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RESPOND

Second Tier LCN Fund Project Closedown Report

31 October 2018

VERSION HISTORY

Version	Date	Author	Status	Comments
V0.1	11 October 2018	Kieran Bailey	First draft	
V0.2	15 October 2018	Kieran Bailey	Issued for peer review	Updated following internal review
V0.3	29 October 2018	Ben Ingham	Issued for approval	UKPN comments incorporated
V1.0	31 October 2018	Paul Turner	Final	

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GLOSSARY OF TERMS

Term	Description
AP	Adaptive protection
BAU	Business as usual
CB	Circuit breaker
CBA	Cost benefit analysis
CBRM	Condition based risk management, now called ...
CNAIM	... Common Network Asset Indices Methodology
CCCM	Common connections charging methodology
CRMS	Control room management system
CT	Current transformer
DG	Distributed generation
DINIS	Distribution network information system
DNO	Distribution network operator
DSO	Distribution system operator
DSR	Demand side response
EAWR	Electricity at work regulation
ECP	Engaged customer panel
EHV	Extra high voltage (refers to 33kV network)
ER	Engineering recommendation
ESCO	Electricity supply companies
ESQCR	Electricity supply, quality and continuity regulation
FAT	Factory acceptance test
FCL service	Fault current limiting service
FCL technique	Fault current limiting technique
FL	Fault level
FLAT	Fault level assessment tool
FLM	Fault level monitor
FLMT	Fault level mitigation technique
GDUoS	General distribution use of system

Term	Description
GUI	Graphical user interface
HAZOP	Hazard and operability
HV	High voltage (refers to 6.6kV and 11kV network)
I&C	Industrial and commercial
ICCP	Inter control centre communication protocol
IPSA+	Interactive power system analysis
LCA	Low carbon assessment
LCT	Low carbon technology
LV	Low voltage
MVA	Mega volt amps
NMS	Network management system
PD	Partial discharge
RMS	Root mean squared
ROEP	Rise of earth potential
RTU	Remote terminal unit
SCADA	Supervisory control and data acquisition
SIL	Safety integrity level
Triad	Three half-hours of highest demand on the GB electricity transmission system between November and February each year, used by National Grid to determine transmission network use of system charges for customers with half-hour metering
TSO	Transmission system operator

1. PROJECT BACKGROUND

The transition to a low carbon economy, guided by The Carbon Plan, will encourage greater use of electricity as reliance on fossil fuels reduces. Low carbon technologies (LCTs) and more two-way flows of energy arising from the connection of LCTs will present a range of new challenges to distribution network operators (DNOs), one of which is an increase in fault current.

Fault level related reinforcement expenditure by all DNOs for the RIIO-ED1 price control period was anticipated to be more than that incurred in DPCR5 and forecasts have indicated that it will increase by 60% to £156m over the annualised DPCR5 expenditure. The traditional fault level reinforcement approach involves costly replacement of switchgear and cables, which significantly increases the cost and time taken to connect new distributed generation and/or load customers. Traditional planning and design approaches would require the reinforcement to be undertaken, even if the anticipated fault level only rises above the network equipment fault level nameplate rating for a fraction of a year.

Respond sought to demonstrate that fault current can be managed at lower cost by deploying intelligent software, with innovative technical and commercial fault level mitigation techniques alongside existing assets. The development of intelligent software, namely the fault level assessment tool (FLAT), continually assesses the fault level on the high voltage electricity network. If fault level rises above a pre-set threshold, commands are issued to enable a fault level mitigation technique to operate in the event of a network fault to manage the fault current safely.

With the anticipated increase in demand (AC machines) and generation connections to the network, the potential maximum fault current may rise above the circuit breaker (CB) fault level rating which, without intervention, could result in disruptive failure of the switchgear.

Network fault levels can fluctuate during the day and there may only be a short time period when switchgear ratings could be exceeded. The traditional solution to this issue is to replace existing switchgear with a type that has a higher fault level rating.

In RIIO-ED1, the cost of replacement of the high voltage (HV) switchgear in a typical primary substation was around £500,000 and this rises to a minimum of £1.2m for extra high voltage (EHV) reinforcement. DNOs are required to maintain safe network operation, so even if the switchgear rating is only exceeded occasionally then this would trigger asset replacement work. Installing expensive, higher specification switchgear in these circumstances could mean that the extra fault level capacity installed is effectively unused for the majority of the time.

1.1 Background to the Respond trial method

The Respond FLAT was developed to demonstrate near real time fault level assessment and adaptive mitigation techniques to overcome the fault level challenge which is faced by all DNOs. The approach took advantage of the fault level fluctuations on the electricity distribution network by deploying intelligent software with innovative technical and commercial fault level mitigation techniques, alongside existing assets. The FLAT assesses the potential maximum fault current and when the potential fault current exceeds the existing switchgear rating, the FLAT issues an ‘enable’ command to one of the innovative fault current mitigation techniques retrofitted alongside existing assets. The Respond mitigation technique only operates when a fault occurs.

The three Respond techniques, designed to reduce fault current across HV and EHV distribution networks, are described below:

- *Adaptive protection (AP)*: the use of adjustable relay protection settings altered to change the sequence of operation of CBs under fault conditions. In the event of a fault, a rated CB, either a bus section CB or a transformer CB, would be opened first to reduce the fault current to within acceptable operating levels before the feeder CB operates to remove the fault.
- *I_S-limiters:* a device capable of detecting and interrupting fault current in less than one millisecond which prevents the fault current reaching its peak value.
- *Fault current limiting service (FCL service):* the use of either AP or I_S-limiter techniques on a customer’s premises to reduce fault current by disconnecting the customer’s own large AC electrical machines (motors or generation), reducing the fault level on the network.

The Respond project trialled the above technologies at sites where there were no fault level issues.

2. EXECUTIVE SUMMARY

Respond has demonstrated that Electricity North West's network fault level can be estimated in near real time. In responding to that estimation, a series of innovative technical solutions were initiated to reduce the fault level without the need for expensive and time-consuming asset replacement. As this approach maximises the use of existing assets and minimises the need for capital investment, Respond has proved that there is potential to realise significant cost savings for customers and improve the connection time of generators and large motors to the network.

2.1 Project scope and objectives

The scope of the Respond project was to demonstrate that fault level could be managed at a lower cost than traditional reinforcement by using existing assets and new commercial techniques. It included the use of intelligent software, namely the FLAT, to continually assess the fault level on the electricity distribution network. When this exceeded a pre-set threshold, the tool was required to issue commands to enable a fault level mitigation technique that would operate in the event of a fault so that the fault current could be interrupted safely.

The Respond project had four main objectives:

- To trial the FLAT software
- To trial two technical and one commercial techniques on the existing electricity distribution network infrastructure to demonstrate effective and efficient fault level control
- To deliver novel and highly transferable solutions that can be applied to the HV and EHV networks by any GB DNO
- To demonstrate the release of network capacity to allow quicker and lower cost connections for customers' demand and generation, thereby enabling DNOs to support the UK's decarbonisation strategy.

To meet these objectives, Respond tested the following hypotheses:

- The method is faster and cheaper to apply than traditional reinforcement
- The method will deliver a buy order of fault level mitigation solutions based on a cost-benefit analysis
- The method facilitates the active management of fault current, using a combination of retrofit technologies and commercial services
- The method enables a market for the provision of an FCL service
- The method uses existing assets with no detriment to asset health
- The method reduces bills for customers through reduced network reinforcement costs.

2.2 Project outcomes

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

Figure 2.1: Project outcomes

Output	Description
Customer engagement materials	Customer engagement materials for purchasing an FCL service were developed, ensuring the Respond premise was described effectively for survey respondents and potential FCL service trial customers.
Monitored data	Fault data was recorded at 11 of 14 trial sites.
FCL service market	Contract templates to procure FCL services were developed to allow the disconnection of customers' equipment for fault level mitigation on the network. Learning about the potential market for this technique was delivered in a customer survey report in May 2017. Commercial arrangements learning was published in May 2018.
Adaptive protection	The retrofitting of new technology onto old technology was deployed successfully at a total of seven sites (five x HV and two x EHV).

Output	Description
I_S-limiter installation	I_S-limiters have been successfully installed at two substations together with I_S-limiter sensing units at a further five locations.
Health monitoring	The Respond methodology will increase the number of fault switching operations of either bus section CBs and/or transformer CBs as well as increase the potential through flow fault levels (make and break). The studies carried out by EA technology have indicated a negligible impact on asset health.
ICCP link between NMS and CRMS	The inter control centre communication protocol (ICCP) link was successfully implemented to allow the Respond signal to be communicated to site. The ICCP interface transferred the status and analogue points from the selected Respond primary substations from the CRMS to the network management system (NMS) and transferred the Respond controls/commands from the NMS to the control room management system (CRMS).
Fault level assessment tool	The FLAT was successfully integrated into the NMS, calculating close to real time fault levels.
Fault level monitors	Fault level monitors were installed across 11 sites on a rotational basis to provide data to validate simulated fault level (FL) studies and validate electrical models.
Carbon impact	The carbon impact of the deferment of traditional network reinforcement was identified through modelling, along with the carbon benefits of the Respond technologies.
Customer engagement	By engaging a range of commercial and technical experts from various industrial and commercial (I&C) organisations, the project successfully developed communications and research materials.
Safety cases	Safety cases have been prepared to document the considerations to be taking when deciding to implement the techniques at various site types.

2.3 Objectives met

The following objectives were met or proven:

- Demonstrate the integration and application of the fault level assessment tool (FLAT)
- Prove that the use of AP and the I_S-limiter can be used to provide effective fault level control
- Demonstrate that Respond is a low cost and highly transferable solution which can be applied to the appropriate EHV and HV networks by any GB DNO
- Demonstrate how fault level mitigation techniques can be used to release network capacity allowing quick and lower cost connections for demand and generation customers.

2.4 Objectives not met

FCL service contract

A project aim was to establish one demand and one generation FCL service contract with existing customers during the trial period. Two FCL service contracts were signed with United Utilities for generation FCL services. Protracted contract negotiations with United Utilities, which lasted over two years, delayed agreement on the commercial terms because of perceived risks associated with acceptance of liability for the consequences of disconnecting water and wastewater treatment processes. This delay restricted the time available to develop the design and technical arrangements required to actively test the interface technologies at the two proposed sites. Consequently, the interface technologies were tested off site.

Despite a robust customer strategy, it was challenging to engage suitable existing customers willing to participate in the FCL service trial due to a number of barriers that were fully documented in the customer report published in May 2018. These issues were also outlined in the six-monthly progress reports and highlighted as a risk. Active discussions took place with 13 organisations who indicated a willingness to participate. One organisation progressed into the final stage of technical and commercial discussions. However, these stalled due to concerns over commercial issues during the Triad charging period. A decision was taken not to progress to the installation stage due to a low learning potential for the remaining trial period.

2.5 Key outputs and main learning

Through the implementation of Respond fault level mitigation techniques (FLMTs), the project has successfully demonstrated that it is possible to operate with fault level above the manufacturer's design fault level ratings, yet operating safely within the design rating for all 11kV and 6.6kV switchgear owned and operated by Electricity North West.

Implementation of technology

The technologies deployed have demonstrated how it is possible to use AP and I_S-limiters, in conjunction with real time fault calculation techniques, to reduce fault level within 33kV, 11kV and 6.6kV networks. The techniques ensure safe operation during faults, where the prospective fault level breaking capacity of the respective switchgear would otherwise be exceeded.

Adaptive protection

The project has demonstrated that it is possible to integrate new digital protection relays into existing protection systems to operate independently, as well as producing an approved design to show how it is possible to deploy AP using existing digital relays. The use of digital relays with disturbance recording facilities, has shown that the AP relays operated correctly, providing fault waveforms for the period before, during and after the fault had been cleared. The results have shown that the fault level reduction, by tripping of the nominated CB, occurs within 120ms.

I_S-limiter

I_S-limiters were successfully deployed into existing networks in two different configurations. The project demonstrated how the I_S-limiter can be used to detect and reduce fault level within 1ms, preventing the fault current reaching its peak.

Due to the extremely fast operating time of the I_S-limiter the disturbance recorders integral to the protection relays at the trial substation were unable to provide any pre or initial fault data for analysis. Digital protection relays monitoring the I_S-limiter current were set to activate at a similar current threshold to that of the I_S-limiter and with no additional time delay (instantaneous settings). These relays did not trip when the I_S-limiter operated, indicating that the I_S-limiter operated faster than the protection relay's capability of 20 to 40ms.

I_S sensing

As part of the project, I_S sensing equipment was installed at five sites. These contained only the detection hardware associated with the I_S-limiter. One device operated and correctly indicated a downstream fault. If an I_S-limiter had been installed at this location it would have operated.

Fault level assessment tool (FLAT)

The project has demonstrated that implementation of the FLAT for calculation of real time fault levels, based on the network model provided, was successful. The FLAT was developed to calculate fault levels either on a five minute or topology change trigger. Following each trigger the FLAT would carry out a nodal fault study and send the desired command to enable or disable the respective FLMT depending on whether the predefined fault level value was exceeded or not.

Inter-control centre communication protocol (ICCP)

An ICCP was successfully implemented to allow communication between the existing CRMS and new, under development, network management system (NMS) in which the FLAT is developed. The ICCP link allows for transfer of communication between the FLAT and the Respond trial sites via the existing production CRMS.

Monitoring

As part of the project, fault level monitors (FLMs) were successfully installed across trial locations. These devices were installed for a significant period of time at each site on a rotational basis and have provided large amounts of data. This allowed a comprehensive validation against simulated network model calculations to determine the accuracy of the electrical network, modelled in both the adopted

Electricity North West power system analysis package: Interactive Power System Analysis (IPSA+) software and the network model developed for the Respond trial networks within the NMS.

Safety case

The FLMTs being trialled introduce changes to the way in which existing equipment is operated.

To support the use of the respective techniques it was necessary to produce a safety case for each one to provide clear and comprehensive evidence that the proposed application of each FLMT is or is not acceptably safe.

Trials & analysis

The Respond trials were designed to obtain a good understating of the accuracy of the existing electrical system parameters in order to validate the use of the FLAT in the live trials and to carry out post-fault operational analysis and network asset evaluation.

Fault level monitoring and modelling of the Electricity North West network

The fault level assessment of the Electricity North West distribution network modelled in IPSA+, compared with the results of the monitored fault level results, showed a high confidence in modelling of the distribution network but also indicated potential network data issues with the upstream system. Discrepancies were identified for fault contributions from asynchronous motors calculated by the fault level monitor when compared to the Engineering Recommendation (ER) G74 guidelines for modelling asynchronous motors forming part of the general load.

Fault level assessment tool validation

The validation concluded that the discrepancies between the FLAT and IPSA+ fault level results were attributed to differences in the fault current calculation methods and mismatches in network data.

Due to the work associated with the development and migration to a new NMS which was running in parallel with the Respond project, there were significant challenges in the migration of data and this proved to be a major hurdle in developing an accurate electrical system model for representation of the Respond trial network. It was shown that the FLAT results were not consistent and in some cases very different to the IPSA+ master model and fault level monitor values.

The trials demonstrated that the FLAT was successfully integrated into the NMS. The AP, I_S-limiter (and I_S sensing) fault level mitigation techniques were successfully enabled and disabled based on the calculations and trigger values set within the FLAT. The trials also demonstrated that the fault level engine was automatically triggered, based on both time and topology changes. As part of the trials the 'fail safe mechanism' was demonstrated to show how loss of communications or the failure of the NMS to send an enable or disable signal (in any five-minute period since the last signal), resulted in the respective technologies defaulting to enabled status on site.

Post-fault operational analysis – adaptive protection

During the trial installation period there was a total of eight successful AP operations across four of the five HV AP sites. The post-fault analyses of each operation demonstrated that the fault level mitigation techniques operated successfully, tripping the designated fault-reducing CBs in approximately 120ms and reducing the fault current accordingly.

An additional benefit arising from the use of digital relays with disturbance-recording capabilities was to show conclusively how faults change from one type to another as they evolve from the initiation phase towards their final clearance phase.

The relay disturbance records also provided further evidence of the speed of operation of oil and vacuum type CBs with tripping times of circa 100ms and 60ms respectively.

Post-fault operational analysis – I_S-limiter

During the period of the trials there were two successful operations. The post-fault analyses for each fault indicated that the I_S-limiter operated as designed and limited the prospective fault current. Without any captured analogue waveforms, however, it was not possible to see the magnitude and duration of the initial fault current.

Due to the extremely fast operating time of the I_S-limiter the disturbance recorders integral to modern protection relays are unable to provide any pre or initial fault data for analysis.

Asset health

Health parameters of transformers and CBs were monitored to understand if the Respond methodology caused any noticeable changes to asset health. The results of the trials showed a negligible impact on asset health on transformer feeder and bus section CBs.

Carbon benefit

The low carbon assessment (LCA) of Respond's carbon impact shows that relative to traditional approaches, both the I_S-limiter and AP provide opportunities for significantly reducing the carbon emissions associated with fault level management on the electricity distribution network.

Customer

Customer research identified that a theoretical market exists for the FCL service. However, appetite is limited and restricted to certain industrial and commercial (I&C) sectors, specifically, non-manufacturing industries and organisations able to cope with equipment being instantaneously constrained for short durations of around ten minutes, without any significant impact on either the plant or the business operation.

The study also identified that the optimal FCL service contract (from the customer's perspective) is likely to be short term, with organisations expressing a preference for agreements limited to one year. This reflects similar findings in Electricity North West's Capacity to Customers (C_2C) project research. Commercial arrangements limited to such a short duration would be inappropriate as a business as usual (BAU) proposition, unless implemented as a temporary measure to provide short-term network resilience, while planning/deploying an alternative long-term fault level mitigation solution.

The Respond customer survey demonstrated that appeal for the FCL service was motivated purely by the financial benefit available to organisations. It suggested that gains in take-up could be achieved in the target market by offering a financial incentive of ~10% over the tested price point of £1,769 per MVA of contribution to fault level reduction, if combined with a short duration contract of just one year. Survey analysis also suggested that greater take-up might be achieved by increasing the availability payment and placing a limit on the maximum number of curtailment events per year. However, this would not be practicable for the DNO in a BAU situation.

The subsequent challenges of engaging appropriate customers in the target market meant that it was only possible to proceed to meaningful discussion with 13 organisations, to investigate commercial terms. Feedback from these customers suggests that survey responses did not accurately reflect commercial reality. Customers in the target market are extremely risk averse and sensitive to other commercial forces, which present some barriers to providing an elective FCL service that is financially viable for the customer, at a price the DNO is willing to pay. Customers were unwilling to assist in cost benefit analysis (CBA) to establish the optimal price point for procuring an FCL service; and customer assessments of an acceptable pricing mechanism were based solely on commercial factors, including perceived risks and income-generation aspirations. These customer estimates took no account of their equipment's contribution to fault current. The challenges of procuring an elective commercial fault level response from existing customers are explained in the customer report published in May 2017.

This situation may change in the future as customers increasingly require cost-effective and early integration of generation and demand connections on ever more constrained networks. As such, application of the method as a new form of constrained connection agreement is considered more appropriate for DNO BAU rollout. This offers a solution that could mutually benefit the DNO and its customers in the future by:

- Providing a quicker, lower cost connection for new connections (and existing customers adding new demand and generation) than a standard quotation
- Negating the cost and complexity of ongoing payments
- Eliminating the requirement for the DNO to enter complex negotiations, as a result of the non-negotiable terms and conditions of a managed connection offer.

3. DETAILS OF THE WORK CARRIED OUT

In order to fully explore the benefits and learning outcomes associated with the Respond solution, the trials and reporting were segmented into four key knowledge areas:

- Customer engagement and feedback
- Technology implementation and effectiveness

- Respond trials
- Data evaluation.

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 method enables a market for the provision of an FCL service.* To test the hypothesis, a two-stage programme of customer engagement was developed.

Customers taking part in the engaged customer panel, pilot or customer survey

Initially, an engaged customer panel (ECP) was convened to guide and evaluate a range of FCL service communication materials. The panel was comprised of I&C demand or generation customers employed in relevant job roles at organisations potentially eligible to provide an FCL service.

The objectives of this research were to address three key questions:

- Which materials were most effective in engaging customers about Respond?
- Which key components of the FCL service needed to be communicated to customers?
- How could learning from the ECP be utilised effectively to design and implement a customer survey to test the Respond hypothesis?

A survey instrument was designed on the basis of this feedback, which was then tested and evaluated by the ECP. This iterative engagement process was influential in guiding refinements to both the survey instrument and the associated communication materials. The ECP communication materials and lessons learned were published on the Respond website in October 2015.

The second stage involved conducting a robust customer survey with a representative sample of I&C demand and distributed generation (DG) organisations from across GB, to establish the appeal of the solution and the optimal price point. A pilot survey was conducted with a previously unengaged group of I&C customers to ensure it was sufficiently robust, understood and able to yield the required learning before the full survey was rolled out. In addition to testing the Respond customer hypothesis, it was anticipated that the survey would identify customers, in Electricity North West's operating region, who would be interested in actively trialling the FCL service.

Customers taking part in the trial

Following analysis of the survey, the project team actively sought I&C demand or DG customers to trial the technical and commercial elements of the FCL service. Two FCL service contracts were signed with United Utilities for generation FCL services. Due to the perceived commercial risk, contract negotiations to commence trials with United Utilities, took considerably longer than was originally envisaged. This delay restricted the time available to develop the design and technical arrangements required to actively test the interface technologies at two proposed sites. Consequently, the interface technologies were tested off-site.

Despite a robust customer engagement strategy, the project team found it extremely challenging to engage with suitable I&C customers already connected in parallel, to Electricity North West's network, that were willing to participate in the FCL service trial. The project team also worked with the wider business to identify new connection customers, meeting the requisite criteria, to promote the commercial opportunity of taking part in the trial. However, there was low appetite for participation among this group.

Active discussions took place with 13 organisations who had indicated a willingness to participate; and one entered the final stage of technical and commercial negotiations. These stalled due to concerns over commercial issues during the Triad charging period. A decision was taken not to progress to the installation stage due to a low learning potential for the remaining trial period.

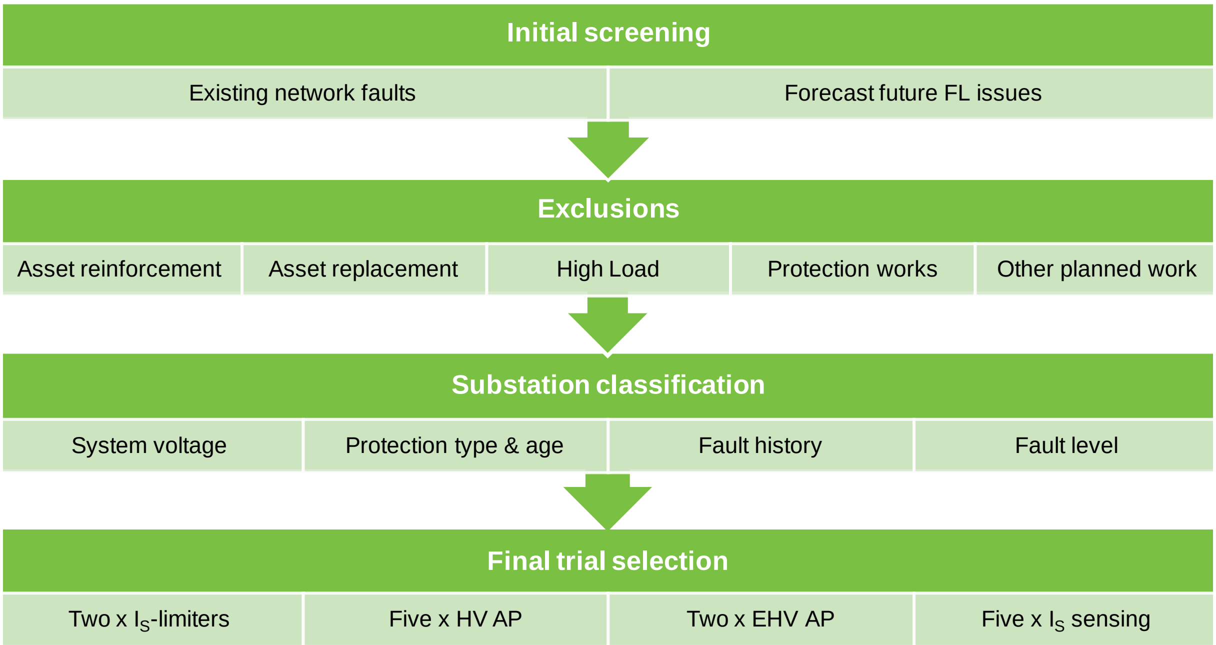
The criterion for trial participation was extended in an attempt to secure an agreement and this strategy was supported with appropriate communications via a range of internal and external channels. This included targeted communications to all potentially suitable organisations identified from the survey and listed on Electricity North West's various customer databases. Repeated direct approaches and newsletters were also issued to customers and associate members of project partner organisations.

3.2 Technology implementation and effectiveness

Site trial selection methodology

The methodology enabled the selection of a representative sample of substations covering a mix of substation ages, relay types, configuration of equipment and considered the known fault history and likelihood of a fault level issue arising during RIIO-ED1 or RIIO-ED2. The steps in developing the methodology are shown in Figure 3.1 below.

Figure 3.1: Site selection methodology



Initial screening

The initial screening was applied to the total population of primary substations on the Electricity North West network to identify sites with existing HV problems (not at the primary) and sites forecast to exceed fault level in the following RIIO-ED1 period.

Exclusions

All sites planned for asset replacement, reinforcement or protection work during the trial period were excluded. In addition all sites with high demand approaching the site firm capacity and substations adjacent to sites for planned outages were discounted.

Substation classification

Voltage levels

The following voltage levels are considered in the selection methodology as these are the substations/ circuits where fault level issues will manifest:

- 33kV and
- 11kV and 6.6kV.

Fault history

In order to increase the chance of the FLMT operating, the fault history for substations and circuits were analysed to understand whether the location would be a good test bed for the trials.

Age and type of substation and protection equipment

This criterion was only used to select sites for the AP trials to ensure a mix of different relay types.

The following categories of equipment were considered in the selection methodology, based on the number, age and type of substation equipment, defined as:

- Electro-mechanical protection (age range between 1960s and 1970s)
- Static electronic relays (approximate age range of 1980s and 1990s)
- Numerical/microprocessor based relays (approximate age range 2000 to date).

Physical constraints

Consideration for sites for the installation of I_S-limiters:

- Standard operational configuration
- Space availability for installation of equipment
- Access to and egress from site
- Potential for installation without planned supply interruptions.

Final trial selection

Following the above methodology 14 sites were selected for the trials, as shown below in Figure 3.2. For further details please refer to the Site selection methodology report.

Figure 3.2: Respond trial sites

Substation	Voltage (kV)	I_S-limiter	I_S-limiter sensing	Adaptive protection
Bamber Bridge	11	✓		
Broadheath	11	✓		
Longridge	6.6		✓	
Hareholme	6.6		✓	
Nelson	6.6		✓	
Athletic Street	33		✓	
Wigan BSP	33		✓	
Mount St	33			✓
Offerton	33			✓
Atherton Town Centre	11			✓
Denton West	6.6			✓
Blackbull	6.6			✓
Irlam	6.6			✓
Littleborough	6.6			✓

Fault level assessment tool development

This intelligent software was deployed to estimate, in real time, the symmetrical root mean squared (RMS) break fault level across the trial network. If the fault level increased beyond the set threshold it was designed to initiate one of the three mitigation techniques below to reduce the fault level below the rating of the switch gear required for operation under fault conditions.

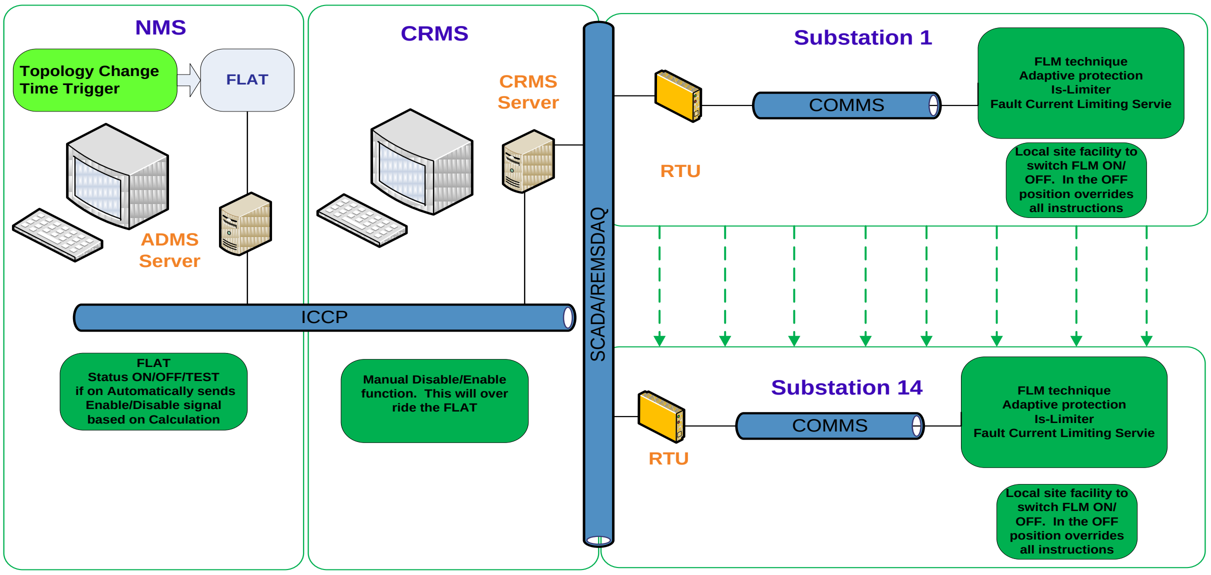
- Adaptive protection
- I_S-limiter
- Fault current limiting service.

The FLAT used the breaker capacity application within the NMS to calculate fault levels in real time for actual network configuration and checked if the calculated fault levels exceeded switchgear ratings. Based on the breaker capacity results the FLAT sent signals to CRMS, to enable or disable the FLMT at the trial sites. Where an enable signal is sent the respective FLMT is conditioned to operate only in the event of a fault that results in the predefined trigger value to be exceeded. When the FLMT is in the disabled state it will not operate for any fault.

Electricity North West's CRMS interfaces with the NMS, using an inter control communications protocol (ICCP) link which was developed specifically for Respond. NMS FLAT signals were sent to CRMS to enable/disable the FLMT on the basis of the calculation results.

Figure 3.3 below shows an overview of the system connectivity.

Figure 3.3: System connectivity



The FLAT was designed to trigger on both topology changes (switch and/or CB status change) or after a specific time. The maximum time between FLAT triggers was designed to be five minutes. If no FLAT signal was received within six minutes of the last signal by the respective fault level mitigation equipment at site the relay automatically enabled the FLMT. An overview of both the AP and I_S-limiter systems are shown below in Figures 3.4 and 3.5.

Figure 3.4: Adaptive protection control system

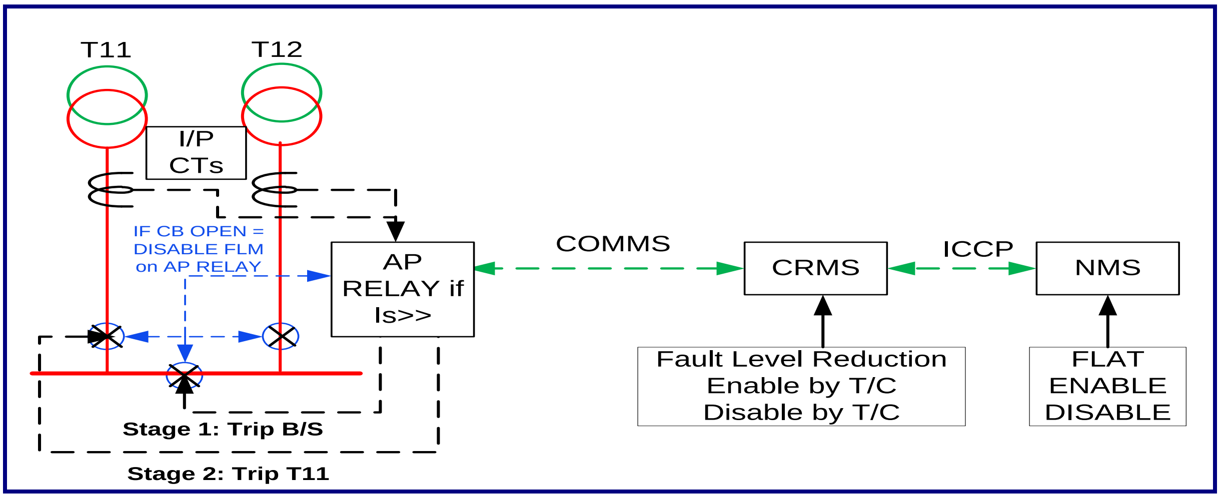
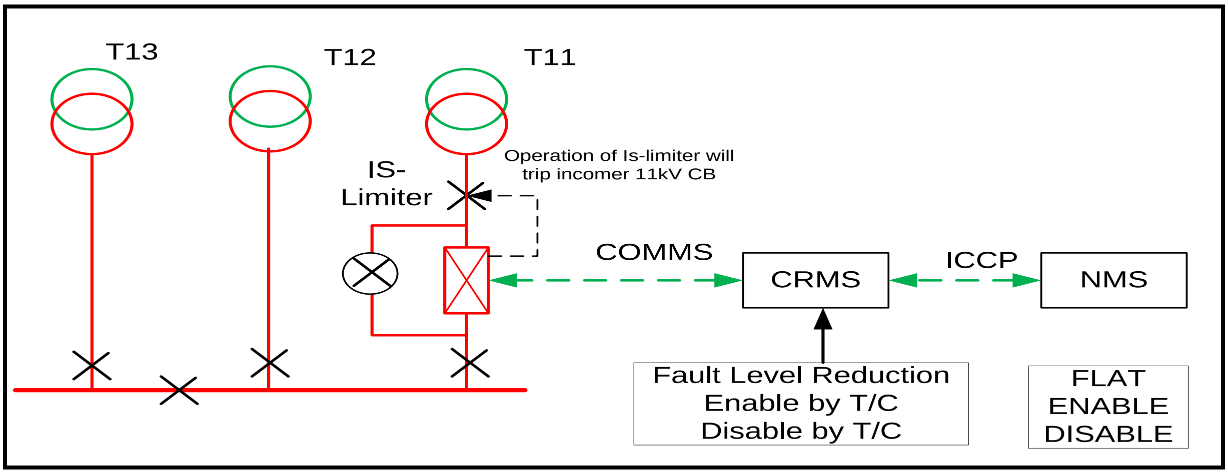


Figure 3.5: I_S-limiter control system



The fault level assessment tool dashboard

The dashboard is a graphical universal interface (GUI) developed within the NMS for control and monitoring purposes. It manually enables/disables the FLAT functionality per site (substation) and sees the current status of all Respond sites and signals in a single window view. The data grid was organised as a table with specific details such as status of the FLAT function, FLAT profile, time of last FLAT run, related execution messages and actual Respond signal status.

Figure 3.6: Fault level assessment tool dashboard

FLAT Control & Monitoring × | Profile Assignment Editor

Substation	Region	Subregion	FLAT Status	Active profile	Respond signal status	Last run
WIGAN GRID (200421)	HV	-	Off	-	Enable FL mitigation techniques	
Denton West (100111)	SMAN	South Manchester	On	Fault Level Assessment	Enable FL mitigation techniques	
ATHLETIC ST (400052)	MLEAS	-	Off	-	Enable FL mitigation techniques	
HAREHOLME (400092)	MLEAS	-	Off	-	Enable FL mitigation techniques	
HINDLEY GREEN (200416)	SLANC	-	Off	-	Enable FL mitigation techniques	
ATHERTON TOWN CENTRE (205318)	SLANC	-	Off	-	Enable FL mitigation techniques	
NELSON (400044)	MLEAS	-	Off	-	Enable FL mitigation techniques	
OFFERTON (302872)	SPEAK	-	Off	-	Enable FL mitigation techniques	
MOUNT ST (100622)	NMAN	-	Off	-	Enable FL mitigation techniques	
LITTLEBOROUGH (304884)	NPEAK	-	Off	-	Enable FL mitigation techniques	
BROADHEATH (100134)	SMAN	-	Off	-	Enable FL mitigation techniques	
IRLAM (100615)	NMAN	-	Off	-	Enable FL mitigation techniques	
LONGRIDGE (400416)	MLWES	-	Off	-	Enable FL mitigation techniques	
BLACKBULL (400403)	MLWES	-	Off	-	Enable FL mitigation techniques	
BAMBER BRIDGE (400201)	MLWES	-	Off	-	Enable FL mitigation techniques	
GIDLOW (200408)	SLAKE	-	Off	-	Enable FL mitigation techniques	

Inter-control centre communication protocol (ICCP)

The NMS FLAT used a custom signal for each Respond site which was sent to CRMS to enable/disable the FLMT on the basis of the calculation results. The Respond signals were sent through the ICCP interface. The ICCP interface transferred the status and analogue points from the selected Respond primary substations from CRMS to NMS and transferred the Respond controls/commands from NMS to CRMS.

For full details refer to the Configuration of NMS and installation of FLAT software report.

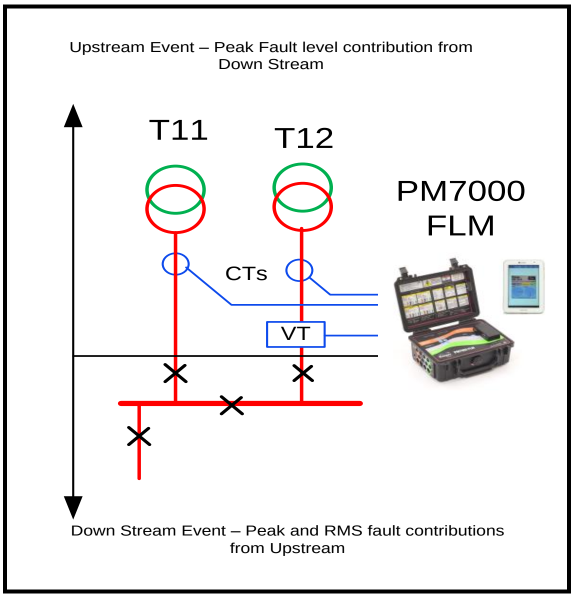
Fault level monitoring

Outram Power Master 7000 FLMs were used to obtain fault level estimation for three phase and single phase systems on radial or interconnected networks. The fault level prediction results were derived from natural disturbances occurring on the network during normal operation, measuring events where voltage changes as small as 0.15% occurred. The principal parameters available from the monitoring process are:

- Peak upstream fault level at ½ cycle (10ms at 50Hz)
    - The upstream FL measured for a downstream event (below monitoring location)
- RMS upstream fault level at, typically 90ms (selectable)
    - The upstream FL measured for a downstream event (below monitoring location)
- Peak downstream (motor) contribution at ½ cycle (10ms)
    - The downstream fault level measured for an upstream event (above the monitoring location).

Figure 3.7 below shows the typical installation arrangement.

Figure 3.7: Typical Outram FLM connection



The FLMs were initially installed at four sites for the purpose of network and fault level validation work carried out by project partners. The monitors were then rotated across a further seven sites to allow Electricity North West to carry out further validation, thus providing a larger representative data set.

These devices were installed to validate Electricity North West's IPSA+ master electrical system model and identify any difference between the simulated and monitored results. Both the FLM and IPSA+ results were used to validate the Respond electrical network model and simulated fault levels.

Respond fault level mitigation installation techniques

AP installation techniques

The AP design was developed to provide fault current information at the sites selected in order to validate the operation of Respond technology. This required two sets of three-phase interposing current transformers (CTs) to be fitted into the T11 and T12 11/6.6kV over-current protection systems. This configuration allowed accurate monitoring and recording during the project.

The use of existing numeric relays on the Respond sites was ruled out due to the combined nature of the over-current and earth-fault legacy blocking systems found on most numeric relays. The straightforward way of achieving sequenced protection for Respond at numeric relay sites would have been to open circuit the blocking inputs from downstream relays to the 11/6.6kV bus section relay but this would have resulted in the 11/6.6kV bus section CB tripping for earth faults as well as over-current faults. On the Electricity North West network the 11/6.6kV system is resistively earthed to reduce earth fault currents (the majority of HV faults are earth fault in nature) and therefore the maximum fault level is controlled to around 20% of the break fault capacity of the 11/6.6kV CBs. Consequently, there is no requirement to implement AP for phase to earth faults on the Electricity North West network. However, this is a method that other GB DNOs could use if they have primary transformers which are directly earthed with correspondingly higher earth-fault levels.

Alternative AP design/installation

As part of the AP installation, two further designs were developed beyond the original project scope with one design implemented at Atherton Town Centre.

The two designs were developed to show that it would be possible to install a simplified and more cost effective method for two scenarios:

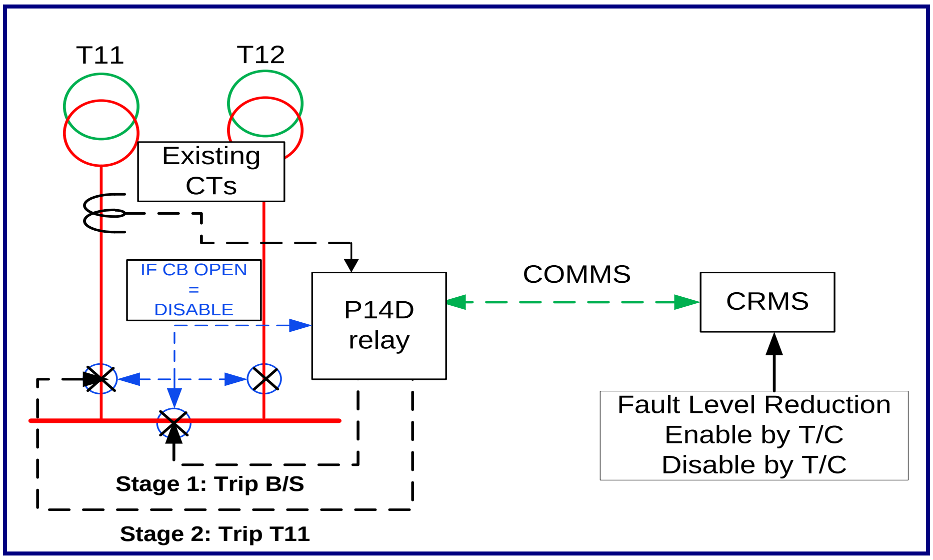
- Primary substation with digital relays
- Primary substation with analogue relays.

Primary substation with digital relays

Substations with existing modern digital relays provide the opportunity to implement AP without the need for new digital relays for the sole purpose of adaptive protection.

A design was produced, but not installed, to demonstrate that a single transformer feeder protection relay could be used to provide AP. Figure 3.8 below shows the scheme overview.

Figure 3.8: AP using existing electronic relays



The design was based on the existing protection scheme at Denton West. In summary:

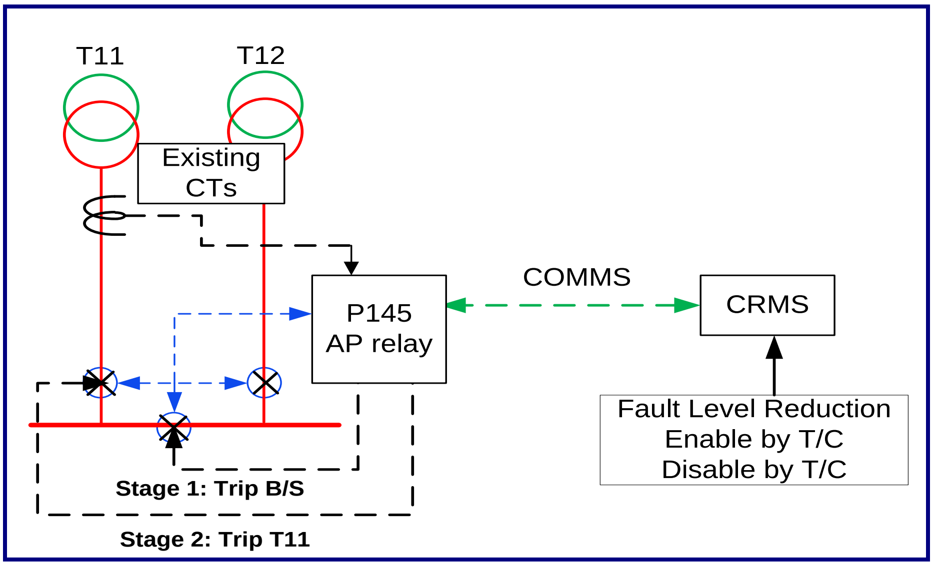
- Both T11 and T12 circuits were restored to the condition they were in before installation of the interposing CTs
- Use existing relay CT inputs (In this case the P14D transformer feeder relay)
- Create new protection settings group
- New protection settings.

All other design principles including operational logic were as per the original design except for the FLAT. For this design the FLAT was not implemented. The principle of this design was for the relay to operate purely based on a single CT input, with an appropriate trigger value.

Primary substation with analogue relays

Substations with analogue relays require installation of a new digital relay. A design was produced and installed at Atherton Town Centre. Again, this scheme was developed to demonstrate that a single transformer feeder protection relay could be used to provide AP. Figure 3.9 below shows the scheme overview.

Figure 3.9: Modified AP scheme at Atherton Town Centre



The design used the AP relay used in the trial with the installation modified as follows:

- Restore the T12 CT circuit to normal
- Re-route the CT circuit from T11 protection panel to the P145 AP relay. No Interposing CTs in circuit, ie single CT input as normal protection.

All other design principles including operational logic were as per original design except for the FLAT. For this design the FLAT was not implemented. The principle of this design was for the relay to operate purely based on a single CT input, with an appropriate trigger value.

For further details on the original design refer to the AP installation and specification report.

AP relays

Respond has demonstrated how the Alstom P140 electronic relay can be used to provide sequential switching to reduce fault level safely for the 11kV and 6.6kV system. As part of the project three methods of installation were designed for the 6.6kV system, of which the first two below were actually trialled. A single installation method was developed for the 33kV system.

- P140 relay with CT inputs from both transformers via interposing current transformers (ICTs)
- P140 relay with direct CT input from one transformer using existing CTs
- Use of existing digital relay on one transformer using a separate setting group.

The use of AP, where unit and instantaneous protection existed, proved to be more onerous and limited due to protection grading and rise of earth potential (ROEP).

I_S-limiters and sensing units

The two I_S-limiters underwent three separate factory acceptance tests (FATs) witnessed by Electricity North West employees both in Germany and the UK during the various build stages. They were installed by Electricity North West employees and commissioned by ABB at Bamber Bridge and Broadheath substations.

Figure 3.10 shows the electrical configurations for Broadheath and Bamber Bridge substations. Photographs of the Broadheath I_S-limiters and bypass equipment are shown in Figures 3.11 and 3.12.

Figure 3.10: I_S-limiter configurations

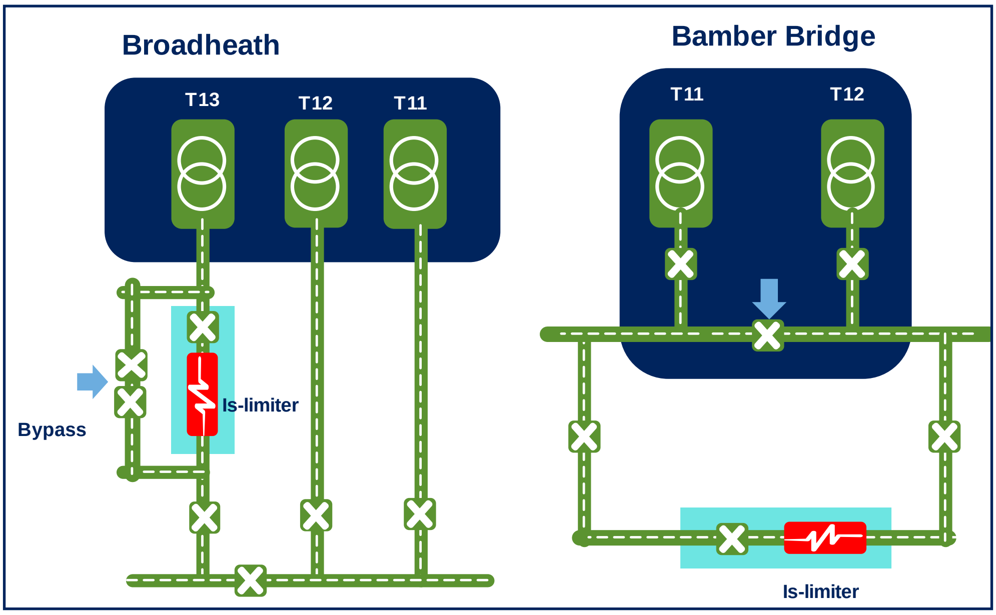


Figure 3.11: Broadheath I_S-limiter and series CB

Figure 3.12: Broadheath I_S-limiter bypass CBs

The I_S-limiters and associated switchgear were housed within purpose-built enclosures as shown in Figure 3.13. The enclosures were situated on raised concrete plinths to ease the installation of the HV cables and were equipped with a controllable environment.

Figure 3.13: I_S-limiter container at Bamber Bridge

Figure 3.14: I_S sensing unit at Wigan BSP

The five I_S sensing units also underwent FATs which were witnessed by Electricity North West – see Figures 3.14 and 3.15. They were installed by Electricity North West employees along with the associated CTs and were commissioned by ABB at Athletic Street, Wigan BSP, Longridge, Hareholme and Nelson substations. The I_S-limiter sensing sites are passive in that no actual fault level mitigation is carried out as they are designed to sense a fault occurrence and send an alarm to the NMS rather than operating a CB to disconnect the faulty part of the network.

Figure 3.15: I_S sensing unit CTs at Wigan on the Gidlow No1 33kV circuit

Fault current limiting (FCL) service

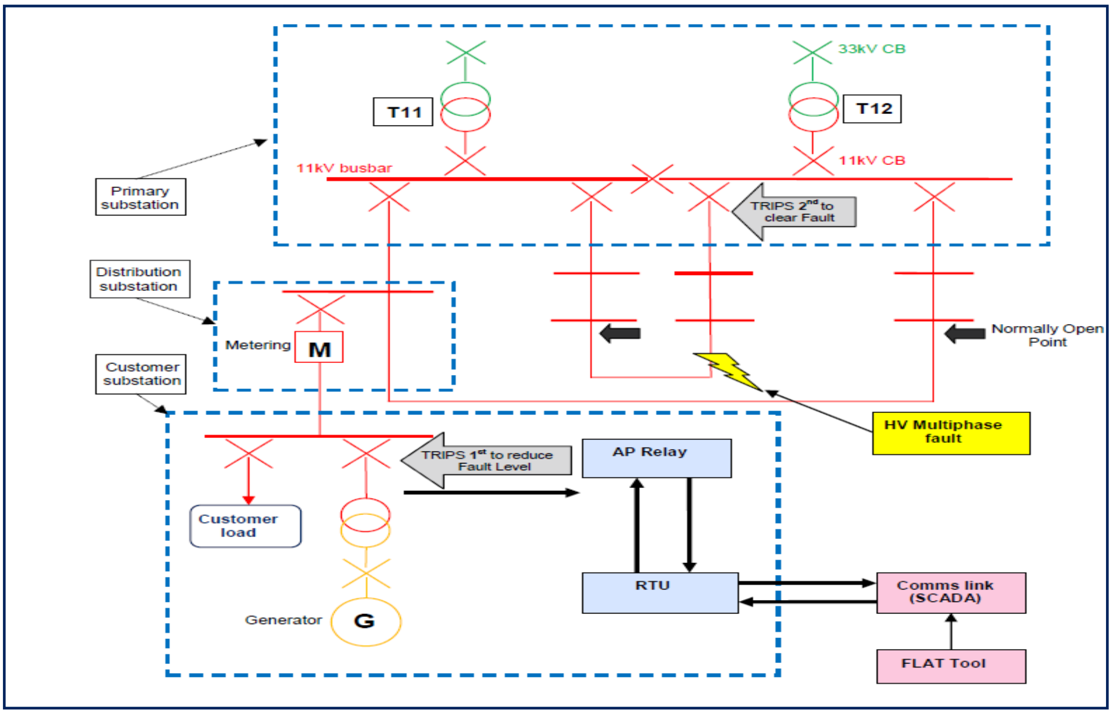
Commercial arrangements

In conjunction with project partner, United Utilities, a commercial contract was developed, containing the terms and conditions for a customer to provide an FCL service.

Specification and design

A generic design to provide an FCL service by tripping a customer's HV CB has been developed. It is based on the AP scheme and incorporates new protection and tripping relays that can be tailored to suit any particular installation. Figure 3.16 shows a typical schematic layout.

Figure 3.16: Generic AP scheme for a customer substation



The generic design consists of an Argus-1 relay (the AP relay) and a tripping relay fitted to a panel situated within the customer's switchroom. The AP relay has an input from the customer's existing switchgear CTs and is connected to the existing CB trip circuit via the tripping relay. There are also outputs to enable and disable the protection and to monitor the protection status. The AP relay communicates with Electricity North West's telecontrol (SCADA) system via a remote terminal unit (RTU). The RTU has an internal battery powered from a standard 230v 13amp socket and the relay panel requires an 110v DC supply from the existing substation battery or alternatively from a dedicated battery and charger arrangement. As not every customer's switch room has a suitable wall space to mount new equipment, an optional freestanding arrangement can be utilised for both the RTU and the AP panel.

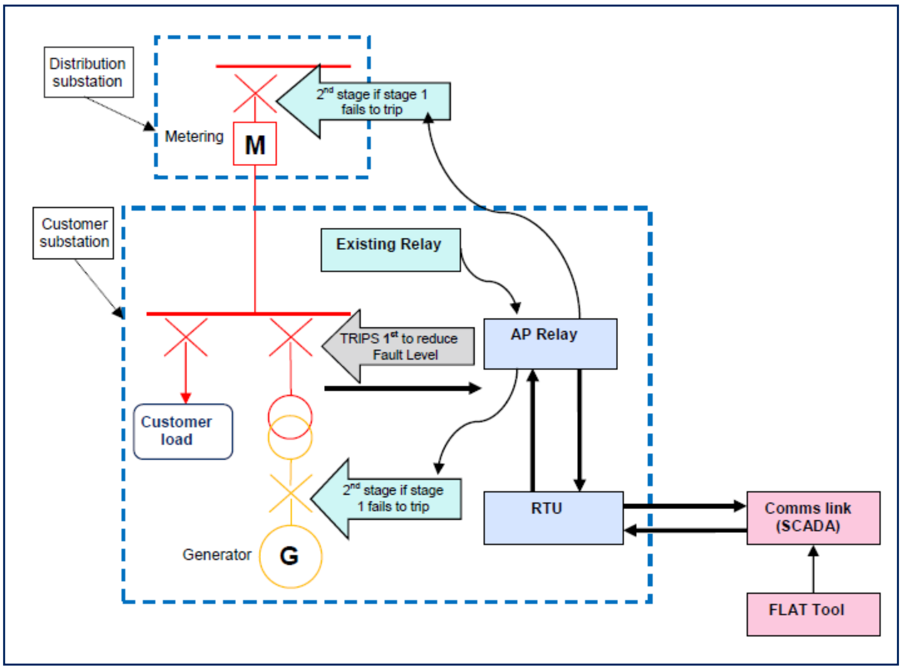
The AP relay is configured so that it cannot be enabled to operate unless a number of pre-requisites are met. After it has been enabled it measures the current contribution from the customer's network onto the Electricity North West network. If this rises above a preset value it then sends a trip signal to the customer's fault level-reducing CB.

A typical arrangement of the relay panel and remote terminal unit is shown in Figure 3.17.

Figure 3.17: Remote terminal unit and adaptive protection panel

In the event of a fault level-reducing CB failing to operate, a second stage of fault level reduction can be provided by tripping another CB. For instance, it may be feasible to use the main incoming high voltage CB to the site as a backup, or in the case of a generator setup, it may be practical to trip the low voltage (LV) CB. Figure 3.18 shows details of the various options of providing a second stage of tripping.

Figure 3.18: AP scheme showing options for second stage tripping



3.3 Respond trials

The objectives of the Respond trials were to demonstrate how a DNO can successfully implement one of the three FLMTs to reduce symmetrical break fault levels and to develop a new mechanism for fault level reduction in GB. As well as being able to test the hypotheses the trials needed to show that the Respond methods did not cause any asset health issues.

The trials and analysis were split into two phases: preparatory installation and post-fault evaluation.

The four Respond trials are summarised below.

Figure 3.19: Trial summary

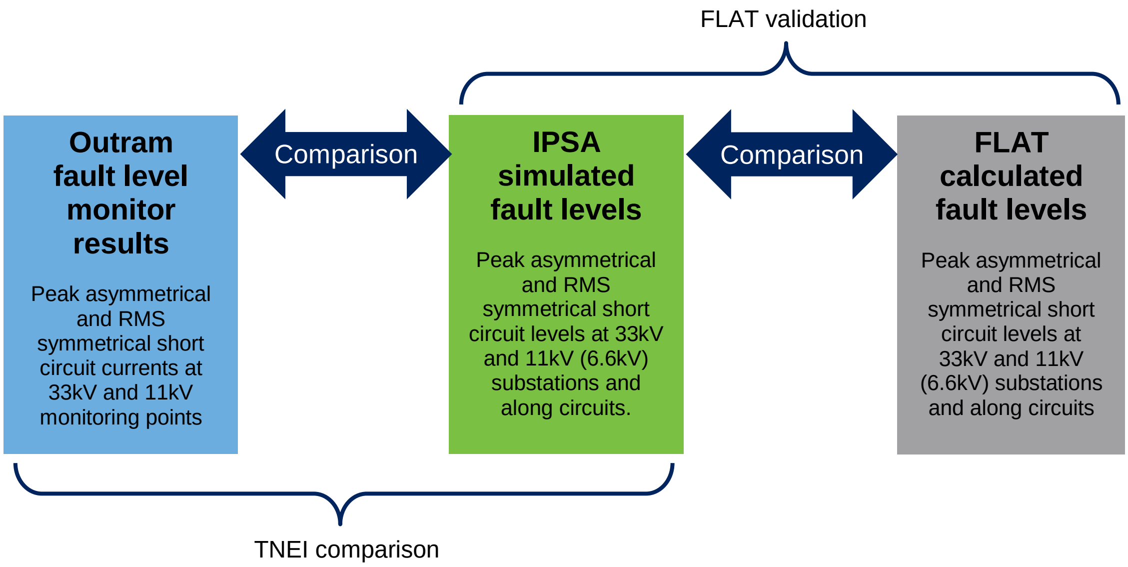
Trial	Description	Period
FLAT validation	Validate the FLAT fault level calculations against the Outram fault level monitor	Pre-live trial
FLAT integration	Installation/configuration of the fault level assessment tool	Pre-live trial
Post-fault analysis	Post-fault operational analysis to demonstrate correct operation of fault level technique	Trial period
Post-fault asset evaluation	Asset health assessment of CBs and transformers	Trial period

Trial 1: FLAT validation

A FLAT validation was undertaken by comparing fault levels calculated through comparison with simulated fault level results obtained using an IPSA+ representation of the Electricity North West electrical distribution network and actual fault level values obtained using the FLM manufactured by Outram Research.

The overall process is shown in Figure 3.20 below.

Figure 3.20: Comparison of fault level calculation methodologies



The validation was based upon four of the 14 trial networks, namely Broadheath 11kV, Denton West 6.6kV, Irlam 6.6kV and Wigan 33kV. Comparisons of three phase peak asymmetrical make and RMS break fault currents were undertaken for all 33kV and 11kV/6.6kV locations within these networks. The scope of the validation was to examine the overall agreement between the FLAT and IPSA+ results.

Methodology

- Outram FLM installed at four locations. The recorded data was issued to Outram Research to produce an independent report to determine the actual fault levels for validation with the IPSA+ simulated results
- TNEI carried out a validation of IPSA+ fault levels compared to the Outram results
- WSP carried out a validation of IPSA+ and FLAT fault level results.

Although the scope of the FLAT validation was to compare fault levels at four Respond locations, further work was carried out to increase the validation to 11 sites. During the live trials the four Outram monitors were rotated across a further seven Respond sites and a comparison with IPSA+ was carried out.

The full Outram research fault level reports can be found on the project website.

Trial 2: FLAT integration

The FLAT trials were developed to demonstrate:

- Correct operation following time and topology changes
- The correct signal was sent to the respective substation for fault level mitigation
- Confirmation from site of actual plant status
- Calculation trigger – time and topology change.

Trials were conducted on a site-by-site basis to confirm the above. As part of the technology commissioning process, initial manual instructions were sent from the Respond dashboard to each site to change the status of the respective installed FLM technology. This test was required to ensure end-to-end communications prior to the start of the FLAT trials. Also, a test was carried out to demonstrate the safety element, where if communications were lost the on-site technology would default to enabled.

To confirm correct operation of the FLAT and FLM status (dashboard and on-site) a series of tests were carried out by modifying the electrical network model configuration and setting the actual fault level rating of the equipment within the model to values below and above the calculated fault level. Tests were also carried out to cause the FLAT to fail.

Test 1: Confirm correct status/operation for time trigger and different plant design ratings

- Note the fault level calculation
- Set the switchgear to test value
- Wait five minutes and confirm calculation carried out by FLAT
- Confirm correct signal status communicated
- Confirm status of equipment in site changed
- Repeat with different plant ratings.

Test 2: Confirm correct status/operation for topology change and different plant design ratings

- Note the fault level calculation
- Set the switchgear to test value
- Make topology change by opening or closing a switch on the electrical network model
- Confirm calculation carried out by FLAT
- Confirm correct signal status communicated
- Confirm status of equipment on site
- Repeat with different plant ratings.

Test 3: Confirm correct status/operation for software failure

- Modify electrical network model to cause FLAT to fail
- Confirm FLAT issues an enabled signal
- Confirm on-site status enabled.

Trial 3: Post-fault analysis

Following the operation of an FLMT a post-fault analysis report was produced to determine correct operation. In particular the post-fault analysis was required to:

- Establish the sequence and timing of events
- Check if the actions were as planned and expected for the particular FLMT
- Quantify current flows throughout the event
- Establish that the correct actions were taken as a consequence of the flow of fault currents, including FLAT decisions and the enabling of the FLMTs before the fault.

A post-fault analysis methodology was agreed with WSP to provide data required to carry out a comprehensive post-fault analysis report for all faults that resulted in operation of an FLMT. For further details please refer to the Post-fault analysis methodology report.

Trial 4: Post-fault asset evaluation

The Respond methodology will result in increased operations of CBs and may increase fault flows through transformers. In order to determine whether or not the techniques cause any detrimental impact to plant the following asset condition monitoring was deployed across the Respond sites:

- Partial discharge

- Dissolved gas analysis
- CB profiling.

EA Technology developed condition based risk management (CBRM) (now called common network asset indices methodology (CNAIM)) models for Electricity North West and were requested to outline a strategy for how the data gathered from the three condition monitoring techniques could be used to assess the effects of the FLMTs on existing assets.

Partial discharge

Partial discharge monitoring equipment was installed to identify if more frequent operation of the CBs operated identifiable change in partial discharge activity on assets where the Respond solutions have been exercised.

- Four sets of partial discharge and acoustic monitoring equipment were supplied by EA Technology
- Equipment was installed at each Respond site at the start of the project to capture one week of background data for comparison
- Equipment was permanently installed at three locations for the trial period (two years)
- One set of equipment was installed at one site for a year and moved to another site for a year
- One week of background data was collated for the remaining sites at the end of the trial
- All data was issued to EA Technology for assessment.

Figure 3.21: Partial discharge monitoring deployments

Site	FLM technique	Internal location	First install	Final install
Broadheath	I_S-limiter	T13 11kV CT chamber 11kV busbar B end T13 11kV CB	Installed for trial period	-
Littleborough	Adaptive protection	6.6kV A-B BS CB 6.6kV BS A side joggle chamber 6.6kV BS B side joggle chamber	Installed for trial period	-
Denton West	Adaptive protection	6.6kV BS Front A side joggle chamber 6.6kV BS Rear B side joggle chamber 6.6kV A-B BS CB	-	One week back data required
Offerton	Adaptive protection	33kV BS CB 33kV BS – B side joggle chamber 33kV BS – A side joggle chamber	-	One week back data required
Atherton T.C	Adaptive protection	11kV A-B BS CT chamber 11kV A-B BS CB T11 11kV CT chamber 11kV A-B BS CB	Installed for trial period	One week back data required
Blackbull	Adaptive protection	6.6kV BS CB CT chamber 6.6kV BS CB	Installed for trial period	-
Mount St	Adaptive protection	33kV BS CB 33kV BS – A side joggle chamber 33kV BS – B side joggle chamber	-	One week back data required
Irlam	Adaptive protection	6.6kV BS busbars 6.6kV BS CB	Installed for trial period	-

Dissolved gas analysis

Dissolved gas analysis (DGA) units were deployed to identify if the tripping of transformer CBs impacted the health of the feeding transformers.

- Two sets of TOTUS DGA monitoring equipment were installed permanently on Broadheath T11 and Wigan GT2
- All data was gathered and issued to EA Technology for assessment.

CB profiling

CB profiling allows operators to identify if there are any defects or issues with the switchgear by taking an initial signature and comparing with future operations. The profiler can detect:

- If the CB operating time is outside limits due to the trip/close coil or main mechanism
- The state of ‘health’ of close and trip coil mechanisms
- The condition of the DC supply and associated wiring
- The presence of ‘sticky’ or faulty CB
- Auxiliary contacts
- The total trip time (relay + CB).

For the trials:

- Four profilers were provided by Kelvatek
- An initial signature was taken at the beginning of the trial of the CBs associated with AP and I_S-limiter installations
- All four profilers were permanently installed
- A final signature was taken at the end of the trial of the CBs associated with AP and I_S-limiter installations
- All data was gathered and issued to EA Technology for assessment.

Figure 3.22 below show the CBs where measurements were taken.

Figure 3.22: Circuit breakers profiled as part of condition monitoring

Site	Voltage	Fault level mitigation technique	Installation
Broadheath	11kV	I_S-limiter	Permanent T13 11kV CB
Littleborough	6.6kV	Adaptive protection	Bus section CB
Denton West	6.6kV	Adaptive protection	Bus section CB
Offerton	33kV	Adaptive protection	Bus section CB
Atherton T.C	11kV	Adaptive protection	Bus section CB and T11
Blackbull	11kV	Adaptive protection	Bus section CB
Mount Street	33kV	Adaptive protection	Bus section CB
Irlam	6.6kV	Adaptive protection	Bus section CB

3.4 Data evaluation

Fault level monitor and fault level validation

Fault level monitors were installed across the Respond trial locations to enable validation of simulation-based fault calculations using IPSA+. The FLMs were installed for a period of time at each location and the data was sent to Outram Research to evaluate and estimate the fault levels for each location. These fault levels were used to validate the simulation-based results.

Real time fault calculation

The implementation of the FLAT has shown, with the correct network model and data, that it is possible to calculate real time fault levels. The use of the FLAT will allow the FLMTs to be enabled only when the network requires it, therefore reducing any operational risk of loss of supply.

The electricity transmission and distribution network is never static due to:

- Network reconfiguration occurring on a daily basis for planned and unplanned work
- National Grid outages which also impact system impedance
- Generator outages becoming far more widespread due to the amount of flexible generation connected, and the markets in which they operate.

As such, the fault level at any primary substation can fluctuate daily, resulting in the need to enable FLMTs for a period of time rather than to be permanently switched in.

Health monitoring

The three health condition measurement techniques installed across the Respond sites have provided a range of data to confirm if the FLMTs had any detrimental impact on the assets involved in the trials. The data obtained from the trials was used to determine impact on asset health, evaluated using the CNAIM developed by EA Technology and adopted by all DNOs.

Carbon assessment

The Respond solution unlocks capacity with a lower requirement for additional assets than traditional reinforcement. It was also proposed that by releasing capacity quicker due to fewer requirements for planning and groundwork, that the Respond solution facilitates emissions savings from other low carbon technologies such as renewable electricity generation.

The carbon impact assessment work sought to test that the Respond method will defer network reinforcement and save carbon.

Modelling and assessment of the potential carbon reduction capability associated with the Respond method was undertaken to evaluate the potential benefits.

4. THE OUTCOMES OF THE PROJECT

4.1 Customer engagement and feedback

A project aim was to establish one demand and one generation FCL service contract with existing customers during the trial period. Two FCL service contracts were signed with United Utilities for generation FCL services. Protracted contract negotiations with United Utilities, which lasting over two years, delayed agreement on the commercial terms because of perceived risks associated with acceptance of liability for the consequences of disconnecting water and wastewater treatment processes. This delay restricted the time available to develop the design and technical arrangements required to actively test the interface technologies at the two proposed sites and consequently, interface technologies were tested off-site.

Despite a robust customer strategy, it was challenging to engage suitable existing customers willing to participate in the FCL service trial due to a number of barriers that were fully documented in the customer report published in May 2018. These issues were also outlined in the six-monthly progress reports and highlighted as a risk. Active discussions took place with 13 organisations who indicated a willingness to participate. One progressed into the final stage of technical and commercial discussions. However, these stalled due to concerns over commercial issues during the Triad period. A decision was taken not to progress to the installation stage due to a low learning potential for the remaining project life.

Customers taking part in the engaged customer panel, pilot or customer survey

An ECP was convened and guided the design and content of a range of FCL service communication materials, ensuring that Respond, and the FCL service specifically, were described effectively. This strategy was successful in ensuring the materials were understood by both survey respondents and customers able to participate in the FCL service trial.

The ECP piloted the survey instrument and was influential in guiding refinements to the final survey instrument and the associated communication materials. These communication materials and the lessons learned from this phase of research were published on the Respond website in October 2015.

FCL service tested in the survey

A robust, targeted campaign, supported by project partners ADE and Ener-G ensured that the project was suitably promoted, to maximise participation in a GB-wide survey, to test the appeal of the FCL service. The project team considered every possible source of customer data, to maximise opportunities for recruiting the optimum number of survey respondents and potential trial participants. The methodology and data sources are documented in the customer report published in May 2017.

The strategy resulted in 103 completed surveys by representatives of I&C demand and DG customers from across GB. This was significantly less than the aspiration of 750 surveys, which demonstrated the challenge of engaging with this market sector, even with support from organisations that have a more direct relationship with large demand and generation customers.

Survey analysis appeared to prove the hypothesis that the Respond method enables a market for the provision of an FCL service. However, it also demonstrated that appetite for the solution was restricted to specific sectors able to cope with having equipment constrained, for short durations, without notice (primarily non-manufacturing industries).

FCL service tested in the marketplace

Communications materials developed and endorsed by the ECP were used to 'pitch' the concept to 13 potential trial participants. The communications strategy and suite of materials were well received by the customers consulted; these customers confirmed the approach was effective in communicating the fault level problem, the objectives of the project generally and the aim of the FCL service trial specifically.

Engaging new connection customers

The project team worked closely with the wider business to promote the method to suitable new connection customers and consultants acting on their behalf. It was recognised that there could be challenges in securing an agreement with a new customer within the limits of the trial period and these were realised. A significant proportion of connection applications that met the criteria, were discounted because extensive reinforcement works, to facilitate connections, could not be completed within project timescales. Other customers, with connection installations near completion, declined on the basis of commercial opportunities and ongoing negotiations with third parties. New connectees were also extremely reluctant to engage in unproven techniques and untested technologies which amplified perceptions of risk among organisations intending to install critical new plant. The common connections charging methodology (CCCM) also introduced significant challenges in relation to the application of payments in the case of a new connection within project timescales. For these reasons it was not possible to agree an FCL service from this sector.

Feasibility challenges identified

Both the DNO and its customers are faced with a number of commercial issues that present varying degrees of concern and must be overcome before the terms of a managed agreement are acceptable to both parties. The project has identified particular concerns about the practicalities of DNOs purchasing a commercial fault level response from existing customers, the reasons for which are fully documented in the customer report published in May 2017.

Furthermore, the project has demonstrated that there is currently low commercial appetite for FCL service provision in the market. However, this may change in the future as customers require more cost-effective connections, which offer the early integration of generation and demand onto increasingly constrained networks.

The project has demonstrated that implementation of the FCL service must be thoroughly assessed on a case-by-case basis using a robust CBA model. This must consider the unique network conditions and an individual customer's fault level contribution, against the whole lifetime costs of the solution. The CBA must also assess these costs in relation to the headroom provided by traditional and alternate new techniques. Certain risk factors apply irrespective of whether the response is purchased from an existing customer, or applied as a new constrained connection. Therefore, the DNO must be confident that the agreement is sufficiently robust and future-proofed to provide mitigation for breach. As such, the CBA should be undertaken in conjunction with a thorough risk assessment, which considers the full lifetime network security implications of implementing the FCL service at any potential customer's site, and critically, the challenges that would arise from the unintentional or malicious isolation of enabling technologies by the customer or early termination of the agreement.

Contract approach and purchase price for the FCL service

The FCL service standard contract (installation and management agreement) was completed and published on the project website in May 2016. This commercial template was made available to customers interested in participating in the project trials and will provide the framework for a new commercial service to mitigate fault level, if and when the solution is adopted as a future BAU solution.

This template is available for dissemination to other DNOs, customers and any other interested parties.

The Respond DCUSA change proposal outlines the different reasons for the service to be provided and how these would affect the charging mechanism. Variations include:

- Is the service being provided by a new or an existing customer?
- Is it needed in response to a general rise in fault level?
- Is it needed for a change in their contribution to the system fault level?
- Is it needed to facilitate a third party connection?

It was not possible to determine the optimum price point, likely to be acceptable to existing customers, to procure an FCL service. However, offering the solution as a constrained connection for new customers negates the cost and complexity of ongoing payments. It also eliminates any requirement for the DNO to enter complex negotiations, to agree terms, because of defined and non-negotiable terms associated with a constrained/managed connection offer.

Conflicts and competition in the market

Potential conflicts with other commercial arrangements and industry players in the current commercial services market have been identified as a barrier to uptake of the FCL service.

Potential loss of revenue from other commercial mechanisms was cited by generators as a barrier to participation in the trial of the FCL service. Customers require greater understanding of the potential timing and number of curtailment events to understand how this relates to loss of revenue through power sales eg GDUoS losses and Triad charges etc. This reassurance is not possible under the terms of an FCL service agreement, as the response could be initiated at any time when a system fault corresponds with high fault level. This requirement prevents the customer from restricting the number of times their equipment could be constrained. It also negates the possibility of them stipulating protected dates/times, or periodically opting out of the arrangement to accommodate their own business needs. As a consequence customers expect high payments to reflect this uncertainty. Feedback suggests that the level of payments for an elective agreement would at least need to offset any risks perceived by the provider and compensates for potential losses associated with forfeiting other commercial demand side response (DSR)/balancing arrangements.

The research also suggests that introducing new elective commercial services in a competitive market will best be achieved by adopting a collaborative approach with customers and their agents/aggregators who understand the specific needs and challenges of the organisations they represent. While the project has demonstrated that conflicts exist that currently deter participation in local schemes, future DNO collaboration with other industry players could offer network and customer benefits from synergies available from customers offering multiple services to the DNO and transmission system operator (TSO). A collaborative approach to embedding new commercial arrangements will become increasingly important as DNOs make the transition to distribution system operators (DSOs).

4.2 Technology implementation and effectiveness

Site selection

A detailed list of the primary substations selected for the Respond trial, based on the selection criteria below can be found in the Site selection methodology document. In brief the following criteria were applied:

- System voltage
- Protection type and age
- Fault history (feeder performance ranking and number of faults)
- Prospective short circuit current in excess of fault level rating
- CB type.

Following a number of iterations of the above selection criteria a total of 14 primary substations were selected.

The primary substations selected for the Respond trial were judged to be representative of the range of primary substations within the total Electricity North West population.

Respond system installations

For the Respond trials, equipment was installed at 14 sites of which three different technologies were tested:

- Five HV AP
- Two 33kV AP
- Two I_s-limiters
- Five I_S-limiter sensing units.

All substations were monitored during the trials. Functions were successfully enabled/disabled from the Respond dashboard via the ICCP link. During the trials there were 11 operations of the FLMTs, all successful:

- Eight HV AP operations
- Two I_S-limiter operations
- One I_S-limiter sensing operation.

4.3 Respond trials

The trials were executed as planned, providing:

- Data to test the project hypotheses
- Data to develop a methodology for fault level validation
- Implementation of real time fault calculation
- Results to assist in the development of the safety cases
- Customer learning though quantitative analysis
- Useful feedback and lessons learned by testing the capability of new technology.

All outputs from the trials have been reported as SDRCs and can be found on the project website.

4.4 Data validation

Fault level validation

The results from the fault level validation have shown a strong level of confidence in the modelling of the Electricity North West network when compared with the measured results obtained using the Outram FLMs. The validation of the FLAT results compared with IPSA+ (results provided by TNEI) was not so strong due to inaccurate model data and configuration of the reduced network model developed in the NMS.

Outram v TNEI fault level results

TNEI carried out an independent network validation at an initial four sites: Broadheath, Irlam, Denton West and Wigan. In order to generate greater confidence, the validation was extended to a further seven sites, with the validation carried out internally to compare the measured results with IPSA+.

The results show the comparisons between measured values (Outram FLM), TNEI values and Electricity North West calculated values for a three phase fault located at the primary busbars at each of the Respond locations. The asymmetrical fault level is split to show the upstream and downstream contributions. The downstream element consists of generation contributions (modelled where known), and asynchronous motors forming part of the general load.

Figure 4.1: Upstream asymmetrical peak make fault contribution

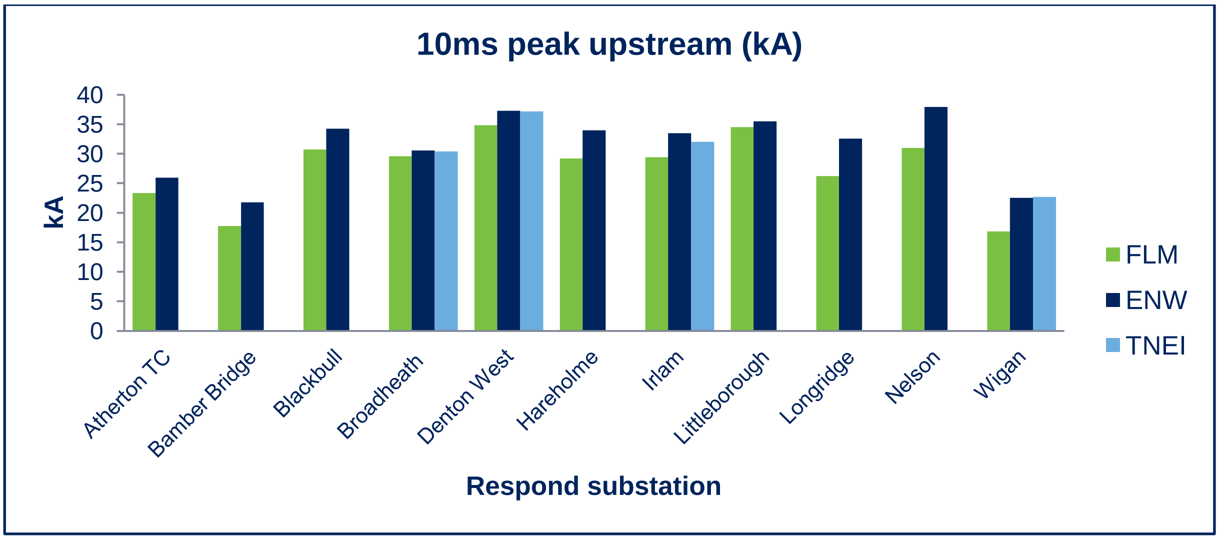


Figure 4.2: Downstream asymmetrical peak make fault contribution

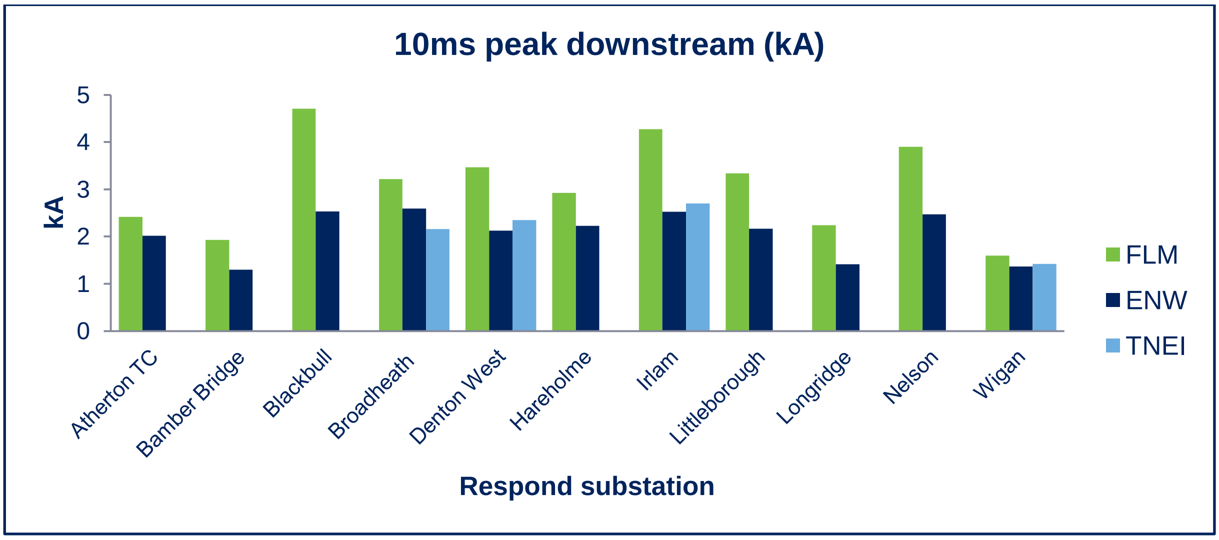


Figure 4.3: Combined asymmetrical peak make fault contribution

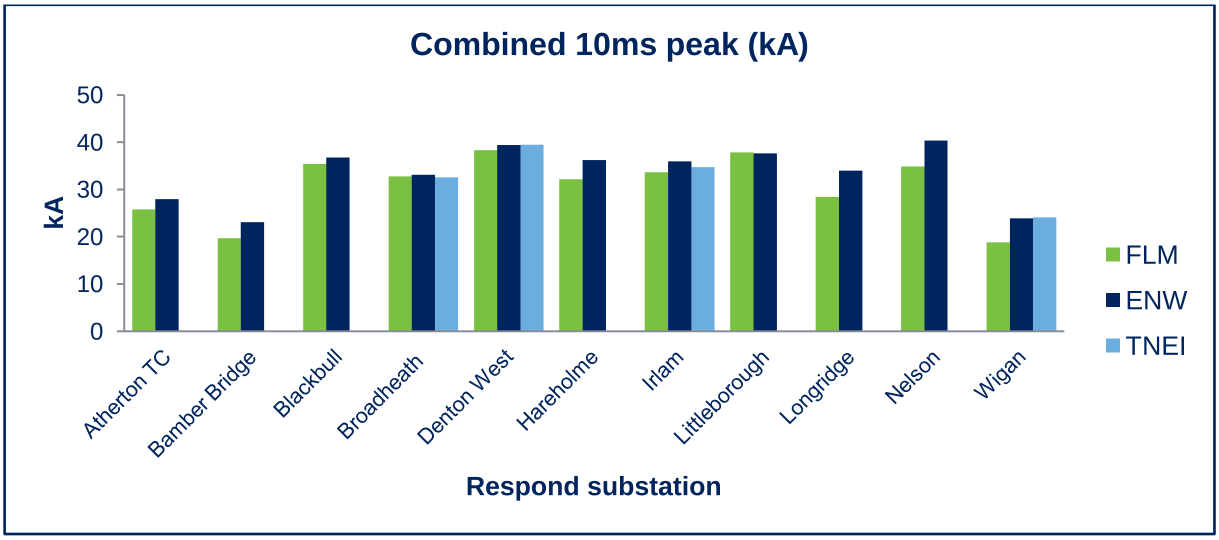
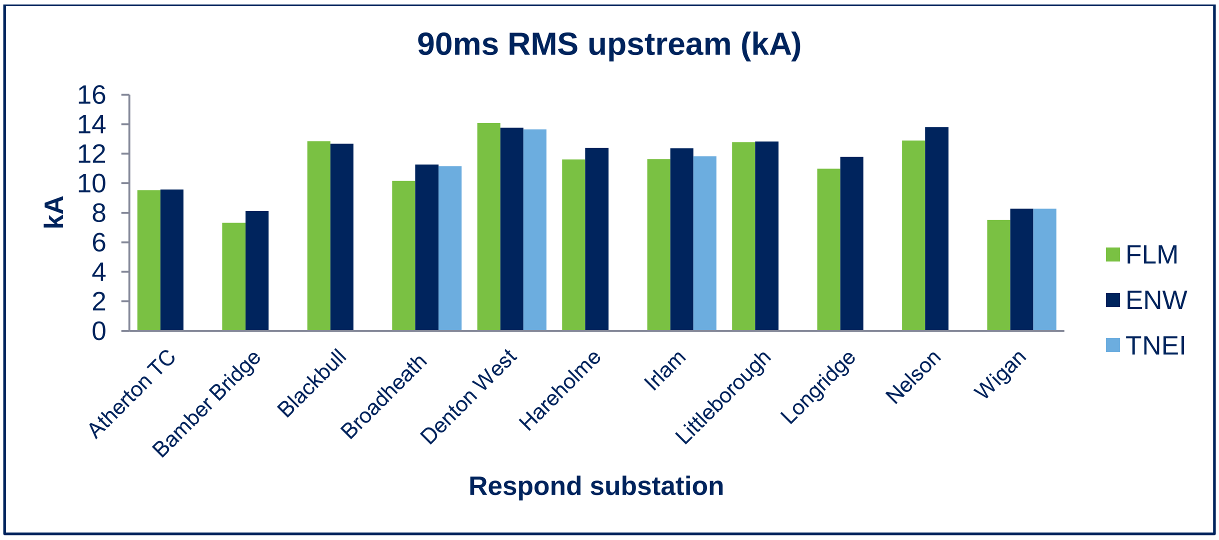


Figure 4.4: Upstream symmetrical RMS break fault contribution



The following graphs show the differences in values compared to the monitored values.

Figure 4.5: Asymmetrical peak make fault contribution – FL difference between methods

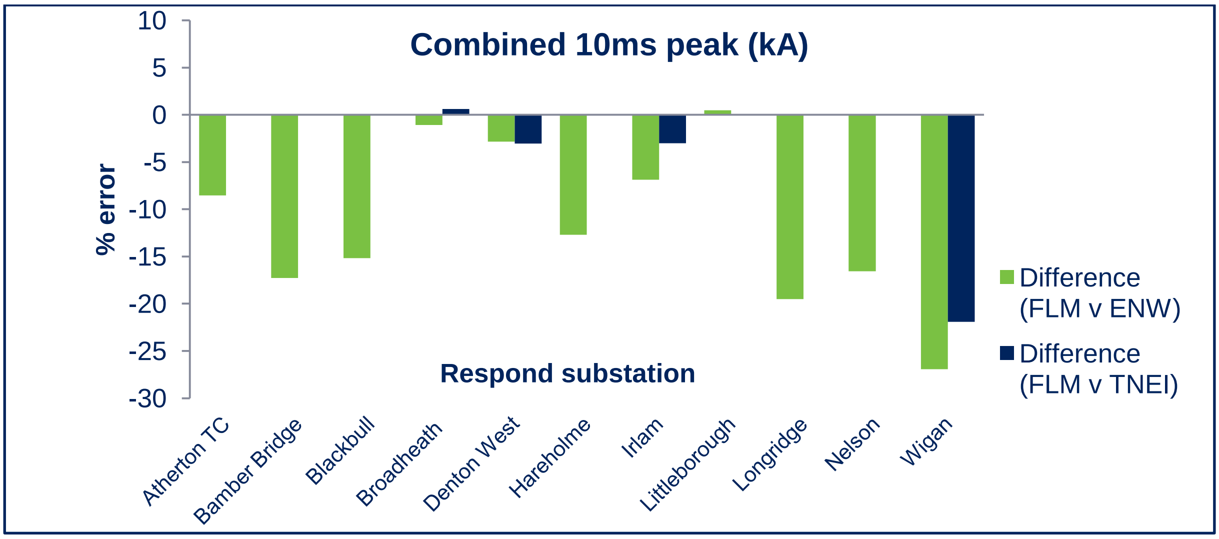
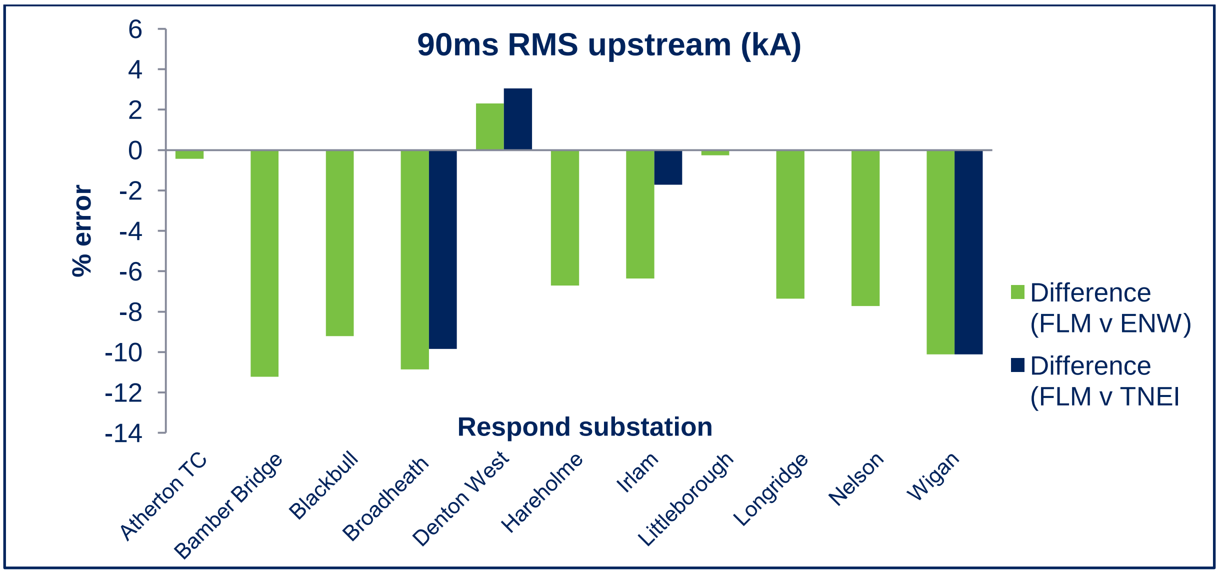


Figure 4.6: Symmetrical RMS break fault contribution – FL difference between methods



The results have shown:

- A strong correlation between the TNEI and Electricity North West results across all values
- A strong correlation for the upstream symmetrical RMS fault levels
- A strong correlation for the combined asymmetrical peak values except at Wigan
- At Wigan the difference between TNEI and measured values for both the symmetrical RMS and asymmetrical peak has indicated a potential network configuration. This error is believed to be due to the running configuration of the National Grid network feeding Wigan which is not modelled explicitly in the Electricity North West network model
- The simulated results for asymmetrical contribution may be overestimated.

The distribution generation connected to the HV network did not have a significant impact at the location of the FLM devices due to its low capacity; therefore the downstream fault contribution is mainly from the asynchronous motors forming part of the general load.

The results of the initial four trial locations consistently suggest the peak make fault contribution from the ER G74 models is most likely underestimated and that ER G74 may need to be revised to reflect the change in load mix. It should be noted that ER G74 was developed in 1992, since when the load mix and appliances used in commercial and industrial environments may have changed.

The industry practice is to employ the same ER G74 model, irrespective of the mix of load in each location or area. This is understandable as it is difficult for the distribution operators to separate consumers or areas of consumers in different categories, ie predominantly households, predominantly industrial.

FLAT v TNEI (using IPSA+) fault level results

The validation concluded that the discrepancies between the FLAT and IPSA+ fault level results were attributed to the differences in the fault current calculation methods and mismatches in network data. FLAT asymmetrical make and RMS break fault levels are generally greater than the corresponding IPSA+ results. Based on the sample of results included in the validation:

- FLAT asymmetrical make fault level results are approximately 15% greater than the corresponding IPSA+ results
- FLAT RMS break fault level results are approximately 9% greater than the corresponding IPSA+ results
- FLAT RMS break fault levels being greater than the corresponding IPSA+ results is partly explained by the assumption that the AC fault current component does not decay away with time up to the break time
- The validation was based upon comparison with the TNEI IPSA+ study results which could be considered a small subset of the Electricity North West network
- Differences between the NMS network model used by the FLAT and IPSA+ model are apparent from the large mismatch between some results.

Figure 4.7: FLAT and TNEI results

Location	Mismatch between FLAT and IPSA+ fault level results at the substation		Average mismatch between FLAT and IPSA+ model fault level results for nodes along feeders	
	Make %	Break %	Make %	Break %
Broadheath	5.2	6.2	19.8	9.4
Denton West	2.2	2.9	16.3	9.6
Irlam	11.7	13.1	22.3	11.1
Wigan	-1	9.4	-	-

FLAT

Due to the works associated with development and migration to a new NMS which was running in parallel with the Respond project, there were significant challenges in the migration of data. This proved to be a hurdle in developing an accurate electrical system model for representation of the

Respond trial network. It was shown that the FLAT results were not consistent and in some cases very different to the IPSA+ master model and fault level monitor values.

The trials demonstrated that the FLAT was successfully integrated into the NMS. The AP, I_S-limiter (and I_S sensing) FLMTs were successfully enabled and disabled based on the calculations and trigger values set within the FLAT. The trials also demonstrated that the fault level engine was automatically triggered based on time and topology changes. As part of the trials the 'fail safe mechanism' was demonstrated to show how loss of communications or failure of the NMS to send an enable or disable signal (in any five-minute period since the last signal), resulted in the respective technologies defaulting to enabled status on site.

Fault level mitigation techniques – trial results

During the trial period there were a total of 11 successful operations of FLMTs. Figure 4.8 below shows the locations, the FLMT installed and the number of operations of the respective technique.

Figure 4.8: Operation of fault level mitigation techniques

Substation	Fault level mitigation technique	No of operations of FLMTs
Bamber Bridge	HV I_S-limiter bus section	2
Broadheath Primary	HV I_S-limiter incomer	0
Atherton Town Centre	HV adaptive protection	3
Denton West	HV adaptive protection	0
Blackbull	HV adaptive protection	1
Irlam Pry	HV adaptive protection	1
Littleborough Primary	HV adaptive protection	3
Monton	EHV 33kV adaptive protection	0
Offerton Primary	EHV 33kV adaptive protection	0
Athletic Street	EHV I_S sensing	0
Wigan	EHV I_S sensing	0
Longridge	HV I_S sensing	0
Nelson	HV I_S sensing	0
Hareholme	HV I_S sensing	1
Totals		**11**

For each operation of either AP or I_S-limiter a post-fault analysis report was produced as per SDRC 9.3.3.

The operation of the I_S sensing unit at Hareholme primary substation, although not reportable, was internally reviewed to ensure correct operation.

An independent analysis carried out by project partners has shown that for each reportable event the respective technologies operated correctly.

Adaptive protection

The AP fault level mitigation operated correctly for eight events. At no time during the trial was there a mal-operation of the AP technology.

The AP relay has a disturbance waveform recorder which provides the evidence to prove that the relay functioned correctly, providing timings and fault level magnitudes relating to the triggers and operation of CBs.

Details were captured for seven of the eight events to successfully show that the AP relay functioned correctly to reduce fault level. For one fault it was found that although the AP operated correctly, the disturbance waveform recorder was not triggered due to an error in the programmable scheme logic.

Results for adaptive protection

The post-fault analysis reports for each fault can be found on the project website.

The following provides a summary of the information obtained to demonstrate the successful operation of the first AP event.

The first operation of AP was at Atherton Town Centre, on the Collier Brook 11kV circuit, on the 29 July 2016 at 22:29.

The instantaneous and RMS disturbance records obtained from the AP relay are shown in Figures 4.9 and 4.10 below.

In these figures, output R3 is the trip signal from the AP to the 11 kV bus section CB and output R12 is the bus section CB 'A' auxiliary contact repeat signal to telecontrol.

Figure 4.9: Instantaneous AP relay recordings

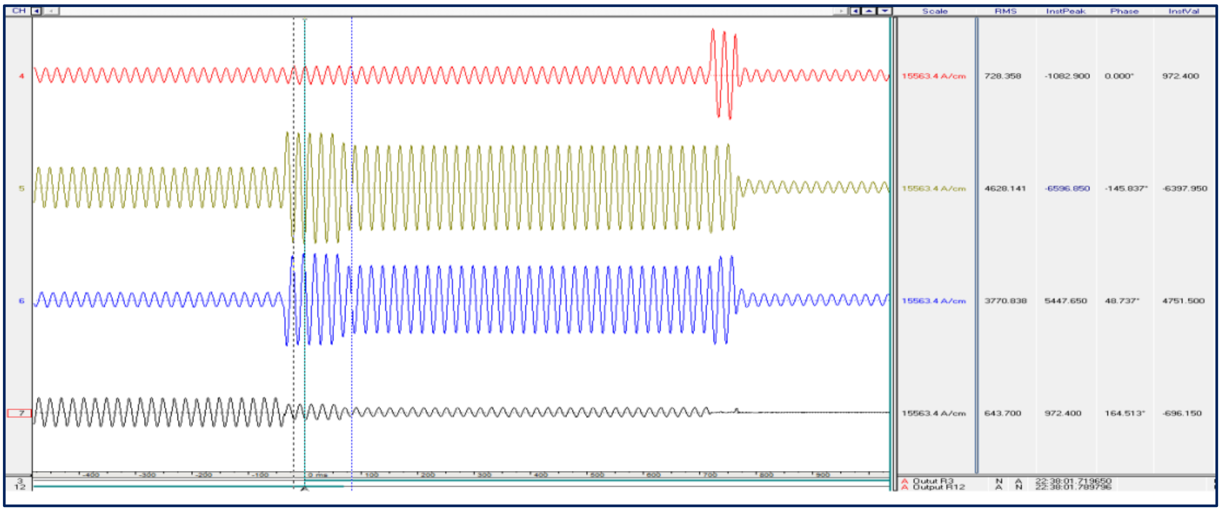
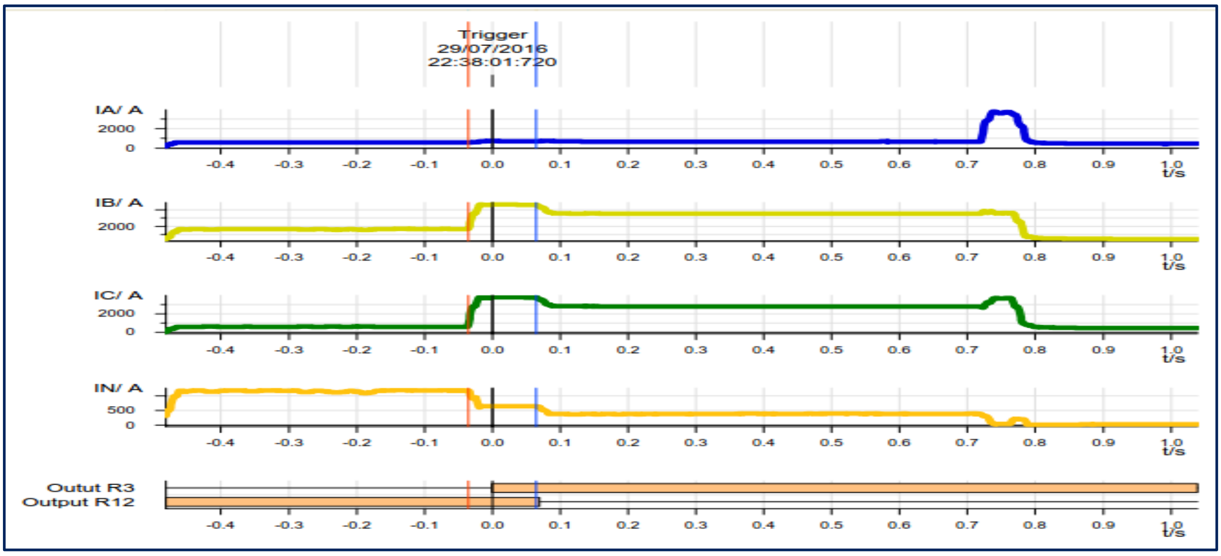


Figure 4.10: RMS adaptive protection relay recordings



- The disturbance records show that prior to the phase to phase to earth fault to which the AP relay responded, there was a yellow phase to earth fault present. The magnitude of the earth fault current was 1161.3A with a corresponding yellow phase fault current of 1644.5A (inclusive of load current).

- The phase to phase to earth fault with 4635.3A and 3779.5A in the yellow and blue phases respectively and with a 645.3A residual fault current, occurred 35.5ms prior to being detected by the AP relay. The 11 kV bus section CB tripped 64.8ms after the trip signal from the AP relay was sent. The total duration of the initial phase to phase to earth fault was 100.3ms.
- After the 11 kV bus section CB tripped, the phase to phase to earth fault current reduced to 3520.8A and 2784.3A in the yellow and blue phases respectively and the residual fault current reduced to 391.4A. These fault currents continued for a further 700.5ms, developing into a three phase fault just before the feeder protection operated ie the fault was eventually cleared 765.3 ms after the AP detected the initial phase to phase to earth fault.
- The phase to phase to earth fault was present for 35.5ms before the AP was triggered. In this case the fault current was only a multiple of 1.025 times the API>3 current setting. For fault currents greater than a multiple of two times the current settings, the detection time should decrease.
- The time between the AP issuing the trip signal and the 11 kV bus section CB tripping is largely dependent on the CB operating time and would not change with fault current.
- Overall, the analysis confirmed that AP operated as expected and reduced the fault current to be interrupted by the feeder CB.

I_S-limiters

The I_S-limiter at Bamber Bridge operated correctly for two events over the trial period. There were no events at Broadheath (the second I_S-limiter installation) that caused operation of the I_S-limiter. During the trials there were no mal-operations of the I_S-limiters.

The I_S-limiter operated as designed and limited the prospective fault current. Without any captured analogue waveforms, however, it is not possible to see the magnitude and duration of the initial fault current.

Unlike adaptive protection, the disturbance recorders integral to the protection relays at the trial substation were unable to provide any pre or initial fault data for analysis due to the extremely fast operating time of the I_S-limiter.

The full post-fault analysis reports can be round on the project website.

Carbon impact

The assessment of Respond's carbon impact shows that relative to traditional approaches, both the I_S-limiter and AP provide opportunities for significantly reducing the carbon emissions associated with the management of fault levels on the network.

The installation of either AP or an I_S-limiter has the potential to reduce carbon emissions by 520,359 kg CO_2e and 40,331 kg CO_2e respectively compared to traditional approaches for managing increasing fault levels.

If rolled out across the Electricity North West area, Respond has the potential to save 6,297,777 kg CO_2e per year; and if rolled out across GB, 88,138,933.89 kg CO_2e per year can be saved.

The carbon impact of the FCL service is estimated at 1070.58 kg CO_2e per installation. The potential benefits of the FCL service on a network asset's useful life was not ascertained as part of the Respond project. However, it is noted that the gross carbon impact of the FCL service is nominal, even without accounting for any carbon benefits that might arise from its effect on the useful life of network assets.

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

Safety case

Safety cases were developed for each of the fault current limiting (FCL) techniques in conjunction with project partners WSP and full details can be found on the project website. The process involved undertaking a review of legislation and regulatory requirements so that the risk criteria could be established. The safety assessment method consisted of an initial risk assessment which was conducted at a hazard and operability (HAZOP) workshop. Where risks could not be controlled by adherence to existing standards and regulations, a quantified risk assessment was undertaken to determine the further control measures that would be required. The outputs of this process were used to develop the safety requirements for the implementation of the three FCL methods.

The HAZOP exercise identified four hazards that represented a significant potential risk to workers on or close to the substations where FCL is applied and to members of the public in close proximity to the affected substations or electricity distribution network. These are:

- Short circuit of the busbar in a substation resulting in excessive fault current
- Short circuit within a CB in the substation resulting in excessive fault current
- Short circuit of the feeder cables such that the withstand current is exceeded
- Short circuit of the overhead line such that the withstand current is exceeded.

Further hazards were also identified which presented no significant change to the situation existing before an FCL system is applied.

The quantified risk assessment used event tree methodology which starts with an initiating event and then considers how this can develop into a range of possible outcomes. By considering the frequency of the initiating event and the probabilities of the subsequent steps in the accident chain the overall frequency of accents is calculated.

Overall risk analysis

Safety requirements (further to those already in place for the existing network and operations) have been established by the risk assessment based on the detailed input data and assumptions. Achievement of these safety requirements would ensure control of the risk associated with each of these scenarios and the defined FCL scheme would present a tolerable safety risk. The safety requirements include:

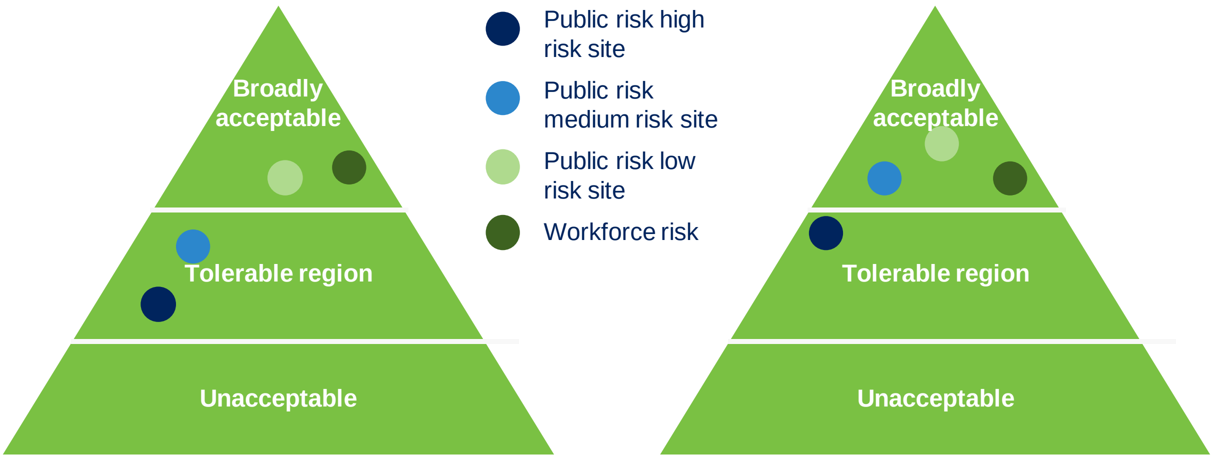
- Application conditions that must be satisfied before applying an FCL technique to a site, ie pre-requisites
- Safety function and performance measures necessary for the FCL system, including meeting safety integrity level 3
- Implementation, operating and maintenance measures necessary to control safety risk of the FCL scheme in use, including compliance with safety management systems, standards, procedures and codes of practice.

Adaptive protection

The analysis has shown that, based on arguably conservative assumptions, it would be acceptable from a safety viewpoint to fit substations with an AP system, provided that they are not high risk sites and that an AP in system one out of one configuration is used for low risk sites and one out of two configuration for high risk sites. The one out of one configuration would be required to meet the safety integrity level 2 (SIL2) requirements of BS EN 61508 and the one out of two configuration would need to meet SIL3. Summaries of the event trees are shown graphically in Figures 4.11 and 4.12.

Figure 4.11: AP risks one out of one (no redundancy, SIL 2 system)

Figure 4.12: AP risks one out of two (with redundancy, SIL 3 system)

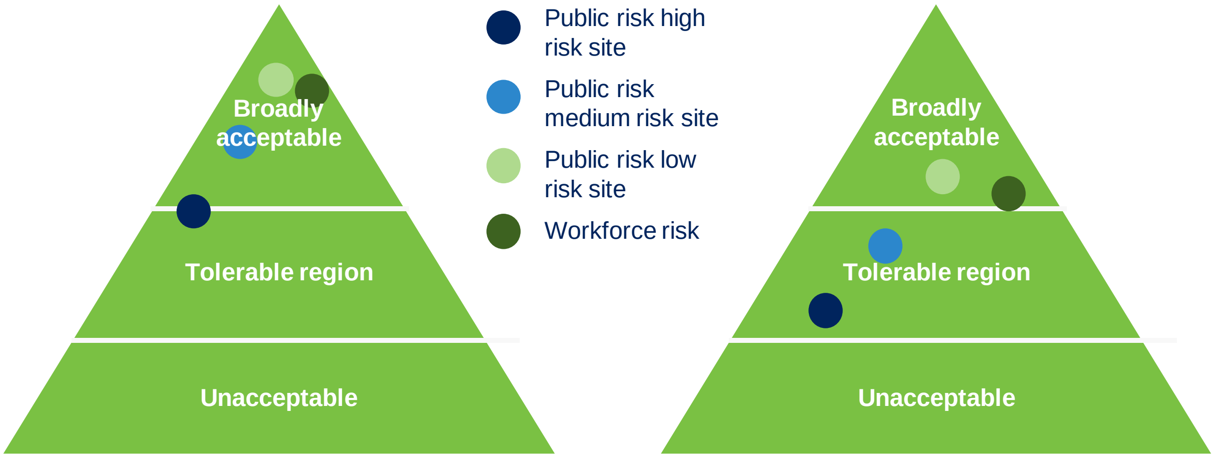


I_S-limiter

The analysis has shown that, based on arguably conservative assumptions, it would be acceptable from a safety viewpoint to fit substations with an I_S-limiter system provided that they are not high risk sites and that it would also be acceptable to install an I_S-limiter at high risk sites that have a risk lower than the median level. A summary of the event tree is shown graphically in Figure 4.13.

Figure 4.13: I_S-limiter risks

Figure 4.14: FCL service risks



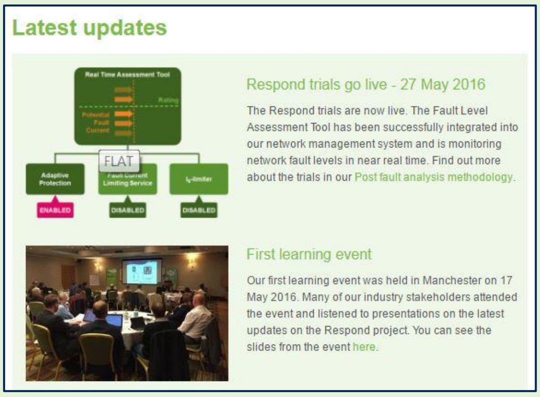
Fault current limiting service

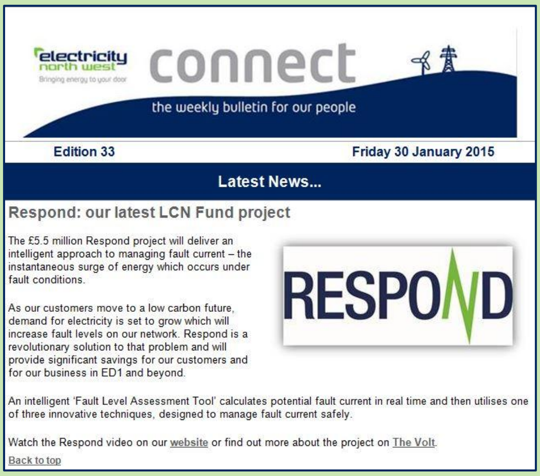
The analysis has shown that, based on arguably conservative assumptions, it would be acceptable from a safety viewpoint to fit low risk substations with an FCL service system but not high or medium risk sites. The FCL service system would be required to meet the SIL2 requirements of BS EN 61508. The event tree is summarised graphically in Figure 4.14.

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

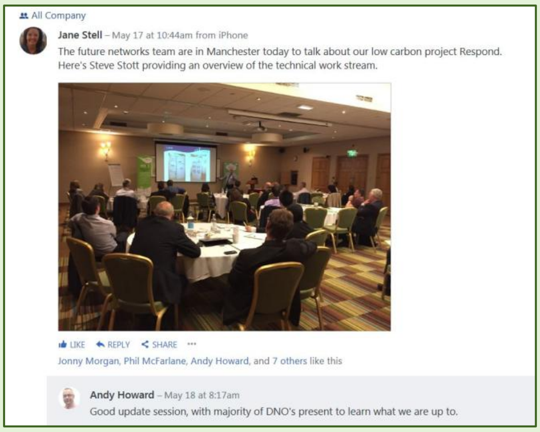
Successful delivery reward criteria

Ref	Description	Date	Evidence
9.1	**Technology**		
9.1.1	Brief and train Electricity North West operational teams, including planning engineers, on fault level mitigation management protocols	Apr 2016	Slides and attendance record
9.1.2	Publish equipment specifications and installation reports for the adaptive protection and the I_S-limiter by September 2016 and the FCL service by April 2018	Sep 2016	Adaptive Protection installation and specification report I_S-limiter installation and specification report
		Apr 2018	FCL service installation and specification report
9.1.3	Publish NMS interface and configuration specifications and commissioning reports	Sep 2016	Configuration of NMS and installation of FLAT software report
9.1.4	Publish report on validation of the fault level assessment tool	Nov 2016	FLAT validation report
9.1.5	Publish updated fault level management, planning, design,	Jun 2018	Updated policies

Ref	Description	Date	Evidence
	protection settings and operation and maintenance policies		
9.2	**Customer**		
9.2.1	Send customer engagement plan and data privacy statement to Ofgem	Jun 2015	Customer engagement plan Data privacy statement
9.2.2	Deliver engaged customer panel workshop by September 2015, lessons learned from testing customer survey materials incorporated into survey and all survey materials published on the Respond website	Sep 2015	ECP materials
		Oct 2015	ECP report
9.2.3	Publish customer survey report and information for customer evaluation of FCL service provision on Respond website	May 2017	Interim customer survey report Final customer report
9.2.4	Publish contract templates for FCL service with new and existing customers and commercial arrangements learning	May 2016	FCL service installation and management agreement
		May 2018	FCL service contract and commercial learning
9.3	**Trials**		
9.3.1	Publish monitoring and analysis procedures for trials on Respond website	May 2016	Respond post-fault analysis methodology
9.3.2	Publicise commencement of live trials on Respond website	May 2016	 Respond website
9.3.3	Publish on Respond website a summary of each fault event three months after each event, with the expectation that a minimum of 18 faults will be reported on		Fault summaries for Respond trials
9.3.4	Publish on Respond website the cost benefit analysis study report and the buy order of Respond/FlexDGrid/traditional reinforcement fault level mitigation solutions	Jul 2018	Cost benefit analysis and buy order interim report Cost benefit analysis and buy order final report

<table>
<tr><th>Ref</th><th>Description</th><th>Date</th><th>Evidence</th></tr>
<tr><td>9.3.5</td><td>Submit a DCUSA change proposal for amending application approach to fault level cost apportionment factor in common connection charging methodology</td><td>Aug 2018</td><td>DCUSA change proposal</td></tr>
<tr><td>9.3.6</td><td>Publish on Respond website the carbon impact assessment report</td><td>Jul 2018</td><td>Carbon impact assessment final report</td></tr>
<tr><td>9.3.7</td><td>Purchase an FCL service from at least one Electricity North West demand customer and one Electricity North West generation customer</td><td>May 2016 – Apr 2018</td><td>FCL service contract and commercial learning</td></tr>
<tr><td>9.3.8</td><td>Publish peer reviewed safety cases on the Respond project website</td><td>Sep 2018</td><td>Adaptive protection safety case
I_S-limiter safety case
FCL service safety case</td></tr>
<tr><td>9.3.9</td><td>Publish asset health study on Respond website</td><td>Jul 2018</td><td>Asset health study</td></tr>
<tr><td>9.4</td><td colspan="3">Learning & dissemination workstream</td></tr>
<tr><td>9.4.1</td><td>Deliver live Respond website and social media forums</td><td>Jul 2015</td><td>Respond website</td></tr>
<tr><td rowspan="2">9.4.2a</td><td rowspan="2">Publicise Respond within Electricity North West in monthly team brief pack and/or Volt (intranet) and/or Newswire (quarterly employee magazine)</td><td>Jan 2015</td><td>
electricity north west
Bringing energy to your door
connect
the weekly bulletin for our people
Edition 33 Friday 30 January 2015
Latest News...
Respond: our latest LCN Fund project
The £5.5 million Respond project will deliver an intelligent approach to managing fault current – the instantaneous surge of energy which occurs under fault conditions.
As our customers move to a low carbon future, demand for electricity is set to grow which will increase fault levels on our network. Respond is a revolutionary solution to that problem and will provide significant savings for our customers and for our business in ED1 and beyond.
RESPOND
An intelligent 'Fault Level Assessment Tool' calculates potential fault current in real time and then utilises one of three innovative techniques, designed to manage fault current safely.
Watch the Respond video on our website or find out more about the project on The Volt.
Back to top</td></tr>
<tr><td>Sep 2015</td><td>
electricity north west
connect
the weekly bulletin for our people
Edition 66 Friday 18 September 2015
Latest news...
Latest project Responds to low carbon challenge
Our latest low carbon project 'Respond' is making great progress.
Since funding was announced last November, the innovation team have put contracts in place with project partners, launched a website, begun a detailed customer engagement exercise, put installation plans in place and, earlier this week, held their first webinar.
Project manager Andy Howard said, "Respond will deliver an intelligent approach to managing fault current – the instantaneous surge of energy, which occurs under fault conditions. As it stands, our network is vulnerable to costly reinforcement due to the increased fault current we expect to see as demand for electricity grows in a low carbon future.
"Respond will deliver a 'Fault Level Assessment Tool', which calculates potential fault current and enables one of three innovative techniques, designed to manage fault current safely."
£ 5.539 million
Build Now to April 2016
Trial May 2016 to April 2018
Decommission & closedown October 2018
Fault Level Assessment Tool
Adaptive protection (5 HV, 2 EHV sites)
Fault Current Limiting (FCL) service
Delivers same capacity but up to 18 x faster
Up to 80% cheaper
Could save GB £2.3 billion by 2050
The £5.5 million project, which runs from January 2015 until September 2018, will maximise the use of our existing assets and, if rolled out across Great Britain, could save £2.3 billion by 2050.
To find out more, watch the webinar, or visit our future networks website.</td></tr>
</table>

Ref	Description	Date	Evidence
		Jun 2016	 Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 104 24 JUNE 2016 **LATEST NEWS...** **Respond project goes live** RESPOND Our low carbon project Respond hit a major milestone last month as we completed the installation of equipment at a number of selected sites and the £5.5 million project went live. Respond will deliver an intelligent approach to managing fault current – the instantaneous surge of energy which occurs when we have a fault. As it stands, we will need to spend millions of pounds on our network because of the increased fault current we expect to see as demand for electricity grows. Working with our project partner Schneider Electric, the Respond 'Fault Level Assessment Tool' has been successfully integrated into our new network management system. *Adaptive Protection* – Re-sequences the operation of circuit breakers – the electrical switches on our network which operate automatically to protect an electrical circuit from damage. *Is-limiter* – A fuse which detects the rapid rise in current when a fault occurs and responds within 1/200th of a second to break the current. *Fault Current Limiting (FCL) service* – A unique opportunity for large demand and generation customers to earn rewards by selling us a fault current limiting response through a managed service agreement. An extensive customer survey across a range of industrial and commercial market sectors has shown that there is an appetite among customers in the non-manufacturing sector to provide this kind of service. We are now seeking up to five large industrial business customers in the North West to trial the FCL service as part of the Respond project. Project manager Paul Marshall said, "I would like to thank all our colleagues from operations and IT&T who have been involved in the delivery of the project and helped us achieve our go live milestone." If rolled out across Great Britain Respond could save £2.3 billion by 2050. The project runs until October 2018. To find out more, visit our project website.
		Jul 2017	 Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 158 14 July 2017 **LATEST NEWS** **Respond technology in action** Our Respond project provides an intelligent approach to managing fault current – the instantaneous surge of energy which occurs when we have a fault on the network. Since the trials went live in May 2016, there have been seven successful operations of the technology in response to a fault. Respond's intelligent software, the 'Fault Level Assessment Tool,' is integrated into our network management system and uses network data to predict fault level in near real time. When fault level approaches or rises above the safety rating of our equipment, the tool 'enables' one of three innovative techniques designed to manage fault current safely. Project manager Paul Marshall said, "It's great news that the technology is working as expected. The Adaptive Protection installations, which re-sequence the operation of circuit breakers to reduce fault level, have successfully operated six times. "We've also had one operation of the IS-limiter at our Bamber Bridge substation. The IS-limiter detects the rapid rise in current when a fault occurs and responds within 1/200th of a second to break the current. It's really encouraging to see the results from the trials so we can get a feel for how the network would operate if Respond is rolled out as business as usual." Respond will benefit all electricity customers in the long term by helping to avoid or defer traditional, expensive and disruptive reinforcement. This will help keep costs down for customers, reduce carbon emissions and allow low carbon technologies to be connected to the network much more quickly. If rolled out across Great Britain Respond could save £2.3 billion by 2050. The project runs until October 2018. You can find out more about Respond on our website.
		Oct 2018	 Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 224 26 October 2018 **LATEST NEWS** **New technology 'Responds' to fault current** Our £5.5 million Respond project will be completed this month. By testing new technology at 14 of our primary substations, Respond has demonstrated an intelligent approach to managing 'fault current' – the instantaneous surge of energy which occurs when we have a fault on the network. Using intelligent software known as the Fault Level Assessment Tool, Respond calculates the maximum potential fault current (or 'fault level') in near real time. When fault level approaches or rises above network equipment ratings, the tool enables or disables one of three Respond mitigation techniques: *Adaptive Protection*: re-sequences the operation of circuit breakers to reduce fault level. During the Respond trials this technology operated eight times following a network fault. *The IS-limiter*: this current-limiting fuse detects the rapid rise in current when a fault occurs and responds within 1/200th of a second to break the current. IS-limiters were installed at two of our substations and operated twice during the trials. *The Fault Current Limiting service*: a commercial solution where large demand and generation customers can earn rewards by selling a fault current limiting response to their local network operator through a managed service agreement. The Respond trials proved the technical feasibility of the service, but an extensive survey showed there is currently no commercial appetite. Project manager Ben Ingham said, "The Respond project has successfully proven that we can manage fault level in real time through our network management system. Our next steps will be to update our policies and procedures so that Respond techniques can be used as part of our business as usual processes." Respond will benefit all electricity customers by helping to avoid or defer traditional, expensive and disruptive reinforcement. This will help keep costs down, reduce carbon emissions and allow low carbon technologies to be connected to the network much more quickly. The project closedown report will be available on our website by 31 October 2018.
9.4.2b	Publish advertorials	Jul 2015	Advertorial July 2015

Ref	Description	Date	Evidence
		Apr 2016	Advertorial April 2016
		Jul 2016	Advertorial July 2016
		Jul 2017	Advertorial July 2017
		Oct 2018	Advertorial October 2018
9.4.2c	Publish newsletter	May 2015	Respond newsletter May 2015
		Nov 2015	Respond newsletter November 2015
		May 2016	Respond newsletter May 2016
		Nov 2016	Innovation update October 2016
		May 2017	Innovation update May 2017
		Nov 2017	Innovation update November 2017
		May 2018	Innovation update April 2018
9.4.3	Knowledge sharing events	May 2016	 Respond event presentation and feedback
		May 2017	Respond event presentation and feedback
		Sep 2018	Respond event presentation and feedback
9.4.3	Webinars	Sep 2015	Webinar slides Webinar recording
		Sep 2016	Webinar slides Webinar recording
		Sep 2017	Webinar slides Webinar recording
		Sep 2018	Webinar slides Webinar recording

Ref	Description	Date	Evidence
9.4.3	Actively participate at four annual Low Carbon Networks & Innovation conferences	Nov 2015	Respond LCNI slides session 3.1. 2015 Respond LCNI slides session 4.3. 2015
		Oct 2016	Respond LCNI presentations 2016
		Dec 2017	Respond LCNI presentation 2017
		Oct 2018	Respond LCNI presentation 2018
9.4.4	Issue project progress reports in accordance with Ofgem's June and December production cycle and publish on Respond website	Jun 2015	Respond progress report June 2015
		Dec 2015	Respond progress report December 2015
		Jun 2016	Respond progress report June 2016
		Dec 2016	Respond progress report December 2016
		Jun 2017	Respond project progress June 2017
		Dec 2017	Respond progress report December 2017
		Jun 2018	Respond project progress June 2018
9.5	**Closedown & business as usual handover phase**		
9.5.1	Issue Respond project closedown report to Ofgem and publish on Respond website	Oct 2018	
9.5.2	Publish Electricity North West's approach to managing fault level reinforcement on Respond website	Oct 2018	Approach to managing fault level reinforcement

5.1 Customer engagement and feedback

FCL service contract

A project aim was to establish one demand and one generation FCL service contract with existing customers during the trial period. Two FCL service contracts were signed with United Utilities for generation FCL services. Protracted contract negotiations with United Utilities, which lasted over two years, delayed agreement on the commercial terms because of perceived risks associated with acceptance of liability for the consequences of disconnecting water and wastewater treatment processes. This delay restricted the time available to develop the design and technical arrangements required to actively test the interface technologies at the two proposed sites and consequently, the interface technologies were tested off-site.

The strategy, challenges and actions taken to secure a managed agreement are set out in the May 2017 customer report and the contract and commercial learning report published in May 2018.

5.2 Technology implementation and effectiveness

The Respond technologies were selected to be novel and highly transferable solutions (to GB DNOs) to manage 'break' fault levels with two techniques to be trialled. The Respond technologies were designed to ensure that all the techniques and applications would ensure safe operation at all times. Both the Is-limiter and adaptive protection were installed on the network at points without fault level issues. The adaptive protection and the I_S-limiter methods both operated safely during real network fault situations on a number of occasions.

The reduction in cost and installation timescales of the adaptive protection method compared to traditional reinforcement was of a similar order to that stated in the project bid document. The I_S-limiter costs and timescales of installation proved to be slightly higher than expected mainly due to equipment accommodation/civil costs.

Adaptive protection was shown to be effective at reducing fault current on a number of occasions. The summated primary current transformer inputs to the adaptive protection allowed an upstream fault current contribution to be measured and thus show that the operation of the relay reduced the fault current following a downstream fault.

The FCL technology could not be implemented on a real customer's site due to the FCL customer recruitment issues. A demonstration version of the type of solution that would be likely to be implemented was designed, constructed and tested off-site.

The I_S-limiter did operate for real network faults, however, it was difficult to demonstrate accurately the timeliness of the operation due to limitations in fault monitoring. Protection relays monitored the series circuit breaker currents going through the I_S-limiters. These relays were set to have no time delay and a current setting at a similar value to that of the I_S-limiter trip. None of the relays operated during the I_s limiter fault trip operations, demonstrating that the I_S-limiters operate faster than conventional protection relays.

5.3 Respond trials

The Respond trials were developed to test the hypotheses of the project. The trials sought to prove that fault current can be managed at a lower cost than traditional asset replacement methods, without impacting the health of the existing equipment and operating safely.

Critical to the project was the implementation of the FLAT to continually assess the fault level. Although the implementation and trials were successful in demonstrating that the FLAT could be used, the data behind the electrical model developed for the project was not of the standard required to allow BAU operation. The settings for the respective technologies resulted in a large number of operations providing sufficient data for project partners with sufficient data to carry out a comprehensive assessment of the Respond techniques.

5.4 Data evaluation

The Respond project was developed to show how innovative fault management techniques could be installed with existing network assets to provide fault level management. The Respond trials were developed to demonstrate that innovative fault management techniques could be used to monitor real time fault levels, issuing commands to enable and disable the respective techniques when a fault level threshold was reached, ensuring that the existing equipment operated safely and without detriment to asset health.

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

- Based on the developed model, the FLAT showed that the correct signals were sent to enable/disable the respective techniques based on required fault level trigger set points.
- The two technical techniques, AP and I_S-limiter, proved to be successful in providing fault level management.
- There was a total of 11 faults across the trial locations, operating correctly each time, providing effective fault level control.
- The post-fault analysis of the AP techniques demonstrated that the AP-operated CB tripped in approximately 100ms on each occasion.
- The post-fault analysis of the two I_S-limiter operations determined that the device operated successfully. Without details to show fault level magnitudes and times, other evidence was available to determine that the I_S-limiter operated well before existing electronic trip protection relays.
- The FLMs installed across 11 of the 14 locations has provided great confidence in the Electricity North West master electrical network modelling, with simulated fault levels within an acceptable range compared with the monitored values.
- Health monitoring installed across the 14 locations has demonstrated that the FLMTs caused no noticeable change to asset health.
- If rolled out across the Electricity North West area, Respond has the potential to save 6,297,777 kg CO_2e per year; and if rolled out across GB, 88,138,933.89 kg CO_2e per year can be saved.

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

6.1 Customer engagement and feedback

Customers participating in the Respond trial

A key customer objective was to seek two demand and generation Electricity North West customers to demonstrate the purchase, implementation and operation of the FCL service. To validate the method from the customer's perspective, organisations providing an FCL service were to be consulted about their experience at strategic phases on the trial, and specifically after each curtailment event. This phase of customer engagement was to be undertaken by the project partner, Impact Research. The delay in securing a managed agreement to trial the FCL service meant there were no on-site installations. It was therefore not possible to evaluate post-fault experience.

Technical design and installation arrangement

A design of the proposed installation arrangement was developed and tested off-site, incorporating new protection and tripping relays. This arrangement can be tailored to suit any particular installation on a site-by-site basis.

6.2 Technology implementation and effectiveness

Site selection

From the initial site selection list four changes were made due to unforeseeable reasons.

Three of the substations were replaced due to discharge issues with existing equipment.

- Shaw substation was replaced by Irlam substation which was the next substation on the list where static electronic protection relays were installed.
- Hall Cross substation was replaced by Offerton substation which was some 60 places below it on the list. While other substations higher on the list also had electro-mechanical protection relays installed, they all had a common ranking of zero faults in 2012/13. Offerton was considered to be better suited to the trial as it is supplied from three BSPs which should provide opportunities to increase fault levels on the EHV network when making system parallels between adjacent BSPs.
- Cheadle Hulme substation was replaced by Broadheath. Broadheath had ten faults in 2012/13 of which three exceeded fault level limits. By comparison Cheadle Hulme had eight faults in 2012/13 of which two exceeded fault level limits.

Hindley Green primary substation was identified for asset replacement and as such was replaced by Denton West primary substation.

Fault level assessment tool development

The FLAT operated correctly based on the data model provided. Unfortunately the data behind the model was of inconsistent quality so the calculated values were not accurate enough to enable the FLAT to be set with realistic trigger values. Therefore, the trigger values were adjusted during the trials.

Fault level monitoring

Undertaken as planned.

Adaptive protection

The use of existing numeric relays on the Respond sites was ruled out due to the combined nature of the over-current and earth-fault legacy blocking systems found on most numeric relays. The straightforward way of achieving sequenced protection for Respond at numeric relay sites would have been to open circuit the blocking inputs from downstream relays to the 11/6.6kV bus section relay but this would have resulted in the 11/6.6kv bus section CB (CB) tripping for earth faults as well as over-current faults. On the Electricity North West network the 11/6.6kV system is resistively earthed to reduce earth fault currents (majority of HV faults are earth fault in nature) and therefore the maximum fault level is controlled to around 20% of the break fault capacity of the 11/6.6kV CBs. Consequently, there is no requirement to implement AP for pure earth faults on the Electricity North West network. However, this is a method that other GB DNOs could use if they have primary transformers which are directly earthed with correspondingly higher earth-fault levels.

Pre-installation work using CT analysing equipment found that extra terminations in the secondary wiring of the over-current CT system using standard 5P20 CTs caused an unacceptable increase in output burden when combined with the interposing CTs. This resulted in increased design cost and additional on-site works to mitigate against this effect.

I_S-limiters and sensing units

Installed as planned.

6.3 Respond trials

No change to approach.

6.4 Data evaluation

No change to approach.

7. SIGNIFICANT VARIANCE IN EXPECTED COSTS

£000s Cost Category	Total forecast	Budget	Variance (%)	Reasons for >10% variance
Labour	1479	1305	13	A number of issues were encountered at the design stage requiring additional resources to resolve
Payments to users	7	61	-88	As the project only secured agreement with United Utilities to trial the FCL service and this was at a late stage in the trials, no payments were made
Decommissioning	74	54	37	Additional work was required to safely decommission all installed equipment

The delay in successfully agreeing a contract to provide an FCL service, leading to insufficient time to test the system under fault conditions, meant that it was not necessary to make either availability payments to customers for taking part in the trial or utilisation payments for the provision of a fault level response.

During the design and installation phase of the AP it was found that additional work was required to integrate the proposed methodology into the existing schemes in the most efficient way.

8. UPDATED BUSINESS CASE AND LESSONS LEARNED

8.1 Customer benefits

FCL service provision – challenges of engaging I&C customers

Electricity North West's previous experience of innovation projects involving I&C customers, most notably in C_2C, provided insight into the difficulties of initially engaging commercial and technical decision-makers in large organisations, the challenge of building relationships and ultimately, agreeing terms for trial participation. This learning identified the value of collaborating with trusted partner organisations that have access to, and well established relationships with, third parties and can assist with introductions. As such, the Association for Decentralised Energy (formerly the Combined Heat and Power Association) and Ener-G, a cogeneration provider, were appointed to help overcome barriers and support customer engagement activities throughout the project. Despite this support and a robust customer engagement strategy, the Respond project team found it challenging to engage suitable Electricity North West I&C customers that were willing to participate in the FCL service trial.

Customer survey analysis suggested that procurement of the service from an existing customer might be achieved by offering a financial incentive of ~10% over the tested price point of £1,769 per MVA of contribution to fault level reduction, if combined with a short duration contract of just one year. However, customer engagement with the 13 organisations consulted suggests that survey responses do not accurately reflect commercial reality and there is an expectation of significantly higher payments influenced by a range of factors, outlined in the customer reported dated May 2017. As such, it was not possible to determine the optimum price point, likely to be acceptable to existing customers. Neither was it possible to establish the most appropriate payment structure for procuring an elective service when balancing guaranteed availability payments against utilisation payments made in response to each curtailment event.

However, offering the solution as a constrained connection for new customers negates the cost and complexity of ongoing payments. It also eliminates any requirement for the DNO to enter complex negotiations, to agree terms because of the non-negotiable conditions associated with a constrained/managed connection offer.

FCL service provision – commercial, security and resilience issues

The FCL service introduces a number of technical and commercial considerations that challenge the suitability and applicability of deploying AP at a customer's site as a viable solution to mitigate fault level.

These issues are documented individually in Section 5 of the customer report, the most notable of which are those associated with security and resilience. A contract with an existing customer to provide an FCL service will have a termination or break clause which could mean that the FCL service could be withdrawn, prior to alternative FCL arrangements being put in place. This situation has the potential to introduce unacceptable risks for the DNO. Certain risks apply irrespective of whether the response is purchased from an existing customer, or applied as a new constrained connection agreement. Therefore, the DNO must be confident that agreed terms are sufficiently robust to 'future proof' a contract. This should provide appropriate penalties and mitigation for breach and offer the requisite levels of network security to safeguard against unintentional or malicious isolation of enabling technologies by the customer or early termination of the agreement.

FCL service provision – the importance of collaboration in a competitive market

Electricity North West's experience in its C_2C project highlighted the difficulties of engaging commercial and technical decision-makers in I&C organisations, the challenge of building relationships and ultimately, agreeing terms for participation in new commercial arrangements.

In C_2C, DNO direct engagement was demonstrated as the most effective route to market, with customers valuing the strong ongoing relationship with the DNO, which provided confidence in the method. It also identified the value of collaborating with trusted partner organisations that have access to, and well established relationships with, potential customers.

Two project partners were appointed to forge these links but the strategy had limited success in overcoming barriers and supporting customer engagement activities, leading to a commercial agreement to trial the service.

Large I&C customers tend to be more educated and engaged with the DNO than most. However even these organisations can be confused about the complex structure of the electricity sector and reticent about entering commercial arrangements outside their core business.

However, the commercial opportunities offered from the TSO have introduced significant income streams, which large I&C customers are increasingly seeking to exploit. As such, the viability of a commercial fault level mitigation services, operated locally by a DNO, is dependent on its acceptability to customers (largely driven by risk versus the incentive available), and its ability to integrate with other well established and emerging TSO schemes.

This underpins the importance of industry and stakeholder collaboration in customer engagement/education, which will be key to providing an effective route to market for products such as the FCL service in the future.

Furthermore, many organisations do not have sufficient internal expertise about the energy market to make decisions about which of the available schemes are most appropriate for their particular organisation. Organisations that are able to derive benefit from entering the commercial energy market tend to do so in collaboration with aggregators or electricity supply companies (ESCO) that are able to manage their load and generation capacity as part of a portfolio of sites.

8.2 Financial benefits

Financial benefits

The business case for the Respond technical solutions is based upon using retrofit techniques to control fault level on the HV network so that the rating of existing plant and equipment is not exceeded and can therefore remain in service until its condition based replacement date. The choice of FLMT is contingent upon the nature and type of fault level issue such as switchgear closing onto a fault (make), opening for a fault (break) or the capability to pass fault current (withstand) and the network to which it will be retrofitted.

A further consideration is that the Respond techniques can generally be installed in a shorter timescale than traditional reinforcement schemes which often require an interim solution of splitting the network to reduce fault levels. This leads to reduced security levels which could have a financial impact arising from increased levels of customer interruptions and customer minutes lost.

To derive the financial benefits it was first necessary to obtain the actual costs of installing the FCL technologies in the trial so that they could be compared with the anticipated costs of traditional methods of reinforcement such as the replacement of switchgear and underground cables. A summary of the costs is shown in Figure 8.1. Although the project was unable to identify a customer willing to provide an FCL service, the anticipated costs have been included for completeness.

Figure 8.1: Cost benefit summary

Equipment	Capital cost	Additional O&M costs	Advantages compared to traditional reinforcement	Disadvantages compared to traditional reinforcement
Traditional reinforcement (replace HV cables at primary substation)	£1,115k	None	N/A	N/A
Traditional reinforcement (change primary HV switchgear)	£442k	None	N/A	N/A
APHV	£43k	None	• Lower capital cost • Reduced design and installation times	• Reduced network security • Operational failure could cause existing equipment to exceed rating
Fault current limiting service	£10k	£30k-£540k	• Low capital cost	• Ongoing annual payments required • Service could easily be terminated
I_S-limiter (protecting primary switchgear or cables)	£402k	£12k pa refurbishment of inserts	• Reduced capital cost • Ability to relocate I_S-limiter to other sites	• Additional space required • Additional civil costs • Ongoing operating costs

The key determinant as to whether the retrofit techniques are applied is the length of time the traditional reinforcement can be delayed to prevent the early replacement of existing assets. The analysis reveals that the initial capital costs of the technical solutions are less than the capital cost of the traditional solution, but the operational and maintenance regimes drive different cost profiles.

The relatively low cost of AP would lead to financial benefits as it costs substantially less than traditional reinforcement. The relatively high cost of installing an I_S-limiter reveals that while there is a marginal saving compared to the cost of replacing a primary switchboard the main financial benefit would be where it was necessary to replace substantial lengths of HV cable. Consideration should also be given to the fact that an I_S-limiter could provide a short-term solution until a permanent reinforcement is completed after which the I_S-limiter could be released for utilisation elsewhere.

As stated in Section 8.1 the costs of procuring an elective FCL service from an existing customer were not determined and would need to be evaluated on a case-by-case basis. The commercial technique is more appropriate, and could prove attractive, to customers seeking new connections on networks with fault level constraints, where the time and costs of traditional reinforcement might otherwise be prohibitive.

8.3 Carbon benefits

In the Respond project the use of AP and Is-limiters, as alternatives to traditional reinforcement, would reduce carbon impact by 502,594 kg CO_2e and 40,331 kg CO_2e respectively.

Assuming an 80% adaptive protection and 20% I_S-limiter split, Respond has the potential to save 542,926 kg CO_2e per year relative to traditional methods for managing increasing fault levels on the network.

Assuming an 80% adaptive protection and 20% I_S-limiter split across GB, the analysis showed the potential for Respond to save 7,432,431 kg CO_2e per year.

8.4 Non-quantified benefits

While Respond demonstrates significant potential financial and carbon saving benefits there are also a number of non-quantifiable benefits that should be noted. The first of these is how the solution will inform discussions in the RIIO-ED2 mid-term review.

A key aspect of RIIO-ED1 is innovation and how customers will benefit from this. The Respond project demonstrates innovation in the novel use of FLMTs to drive the greater utilisation of existing assets. Respond follows the strategy of generating additional value for customers and stakeholders from the greater use of existing assets.

Another key consideration for RIIO-ED2 and beyond is the delivery of network services with long-term value for money for existing and future consumers. Learning from Respond and previous projects has demonstrated that the innovative use of fault level management has the potential to be offered as an ancillary service. The project has confirmed the solution can play a role in the delivery of a secure and sustainable energy sector, reducing the carbon intensity of the provision of current balancing services.

9. LESSONS LEARNED FOR FUTURE INNOVATION PROJECTS

9.1 Customer engagement and feedback

The challenges of engaging I&C customers in new commercial initiatives should not be underestimated.

Electricity North West anticipated difficulties in engaging the decision-makers in large I&C organisations in Respond, because of the challenges encountered in its project C_2C project. In anticipation of this the project team considered every possible source of customer data, to maximise opportunities for recruiting the optimum number of survey respondents. This was expected to attain meaningful results from a sufficient number of organisations that theoretically met the criteria to provide an FCL service.

This data set consisted of over 1,600 organisations from across GB. Despite such an extensive reach the project team was only able to achieve 103 customer surveys from an aspiration of 750 and the strategy failed to secure an FCL service contract to trial enabling technologies.

The enhanced customer engagement activities required to maintain momentum in the survey and promote the trial was time and resource heavy. As a consequence customer activities incurred additional and unforeseen costs and extended the survey fieldwork period.

The criteria for trial participation were extended to include both HV and EHV connected customers' operating equipment with capacity ranging from 500kVA to 15MW. This strategy was supported with appropriate communications via a range of internal and external channels. These included newsletters from Electricity North West and project partners ADE and ENER-G, repeated direct approaches to potentially suitable organisations and presentations at various partner forums. This strategy failed to secure the agreement of terms to trial the solution at a customer site, suggesting that there is currently little appetite for this provision in the marketplace. This situation may change in the future when networks become increasingly constrained, meaning customers could find alternative arrangements more appealing. The FCL service provides a mechanism which offers greater choice for customers to connect quickly and at significantly less cost for networks that would otherwise require substantial reinforcement.

Unlike the C_2C project, aggregators and agents were not directly engaged to provide a distinct route to market for the FCL service. However they were encouraged to take part in the survey and a number were consulted directly to provide feedback on the merits for their portfolio of customers. This research demonstrates the need for DNOs to develop greater commercial acumen and more cohesive relationships with the TSO, aggregators and ESCOs as they make the transition to DSO. This will be essential in successfully embedding new commercial schemes, such as the FCL service, into BAU and delivering choice and synergy benefits to customers that may be available from other local and nationally operated demand side and balancing arrangements.

9.2 Technology implementation and effectiveness

AP is a low cost solution to resolve fault break issues in non-unit protected systems. However, both ESQCR regulation 6 and electricity at work (EAW) regulations 4, using definitions of regulation 2, make its use in unit protected environments questionable.

The use of the FLAT to turn FCL techniques on and off via a remote control SCADA system inevitably means some time delay can occur between a calculation indicating that fault level has been exceeded and the correct FCL technique being employed. While SCADA is working correctly this delay will be only a few seconds. If SCADA fails, a delay of five to six minutes will occur before the on-site FCL device will automatically turn itself on (as it assumes there is a SCADA fault and therefore fails-safe). The reason for the six-minute delay not being shorter is to prevent the SCADA system becoming overloaded with FCL ‘stay off’ signals. The implication of this is that for a short period the fault level of the equipment may be exceeded without an FCL being employed. As such it may be prudent to enable FCL permanently once it has been calculated that such a risk exists. The I_S-limiter is a significant investment and a considerable undertaking to install in comparison to AP. The advantage of the I_S-limiter in comparison to AP is its speed of operation. It is suggested that resources be made available for high speed transient recorders in any future projects involving fast acting protection systems like I_S-limiters. This is needed to validate the operating times of current limiting devices claimed by their manufacturers.

9.3 Respond trials

The Respond data model was a significant issue, as large amounts of data were either missing or incorrect. The development of the new NMS, which provided the FLAT, was not at a stage to enable the accurate development of a system model for the project.

10. PROJECT REPLICATION

10.1 Customer engagement and feedback

The importance of effective industry collaboration cannot be understated in providing an effective route to market for new commercial concepts such as the FCL service in the future.

Large I&C customers are generally more educated and engaged with the DNO than most. However even these organisations can be confused about the complex structure of the electricity sector and reticent about entering commercial arrangements outside their core business.

Many organisations do not have sufficient internal expertise about the energy market to make decisions about which of the available schemes are most appropriate for their particular organisation. Furthermore, organisations that are able to derive benefit from entering the commercial energy market tend to do so in collaboration with aggregators or ESCOs. These third parties operate a commercial model which promotes the identification of organisations able to provide certain services. They are able to provide expert guidance about the most appropriate commercial service/s for individual businesses and the most lucrative terms, allowing them to optimise both their own and their customers’ earning from the appropriate revenue streams. These organisations can also assist with navigating often complex operating arrangements, which can constrain a customer’s ability to agree to new commercial services, particularly where critical plant is owned, operated and subject to warranty conditions dictated by a third party provider.

10.2 Technology implementation and effectiveness

AP is readily transferable to other DNOs that use dual upstream in-feed primary substations ie substations where an 11/6.6kV bus section CB is fitted and its opening does not result in a loss of supply. It is less likely to be transferable to DNO environments with downstream unit protection or single in-feed site. AP proved effective at reducing fault currents on eight occasions during the Respond trials. The transferability to other DNOs of the FLAT to turn FCL techniques on and off via remote control SCADA system will depend on the capabilities of their network management system and associated SCADA network. The use of a FLAT also requires that the network models and the electrical properties data are sufficiently accurate to make the calculations of the FLAT meaningful and appropriate.

Like AP, the I_S-limiter is also readily transferable to other DNOs. However, the I_S-limiter requires much more space to install than AP and so may not be easy to implement in substations with space constraints such as those in city centres. The I_S-limiter operated for network faults twice during the trials.

10.3 Respond trials

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

- Electrical system model
- Plant data records
- Network constraints
- Levels of embedded generation
- Outage plan for all primary substations
- Network fault levels (33kV, 11kV and 6.6kV)
- Protection settings.

10.4 Data evaluation

Respond software and data requirements

Software components

Name	License	Role
MS Excel	Commercial	Protection settings database, raw fault level data, fault level validation data/results sheets. Convert FLAT output files
TNEI, IPSA+	Commercial	Simulation for the Electricity North West network, fault level studies for validation purposes
TNEI, in-house scripts for model data conversion	-	Translate DiNIS export files into IPSA+ readable files
DINIS	Commercial	Simulation for the Electricity North West network, fault level studies for validation purposes
Schneider, FLAT	Commercial	Simulation for the Electricity North West Respond network model, real time fault level studies, part of the NMS suite of applications
Pronto	Commercial	Logger and data management application for analysis of fault level monitors used to measure fault level
Kelvatek, Relay Pro	Commercial	Analyse CB profile data from the Kelvatek P3 CB analyser
Kelvatek, Trans Pro	Commercial	Analyse DGA results from the Kelvatek Totus DGA equipment
EATL, PD Data Analysis Studio	Commercial	Analyse partial discharge (PD) data recorded using the EA Technology PD monitoring equipment
GE, MiCOM S1 Agile	Free	Fault level data extraction from AP relay

Data requirements

- Field measurement data for:
  - Fault level analysis
  - DGA
  - CB opening/closing times
  - Protection relay operations
- Simulated fault level results for validation purposes.

11. PLANNED IMPLEMENTATION

The Respond project used existing off-the-shelf products as well as existing equipment to which configuration changes and some new designs were made. As such there are no technical hurdles to prevent the full implementation of Respond in any GB DNO.

The use of intelligent software has demonstrated that, with an accurate electrical system model, it is possible to enable and disable FLMTs as and when required.

Additional alternative designs for AP were developed outside the original scope; one installed design demonstrated that AP can be implemented without the need for real time fault monitoring. With this design the AP fault level mitigation is always enabled (with system normal) and operates when the pre-defined trigger value is exceeded.

The initial and alternative designs have provided DNOs with options on how to implement the Respond techniques, with or without intelligent software.

12. LEARNING DISSEMINATION

This closedown report is a key element of the dissemination approach to share project learning.

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

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

A peer review of the closedown report was completed by Northern Powergrid; the closedown report was revised in-line with the comments made during this process.

In addition a summary of the project outcomes and lessons learned have been presented at the following events:

- Respond webinars – Sep 2015, Sep 2016, Sep 2017,Sep 2018
- LCNI conferences – Nov 2015, Oct 2016, Dec 2017, Oct 2018
- Knowledge sharing event – May 2016, Jul 2017, Jul 2018.

Electricity North West consulted with other DNOs at the Respond workshop regarding preferred methods to receive learning. Bespoke one-to-one knowledge dissemination sessions are available for DNOs and Ofgem. All knowledge dissemination materials have been published on the project website and key stakeholders made aware of the materials 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	19 June 2015	Progress report no 1
Project progress report no 2	18 December 2015	Progress report no 2
Project progress report no 3	19 June 2016	Progress report no 3
Project progress report no 4	19 December 2016	Progress report no 4
Project progress report no 5	19 June 2017	Progress report no 5
Project progress report no 6	19 December 2017	Progress report no 6
Project progress report no 7	19 June 2018	Progress report no 7

13.2 Key learning documents

Title	Date	Summary
Technology		
I_S-limiter specification & installation	Sep 2016	The methodology for the installation and commissioning of the I_S-limiters
AP specification & installation	Sep 2016	Describes the methodology used when installing the AP relay
Configuration of NMS & installation of FLAT software	Sep 2016	Overall system functionality and acceptance testing to commission the fault level assessment tool

Title	Date	Summary
Fault level assessment tool validation report	Nov 2016	Validation of the FLAT demonstrated through comparison with simulated fault level results
FCL service specification & installation	Apr 2018	Equipment specifications and installation configurations that could be used to provide FCL services
Updated policies	Jun 2018	Updated fault level management, planning, design, protection settings and operation and maintenance policies
Customer		
Customer engagement plan	Jun 2015	Sets out how Electricity North West will engage and interact with customers during the Respond project
Data privacy statement	Jun 2015	How customers' personal data was managed during the Respond project and how the project complies with the Data Protection Act 1998
ECP materials	Sep 2015	Methodology and key findings from research undertaken with an engaged customer panel to establish how best to communicate the Respond project
ECP report	Oct 2015	Interim findings from a survey of industrial and commercial demand and distributed generation customers
FCL service customer report	May 2017	Qualitative evidence and commercial learning from the development of the commercial framework to purchase the FCL service
FCL service contract and commercial learning	Apr 2018	Commercial learning from research with new and existing customers on the provision of FCL services
Trials		
Site selection methodology	Feb 2016	Describes how the Respond substation sites were selected to ensure the trial results are representative of the GB population
Respond post-fault analysis methodology	May 2016	A report on how the performance of the fault level mitigation techniques are assessed following a fault
Cost benefit analysis and buy order final report	Jan 2018	Final report on the cost benefit analysis of Respond fault level mitigation techniques
DCUSA change proposal	Mar 2018	Change proposal for amending the application approach to the Fault Level Cost Apportionment Factor in the Common Connection Charging Methodology
Carbon impact assessment report	Jul 2018	Final report on the carbon impact of Respond compared to traditional approaches for managing fault levels
Asset health study	Jul 2018	Condition monitoring of network assets which may be affected by the Respond project
Adaptive protection safety case	Sep 2018	Safety assessment of the Respond adaptive protection scheme, produced by WSP with input from and peer review by other distribution network operators
I_S-limiter safety case	Sep 2018	Safety assessment for installation of Is-limiters as a fault level mitigation technique on the electricity distribution network
FCL service safety case	Sep 2018	Safety assessment for implementing FCL services on the electricity network

14. CONTACT DETAILS

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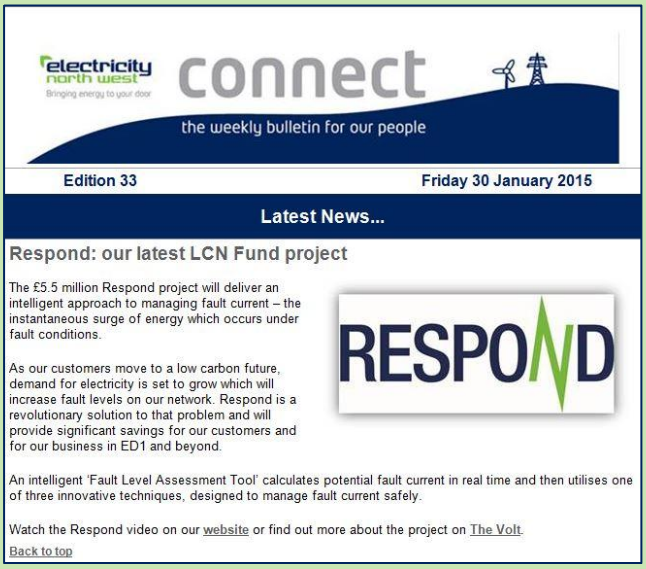
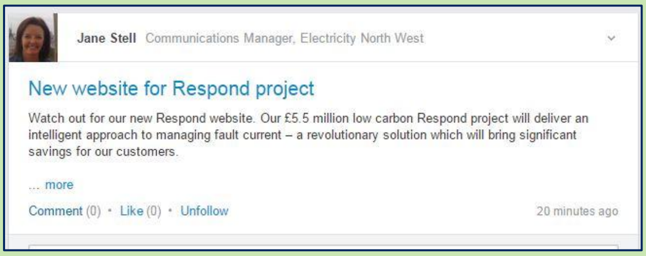
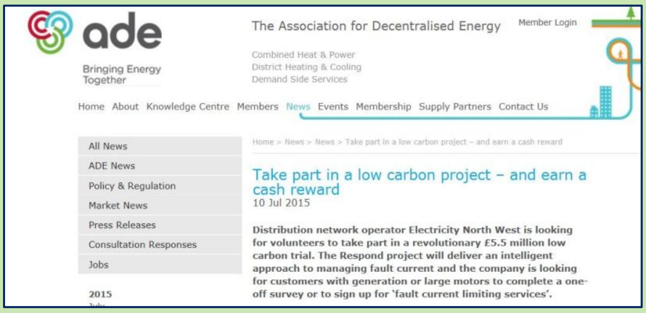
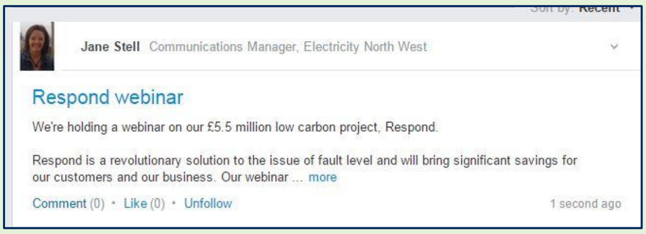
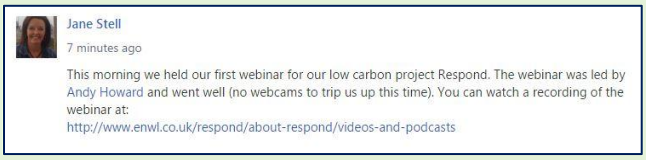
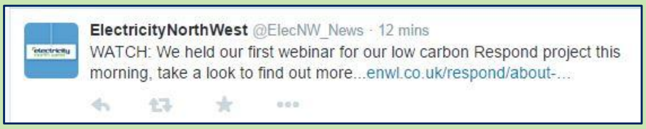
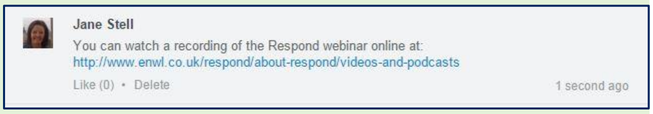
15. APPENDICES

A: Respond learning and dissemination activities

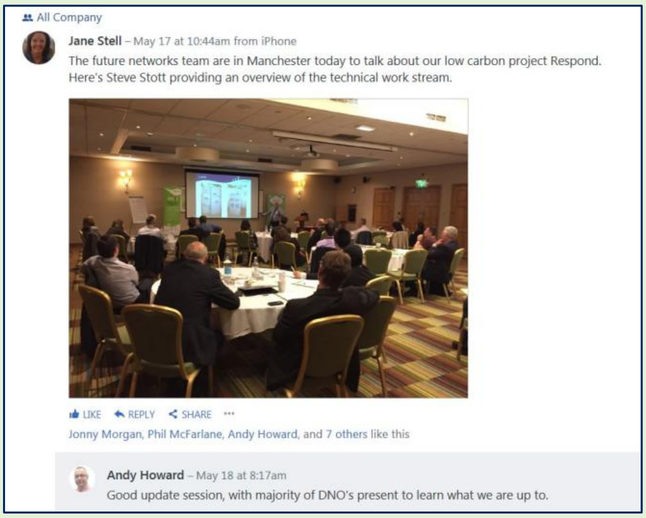
Date	Activity	Audience	Evidence
Nov 2014	Respond introductory video on YouTube	All stakeholders	You Tube
Nov 2014	Press release announcing Respond funding	All stakeholders	Press release
Nov 2014	Respond funding announced on Twitter	All stakeholders	ElectricityNorthWest @ElecNW_News · Nov 24 We've just been awarded £4.5m from @ofgem for our innovative Respond trial to help meet future demand in electricity bit.ly/1y4Fmit
Nov 2014	Employee announcement in Connect weekly e-bulletin	All employees	electricity north west Bringing energy to your door connect the weekly bulletin for our people Edition 26 Friday 28 November 2014 Latest news... **Electricity North West responds to future demand with new £5.5m trial**  We are delighted to announce that we have won funding for our latest future networks project, following our submission to Ofgem's Second Tier Low Carbon Networks Fund. Our project, 'Respond', will deliver an intelligent approach to managing fault current – the instantaneous surge of energy which occurs under fault conditions. As our customers move to a low carbon future, demand for electricity is set to grow which will increase fault levels on our network. Respond is a revolutionary solution to that problem and will bring significant savings for our customers and our business. Respond will deliver a 'Fault Level Assessment Tool' which calculates potential fault current in real time and then utilises one of three innovative techniques, designed to manage fault current safely. The project, which runs from January 2015 until September 2018, will maximise the use of our existing assets, reduce costs to customers and speed up the connection of solar panels, electric vehicles and heat pumps. This is the fourth consecutive successful bid for tier 2 funding following Capacity to Customers in 2011, CLASS in 2012 and Smart Street last year. We have now won over £37 million of competitive research and development funding and this latest win is a great testimony to our leadership of innovation in the industry and the capability of our people. You can find out more about our other low carbon projects at www.enwl.co.uk/thefuture.
Nov 2014	Introductory webpage on innovation website	All stakeholders	 Webpage

Date	Activity	Audience	Evidence
Jan 2015	Employee overview on the Volt intranet	All employees	 Respond **Active fault level management** Respond is the fourth of our second tier projects under Ofgem's Low Carbon Networks Fund. Funding for the £5.5 million project was announced on 24 November 2014. Respond will deliver an intelligent approach to managing fault current – the instantaneous surge of energy which occurs under fault conditions. As our customers move to a low carbon future, demand for electricity is set to grow which will increase fault levels on our network. Respond is a revolutionary solution to that problem and will provide significant savings for our customers and for our business in ED1 and beyond. An intelligent 'Fault Level Assessment Tool' calculates potential fault current in real time and then utilises one of three innovative techniques, designed to manage fault current safely: 1. Adaptive Protection – also known as sequential tripping. This technique re-sequences the operation of circuit breakers and is retrofitted into existing substation equipment. 2. Fault Current Limiting service (FCL service) – industrial, commercial and generation customers can operate their equipment so they can offer fault level management services to DNOs using new technology trialled under Respond. This commercial solution will enable customers to earn rewards and will benefit all distribution customers through reduced reinforcement. 3. IS-limiters – an existing technology capable of detecting and interrupting part of the fault current in less than one millisecond. This fast interruption prevents the fault current reaching its peak value. The IS-limiter is used on private networks in the UK and extensively on public networks in Europe, USA and Australia as a fault current mitigation technique. This will be the first installation on a British DNO network.
Jan 2015	Employee overview on Respond project in Connect weekly e-bulletin	All employees	 Edition 33 Friday 30 January 2015 Latest News... **Respond: our latest LCN Fund project** The £5.5 million Respond project will deliver an intelligent approach to managing fault current – the instantaneous surge of energy which occurs under fault conditions. As our customers move to a low carbon future, demand for electricity is set to grow which will increase fault levels on our network. Respond is a revolutionary solution to that problem and will provide significant savings for our customers and for our business in ED1 and beyond. An intelligent 'Fault Level Assessment Tool' calculates potential fault current in real time and then utilises one of three innovative techniques, designed to manage fault current safely. Watch the Respond video on our website or find out more about the project on The Volt. Back to top
May 2015	Stakeholder newsletter	All stakeholders	Newsletter page
Jun 2015	New website launched	All stakeholders	Website
Jun 2015	New website promoted on Yammer	All employees	 Jane Stell 8 minutes ago More future networks stuff ... watch out for our new Respond website. This £5.5 million project will deliver an intelligent approach to managing fault current – a revolutionary solution which will bring significant savings for our customers. You can see the website at www.enwl.co.uk/respond. Respond www.enwl.co.uk Respond is a £5.5 million project funded by Ofgem's Low Carbon Networks Fund which will deliver an intelligent approach to managing fault current...

Date	Activity	Audience	Evidence
Jun 2015	New website promoted on Linked In	All stakeholders	
July 2015	New website promoted on Twitter	All stakeholders	
July 2015	ADE newsletter	Commercial and industrial customers	
July 2015	New video promoting FCL service	Commercial and industrial customers	You Tube
July 2015	Advertorial in E&T magazine	All stakeholders	Advertorial
Aug 2015	Mailing to COMA customers	ENW commercial customers	COMA mailshot
Aug 2015	E-mail campaign to ADE members	ADE members	ADE mailshot
Aug 2015	E-mail campaign to Ener-g customers	Ener-g customers	Ener-g mailshot
Aug 2015	ECP materials – Q&A, analogy		ECP materials
Sep 2015	Webinar on Linked In		
Sep 2015	Webinar on Twitter		

Date	Activity	Audience	Evidence
Sep 2015	ADE on Twitter	All stakeholders	 ElectricityNorthWest @ElecNW_News · 2 hrs RT @theADEuk: Andy Howard from @ElectricityNW is here to talk about the new RESPOND project
Sep 2015	Webinar	All stakeholders	Webinar recording Webinar slides
Sep 2015	Webinar on Yammer	All employees	 Jane Stell 7 minutes ago This morning we held our first webinar for our low carbon project Respond. The webinar was led by Andy Howard and went well (no webcams to trip us up this time). You can watch a recording of the webinar at: http://www.enwl.co.uk/respond/about-respond/videos-and-podcasts
Sep 2015	Webinar on Twitter	All stakeholders	 ElectricityNorthWest @ElecNW_News · 12 mins WATCH: We held our first webinar for our low carbon Respond project this morning, take a look to find out more...enwl.co.uk/respond/about-...
Sep 2015	Webinar on LinkedIn	All stakeholders	 Jane Stell You can watch a recording of the Respond webinar online at: http://www.enwl.co.uk/respond/about-respond/videos-and-podcasts Like (0) • Delete 1 second ago
Sep 2015	Internal comms update	All employees	 electricity north west Bringing energy to your door connect the weekly bulletin for our people Edition 66 Friday 18 September 2015 Latest News... Latest project Responds to low carbon challenge Our latest low carbon project 'Respond' is making great progress. Since funding was announced last November, the innovation team have put contracts in place with project partners, launched a website, begun a detailed customer engagement exercise, put installation plans in place and, earlier this week, held their first webinar. Project manager Andy Howard said, "Respond will deliver an intelligent approach to managing fault current – the instantaneous surge of energy, which occurs under fault conditions. As it stands, our network is vulnerable to costly reinforcement due to the increased fault current we expect to see as demand for electricity grows in a low carbon future. £5.539 million Build Now to April 2016 Trial May 2016 to April 2018 Decommission & closedown October 2018 Fault Level Assessment Tool Adaptive protection (5 HV, 2 EHV sites) Fault Current Limiting (FCL) service Delivers same capacity but up to 18 x faster Up to 80% cheaper Could save GB £2.3 billion by 2050 "Respond will deliver a 'Fault Level Assessment Tool', which calculates potential fault current and enables one of three innovative techniques, designed to manage fault current safely." The £5.5 million project, which runs from January 2015 until September 2018, will maximise the use of our existing assets and, if rolled out across Great Britain, could save £2.3 billion by 2050. To find out more, watch the webinar, or visit our future networks website.
Oct 2015	Update on Yammer	All employees	 All Company Paul Marshall – October 30 at 3:52pm We have completed a productive workshop with Schneider to develop a Fault Level Assessment Tool (FLAT) which will provide near real time fault level assessment of our network every five minutes or when there is a topology change. This is part of the Future Networks RESPOND project which will allow ENW to be able to apply adaptive mitigation techniques to overcome the fault level challenges faced by all DNOs at much lower cost. The FLAT tool will deliver an intelligent approach to managing fault level – the potential maximum amount of fault current that flows when a fault occurs. When fault level approaches or rises above our equipment fault level ratings, the FLAT tool will trial the management of fault currents on certain sites by instructing one of three fault level mitigation techniques known as Adaptive Protection, the IS-limiter and the Fault Current Limiting service. This will help increase capacity on electricity networks, minimise disruption and lower costs for customers. Watch this space for further updates. UNLIKE REPLY SHARE ··· You, Kate Quigley and DEBORAH MARSHALL like this

Date	Activity	Audience	Evidence
Nov 2015	Presentation at annual LCNI conference	Industry stakeholders	 Session 3.1 slides – 25 November 2015 Session 4.3 slides – 26 November 2015
Nov 2015	Industry newsletter	All stakeholders	Newsletter page
April 2016	Advertorial	All stakeholders	Advertorial
April 2016	Knowledge sharing event on Twitter	All stakeholders	
April 2016	Knowledge sharing event on Linked In	All stakeholders	

Date	Activity	Audience	Evidence
May 2016	Go live promoted on website	All stakeholders	
May 2016	Knowledge sharing event	All stakeholders	Slides and event survey results
May 2016	Knowledge sharing event on Yammer	All stakeholders	
May 2016	Knowledge sharing event	All stakeholders	
May 2016	Industry newsletter	All stakeholders	Newsletter page

Date	Activity	Audience	Evidence
June 2016	Internal update	All employees	 Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 104 24 JUNE 2016 LATEST NEWS... **Respond project goes live** RESPOND Our low carbon project Respond hit a major milestone last month as we completed the installation of equipment at a number of selected sites and the £5.5 million project went live. Respond will deliver an intelligent approach to managing fault current – the instantaneous surge of energy which occurs when we have a fault. As it stands, we will need to spend millions of pounds on our network because of the increased fault current we expect to see as demand for electricity grows. Working with our project partner Schneider Electric, the Respond 'Fault Level Assessment Tool' has been successfully integrated into our new network management system. *Adaptive Protection* – Re-sequences the operation of circuit breakers – the electrical switches on our network which operate automatically to protect an electrical circuit from damage. *Is-limiter* – A fuse which detects the rapid rise in current when a fault occurs and responds within 1/200th of a second to break the current. *Fault Current Limiting (FCL) service* – A unique opportunity for large demand and generation customers to earn rewards by selling us a fault current limiting response through a managed service agreement. An extensive customer survey across a range of industrial and commercial market sectors has shown that there is an appetite among customers in the non-manufacturing sector to provide this kind of service. We are now seeking up to five large industrial business customers in the North West to trial the FCL service as part of the Respond project. Project manager Paul Marshall said, "I would like to thank all our colleagues from operations and IT&T who have been involved in the delivery of the project and helped us achieve our go live milestone." If rolled out across Great Britain Respond could save £2.3 billion by 2050. The project runs until October 2018. To find out more, visit our project website.
July 2016	Industry newsletter	All stakeholders	Newsletter page
July 2016	Advertorial	All stakeholders	Advertorial
Aug 2016	Update on Yammer	All employees	 All Company Steve Stott – August 3 at 2:59pm Well done to all Future Networks and Operations team members involved in the Ofgem bid and delivery stages of the Respond project. We had our first operation of the Respond technology last Friday 29th July. The Respond 11kV Adaptive Protection system operated during a two phase to earth fault on an 11kV feeder circuit out of Atherton Town Centre Primary in South Lancashire. The Adaptive protection system successfully reduced the fault current before the 11kV feeder circuit breaker tripped. This project is proving various technologies in order to help us manage rising fault current levels as the amount of distributed generation connected to our system increases, without the need for expensive and disruptive asset reinforcement. UNLIKE REPLY SHARE ··· You, Andy Howard, Rita Shaw, and 5 others like this
Sep 2016	Webinar on Linked in	All stakeholders	 Jane Stell Communications Manager, Electricity North West OWNER **Respond webinar, Thursday 29 September 2016** Register for our next webinar on our innovative project, Respond, at https://www.eventbrite.co.uk/e/respond-webinar-2016-registration-26917646405
Sep 2016	Webinar on Twitter	All stakeholders	 **ElectricityNorthWest** @ElecNW_News Sign-up to our webinar to discover more about how we're planning for the future with our #lowcarbon project Respond eventbrite.co.uk/e/respond-webi... 3:05 pm - 9 Sep 2016 **Respond Webinar 2016** As our customers move to a low carbon future, demand for electricity is set to grow which will increase fault level on our network (the potential maximum amount of fault current that will flow when a... Eventbrite @eventbrite
Sep 2016	Webinar	All stakeholders	Webinar slides Webinar recording

Date	Activity	Audience	Evidence
Sep 2016	Connect internal bulletin	All employees	 Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 118 30 SEPTEMBER 2016 LATEST NEWS... **Stakeholders Respond to project webinar** RESPOND Earlier this week, stakeholders from across our industry tuned in to our Respond webinar. Project manager Paul Marshall presented the webinar followed by a question and answer session with innovation team colleagues Paul Turner, Steve Stott and Tracey Kennelly. Paul said, "Webinars are a great opportunity to reach our stakeholders and promote our innovation projects. Using this kind of technology means we can share information and engage with a wider audience without the time, inconvenience and cost of everyone having to travel to an event. It's also great for our carbon footprint." Respond will deliver an intelligent approach to managing fault current – the instantaneous surge of energy which occurs when we have a fault. The project's intelligent software, the 'Fault Level Assessment Tool,' has been integrated into our new network management system and uses network data to predict fault level in near real time. When fault level approaches or rises above our equipment ratings, the tool will 'enable' one of three innovative techniques designed to manage fault current safely. If rolled out across Great Britain Respond could save £2.3 billion by 2050. The project runs until October 2018. The slide presentation from today's webinar is available to view on the key documents page of our website, or you can watch a recording of the webinar here. To find out more about Respond, visit our project website.
Oct 2016	Presentation at annual LCNI conference	Industry stakeholders	Slide presentation
Oct 2016	Promotion of LCNI conference in internal magazine and Connect e-bulletin	All employees	 Innovation Flying the flag at our industry conference Innovation as business as usual "We have already seen a number of our innovation projects adopted into our day-to-day processes"  Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 120 14 OCTOBER 2016 LATEST NEWS... **Flying the flag at our industry conference** Earlier this week many of our colleagues attended the Low Carbon Networks & Innovation Conference at Manchester Central. As the conference took place in our region, Electricity North West co-hosted the event with the Electricity Networks Association. This meant we had a great opportunity to promote our brand and fly the flag for Electricity North West. Around 1300 delegates attended the three-day event which showcased our network innovation projects through a programme of project-focused presentations and workshops. Our innovation team presented on a number of themes, including a workshop on our strategy for the future of customer service, and our key innovation projects: Celsius, Respond, Smart Street and CLASS. There was also an opportunity to share findings from our smaller-scale projects on oil regeneration and demand scenarios. Engineering & Technical Director, Steve Cox, said: "This year's event has been better than ever. It's a fantastic way to see firsthand how our sector is changing. It was also a great year for Electricity North West as co-host. Our new exhibition stand stood out from the crowd with our distinctive branding and the creative ways we used to promote our innovation strategy and our projects." You can find out more about the conference and watch out short highlights video at www.enwl.co.uk/lcni2016. Back to top
Oct 2016	Industry newsletter	All stakeholders	Newsletter page

<table>
<tr><th>Date</th><th>Activity</th><th>Audience</th><th>Evidence</th></tr>
<tr><td>Jan 2017</td><td>Innovation roadshow</td><td>All employees</td><td></td></tr>
<tr><td>May 2017</td><td>Industry newsletter</td><td>All stakeholders</td><td>Newsletter page</td></tr>
<tr><td>Jul 2017</td><td>Connect internal bulletin</td><td>All employees</td><td>
Connect
The weekly bulletin for our people
Stay connected...
electricity north west
Bringing energy to your door
ISSUE 158 14 July 2017
LATEST NEWS
Respond technology in action
Our Respond project provides an intelligent approach to managing fault current – the instantaneous surge of energy which occurs when we have a fault on the network. Since the trials went live in May 2016, there have been seven successful operations of the technology in response to a fault.
Respond's intelligent software, the 'Fault Level Assessment Tool,' is integrated into our network management system and uses network data to predict fault level in near real time. When fault level approaches or rises above the safety rating of our equipment, the tool 'enables' one of three innovative techniques designed to manage fault current safely.
Project manager Paul Marshall said, "It's great news that the technology is working as expected. The Adaptive Protection installations, which re-sequence the operation of circuit breakers to reduce fault level, have successfully operated six times.
"We've also had one operation of the IS-limiter at our Bamber Bridge substation. The IS-limiter detects the rapid rise in current when a fault occurs and responds within 1/200th of a second to break the current. It's really encouraging to see the results from the trials so we can get a feel for how the network would operate if Respond is rolled out as business as usual."
Respond will benefit all electricity customers in the long term by helping to avoid or defer traditional, expensive and disruptive reinforcement. This will help keep costs down for customers, reduce carbon emissions and allow low carbon technologies to be connected to the network much more quickly. If rolled out across Great Britain Respond could save £2.3 billion by 2050. The project runs until October 2018.
You can find out more about Respond on our website.</td></tr>
<tr><td>Jul 2017</td><td>Advertorial</td><td>All stakeholders</td><td>Advertorial</td></tr>
<tr><td>Jul 2017</td><td>Innovation learning event on social media</td><td>All stakeholders</td><td>
Jane Stell · Group Owner ··· 5m
Communications Manager, Electricity North West
Electricity North West annual innovation learning event
Join us for our first first annual learning and dissemination event where we'll tell you all about our innovation strategy and our portfolio of innovation projects.
There will also be an opportunity to network with some of our key project partners and other industry stakeholders.
You can sign up at https://www.eventbrite.co.uk/e/innovation-learning-event-may-2017-registration-33215715098 Show less</td></tr>
</table>

<table>
<tr><th>Date</th><th>Activity</th><th>Audience</th><th>Evidence</th></tr>
<tr><td>Jul 2017</td><td>Innovation learning event on Twitter</td><td>All stakeholders</td><td>
</td></tr>
<tr><td>Jul 2017</td><td>Innovation learning event on Linked In</td><td>All stakeholders</td><td>
</td></tr>
<tr><td>Jul 2017</td><td>Innovation learning event</td><td>All stakeholders</td><td>Slide presentation and survey results</td></tr>
<tr><td>Sep 2017</td><td>Promotion of webinar on Twitter</td><td>All stakeholders</td><td>
</td></tr>
<tr><td>Sep 2017</td><td>Webinar</td><td>All stakeholders</td><td>Webinar slides
Webinar recording</td></tr>
<tr><td>Nov 2017</td><td>Industry newsletter</td><td>All stakeholders</td><td>Newsletter page</td></tr>
<tr><td>Dec 2017</td><td>LCNI conference</td><td>Industry stakeholders</td><td>Slide presentation</td></tr>
</table>

Date	Activity	Audience	Evidence
Dec 2017	LCNI presentation on Twitter	All stakeholders	
Feb 2018	DNO update	UKPN innovation team	Presentation
Apr 2018	Industry newsletter	All stakeholders	Newsletter page
Jul 2018	Innovation learning event	All stakeholders	Slide presentation and survey results
Sep 2018	Webinar	All stakeholders	Webinar slides Webinar recording
Oct 2018	Advertorial	All stakeholders	Advertorial
Oct 2018	LCNI conference	Industry stakeholders	Slide presentation
Oct 2018	Connect internal bulletin	All employees	 Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 224 26 October 2018 LATEST NEWS **New technology 'Responds' to fault current** Our £5.5 million Respond project will be completed this month. By testing new technology at 14 of our primary substations, Respond has demonstrated an intelligent approach to managing 'fault current' – the instantaneous surge of energy which occurs when we have a fault on the network. Using intelligent software known as the Fault Level Assessment Tool, Respond calculates the maximum potential fault current (or 'fault level') in near real time. When fault level approaches or rises above network equipment ratings, the tool enables or disables one of three Respond mitigation techniques: *Adaptive Protection*: re-sequences the operation of circuit breakers to reduce fault level. During the Respond trials this technology operated eight times following a network fault. *The IS-limiter*: this current-limiting fuse detects the rapid rise in current when a fault occurs and responds within 1/200th of a second to break the current. IS-limiters were installed at two of our substations and operated twice during the trials. *The Fault Current Limiting service*: a commercial solution where large demand and generation customers can earn rewards by selling a fault current limiting response to their local network operator through a managed service agreement. The Respond trials proved the technical feasibility of the service, but an extensive survey showed there is currently no commercial appetite. Project manager Ben Ingham said, "The Respond project has successfully proven that we can manage fault level in real time through our network management system. Our next steps will be to update our policies and procedures so that Respond techniques can be used as part of our business as usual processes."