33kV Superconducting Fault Current Limiter

CET 1001 / LNCF-T1-001

Final Closedown Report

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Author	Chris Goodhand

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1. Executive Summary

This project is to facilitate the faster connection of distributed generation (DG) from renewable sources at the distribution level, by mitigating possible fault current management constraints.

This is being achieved through the trialling of a superconducting fault current limiter at 33kV placed at the boundary of the transmission and distribution networks at a substation jointly owned by National Grid and Northern Powergrid.

This closedown report contains the information mandated for closedown reports in Ofgem's Low Carbon Network Fund governance.

The project has been brought to a conclusion without achieving the stated objectives. The SFCL device has now failed high voltage testing twice. As a result we have been unable to meet the requirements of either the installation outage schedule or the project time limits mandated by Ofgem. We have concluded that at this time the technology is not capable of meeting the required performance specification. Despite this a great deal of learning that is of direct and immediate use, both to ourselves and others interested in the application of this type of technology, has been generated through the course of the project.

During the course of 2014 the original manufacturer of the SFCL went into administration. The technology and the project were bought by ASG of Genoa, Italy. ASG are currently trying to address the design and manufacturing issues that caused the HV testing failure. If this is successful it we will look to resurrect this project and complete the final installation phase. A decision on this will be made during the first half of 2015.

This closedown report details all of the outcomes of the project delivery process up to the point at which it was formally closed down on the 12th October 2014. All of the technical reports, milestone assessments, developed specifications, device modelling outputs, layouts, and required ancillary equipment have been included. Together these documents provide the full description of all of the issues requiring consideration and the decisions made. We believe that this learning will be an invaluable input into other DNO projects looking to deploy fault current limiter technology.

The reports and documentation generated are very detailed and this closedown report provides a brief summary of their content.

The learning outcomes are also detailed. The intention, as outlined in the interim closedown report, was to review this learning following the installation of the device but this has not been possible. However, based on the learning from the earlier phases of the project several firm recommendations with respect to the process of delivering such technology have been made. The overall level of positive engagement and commitment received from National Grid has been excellent throughout and has made a major contributor to the positive outcomes of this project. We would like to put on record our gratitude for their support.

With the experience from this activity, and a previous trial at 11kV, there is now sufficient confidence to specify fault current limiters as a standard network solution at 11kV for deployment during ED1. It is recommended that appropriate standards and policies are now generated to facilitate this within Northern Powergrid. These are planned for review and update during 2015.

2. Project Background

To facilitate the connection of distributed generation (DG) from renewable sources at the distribution level, the network needs to be capable of withstanding the consequential increase in fault level associated with such connections.

Strategically placed Superconducting Fault Current Limiters (SFCLs) could provide distribution networks with improved capability by limiting the fault current to within the rating of existing switchgear. The installation of SFCLs may allow for the accelerated connection of both renewable and non-renewable generation whilst reducing the need for major network reinforcement which is often required to cope with the increased fault level, typically before new DG can be connected.

Currently, a number of primary and supply point substations on the Northern Powergrid network have been identified as having a maximum switchgear duty greater than 95% of the make/break duty rating. This would be typical for the UK network as a whole. The connection of additional DG to these sites may increase the fault level beyond the switchgear rating.

3. Scope and Objectives

This project was designed to trial a specific piece of new equipment that has a direct impact on the operation and management of the distribution system.

The first phase of the project was to identify suitable locations for the installation and undertake a feasibility and systems readiness study to analyse the network, outlining the optimum application and specification, and confirm the business and carbon cases.

The second phase was to design, build, install and commission a three-phase 33kV superconducting fault current limiter on the Northern Powergrid distribution network.

It was proposed, and following site surveys, agreed with National Grid, that the unit was installed at a 275/33kV substation in South Yorkshire to facilitate future connection of DG and additional load by limiting the likely increase in fault current to within the rating of the 33kV switchgear. Increase in fault level is typically managed through an operational management switching procedure which, in limited circumstances, may increase the risk of loss of supplies to customers.

4. Success Criteria

The original project success criteria, as stated at project registration were as follows:

The project will be judged successful on completion of the following deliverables:-
- Robust carbon impact cases developed for different network scenarios
- Indicative business case developed
- Successful power system modelling of the unit
- Successful type testing of SFCL components
- Successful operation of SFCL, cryogenic cooler and auxiliary components
- Operational experience relating to the SFCL, cryogenic cooler and auxiliary components documented
- Network events and SFCL response captured electronically
- Running costs documented

- Maintenance requirements documented
- Identification of required changes to policy and operational documentation
- Successful dissemination of information and learning to DNO peer group.

4. Work Carried Out

The project was a collaborative activity with National Grid, Applied Superconductor Ltd (ASL), an SME based in Blyth, Northumberland, to produce a superconducting fault current limiter (SFCL) suitable for use at 33kV. Atkins has acted as the key design and installation contractor. ASL was replaced by ASG Power Systems Limited in early 2014, the result of ASL going into administration.

The project builds on previous work, conducted through IFI, and in collaboration with ASL, Energy North West and Scottish Power Energy Networks. This previous work designed, built and network-tested fault limiter units at 11kV. The project was evolutionary, with three different versions of the equipment being used. This project uses the latest version of the trialled technologies.

The project was not designed to provide a piece of business as usual, “field ready” equipment. The project’s purpose is to investigate the option of using SFCL as an alternative to standard switchgear upgrade or network reinforcement in circumstances where fault level is becoming a barrier to further connection of DG.

The project sought to take such a device through the process of specification, manufacturing, installation, commissioning and operation, exploring and identifying the implementation issues raised. The success criteria listed in the section immediately above detail the key milestone stages in the process required to achieve the desired implementation.

The work carried out following the initial surveying phases of the project have included very close working with National Grid (NG) Electricity Transmission. The site chosen for installation was a site jointly owned with NG, the device actually being placed inside one of their compounds, necessitating a very high degree of co-operation between all parties

5. Project Outcomes

5.1 Current Status

The project has been halted without completion of the initial objective. The SFCL device has not met the high voltage testing requirements, either initially or, following remedial work, at repeat testing.

Designs, both for the device itself and for the site, have been completed. Site preparation, including all building and civil work on site is complete, as is initial electrical work.

Project work on site has been completed, and the site has been made safe and secure. An option for completing the project, predicated on successful testing of the device at some point in the near future, has been identified.

Despite being unable to complete the entire project, the stage-gate phasing has allowed a substantial amount of learning to be identified and this is detailed in the project’s working documents. The content and conclusions of these are summarised below.

5.2 Outcomes

Key outputs to date have been:

- Phase 1 completion report (Appendix 2)
- Network Impact Report (Appendix 3)
- Design Report Summary (Appendix 4)
- Modification Application for Jordanthorpe site (Appendix 5)
- Balance of Plant report (Appendix 6)
- High Voltage Testing report (Appendix 7)
- Design Intent Document (Appendix 8)

These documents are shown in the indicated appendices to this report and together capture the detail of the project learning. A short summary of the contents of each is given below.

5.2.1 Phase 1 completion report

Phase one of the project was designed to ensure that a complete and fully reviewed project plan was in place for the subsequent, substantive activities. There were several issues which could not be fully explored during the scoping and initiation phase of the project which needed to be understood before the project could be confirmed as viable. Pre-eminent amongst these was the need to fully understand project risk.

Phase one of the project specifically set out to identify:

- Circuit and site for installation;
- SFCL specification;
- Finalisation of the budget and project risk register;
- Identification and development of the processes required to produce the business and carbon cases;
- Identification of project success criteria and confirmation of learning approach for the project; and
- Identification of gate requirements for stage two of the project.

In general the requirements were met. The prosecution of the business case confirmed that the project appeared to be financially viable and that the product itself could potentially be viable as a piece of business as usual plant.

An in-depth assessment of potential sites was carried out, centred on the Sheffield 275/33kV ring. Following considerable discussion with NG, the site's joint owners, the Jordanthorpe site was selected for the device installation.

The criteria for this selection are detailed in the NGET briefing paper which is attached to the phase one report. Items considered include make and break duty of the switchgear at each location, current headroom available, the amount of physical space available plus other project risks such as scheduled engineering work in the locality during the project.

The project risk assessment and budget were confirmed, although in both cases as would be expected in a project of this type, these required review at a later date.

During phase one, an opportunity to use a postgraduate student to help develop the carbon case approach was identified. The quality of the output produced was poor and of insufficient quality to be used as a part of the project. This meant that the original intention to create a standard approach to carbon cases was not met. Subsequently this project requirement was overtaken by discussions at Ofgem's Innovation Working Group where a standard approach to carbon benefits was identified and captured as best practice.

5.2.2 Network Impact Report

This report details the following:

- Chosen network configuration;
- Zenergy modelling report;
- Identification of network modelling data;
- Required protection scheme;
- Test lab and network impact information; and
- Network loss assessment.

A key issue arose with the network impact loss assessment. The insertion loss of the SFCL, under normal, non-fault conditions, appeared to be higher than originally envisaged. This raised questions about the economic viability of the SFCL when compared with alternative technologies. As a result of this the project was temporarily halted whilst a full business case review and investment appraisal was instigated.

The ultimate conclusion of this study was that the non-fault insertion losses for the SFCL were not excessive, especially when compared with competing technologies, and that the degree of fault current clamping that the unit could provide was better than other technologies assessed, such as a series reactor. Carbon saving was also superior to all other options bar a full board replacement. On this basis the project, following review by the project board was allowed to proceed. It was intended that the business case for the use of the SFCL would be reassessed at project completion using the recently established Ofgem cost—benefit framework developed for the ED1 well justified business planning process. This has not been possible and it is not currently possible to determine any of the anticipated business benefits.

5.2.3 Design Report Summary

The Design Report was the output from that section of the project which was funded by ASL and not by the LCN fund. This was to ensure that any intellectual property rights generated here could be retained by ASL and would not need to be put into the public domain. The central issue was the governance requirement of having to licence background IP to support any newly generated foreground IP. This could potentially compromise ASL's core technology and compromise the contractual relationship and licensing agreement with the ultimate technology owner Zenergy.

In the spirit of sharing learning, ASL agreed to release a summary of the design report and this has been included as an appendix of this report.

This report details, sometimes at relatively high level, the device specification in the context of the local network, the general protection arrangements and the preferred site layout. Those elements of the work carried out here that have been retained by ASL include the internal device drawings and technical design aspects of how the SFCL, applying the company's core intellectual property, delivers the specification.

5.2.4 Modification Application

Following considerable investigation and discussion with National Grid, a modification application (mod. app.) was submitted in mid July 2011. This was in accordance with National Grid's TP105 self-build agreement as this was deemed the most appropriate methodology for the proposed delivery.

The document includes our final preferred configuration for connection of the device at the Jordanthorpe site, based on both the design impact report and previous site survey information from the phase 1 completion report. The analysis required to produce this document ensured that the issues around device location and connection within the compound were thoroughly explored. This has allowed a lower cost implementation than was originally planned at the end of phase one of the project, although that in itself was still above initial estimates at project conception.

The main reason for this cost reduction was site specific. An old transformer bund and compound was available at Jordanthorpe, close to the 275/33kV supergrid transformer and the preferred installation location. National Grid agreed that this could be used to site the device and allowed a bus-bar implementation rather than the cable connected version thought necessary earlier.

The preparation of the modification application and the associated discussions with NG identified the difficulties of trying to use standard business processes to deal with non-standard technology applications such as this. A high degree of interaction between all project participants has been required. This became more so with the increasingly tight schedule for the project.

The processes selected to manage the project is discussed in more detail later in this report

5.2.5 Balance of Plant Report

The balance of plant report is the final design report for the project. Together, with the previous reports this forms the final specification for the project, the device and the ancillary equipment used.

A full functional specification for the device and its installation is included. This also forms the specification for the project buildings and civils and forms a part of the contract with the key subcontractor Atkins.

The specification provides a description of the electrical network configuration and the works necessary to facilitate the connection of the SFCL, which includes the installation of a new 33kV circuit breaker, isolators and earth switches and associated protection. It represents the final embodiment of the project implementation and the culmination of the accumulated learning to the point that physical on-site work commenced.

The contract let was for the design, engineering, supply, delivery to site, off-loading, installation and erection, testing and commissioning, and site clearance. All of these requirements are shown as part of this report.

5.2.6 High Voltage Testing Report

The high voltage testing report presents the results obtained at IPH, Berlin. These tests were designed to ensure that the SFCL would meet all of the defined functional requirements to demonstrate that it could be safely used on the network prior to actual installation. As such this represented the key electrical and thermal testing of the device.

Two lots of testing were undertaken. The first run was conducted during December 2013. The SFCL successful completed thermal, acoustic and magnetic testing. During subsequent short circuit testing an internal short on one of the superconducting solenoid coils was detected and testing could not be successfully completed.

At this time ASL went into administration. The rights to the technology were bought out by ASG Power Systems with whom Northern Powergrid was able to reach agreement to complete the project.

Following remedial work on the fault current limiter at ASG in Genoa a second run of testing was scheduled to be undertaken in Berlin in May 2014. It became clear very quickly that a further short circuit in the superconducting solenoid was present that testing could not be completed.

Subsequent analysis indicates that design modifications of the solenoid coils are likely to be required for successful implementation of an SFCL at 33kV and that improved manufacturing quality assurance is required to avoid the problems experienced to date.

Work to deliver these improvements continues at ASG and provides a potential option to complete the installation of the device at a later date and as a separate project.

5.2.7 Design Intent document

The design intent document sets out the arrangements for connection of the SFCL device and its local and upstream implications for the NG network.

The issues identified and the documented arrangements for their mitigation are relevant to the connection of similar fault current limiting devices, of both superconducting and other core operating technologies.

6. Performance against Original Project Aims

In terms of project content the project has performed well against the original aims. The practical issues associated with the specification, installation and commissioning of fault current limiters at 33kV have been thoroughly explored up to this point in the project.

6.1 Schedule Variance Analysis

Project performance against original schedule has been the key disappointment. The project was originally envisaged to deliver and install the device inside sixty-five weeks. The project took greater than twice this time before the first attempt to type test the device at IPH Berlin in December 2013 which subsequently failed.

The December 2013 schedule, drawn up following this first HV testing failure is shown as Appendix 1. This shows the key project tasks that still required completion their duration and scheduled delivery at that time.

All of these tasks were still incomplete at the time of the second HV testing failure. The appendix has been included to indicate the scale and nature of the remaining tasks required to complete the project. This schedule will form the basis of any new project if we believe that the project can be re-initiated and completed at a later date.

The following table shows the original project schedule and associated milestones.

Phase		Phase Description	Delivery Week Baseline	Delivery Week Actual
1		Project Commenced –Down Payment	0	0
1		Phase 1 Complete	4	9
2		Phase 2 Set Up	5	11
2		Network Impact Report	11	26
2		SFCL Design Report (ASL internal cost)	17	
2		SFCL Material Procurement	18	40
2		BOP Design Report	27	80
2		SFCL Factory Test Complete	48	Failed at 164 and 185
2		SFCL Type Test Complete	55	
2		Commissioning Complete	65	
3		Project Close Down Report	119	

Several issues have been identified which have contributed to the overall project delay.

1. The impact of the use of a National Grid (NG) shared site, that is a 275/33kV substation, on the Sheffield ring was not correctly assessed at project planning. A shared site was selected to improve the learning output of the project, by exploring the necessary interaction with NG at the boundary, both technical and commercial of the transmission and distribution networks. Furthermore the fault level impact where the 132kV intermediate voltage was absent was likely to be of more interest for the project. However the complexity of the specific site chosen and the nature of the construction and electrical design required both additional cost and time to allow implementation.

   It was anticipated that much of the network impact assessment work could be undertaken without making choices about the precise site that would be used. This proved not to be the case and initial discussions with NG were required before several key decisions could be made. This impacted the project critical path.

2. A second issue arose following the design report milestone for the project. It was thought that the insertion losses for the SFCL device would be low to the point of being negligible. Once the design modelling and assessment exercise had been completed it became clear that this would not be the case. Under these circumstances it was necessary to revisit and reassess the original business and

carbon cases for the project to ensure that it was economically sensible to take the project forward.

3. Up to this point the expended costs had been relatively low but the acceptance of the design report would instigate major expenditure associated with the actual building of the equipment. It was therefore deemed prudent to ensure that the new situation and risks were adequately assessed and that key stakeholders, primarily the project partners and Ofgem, had been consulted before the project went forward. The additional tasks and time taken to consider the analysis introduced a further delay project schedule.

Two further delays were introduced by issues at the SME supplier of the equipment Applied Superconductor (ASL).

4. The supplier of the core technology for the SFCL device, Zenergy, made the decision to cease business and went into administration. This had two major effects both of which impacted on the project delivery schedule.

   Firstly the technology required to complete device manufacture was no longer available. After considerable negotiation, across three continents, ASL eventually acquired the rights to the technology by buying Zenergy's IP portfolio and securing some of the key personnel.

   Secondly the device's magnets, which were being produced by Zenergy, and were within a few days of completion, were sent for scrap by the administrator. This was despite extensive negotiations over several weeks to secure these key components. This required ASL, once the IP had been obtained, to identify a new manufacturer and having to rebuild the components from scratch. Furthermore the new manufacturer was less familiar with the technology than Zenergy had been. This lengthened the lead time for the magnets compared with the original plan and further compounded the already considerable delay in the SFCL delivery.

In parallel with the ASL process to secure the underlying technology consideration was given to the use of alternative fault current limiting approaches not requiring superconducting magnets. The differences in the device properties and capabilities compared with the core technology around which the project had been designed eventually ruled out this option. In effect the project would have been new, with both the "problem" and the potential "solution" to the problem, as defined in the LCN fund project registration governance requirements, being different to that originally envisaged.

Together these processes associated with the loss of Zenergy added around 45 weeks to the overall project schedule.

Taken all together these several different issues added around 75 weeks to the original project schedule. It became clear that the project would not be complete within three years required by the LCN fund governance but that it was still possible to complete the device installation, and thus the bulk of the expenditure, within that time. Ofgem were advised of this in January 2013, at the same time pointing out that there remained a considerable risk, given that there was no slack in the project schedule, of missing the three year limit if there were any further delays.

In late July 2013 one of the components of the SFCL failed during routine quality and technical testing at the manufacturers. The need to perform some re-manufacturing introduced a four month delay in the delivery schedule.

This delay had a severe knock-on impact with respect to re-scheduling. The location for the device installation requires super-grid transformer outages arranged through NG's year-ahead booking system. The outage slots booked for late August 2013 could no longer be met.

Furthermore such outages were only available during summer time, whilst the UK is on British Summer Time, due to load-related, unplanned outage risk.

The revised plan was that the SFCL would be available in early summer 2014, having completed manufacturing and testing. Suitable installation outages could not be secured until late July 2014, with a scheduled commissioning date for the SFCL in September 2014. The site works would then closed down at the end of October 2014

As the SFCL was originally scheduled to be installed during August 2013 the building and civil work, as well as a lot of the preliminary electrical works, was well advanced and approaching completion. In order to suspend the project safely the site work was continued to the point at which both NG and Northern Powergrid could be satisfied that the site posed no risk and met all individual and joint statutory health and safety responsibilities. The site was temporarily closed down in October 2013 and left safe for the winter.

Work on manufacturing and testing continued through the winter. The device failed functional and HV testing during December 2013. Very shortly after that ASL went into administration.

Several potential purchasers of the technology were identified by the administrators. One of these, ASG of Genoa, Italy bought the assets of ASL and agreed to pick up and complete the project. ASG had the advantage that they were part of the original project supply chain with substantial experience in the materials technology.

With the help of ASG we were able to complete contractual discussions for project completion during the early part of 2014 without compromising the revised project schedule.

The site was re-opened in April 2014. A small amount of additional site work had been undertaken at the time that the device failed testing for the second time. Analysis of the root cause of the problem indicated that a solution would not be available quickly. In consequence the project was halted.

[Subsequent analysis of the root cause of the problem indicate that shorting of the magnetic coil turns due to a manufacturing defect appears to have been a major fact in the failure. The resolution for this is a major re-design and re-manufacturing exercise.]

Having made the decision to close down the project it was necessary to perform remedial work at Jordanthorpe to restore the site and to allow it to be left permanently, as opposed to temporarily, to meet ESQCR requirements.

To preserve options for the future the final site condition is such that the SFCL can be installed at a later date with the minimum possible amount of repeat civil and electrical work.

Up to the point of closedown, no modifications were made to the planned approach, as registered with Ofgem at project initiation, either "problem" or "solution" during the course of the project. Milestone reviews at key decision points have been undertaken and the project has been re-assessed at those times.

6.2 Cost Variance Analysis

The original project registration with Ofgem was for eligible, recoverable spending of £2,880,000, equivalent to a total project value of £3,200,000, once the business contribution of 10% is accounted for. This sum included £2,600,000 of disbursed spending to ASL for the SFCL and £600,000 for installation design and delivery costs.

The final amount spent on the project is £3,043,027 which gives an LCN fund project value of £2,738,724. This value is slightly lower than the total spending reported in the interim closedown report.

Item	Initial Assessment	Spending to Oct 2014	Variance
33kV SFCL	£2,515,000	£2,244,500	-£270,500
Aux transformer	£20,000		-£20,000
Building and Civil works	£163,861	£156,953	-£6,908
C&E Design		£114,513	£114,513
Cables & conductors	£231,862	£126,365	-£105,497
Cable Installation	£37,336	£22,200	-£15,136
Circuit Breakers	£125,000	£92,028	-£32,972
Earthing, multicores, protection and commissioning	£57,174	£89,690	£32,516
Project set up	£9,593	£8,717	-£876
Site welfare	£4,557	£33,031	£28,474
Modification Application/Design	£0	£35,000	£35,000
Contingency	£35,617		-£35,617
Site Restitution		£51,831	£51,831
Internal project management		£68,200	£68,200
Total	**£3,200,000**	**£3,043,027**	**-£156,973**

This is the result of ASL's administration and the renegotiation of the milestone payments for the SFCL construction when the project was taken over by ASG and a re-assessment of the earned value.

The original estimates for the project included contingency for building, civil and electrical works, these were originally estimated by comparison with similar projects, at a value of around £500k. As the project has progressed this increased significantly and final out-turns would have been around £800k had the project run to expected completion.

At project inception it was necessary to make some estimates of project costs. The magnitude of any spending required would not be known until some of the early project milestones had been delivered. In particular the network impact report and the design milestone report were significant as they defined the site that was to be used and detailed the precise installation configuration.

Our initial estimates required some refinement, primarily as the result of the decisions taken around installation location which had been taken to enhance project learning.

Once these assessments were complete, in September 2011, our worst-case assessment of costs at this time suggested that a total budget allowance of around £4.1m would be appropriate. This assumed that a relatively large amount of protection would be required around the device to satisfy NG operational and network risk requirements

The nature of the project demanded a relatively large degree of contingency. This assumption was by no means certain but formed the basis of the project's re-assessment of costs which, in turn, were used as the basis of the investment appraisal for the project when it was re-authorised following the end of phase 1.

Additionally efforts to reduce project costs were made. Subsequently we were able to reduce the concerns that NG had regarding the device and design an improved installation requiring less protection equipment. This bought down the expected cost considerably and the final budgeted outturn, assuming project completion, was £3,486,000.

7. Lessons Learnt for Future Projects

A considerable amount of experiential learning has been developed regarding the way this type of project needs to be managed. This learning has an impact both on the way future projects should be run and on the facilitation of replication.

Standard commercial and technical boundary definitions need careful consideration

The use of a jointly owned site has been particularly informative in identifying implementation details which would not have been apparent had the option for a Northern Powergrid site been taken.

A key issue has been the nature of the system interface between the transmission and distribution networks and the ownership boundary.

It is not possible to conduct a project of this type if the boundary between the systems is considered to sit at the ownership boundary. For maximum effect, and therefore cost benefit, the device needs to be embedded in National Grid's network. This is the case for both this project and for future similar installations.

The benefit of the device is on the distribution network but the installation is on the transmission network. As well as for this specific device, this is likely to be the case for other types of technology in the future which improve the overall effectiveness of the system as a whole. This would indicate that new technical, operational and contractual arrangements will need to be developed to allow the cost effective evolution of the total network system to accommodate low carbon technologies or other approaches to maximise value for money for the customer.

One of the significant issues that arose from the nature of the boundary was for the type registration of equipment. Type registration is required for equipment on the National Grid network but such registration is often not available for 33kV equipment, for which National Grid does not generally have a requirement. Specific type registration issues for key equipment are discussed further in the section below on the facilitation of replication.

For this project the installation boundaries and how the various responsibilities were allocated can be summarised as per the following table:

	Standards	Ownership	Operational
Civils	National Grid	National Grid	National Grid
Fault current limiter	National Grid	Northern Powergrid	National Grid
Isolators	National Grid	Northern Powergrid	National Grid

	Standards	Ownership	Operational
Bypass breaker	National Grid	Northern Powergrid	National Grid
Low voltage supply	National Grid	National Grid	Northern Powergrid
Protection - Bypass	National Grid	Northern Powergrid	Northern Powergrid
Protection – Trip	National Grid	National Grid	National Grid
Maintenance	Northern Powergrid	Northern Powergrid	Northern Powergrid
National Grid Scada	National Grid	National Grid	National Grid
Northern Powergrid Scada	Northern Powergrid	National Grid	Northern Powergrid
Safety	National Grid	National Grid	National Grid
Power quality meters	National Grid	Northern Powergrid National Grid	Northern Powergrid National Grid
Magnetic field	National Grid	Northern Powergrid	National Grid
Land	National Grid	National Grid	National Grid

The project has been able to overcome these boundary issues, mostly as the result of very close working between the Northern Powergrid, National Grid, ASL (subsequently ASG) and Atkins teams. It seems unlikely that this level of personnel, and therefore the degree of oversight, would be applied for business-as-usual implementations and a standard approach needs to be agreed to avoid this. The final embodiment of this is likely to be a complex commercial and legal issue. The project intended to consider this further following successful completion of installation and commissioning, but such an agreement itself, beyond the identification of need, probably sits outside of the scope of this project. That the project has not been able to deliver this means that this issue remains important for determination in similar future projects and needs to be designed into the learning outcomes as the opportunity arises. New network devices, such as storage, or energy transfer technologies such as hydrogen generation are examples of where this issue may be important.

A shared technical vocabulary needs to be developed early

Another issue that became apparent as the project progressed was that there was no standard way of showing a network asset of this type on network drawings or indeed naming the device. Whilst this was relatively easy to overcome it is likely to be the case with any new type of asset developed through either an LCN fund or, under RIIO, a Network Innovation Allowance project and is an issue that needs to be addressed early rather than later in the project schedule.

Robust learning is delivered before project conclusion

Although the project did not achieve its ultimate objective a lot of learning has been generated, particularly with regard to the circumstances under which an SFCL, or other fault current limiting device, might be specified and used. In particular the relative advantages and disadvantages of various installation configurations and location of the device within the circuit have been determined. We believe that the final design selected was sound and the process for achieving that design was robust.

We regarded this as particularly important in determining how to achieve the maximum technical impact for the investment made. As such this is potentially significant in determining whether a positive benefit can be achieved economically for this asset class. Furthermore such information should be particularly useful in saving other DNOs time and effort, and ultimately customer's money, in the design phase of similar projects for fault current limiting devices.

Further details of the options considered and modelled are presented in detail in the reports on the project's initial study work – the Design Report and the Network Impact Assessment which are included as appendices.

Further useful experiential learning has come from the project journey and recommendations based on this learning that allow the facilitation of replication are given in section 9 below.

8. Further Implementation of Fault Current Limiters

The Together with the experience that we have gained through the implementation of the 11kV SFCL device we now have sufficient confidence to recommend 11kV fault current limiters in general for use as a business-as-usual option for those areas on the network where fault level capacity is constrained and a good economic case can be made against alternative mitigation. The learning gained is being used to create the appropriate standards and design policies. These will be available during 2015.

The site closedown has preserved the option to resurrect and complete this project at a later date. There is a large amount of sunk cost and the additional resources required to meet the final implementation and learning objectives are relatively small. This is entirely dependent on the ability of ASG to identify and rectify the root cause of the testing failure and to successfully complete all of the required functional HV testing. If these conditions can be met a decision will be taken regarding project completion, probably funded under the new ED1 Network Innovation Allowance. This decision will be based on the potential cost to completion, the value of the additional potential learning and the technical state of the art, with respect to such fault current limiting devices, and other DNO's project outcomes at that time.

A full assessment of the project and benefits to the customers will be made, in line with innovation stimulus governance procedures and business investment appraisal, before any new project is initiated

This approach has been agreed in principle with Ofgem but will be subject to further discussion, at the appropriate time, if it is believed that that completion of the project learning provides value for the customers' money required.

9. Facilitation of Replication

All of the key design documents that are required to replicate the outcomes of the project are included in this report. The key technical decision making is generally included in the milestone reports, which are attached to this report as appendices.

Together these documents capture the outcomes of the project to date and, together, represent a guide to implementation of the project to this point.

It needs to be appreciated that since the project is not yet complete it has not yet been possible to validate some of the decisions made and set out here. The assessment of the quality of those decisions and therefore the usefulness of those for informing the learning for subsequent implementations is not yet known.

It was stated in the interim closedown report that this would be more fully evaluated once installation and commissioning was complete. No further learning with respect to this was developed during the final stages of the project however the recommendations made previously still stand:

9.1 Process Adopted

The process of engaging with National Grid with respect to design and project assurance is complete. The overall level of positive engagement and support received from National Grid has been excellent and has made a major contributor to the positive outcomes of this project.

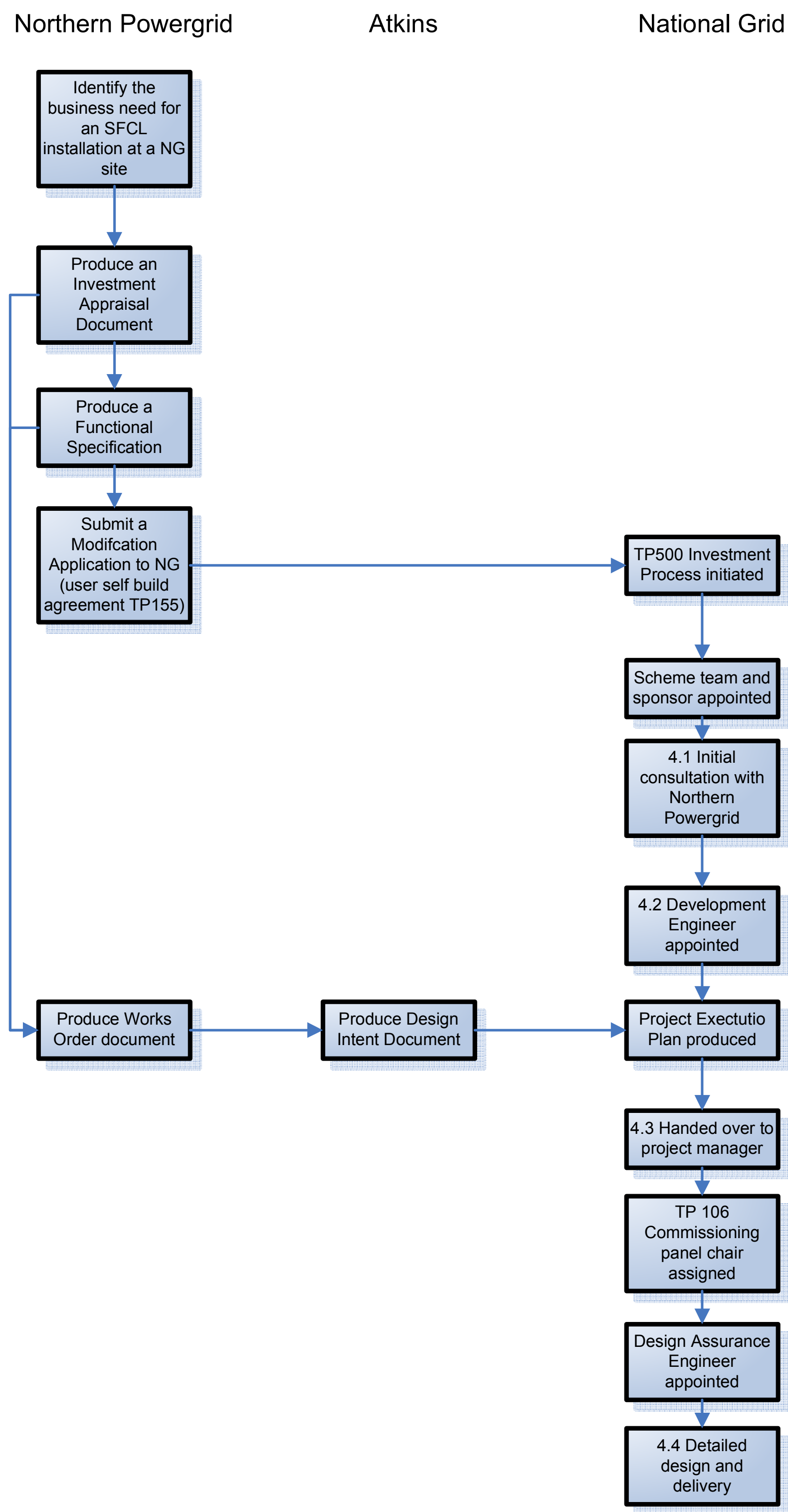
The project has generally used National Grid procedures for this due to the point of electrical connection and physical location of the device on the jointly owned site – that is to the NG owned network on the NG side of the property boundary. The adoption of this process has proved to be extremely useful in ensuring that all of the complex arrangements for a project such as this have been adequately captured and addressed. Furthermore the use of this framework has provided clear visibility of project requirements to the supporting teams from the various businesses, as well as to the core team. This is important in a project of this nature and is recommended for further applications of this specific technology or other similar projects.

The overall process adopted was as shown in the flowchart shown on the following page.

The key document that captures the agreed elements of the design is the design intent document (DID). This feeds into National Grid's Investment process, TP500. The DID lays out the key arrangements that embody the full set of final design decisions. The DID is attached to this report as Appendix 8 and details the following:

1. Design Team list
2. Related documentation and drawings status
3. Scope of work
4. Substation HV equipment
5. Protection, control & telecommunications
6. Civil, structural and building engineering
7. Overhead line
8. HV cables
9. Substation Design Specification (SDS)
10. Contract Drawing Schedule (CDS)
11. Procedural requirements

As such it provides a summary of all the technical design decisions and their impact on the actual physical requirements to implement and a summary of key considerations for future implementations.



9.2 Type Registration

A related issue was that of type registration.

It is generally a requirement that equipment installed on the NG system is NG Type Registered. Consideration was given to this requirement in respect of each of the following pieces of equipment:

1. The SFCL device
2. Bypass circuit breaker
3. Disconnectors
4. Power quality meters
5. Protection relays

SFCL - As a developing technology within the context of an innovation project, the cost of undertaking full type registration of the SFCL device was assessed to be prohibitive, however the SFCL device followed the type registration process as much as was economically practical.

Type tests, broadly conforming with IEC 60076 Part 6 Clause 8 for series reactors and NG document TS3.2, were agreed with NG who were invited to witness type testing.

The benefit of this approach was that through collaboration between NG and ASL, the standards most relevant to the SFCL were identified and interpreted to pragmatically set the required standards for SFCL technology.

Bypass circuit breaker -As NG rarely procures 33kV rated equipment, no 33kV circuit breakers have been NG type registered. It was therefore necessary to specify a 72.5kV rated circuit breaker that had been NG type registered. This impacted on the cost of project implementation.

Following procurement of a circuit breaker that was believed to be NG type tested, it subsequently came to light that a spring mechanism modification had been undertaken by the manufacturer on the circuit breaker and consequently the type registration was no longer valid for the product. This was taken up with NG and derogation was agreed for the 72.5kV circuit breaker.

Disconnectors - As with the circuit breakers, it was necessary to procure 72.5kV disconnectors that had undergone NG type registration. 72.5kV units were procured with the required type registration EGI code.

Power Quality Meters - The power quality meters were specified by NG. These devices are the latest generation of quality meters previously installed by NG. Type registration had not been undertaken by NG on the new products at the time of project delivery.

Protection Relays - Type registered protection relays were procured, but an intellectual property issue prevented the manufacturer including the type registered relay configuration. To overcome this, the configuration was obtained from another NG installation.

Implications - Several items of equipment making up the installation have not been type registered as would normally be required. In the spirit of the collaborative innovation project, derogation has been provided by NG following appropriate referral to specialist colleagues. The installation of an SFCL in a business-as –usual scenario would require that the device itself and all associated equipment are appropriately type registered.

Mitigation - The requirement for NG type registration could be overcome if the ownership boundary was changed such that all the equipment is owned and operated by Northern Powergrid. This would enable Northern Powergrid assessed 33kV products to be specified in the design.

As discussed previously changes of boundary ownership would not have been straight forward, or economically sensible, in the case of this project. The significant cost benefit in installing the SFCL and associated plant within the NG compound, allowing busbar connection of the SFCL, bypass circuit breaker and disconnectors determined that the equipment would be placed under NG safety rules and any consequences would need to be managed on a case by case basis.

Consideration could be given by ASL to undertake type registration of an appropriate 33kV breaker for use in future NG system applications, and thus present a complete installation package. This will be given more detailed consideration once installation is complete along with the other issues of the impact of ownership boundaries and responsibilities.

9.3 Dissemination Event

A dissemination event, to review the key learning, from this and the previous 11kV project was held during October 2014. A field visit to see the fully working 11kV SFCL unit was also undertaken.

Those attending included all of the other GB DNOs, several manufacturers of fault current limiters and several other interested parties such as Tata Steel and ETI.

The event also presented the opportunity to share experiences and learning with the other DNOs on their fault current limiter and more general fault management projects. Useful discussion on implementation and transfer in to business as usual were also held.

10. Progress Against Original Success Criteria

Deliverable	Status	Comments
Robust carbon impact cases developed for different network scenarios		Included in Phase 1 completion report, Appendix 2
Indicative business case developed		Included in Phase 1 completion report, Appendix 2

Deliverable	Status	Comments
Successful power system modelling of the unit	Green	Included in Design Report, Appendix 4, and Network Impact Report, Appendix 3.
Successful type testing of SFCL components	Amber	Some information available from HV testing programme although this was not completed due to insulation failure. See HV Testing Report, Appendix 7
Successful operation of SFCL, cryogenic cooler and auxiliary components	Amber	
Operational experience relating to the SFCL, cryogenic cooler and auxiliary components documented	Red	Requires period of SFCL operation to determine.
Network events and SFCL response captured electronically	Red	
Running costs documented	Red	Requires period of SFCL operation to determine.
Maintenance requirements documented	Red	
Identification of required changes to policy and operational documentation	Amber	Changes to policy identified and confirmed for 11kV devices. Documentation to be updated during 2015. Design Intent Document, Appendix 8, identifies key processes.

Deliverable	Status	Comments
Successful dissemination of information and learning to DNO peer group.		Dissemination event held 2nd October 2014 to DNOs and FCL manufacturers

11. List of Appendices

Note : Appendices 2, 3 and 4 are the working milestone documents. The original source documents were lost during the ASL administration which means that these appendices contain a small number of broken links although these do not detract from the conclusions drawn.

Appendix 1 : Revised Project Schedule, as at 1st December 2013

Appendix 2 : Phase 1 completion Report

Appendix 3 : Network Impact Report

Appendix 4 : Design Report Summary

Appendix 5 : Modification Application

Appendix 6 : Balance of Plant Report

Appendix 7 : HV Testing Report

Appendix 8 : Design Intent Document (DID)

Appendices

Appendix 1 – Revised Project Schedule for 2014

Appendix 1 - Project plan SFCL 2014.pdf

Appendix 2 : Phase 1 Completion Report

Appendix 2 - Phase 1 completion report with attachments.pdf

Appendix 3 : Network Impact Report

Appendix 3 - Network Impact Report.pdf

Appendix 4 : Design Report Summary

Appendix 4 - Design report summary with attachments.pdf

Appendix 5 : Modification Application

Appendix 5 - Modification Application.pdf

Appendix 6 : Balance of Plant Report

Appendix 6 - Balance of Plant report with attachments.pdf

Appendix 7 : HV Testing Report

Appendix 7 - HV Testing Report.pdf

Appendix 8 : Design Intent Document (DID)

Appendix 8 - Design Intent document.pdf