand the major sources of emissions in each to better enable management of distribution networks.

A robust and comprehensive methodology, detailed in Section 3.4.2 above, was developed to inform the carbon impact model. This model then took inputs from the power flow assessment and associated economic modelling of the economic modelling work package. This economic modelling work package identified optimal time series investments to enable growth in demand and renewable distributed generation. Three different investment perspectives were examined. The first, the baseline, uses traditional reinforcement techniques and principles, overlaying lines and upgrading substation transformers. The second, interconnected C_2C, uses interconnected C_2C network topology in combination with the purchase of realistic levels of demand side response (DSR) contracts from customers. The third, 'OSS', uses an optimal investment strategy based on minimising network investment and social costs (network reliability, technical losses and associated emissions). This allows both traditional reinforcement and C_2C techniques in their optimal combinations to be deployed to minimise investment, the cost of losses and the carbon impact when converted to an economic measure (Ofgem specified traded carbon prices) are considered.

Exploring the various carbon impacts of the C_2C Method through a scenario method reveals a number of features that may inform future deployment.

- The net impact shows no correlation with reference to the circuit on which C_2C may be deployed
- Asset emissions reductions are observed in all but 8% of scenarios and circuit combinations. In cases where C_2C is not able to meet all growth over the 45 year period, the timing of network reinforcement is deferred.
- Operations impacts arising from change in network losses are sensitive to the existing composition of the network and the additional demand or generation that is to be accommodated. As a result the benefits are very wide ranging.
- For the set of scenarios where increases in network demand are simulated, traditional reinforcement triggered by capacity constraints in this exercise can lead to a substantial network losses improvement. The use of DSR and interconnection in the C_2C Method does not trigger such investments and increases utilisation of existing assets. This results in a lost opportunity to reduce operations carbon impact.

- Increases in renewable distributed generation tend to reduce operations carbon impact from losses and C_2C is therefore favoured as a method for capacity release.
- Net impacts, whether positive or negative, are typically modest at less than 15% of the base case net carbon impact.
- Variation across load growth scenarios, both demand focussed and generation focussed, does not qualitatively alter the direction of net carbon impact on most circuits relative to the base case. The corollary of this is that the decision to deploy C_2C on a given circuit, or not, will most likely be robust to a range of possible future circumstances.
- When calculated over a shorter time horizon the benefits of interconnected C_2C and OSS approaches are increased by a few percentage points over a 45 year measure, or in the case of demand growth scenarios the negative impact is reduced. The asset emissions reductions have greater influence on this measure. Although useful in exploring the pattern of impacts, the 20 year horizon is less conceptually justifiable than 45 years.
- The grid emissions factor assumed for losses is a significant external factor that may alter the net impact. If a low carbon grid scenario is assumed, for instance National Grid's Gone Green, then the scale of impact and hence the possibility for gains is limited. However, if high carbon emissions are maintained, either because of failure to decarbonise the grid as a whole, or because marginal emissions continue to be met by gas power stations, then the benefits are greater.
- The OSS strategy due to the optimal combination of reinforcement and DSR outperforms the pure deployment of DSR (interconnected C_2C) in almost all circumstances from a carbon impact perspective. This is especially significant in demand growth scenarios.

As well as the specific outcomes in relation to the C_2C Trial, this carbon impact assessment has identified a number of important issues in the consideration of the carbon impact of smart grid solutions.

- A new method for estimating emissions reductions from direct and indirect sources has been demonstrated including a means of calculating short term facilitated carbon reductions, a novel impact category in the GHG accounting literature. Trial scale and future scenarios have been defined, boundaries clarified, baselines established and data sources identified.
- Capacity released is a poor proxy for net carbon impact. Facilitated reductions are highly conditional on assumptions, vulnerable to double counting, and for the demand growth set of scenarios examined, substantially lower than the absolute changes identified in assets and operations.
- A demand growth trend increases the losses in all circuits as they approach their firm capacity. In the base case this phenomenon is partially offset by a reduction in impedance that accompanies the introduction of traditional reinforcement assets. However, smart solutions such as C_2C will enable greater utilisation of assets and defer capital network investment at the expense of comparatively higher losses.

In addition it can also be concluded that the hypothesis *'The C_2C Method will facilitate a reduction in the carbon costs of network reinforcement.'* is valid when considering the results of asset carbon impact, under increasing demand growth scenarios.

Economic modelling

The CBA methodology was used to assess the C_2C Method based on a wide range of assumptions and considering 36 C_2C Trial networks. The sensitivity studies have been used to validate the robustness of high level conclusions, and bring about an increased understanding of the conditions that increase or decrease the economic attractiveness of the C_2C Method.

The following observations have been drawn:

- The C_2C Method can be an attractive means to defer or even avoid costly line reinforcements and substation upgrades
- From the economic perspective, both C_2C configurations (radial or interconnected) can be a better option than traditional interventions, particularly when demand growth is modest (or uncertain), as it can lead to significant capital savings from investment avoidance
- From the power losses perspective, the interconnected C_2C (interconnected C_2C) configuration is a beneficial option, particularly in scenarios where demand is expected to increase significantly. In such scenarios, interconnected C_2C can lead to significant capital savings (from investment deferral) and power losses reductions (from combinations of interconnected C_2C and reinforcements)
- The conditions that make the C_2C Method attractive have been identified (reference demand level, substation capacity, and DSR availability and capital investment costs). It is therefore possible to deploy the C_2C Solution without the need of an optimisation approach. In other words, the use of an optimisation engine is indeed expected to minimise overall costs and facilitate C_2C deployment. However, even without the aid of optimisations, deploying C_2C standalone can outperform the

baseline, if it is implemented under favourable conditions (eg uncertain demand growth and capital intensive reinforcements)

- The radial C_2C configuration is preferred under all condition to optimise for DNO network investment costs only, whereas interconnected C_2C is preferred based on optimisation of DNO network investment and social costs.

Most of the above-mentioned observations are also valid subject to an increased penetration of DG in the distribution system (instead of demand growth). However, this excludes all observations regarding impacts of the C_2C Method on power losses. In such a case, the increased penetration of DG is likely to result in power losses reduction (assuming realistic and modest DG penetration levels), which lessens the adverse effect that increased asset utilisation (attributed to the C_2C Method) can have on power losses.

4.4.3 The use of post-fault demand response in security of supply requirements

The need for guidance on how DSR should be accounted for within security of supply assessments has been recognised. However, due to the planned overall review of ER P2 and the associated onerous change process, it was judged inappropriate to change ER P2 to accommodate DSR in the short term; rather the associated application guide ETR 130 has been modified to provide appropriate clarity.

The results of this review, the consultation and industry workshop were all taken into consideration when developing proposals for changes to ETR 130 to accommodate DSR in the short term. The proposed amendments to ETR 130 can be found detailed in the Accommodating Demand Side Response in Engineering Recommendation P2/6 – Change Proposal report.

It was proposed that:

- In the short term an appropriate allowance for DSR should be taken into account when calculating group demand or by adjusting network capability. It is up to each DNO to justify and formally record its approach for each DSR connection.
- It is up to each individual DNO to decide on the percentage of DSR that it will take into account when calculating group demand and this value should be recorded.
- At this current time it is the view of the industry that for EHV networks the gross level of demand (group demand plus the responsive demand) should be curtailed to ensure that the system is able to maintain supplies to customers while responsive demand is disconnected.

The changes to ETR130 have been ratified by the GB Distribution Code Review Panel.

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

Successful delivery reward criteria

Title	Criterion	Required Evidence	Actual Evidence
HV Circuit Selection	1. Finalise HV circuit selection to identify HV circuits for the Trial. 2. Develop HV circuit variation methodology (recognising HV circuits may need to be varied in the Trial and to mitigate the perceived risk of anti-competitive behaviour). 3. Publicise HV circuits selected to be included in the C_2C Trial and publish methodologies for HV circuit selection and variation.	1. In June 2012, publish the HV circuits included within the C_2C Trial, the HV Circuit Selection Methodology and the HV Circuit Variation Methodology on the C_2C Project's website. 2. In October 2012, publish information pamphlet on the HV circuits selected for Trial.	HV Circuit Selection Methodology List of Trial HV Circuits HV Trial circuit leaflet Trial area search
Engineering Recommendation P2/6 Derogation Application	1. Revise Engineering Recommendation P2/6 derogation, taking into consideration comments from Ofgem consultation, and include selected HV circuits in derogation application's Appendix. 2. Apply for Engineering Recommendation P2/6 derogation for the C_2C Project from Ofgem.	1. In June 2012, submit derogation application to Ofgem.	Application for definite derogation from ER P2/6

Title	Criterion	Required Evidence	Actual Evidence
Demand response customer segmentation methodology	1. Update and enrich customer data for I&C customers on selected HV circuits. 2. Undertake customer survey of I&C customers on selected HV circuits. 3. Create customer segmentation model.	1. Customer data updated in April 2012. 2. Customer survey completed in June 2012. 3. Demand response customer segmentation model completed and published on C_2C Project's website in July 2012.	Customer segmentation report
Customer Engagement	1. Finalise Customer Engagement Plan to Ofgem. 2. Develop C_2C Project's website. 3. Finalise and publicise the C_2C Connection Offer process. 4. Develop new C_2C commercial templates for new connections and existing customers. 5. Produce customer marketing/ campaign materials and magazine advertisements. 6. Generate customer e-mail database and e-mail customers directly. 7. Deliver customer seminars and workshops.	1. Customer Engagement Plan approved by Ofgem in June 2012 and C_2C Project's website live in June 2012. 2. Trial HV circuits published in June 2012. 3. C_2C Connection Offer process published in September 2012. 4. First trade magazine article published in September 2012. 5. First leaflets distributed in October 2012, with subsequent leaflets delivered as per Project Plan. 6. New C_2C commercial templates for new connections and existing customers available for issue to customers by December 2012. 7. First customer seminar/ workshop delivered in December 2012, with subsequent seminars/ workshop delivered as per Project Plan. 8. Various engagement programs continued through until Dec 2014, using various channels including website and e-mail.	Customer Engagement Plan Project website List of Trial HV circuits Connections process First trade article Customer business leaflet Commercial templates (existing) Commercial template (new) Customer seminar slides Stakeholder newsletters
Technology Implementation and Project `go live'	1. All software designed, tested, built and implemented. 2. All hardware including remotely controlled actuators, network monitoring equipment and communications infrastructure installed on the network. 3. Testing to prove capability of network management system to monitor and manage network events (thereby releasing network capacity and allowing customers to engage in managed contracts for new connections and new demand response contracts).	1. Software design completed by April 2012. 2. Software and IT hardware installation, testing and commissioning completed by March 2013. 3. Actuators, communication and monitoring equipment installed, tested and commissioned by March 2013. 1. Live Trials commence April 2013. 2. Demand response capability test completed for all contracted C_2C customers by March 2015.	Functional design specification Demand response capability test Appendix C
Development, consultation and submission of ER P2/6 change proposals	1. Develop a set of recommendations for potential changes to Engineering Recommendation P2/6.	1. Complete simulation exercises to inform discussions by April 2013. 2. Hold workshops between April 2013 and July 2013 to inform proposals. 3. Issue industry consultation between September 2013 and December 2013. 4. Issue recommendations report in September 2014.	Accommodating DSR in ER P2-6 C_2C - P2-6 review external workshop C_2C ER P2-6 consultation letter Accommodating DSR in ER P2-6 (revised)

Title	Criterion	Required Evidence	Actual Evidence
Dissemination of knowledge	1. Database established for collection and dissemination of network data to academic institutions. 2. Dissemination milestones met throughout the course of the C_2C Project including quarterly publications, periodic reports to Ofgem and regular Project website updates. 3. Identification of suitable industry conferences to attend. 4. Drafting of white papers for industry journals and magazines. 5. Production of final C_2C Project closedown report.	1. Network data made available to stakeholders throughout C_2C Project and available for at least 18 months after Project closedown. 2. Six-monthly progress reports submitted to Ofgem/ industry throughout C_2C Project. 3. Five industry conferences attended and presented at by March 2015. 4. LCN Fund Annual Conference attended and presented at by December 2014. 5. Published (or had accepted for publication) six white papers for magazines or journals for industry or academic audiences, as per Project Plan, throughout C_2C Project. 6. Closedown report submitted to Ofgem in March 2015.	Network data Six-monthly reports LCNI slides 2012 LCNI slides 2013 LCNI slides 2014 White papers on IET website Conference slides Closedown report submitted to Ofgem in March 2015 is classed as a consultation to enable DNO peer review which is a recent governance change (under notice)
Demand Response Contracts	1. Enter into a number of new commercial arrangements for the provision of a demand and/ or generation response, including both: i) New C_2C managed connection agreements; and ii) New C_2C managed demand and/ or generation response contracts.	1. New managed contracts entered into with demand and/ or generation customers or their agents, including: i) At least ten C_2C managed connection agreements by March 2015; and ii) At least ten C_2C managed contracts for demand and/ or generation response with existing customers, either directly and/ or via an agent by September 2014.	List of managed agreements

5.1 Customer engagement and feedback

5.1.1. Engaging and understanding I&C customers

This activity was successful in engaging 1287 I&C customers on C_2C circuits. Each received a leaflet outlining the scope, size and areas of the distribution network included in C_2C and how to participate in one of the Trials.

This was followed by a quantitative survey with 180 I&C customers which successfully identified the potential interest in C_2C, the type of customers likely to be most interested in the concept and the specific attributes that would be most influential in any eventual acceptance of the contract.

5.1.2 Communicating with domestic customers

To embed on-going stakeholder engagement an engaged customer panel (ECP) was formed consisting of three groups of ten customers. The research explored the extent to which customers understood C_2C, its benefits, any perceived barriers to its success and whether customers needed to be told about it. This activity was successful as feedback from the ECP was used to help design a leaflet which was sent to 382,000 households on C_2C Trial circuits.

5.1.3 Monitoring the effects of demand side response on customers

Two types of research were undertaken to understand any impact of C_2C on overall customer experience by measuring any effect on the perceived reliability of customers' power quality, interruption frequency and duration. During the Trial feedback was sought from customers on affected circuits who had experienced an unplanned interruption. 703 quantitative surveys were completed with domestic (576) and I&C customers (127) following 32 feeder faults on C_2C Trial circuits. In addition, detailed customer research with 350 domestic and I&C customers on C_2C Trial circuits and 311 domestic customers not on C_2C circuits was carried out across three separate phases of monitoring research.

This research element of the customer engagement approach was successful as it has provided sufficient evidence based on a large sample of 1364 customers, within an accepted statistical margin of error, that the C_2C Method had no adverse effect on customers' perceptions of power quality, and in fact that it served to improve customer perception of power quality and supply reliability.

5.2 Technology implementation and effectiveness

5.2.1 Trial area selection and deployment

The activity was successful in identifying a representative sample of HV circuits for inclusion in the Trial. However the original plan was to have 180 closed HV rings and ten radial (high fault rate) HV circuits.

The actual outcome was:

- 153 closed HV rings
- 27 open rings (new 'circuit type' due to existence of hand-charged springs that prevent auto enclosure)
- Ten high fault rate HV circuits.

5.2.2 Development of adaptive network control functionality

Network automation functionality

All Trial networks had the requisite number of additional automation points installed prior to Trial 'go-live'. During the rollout the installation was halted because of a software problem with the Remsdaq RTU devices. However, a software upgrade was issued and applied to all units that had already been installed. This issue caused approximately three weeks delay to the rollout but all devices were successfully installed by the end of March 2013.

Network management system development

An effective centralised network and customer management solution was developed and successfully interfaced with existing NMS capability. 20 fault events occurred on designated C_2C ring networks during the Project, demonstrating successful automatic network segregation and fault sectionalising. Evidence of the Solution's ability to prioritise and restore multiple managed customers was demonstrated via a robust testing schedule undertaken under a range of scenarios and network conditions.

Automation of customer demand

An automation solution was installed and commissioned for each of the customers participating in the Trial. This enabled Electricity North West to control either all or part of the customer's load in accordance with the requirements of the managed connection agreement. The operation of the actuators and associated communications was tested at the commissioning and decommissioning stages and all of the installations operated as designed.

In order to test the automation solution with an aggregator, Electricity North West installed and connected a remote terminal unit adjacent to the aggregator's remote terminal unit. A trip/close signal was connected to the Electricity North West remote terminal unit which in turn passed it to the aggregator's remote terminal unit to initiate the switch operation. Confirmation of the state of the switch was then communicated back to both the aggregator and the Electricity North West control room.

5.3 Developing the commercial framework for post-fault demand response services

5.3.1 Commercial templates

This activity solved the issue described in the Full Submission of requiring a suite of commercial templates that would cover all permutations of existing and new demand/ or generation customers. The templates were published on time in accordance with the SDRC and were ready prior to the appointment of npower who acted as an agent to procure post-fault demand response from I&C customers connected to the Trial circuits.

5.3.2 Purchase of demand response from new customers

The process that was developed for HV applications complied with the requirements described in the Full Submission of 'producing two quotes' for C_2C eligible projects. However, a three month extension to the Project was required to obtain the required ten managed connection agreements.

In most cases the C_2C quote lagged the standard quote due to the fact that the requirement to reinforce the network was not known until the standard quote had been produced and sent to the customer to keep within GSOP standards. At this stage a detailed network study was required to ascertain if there was a constrained network solution prior to producing a C_2C quotation.

Due to the relatively small number of C_2C opportunities identified by the connections planners it was decided that the Project team would manually check all of the standard schemes that had been quoted to ascertain if they were eligible for inclusion in the Project. This process identified a further nine opportunities.

The process that was developed for EHV applications also complied with the requirements described in the Full Submission in that a C_2C offer was presented to the customer. However, it should be noted that the BAU process usually involved investigating a number of options with varying degrees of constraint. As it would be inefficient for the company to expend planning resource to produce a detailed estimate for every solution it was usual to present a conditional offer to EHV customers with the finalised design and associated costs being confirmed after acceptance.

5.3.3 Existing customer engagement and agreements

This element of the Project performed well against its aims. Successful engagement with aggregators and agents was established and was pivotal in securing the required ten existing customer agreements within a budget of £300k. The final mix of agreements purchased were four direct, four via npower and one with Flexitricity, giving reasonable indication of the cost to market associated with each method.

The agreements secured in conjunction with Flexitricity successfully demonstrated an aggregator implementation of the method using their system and controls.

5.4 Evaluating and enabling the benefits of post-fault demand response

5.4.1 Network performance modelling

The work undertaken in this area performed well against its aims and a robust and detailed analysis has been performed in order to validate the following relevant C_2C Project hypotheses:

- The C_2C Method will release significant capacity to customers from existing infrastructure.

  Through the use of DSR and interconnected network operation, C_2C operation was shown to have the potential to accommodate a significant increase in demand and DG connections on HV circuits.

- The C_2C Method will enable improved utilisation of network assets through greater diversity of customers on the network ring.

  This hypothesis can be validated in two parts. Firstly, the increase in demand and DG capacity due to C_2C operation, specifically due to DSR, leads to improved utilisation of existing assets, without requiring reinforcement. Secondly, there is a greater opportunity for improved demand diversity through interconnected (closed-ring) operation because when more customers are connected to a ring there is more diversity; this has been demonstrated using historical demand data.

- The C_2C Method will reduce like-for-like power losses initially but this benefit will gradually erode as newly released capacity is utilised.

  This hypothesis can be validated in two parts. Firstly, there is an initial reduction in losses that can be gained through closing the NOP which, at the maximum level of demand without C_2C deployment, results in an average decrease in peak instantaneous losses of 8% for the studied circuits. Secondly, as demand increases, facilitated by C_2C operation and the consequent avoidance of reinforcement, there is a marginal increase in losses relative to radial reinforced networks.

- The C_2C Method will improve power quality resulting from stronger electrical networks.

  C_2C operation is likely to have only a marginal impact on power quality. The future growth in demand and generation may affect power quality, but this depends on the type of the connection.

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

Interconnected C_2C operation generally releases more demand capacity than radial C_2C operation

Interconnected C_2C operation typically facilitates HV network configurations where one feeder is relatively more heavily loaded than the other feeder comprising the ring circuit. The lower-loaded feeder can supply load current to the other feeder via the NOP, thereby ‘balancing’ the power flows across both feeders. Such configurations improve the utilisation of existing assets but are not possible with radial C_2C without circuit reinforcement. In some cases, radial C_2C operation can release more demand capacity than interconnected C_2C. This generally occurs when one feeder comprising the ring circuit has higher impedance than the other feeder. Similarly, interconnected C_2C operation generally releases more DG capacity than radial C_2C operation.

Interconnected C_2C operation generally results in slightly lower losses than radial C_2C operation

On average, at maximum C_2C demand, there is a marginal reduction in losses of approximately 0.09% (as a percentage of demand) for interconnected C_2C operation as opposed to radial C_2C operation.

Results cannot be generalised by circuit type

The results for demand capacity, DG capacity and losses depend significantly on individual circuit topologies, the ratings of circuit sections and load or DG locations. There is substantial variation in these characteristics throughout the circuits considered as part of the Trial. It is therefore difficult to generalise the results for a specific circuit type, eg by urban vs rural feeders, or by load type. Bespoke system modelling, as performed for the studies in this report, is required to quantify the impact of C_2C operation for each application to HV circuits.

The demand growth methodology affects radial C_2C asset utilisation

The methodology for assessing the demand released by C_2C operation assumes uniform growth in demand that is proportional to existing load capacities. In some cases for radial C_2C operation, this approach may appear to lead to under-utilisation of one of the HV feeders comprising the ring circuit. This is because the adopted methodology considers that each individual feeder cannot be loaded up to its limit independently of the other feeder; both feeders are limited by a constraint on either feeder. If the NOP location was re-selected to 'balance' the two feeders prior to interconnection, then these scenarios (where load is concentrated on one feeder) would generally be avoided – meaning that radial C_2C operation would always be preferable in order to maximise released demand capacity.

5.4.2 The use of post-fault demand response in security of supply requirements

The recommendations detailed in section 4.4.3 to incorporate DSR within ER P2/6 have been obtained following a successful industry-wide consultation exercise and recognises in the short term the need for a number of modifications to ETR 130. These modifications have been designed to provide timely guidance on how DSR should be accounted for within network security of supply assessments. The work presented as part of the Project provides a valuable bridge between current assessment methodologies and a future P2/7. The recommendations are sufficient to enable the early adoption of DSR by network operators in a consistent and prudent manner.

All internal and external industry consultations and the final recommendation report were completed to scope and timescale commitments.

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

6.1 Customer engagement and feedback

6.1.1. Engaging and understanding I&C customers

No changes were required to the planned approach.

The I&C customer engagement framework was peer reviewed by Ken Willis, University of Newcastle who said, '*The customer engagement framework proposed by Impact Research on C_2C is comprehensive.'* He concluded that *'the framework is meticulous and detailed, and will lead to an understanding of the level of interest among customers in C_2C; identify barriers and motivations.'* A detailed summary of this report can be found here.

The I&C customer engagement analysis was also peer reviewed by Ken Willis. He concluded that *'the customer segmentation report provides an effective overview of the survey results. The analysis is meticulous and detailed. It provides a good understanding of the customers' perceptions of C_2C, and the level of interest among customers in C_2C; together with contract attributes that affect acceptance of C_2C by I&C customers.'* A detailed summary of this report can be found here

6.1.2 Communicating with domestic customers

No changes were required to the planned approach.

6.1.3 Monitoring the effects of demand side response on customers

The initial wave of survey results suggested that for domestic customers, the introduction of C_2C improved perceptions of the occurrence of faults. Faults under C_2C conditions are generally shorter in duration than on circuits outside of C_2C, so the question remained: were these lower levels of observation amongst customers on Trial circuits a result of fewer faults actually taking place or a result of customers finding them harder to detect, thus enhancing perception of power quality? To answer this, actual fault data was then cross-referenced and compared with customer data. This allowed further examination of the effects of the C_2C Method on customers by establishing if there was a correlation between customer perceptions of power quality events and reality. This alternative approach to the original methodology provided more comprehensive and robust analysis than originally planned.

6.2 Technology implementation and effectiveness

6.2.1 Trial area selection and deployment

As part of the selection exercise the need for an additional 'type of circuit' was introduced namely 'HV open ring'. This was required because a number of circuits that met the loading criteria and connections activity criteria were controlled via circuit breakers with hand-charged springs. This essentially means that the circuit breakers only have the capability to re-close on one occasion before requiring recharging by hand. Running two feeders in a closed ring configuration may increase the number of re-closes on one of the circuit breakers which is not possible with this circuit breaker type resulting in the loss of restoration performance.

This new type of circuit had the following benefits:

- It enabled the circuits with high connection activity and circuit loading to be kept in the Trial which would give a higher likelihood of attracting a new C_2C connection during the Trial period.
- The inclusion of feeders with hand-charged spring circuit breakers in the Trial increased the selection opportunities by 30% and will importantly increase the business as usual potential by proving the C_2C Method can be deployed on circuits of this type for a period of time until hand-charge spring circuit breakers devices are gradually removed from the network.
- This additional C_2C network configuration would make C_2C a viable option for circuits which interconnect between primaries and open bus-sections making the C_2C Method applicable for significant proportions of distribution networks.

This may require some DNOs to modify the ARS (automatic restoration sequence) software to operate on open ring circuits.

In addition, operational constraints were identified and need to be considered at the planning stage for any future large scale rollout. These constraints include:

- Insufficient alarms at the primary substation to allow automatic restoration sequence functionality on the closed ring
- Fault level issues that prevented the auto-reclose feeding HV circuit breakers
- Inability to deploy remote control on some midpoint substations due to design of HV switchgear
- Lack of LV supplies at certain switching stations.

6.2.2 Development of adaptive network control functionality

Network automation functionality

It was intended that all C_2C ring networks within the Trial would have additional automation installed at the NOP between the two adjacent feeders as well as typically the individual feeder mid-point. As part of the installation phase site surveys were conducted to ascertain the feasibility of installing RC at these locations across the network. In a number of instances these locations had to be changed. This was due to the inability to deploy RC on some mid-point substations due to the design of the HV switchgear or the lack of LV supply required for the RC equipment.

Network management system development

In order for the dual processing of C_2C fault events between Electricity North West's NMS system and GE's POF to work effectively it was necessary to keep both systems synchronised. At the design stage Electricity North West's initial requirement was to create interfaces with weekly refresh and a 24-hour reload relating to the assets and real time updates to analogues and switch states. However due to the data interface limitations between the two systems the final system design had to allow incremental updates only relating to assets, a maximum reload time in event of a required re-synchronisation of three hours and real time analogue and state updates within seconds.

Splitting the fault process between two NMS system significantly increased difficulty, but a working solution was developed that significantly outperformed the initial requirements. This demonstrates that a GB-wide rollout is realistic and achievable.

Automation of customers' demand

Through the specification, design and installation stages of Trial customers' automation arrangements the most appropriate approach for new installations requiring high voltage switchgear was to install an approved circuit breaker actuator so this could be specified at the order stage. A notable exception was the Long and Crawford T4GF3, a common HV switchgear variant across the UK. Due to a temporary operational switchgear restriction on operating the switch fuse it was not possible to fit automation to these units. Consequently, it was necessary to develop LV automation solutions to control the existing loads supplied via this type of switchgear.

Low voltage supplies were not always available in HV switch rooms controlling HV customers so it was necessary to have LV wiring installed to power the RTU and actuator. This was achieved by either extending the customer's LV wiring from their adjacent switchroom or by installing an LV service directly from the DNO network.

6.3 Developing the commercial framework for post-fault demand response services

6.3.1 Commercial templates

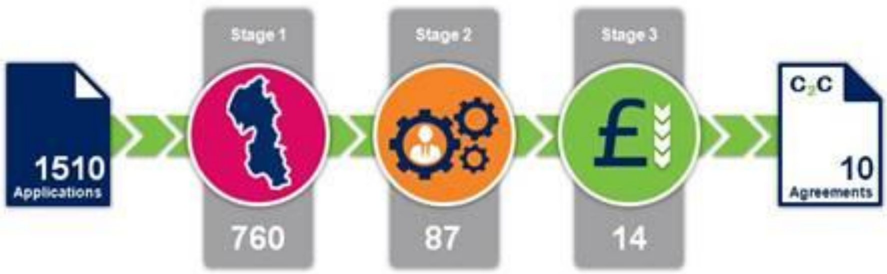
No issues were encountered with the activity of producing the commercial templates, as intended customers were engaged and the results from this used as an input to the development of the templates. An additional step undertaken during the Project was to hold a series of customer focus groups and one-to-one meetings to further explore the potential motives and barriers to participation in the Trial and subsequent acceptance as business as usual. This was essential to developing a commercial offering that would be attractive to potential Trial participants as it provided an opportunity to engage directly and in real time with potential Trial participants or their agents.

6.3.2 Purchase of demand response from new customers

The SDRC had a target of ten managed agreements with customers seeking new connections or additional load/ export capacity by September 2014 and the Project had only secured 6. The primary reason for this difficulty was a reduction in maximum demand on our Trial circuits. Since the Project was planned in 2009 there had been an average reduction of 6.6% in maximum demand across the Trial circuits thereby increasing the amount of demand / generation that could have been connected without needing reinforcement. This change resulted in a lower need for reinforcement and hence less benefit offered to customers for accepting one of the trial contracts in the trial period.

The two options were to secure a lower number of agreements in the set time period or to submit a change request to extend the time period and still secure ten agreements. The decision was taken to submit a change request after carrying out a consultation with our academic partners and other DNO's. The reason behind this decision was that securing ten agreements would provide increased evidence of the acceptability to customers of such agreements when used to manage point load or generation growth. Such evidence was a key learning outcome from the project and likely to encourage the utilisation of the C_2C contracting methodology on a business-as-usual basis. Extending the project did also result in more customers directly benefiting from the Trial by obtaining a connection agreement that avoided the cost of reinforcement.

A wholesale review of 'all' potential C_2C opportunities was undertaken by looking at quotations that had been registered during the **six** months prior to the Project start date to ascertain if there were any C_2C opportunities. Quotations that had expired 12 months prior to the Project start date were also scrutinised to ascertain if there were any C_2C opportunities.



During the Trial period new connections volumes eligible for C_2C was 80 per month. Therefore to ensure GSoP compliance for standard quotations a twin track approach to producing C_2C quote was established. This allowed the connections planner to concentrate on business as usual standard quotations but additional internal resource was used to develop a C_2C Solution in a timely manner.

Ten new connection managed customer agreements were secured by March 2015 the agreed extension end date.

One area requiring modification was the need to consider interruptible capability for part of a customer's new supply. The traditional approach to accommodating new demand on the network was to consider the application for the demand as a whole. However, while making the C_2C presentations it became apparent that for both demand and generation new connection customers it was feasible for a C_2C solution to be offered that constrained only part of the demand. This allowed the customer to have part of their demand under normal conditions and the remainder under a C_2C constraint. Revision of the commercial framework to reflect this potential bespoke requirement has been made for future deployment.

6.3.3 Existing customer engagement and agreements

There were two issues encountered during the Project:

- Enernoc declined to participate in the tender process due to a change in their strategic direction and UK presence
- There was no consensus among Partners and suppliers around likely size of incentive required to motivate customers to enter into an existing customer managed agreement.

The competitive tender process was not envisaged as necessary when the Project plan was developed. This process culminated in npower being awarded the contract to secure ten existing customer agreements. Electricity North West also retained plans to work with original Project Partner Flexitricity to secure a small number of agreements.

It is of the opinion of Electricity North West that modifications to the planned approach were required as the intended process did not promote any competition amongst Partners and suppliers. In conducting the tender process, competition was created between potential suppliers which served to optimise the quoted commission costs. The innovative incentive arrangements that were proposed by the aggregators in the form of an inversely proportional aggregator commission customer contract cost relationship delivered maximum value from the proposition.

6.4 Evaluating and enabling the benefits of post-fault demand response

6.4.1 Network performance modelling

Quality of input data was essential to the modelling and simulation process. Errors and inconsistencies within data sources used for creating circuit simulation models required manual verification of circuits using operational diagrams. In addition historical feeder demand data was cleansed using a development script based on Chebyshev's inequality method.

Full monitoring (ie monitoring equipment installed at every HV substation on a ring) of one or more circuits was initially intended to build up high accuracy models with a full suite of monitoring input data. However 'full' monitoring was practically challenging due to operational constraints at many HV locations; thus rendering only some substations suitable. A simulation exercise was then conducted based on the models developed of the Trial circuits and the available monitoring data. Results revealed that the original methodology was not appropriate due to the wide variation of results dependent on circuit type. Therefore 'full' circuit monitoring of a relatively small number of circuits would be statistically insignificant. Consequently, this approach was not needed and the installation issues did not have a significant impact on the analysis results.

6.4.2 Economic and carbon modelling

For both cases of the carbon impact assessment and economic modelling the planned approach and outline methodology was developed in detail during the Project therefore all areas of challenge could be fully explored and subsequently critiqued. One area that was common to both work packages was the requirement to address future demand uncertainty through the concept of scenarios. Real data was collected about the C_2C Solution being deployed on Trial circuits, but it was quickly recognised that measuring these impacts would only identify a small part of the potential of the Solution and not reveal its broader consequences. Therefore multiple scenarios for future deployment were developed. These scenarios included drivers for deployment, ie general and point load growth reaching network constraints, and general properties of the energy system and scale of deployment. The calculations based on these assumed scenarios have been framed in a consistent and universal format such that they are transferable across scales and changeable based on input parameters.

Scenario methods are used to explore different technical or policy options when future circumstances are unknown and, due to the complexities of human society, unpredictable. Each scenario is not a forecast of a likely future, but rather a plausible and coherent set of future circumstances. Examining the performance of different options against these possible futures allows for more robust decision making.

6.4.3 The use of post-fault demand response in security of supply requirements

An industry consultation has always been in the scope of the Project. However it was decided to accelerate this consultation to avoid an overlap between it and the industry review of ER P2/6 and to fit in with Ofgem's timetables for ED1 and WS6 (Smart Grids Forum). Electricity North West believed it was beneficial to the Project and the industry as a whole to conclude this debate as soon as practicable. To that end the C_2C team have engaged with all the DNOs and various industry stakeholders.

7. SIGNIFICANT VARIANCE IN EXPECTED COSTS

The project will be completed within the £10 million budget with spend at £8.6m. Full project expenditure can be found in Appendix F.

£000s Cost Category	Total Forecast	Budget	Variance	Reasons for >10% variance
Labour	1,589	1,755	165	Lower than expected new connection volumes to study and lower IT maintenance costs
Equipment	2,625	3,078	452	Less new RC required due to existing RC on circuit selected
Contractors	2,790	3,012	222	Less new RC required due to existing RC on circuit selected
IT	610	740	129	License efficiencies
IPR costs	0	0	0	-
Travel & Expenses	0	0	0	-
Payments to users	239	300	61	Lower than expected payments to existing managed customers
Contingency	332	947	614	-
Decommissioning	0	0	0	-
Other	406	445	39	-

8. UPDATED BUSINESS CASE AND LESSONS LEARNT FOR THE METHOD

Customer benefits

The University of Manchester and Tyndall Centre for Climate Change Research has undertaken modelling work on the potential benefits of the rollout of C_2C into business as usual. This modelling was based on assessing the reinforcement needs and alternative C_2C Method based interventions across a representative sample of Trial circuits. Under the C_2C Project Electricity North West has robustly modelled the benefits arising from the Method.

Financial benefits

The principal benefit to customers of the C_2C Solution is that it enables significant additional network load and generation to be connected, without incurring the high levels of expenditure associated with traditional HV and EHV network reinforcement. Electricity North West's analysis shows that if the technical and commercial elements of the C_2C Solution were adopted across the Electricity North West network, it would release 3.1GW of existing capacity on the HV networks, without reinforcement. This is opposed to the 2.4GW suggested in the full submission. **This is an improvement of an additional 30% compared to the existing firm capacity released stated in the submission**. Analysis of electrical energy scenarios to 2050 suggests the C_2C Method with the availability of DSR could replace much of the traditional HV reinforcement activity up to 2050.

In this respect, given the context of adopting an operational strategy to substitute for traditional network reinforcements, a suitable framework has been developed that can properly quantify the different economic benefits and costs associated with the alternative network interventions. For such purposes, a search and optimisation model based on the Ofgem's RIIO-ED1 cost benefit analysis (CBA) framework has been used. The results from this are used as a robust means of updating the Project business case.

The model is used to evaluate the option to implement the C_2C Solution as a standalone alternative to traditional line and substation reinforcements or in conjunction with traditional interventions to form an optimised solution from a minimisation of network cost perspective. The framework captures the range of benefits generated by the Method with the introduction of a range of scenarios for future demand growth overlaid with best view forecasts. For clarity, investment strategies based on traditional reinforcements have been referred to as the baseline; whereas investments based on C_2C interventions have been called C_2C based investment strategies (C_2CS). It should be noted that realistic levels of DSR availability have been considered in this Solution. The investment strategy based on minimising network investment costs is referred to as the optimal investment strategy (OSI). The planning horizon for this updated analysis is 45 years and assumes a typical HV ring network requires intervention within the first three years.

For detailed set of assumptions and modelling input see Economic modelling sensitivity analysis.

The delivery of the required network capacity across the North West is dependent on the level of expected demand, based on a 20% peak demand increase plus the DECC High LCT uptake (scenario 1) and a 11% peak demand increase plus the DECC Low LCT uptake (scenario 4). The anticipated average costs are presented below.

	Baseline – scenario 1	C_2CS – scenario 1	OSI – scenario 1	Baseline – scenario 4	C_2CS – scenario 4	OSI – scenario 4
NW delivery cost	£370m	£430m	£320m	£250m	£190m	£160m
GB delivery cost	£5.08bn	£5.91bn	£4.40bn	£3.44bn	£2.61bn	£2.20bn

It is clear to see under high demand expectancy that the deployment of the C_2C Solution in conjunction with traditional reinforcement to form an economically optimised strategy has the potential to reduce total future HV network reinforcement costs (ie both customer and DNO funded) by approximately £50m. However, the avoidance of future expenditure under a lower demand requirement can be met with the C_2C Solution delivering £60m of benefits. Should the C_2C Solution be scaled up and rolled out across suitable GB networks, the customer savings are even more significant.

Importantly this saving would not require customers to moderate their load or generation usage in terms of time or level of use, other than under rare fault conditions. This limited restriction to customer usage of networks coupled with the significant financial savings on reinforcement costs are the principal customer benefits of the C_2C Project.

Carbon benefits

The C_2C Solution negates the need for much of the engineering works associated with reinforcement, by better using the installed network capacity. This has two significant spin off benefits.

Firstly it enables much more rapid connection of load and generation, as little or no engineering works are required. This will enable customers to move to low carbon heat and motive technologies and adopt distributed generation technologies without waiting for works to be completed (on the higher voltage networks). Based on advancing connections by around six months, the C_2C Method could directly claim to facilitate 39-67 thousand tCO2e of emissions reductions in Electricity North West network area (depending on how the capacity is used). On the scale of Great Britain, this carbon saving would be of the order of 0.5-0.9 million tCO2e to 2035. It is anticipated that this will become an increasingly important factor as the growth in connection of new loads and generation accelerates. Without such techniques network operators may not be able to construct sufficient capacity quickly enough to meet customer needs.

	Baseline - C_2C Scenario 1	Baseline - C_2C Scenario 4	Baseline - OSS Scenario 1	Baseline - OSS Scenario 4
Facilitated emissions reduction (tCO_2e)	67 000	39 000	54 000	36 000

Although enabling release of capacity is the primary benefit, the second benefit is that the technique significantly reduces the carbon associated with asset installation and construction, and it reduces disruption and pollution to customers arising from constructing these new assets. The Tyndall Centre indicates that C_2C Solution deployment in conjunction with strategic traditional reinforcement on Electricity North West's HV network in the period 2015 - 2035 would give a net network wide reduction of 237-328 tCO2e. This is based on saving some 58-89 thousand tCO2e network wide from reduced deployment of assets, but decreasing carbon associated with losses by 179-239 thousand tCO2e relative to traditional reinforcement techniques.

	C_2CS Scenario 1	C_2CS Scenario 4	OSS Scenario 1	OSS Scenario 4
Assets emissions reduction (tCO_2e)	77 000	110 000	58 000	89 000
Operations emissions reduction (tCO_2e)	-214 000	-106 000	179 000	239 000
Total reduction (tCO_2e)	-137 000	7 000	237 000	328 000

Non-quantified benefits

Whilst the C_2C Method demonstrates significant financial and carbon saving benefits it has been demonstrated that there are also a number of non-quantifiable benefits that should be noted. One of the key aspects of RIIO-ED1 is innovation. The C_2C Project has demonstrated innovation through pioneering use of quality of supply driven advancements, the development of new demand and/or generation side response arrangements and effective customer segmentation. Another key consideration of RIIO-ED1 is the delivery of network services with long-term value for money for existing and future consumers. Learning from C_2C the Project has informed whether the innovative use of automation and demand and/or generation side response can offset network reinforcement and pave the way for better value for money delivery of network services.

It has also informed that the Solution can play a role in the delivery of a sustainable energy sector, reducing the carbon intensity of current network operations.

In addition to alignment to the objectives of RIIO-ED1, the Method also supports the evolution of new forms of demand side contracts and hence promotes competition in the demand side response market. Traditional demand side response forms have not yet proven to be acceptable to customers without strong and often (from a DNO perspective) financially unjustified incentivisation. The introduction of new forms of low intrusion DSR will engage customers in the new DSR markets via connection benefits and thereby promote further follow-on DSR engagement. Network companies can be expected to support growth in the demand side and its integration into market and balancing activities. This will help ensure that benefits are passed through to the customer.

DNOs have the capability to earn a reward through a discretionary mechanism within the RIIO-ED1 framework by demonstrating a notable losses improvement. However DNOs currently have no regulatory incentive to benefit from reducing asset-related carbon emissions. Results from the C_2C Project will help inform this discussion, based on the relative changes in capital investment efficiencies versus losses, how that would affect the choice of circuits to which the C_2C Solution alone might be applied.

9. LESSONS LEARNT FOR FUTURE INNOVATION PROJECTS

Within the Electricity North West future networks team there is a close relationship between the Project delivery and bid development teams. The bid development team are notified of lessons learned via informal direct communication and more formally by inclusion in the review of six monthly progress reports and attendance of Project steering groups. Therefore, there is an ongoing process of informing the bid development team of lessons learned during delivery.

9.1 Customer engagement and feedback

9.1.1. Engaging and understanding I&C customers

Customer database: to recruit I&C customers to participate in the survey, Electricity North West provided Impact Research with a database of I&C customers on the selected C_2C circuits. However the database contained very few telephone numbers and one of the biggest barriers was the telephone number not being recognised. The lack of contact numbers is likely to be problem for any DNO whose customer records are sourced from the address management system (AMS) managed by suppliers as some customer records are incomplete or inaccurate.

As a distribution business, the absence of a detailed customer database also created challenges when attempting to contact role holders within organisations who were responsible for the energy usage. It took on average three calls to reach the most appropriate contact, which normally meant going through the switchboard, verifying the correct company, explaining the objective of research and then being referred on, which could involve multiple call backs. The switchboard can often be a blocker. Some companies operate a policy whereby they will not put callers through to the relevant department without a named contact. On these occasions list brokers and social media platforms like Linked In were used to source named contacts.

To replicate a similar activity, additional time should be allowed to source accurate telephone numbers and recruit customers to take part. It is recommended that a suitable fieldwork period for recruiting I&C customers to take part in a survey like this would be 6-8 weeks or ten weeks during seasons that include peak holiday periods like summer and Christmas. A partnership with a supplier/appropriate third party would also be beneficial to help obtain accurate customer data.

Survey completion incentivisation: to ensure the highest possible survey completion rate in the time permitted, a number of incentives and support arrangements were implemented, namely:

- Online vouchers were offered and processed if customers took part within a specified time
- Donations were offered to a choice of several different charities.

Amongst the population that were recruited, one of the biggest barriers to completing the survey was customers not having time to take part within the survey fieldwork period allocated. The main issue was that the survey was considered important but not urgent hence, a lot of the 500 customers who had initially agreed to take part, did not, despite the significant effort that went into finding the most suitable person to speak to followed by a number of reminders. It became apparent after a short time that I&C customers placed a much higher value on their time than anticipated and required a wider range of support and incentives to be offered, namely:

- A Kindle prize draw to all participants
- Interviewer assisted telephone surveys instead of an online self-completion method
- Appointments to complete the survey at convenient times for customers, sometimes out of hours
- Providing proof of donations to charities on request.

This led to an increase in the number of completed surveys during the later stages of fieldwork which meant a statistically robust sample size could be attained. When considering recruiting I&C customers to participate in research, consideration should be given to offering a wide range of support and incentives.

The use of third party aggregators: as part of the original Project plan and in addition to Electricity North West, it was the role of EnerNOC, Flexitricity and npower to achieve ten acceptances of the C_2C managed connection agreement. However, customer feedback in the post acceptance survey has suggested that this is not the optimal method of engaging with customers in the first instance. Only a quarter of customers who accepted the C_2C managed connection agreement were comfortable with being approached by a third party aggregator. It is therefore recommended that the commercialisation of the C_2C Method is achieved through customers having direct communication (preferably face-to-face) with a single point of contact at their respective DNO.

Quantifying the cost of an interruption to customers' supply: the post acceptance survey analysis demonstrated the importance of the risk versus reward ratio for organisations, when decision makers are contemplating the appeal of the C_2C commercial agreement. It would therefore be prudent in future research of a similar nature to acquire a deeper understanding of this aspect of an organisation's decision-making process. This would aid a DNOs' understanding of, for example, the financial cost to a customer of losing a day of power. This would subsequently assist in improving the financial rewards offered within the C_2C commercial agreement and their targeting to specific types of organisations.

9.1.2 Communicating with domestic customers

Engaged customer panel: The ECP demonstrated that customers have little or no understanding of Electricity North West, the role of a DNO versus suppliers, decarbonisation, the increasing demand for electricity and the need to potentially expand the electricity network. Participants needed an understanding of this before the concept of C_2C could be introduced.

The ECP further demonstrated that the most effective way of communicating this information is through a simple question and answer factsheet, video material and a C_2C concept board which explains how C_2C could address the Problem and how customers on a C_2C Trial circuit were affected. To maintain interest and credibility customers must also be reassured on the reliability of their supply.

A key learning outcome was that most customers needed educating about the role of DNOs and why projects such as C_2C are necessary to meet future electricity demand. Only when this had been established could awareness material on the Project be effectively presented. When forming an ECP, consideration must be given firstly to educating customers about the electricity sector and the current challenges it faces. As the C_2C ECP was the first to be undertaken by the future networks team, it has provided knowledge and experience on which to base successful ECPs for future second tier projects.

9.1.3 Monitoring the effects of DSR on customers

Post-fault survey: any research with customers regarding a specific event must be conducted as soon as possible after the event. Originally customers were surveyed within five days of the fault but the majority of customers could not recall (unprompted) the time and date of the relevant fault and approximately a quarter could not recall the duration. The increased number of SDIs further contributed to this. However, 14% of customers who could not remember the fault duration claim it was because the fault was too long ago.

The implication of this is that any future customer engagement on a specific event must be carried out promptly after the event to maximise the volume of customers who recall a fault and minimise any possible confusion with other events. It is recommended that post-event customer engagement takes place within 48-72 hours of the event occurring.

PSR customers: Levels of acceptance of fault durations are generally higher amongst vulnerable customers than the rest of the population. However, analysis shows that these levels vary according to the reason for which customers are eligible for priority service. The highest levels of acceptance were amongst customers aged 60 years or older, while customers with medical equipment at home were the least accepting. This suggests that for PSR customers, individual circumstances are more likely to influence perception and tolerance of a fault, whether under C_2C or 'business as usual' conditions.

Use of network data: extracting, matching and overlaying fault data onto customer perception information provides considerable insight into the drivers of power supply quality. This exercise involves careful analysis of what, if anything, the customer has detected compared to actual faults and the duration of those fault(s) should they fall within the same time period.

This exercise has validated the hypothesis that the C_2C Method does decrease the average fault duration and improve power quality for those directly exposed to C_2C conditions. Without differentiating between C_2C activated faults and other faults on C_2C Trial circuits, it would not have been possible to support the hypothesis with such confidence.

Nor would it have been possible to understand the extent to which customers actually find fault occasions discernible. Significantly more customers on control circuits failed to correctly identify the existence (or not) of a fault during the C_2C Trial period. There may be some correlation here with the significantly higher (perceived) observation of dips and spikes on control circuits, with the possibility that some customers confuse dips and spikes as being supply interruptions.

I&C customer sample: the proactive monitoring survey methodology was predominantly focused on achieving a robust and representative sample of domestic customers on C_2C Trial circuits and control circuits. To supplement this, the views of a small number of I&C customers on C_2C Trial circuits were captured, mainly as a means of comparing the ten I&C customers who had signed up to the C_2C Trial.

A sample of approximately 50 I&C customers surveyed in each phase of the research would have provided greater opportunity for statistical analysis. For instance, the ability to understand sensitivity to changes in power quality in different I&C industry sectors.

It is also worth noting that the addition of an I&C benchmark of customers on control circuits would have enhanced the significance of the findings that can be drawn from changes in power quality perception on C_2C Trial circuits amongst I&C customers.

9.2 Technology implementation and effectiveness

9.2.1 Trial area selection and deployment

When considering the requirement to pre-select the Trial circuits it was important to avoid any potential customer discrimination concerns. Retrospectively for the purposes of running a successful Trial that maximised learning potential and attracted the most participants it may have been preferable to select C_2C circuits on a first come first served basis where they meet the technical viability criteria.

A note of caution with this approach: it may have required a reactive process for application of required P2/6 derogations on potential areas of non-compliance.

The selection criteria placed an upper limit on circuit fault rate and excluded circuits from the Trial where there had been greater than five faults in the preceding five years. The rationale was that when radial circuits were combined to make closed ring circuits the fault rate is inherently doubled and it was judged that this would lead to an unsatisfactory level of interruptions for Trial participants. The count of historic faults included faults on 'spur' lines that in hindsight could have been discounted as for the majority of instances this does not affect the main line and hence would not lead to an unsatisfactory high level of system performance. This would have increased the number of potential rural circuits beyond the representative number in the selection and enabled further learning on this class of circuit.

9.2.2 Development of adaptive network control functionality

Network automation functionality

During the Trial the RC devices were contacted by GSM dial-up which meant that an RC device with communication issues would not come to light until a connection attempt was made. As part of a wider regular testing schedule, devices are called every evening but the connection issues can be intermittent and are not always captured. During the Trial RC failure did not have a significant impact on system performance. However Electricity North West recognises that to deliver increasing levels of adaptive network control, a high level of automation availability is required. Therefore post Trial, the RC devices are moving to a centralised scanned system where the devices are connected at all times and any communication issues will be apparent in real time. It is also worth noting that should issues arise then a DNO may consider a priority repair system for critical RC devices unless there is NMS capability to re-assign to an alternative device.

Network management system development

The network management system has ARS software which carries out automatic sectionalisation of an HV ring in the event of a fault. For the Trial every closed NOP which formed a ring was referenced at the primary circuit breakers so that ARS knew which RC device to open to split the ring. This referencing involved manually writing the RC switch reference in both primary circuit breakers' records. This was time consuming and had to be checked for data errors a number of times to confirm correct. Moving to a BAU situation ARS should be able to automatically select the closed NOP on a C_2C ring which would remove the need for this manual selection.

For the Trial, ARS would try to open the closed NOP on two occasions. If this device failed to open or confirm open, for example, due to a communication issue, then the sequence would stop leaving all customers off supply. This was not an issue in the Trial but could be if deployed on a greater network area. In the event of failure to open off a closed NOP RC device, the ARS software should be altered to look at using other RC devices in the ring that will enable a circuit split and minimise customer restoration times.

Automation of customers demands

It is the view of Electricity North West that the installation of automation at customers' premises proved successful and enabled their electricity demand to be controlled.

In terms of project management it would have been easier to identify the automation solutions required for managing customers' load early in the Project so that this could be used as a cost effective criterion for selecting existing and new customers.

Selecting customers prior to developing automation solutions led to delays in the installation of control mechanisms for customers' load. While Electricity North West had automation solutions for ring switches on its own HV ring main units, there was a requirement for retrofit solutions to be developed and approved for the HV circuit breaker controlling the customers' load. Similarly there was a requirement to develop technical solutions to control and manage LV loads.

The installation of automated switches to customers' LV and HV switchboards highlighted a number of issues:

- A responsibility schedule was required to clearly show the control boundary
- The HV switch was not part of the Electricity North West network unless there was an HV operation and maintenance contract in place with Electricity North West
- The customer required the capability of manually controlling their switch so it was feasible that they could override the automation
- RTUs installed in customers' switchrooms could be switched to manual by the customer thereby disabling the automation
- Electricity North West operational staff were not familiar with the operation of customers' LV switchgear and required training
- The introduction of new types of automation to the Electricity North West network required company policies to be updated and approved prior to installation.

Electricity North West now recognises that the requirement to develop technical solutions to control the customer's demand in all possible connection situations is not feasible (specifically Long & Crawford GF3 variants subject to an operational instruction limiting their operation and Schneider RN2C). Therefore C_2C solutions involving additional loads or the purchase of network capacity should be restricted to those customers for which a technical solution to control demand is available. Any customer supplied at LV requires a bespoke solution on their switchgear.

9.3 Developing the commercial framework for post-fault demand response services

9.3.1 Commercial templates

Due to the extensive engagement required to develop the commercial templates it has been concluded that any form of new customer contractual relationship requires open and honest discussions. Customers' acceptance of the new arrangements changed as the concept became more clearly understood and as a result, their attitude to risk also changed. This was particularly noticeable for those customers that went on to sign a C_2C managed agreement. The risk vs. reward balance was at the heart of the decision-making process. Customers and Electricity North West quickly learnt that it was essential to help potential participants develop their own impact assessments for a C_2C event.

9.3.2 Purchase of demand response from new customers

During the Trial the volume of new connections requiring reinforcement was lower than anticipated and investigation revealed that the maximum demand loadings of primary transformers had fallen by 6.6% in the period 2009 to 2013 which resulted in more headroom being available on the HV network. This resulted in significantly fewer eligible C_2C opportunities. However it was still essential for Electricity North West to evaluate the suitability of the C_2C Method as an alternative to network reinforcement for new connection customers. Therefore a detailed and extensive customer engagement and education exercise was carried out with all eligible Trial participants. Establishing closer relationships with connections applicants led to a better understanding of their needs and highlighted a number of key learning points that are important for rollout success:

- Until the concept of post-fault demand response is mature it may be necessary to present the C_2C solution personally to the new connections customer in order to articulate and explain the benefit of a constrained electricity supply. Based on Trial experiences the original applicant was not the end-user and therefore could not enter into the managed connection agreement. So additional presentations were required to brief client technical representatives, financial representatives and senior management to decide on the C_2C offer. Sustained engagement is fundamental to giving customers confidence in a managed connections arrangement. DNOs need to commit resource to this in the early stages of rollout.
- The traditional approach to accommodating new demand on the network was to consider the application for the demand as a whole. However, whilst making many of the C_2C presentations to potential eligible new connections customers it became apparent that for both demand and generation that it was feasible for a C_2C Solution to be offered that constrained part of the demand. This allowed the customer to have part of their demand under normal conditions and the remainder under a C_2C constraint. Revision of the commercial framework to reflect this potential bespoke requirement has been made for future deployment.

9.3.3 Existing customer engagement and agreements

It is the view of Electricity North West that the tender process proved successful and created competition resulting in reduced Project cost and therefore reduced overall cost for customers. Where it is not practical to complete this type of work during the preparation of the bid, Electricity North West now recognises the value of creating competition in areas where it is in the best interest of customers to do so. If this scenario were to repeat itself the high level process would be documented within the bid document and all stakeholders made aware of the need and intention to create competition.

In addition, placing KPIs within the contract with npower allowed an option for Electricity North West to step in if the schedule was not adhered to. This option was exercised to ensure the contracts were procured in a timely fashion. It also resulted in a balance of five agreements procured directly, four via npower acting as agent for Electricity North West and one using Flexitricity aggregator arrangements.

9.4 Evaluating and enabling the benefits of post-fault demand response

9.4.1 Network performance modelling

Many of the power quality monitoring challenges encountered did not affect the results of the C_2C analysis work, but may be relevant for other applications and to DNOs wanting to track the long-term effects of any new intervention on the network.

Deployment and organisation

Pre-existing remote communications provided a significant initial cost saving during the Trial, because the following costs were avoided: communications hardware; a mobile data plan from a mobile service provider (assuming this approach is used); and the central server for data storage. There may also be issues with poor or non-existent mobile coverage at some locations. Periodic visits to monitoring locations are required to collect data, which has an associated cost and is time-consuming. It is difficult to know that a monitoring device has malfunctioned until the substation is next visited. Retrieving data from a monitoring device will likely cause an interruption to the monitoring. There is a significant amount of work involved with manually copying data from a ‘batch’ of multiple devices (each of which may contain many thousands of small files, which exacerbates the problem) and organising the aggregate data into directories. This process is also very prone to errors and, where possible, should be automated. There is limited opportunity for the clocks of monitoring devices to be cost-effectively synchronised automatically (eg using Simple Network Time Protocol). However, a local GPS receiver or an atomic clock could provide excellent absolute time accuracy, if required by the application.

Recovering from errors

Some issues can be detected and resolved after the data have been collected. Nevertheless, a relatively simple problem can affect multiple derived measurements, and can entail a complex post-processing stage to correct the initial error. For example, an incorrect current sensor polarity affects: real power (load on the affected phase would appear as generation), power factor, negative sequence, and harmonic angles. Furthermore, if the monitoring device calculates minimum, maximum, and average values over a given sampling period (either on a per-phase basis, or as an average of the individual phases), then all these values may need to be retrospectively recalculated (if possible) to properly reconstruct the actual data. There is also the possibility of confusing genuine anomalies with installation errors. For example, although generation on just a single phase is unlikely in practice, it is possible and such unusual behaviour would be of interest to the network operator.

It is likely that the data storage scheme used by the monitoring device is not suitable for scaling to analysis applications that involve multiple monitoring locations and require random access to the data. For example, CSV files are very inefficient because numerical values are encoded as text, which increases storage requirements and requires conversion for querying data. Therefore the data must be pre-processed and added to a suitable database; this may be a time-consuming operation, but only needs to be implemented once. Data should be stored as efficiently as possible, but without affecting the precision of the measurements. Many databases support real-time lossless compression (and there are trade-offs for various algorithms), with only a small performance penalty. In some cases, compression can improve performance due to reduced disk accesses. It may not be necessary to use a relational database (such as Oracle, MySQL or PostgreSQL) if no foreign keys are required in the database schema. Therefore, simpler 'table-based' storage formats, such as the hierarchical data format (HDF), could be used.

Care must be taken when attempting to visualise yearly trends from, for example, five-minute sampled data; over a year this involves over 100 000 values per measurement point. An appropriate algorithm must be used to down-sample the data for visualisation; otherwise aliasing may distort the data. Furthermore, five-minute minimum and five-minute maximum values should not be averaged over time when re-sampled because this would 'flatten' trends.

9.4.2 Economic and carbon modelling

Carbon impact assessment

As well as the specific outcomes in relation to the C_2C Trial, the carbon impact assessment has identified a number of important issues in consideration of the carbon impact of smart grid solutions.

- A new method for estimating emissions reductions from direct and indirect sources has been demonstrated including a means of calculating short-term facilitated carbon reductions, a novel impact category in the GHG accounting literature. Trial scale and future scenarios have been defined, boundaries clarified, baselines established and data sources identified.
- Capacity released is a poor proxy for net carbon impact. Facilitated reductions are highly conditional on assumptions, vulnerable to double counting, and for the demand growth set of scenarios examined, substantially lower than the absolute changes identified in assets and operations.
- A demand growth trend increases the losses in all circuits as they approach their firm capacity. In the base case this phenomenon is partially offset by a reduction in impedance that accompanies the introduction of traditional reinforcement assets. However, smart solutions such as C_2C will enable greater utilisation of assets and defer capital network investment at the expense of comparatively higher losses.

Economic modelling

As analysis for this work package was only contained to the 36 HV meshed C_2C networks, the computational challenges associated with systematic search and optimisation solutions could be managed. However computational challenges may arise in future applications of the Method, particularly if the analysis were to be extended to the LV network, the rest of the HV network and/or the EHV network. For example:

- Part of the study requires the use of optimisation engines, which are commonly available for universities, but are not widespread amongst DNOs. Furthermore, due to the complexity of the distribution network and the investment decisions that have to be considered when modelling the C_2C Method, commercial optimisation software would be unable to guarantee acceptable results (or finding a feasible solution). Therefore a bespoke optimisation engine was developed using the most basic programming functions to facilitate replication in most available programming languages (eg C/C++, Fortran and Java). The nature of the optimisation engine would, in principle, facilitate its use by other DNOs. Another key characteristic of the optimisation engine is its use of heuristics (ie exhaustive searches) rather than mathematical programming tools, which allows the engine to guarantee finding optimal solutions regardless of the complexity of the study. However, it is important to note that exhaustive searches can become computationally expensive (or unfeasible) for large problems,. This was manageable in this study due to the relatively small size of the problem and the use of techniques to further reduce the size of the problem.
- If the C_2C Method were to be extended to include the LV, EHV and/or rest of the HV network, the associated optimisation problems may become computationally difficult. Additional search space reduction techniques could be developed to reduce the size of the problem and potentially make it

feasible. Alternatively, the problem would have to be simplified to allow computational flexibility, with the cost of reducing the fidelity of the model and thus the accuracy of the solutions.

10. PROJECT REPLICATION

10.1 Customer engagement and feedback

10.1.1. Engaging and understanding I&C customers

The list of physical components required to replicate this activity is shown below:

- Customer video
- Customer leaflet
- I&C questionnaire
- Database of I&C customers in Trial area.

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

- Knowledge of Trial area
- Knowledge of methods used to enhance the accuracy of customer contact data
- Knowledge of various methods of recruiting participants for survey
- Knowledge of market research methodology and execution, including, but not limited to, survey design and statistical analysis
- Knowledge of IT systems to produce the physical components above for recruitment, design, analysis and reporting.

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

- Producing a video - £9k
- I&C survey - £98k
- Designing, printing and mailing a leaflet (including USB video) to 1400 customers - £42k.

10.1.2 Communicating with domestic customers

The list of physical components required to replicate this activity is shown below:

- Recruitment quotas
- Recruitment screener
- Stimulus materials
- Discussion guide
- Database of customers in the Trial area.

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

- Knowledge of Trial area
- Knowledge of customer mix on Trial area
- Knowledge of various methods of recruiting customers for ECP
- Knowledge of qualitative research methods required to produce the physical components listed above for recruitment, design, analysis and reporting.

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

- Conducting an ECP (nine focus groups across three phases and two locations) - £40k
- Designing and printing a leaflet - £8k
- Mailing a leaflet to 320,000 customers - £35k.

10.1.3 Monitoring the effects of demand side response on customers

The list of physical components required to replicate this activity is shown below:

- Database of customer MPANS on Trial circuits
- Sample of customer MPANs not on Trial circuits for control group (similar in customer mix and typology to Trial group)
- Post-fault survey
- Ongoing monitoring survey.

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

- Knowledge of customer mix in Trial area
- Knowledge of methods used to enhance the accuracy of customer contact data
- Knowledge of various methods of recruiting participants for survey

- Knowledge of market research methodology and execution, including but not limited to survey design and statistical analysis
- Knowledge of IT systems to produce the physical components above

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

- Post-fault survey - £55k
- Ongoing monitoring survey - £52k.

10.2 Technology implementation and effectiveness

10.2.1 Trial area selection and deployment

The following list contains the necessary information to replicate this activity

- The C_2C Trial circuit selection criteria.
- Nafirs fault statistics
- HV network diagrams
- DNO asset register to identify plant types and constraints.

10.2.2 Development of adaptive network control functionality

Network automation functionality

Network automation is an established business as usual activity for all DNOs, with a range of commercially available RC and associated communication equipment.

Network management system development

All the automation restoration sequence algorithms, real-time power flow analysis and customer management and optimisation required to implement the C_2C Method have been productised by GE and are commercially available as an option associated with the PowerOn APRS module.

Automation of customers' loads

The physical components required are a range of factory fitted or retro-fit actuators for the range of HV switchgear that controls customers' load. For LV switchgear it is necessary to either install a motorised MCCB in series with the customer's incoming supply or change the customer's main switch for a motorised unit. For any type of actuation a remote terminal unit (RTU) is required to provide a communication link to the central control system.

Actuators, LV MCCBs and RTUs are commercially available from either switchgear manufacturers or independent suppliers (retro fit units).

For business as usual, detail of the newly developed actuators need to be incorporated in company standards. Embedding devices within customer HV/LV networks should be considered for the purposes of operations and maintenance.

The anticipated business as usual cost of installing automation is in the order of £5k for each installation.

10.3 Developing the commercial framework for post-fault demand response services

10.3.1 Commercial templates

The following components are required to replicate this activity:

- Customer segmentation report
- National Terms of Connection Agreement
- Distribution Connection and Use of System Agreement (DCUSA)
- C_2C knowledge sharing event slide pack

10.3.2 Purchase of demand response from new customers

- Process charts
- New customer agreements.

If limiting size of C_2C rollout:

- Postcode checker on website (for customers)
- Internal postcode checker (for identification of connection applications close to C_2C circuits).

10.4.3 Existing customer engagement and agreements

Existing customer agreements

The anticipated business as usual costs of conducting a tender for the supply of aggregator services to purchase post-fault DSR are in the region of £30k.

10.4 Evaluating and enabling the benefits of post-fault demand response

10.4.1 Network performance modelling

Simulation studies: Software components

Name	License	Role	Comments
IPSA 2.4.2	Commercial	Simulation of Electricity North West circuits: load flow and fault level studies	This requires licenses for the load flow and fault level components of IPSA. The license may also need to support a relatively large number of busbars to successfully import real circuit data
Python	Free, open source	Automation of simulation processing and generation of results	
Multi-processing	Free, open source	Distributes circuit processing efficiently over multiple CPU cores	Python library
Networkx	Free, open source	Manipulation of circuit data as mathematical graphs	Python library
Numpy	Free, open source	Numerical analysis of simulation results	Python library
Matplotlib	Free, open source	Visualisation of simulation results	Python library
MATLAB R2014b	Commercial	Pre-processing of historical feeder demand data	
Python	Free, open source	Automation of processing and generation of results	
Pytables	Free, open source	Efficient storage and querying of power quality monitoring data	Python library
Numpy	Free, open source	Numerical analysis of data	Python library
Matplotlib	Free, open source	Visualisation of results	Python library
MATLAB R2014b, with Simulink	Commercial	Monte Carlo simulations of THD	

Data requirements

- Circuit data (either as IPSA files, or a format that can be converted to IPSA)
- Impedance data for circuit conductor types
- Circuit meta-data, including: nominal voltage, NOP locations etc
- Circuit historical demand data (or other method of obtaining loss load factor values for all circuits)
- Circuit operational diagrams for manual verification of circuit topologies
- Access to Electricity North West Long Term Development Statement data [1].

Power quality analysis: Software components

Data requirements

- Power quality monitoring data, captured during the Project Trial. The data must be organised in a consistent format to facilitate pre-processing
- Log of all relevant circuit switching activities for duration of Project Trial.

Power quality monitoring: Software components

Name	License	Role	Comments
Python	Free, open source	Automation of processing and generation of results	
Pytables	Free, open source	Efficient storage and querying of power quality monitoring data	Python library
Numpy	Free, open source	Numerical analysis of data	Python library
Pandas	Free, open source	Processing of large amounts of time-series data	Python library
Twisted	Free, open source	Web server	Python library
Ultra JSON	Free, open source	Encoding of data for HTTP-based API	Python library

Data requirements

- Pre-processed monitoring data

Access to intellectual property

Graphical access to the power monitoring data captured during the C_2C Trial is publically available on the University of Strathclyde's website. Access to the raw data is also available on the C_2C project website.

References

[1] Electricity North West Ltd, '*Long Term Development Statement - Fault level information,'* 2014. [Online]. Available: https://www.enwl.co.uk/secure-area/ltds-document-library/fault-level-information.

[2] X. Chen, C. Kang, X. Tong, Q. Xia, and J. Yang, '*Improving the Accuracy of Bus Load Forecasting by a Two-Stage Bad Data Identification Method*,' IEEE Trans. Power Syst., vol. 29, no. 4, pp. 1–8, 2014.

[3] CIGRE/CIRED Joint Working Group C4.112, *Guidelines for Power Quality Monitoring: Measurement Locations, Processing and Presentation of Data*. 2014.

10.4.2 Economic and carbon modelling

Carbon Impact Assessment:

The following list contains the necessary information to replicate this activity

- SimaPro software.
- Database of asset embodied carbon
- Reinforcement and power flow simulation delivering the following time series outputs:
  - Assets required (line km, numbers of transformers in 4 size classes)
  - Losses attributed to network (MWh)
  - Losses attributed to DG (MWh)
  - Capacity released (MW)
- Scenarios of grid carbon intensity through relevant period

References

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

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

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

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

Jones, C. I. and M. C. McManus (2010). "*Life-cycle assessment of 11 kV electrical overhead lines and underground cables.*" Journal of Cleaner Production 18(14): 1464-1477.

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

Turconi, R., C. G. Simonsen, I. P. Byriel and T. Astrup (2014). *"Life cycle assessment of the Danish electricity distribution network."* International Journal of Life Cycle Assessment 19(1): 100-108

Economic modelling:

The following list contains the necessary information to replicate this activity

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

Knowledge required to replicate the outcome:

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

11. PLANNED IMPLEMENTATION

During the lifetime of the Project the C_2C concept has become readily established and has subsequently been deployed by other DNOs as a business as usual activity. For Electricity North West, the C_2C Method will form part of a suite of strategic interventions for RIIO-ED1 and where appropriate, actively implemented to defer or avoid network reinforcement issues. As expected the deployment of the Method will be reviewed on an individual need basis and subject to a favourable business case comparison to other solutions.

In terms of deciding how and when to implement the Method, Electricity North West is building on the learning from the Project which identified the factors the make the solution most attractive and allow for full realisation of benefits from a technical and commercial perspective. The requirement for network capacity in a particular location, via DSR or other means, is dependent on the level of demand response required over time. So to facilitate the transfer of C_2C to business as usual, Electricity North West identified two needs which have been addressed since late 2013 in the IFI project 'Demand Forecasts and Real Options'. The former project has improved peak demand forecasts, resolving uncertainties where possible by improvements to inputs and methodology, and acknowledging the significant remaining uncertainties by generating credible sets of scenarios. The bulk of these improvements are being delivered now for implementation in June 2015. Secondly the latter IFI project has worked with the University of Manchester to build a prototype 'Real Options' decision-support tool. This provides cost and risk information to assist decisions about when C_2C and/or different scales of traditional reinforcement are the best ways to provide capacity. The tool reflects the learning from the Tier 2 project about the form and costs of deploying C_2C, and about the technical limits to C_2C DSR capacity release. The tool also uses the improved demand scenarios and extra information about C_2C potential for a particular network. The prototype real-options tool is still at an early stage of development, but is expected to demonstrate what price and scale of C_2C would provide value for customers and a DNO, compared to the traditional reinforcement strategy.

Electricity North West is implementing one of the Project's key technical recommendations – that networks should be analysed on an individual basis, as generalisation of benefits is not accurate and very much specific to the combination of network composition, topology and demand locations. To this extent company planning policy is being updated to reflect the requirements of the C_2C Solution. During first stage deployment of the C_2C Method Electricity North West will employ a radial network configuration. The requirement for closed ring C_2C will be implemented thereafter where it leads to additional latent capacity release and significant losses improvement can be achieved. In order to realise maximum network rollout Electricity North West is actively seeking a commercially available ret-vac solution for hand-charged switchgear variants.

Implementation of the Solution is dependent on development work currently being undertaken in Electricity North West's new NMS. This will replicate the functionality provided during the Trial across the entire network. Namely it will have the ability to disconnect all or part of a managed customer's system in the event of a fault and then optimise the reconnection of customers in accordance with network and contractual constraints after the network fault has been isolated.

As part of the Project, Electricity North West has produced commercial templates for the provision of post-fault DSR from existing or new customers with demand and/or generation capability. For Electricity North West the templates are ready for BAU, other DNOs will need to review and modify the templates to align with their own standard terms and conditions. As an indicator of changing customer expectations for innovative cost effective solutions, within the Electricity North West area the C_2C commercial offering has become the standard solution for all DG new connections. It is intended that this arrangement will remain in place based on excellent feedback regarding cost of connection and speed of facilitating such connection.

It was apparent from the Project that there are expected commission levels associated with using external organisations to procure DSR on a DNO's behalf. The Project also raised the question of how effective third parties are compared to a DNO's own resources. Based on the agent/aggregator set up and commission fees identified during the Project, Electricity North West has taken the decision that under business as usual they will perform this activity 'in house'. Currently a DSR implementation team is being established to fulfil the customer identification and contract negotiations requirements.

Electricity North West is establishing a suite of standard technical solutions to control customers' load and incorporate them in company planning policy. This will include the operation and maintenance of the technical solutions in the company operations manual. Familiarisation of all operational staff with the range of technical automation solutions especially those installed on customers' networks will be undertaken.

12. LEARNING DISSEMINATION

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

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

- Customer engagement and feedback
- Technology implementation and effectiveness
- Commercial framework for demand response services
- Evaluating the benefits of post-fault demand response.

A peer review of the closedown report was completed by Northern Powergrid. Suggested improvements and recommendations that will enable other DNO's to understand and implement C_2C were received and adjustments to the closedown report made. See Appendix G.

In addition a summary of the Project outcomes and lessons learned have been presented at the following events: C_2C April 2013 knowledge dissemination event, November 2013 LCNF Conference, C_2C January 2015 knowledge dissemination event.

Electricity North West has conducted a consultation with other DNOs at the '2014 LCNI Fund DNO Only Day' regarding preferred methods to receive learning. Electricity North West will offer bespoke 1:1 knowledge dissemination sessions with each DNO and Ofgem. All knowledge dissemination material has been published on the Project website and key stakeholders made aware of the material and how to access it.

13. KEY PROJECT LEARNING DOCUMENTS

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

13.1 Project progress reports

Title	Date	Website Link
Project Progress Report No 1	18 June 2012	Progress report no 1
Project Progress Report No 2	13 December 2012	Progress report no 2
Project Progress Report No 3	13 June 2013	Progress report no 3
Project Progress Report No 4	16 December 2013	Progress report no 4
Project Progress Report No 5	19 June 2014	Progress report no 5
Project Progress Report No 6	19 December 2014	Progress report no 6

13.2 Key learning documents

Title	Date	Summary	Website Link
Customer segmentation report	Aug 2012	Learning from a strategic piece of market research undertaken to understand the potential take-up of new demand side response commercial offerings across various customer segments.	Customer segmentation report
Customer survey white paper	Oct 2012	This paper describes the research designed to identify the level of interest in C_2C, the needs of different customer segments and the value they place on the different elements of a C_2C contract.	White paper – C_2C customer survey
White paper – circuit selection	Dec 2012	This paper looks at learning from the selection of circuits as part of a wide-scale post-fault demand side response Trial	White paper Dec 2012
Engaged customer panel findings	Mar 2013	Research undertaken with an engaged customer panel which helped formulate effective communication plans to customers affected by C_2C.	Engaged customer panel report
White paper - Calculating network losses	June 2013	This paper describes the effects of meshed distribution system operation on network electrical losses within C_2C.	Calculation network losses
Accommodating DSR in ER P2-6	Feb 2014	This report presents the results of a review of ER P2/61, its supporting document ETR 1302 and a set of proposed changes to how they might accommodate responsive demand.	Accommodating DSR in ER P2-6
Technical data	April 2014	As part of the ongoing work to understand the capability and benefits of the C_2C closed ring configuration, network monitoring devices were deployed on 36 closed ring networks. The raw data from these monitoring devices was updated regularly during the Trial and made available on the website.	Technical data
White paper - Carbon impact assessment	June 2014	Findings from the Tyndall Centre for Climate Change Research on carbon impact, the major sources of emissions and areas where C_2C can provide savings and where it may increase emissions.	Carbon impact assessment
Carbon impact assessment methodology and literature review	June 2014	This review and methodology examines the academic literature on carbon accounting and the environmental impact of electricity networks.	Carbon impact assessment methodology and literature review
White paper - DG capacity	Dec 2014	This paper documents work undertaken by the University of Strathclyde to quantify the ability of C_2C network operation to accommodate additional DG capacity. This has been achieved using simulation models based upon actual system data from a representative proportion of the C_2C Trial circuits.	DG capacity
Development of cost benefit analysis methodology	Nov 2014	This work seeks to set the basis for a general framework for the economic assessment of the C_2C solution as an alternative to traditional network reinforcement practices.	Economic modelling methodology
Analysis of technical performance	Dec 2014	This report documents work undertaken by the University of Strathclyde to quantify the technical performance of C_2C network operation on electrical distribution systems.	Technical performance report
Sensitivity analysis of the expected economic value of the C_2C method	Jan 2015	A report on the general framework for the economic assessment of the C_2C solution as an alternative to traditional network reinforcement practices	Economic modelling sensitivity analysis

Title	Date	Summary	Website Link
Carbon impact assessment scenario results	Feb 2015	Scenario methods are used to explore different technical or policy options when future circumstances are unknown and, due to the complexities of human society, unpredictable.	Carbon impact assessment scenario results
Carbon impact assessment trial results	Feb 2015	The purpose of this research is to quantify the impact of the C_2C Solution, compare this to traditional reinforcement and understand the major sources of emissions in each to better enable management of distribution networks.	Carbon impact assessment trial results
Carbon impact assessment report	Mar 2015	This report describes a suite of scenarios for 36 circuits exploring the potential impact of the C_2C Solution under different future circumstances.	Final carbon impact assessment report
White paper - Demand response in smart distribution network planning	March 2015	This paper proposes a methodology to explicitly model and quantify capital and social costs trade-offs, which can be incorporated into the existing distribution networks regulatory framework.	White paper - Demand response in smart distribution network planning
Reactive post-fault customer report	March 2015	Findings from customer survey carried out to understand acceptability of fault duration as opposed to other measures of power quality.	Reactive post-fault customer report
Proactive power quality monitoring report	March 2015	Findings from quantitative customer survey into customers' perceptions of their power quality and reliability during the Trial period.	Proactive power quality monitoring report

14. CONTACT DETAILS

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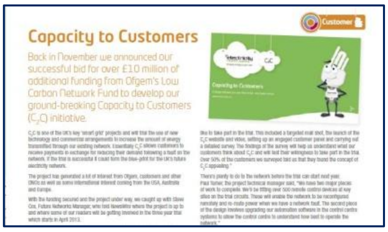
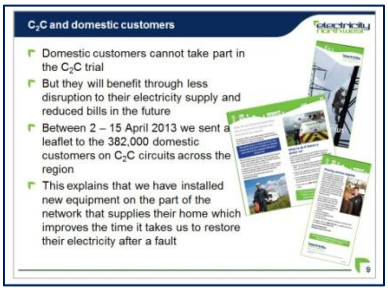
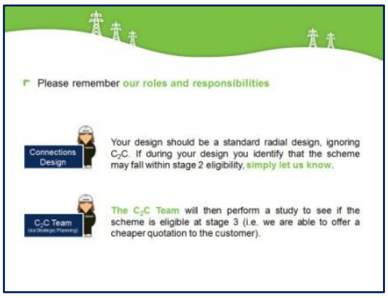
APPENDICES

Appendix A: Capacity to Customers learning and dissemination activities

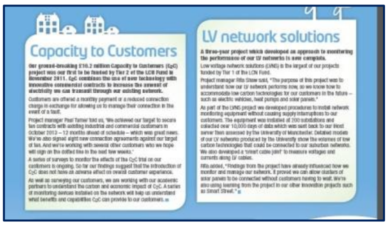
Date	Activity	Audience	Evidence
Nov 2011	Flash video explaining C_2C concept	All	You Tube
June 2012	Launch C_2C website	All	C_2C website
June 2012	Publish Trial circuits	Trial customers	Trial area postcode search
June 2012	Six-monthly Project progress report no 1	Ofgem	Project progress report no 1
July 2012	Attended WPD LCNF knowledge sharing event		
Sep 2012	C_2C page on company intranet	Electricity North West employees	
Sep 2012	Trade magazine article on C_2C Project introduction	All	Utility Week article
Sep 2012	Publish C_2C connection offer process online C_2C website	I&C customers in Trial areas	C_2C connections process
Sep 2012	Story in internal magazine NewsWire	Electricity North West employees	
Sep 2012	Chaired IET Smart Grid 2012 event	Industry and regulatory stakeholders	
Sep 2012	Presented at Smart Grid Demonstrator Forum (Brunel University)	Industry and regulatory stakeholders	
Oct 2012	Low Carbon London Knowledge Sharing Event Attended	Industry and regulatory stakeholders	
Oct 2012	Attended Distribution Automation Europe conference	Industry and regulatory stakeholders	
Oct 2012	Distribute customer leaflets	I&C customers in Trial areas	Commercial customer leaflet
Oct 2012	White paper on customer survey published on C_2C and Utility Week websites	All	White paper – C_2C customer survey

Date	Activity	Audience	Evidence
Oct 2012	LCNI annual conference	Industry and regulatory stakeholders	Presentation to LCNI annual conference (part1) Presentation to LCNI annual conference (part2)
Nov 2012	Presented at DG forum	Industry and regulatory stakeholders	
Nov 2012	Trade magazine article on C_2C survey	All	E&T magazine article
Dec 2012	Six-monthly Project progress no 2	Ofgem	Project progress report no 2
Dec 2012	Story in internal magazine NewsWire	Electricity North West employees	
Dec 2012	Customer seminar/workshop	All	C_2C customer seminar
Dec 2012	White paper on circuit selection	External stakeholders	White paper Dec 2012
Jan 2013	P2/6 technical workshop	Industry stakeholders, DNOs	Presentation - Review of standards accommodating response demand in ER P2/6
Jan 2013	Trade magazine article on C_2C commercial templates	All	Utility Week article
Jan 2013	C_2C newsletters issue 1	All	C_2C newsletters
Feb 2013	Customer mailing	All domestic and I&C customers on Trial circuits	C_2C Customer good news leaflet
March 2013	Engaged customer panel findings report	Ofgem	Engaged Customer Panel Findings
March 2013	Story in internal magazine NewsWire	Electricity North West employees	
March 2013	Trade magazine article on C_2C Project update	All	E&T magazine article
April 2013	C_2C knowledge sharing event	External stakeholders	C_2C knowledge sharing event
April 2013	C_2C newsletter issue 2	All	C_2C newsletters
April 2013	Presented at Ofgem learning & dissemination workshop,	Industry and regulatory stakeholders	

Date	Activity	Audience	Evidence
April 2013	Presented at Demand Side Response seminar (with npower)	Industry and regulatory stakeholders	
May 2013	Presented at SmartGrid GB/Electricity North West workshop	Industry and regulatory stakeholders	
May 2013	Trade magazine article on C_2C sales promotion	All	E&T magazine article
June 2013	White paper on calculating network losses published on C_2C and IET websites	External stakeholders	White paper June 2013 IET white papers
June 2013	Six-monthly Project progress report no 3	Ofgem	Project progress report no 3
June 2013	C_2C briefing sessions	Customer contact centre	
June 2013	Presented at SMI's European Demand Response Seminar		
July 2013	Presented at WPD substation monitoring knowledge sharing event		
July 2013	C_2C newsletter issue 3	All	C_2C newsletters
Aug 2013	Internal briefing to connections team	Internal connections teams	
Sep 2013	Presented at NEA Annual Conference	Industry and regulatory stakeholders	
Oct 2013	Presented at EA Technology DSR Forum – Customers	Industry and regulatory stakeholders	
Oct 2013	Presented at SMi's Distribution Automation Europe Conference	Industry and regulatory stakeholders	
Nov 2013	LCNI annual conference	Industry and regulatory stakeholders	LCNI conference slides
Nov 13	Presented at Fourth Customer Seminar		

Date	Activity	Audience	Evidence
Nov 2013	Trade magazine article on monitoring effects of C_2C	All	E&T magazine article
Dec 2013	Six-monthly Project progress report no 4	Ofgem	Progress report number no 4
Dec 2013	C_2C newsletter issue 4	All	C_2C newsletters
Dec 2013	Submitted UoS – 'Analysis and Quantification of the benefits of interconnected distribution system operation' APAP 2014, South Korea	Industry and regulatory stakeholders	
Jan 2014	Trade magazine article on C_2C Project update	External stakeholders	E&T magazine article
Jan 2014	Submitted paper: UoM – 'Distribution Network Reinforcement Planning'	Industry and regulatory stakeholders	
Jan 2014	Attended Save Project - Customer engagement lessons learnt workshop	Industry and regulatory stakeholders	
Feb 2014	P2/6 change proposal	Ofgem, external stakeholders	P2/6 change proposal
Feb 2014	C_2C newsletter issue 5	All	C_2C newsletters
Feb 2014	Attended Delivering for the future seminar		
Feb 2014	Submitted paper: UoM – 'Distribution Network Capacity Increase via the use of Demand Response During Emergency conditions: A cost benefit analysis framework for Techno Economic Appraisal'	Industry and regulatory stakeholders	
March 2014	Trade magazine article on analysing the effects of new technology on the electricity networks	All	E&T magazine article
March 2014	Presented at DSR forum	Industry and regulatory stakeholders	
March 2014	Presented at Future of Utilities event	Industry and regulatory stakeholders	
April 2014	Presented at UoS – 'Increasing Distribution Network Capacity using Automation to Reduce Carbon Impact' DPSP 2014, Denmark	Industry and regulatory stakeholders	
April 2014	Attended WPD - LV network templates	Industry and regulatory stakeholders	

Date	Activity	Audience	Evidence
April 2014	Presented at Fifth customer seminar	Industry and regulatory stakeholders	
April 2014	C_2C newsletter issue 6	All	C_2C newsletters
April 2014	Technical data published	External stakeholders	Technical data
April 2014	C_2C customer seminar	External stakeholders	C_2C customer seminar presentation slides
April 2014	C_2C customer seminar on Twitter	External stakeholders	
May 2014	Presented at UoM – C_2C concept presented at 'Electric Energy Systems – University Enterprise Training Partnership', Portugal		
May 2014	Attended National Grid demand customer seminar		
June 2014	Six-monthly Project progress report no 5	Industry and regulatory stakeholders	Progress report no 5
June 2014	White paper on carbon impact assessment published on C_2C and IET websites	Industry and regulatory stakeholders	White paper June 2014 IET white papers
June 2014	Presented UoM – 'Distribution Network Capacity Increase via the use of Demand Response During Emergency conditions: A cost benefit analysis framework for Techno Economic Appraisal' at CIRED 2014, Rome	Industry and regulatory stakeholders	
July 2014	C_2C newsletter issue 7	All	C_2C newsletters
Aug 2014	Presented UoM – 'Distribution Network Reinforcement Planning Considering Demand Response Support', at PSCC 2014, Poland	Industry and regulatory stakeholders	
Sep 2014	End of Trial letter	Existing C_2C customers	End of Trial letter
Oct 2014	LCNI annual conference	Industry and regulatory stakeholders	
Oct 2014	C_2C newsletter issue 8	All	C_2C newsletters

Date	Activity	Audience	Evidence
Oct 2014	Presented at UoS- Increasing Distribution Network Capacity using Automation to Reduce Carbon Impact', IET Protection Seminar, Birmingham	Industry and regulatory stakeholders	
Oct 2014	Presented at Smart Grid Forum (WS6) Consumer Demand Side Response Day	Industry and regulatory stakeholders	
Oct 2014	Participated in Smart Grid Forum – Workstream 7	Industry and regulatory stakeholders	
Oct 2014	Presented at IEEE ISGT Europe, Istanbul	Industry and regulatory stakeholders	
Nov 2014	Presented at Northern Ireland Electricity visit	Industry and regulatory stakeholders	
Nov 2014	Participated in WPD - Distribution networks: A Balancing Act	Industry and regulatory stakeholders	
Nov 2014	Article in November issue of employee magazine, NewsWire	Electricity North West employees	 Capacity to Customers LV network solutions
Dec 2014	Six-monthly Project progress report no 6	Industry and regulatory stakeholders	Progress report no 6
Dec 2014	White paper on DG capacity published on C_2C and IET websites	Industry and regulatory stakeholders	White paper December 2014 IET white papers
Jan 2015	C_2C final learning and dissemination event	Industry and regulatory stakeholders	Slide presentation
Jan 2015	C_2C final learning and dissemination event on internal social media channel Yammer	Electricity North West employees	
Jan 2015	C_2C final learning and dissemination event on Twitter		

Date	Activity	Audience	Evidence
Feb 2015	Story in internal magazine NewsWire	Electricity North West employees	
April 2015	C_2C newsletter issue 9	All	C_2C newsletters

C2C shows the way forward

Last month we held the final dissemination event for our £10.2 million low carbon project Capacity to Customers (C2C). The three year project is now complete and has provided a blueprint for the UK's future electricity network.

By combining new technology with innovative commercial contracts C2C increases the amount of electricity we can transmit through our existing network. This avoids reinforcement costs and benefits all of our customers.

During the project we have proved:

C2C releases extra capacity and delivers economic and carbon benefits

The future networks team worked with academic partners to prove that C2C can unlock capacity for demand and generation and produced an implementation model that can be adopted by other DNOs. This shows that C2C unlocks real benefits for customers such as quicker new network connections at lower cost and cheaper DUoS costs.

Our industrial and commercial customers are willing to sign up to C2C contracts

Customers were offered a monthly payment or a reduced new connection charge in exchange for allowing us to manage their connection in the event of a fault. During the project we signed up 10 existing customers and 10 new connection agreements.

FUTURE NETWORKS CUSTOMER DELIVERY MANAGER KATE QUIGLEY TAKES DELEGATES THROUGH OUR CUSTOMER RESEARCH FINDINGS AT THE DISSEMINATION EVENT, HELD IN LONDON IN JANUARY 2015.

C2C improves our customers' power quality perception

We surveyed customers on the trial circuits to monitor the effects of C2C technology on power quality. Our findings show that the introduction of C2C did not have an adverse effect on overall customer experience and in many cases improved customer perception of their electricity service. ■

Head of engineering **Steve Cox** told NewsWire...

"C2C is only the start of transforming how we offer new services and value to our customers. It's great to see C2C already delivering benefits for our customers and shareholders. Over the next few years we will see many changes like this as our projects move from research to become business as usual."

Appendix B: npower Commission Model

npower proposal Feb 13			
	kVA categories/ % commission		
	100-500	500-1500	1500->300
10000	40	35	30
12000	26	24	22
14000	18	17	15.5
16000	14	13	11.5
18000	12	11	9.5
20000	**10**	**9**	**7.5**
22000	9.5	8.5	7
24000	9	8	6.5
26000	8.5	7.5	6
28000	8	7	5.5
30000	7.5	6.5	5

Appendix C: Demand response capability test

Customer	Total Load (kVA)	Managed load (kVA)	Date & time of test
Bolton Arena	800	800	6th Oct 2013
Ritherdons	150	130	19th July 2014
Broadstone Mill	341	160	24th July 2014
Rotalac Plastics	600	600	12th July 2014
Premier Castings	487	487	16th August 2014
Arrow Packaging	185	185	2 May 2014
W Howard	800	800	7th Oct 2013
United Utilities Franklaw	5200	5200	10th April 2014
Hitachi Automotive Systems	1800	1800	29th July 2014
Rollins Bulldog Tools	630	630	10th April 2014
Warburtons	2000	800	18th November 2014
Float Glass Industries	2000	600	3rd December 2014
Data Centre Preston	500	500	7th November 2014
Data Centre Blackburn	500	500	9th December 2014
Innovia Films	18000	6000	2nd February 2015
Innovia Films	10500	10500	2nd February 2015
Iggesund	45000	5000	8th April 2014
Iggesund	49900	4900	18th March 2015
MAG	38000	8000	17th March 2015
Transport for Greater Manchester	2700	2700	17th March 2015

Appendix D: Managed customers existing and new

	Existing customer	New customer
Benefit	Monthly Payment	Cheaper connection charge
Length of contract	Rolling year	Indefinite (unless connection charge saving repaid)
Contract notice period	As per agreement (average in trial 1 month)	Indefinite (unless connection charge saving repaid)
Number of managed events per year	As per agreement (average in trial 3)	Unlimited
Duration of event	As per agreement (average in trial 8 hours)	As per agreement (average in trial 8 hours)
Protected time of day	Yes	No
Protected days	Yes	No
Scheduled outage days	As required	As required

Appendix E: Multiple managed customer rules

The following are the restoration rules followed by the algorithm to determining how to restore customers.

1) If a customer is considered normal at the time the study is invoked the priority will be given to restore them.

A customer who has a contract allowing them to go off between 7pm and 8pm will be considered normal if the study is initiated at 6.59pm. If the study is initiated at 7.01pm, they will be considered as a managed customer.

For the purposes of restoration if a managed customer is to be considered normal, they are valued exactly the same as any other customer.

2) The next group of customers to be restored would be the pay per fault managed customers; the restoration will suggest the most cost effective solution for the capacity. No customers signed up for the pay per fault option during the trial

NOTE: this means if two pay per fault customers at £1000 can be restored over one at £1500 we would restore the two. Likewise if one customer is £3000 and two are £1000 we would restore the expensive one (subject to capacity).

So the restoration will work by

- Overall cost of leaving pay per fault customers off supply.
- If the cost is the same restore the customer with the least remaining outages allowed.
- Eg: it cost the same to leave both customers off; one has been off twice out of a total of 4 and the other once out of a total of4. Restore the 2/4 customer as it has already used a higher % of its allowance.
- If the cost and remaining outages are the same for the scenario, restore by largest count of customers.
- Eg: it costs £2000 to leave one customer off or 2 x £1000 to leave two customers off.
- The assumption for this is there could be network conditions in the future that benefit from the flexibility of more managed customers distributed across the ring instead of a single large on one section of the ring.
- If above are the same restore by the least % of contract remaining.
- Eg: if two customers will cost £1000 each and one must be left off then restore the customer with the most amount of time till the contract expires as they may be available longer.
- If that is the same, return the solution that gets the most overall consumption back on supply

3) The next group of customers to be restored will be the managed customers who have been paid in advanced.

- Restore the customers with the least remaining number of outages allowed.
- Returning the solution that gets the largest number of customers back on supply
- If there are 2 solutions that will restore the same number of customers, restore by the least % of contract remaining
- If that is the same, return the solution that gets the most overall consumption back on supply.

4) The final group of customers to be restored will be the managed customers who have a reduced connection charge.

- Returning the solution that gets the largest number of customers back on supply
- If there are 2 solutions that will restore the same number of customers, restore the customers effected on the last occasion first
- If that is the same, return the solution that gets the most overall consumption back on supply

Note: customers with a generator will be treated as a generator. They will still be restored in the above order with respect to cost (assuming they don't cause a voltage violation) however, all other things being equal, they should always be brought back on first as they are consuming 0 amps. It should be noted that their generation contribution will not be taken into account unless a subsequent study is run after they have been brought back on supply.

Appendix F: Detailed Project Expenditure

£'000s Excluding Partner Funding Ofgem Cost Category	Actual	Total Project Re-based Budget	Variance	Comments
Labour	**1,589**	**1,755**	**165**	**Favourable to budget (Connections efficiencies)**
Monitoring Equipment Installation - Labour	63	22	(41)	Higher than expected install unit rate. Manual collection of data & removal of equipment at end of Trial not budgeted.
Business input into specs and testing & CIO System Design Approval	27	20	(7)	greater than expected input required into specs
Connections – Clerical	61	65	5	Efficiency
Connections - Customer Relationship Management	180	241	60	Lower than anticipated connection volumes led to project extension.
Dissemination - ENWL & Customer engagement via email & training	34	28	(6)	higher dissemination costs than expected
Maintenance & Support for PowerOn Fusion	70	187	117	Efficiency
Project Management - ENWL (Labour)	803	790	(13)	
Involvement in developing Future Network Planning/Operational Standard	9	15	5	Efficiency
Connections - Connections Design (Labour)	241	303	62	Lower than anticipated volumes led to a project extension
Remote Control Installation - ENWL Labour	102	84	(17)	Resolution of post go live bug fixes. Offset by outperformance of contractor costs.
Equipment	**2,625**	**3,078**	**452**	**Favourable to budget (Remote control efficiencies)**
Publicity Materials - Informational Pamphlets & postage & packaging	17	18	1	
Remote Control Installation - Plant	1,812	1,954	142	Efficiency
Monitoring Equipment Installation - Plant	179	112	(68)	Higher than expected equipment unit cost.
Remote Control Installation - Materials	218	563	345	Efficiency
Commissioning SCADA link to Remote Control Devices	0	31	31	Efficiency
Delivery and configuration of GE IT hardware and software	399	399	0	
Contractors	**2,790**	**3,012**	**222**	**favourable to budget (Remote control efficiencies)**
Demand Side Response Customer Survey	402	391	(11)	
Project Management - ENWL (Contractors)	87	115	27	Efficiency
Remote Control Installation - Labour	620	760	140	Efficiency
Remote Control Installation at Customers' Premises	74	159	85	Efficiency due to existing remote control
Contractors Travel & Publicity - Informing Affected Customers	37	42	5	Efficiency
Carbon Analysis	41	40	(1)	
Data Analysis and Economic Modelling	192	185	(7)	
Power System and Technical Modelling	182	175	(8)	
Project Management - GE	351	351	0	
Circuit Selection	38	32	(7)	Took longer than expected
Developing Future Network Planning/Operational Standard (Contractors)	50	53	4	Efficiency
Implementation of PowerOn Fusion	714	709	(5)	
IT	**610**	**740**	**129**	**Favourable to budget (IT licences efficiencies)**
Data Capture and Cleanse	54	55	1	
Database Licenses	10	100	91	Efficiency, one licence required at £10k.
Develop CRMS Reporting Capability	10	11	1	Efficiency
Develop CRMS/PowerOn (SOAP) Interface	81	87	6	Efficiency
Develop New Interface to PowerOn Fusion	92	87	(4)	higher than expected costs
Develop Real-time Data Update Functionality	53	55	2	
Develop Visual Display Functionality for CRMS	78	73	(5)	higher than expected costs
Initial Data Load Functionality	88	55	(33)	higher than expected costs
System Integration & Testing	73	66	(7)	higher than expected costs
Testing and Development Workstation	4	10	6	Efficiency
Upload and Store Estimates (into historian)	45	85	40	Efficiency
Upload CRMS Diagram and Managed Loads	24	55	31	Efficiency
IPR Costs	**0**	**0**	**0**	
Travel & Expenses	**0**	**0**	**0**	
Payments to users	**239**	**300**	**61**	Efficiency
Demand Side Response	239	300	61	Efficiency
Contingency	**332**	**947**	**614**	**Favourable to Budget (RC & connections efficiencies)**
Development and Preparation	14	44	29	Efficiency
Remote Control Installation	0	284	284	Efficiency
Publicity, Training and Dissemination	80	125	46	Efficiency
DSR and Interruptions	13	101	88	Efficiency
Project Management	3	28	25	Efficiency
Connections	7	102	94	Contingency utilised as a result of extenstion to project.
Monitoring Equipment	82	77	(5)	Higher than expected unit rates for labour and equipment.
Installation and configuration of IT and Implementation of PowerOn Fusion	108	109	1	
Circuit selection and data upload	9	24	15	Ongoing data upload and management, change to plan in last reporting period.
Analysis, Modelling and Development of Standards	0	41	41	Efficiency
System Integration & Testing	16	13	(4)	higher than expected amount of testing
Decommissioning	0	0	0	
Other	**406**	**445**	**39**	**Favourable to budget (Accommodation efficiencies)**
Publicity and Dissemination	289	257	(31)	Higher than expected unit costs of workshops/ seminars and trade articles
Accommodation	118	160	43	
Unplanned interruptions during trial	0	27	27	
	8,593	**10,275**	**1,683**	

Appendix G: Northern Power Grid peer review

The closedown report was well written and complies with the closedown report specification. It gives a good overview of the project, what it was trying to achieve, what it did achieve and the obstacles overcome along the way and, together with the linked subsidiary document, it provides sufficient detail for others to replicate the project. The links to the subsidiary documents both within the main body of the report and also in the summary tables are useful (in fact essential) and in one place these links could appear sooner in the document. A few comments / clarifications and corrected typos have been highlighted in your closedown document.

The closedown report follows the Ofgem template well and the section on replicating the project is useful for anyone that does want to replicate the whole project. It would be useful if the closedown report could include a reference to a subsidiary document that provides a concise "DNO implementation toolkit" containing only the essential implementation knowledge such as:

- Version of Power-On Fusion required (or details of specific module)
- Details of any preliminary circuit assessment that need to be done to determine whether C_2C can be offered
- New ETR 130 considerations to take into account
- Links to the specifications for the actuators, MCCBs, etc used for different types of switchgear
- Links to specifications for the RTUs
- Details of the data cleanse activity undertaken on the customer data and the process that you have for keeping this up to date
- Links to the communication materials used to explain the concept to a) new connections customers, b) existing customers to encourage them to sign up as a C_2C provider
- Copies of the C_2C contracts (already clearly signposted form the closedown report)
- Details of the supplier/aggregator performance contract for the recruitment of C_2C providers from the existing customer base.
- Details of the suggested BAU process changes in planning, system design and connections activities
- Details of the operational changes required to set up and monitor C_2C after implementation.

All this information is probably available within your suite of documents but DNOs would find it useful if the key implementation information could be brought together somehow in one concise document with hyperlinks.

The closedown report was adjusted in response to this peer review and an Implementation guide produced.