Fault Current Active Management

A First Tier Low Carbon Networks Fund Project

Closedown Report

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CONTENTS

VERSION HISTORY

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1 EXECUTIVE SUMMARY

1.1 Aims

This project investigated a range of techniques which can be used to manage fault levels on the UK distribution network. The techniques were assessed in a series of desktop exercises, simulations and tests to understand their capabilities in the management of fault level.

Fault Level is defined as the potential maximum current that will flow when a fault occurs.

Distribution network operator (DNO) networks are designed and operated to provide safe, reliable and cost efficient distribution of electrical energy. On occasion networks experience faults; when these occur protective devices such as circuit breakers (CBs) safely interrupt the flow of fault current and limit the loss of supply to connected customers. The purpose of CBs is to remove fault current from the network safely and quickly.

In an distribution network, the combination of disconnector switches, fuses or circuit breakers used to control, protect and isolate electrical equipment are known as switchgear.

All switchgear on a DNO network has three fault level ratings assigned by the manufacturer. Normally the fault capability of the switchgear is described in terms of an assigned rating - kA ie fault current and the three types “through fault withstand”, “breaking capacity” and “making capacity” will each have a fault current value assigned. The through fault withstand is the amount of current that can safely pass and for what length of time, ie 21kA for 3s. The breaking capacity is the maximum current that the switchgear can safely interrupt; whilst the making capacity is the maximum current which the device can safely conduct at the instant of closing.

All demand and generation connected to a network contribute to the current flowing in the event of a fault. As the amount of generation and demand connected increases, the fault level will increase. This increase can lead to instances where the fault level rises above the rating of the switchgear.

Traditionally, the solution to this issue is to replace the existing switchgear and/ or cables with a type that has a higher fault current rating. The cost of resolving this issue and the connection time associated with the design, procurement and installation of new switchgear and/ or cables can often make it uneconomic for a customer to accept a connection offer.

For these reasons it is appropriate to seek alternative innovative ways of managing fault currents which allow DNOs to respond to customer connection requests in a more timely and economical manner.

1.2 Methodology

The techniques investigated in this project are aimed at managing the breaking capacity and through fault withstand. Fault making capacity can be effectively managed through existing network operating protocols.

This project identified two techniques which can be used to address the problem; I_S-limiters and adaptive protection.

1.2.1 I_S-limiters

Whilst not traditionally used on UK networks, I_S-limiters can be particularly effective at managing through fault withstand and will operate in just 0.6ms. Given concerns raised previously within the industry associated with the suitability of such devices to operate safely, this project investigated the specific safety related and design issues associated with this equipment and its application for management of through faults.

1.2.2 Adaptive protection

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

1.3 Outcomes

FCAM has investigated the suitability of a range of techniques to manage fault level on the electricity distribution network. This investigation has been conducted via research, testing and simulation using independent consultants, manufacturers and universities.

This work produced a series of reports on the suite of solutions which all use a new application of existing commercially available technology.

The investigations showed a relatively low risk for deployment of I_S-limiters and Electricity North West have identified specific applications of deployment for through fault withstand issues.

A cost effective method to manage both through fault withstand and breaking capacity is adaptive protection. Testing was successfully conducted which confirmed that the longer clearance times associated with adaptive protection did not cause any undue damage to other equipment on the network.

1.4 Key learning

The project has successfully shown through a combination of research and simulation that I_S-limiters and adaptive protection can be used either separately or in combination to provide low cost and reliable fault level management.

The investigations into the safety case for use of Is-limiters showed a relatively low risk for deployment but Electricity North West recognises that further work is required on the risk assessment ahead of business as usual use.

Studies and simulations have shown that there are various ways to implement low cost adaptive protection depending on the installed asset base and complexity required.

Electricity North West aims to build on the learning from FCAM by deploying the techniques in the LCNF Second Tier project, Respond.

1.5 Conclusions

The project has successfully shown how lost cost innovative use of existing technology can provide effective fault level management and avoid the need for traditional methods. For small networks this can be managed on a local level but these techniques can also be scaled and further optimised for larger networks through a central control system. The Respond project will investigate this further.

2 PROJECT BACKGROUND

This section reproduces the 'Problem' and 'Method' as stated in the original project registration.

Historically DNO networks are designed to cater for unidirectional power flow, predictable fault current paths and predictable fault current levels. With the increasing levels of distributed generation connected to the DNO network the system has become much more complicated particularly for power flows and fault current levels.

Generators provide an additional infeed to the network under fault conditions which leads to much larger fault currents then previously seen. This results in more areas of the network running close to or possibly beyond the designed fault current levels.

Traditional methods to overcome this problem would be to change the switchgear for that of a higher rating which increases either the cost of a connection for a generator or the DNO's reinforcement spend.

Alternative methods to control fault current level are vital for DNOs to ensure the generators can be connected in a timely and cost effective manner whilst ensuring that the network does not become overstressed under fault conditions leading to a possible failure of any asset.

3 PROJECT SCOPE

The 'Scope' here is as stated in the original project registration.

Electricity North West proposes to investigate new techniques including innovative use of existing protection to control fault level. Electricity North West proposes to carry out an independent risk assessment on the use of existing and new assets for fault current management. This risk assessment will investigate any safety issues and any impact to customers as a consequence of using the different methods.

It is intended that the project will carry out detailed investigations of three different areas of the network through the use of simulation techniques.

- A generator connection and associated infeed
- Lower rated RMU on the distribution network
- Lower rated feeder CB at a primary substation.

Through modelling and measurement Electricity North West aims to compile a picture of how the fault currents vary both across the network and over time.

- To install fault current monitors at strategic points on the Electricity North West network to help validate models through measurement
- To produce an independent risk assessment on the use of existing and new assets for fault current management
- To develop new techniques to control fault current level using existing assets.
- To carry out simulations to prove the concepts.

4 SUCCESS CRITERIA

The following 'Success Criteria' are as stated in the original project registration.

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

5 DETAILS OF WORK CARRIED OUT

To address the Scope outlined above, Electricity North West investigated two main methods to manage fault level, namely, I_S-limiters and adaptive protection. The following sections detail the work carried out to assess each of these techniques.

5.1 I_S-limiter

5.1.1 What is an I_S-limiter?

The I_S-limiter, manufactured by ABB, is a combination of an extremely fast-acting switch, (which can conduct a high-rated current but has a low switching capacity), and a fuse with a high breaking capacity mounted in parallel. (Full details of the product can be found in the manufacturer's literature in Appendix 1.)

The I_S-limiter insert is the operational part of the device and is shown in detail below. Once the device has operated the entire insert must be changed for a new one. Inserts then need to be returned to the manufacturer for refurbishment and re-use.

Figure 1: I_S-limiter Insert

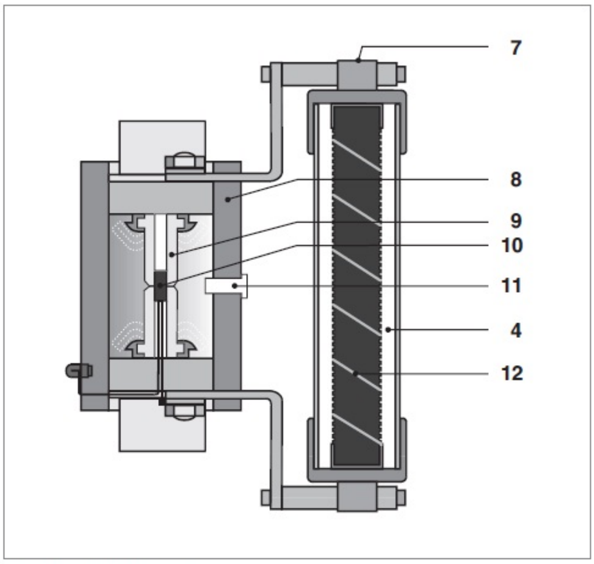


Figure 2: I_S-limiter insert
4 Fuse
7 Fuse indicator
8 Insulating tube
9 Bursting bridge
10 Charge
11 Main conductor indicator
12 Fuse element

By dividing the two functions of the switching device (ie conducting the operating current and limiting the current when a short-circuit occurs) into two paths, the I_S-limiter can conduct a high operating current without loss and also limit the short-circuit current at the first rise.

In order to achieve the desired short opening time, a small charge is used as a stored energy mechanism to interrupt the switch (main conductor). When the main conductor has been opened, the current still flows through the parallel fuse, where it is limited within 0.6 milliseconds and then finally shut down at the next voltage zero.

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

The settings for the I_S-limiter are calculated on a case by case basis by ABB as discussed in the ABB papers in Appendices 2 and 3. ABB requires specific network data to calculate the settings - including the configuration, fault level and details of any infeeds. It is important to note that if there are any changes to the network which will impact these settings ABB need to be informed and the settings re-calculated. As part of the project Electricity North West asked ABB to calculate some theoretical settings based on part of our network. The results of this calculation can be seen in Appendix 4.

5.1.2 Applications of an I_S-limiter

As the I_S-limiter will disconnect parts of the network before the peak of fault current is reached it should be deployed in areas which will give the greatest effect.

ABB recommend that the device can be installed at:

- Substation bus-section – to disconnect half of the substation demand infeed to the fault
- Incoming transformer circuit – to disconnect the infeed associated with one transformer
- Customer's point of connection – to disconnect the infeed from a large motor or generator.

Electricity North West chose to investigate only the applications associated entirely within the DNO network, ie in the bus section or incoming transformer circuit.

5.1.3 Previous concerns regarding I_S-limiter use

In 2002 PB Power was commissioned to investigate these devices which resulted in the document "Development of a Safety Case for the Use of Current Limiting Devices to Manage Short Circuit Currents on Electrical Distribution Networks".

This document concluded that installing current limiting devices in order to avoid plant being operated beyond its rating will give some difficulties in complying with UK safety legislation.

There were concerns that the device could not be fully tested and there was no way to be certain the device would not fail to operate.

5.1.4 How did the project address the concerns?

As the PB Power work was more than 10 years old, Electricity North West employed ABS Consulting (an independent consultant who have extensive knowledge in creating safety cases for the nuclear industry) to conduct a new Failure Mode Effect and Cause Analysis and associated risk assessment. The full reports produced as a result of this work can be seen in Appendices 5, 6 and 7.

The work done by ABS Consulting revisited the risk with new "in service" information from ABB. Electricity North West recognises that this work does not completely address all the concerns but it has given confidence in the decision to deploy these devices.

5.1.5 What did the new risk assessment discover?

The work carried out by ABS Consulting concluded that:

- The most prominent hazard identified was the loss of network electrical supply caused by the I_S-limiter tripping. The potential consequence of this would be a loss of supply to customers for the duration it took to replace the trip inserts.
- The system is to be installed in three phase installations. There are three possible fault scenarios:
    - Phase to phase short circuit;

- o Single phase to earth: the Electricity North West network is operated with a resistance earth. Therefore the “earth” fault current is limited by the resistance; and
- o All phases to earth: as single phase.

For all faults involving more than one phase the I_S-limiter construction offers redundancy as each phase is completely independent and only one phase is required to operate.

1. The design of the I_S-limiter relies on components using proven technology. It is acknowledged that the use of a small explosive charge is novel to the electricity supply industry. However, the use of similar devices in large numbers in modern cars as a proven safety feature suggests that this is now acceptable technology.

2. There is no way to actually test the tripping mechanism. It is possible to test the triggering circuitry, but the operation of the actual tripping device (i.e. the pyrotechnic charge) cannot be tested. This is not an unusual situation, eg, mechanical systems that use Bursting Discs to release pressure have similar disadvantages. The trip inserts are returned and tested at the end of their service life. ABB has no record of any returned inserts failing to trip on demand and also has no record of an in service I_S-limiter failing to trip on demand.

3. The I_S-limiter has been in service since 1961 and has in excess of 120,000 device years of operation. In that time, ABB have no record of the Is-limiter device failing to operate on demand. There have been five cases of spurious trips. Investigation showed that all were related to a change in the network by the operators. Therefore, a ‘proven in use’ argument can be made based on the last 10 years of successful operation.

4. The advantage of an I_S-limiter is that because it interrupts the fault current before it reaches its peak, the downstream circuit never sees the full current. The principal issue with the I_S-limiter is one of being able to demonstrate reliability. Should the I_S-limiter operate as designed, then there is no reason that would prevent their use. However, the PB report is quite clear that should the I_S-limiter fail to operate, and equipment downstream was overstressed, the network operator would be in breach of current legislation.

5. A definitive figure of accepted reliability is not available for this application, but in the nuclear industry, a probability of failure on demand of the order of 1×10^{-6} would be required. Work carried out calculated the failure on demand of an I_S-limiter as 4.9×10^{-5} which is considered acceptable.

6. It is thus considered that the I_S-limiter is appropriate for use in the UK, based on its assessed reliability performance on demand and its current use in Europe.

This work has shown that the risk associated with the operation of I_S-limiters is low. Electricity North West recognises that this work does not completely address all concerns but it has given confidence in the decision to deploy these devices.

5.1.6 What’s next for I_S-limiters in Electricity North West?

As part of the Second Tier Respond project Electricity North West will install two full I_S-limiters. It should be noted that although the risk is low the decision was taken to install these devices in areas with a through fault withstand issue rather than a breaking capacity issue as breaking capacity can be managed through lower cost adaptive protection techniques

Based on the work conducted by ABS it is Electricity North West’s view that applications of the I_S-limiter to manage fault break issues could be considered in future projects.

5.2 Adaptive protection

Adaptive protection can be used to manage breaking capacity but may lead to longer clearance times ie 1s rather than 0.5s. Before deployment of this technique it is necessary to understand the through fault withstand capability of existing switchgear and the sequence of protection needed to manage breaking capacity. The project investigated the withstand capability through testing and protection sequencing through simulation.

5.2.1 Through fault withstand capability of existing equipment

Adaptive protection can be used to manage breaking capacity but may lead to longer clearance times ie 1s rather than 0.5s. Before deploying this technique it is necessary to understand the through fault withstand capability of existing equipment.

Manufacturer's design to a 3 second fault clearance but in reality faults are cleared in less than 1 second. Electricity North West believes that switchgear is capable of withstanding higher values of fault current for a time less than 3 seconds. Proving this hypothesis is crucial for the deployment of adaptive protection with longer clearance times.

The switchgear at primary substations has higher fault ratings, ie 25kA for 3 seconds, than the equipment installed remote from the primary substation. The weakest point of the HV network can be the ring main units and associated cables installed at distribution substations.

Electricity North West employed the services of EPS UK, an engineering solutions provider, to assess the types of HV switchgear installed remote from the primary substation. This range of equipment is made up of ring main units of various ages and manufacturers.

EPS UK carried out an analysis of the Electricity North West asset database and reached the following conclusions. The full analysis report can be found in Appendix 8

There are a total of 11580 ring main units of which:

- 95% of all ring main units are covered by 6 of the 7 types shown in Table 1
- 67% are Long & Crawford T3GF3 or T4GF3
- 17.7% are Schneider RN2C
- 10.2% are Lucy Sabre.

Table 1: Ring main unit populations in Electricity North West April 2014

Type	Quantity	Percentage of Total	3 Second Fault Rating
Long & Crawford T4GF3	6 909	59.66%	21.9kA
Schneider RN2C	2 044	17.65%	21.9kA
Long & Crawford T3GF3	869	7.50%	13.1kA
Lucy Sabre VRN2a	641	5.54%	21.9kA
Lucy Sabre VRN	318	2.75%	21.9kA
Lucy Sabre VRN2	219	1.89%	21.9kA
English Electric T3/OF	133	1.15%	13.1kA

In order to understand the capability of these devices EPS recommended conducting direct tests. The availability of test stations to perform withstand tests is limited and an independent test station in Germany was chosen. To ensure the return on expenditure for this activity was maximised, Electricity North West elected to test two switchgear types. The T3GF3 was selected first, even though it is the third most prevalent switchgear type, as it has the lowest fault rating. The T4GF3 is the switchgear type most prevalent in Electricity North West and was selected as the second unit.

Figure 1: Test setup for ring main units

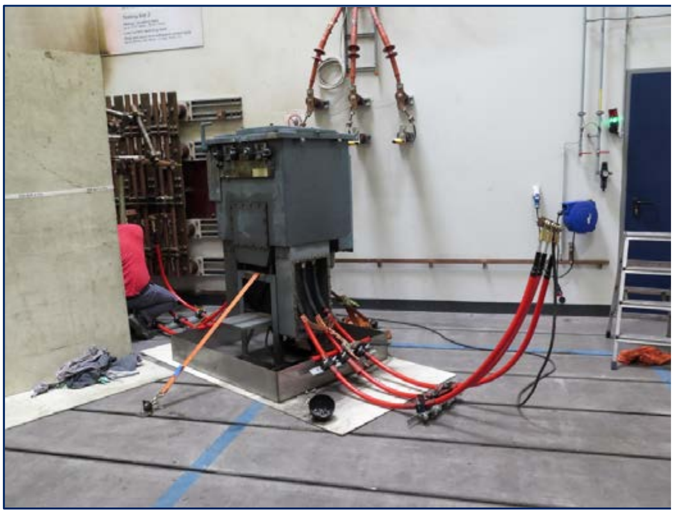


Table 2: New tested ratings for ring main units

Type	Manufacturer's Rating		Tested Rating	
	Current	Time	Current	Time
Long & Crawford T4GF3	21.9kA	3 seconds	25kA	1.5 seconds
Long & Crawford T3GF3	13.1kA	3 seconds	15kA	1.5 seconds

The tests showed that the switchgear can successfully withstand higher fault levels albeit for a shorter time. Given that protection schemes will clear a fault within 1 second these higher ratings can be used to assist with fault level response for new breaking capacity protection schemes. The full report for these tests can be found in Appendices 9 and 10.

5.2.2 How does adaptive protection work?

Adaptive protection is the use of adjustable protection relay settings that can be changed in real time, based on signals from local sensors or a central control system (such as a Network Management System), to alter how the protection scheme operates.

The principle of how adaptive protection can be used to manage fault level is depicted in Figures 3 and 4.

Figure 3: Normal protection operation

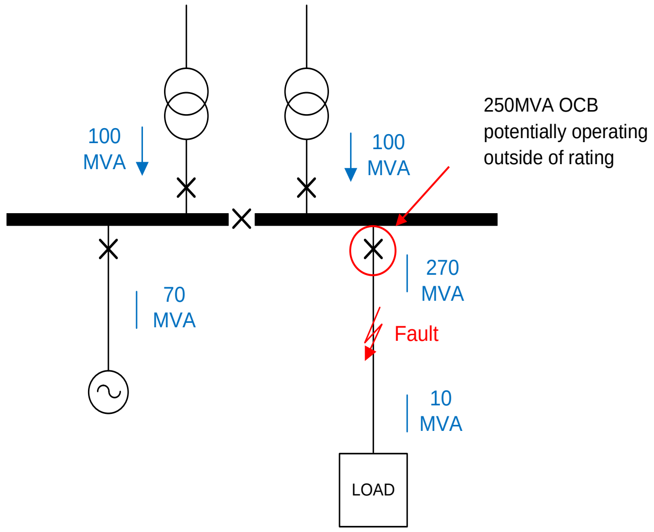
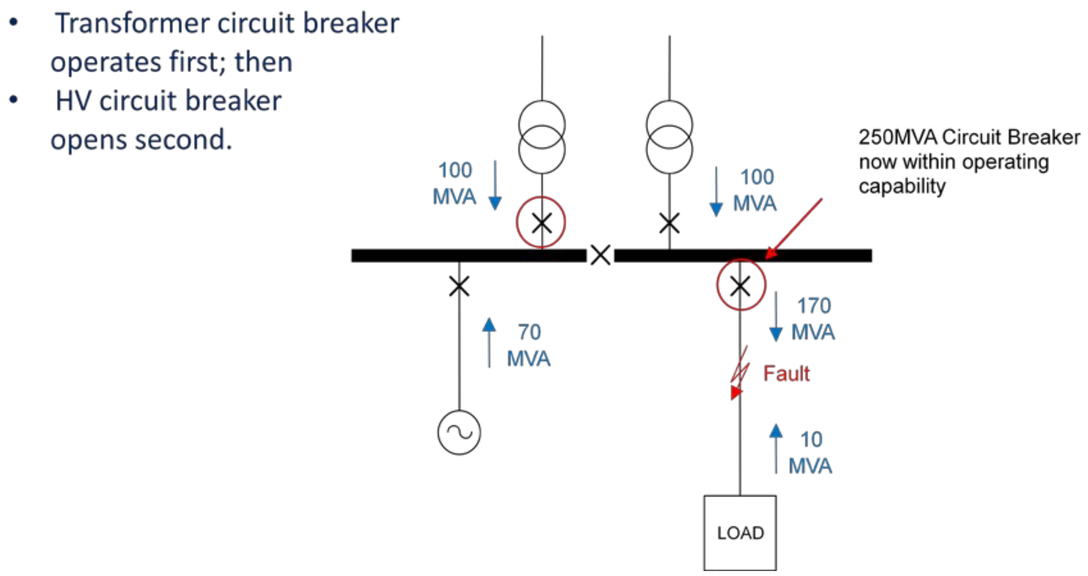


Figure 4: Adaptive protection operation



5.2.3 How can adaptive protection be deployed?

To understand the different forms adaptive protection can take, Electricity North West employed the services of Siemens to conduct some studies. Siemens was chosen as they are our current supplier of protection equipment and Electricity North West has a significant number of their relays installed. An overview of the methods investigated is given here whilst the full report from Siemens can be found in Appendix 11.

Siemens looked at the existing protection currently employed on the Electricity North West network. After reviewing the types of protection, recommendations were made on how they can be utilised for adaptive protection schemes.

Adaptive protection option 1

One option for adaptive protection would be the use of a control command to relays to change setting groups and alter the order in which circuit breakers will operate. For this the fault levels would need to be monitored and, if exceeded, a command would be issued. This will ensure that one of the incoming transformer circuit breaker operates and opens before the feeder circuit breakers.

To allow this option to be deployed modifications will need to be carried out to existing site protection schemes.

1. For older sites with all electromechanical relays, the protection setting on the circuit breakers would need to be changed. The time delay would be increased on the circuits with the potential of exceeding the fault level. This would be a permanent change. On one of the transformer incomer circuits a numerical relay would need to be installed in order to allow a change of setting groups. Setting Group 1 would be for normal operation, and the second, Setting Group 2, would be with a reduced time setting for operation where the fault level is exceeded. SCADA would be used to remotely switch between the two groups, depending on the network conditions.

2. For sites with newer numerical types of relays, it will be possible to programme these with two settings groups to allow different settings dependent on the network conditions. As before, Setting Group 1 will be for normal operation, and Setting Group 2 will be with a reduced time setting for when the fault level is exceeded. SCADA will be used to issue commands to switch between the groups.

   This is the most basic form of adaptive protection and will require a change of a maximum of two relays and as such it can be widely retrofitted to the Electricity North West network. This is the Electricity North West preferred option and will be deployed in Respond.

Adaptive protection option 2

A second option would be the use of a blocking scheme.

In newer circuits of the Electricity North West network, there is already a busbar blocking scheme actively in service which uses binary outputs to blocks the bus section from operating for healthy conditions. If, however, there was a circuit breaker failure the binary output will open and remove the block to the bus section allowing it to open thereby, securing supplies to half of the switchboard.

This could be adapted for fault current management by routing a second stage of protection to operate when the fault current is higher than the break duty of the circuit breaker. This can then operate the binary output in parallel with the CB Fail protection function. If there is a fault that exceeds the break capacity of the breaker, the binary output will open and remove the block to the bus section allowing it to open thereby, removing the infeed from half of the switchboard.

This form of blocking protection is only available at a small number of sites therefore if Electricity North West wished to deploy this widely it will require significant protection changes.

Adaptive protection option 3

Due to limitations of the previous options Siemens proposed implementing a new scheme to monitor the system currents and control the circuit breakers. This would be based on utilising the IEC 61850 communications protocol. Using the IEC 61850 protocol would allow information to be passed from one relay to another in an ethernet network, with the use of switches.

One advantage of this type of scheme is that hardwiring would be kept to a minimum, with only circuit breaker indication, and binary outputs being used for tripping purposes. Therefore relays with a minimum I/O count could be specified, assuming a basic scheme. With this philosophy the cost of material as well as installation time spent wiring would also be greatly reduced, as traditional wiring for signals between the relays would be achieved with connection of a fibre or electrical RJ45 connection.

A second advantage is the GOOSE (Generic Object Oriented Substation Event) messages being used for interbay communication, to pass the information from relay to relay, are high speed. A typical operating time would be 8 ms.

A disadvantage to this proposal is that it will require a complete change of protection at a substation as no sites within Electricity North West currently use this protocol.

When the various forms of adaptive protection were identified Siemens then developed simulations and tests using real network data from Electricity North West. The results of these tests can be seen in Appendix 11. All of the 3 options operated as intended and they would all be suitable for the management of fault current.

5.2.4 Disconnection of electrical machines

Electricity North West investigated extending the adaptive protection technique to disconnect the infeed from a customer's electrical machine, ie large motor or generator as a means to manage the fault level. In this case the machine will be disconnected prior to the feeding circuit breaker opening.

To assess the feasibility of this Electricity North West asked The University of Manchester to conduct an initial investigation covering a wide range of possible conditions and identify the areas and phenomena for further detailed simulation and analysis. Their report, found in Appendix 12, details the work completed.

The main results of the analysis carried out during the project analysed three methods of disconnection, namely passive flux discharge, active flux discharge and total machine disconnection.

Passive flux discharge is where the excitation voltage is disconnected via a switch. It can result in an average reduction of up to approximately 9% of machine fault current, 200ms after the fault occurs. No reduction is seen in the first peak of fault current and only very small reductions are made within the first 50 ms (the most severe fault period).

Active flux discharge is where an additional resistance is placed in series with the field winding to further reduce the current. It is possible to make very large reductions of up to 80% within a 200ms period. However, it is still not possible to reduce the first peak of fault current. It is important to note that the addition of a resistance connected to the field winding (which can be difficult to implement) can potentially result in overvoltages on the field windings and must be very carefully assessed.

The effects of machine fast disconnection following the fault were also analysed. The fault current contribution by the machine in this case is reduced; however, practical implementation of such a scheme is not trivial and will require excellent protection coordination.

The study compared fault current contribution between synchronous and induction machines. This showed that induction machines contribute far less to fault currents and their contribution decays within 150-200ms due to the fast decay of the machine flux.

From this work it is feasible to disconnect machines to manage fault level but the protection requirements are not trivial. In the Respond project Electricity North West will investigate the practical and commercial aspects of this form of adaptive protection.

5.3 Monitoring of fault level

The project installed two fault level monitors at primary substations in the Electricity North West area. These monitors were left in situ for around 3 weeks to measure the natural disturbances which occur on the network.

Analysing the information from the natural disturbances can give a prediction of the fault level associated with that portion of the network.

The results from this monitoring were then compared to the fault level calculations performed by the Electricity North West network models.

6 PROJECT OUTCOMES

As can be seen from section 5 the results of this project are a series of reports covering the different techniques to manage fault level. These reports offer a suite of solutions to the issue of increasing fault levels on distribution networks.

There is no change to the Technology Readiness Level as a result of FCAM. All of the techniques explored make novel use of commercially available technology. This project focussed on new methods of application.

6.1 I_S-limiters

I_S-limiters can be used for managing both through fault and breaking capacity issues but previous work revealed risks associated with the operation of the devices. FCAM reviewed the previous work and updated it with the latest “in service” information.

The investigations showed a relatively low risk for deployment but Electricity North West have chosen to only deploy for through fault issue as breaking capacity can be managed through lower cost adaptive protection techniques. Based on the work conducted by ABS it is Electricity North West’s view that applications of the I_S-limiter to manage fault break issues could be considered in future projects.

6.2 Adaptive protection

Adaptive protection can be successfully used to manage both through fault and breaking capacity.

The work carried out by EPS UK, detailed in Appendices 7, 8 and 9, demonstrates that distribution switchgear is capable of carrying more current than the declared rating albeit for a much shorter time. Having this extra capacity will allow the use of adaptive protection with slightly longer clearance times without any adverse effect on the distribution switchgear.

The Siemens investigations, detailed in Appendix 11, shows that adaptive protection can be implemented in a number of ways which vary in complexity and cost. For adaptive protection to be successful at least one of the relays on site would need to be a modern numerical relay with the ability to be remotely switched between different settings groups.

Option 1 described in section 5 provides a simple retrofit solution which can be widely adopted across DNO networks as it can be applied to all types of relays currently deployed, with minimal changes required.

An extension to the network adaptive protection is the disconnection of a customer's electrical machine. The work carried out by the University of Manchester demonstrates that it is possible to disconnect an electrical machine to provide fault level response but the protection requirements are not trivial. In the Respond project Electricity North West will investigate the practical and commercial aspects of this form of adaptive protection.

6.3 Monitoring of fault level

This monitoring and comparison described in section 5 showed good correlation between measured and calculated values. This gave Electricity North West confidence in the network modelling used to calculate fault levels.

In the Respond project Electricity North West will carry out more monitoring to provide further confidence in both our network models and the new central assessment tool which will calculate fault level in near real time.

7 PERFORMANCE COMPARED TO AIMS

The success criteria for this project were:

- Installation of fault current monitors at strategic points on the Electricity North West network to help validate models through measurement.
- Delivery of an independent risk assessment for techniques for fault current management.
- Development and simulation of new techniques to control fault level using existing assets.
- Production of design criteria for the new techniques to control fault level.

The following sections will discuss each criterion in turn and detail the successes and failures.

7.1 Installation of fault current monitors to validate models through measurement

FCAM deployed a small number of fault current monitors to validate the network models. The calculation results from the network modelling showed good correlation with the site measurements. This gave increased confidence that our network models remain valid and that these can be relied upon to support future investment decisions.

7.2 Delivery of an Independent risk assessment for techniques for fault current management

In relation to both adaptive protection and disconnection of electrical machines, although it is not a formal risk assessment, the project delivered confidence in the use of both adaptive protection and disconnection of electrical machines through the work conducted by EPS. When adaptive protection is used the fault clearance time will be extended by approximately 0.5s but full clearance will be achieved within 1s. The testing carried out at the independent test station showed that switchgear can withstand the higher fault currents for this increased time but the maximum clearance time should be kept below 1.5s.

In relation to the use of I_S-limiters, the project also delivered a HAZOP study and safety case on in a distribution network. This work showed the reliability of these devices to be high, with no evidence of a failure to operate on demand. ABS Consulting used to conduct this work are an independent consultant in the nuclear industry for this type of work.

The Respond project will further develop both of these risk assessments based on Electricity North West's experiences of the operation of the techniques.

7.3 Development and simulation of new techniques to control fault level using existing assets

In terms of use of new techniques on existing assets, this success criterion refers to adaptive protection and operating a customer's asset.

The project reviewed how to enhance existing protection schemes to provide fault level control. This involved either operating our own assets in a different sequence or operating a customer's asset to remove their contribution. Various forms of both techniques were investigated and simulated by Siemens and the University of Manchester.

Electricity North West used the outputs from this simulation work to decide which forms of the techniques are to be deployed in the Respond project.

7.4 Production of design criteria for the new techniques to control fault level

The proposal produced by ABB (Appendix 4) provides guidance on the network parameters required to calculate the tripping values for the I_S-limiter. The project has shown that the I_S-limiter will be most effective if installed in a bus section or the incoming transformer circuit as this will provide the greatest reduction in fault current contribution.

Siemens have demonstrated different forms of adaptive protection. Electricity North West has decided to implement the simplest form which only requires the changing of up to 2 relays at site. This change of protection can be carried out using standard design and installation procedures. Therefore there is no requirement to produce new design criteria for this technique.

As the machine disconnection is an extension of this adaptive protection it will also be partially covered by standard design policies. There may be a requirement to produce some different policies regarding the customer interface but this has not been investigated in this project.

All of the techniques will be deployed in the Respond project and this project will produce the detailed design, installation, protection setting and operational policies.

8 REQUIRED MODIFICATIONS

At the onset of the project expectations were that small site trials of one or more of the techniques would be performed with the aim of validating the simulations and to inform practical considerations of wide scale deployment.

The initial reports received from the partners regarding the various techniques were very encouraging and Electricity North West decided it was appropriate to expand the trials to form a wider scale deployment as part of a larger LCNF Second Tier project. The requirements of this project were thus limited to concentrate solely on simulation and risk assessment and to inform the design of the trials in the larger Second Tier project.

The small scale trials intended for this project are now part of the Electricity North West Second Tier project, Respond, which started in January 2015 (www.enwl.co.uk/respond). Respond will use a centralised software system to calculate the fault level and send instruction to enable or disable the different techniques.

9 VARIANCE IN COSTS AND BENEFITS

9.1 Costs variance

The original project budget was £854k but the final cost of the project was £261k. From the breakdown in table 3 it can be seen that the majority of elements were delivered without significant cost variances. The reduction in cost comes from the absence of a trial. As stated previously this trial work will now be carried out in the Respond project. Internal technical support was not originally forecast. This was an oversight which has been corrected in future projects. The technical support provided technical expertise for the risk assessment, network modelling processes and academia as well as defining the switchgear testing.

Table 3: Project cost summary

Item	Category	Estimated Costs £k	Final Costs £k rounded
1	Programme & Project Management	29	31
2	Project Technical Support	0	43
2	Materials Procurement and Installation	645	0
3	Risk Assessment	40	41
4	Switchgear Testing and Analysis	80	84
5	Network Modelling	25	26
6	Research Support, including academic	35	36
	Total	**854**	**261**

9.2 Benefits variance

All the investigations and simulations of the different techniques have produced the expected benefits. As the trial elements will be performed as part of a separate project the expected benefits of these elements are no longer relevant. The trial will now form part of the Second Tier Respond project which will build on the work presented in this report.

There is a significant benefit to the testing work conducted with EPS. This work proves that switchgear can withstand higher currents and provides the reassurance that the longer clearance times associated with adaptive protection will not cause any damage.

The safety case work carried out by ABS Consulting gave increased confidence in our decision to deploy I_S-limiters.

10 LESSONS LEARNT

The project has successfully shown how lost cost innovative use of existing technology can provide effective fault level management. For small networks this can be managed on a local level but can also be expanded and optimised for larger networks through a central control system.

Studies and simulations have shown that there are various ways to implement adaptive protection. Electricity North West have chosen to implement option 1, as described in Section 5, as this is the most cost effective solution and can be deployed on a much wider scale.

This project has produced:

- Switchgear capability test reports
- A HAZOP study and safety case on the use of I_S-limiters
- Simulation and test reports on adaptive protection
- Simulation and test reports on the disconnection of electrical machines.

Electricity North West will build on the learning from these reports in the LCN Fund Second Tier project, Respond. There are plans to present this work at the LCNI conference and the reports will be made available on the Electricity North West website.

11 PLANNED IMPLEMENTATION

As stated previously, Electricity North West will implement the learning from this project through the Respond project (www.enwl.co.uk/respond).

Respond will install I_S-limiters and adaptive protection as techniques to manage fault level. It will also investigate the practical and commercial aspects associated with disconnecting a customer's machine. These techniques will be managed through a central software system which will calculate the fault level in near real time and issue commands to enable or disable the appropriate technique.

The FCAM project is thus considered as a forerunner project enabling Respond.

12 FACILITATE REPLICATION

The report from Siemens (appendix 11) contains the appropriate information to allow DNOs to deploy adaptive protection using their existing infrastructure and design processes. The methodologies in the report are not confined to Siemens relays and can be readily applied to any manufacturer's equipment.

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

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

13 APPENDICES

1. ABB I_S-limiter brochure
2. ABB Paper – Calculation of Tripping Values
3. ABB Paper – Settings Calculation
4. ABB Proposal – Electricity North West Application of I_S-limiter
5. ABS Consulting – Feasibility of a Safety Case for ABB Surge Limiters
6. ABS Consulting – Hazard and Operability Study Report
7. ABS Consulting – Developing the Safety Case for ABB Surge Current Limiters
8. EPS UK – Analysis of Electricity North West Asset Database
9. Test Report for T3GF3
10. Test Report for T4GF3
11. Siemens – Report on Adaptive Protection Schemes
12. University of Manchester – Investigation of Fault Current Contribution and Management of AC Machines