CE Electric UK

Applied Superconductor

LCNF Sheffield 33kV Fault Current Limiter Phase 1 Completion Report

CONFIDENTIALITY (Confidential or not confidential) : **Not Confidential**
PROJECT: CE-Electric LCNF Sheffield **33kV Fault Current Limiter**

Milestone 1: Phase 1 completion report

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REVISION HISTORY RECORDS

Revision	Date	Creation / Update summary
Issue 1	5/11/2010	Customer first issue for comment
Issue 2	15/11/2010	Updated with learning document referenced and new front pages
Issue 3	19/01/2011	Integrated version

Executive Summary

Ofgem has introduced a Low Carbon Network Fund, to be used to trial technologies which have the potential to support Great Britain's move towards a lower carbon based economy. One electricity network issue, exacerbated by both the connection of embedded generation and load growth caused by moving to a more electric centric economy, is that of fault levels. CE Electric UK has initiated a Low Carbon Network Fund project with the aim to install a Superconducting Fault Current Limiter (SFCL) at a National Grid 275/33kV Grid Supply Point substation in Sheffield. Sheffield has been chosen since there are five (of the seven) 275/33kV substations which have high fault levels and have operational restrictions in place to manage this.

Phase 1 Objectives

This project is split into a number of phases. This report covers Phase 1, the aim of which is the reduction of project risk by carrying out work on several key areas:

- Site and Circuit Selection
- SFCL Specification
- Finalisation of Project Budget & development of Risk Register
- Development of processes required to develop Business and Carbon Cases
- Development of processes required to capture Low Carbon Network Project objectives and success factors (including new areas of learning).

Site & Circuit selection

ASL and CE Electric have worked on narrowing the sites under consideration. All nine Sheffield 33kV sites were on the initial list of sites considered, seven NG 275kV fed, the other two CE 132kV fed. These have been reduced to five sites, four with high fault level and a CE fed site as a back-up were no NG site to prove possible. Two circuit selection configurations are also being considered; bus tie and transformer tail installations. The report discusses the relative merits of the sites. Currently Jordanthorpe and Norton Lees are the front runners, subject to the transformer tail option being approved by CE from an additional project cost point of view, and by National Grid from a technical and legal contract point of view. National Grid has been consulted and it is clear that NG's internal processes pose delay potential to the originally envisaged programme.

SFCL Selection

To reduce the risk to the project timescales, a SFCL specification has been selected that can be placed on any site. This will allow early delivery of the orders placed milestone.

Finalisation of project budget and risk register

ASL and CE have worked together on the project budget and risk register. The transformer tail and new switchboard is considerably more expensive (by approx £250k) than the bus tie application. This is still the preferred option as it offers greater repeatability and delivers more fault-level headroom for DG connection.

Development of business and carbon cases and learning objectives

Some thought and initial work has been given to the development of the business and carbon cases. Learning objectives have also been further considered, in particular to ensure any hardware required for the learning outcomes is included in the project budget. Specifically the following learning outcomes would be expected:

- Identification of cases where use of the SFCL could be used to mitigate DG connection issues
- Identification of control and operational issues associated with use of such equipment and proposing means of addressing these
- Assessment of potential carbon benefits
- Assessment of potential business benefits
- Assessment of impact of equipment on policies, codes of practice, section level procedures and identification of required revisions

Dissemination will be through the production of a "how to" manual that details the new knowledge outlined above.

Conclusions

The object of Phase 1 has been to de-risk the project. This has been achieved by down selecting sites to a level where a single specification limiter could be installed on any of the sites, pushing the final decision date into Phase 2, to allow more time to interface with National Grid.

Introduction

Ofgem has introduced a Low Carbon Network Fund, to be used to trial technologies which have the potential to support Great Britain's move towards a lower carbon based economy. One electricity network issue, exacerbated by both the connection of embedded generation and load growth caused by moving to a more electric centric economy, is that of fault levels. CE Electric UK has initiated a Low Carbon Network Fund project with the aim to install a Superconducting Fault Current Limiter (SFCL) at a National Grid 275/33kV Grid Supply Point substation in Sheffield. Sheffield has been chosen since there are five (of the seven) 275/33kV substations which have high fault levels and have operational restrictions in place to manage this. The aim of this report is to present the work which has been undertaken in the following areas:

Key deliverables from Phase 1

- Site and Circuit Selection
- SFCL Specification
- Finalisation of Project Budget & development of Risk Register
- Development of processes required to develop Business and Carbon Cases
- Development of processes required to capture Low Carbon Network Project objectives and success factors (including new areas of learning).
- Stage gate to Phase 2

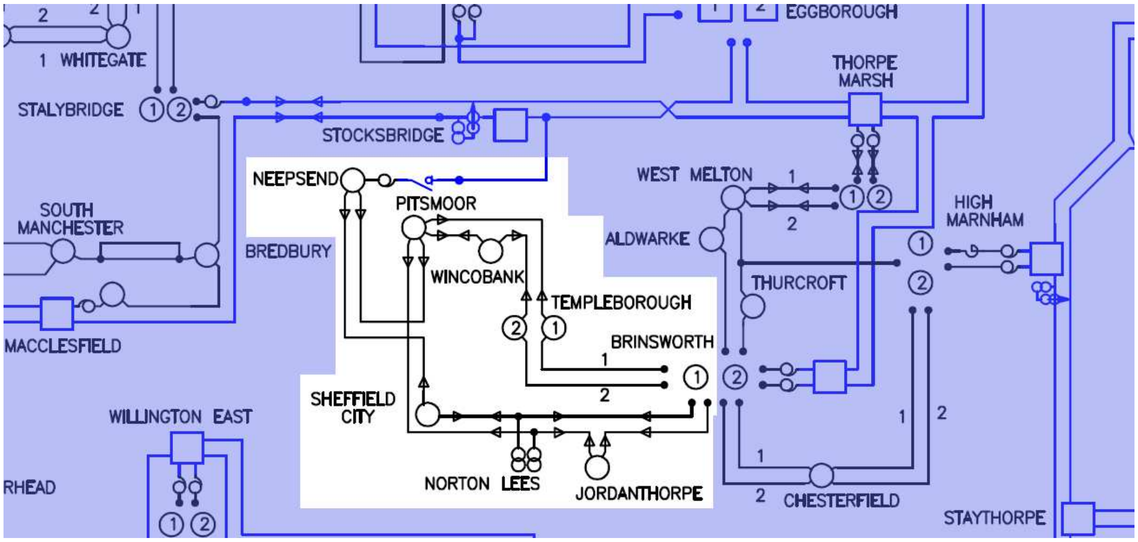
In terms of the general project programme, CE Electric UK's plan is to commission a SFCL in approx 18 months. CE Electric UK has the responsibility to manage fault levels at these sites. Fault levels are calculated by CE Electric UK using the information provided by NG in their week 42 submission in conjunction with an assessment of the fault level contribution from its own network. From an operational and planning perspective NG would rely on the declaration of fault level by CE Electric UK – i.e. there is no special requirement to 'convince' NG that the SFCL will cap fault levels to a specific level. The unit will be installed as a trial initially, and then depending on its success, a decision will be taken either to recover the unit (for potential application elsewhere), or to retain it on site and defer asset replacement of the switchgear until required from an asset condition perspective. A key element of the project is to capture the learning points so that they can be shared and applied to other sites / projects / installations where there is an interface with NG.

The scope of Phase 1 of the project is to create a de-risked project programme and budget which picks up the key objectives identified in the OFGEM LCN Fund Tier 1 Registration Document and CE Electric's internal authorisation process. This has been fully undertaken apart from final nomination of the trial site; instead, detailed specifications have been prepared for each of a shortlist of 3 sites and the achievability of each of these has been confirmed. All of the data required for the selection process have been collected.

1 Project Kick Off

Site Survey

A survey of possible sites in and around Sheffield has been undertaken. Six 275/33kV sites fed by NGT and two 132/33kV sites were visited on 17th August 2010.



There are five possible sites that meet the physical and electrical criteria for an SFCL trial; these are Norton Lees, Jordanthorpe, Attercliffe, Neepsend and Pitsmoor 3&4, with Jordanthorpe and Norton Lees as front runners. Investment of £40k is planned in the DPCR5 period at both Norton Lees and Jordanthorpe to put into place schemes to manage the fault level. Only two sites (Attercliffe and Blackburn Meadows) are not joint sites so the cooperation of NG is likely to be essential and this presents a risk to the project. To mitigate this and set expectations prior to the scheduled meeting on Oct 28th a briefing note was sent to NG.

The briefing note is included here as Appendix 1
A1 NG Briefing Paper.pdf

The Power-point presentation used at the meeting is Appendix 2
A2 NG meeting.pdf

Further mitigation of project impact from NG can be achieved by designing equipment to meet several different installation scenarios. This can be achieved at little marginal cost as the vast majority of the work is common. A final decision on which scheme to take up would not be required until milestone 3 in phase 2 of the project is reached.

The preference would be to install the SCFL in a transformer tail but this requires further technical and legal discussion with NG. Installation of the SFCL in the bus section is likely to raise fewer implications between CE and NG, but in this position the fault capping level is reduced. There are a series of options of where to place the device and from a learning perspective it would be useful to investigate the implications of all of these even if only one can be pursued. This will be included in phase one and two of the project.

2 Site, Circuit & Application Selection

This work package is to identify the major issues at the various potential sites to assist with the selection of a single trial site so that a Modification Application for the site can be submitted to NG.

Initial Selection

In Sheffield, there are seven NG 275/33kV substations. Of these, Pitsmoor 1&2 and Wincobank do not have fault level issues and are therefore excluded from the selection process. In addition, the Sheffield City switchboard is scheduled for replacement within the current distribution price control period and is also excluded from the selection process. There are four remaining sites; Jordanthorpe, Neepsend, Norton Lees and Pitsmoor 3&4.

Site	Make (% of board capability)	Break (% of board capability)	Max Demand 2007/8 (Forecast 012/13)	Power Factor	Firm Capacity	Transformer size
	kA	MVA	MVA		MVA	MVA
Jordanthorpe	44.4 (101.6%)	894 (89.4%)	74.06 (75.93, +2.5%)	0.98	110	100
Neepsend	42.7 (97.7%)	813 (81.3%)	91.88 (94.01 +2.2%)	0.95	144	120
Norton Lees	47.3 (108.2%)	955 (95.5%)	71.42 (73.83 +3.3%)	0.99	110	100
Pitsmoor 3&4	46.2 (105.7%)	925 (92.5%)	77.17 (88.55 +14.7%)	0.93	114	100

I think we should add a similar table and sentenance about Attercliffe here.

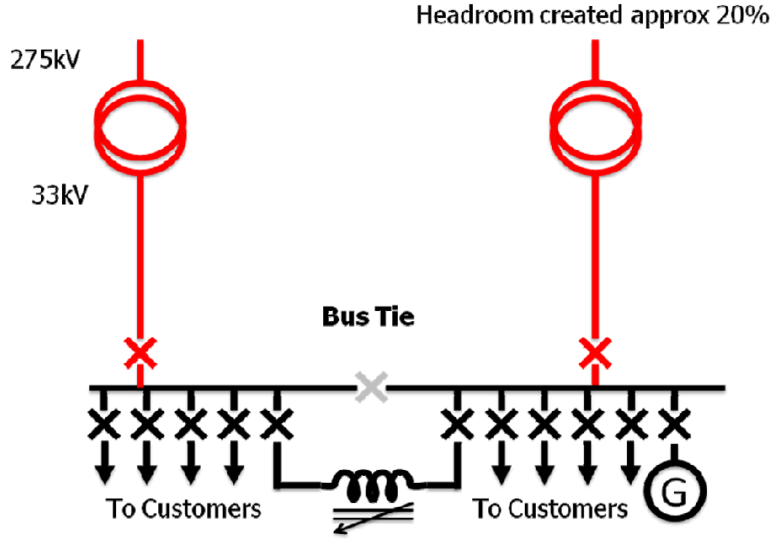
Applications of Fault Current Limiter

Fault Current Limiters can be resistive or inductive, and can be connected between a transformer and the switchboard, around the bus section circuit breaker or in a feeder circuit.

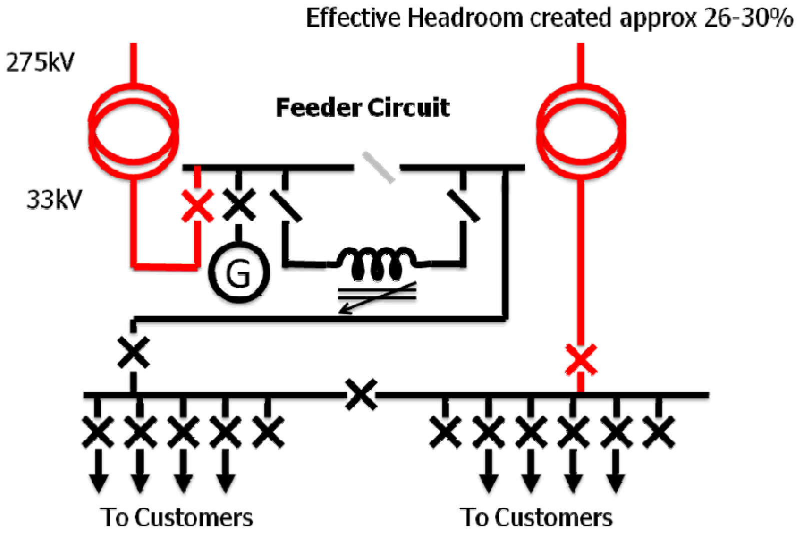
Resistive fault current limiters have very large clipping ratios (80-90%) and raise the power factor of faults as they introduce resistance into the circuit. In a resistive fault current limiter the superconductor material carries load current and once it has limited the fault current the superconductor must be taken out of service to allow it to cool down.

Inductive fault current limiters are based on iron cored reactors. There are currently two types of inductive fault-limiting technology, referred to as Shielded Core and Pre-saturated Core. A Shielded Core limiter is in effect a current transformer with a superconducting secondary winding which reverts to a resistive state during a fault. In a Pre-saturated core limiter, the line current passes through a winding, normally of copper, around a ferromagnetic core which is driven into saturation by a dc bias winding. To the network, when carrying normal current the limiter looks like an air cored reactor with a low reactance; however during a fault the dc bias is overcome and the iron core appears in the circuit resulting in a high reactance thus limiting the prospective current. No reset time is needed after a fault. Clipping ratios of up to around 40% are achievable with this technology. Given the current (low) state of technology readiness of the Shielded Core technology, a Pre-Saturated Core unit will be supplied for this project.

A SFCL installed in the bus section position (shown below) limits the fault current from one half of the board, thus limiting the contribution from one transformer and any fault contribution from demand and generation connected to the network supplied from that half of the board. The fault-level headroom of a switchboard to accommodate locally connected generation can typically be increased by ~20% in this way with a 40% clipping limiter. To achieve a bus section SFCL deployment, either a spare breaker is needed on both sections of the board, or the board will need to be extended to provide these. The spare breakers on all of the candidate switchboards are rated at 800A which is less than the 2000A rating of the existing bus section circuit breakers. Studies of the distribution of local load supplied from each side of the switchboard in all credible scenarios would be needed to ensure that 800A breakers and SFCL are sufficient for this application. Neepsend site has breakers available for a bus section application without further work, and Norton Lees could be re-configured to accommodate a bus section application.



An SFCL installed in a transformer tail (shown below) limits the fault current from one transformer. The fault-level headroom of a switchboard to accommodate locally connected generation can typically be increased by 18% in this way (assuming a 10% contribution from the network). If, however, the generation was also connected to the transformer side of the SFCL (also shown below), an effective headroom improvement of circa 28% can be achieved as the generator fault level contribution is also limited. All sites are capable of housing a transformer tail application; however the Neepsend site would require flood protection as part of the installation, making its choice less attractive.



NGT Meeting

A meeting was held between CE Electric, NG and ASL at Warwick on 28th October 2010. A series of questions was put to NGT regarding their practices and preferences and discussion with NGT on these are ongoing. No major issues threatening the project have been identified although there are concerns that it might be difficult to meet the timescales envisaged for the project.

3 SFCL Specification

Site Characteristics

Option 1: Bus Tie application

In this option CE Electric will utilise their existing switchboard breakers, rated 800A, to bypass the bus section switch (incidentally rated 2000A), and run the board tied through the SFCL. Potentially there could be occasions when the board would need to be run split in this situation for example if the 800A breakers were to be continuously overloaded.

There are two installations under consideration for this configuration as follows in the following table:

Site	Prim' Volts	Prospective Fault Current		System Impedance 100MVA base		Max Load (07/08)		Single Trans' Cap'ity	Transformer impedance on 100MVA base		
	kV	Make kA	Break MVA	R (%)	X (%)	MVA	PF	MVA	R (%)	X (%)	B (%)
Attercliffe	132	33.5	707	1.11	14.34	60	.95	60	.8	21	
Neepsend	275	42.7	813	.28	12.38	92	.95	120	.4229	23.58	-0.24

For each installation, a normal current of 800A will apply.

Option 2: Transformer tail application

In this option CE Electric will ultimately want to install the SFCL in the transformer tail with no additional breakers. In this trial they will however want to install bypass and isolating breakers. We would like however to design the SFCL to suit the ultimate configuration. If the transformer circuit-breaker on the other side of the switchboard (the side without the SFCL) were to trip for example due to an upstream fault, or needed to be opened to allow maintenance to be carried out, the SFCL would need to carry the board load continuously. CE Electric have asked us to rate this as 2000A (the same as the breakers) even though the transformer nominal ratings are often less than this. This is in part because these transformers have a load cycle capacity of 1.3.

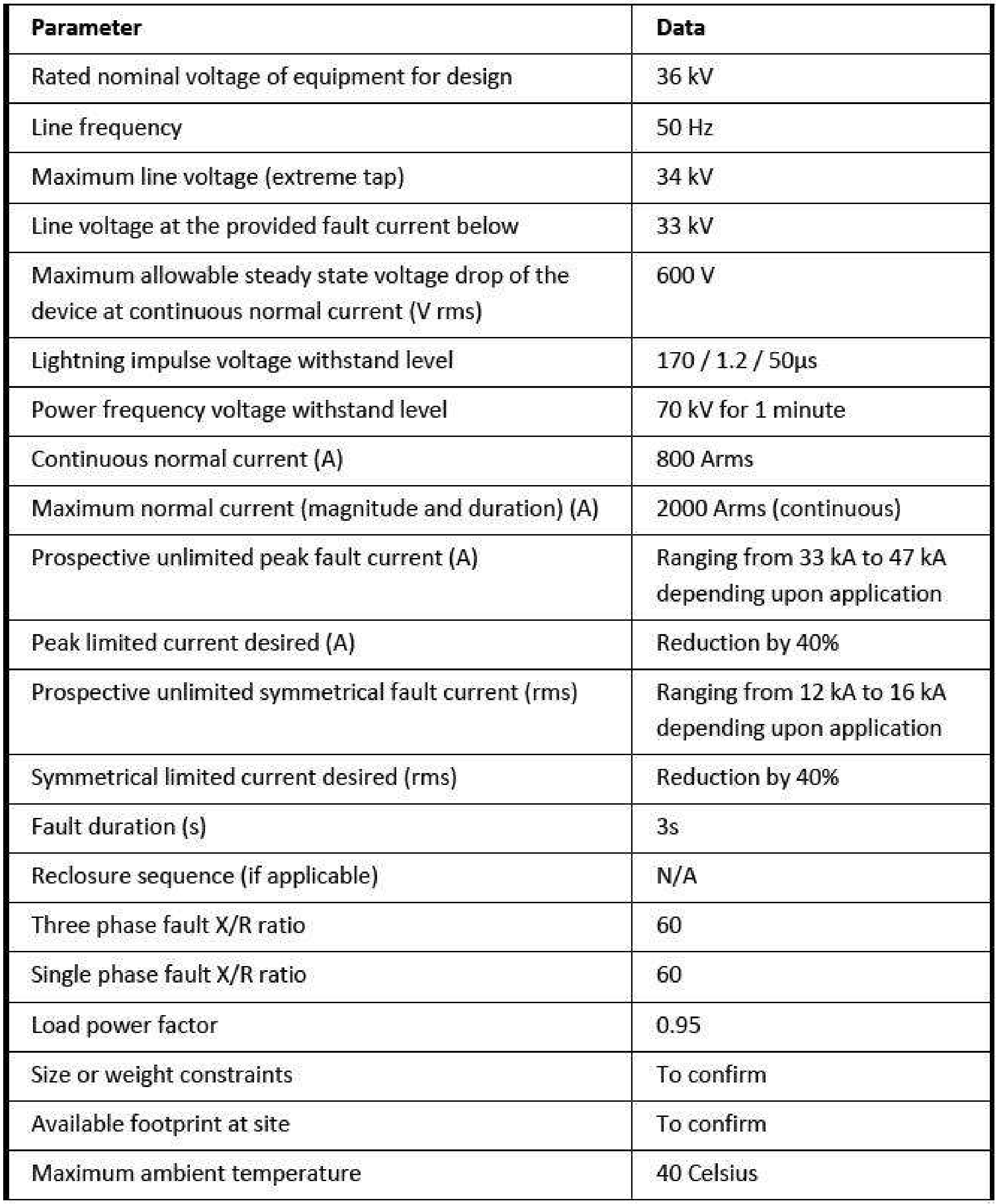
In spite of this need for a high continuous normal current rating, the insertion voltage of around 600V could apply at 800A (45MVA) which roughly represents half the board load at peak demand for the Pitsmoor peak load forecast in 2012. There are four installations under consideration for this configuration as follows in the following table:

	Prim' Volts	Prospective Fault Current		System Impedance 100MVA base		Max Load (07/08)		Single Trans' Cap'ity	Transformer impedance on 100MVA base		
Site	kV	Make kA	Break MVA	R (%)	X (%)	MVA	PF	MVA	R (%)	X (%)	B (%)
Attercliffe	132	33.5	707	1.11	14.34	60	.95	60	.8	21	
Jordanthorpe	275	44.4	894	.39	11.36	74	.98	100	.595	20.9	-0.25
Norton Lees	275	47.3	955	.34	10.64	72	.99	100	.537	19.70	-0.32
Pitsmoor 3&4	275	46.2	925	.37	10.91	77	.93	100	.503	20.24	-0.42

For each installation, a normal current of 800A could apply for insertion voltage (if this is helpful) and 2000A for continuous max demand.

Initial Specification

On the basis of the above, Zenergy Power were asked to consider a "generic" specification able to be adapted to any of the above locations and providing a fault current clipping factor of 40%, such that the fault current passing through the limiter would be reduced to 60% of its prospective magnitude in terms of peak both and symmetrical levels. The generic specification is given in the table:



Parameter	Data
Rated nominal voltage of equipment for design	36 kV
Line frequency	50 Hz
Maximum line voltage (extreme tap)	34 kV
Line voltage at the provided fault current below	33 kV
Maximum allowable steady state voltage drop of the device at continuous normal current (V rms)	600 V
Lightning impulse voltage withstand level	170 / 1.2 / 50µs
Power frequency voltage withstand level	70 kV for 1 minute
Continuous normal current (A)	800 Arms
Maximum normal current (magnitude and duration) (A)	2000 Arms (continuous)
Prospective unlimited peak fault current (A)	Ranging from 33 kA to 47 kA depending upon application
Peak limited current desired (A)	Reduction by 40%
Prospective unlimited symmetrical fault current (rms)	Ranging from 12 kA to 16 kA depending upon application
Symmetrical limited current desired (rms)	Reduction by 40%
Fault duration (s)	3s
Reclosure sequence (if applicable)	N/A
Three phase fault X/R ratio	60
Single phase fault X/R ratio	60
Load power factor	0.95
Size or weight constraints	To confirm
Available footprint at site	To confirm
Maximum ambient temperature	40 Celsius

4 Scope of Supply, Detailed Project Budget and Risk Register

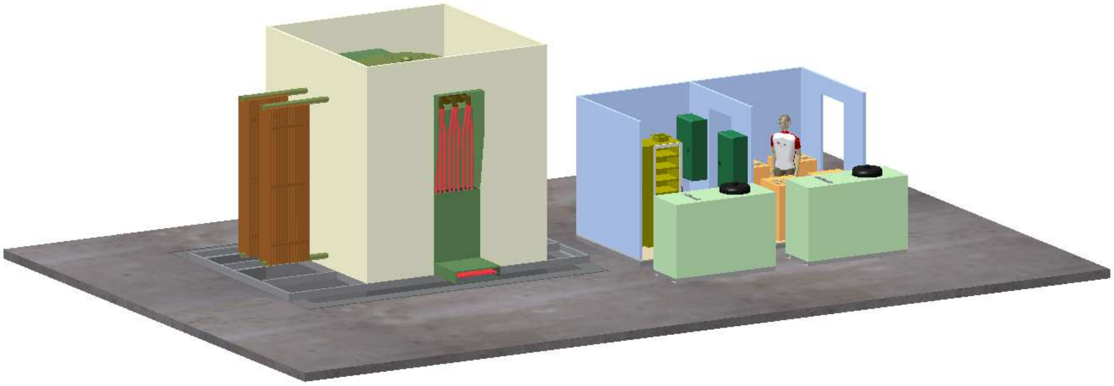
The following information was prepared to inform the preparation of the budget for the project. For the sites most likely to be chosen, location and cabling details have been considered and are presented in Appendix 5
A5 Scoping Drawings.pdf

Fault Current Limiter

The Fault current limiter (FCL) comprises an oil filled stainless steel tank with copper AC windings wrapped around two iron cores. The windings are wrapped clockwise round one and anticlockwise round the other. The copper windings emerge through bushings and are connected to the cable boxes where terminations are made. On the outside of the tank there are two toroidal (polo shaped) cryostats (vacuum insulated tanks) housing a winding of hundreds of turns of superconducting tape. The superconductor is also in close contact (although electrically insulated) with a copper thermal bus bar which provides cooling to keep the superconductor at its operating temperature. The tape carries approximately 100 Amps and 2 Volts is dropped over the cable/current lead (entry point into the cryostat) and winding arrangement.

The superconducting winding drives the iron cores into saturation such that normal current sees the AC winding as an air cored reactor, but fault current sees it as an iron cored reactor. This reactor arrangement weighs approximately 20 tonnes, houses approximately 4000 litres of oil. It has dimensions approximately 5m by 6m with height 5m (based on the 11kV unit but allowing some additional height for bushings (height 4.3m->5m) and internal cable box spacing (4.1m->5m).

The thermal bus bar is cooled by a cryocooler, the cold head of which is housed in the cryostat. Vacuum insulated pipes containing helium gas are connected to compressors. These are housed in an auxiliary enclosure (4.2m long by 2.4m x 2.4m) as are the power electronics which generate the DC supplies. Also to be housed locally is a 33kV/415V transformer to generate LV supplies (Dimensions 1m x 1.1m x 1.9m tall) and on non-bus section installations a switchboard (1.7 deep x 2.8 high x 3m, 3.6m or 4.2m long depending upon the site – shorter at Attercliffe transformer tail, longest at Pitsmoor) which will need housing in a room so an additional 1m on all dimensions is sensible. The site may also require some fencing, so we have allowed a footprint of 13m x 9m for the Fault current limiter.



FCL reactor unit, auxiliary enclosure (blue) and two water chiller units

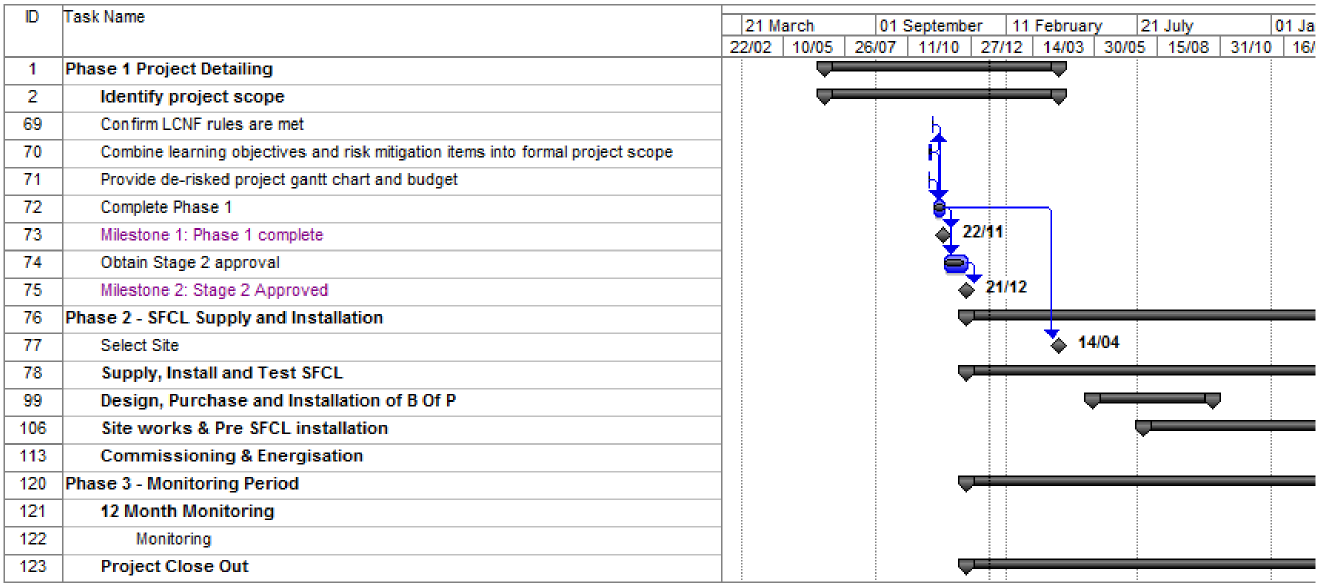
Sheffield 33kV Project Budget **Item**	**Attercliffe Bus Tie**	**Attercliffe Transformer tail**	**Jordanthorpe Transformer tail**	**Neepsend Bus Tie**	**Norton Lees Transformer tail**	**Pitsmoor Transformer tail**
33kV Cable between the FCL and the board(s) (800A or 2000A)	335.5m	421.7m	242m	38.3m	195m	219.6m
33kV Cable between the board and the LV transformer (circa 18A)	169.1m	186.6m	197.9m	56.2m	27.8m	29.1m
Refurbishment of 33kV Switchgear	3 Panels	2 Panel	1 Panel	3 Panels	1 Panel	N/A
Purchase of new switchgear	N/A	5 panel	5 panel	N/A	5 panel	6 panel
Protection changes	Yes	Yes	Yes	Yes	Yes	Yes
Comms Channels	Yes	Yes	Yes	Yes	Yes	Yes
Transformer, LV fuses, LV Distribution board, meter and MPAN number	Yes	Yes	Yes	Yes	Yes	Yes
Fencing	Yes	Yes	Yes	Yes	Yes	Yes
New switchboard housing, lights, heat, ventilation, tripping battery and charging unit.	N/A	Yes	Yes	N/A	Yes	Yes
Civil Foundations	Yes	Yes	Yes	Yes including flood barriers	Yes	Yes
NGT costs	N/A	N/A	Yes	Yes	Yes	Yes

Risk Register

A detailed FMEA for the project was undertaken. The results are given in Appendix 6
A6 Risk FMEA.xls

5 Project Programme

Top-level Plan



ID	Task Name
1	**Phase 1 Project Detailing**
2	**Identify project scope**
69	Confirm LCNF rules are met
70	Combine learning objectives and risk mitigation items into formal project scope
71	Provide de-risked project gantt chart and budget
72	Complete Phase 1
73	Milestone 1: Phase 1 complete
74	Obtain Stage 2 approval
75	Milestone 2: Stage 2 Approved
76	**Phase 2 - SFCL Supply and Installation**
77	Select Site
78	**Supply, Install and Test SFCL**
99	**Design, Purchase and Installation of B Of P**
106	**Site works & Pre SFCL installation**
113	**Commissioning & Energisation**
120	**Phase 3 - Monitoring Period**
121	**12 Month Monitoring**
122	Monitoring
123	**Project Close Out**

The full plan is given in Appendix 7
A7 CE 33kV Project Plan.mpp

Milestones

Milestone Title:	Phase 2 Set-up		
Objectives To roll out the project as detailed in phase 1.			
Work Description Kick-off meeting – Project team confirmed Confirmation of deliverables & project scope document from phase 1 Agree Programme Review Risk register			
Summary of deliverables			
Ref	**Title**	**Due Date**	**Comments**
D1	Project scope document	22/11/10	
D2	Project Programme	14/12/10	
D3	Risk Register	22/11/10	
		Milestone Value	£150,000

Milestone Title:	Network Impact report

Objectives

Ensure that the Fault Current Limiter interacts with the network such that the target fault level headroom is achieved and that the limiters impact on the network is fully understood.

Work Description

Identify the connection points/configuration for the FCL and new breakers.

Take CE/National Grid network data and simulate the FCL in the network.

Identify the generation type and size that it is proposed to connect in the carbon case.

Run transient analysis software to generate waveforms of the FCL operation with and without the generation connected.

Analyse the waveforms to determine the % reduction in peak and symmetrical fault level and deduce X/R ratio

Analyse the waveforms to identify any impact on voltage (overvoltage, harmonics)

Make available a dynamic PSCAD model suitable for IPSA and DIgSILENT software.

Summary of deliverables

Ref	**Title**	**Due Date**	**Comments**
D1	Network Configuration identified	25/01/11	E.g. Bus section connection with a new 5 panel board as per a schematic diagram.
D2	Zenergy report of the FCL in network received and analysed	25/01/11	Comment of fault level reduction, X/R, Voltage, etc
D3	PSCAD model suitable for IPSA and DIgSILENT software made available	25/01/11	Liaise with DIgSILENT and IPSA Engineers
		Milestone Value	£150,000

Milestone Title:	SFCL Design Report

Objectives

To ensure the FCL delivers the required performance

To ensure that any intangible objectives to be delivered by Zenergy are covered in this report, e.g. inclusion of devices for waveform capture, kWh meters, etc.

To ensure that the FCL is sufficiently specified so that all interfaces and balance of plant requirements are identified.

Work Description

Physical dimensions and specifications are understood – size, weight, layout, access (install/maintain/Decommission),

Health and Environmental issues are understood – Oil, Noise, helium, EMC, Colour, etc

Safety devices and their implications e.g. exclusion zones, earth connection.

Power requirements understood – max, operating, interruptible, back-up, etc

Internet comms scheme identified

Connection points identified – Physical position, type, etc

Control room comms identified

Zenergy Exclusions identified

Summary of deliverables

Ref	**Title**	**Due Date**	**Comments**
D1	Design report from Zenergy approved by ASL and CE	26/05/11	ASL Contribution to Project
		Milestone Value	£85,000

Milestone Title:	SFCL Material Procurement		
Objectives To ensure all material ordered in a timely manner to ensure delivery date is achieved.			
Work Description Identify all long lead items and place orders. Identify materials which require pre booking of supplier capacity and secure manufacturing slots. Complete SFCL material specification process to a level where all key/long lead items can be ordered.			
Summary of deliverables			
Ref	**Title**	**Due Date**	**Comments**
D1	Commence ordering Long lead materials booking capacity with strategic suppliers	15/04/11	
D2	All major/key material sub orders placed and pre booked capacity confirmed.	02/06/11	
		Milestone Value	£415,000

Milestone Title:	Balance of Plant Design Report		
Objectives To ensure that all necessary hardware is provided such that all the project objectives can be met.			
Work Description Develop schemes to deliver the hardware to meet all objectives and risk mitigation items Ensure all the Zenergy exclusions are covered Develop CE FDS and IAD documentation Develop ASL Balance of plant report Develop full objective (including risk mitigation actions) check list and confirm all hardware required is included in either the Zenergy / CE or ASL (or combinations thereof) scope			
Summary of deliverables			
Ref	**Title**	**Due Date**	**Comments**
D1	CE Functional Design Specification Document & Investment Approval Document	28/07/11	ASL will support CE in the development of these documents as required
D2	ASL Balance of plant design document	28/07/11	
D3	Full objective and risk mitigation design check-list	28/07/11	Check that either the Zenergy/CE or ASL design (or in combination) delivers all the hardware necessary to deliver the objectives.
		Milestone Value	£200,000

Milestone Title:	SFCL Factory test complete

Objectives

To make sure that the FCL has been built, assembled and tested in the factory prior to type testing, so that the chance of passing the type test is higher.

Work Description

Identify factory tests to be performed and pass/fail criteria in a document.

Build the FCL.

Carry out tests on the FCL unit in the factory. Tests to include:

AC winding DC resistance test to IEEE Std. C57.16-1996
Insulation Resistance to IEEE Std. C57-12.01-2005
V-I curve of HTS coils
Electromagnetic Characterisation
FCL Impedance Voltage Drop to IEEE Std. C57.16-1996
Total Losses to IEEE Std. C57.16-1996
AC Induced losses in HTS coil

Issue a test certificate confirming that all the tests were passed.

Summary of deliverables

Ref	**Title**	**Due Date**	**Comments**
D1	Factory test document Issued	26/05/11	
D2	Test certificate issued	16/02/12	Issued by Zenergy.
		Milestone Value	£800,000

Milestone Title:	SFCL Type Test Complete		
Objectives To test the SFCL in a test lab to ensure that it will perform adequately in the network			
Work Description Agree testing criteria for this type test Book test lab(s) Perform type tests in a Test Lab (Probably in Philadelphia), witnessed by ASL, optional for CE/National Grid. Receive provisional type test report Receive Type test report			
Summary of deliverables			
Ref	**Title**	**Due Date**	**Comments**
D1	Type Test Criteria agreed	26/05/11	
D2	Type Test Completed	12/04/12	Draft report issued
D3	Type Test Report Issued	12/10/12	
Milestone Value			£400,000 (on completion of D2)

Milestone Title:	Commissioning Complete		
Objectives To make the necessary modifications to the CE/National Grid site To install the FCL onto the site To make and test all the connections To make live			
Work Description Install the civil, electrical and other infrastructure necessary to receive the FCL on site Install the FCL on site Make all the necessary connections Draw a vacuum and cool down the FCL superconducting winding Perform installation tests Make live			
Summary of deliverables			
Ref	**Title**	**Due Date**	**Comments**
D1	SFCL Energised	22/06/13	
		Milestone Value	£150,000

Milestone Title:	Project Close Down report		
Objectives To detail performance against all the project objectives			
Work Description Write a report detailing the performance against all the project objectives.			
Summary of deliverables			
Ref	**Title**	**Due Date**	**Comments**
D1	Carbon Case Report	15/11/11	
D2	Business Case Report	23/08/11	
D3	Learning (Commercial) Report	38/12/12	
D4	Learning (Operational) Report	21/06/13	
D5	Final Report	05/07/13	
		Milestone Value	£50,000

6 Business Cases

SFCLs provide a new approach to the creation of headroom for the connection of generation. Business models will be prepared for transformer tail and bus section deployed SFCLs installed in typical 33kV substations based on actual GSPs in the Sheffield area (where there are currently problems with high fault level) and direct comparisons will be made with the traditional methods adopted by the DNOs. This analysis will include full Net Present Value, discount cash flow return and payback type evaluations using CE NPV spreadsheets and methodology. Alternative ways of creating headroom such as transformer or board replacement and auto close schemes will be considered. Likewise, operating costs (e.g. losses, energy consumed, CI/CLM exposure and maintenance) will be included in the evaluations.

In preparing the business case, the regulatory implications need to be considered including the different regulatory treatment of capital and operational expenditure associated with providing generation connections e.g. apportionment rules, enhanced return on DG related assets / GDUoS etc.

Network Performance

The installation of SFCLs at strategic positions in the network can lead to improvements in the performance of the network, particularly when compared with traditional solutions to rising fault level, such as network splitting or the installation of high impedance transformers. This includes quality of supply to customers and improved efficiency through reduction in network losses. One approach to evaluating these would be to undertake system modelling with CE engineers, using the Sheffield 33kV network as a basis. A traditional risk assessment could be used to assess the CI/CML network risk benefits of using FCL rather than say network splitting. Comparison with other traditional methods such as switchgear replacement could also follow this approach but there would be a need also to consider the general network risk reduction benefits associated with replacing old assets. IPSA / DINIS modelling would probably help to assess network loss benefits, but these models are snapshot models where as to form a reasonable view of losses over a period multiple runs could be needed. Which scenarios would be modelled would need careful consideration.

Reduced Stress on Switchgear

SFCLs by their operation control the energy created during a fault to well below any equipment in the effected circuit's design capability. This effect will lead to reduced stress in key components (such as mechanisms, contacts, springs etc). The question for this project is how to quantify the reduction in stress and therefore the reduced maintenance costs, reduction in circuit outages and ultimately the increased life of the equipment. To answer this question ASL will work with CE Electric Engineers, and if necessary external consultants to try and quantify these benefits.

Future Low Carbon Network

The move from a fossil fuel dominated energy mix to a future low carbon economy has led to the concept of the 'Smart Grid', recognising that greater flexibility in the network will be required to manage increased variability in supply, more controllable demand and support energy storage . Although a large amount of discussion revolves around the IT infrastructure required to manage this flexibility, there is almost an inbuilt assumption that the electrical network will have the capacity to support this flexibility. In reality the future low carbon economy will have a variety of impacts on electricity networks, including fault levels and new electricity network infrastructure. These could include:

- The Electric battery or Hydrogen fuel cell Vehicle related electrical infrastructure could require new electricity charging points or electrolysis plants, This increase in demand could encourage the meshing of radial networks or the addition of increased capacity at bulk supply points. These new networks may provide opportunities for SFCL technology.
- Connecting significant additional load will need new BSPs raising fault level, probably mainly at 11kV
- Generation of electricity from renewable sources such as wind, tidal, marine current, wave, hydro, waste and biomass sources could be embedded into existing distribution networks. These generators either directly connected to the grid, or through power electronic interfaces, will provide some current into a fault, potentially exceeding the electricity networks fault current handling capacity. SFCLs could facilitate the embedding of renewable and non renewable generation.
- Large scale renewable power-stations such as offshore wind-farms will require new networks. Reducing the fault handling requirements of the off-shore infrastructure by the installation of a fault current limiter can reduce the amount of screening copper in the cables, and thus make a small difference to the cable size which when wound on a drum will allow extra cable to be carried by the cable laying ship.
- Storage technologies such as batteries and heat pumps / Stirling engines (for thermal storage and electricity production) would both add to fault levels on electrical networks. These technologies could reasonably be expected to connect to distribution networks. The project will include collecting data on the fault contributions of these devices and inverter-connected devices of various types. It will be essential to clarify the typical short circuit contribution from inverter connected technology since this technology is becoming more widespread with the reduction in price of high power semiconductors.

7 Carbon Cases

Introduction

This project is about the evaluation of superconducting fault current limiter (SFCL) technology to facilitate the connection of generation to the 33kV electricity distribution network. Since the SFCL technology is new, and connection of generation to 33kV networks is not, the evaluation of the carbon benefit of the technology is not clear. Part of the overall project to trial a 33kV SFCL is to evaluate the carbon saving attributable to the SFCL and build up robust and documented techniques for capturing this.

Approaches to identifying the SFCL attributable carbon saving

It can be argued that Distribution Network owners can always accommodate new generation on their networks; the connection problem just needs the appropriate level of financial resource and time. The following approaches should be evaluated and the most appropriate one(s) adopted:

- If a SFCL is needed to create fault current headroom to allow a generator connection to proceed, all of the headroom created can be attributed to the SFCL and so all of the carbon saving can also be attributed to the SFCL.
- If a SFCL creates more connection headroom than a conventional solution (e.g. transformer replacement, series reactor, switchboard replacement, etc) then the difference in headroom created and its associated carbon saving can be attributed to the SFCL.
- If a SFCL solution is capable of being implemented in a more economic way than the conventional solution and this affects the decision of the generator to go ahead or not, then the carbon saving of the generator connection can all be attributed to the SFCL
- If a SFCL solution is capable of being implemented more quickly than a conventional solution due to difference is relative lead times, outage requirements or other issues, then the carbon benefit of the generator connection being brought forward by that period of time can all be attributed to the SFCL.

Evaluation methods for the carbon saving

There are many factors that affect the evaluation of the carbon benefit that can be attributed to the creation of the headroom to connect the generation. These are largely independent of the specific connection request. The following should be considered:

- The type of SFCL - resistive or pre-saturated core technology. The relative merits of the two technologies.
- Position of the FCL in the network, e.g. generator infeed, transformer tail, bus tie, etc.
- Other constraints for the generation connection, e.g. thermal capacity of the transformer, reverse flow capability, voltage control issues, etc.
- Generator type (Synchronous, Double fed induction, Power Electronics, etc) and fault current impact.

- Baseline carbon case – Average or marginal carbon emissions, network losses
- New generation carbon case – new carbon emissions, load factor, new network losses

Operational impact of the SFCL and conventional technologies

The SFCL, and for conventional solutions, the series reactors or high impedance transformers have operating losses in terms of impact on power factor and on losses/energy consumed. These should be evaluated as part of the carbon case evaluation and indeed as part of the project.

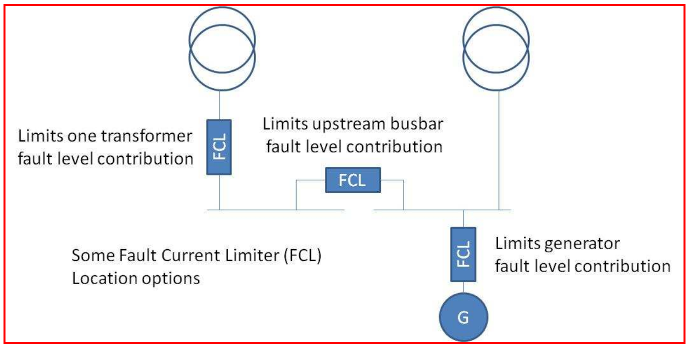
Lifecycle impact of the SFCL and conventional technologies

The SFCL or conventional solution will also have some embedded energy in their manufacturing and decommissioning. These too may need to be evaluated as part of an overall carbon case for the SFCL. There will also be issues associated with the lifespan of the solution and how it relates to the asset replacement / reinforcement that may be triggered by other drivers, taking a DCF approach if this is considered appropriate.

Carbon Case development – Proposed Methodology

1. **Substation data :**
    a. Voltage
    b. Fault level capability: Make
    c. Fault Level capability: Break
    d. % of fault level capability used
    e. Transformer size
    f. Transformer reverse flow capability

2. **Determine fault level headroom generated by the addition of a fault current limiter**



Pre-saturated core:

Pre-saturated core limiters reduce the fault current to a percentage of the prospective fault current. The maximum limiting practicable is to about 60% of the prospective. This degree of limiting reduces the fault current by 40%; such a limiter has a "clipping ratio" of 40%.

Resistive

Resistive FCLs limit to a maximum instantaneous current, which is a multiple of the trigger current level, typically between 2x and 10x the trigger current level. The trigger current level is the instantaneous current at which quench is initiated; it is set to be (rated normal current + safety margin for transients) x √2. For example a 1250A rated limiter with a safety margin of 1.6x would have an instantaneous let-through of 1250A x 1.6 x √2 x material multiplier = 5.6kA to 28kA. This would be the peak (make) value, with the break value capable of being tailored by design.

3. **Determine the amount of electrical generation of a given type which can be connected within the new headroom from rules of thumb to return the board back to the status quo**

	Synchronous	DFIG	Convertor
Load	I_n	I_n	I_n
Contribution to Break	$6\ I_n$	$2\ I_n$	$1.2\ I_n$
Contribution to Make	$16.8\ I_n$	$6\ I_n$	$1.2\ I_n$

4. **Determine from the location and voltage level generation types which could be connected here**

Generator Type	**Location Restrictions**	**Electrical Generator**
Wind	Space to put up wind turbines, sufficient wind speeds. Farm Size 1MW-120MW	DFIG or convertor
Wave	Shore-line. Size 0.2MW	Convertor
Tidal	Shore-line. Estimated Size 1MW	Convertor
Solar	Space for solar cells. In UK under 1MW.	Convertor
Hydro	River, lake, head, flow 1-100MW	Synchronous
Land fill gas	Land fill sites 1-23.8MW	Synchronous
Natural gas CHP	Gas main availability 0.1-1240MW	Synchronous

Generator Type	Location Restrictions	Electrical Generator
Biomass CHP	Source of biomass – usually rural or by a port, however some large ones in Slough. Range 0.1 - 44MW	Synchronous
Biomass Electricity	Source of biomass – usually rural or by a port. Range 0.1 - 38 MW	Synchronous
Electricity from Waste	Near a waste product stream – usually city outskirts. 0.3-35MW	Synchronous

Source for sizes: Dukes table 5.11 & NGC Seven Year Statement Table 4.1

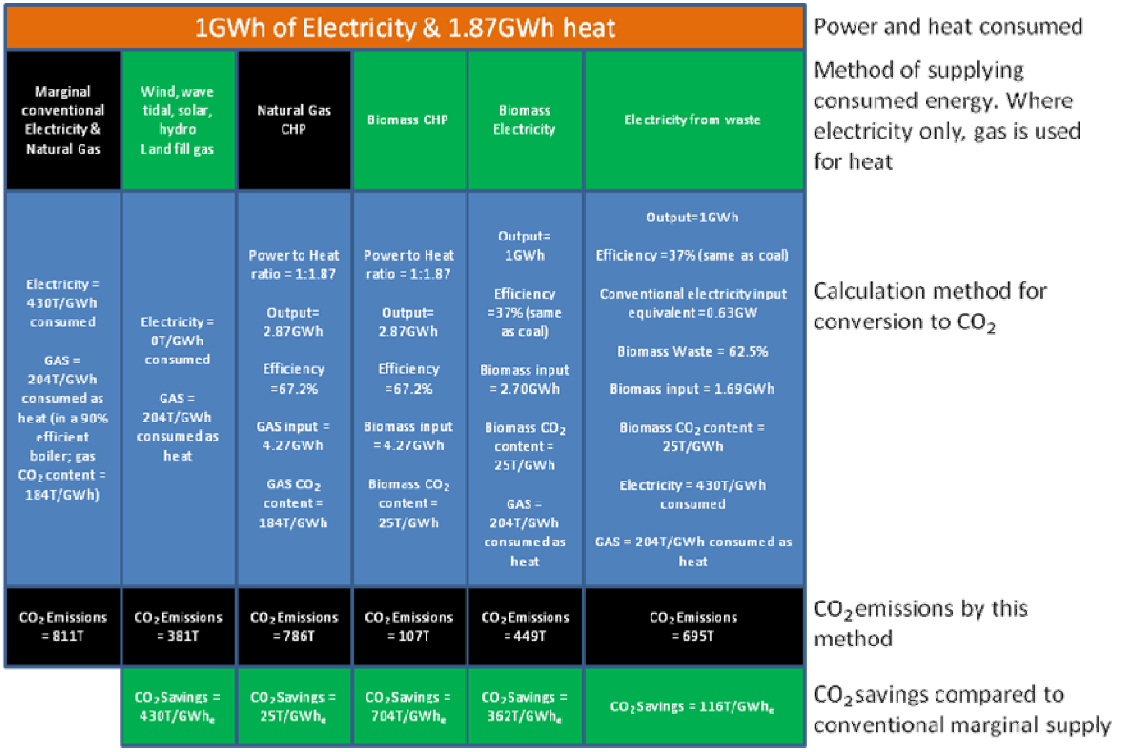
5. Determine from the *generation type load factors* the amount of energy generated by the selected generation types

Generator Type	Load Factor	Carbon Dioxide saving
Wind (On-shore)	27.0%	430T/GWh
Wind (Offshore)	30.4%	430T/GWh
Wave	approx 40%	430T/GWh
Tidal	approx 40%	430T/GWh
Solar	approx 18.3%	430T/GWh
Hydro	37.4%	430T/GWh
Land fill gas	59.8%	430T/GWh
Natural gas CHP	58.3%	25T/GWh
Biomass CHP	58.3%	704T/GWh
Biomass Electricity	56.3%	362T/GWh
Electricity from Waste	37.2%	116T/GWh

Efficiencies generally from dukes

6. Calculate the carbon savings: min, max, average, central case.

Calculate the energy per year of the additional generation and the associated carbon saving



1GWh of Electricity & 1.87GWh heat						Power and heat consumed
Marginal conventional Electricity & Natural Gas	Wind, wave tidal, solar, hydro Land fill gas	Natural Gas CHP	Biomass CHP	Biomass Electricity	Electricity from waste	Method of supplying consumed energy. Where electricity only, gas is used for heat
Electricity = 430T/GWh consumed GAS = 204T/GWh consumed as heat (in a 90% efficient boiler; gas CO$_2$ content = 184T/GWh)	Electricity = 0T/GWh consumed GAS = 204T/GWh consumed as heat	Power to Heat ratio = 1:1.87 Output= 2.87GWh Efficiency =67.2% GAS input = 4.27GWh GAS CO$_2$ content = 184T/GWh	Power to Heat ratio = 1:1.87 Output= 2.87GWh Efficiency =67.2% Biomass input = 4.27GWh Biomass CO$_2$ content = 25T/GWh	Output= 1GWh Efficiency =37% (same as coal) Biomass input = 2.70GWh Biomass CO$_2$ content = 25T/GWh GAS = 204T/GWh consumed as heat	Output=1GWh Efficiency =37% (same as coal) Conventional electricity input equivalent =0.63GW Biomass Waste = 62.5% Biomass input = 1.69GWh Biomass CO$_2$ content = 25T/GWh Electricity = 430T/GWh consumed GAS = 204T/GWh consumed as heat	Calculation method for conversion to CO$_2$
CO$_2$ Emissions = 811T	CO$_2$ Emissions = 381T	CO$_2$ Emissions = 786T	CO$_2$ Emissions = 107T	CO$_2$ Emissions = 449T	CO$_2$ Emissions = 695T	CO$_2$ emissions by this method
	CO$_2$ Savings = 430T/GWh$_e$	CO$_2$ Savings = 25T/GWh$_e$	CO$_2$ Savings = 704T/GWh$_e$	CO$_2$ Savings = 362T/GWh$_e$	CO$_2$ Savings = 116T/GWh$_e$	CO$_2$ savings compared to conventional marginal supply

Carbon saving data from dukes (efficiencies and biomass content in waste) and from DEFRA greenhouse gas conversion factor table.

Worked example:

1. Switchboard.

Voltage 33kV
Switchgear Ratings: Make 43.7kA; Break 17.5kA (1000MVA)
Capability used: 95%, i.e. Fault level must be returned to 95% of make and break capacities i.e. 41.52kA peak; 16.63 rms symmetrical
Transformers: 2 x 100MVA
Reverse flow capability: 100MVA

2. SFCL Location & type

Pre-saturated core in Bus Section.
½ board fault level at 95% capability utilisation = 41.51/2 = 20.76kA peak; 16.63/2 = 8.31kA rms symmetrical
Reduce this by 40% using the FCL
Additional Fault Level headroom for generation is: 8.30kA peak; 3.32kA rms symmetrical

3. Additional Generation capacity

	Fault current headroom	Synchronous Generator	DFIG Generator	Convertor Generator
Make, Current	8.30	8.30/16.8=0.49kA	8.30/6=1.38kA	8.30/1.2=6.92kA
Make, Power		0.49kA x 33 x √3 = 28MVA	1.38kA x 33 x √3 = 78.9MVA	7.88kA x 33 x √3 395MVA
Break, Current	3.32kA	3.32/6=0.55kA	3.32/2=1.66kA	3.32/1.2=2.03kA
Break, Power		0.55kA x 33 x √3 =31.4MVA	1.66kA x 33 x √3 = 94.9MVA	2.03kA x 33 x √3 = 116MVA
Max additional Generation		28MVA (limited by make)	78.9MVA (Limited by make)	100MVA (Limited by transformer reverse flow capability)

Note: No allowance has been made for voltage limits etc.

4. Suitable Generator Types:

Location: Sheffield, 32-100MVA generator size

Generator Type	Reasonable	Justification, limitations
Wind	Unlikely	No space in the city, possible at Jordanthorpe
Wave	No	No sea
Tidal	No	No tidal water
Solar	No	Size of connection (too small for 33kV)
Hydro	No	No resource
Land fill gas	Yes	Only 20MW (UK's largest=23.8MW)
Natural gas CHP	Yes	Lots of CHP schemes including some in Sheffield
Biomass CHP	Yes	e.g. like Slough; (UK's largest=44MW)
Biomass Electricity	Yes	e.g. like Slough; (UK's largest=38MW)
Electricity from Waste	Yes	e.g. like Slough; (UK's largest=35MW)

5. Generation and carbon saving

Generator	Generator type	Generator Size	Load Factor	Annual Generation GWh	CO_2 saving factor T/GWh	Carbon dioxide saving Tpa
Land fill gas	Synchronous	20MVA	59.8%	104.8	430	45,064
Natural gas CHP	Synchronous	28MVA	58.3%	143.0	25	3,575
Biomass CHP	Synchronous	28MVA	58.3%	143.0	704	100,672
Biomass Electricity	Synchronous	28MVA	56.3%	138.1	362	49,992
Electricity from Waste	Synchronous	28MVA	37.2%	91.2	116	10,579

6. Carbon Saving.

The application of a FCL to generate headroom on a typical 33kV board in Sheffield will save 3.5 to 100 kilo-tonnes of carbon dioxide per year depending on generation type and likely size. Taking as a central case of the generation of electricity from a large biomass plant, would save 50kt of carbon dioxide per year.

Sheffield specifics

In the development of the generic carbon case approach, examples should be used for Sheffield wherever possible. Fault level constraints and the applicability of the technologies in this network should be examined. For example the Jordanthorpe substation may be suitable for Wind connections (since to the south there is open ground not in the Peak

District National Park) whereas at other city substations, Combined Heat and Power, Energy from Waste and Biomass may be more likely. Nowhere in Sheffield is suitable for wave or tidal generation connections; however other CE Electric substations between Berwick and Cleethorpes may well be suitable, so need to be included in the generic model.

Example Study

An example study is described in detail in Appendix 8
A8 Generic Carbon Case.pdf

Conclusion

There are many factors to be considered in the development of the carbon case attributable to FCLs. An outcome from this project is to develop robust and documented techniques for evaluating these factors. To make them robust, some sort of external help should be considered. To ensure they also sit comfortably with the internal processes of CE Electric, internal support from CE will be needed. Ofgem may also have a view on this process and should at least be consulted.

8 LCNF Selection Criteria

Review of First Tier LCN Project Registration

The final stage of Phase 1 of the project is to review the First Tier LCN Project Registration Document and confirm that the original scope and objectives are still valid and achievable. The original Scope and Objectives were to trial a new piece of technology (i.e. a Superconducting Fault Current Limiter) which has a direct impact on the operation and management of the distribution system. The validity of the original criteria will be assessed against the most relevant sections of the Registration Document.

Scope and Objectives

The scope of Phase 1 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 identification of suitable sites has now been completed following detailed sites surveys, technical reviews with Zenergy (the core technology provider) and NG (a potential co-host for the installation). A short list of acceptable sites has now been agreed and a generic and adaptable SFCL specification completed. This has allowed the balance of plant scope for each installation to be created which in turn has allowed validation of the budget assumptions made in the application.

Success Criteria

A set of success criteria where identified during registration. 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, cryocooler and auxiliary components
- Operational experience relating to the SFCL, cryocooler and auxiliary components documented
- Network events and SFCL response captured electronically
- Running costs documented
- Maintenance requirements documented
- Required changes to policy and operational documentation identified
- Information and learning disseminated to DNO peer group

During Phase 1 these have been reviewed in terms of whether they are still relevant and measurable. These have been validated through the detailed review process. Where equipment will be required to capture information, suitable provision will be allowed for in the budget. Where a new process is required, again this has been identified and included in the scope documents.

Predicted End Date – June 2013

The project completion date of June 2013 allows for a two year build and followed by twelve months monitoring. Critical to the Project end date were the site selection process and the SFCL specification completion to allow manufacture to commence. All data required to complete the selection process have been collected and a generic, adaptable specification for the SFCL has been prepared. Zenergy Power has confirmed that a unit can be provided for any of the nominated sites, so despite not having been able to select the site by the specified date, it should still be possible to deliver the project on time.

Potential for new learning

During the registration process, new areas of learning were identified. The key learning to be delivered by the project is the understanding of the circumstances under which the SFCL can be used to mitigate fault level issues which are a barrier to distributed generation connection and how the SFCL can then be designed for and operated in distribution networks.

Specifically the following learning outcomes would be expected:

- Identification of cases where use of the SFCL could be used to mitigate DG connection issues
- Identification of control and operational issues associated with use of such equipment and proposing means of addressing these
- Assessment of potential carbon benefits
- Assessment of impact of equipment on policies, codes of practice, section level procedures and identification of required revisions
- Dissemination will be through the production of a "how to" manual that details the new knowledge outlined above

Risks

In the Registration process risks where identified in two areas, Technology and Project. The main Technology Risk is around matching the capability envelope of the SFCL technology

with the site/application selection process. The robust site selection process should have successfully matched the short listed sites to the SFCL capability envelope.
The main Project Risk was identified as being related to the potential site owners (i.e. NG) because NG had not at that time been involved in the process but would be essential to it. An early Stage 1 goal was set to engage with NG and to develop a process together enabling the installation of a SFCL on one of their sites. As a backup, in case NG engagement was likely to put the project at risk, potential sites where NG has no influence have been included. The review of these alternatives has been included in the site selection document.
As part of the general de-risking of the project, a detailed risk assessment has been developed and is included as Appendix 6
A6 Risk FMEA.xls

9 Conclusion

The Phase 1 review process has considered all of the project objectives declared in the Tier 1 LCNF Registration document and in conclusion, views that all said objectives are valid and can be achieved within the time frame set by OFGEM.

The review has assessed the project and technical risks. The mitigation strategies discussed in the site selection document and the risk register have fully addressed them. In terms of learning (which ultimately is the overriding project deliverable), an opportunity for further learning has been identified beyond that originally identified in the Registration document. The strategies for capturing and disseminating the learning should be achievable within the time-frames set by OFGEM.

Learning Objectives

Category	Title	Detail	Learning Objectives	Methodology	Comments
Business Case	Review Benefits Of SFCLs	**Comparison of traditional ways of resolving fault level problems.** High Imp Transformer, Switchgear Reactors New supply point Split Network Resistive SFCL Inductive SFCL **Comparison methods** Capital Cost Operational cost Time Fault level Reduction **Further benefits** Equipment stress Meshing networks Power Quality Quality of Supply Network topology Losses	How to make the comparison. Does this have an impact of how DNO revenues are calculated?	Energy, maintenance EA Tech IPSA trial Simon Blake Cu Losses	OFGEM involvement? How will this project learn about operational costs: Energy Meter? How will this project learn about maintenance costs: Perform Maintenance? How will this project learn about power quality: Power Quality Analyser, Fault level recorder? How will this project learn about further benefits: Studies? This learning would be reduced without a NG involvement (NG Costs)

Category	Title	Detail	Learning Objectives	Methodology	Comments
Carbon Case	Head room for Generation	Development of processes to deliver carbon cases for multiple scenarios Generation Types. Impact on fault levels Load factors Likelihood of connection (e.g. tidal)	To be able to produce a carbon case for any request to connect	Desktop Energy consumed Life cycle carbon analysis Load profile	Sheffield University PhD students This learning would be reduced without a NG involvement (NG constraints like transformer reverse flow))
Commercial	Who gets (generation) connection benefit	Who pays and who gets benefit discussion	Possible new ideas on commercial relationship between DNO and Generation Developers	Sharing benefits?	OFGEM Involvement This learning would be achievable without a NG involvement
Operational	Impact on Network	Impact of SFCL on protection and control. Also network stability. Tolerated voltage drop and load sharing. Live Event – Actual fault event	Understand impact and development of strategies to manage any unexpected effects. Ability to capture event to enable analysis of impact on control, protection etc	Tests Fault Recording Equipment	Voltage drop modelling Fault level modelling Load sharing measurement Transformer tap regime This learning would be reduced without a NG involvement (NG Control and protection schemes)

Category	Title	Detail	Learning Objectives	Methodology	Comments
Operational	Maintenance/Life	Develop	Development of	Meter Point	One

	Time costs	understanding of operational costs. Energy, Maintenance, losses, mag field	strategies to mitigate costs, e.g. maintenance Possible feedback into generic SFCL purchase specification. Also future design standards	Admin Number X/R?	Maintenance of SFCL to be carried out during year one monitoring period. This learning would be reduced without a NG involvement (Access and outage planning)
Operational	Type Tests/Standards	Development of industry accepted test standards, Voltage, PD Short circuit Thermal EMC & Harmonics Environmental	Relevant standards developed.	Scunthorpe Gap analysis	This learning would be reduced without a NG involvement (NG buy-in to standards)
Operational	Environmental Issues	Full environmental impact assessment carried out Mag field Oil, midel Noise Gas	Understanding of what the issues are and how to mitigate them	Mag Field measurement?	This learning would be achievable without a NG involvement
Commercial	NG Road Map	Development of understanding of how SFCLs will be deployed on substations owned by or with NG assets	Understanding of what the issues are and how to mitigate them	Meetings, barriers	This learning would be completely removed without a NG involvement

Category	Title	Detail	Learning Objectives	Methodology	Comments
Operational	DNO Policies	How to	Understanding of	IPSA, DINIS	This learning

		integrate SFCLs into CE processes for future roll out	what the issues are and how to mitigate them	models, Operational Handbook Design policies	would be achievable without a NG involvement
Commercial	Demonstration of potential generation headroom – creation of generation clusters	DNO could advertise available network capacity	Changing the DNO role in the connection of generation process	Combined Workshop	OFGEM Involvement This learning would be reduced without a NG involvement (NG constraints)

10 Stage Gate to Phase 2

The following table summarises the Phase 1 activities and gives the status of each at the time of this report. The ideal position is that all the answers are "yes". Where the answer is "no" it has been accepted that the activity can be moved to Phase 2.

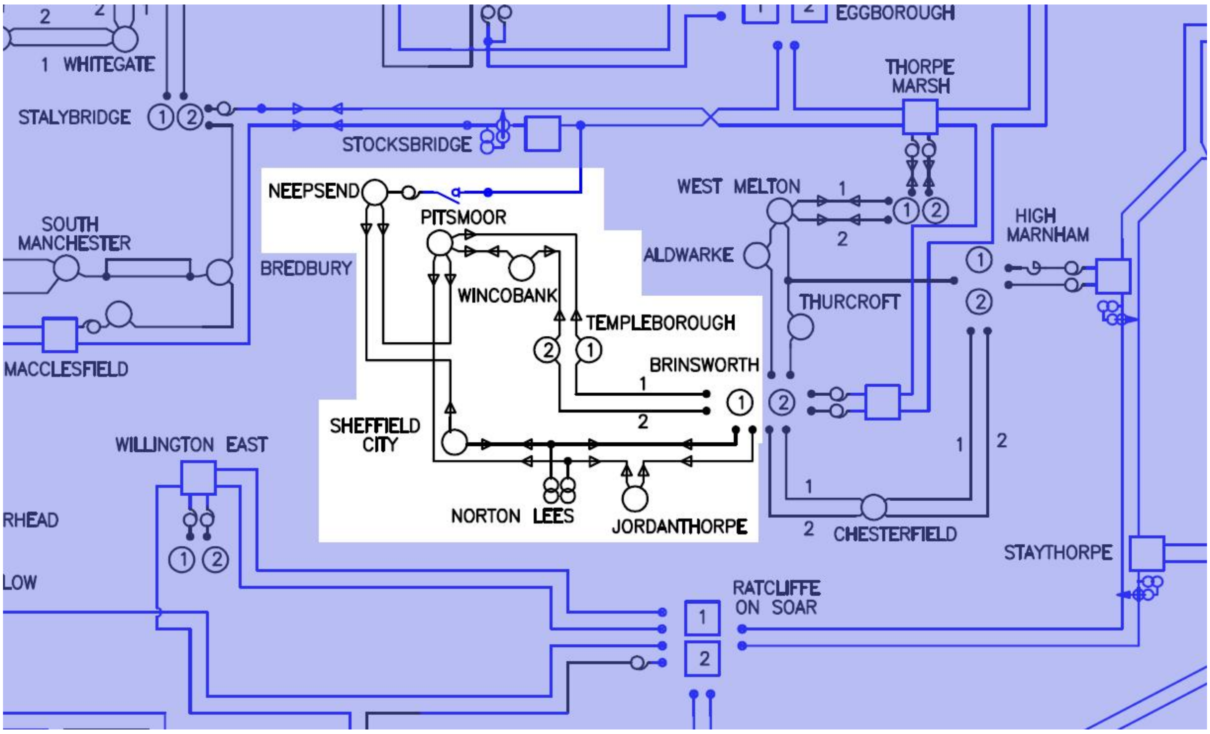
STAGE GATE REVIEW	Answer
Section 1: Kick off	
Has a kick off meeting between CE and ASL been held?	Yes
Has a FMEA risk assessment been developed?	Yes
Has the risk assessment been reviewed and accepted?	Yes
Section 2: Site Selection	
Have 33kV sites been identified, LTDS and Seven Year Statement data been captured	Yes
Have the sites been visited to consider practical constraints?	Yes
Has a report been written on the site visits?	Yes
Has a briefing document been written for NG?	Yes
Has a NG meeting been held?	Yes
Has a clarification document for site down-selection been produced for NG?	Yes
Do we have a technical response from NG to the document sufficient to inform the site selection process?	No
Section 3: Specification	
Has a general specification been raised for a Zenergy fault current limiter	Yes
Has the modification of the specification relating to the sites down-selected been sent to Zenergy?	Yes
Do we have a technical response to the document sufficient to inform the site selection process?	No
Section 4: Project Budget	
Have the items which require budget been identified?	Yes
Has the CE budget for all options been developed?	No
If an option requires budget in excess the LCNF application, have additional CE funds been allocated or identified?	No
Has the budget been finalised?	No
Section 5: Programme	
Has a realistic project programme been identified?	Yes
Has a date for final site selection been identified?	Yes
Does the project complete within the 3 years allowed for the LCNF projects?	Yes

Section 6: Business Case evaluation	
Have approaches to developing business cases been identified?	Yes
Section 7: Carbon Case evaluation	
Have approaches to developing carbon cases been identified?	Yes
Section 8: Learning	
Have the key deliverables, particularly learning, from the LCN project registration process been identified?	Yes
Have the learning objectives been developed to a point where they are clearly understood?	Yes
Have processes and equipment required to measure the learning points been identified?	Yes

Applied Superconductor

33kV Fault Current Limiter Project

18th October 2010



CONFIDENTIALITY (Confidential or not confidential) :	**Not Confidential**
PROJECT: Sheffield 33kV Fault Current Limiter	

UNIT APPROVAL	**Name**	**Date**
WRITTEN BY :	Adrian Wilson	18.10.2010
CHECKED BY :	Chris Waller	18.10.2010
APPROVED BY :	Adrian Wilson	18.10.2010

REVISION HISTORY RECORDS

Revision	**Date**	**Creation / Update summary**
Issue 1	6/10/2010	Customer first issue for comment
Issue 2	18/10/2010	Issue with CE comments incorporated

Contents

Introduction

CE Electric have initiated a project under Ofgem's Low Carbon Network Fund to install a pre-saturated core fault current limiter into the 33kV network on a National Grid fed site in Sheffield. This document is intended as a briefing document for a meeting between National Grid, CE Electric and Applied Superconductor. It covers :

- The background to the project - distributed generation and fault level
- Project objectives
- An introduction to fault current limiters
- An introduction to the potential sites - the selection of the front runners

and most importantly, the interfaces between this project and National Grid.

Project Background

Low Carbon Environment

World, European and UK Governments have agreed to tackle global climate change by reducing carbon emissions. As an important component of UK energy consumption, electricity generation and supply will play a large role in achieving the UK's share of carbon reduction. Government, the regulator, transmission and distribution network operators have, under the Electricity Networks Strategy Group, identified that it is critical to deliver a range of well targeted pilot projects between 2010 and 2015 in the expectation that many of them will prove to be technically and economically successful and therefore available for UK wide application from 2015 onwards. Ofgem have made £500m funding available to distribution under the Low Carbon Network Fund to distribution companies and this project is largely funded by that fund.

Distributed Generation and Fault Level

The Government's targets for reducing carbon emissions means the UK needs to reduce its dependence on fossil fuels and adopt cleaner energy sources. Generators using renewable energy are sited near their energy sources (on hills for wind, by the sea for tidal and wave power, near landfill sites or digesters for gas, etc). Combined heat and power schemes, which recover waste heat from the process of generating electricity, need to be installed in locations where there is a need for heat. These sites are rarely connected to the National Grid system and in any case connecting to this voltage level would be unfeasible for generators of moderate capacity (typically under 50MW) which are likely to connect in Sheffield. Generator connections are therefore being made to local distribution networks but these have limited capacities to handle short circuit fault currents.

To facilitate the connection of generation from renewable sources at the distribution voltage level, the network needs to be capable of withstanding these consequential increases in fault level. Traditional approaches to managing increasing fault levels lead to time consuming, costly infrastructure upgrades which may cause the proposed generation development to not proceed.

Applied Superconductor

Applied Superconductor, established in 2004, recognised this fault level barrier to the connection of distributed generation and through collaboration with suppliers and three distribution network operator customers developed a project to build, test and deploy a total of three 11kV superconducting fault current limiters (SFCLs) on the distribution networks of the partner DNOs. The initial limiter, trialled successfully on the Electricity North West distribution network, was a resistive unit where the normal and fault current flows through superconducting elements which are capable of reducing fault currents by circa 80%. The amount of superconductor in a unit scales with the voltage and current as does the cooling required, and after clearing a fault the elements have to be removed from the circuit and allowed to cool back to operating temperature which means the unit cannot ride through faults. Applied Superconductor’s second unit is a similar resistive device with a higher normal current tailored to the Scottish Power Manweb meshed network area.

Applied Superconductor’s third device is a pre-saturated core unit where the load current (copper) conductors are wound round an iron core, and the iron core itself is driven into saturation by a dc winding made of superconductor. Under normal current operation the unit looks to the network like an air cored reactor, however under fault conditions the fault current drives the iron core out of saturation and then it looks like an iron cored reactor to the faulted network, increasing its impedance and reducing the fault current flowing by up to circa 40%. It is this type of device that the proposed project will scale up to 33kV and trial at a Grid Supply Point in the Sheffield area, demonstrating both the limitation of fault current and the creation of additional headroom which could be used to release capacity so that new low carbon generation can connect.

Project Objectives

Project learning objectives

The key learning to be delivered by the project is the understanding of the circumstances under which the SFCL can be used to mitigate fault level issues which are a barrier to distributed generation (DG) connection and how the SFCL can then be designed into and operated within distribution networks.

Specifically the following learning outcomes would be expected:

- Identification of network and physical circumstances where use of the SFCL could be used to mitigate fault level issues and address potential future DG connection issues.

- Identification of design, construction, commissioning, protection, control and operational issues associated with use of such equipment.

- Assessment of actual carbon benefits/confirmation of initial carbon case.

- Assessment of impact of equipment on policies, codes of practice, section level procedures, financial authorisation processes (including the financial justification) and identification of required revisions.

- Dissemination will be through the production of a "how to" manual that details the new knowledge outlined above.

Demonstration Objectives

This project trials a specific piece of new equipment that has a direct impact on the operation and management of the distribution system and potentially the transmission system.

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

The second phase is to design, build, install and commission a three-phase 33kV SFCL on the CE distribution network. It is proposed, subject to site surveys and agreement with National Grid and other partner organisations, that the unit is installed at a 275/33kV substation in South Yorkshire to limit the fault current to within the rating of the 33kV switchgear. This is currently managed through an operational management switching procedure which in some circumstances may increase the risk of loss of supplies to customers.

Pre-saturated Core Fault Current Limiter

Pre-saturated Core Limiter

The pre-saturated reactor principle of operation is illustrated in Figure 1, which shows a pair of ferromagnetic cores, both of which are driven into saturation by the magnetic field produced by a superconducting coil common to both cores. Each core also passes through a high capacity winding of a few turns which carries the line current.

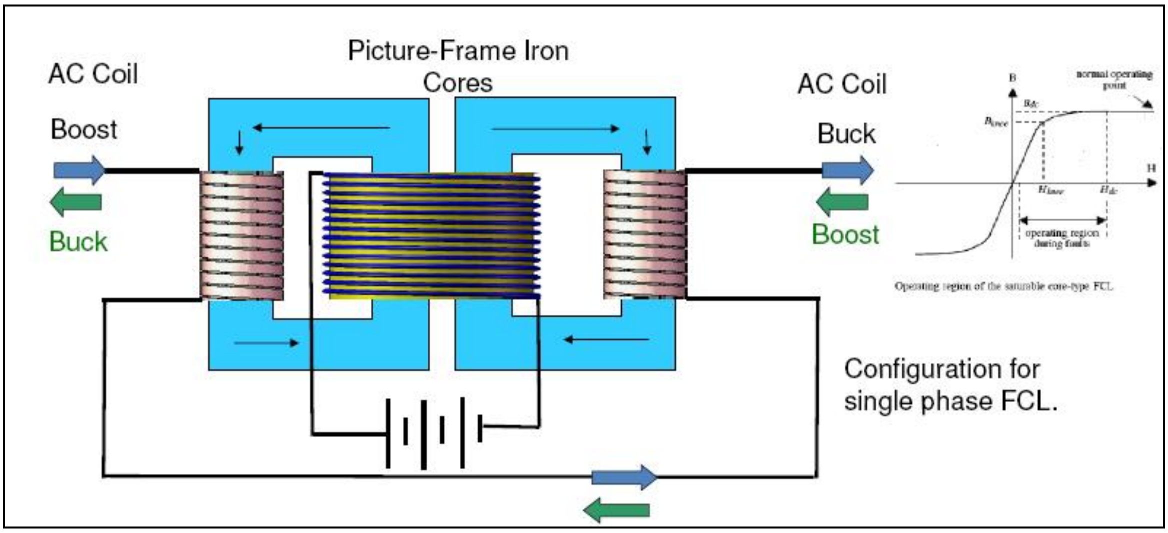


Figure 1: Pre-saturated core FCL

Current flowing from left to right (blue arrow) augments the field in the left hand core, but reduces the field in the right hand core. If the current reaches a sufficient level (i.e. fault current flows), the right hand core becomes de-saturated, resulting in a sudden and substantial increase in the inductance of the right-hand line-current winding. The converse applies for current flowing from right to left (green arrows). This action, which inserts inductance into the faulted circuit for a short time during each half cycle, is able to reduce the magnitude of the fault current when this is large enough to initiate de-saturation. The level at which this occurs can be varied to suit the requirements for a given FCL application.

This process provides a fault current limiter able limit the current by up to 40%, i.e. to 60% of the unlimited value. Limiting starts at fault inception and the first peak is limited, again by up to 40%. The limiter can carry the limited current for long periods of time, up to 3 seconds. When the fault is cleared, the limiter impedance reverts to its lower pre-fault level and load flow can be immediately supported.

Extensive high-voltage and load and fault current testing was carried out by Zenergy Power at Powertech in Canada to confirm the FCL ratings. While these ratings are not the same as the unit that will be deployed at Sheffield or even the Scunthorpe 11kV unit, they do demonstrate that short circuit withstand capability approaching 1 second (3s will be tested in this trial) and 16% limiting (black line compared to the red one) has already be achieved. We expect to deliver circa 40% limiting. The operation of the FCL under fault conditions at 23kA rms, 63kA peak is shown in Figure 2.

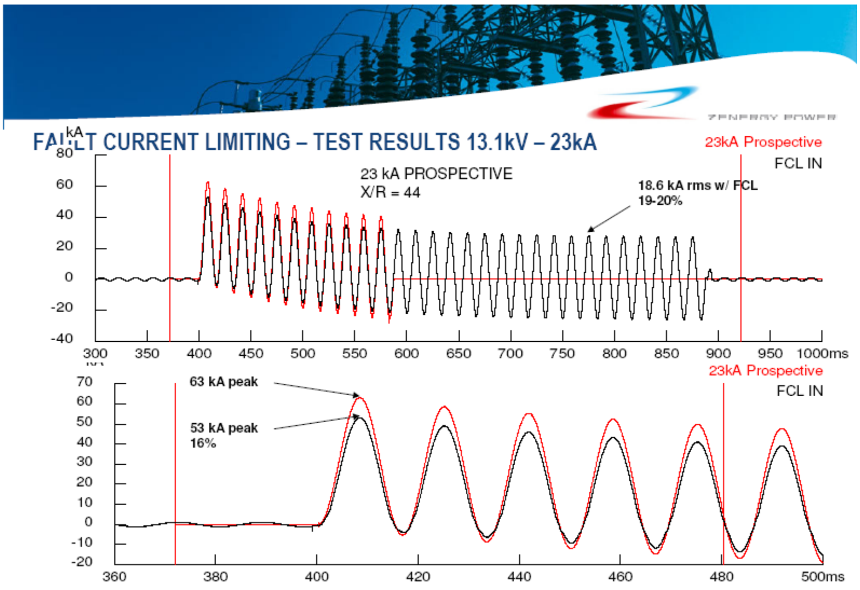


Figure 2: Fault clipping behaviour

Site Selection

Background to the Sheffield ring Fault Level issues

The Sheffield 275kV ring (which actually comprises four half rings) is shown in Appendix 1. It does not show the 132kV network which does not form part of the ring.

There are seven 275/33kV GSPs in the Sheffield district (counting Pitsmoor as two grid supply points) supplied from the 275kV Sheffield Ring. Sheffield City, Neepsend and Pitsmoor 3 & 4 are inter-connectable at 33kV, as are Norton Lees and Jordanthorpe, but the 33kV circuit breakers on the interconnecting circuits are normally open.

Of the seven Grid Supply Points (GSPs) only Wincobank and Pitsmoor 1&2 have no fault-level issues on the 33kV busbars. The others have peak fault levels exceeding the making capacity of the 33kV switchgear and at Norton Lees the symmetrical fault level exceeds 95% of the switchgear breaking capacity.

There are also five 33/11kV primaries where there are fault level issues on the 33kV switchgear which are currently operationally managed. Part of this project will be to evaluate how 33kV fault level mitigation measures cascades down the 33kV network.

ASL has been considering how fault-current limiters could be optimally deployed in the Sheffield network in order to:

- Alleviate immediate fault level issues so that operational restrictions may be removed and existing 33kV and 11kV switchgear may continue to be used and operated as originally envisaged
- Improve the network resilience to 33kV faults whilst the operational procedures associated with the restrictions are being implemented.
- Facilitate the connection of distributed generation without triggering fault level concerns.
- Allow the 33kV network to be run with some of the interconnection circuit breakers operated normally closed, to increase load capacity.

In addition to the grid supply point substations supplied from the Sheffield ring there are two BSPs fed from the 132kV network in Sheffield which in turn is supplied from West Melton GSP.

Specifics of the various sites

There are nine Grid or Bulk Supply Points feeding the city of Sheffield, seven fed from the 275kV Sheffield ring and two from CE’s 132kV network (which in turn is fed from the Grid at West Melton). These sites are as follows:

Attercliffe

Attercliffe Bulk Supply Point (BSP) is a 132/33kV substation equipped with two 60MVA transformers connected to the 132kV network. At 33kV Attercliffe could be connected via intermediate substations to Sheffield City and Pitsmoor Substations. The 33kV Ferguson Palin switchgear board has three bus sections, each section having at least one of the four spare breakers. It is situated in the centre of the city and has potentially some space for the installation of additional equipment.

Blackburn Meadows

Blackburn Meadows BSP is a 132/33kV substation equipped with two 60MVA transformers connected to the 132kV network. There are no 33kV interconnection opportunities at this substation via the YEDL network. The 33kV Reyrolle L42 switchboard has two bus sections, each section having one spare breaker. It is situated at the north east of the city, adjacent to the M1, technically just in Rotherham. It has significant protection from flooding and the site is quite compact although there may the potential to install additional equipment.

Jordanthorpe

Jordanthorpe Grid Supply Point (GSP) is a 275/33kV substation equipped with two 100MVA transformers connected to the 275kV network. At 33kV Jordanthorpe could be connected via an intermediate substation to Norton Lees Substation. The 33kV AEI switchgear board has one bus section and there is one spare breaker. It is situated on the southern edge of the city in an almost rural location with seemingly plenty of space to install additional equipment.

Neepsend

Neepsend GSP is a 275/33kV substation equipped with two 120MVA transformers connected to the 275kV network. At 33kV Neepsend could be connected via an intermediate substation to Sheffield City Substation. The 33kV AEI switchgear board has one bus section and there are three spare breakers, at least one on each bus section. It is situated on the north-west edge of the city in an almost rural location with seemingly plenty of space to install additional equipment. The 275/33kV substation is on one side of the River Don whilst the 400/275kV substation is on the opposite side of the river. The 400kV supply appears to be normally open at this site.

Norton Lees

Norton Lees GSP is a 275/33kV substation fed equipped with 100MVA transformers connected to two separate loops of the 275kV network. At 33kV Norton Lees could be connected via an intermediate substation to Jordanthorpe Substation. The 33kV AEI switchgear board has one bus section and there are two spare breakers both on the same bus section. The 33kV circuits cannot be (sensibly) transferred to create a spare on either bus section. It is situated towards the south of the city in a suburban location with seemingly plenty of space to install additional equipment.

Pitsmoor 3&4

Pitsmoor 3&4 GSP is a 275/33kV substation equipped with two 100MVA transformers. These are connected to a 275kV substation which also feeds Pitsmoor 1&2 (supplying an individual customer) and which interconnects four half loops of the 275kV rings (See Appendix 1). At 33kV Pitsmoor 3&4 could be connected via an intermediate substation to Attercliffe. The 33kV South Wales Switchgear board has one bus section and there are no spare breakers. It is situated towards the north of the city in an industrial location with seemingly plenty of space to install additional equipment.

Sheffield City

Sheffield City GSP is a 275/33kV substation equipped with two 100MVA transformers connected to a 275kV substation. At 33kV Sheffield City 3&4 could be connected via an intermediate substation to Attercliffe Substation and via an intermediate substation to Neepsend Substation. The33kV Reyrolle

L42 Switchgear board has one bus section with a spare breaker on each section. It is situated in the centre of the city in a retail location with very limited space.

Wincobank

Wincobank GSP is a 275/33kV substation equipped with two 100MVA transformers connected to a 275kV substation. At 33kV Wincobank is an islanded site with no 33kV interconnection. The 33kV GEC switchgear board has one bus section and there is a single spare breaker on each section and two further circuit breakers that may be available. It is situated towards the north east of the city immediately to the north of Meadowhall shopping centre on a compact site.

Site selection process

To select the best site for this Fault Current Limiter trial the following considerations have been made:

Each issue is scored out of five and attributed to sites with the following codes:

Code	Site
A	Attercliffe (132/33kV Bulk supply point)
BM	Blackburn Meadows (132/33kV Bulk supply point)
J	Jordanthorpe (275/33kV Grid supply point)
NE	Neepsend (275/33kV Grid supply point)
NL	Norton Lees (275/33kV Grid supply point)
P	Pitsmoor 3&4 (275/33kV Grid supply point)
S	Sheffield City (275/33kV Grid supply point)
W	Wincobank (275/33kV Grid supply point)

Site scoring

A number of different criteria have been used to evaluate site suitability for various connection options. These include for each site:

- the fault level in the site (both make and break),
- site physical suitability (considering space, security, flooding, access, installation complexity and noise sensitivity),
- planned work under DPCR5,
- degree of National Grid interaction required,
- the head room generated for generation by the Fault Current Limiters installation in a transformer tail installation (see figure 3) and
- the sites suitability for a bus tie application (see figure 4).

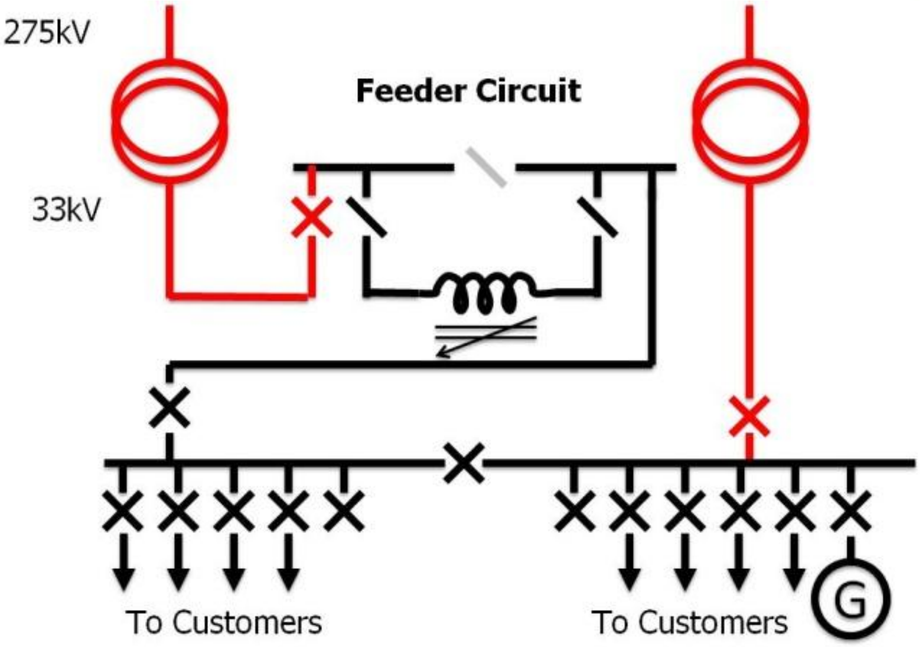


Figure 3: A Transformer Tail connected fault current limiter

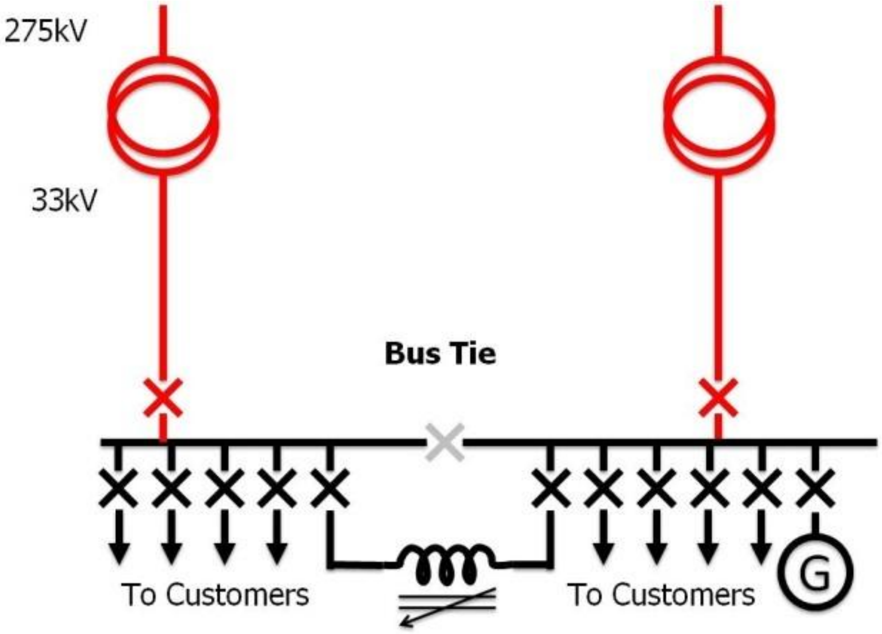


Figure 4: A Bus tie fault current limiter

Selected sites

Comparing the scores for the various site attributes reveals the following table (higher scores are better):

Site	**A**	**BM**	**J**	**NE**	**NL**	**P**	**S**	**W**
Break Fault Level	0	0	3	0	5	5	3	0
Make fault level	0	0	5	3	3	5	5	0
Total site physical suitability	7	4	8	5	7	9	6	8
Impact on DPCR5 Planned work	5	5	4	5	4	5	0	5
Total National Grid interaction risk	5	5	0	3	0	0	3	3
Potential Head room created	2	2	4	5	4	3	3	3
Total site General attractiveness	**19**	**16**	**24**	**21**	**23**	**27**	**17**	**16**
Additional score for Bus Section	5	5	1	5	1	0	5	5

Transformer Tail

From the analysis, the Pitsmoor 3&4 site would also prove the best site for a transformer tail application followed by Jordanthorpe and Norton. Since a transformer tail application has a large interaction with National Grid, the risk to the project is higher than with a bus section installation or on a CE owned site. Attercliffe is the best CE only site for a transformer tail were this option be needed, however it scores low on fault level issue and head room created.

Bus Section

Neepsend is evaluated at the best site for a bus tie installation. It has a relatively low physical site suitability since it has a flood risk on this site from the River Don. Due to planned DPCR5 work (Sheffield City), lack of fault level issue and space (Wincobank) and the requirement to extend the board at Jordanthorpe and Norton Lees, the next best alternative is the CE site at Attercliffe.

National Grid Interfaces

Introduction

Assuming that a Grid Supply Point site is selected, there will have to be interaction with National Grid. This is advantageous since it is the Grid Supply Point Sites that have fault level issues, the highest generation connection capacity to be delivered by the fault current limiter and there will be other sites around the UK where similar issues are likely to arise. Given that these sites meet more of the objectives of LCN Fund projects, it seems reasonable to explore the possibility of being able to resolve these issues as part of this project. The following sections identify some of the potential interface issues that are likely to occur.

Site ownership

The Grid Supply points are largely (if not exclusively) owned by National Grid. To facilitate a 33kV fault current limiter, a footprint of approximately 9m x 5m will be required. Assuming a security fence is also required then 13m x 9m will be needed to create the required clearances. How the use of this land and access/egress for the duration of the project is secured will need to be agreed between the companies' estates departments and their legal teams.

National Grid planned work

National Grid may have work planned for these sites. This may have a material impact of the decision as to which site the trial should be conducted. An initial assessment of the Seven Year Statement did not identify any major works.

Asset ownership

The SGT, 33kV transformer tail and 33kV transformer circuit breaker up to the point of the clamp onto the 33kV busbars are owned by National Grid. If the solution were to install a new 33kV board between the SGT and existing 33kV transformer circuit breaker there will be a need to make a formal Modification Application to address the creation of the new ownership boundary, termination changes and new exit charges. Funding for the new 33kV transformer circuit breaker will also need to be considered.

Control / indication of CE Equipment

If either style of application (bus section or transformer tail) is chosen, National Grid may have the right to receive status indication or possibly control of the 33kV bus section circuit breaker. Any such rights may need to be amended in the new scheme.

Protection

Reducing fault current flowing from one transformer will result in an increased operating time of most types of protection. Further, the variable impedance of the fault current limiter could affect some types of protection schemes (e.g. Distance protection, although it is not expected that it will fitted to these boards). Inserting the Fault Current Limiter into a transformer tail will necessitate the moving of most of the protection functions to the new transformer circuit breaker and board; Additional protection will be needed to protect the existing networks from a Fault Current Limiter induced fault. The latter will almost certainly be some sort of unit protection scheme.

Control

Definition of the control requirements of the new scheme will need to be identified. This could include the monitoring of circuit new breakers, the operation (e.g. trip or close inhibit) of new breakers and of course changes to SCADA. Control procedures will also need to be written and some form of training of control room staff could also be necessary.

Testing

The type testing for industry acceptance of SFCL technologies is an emerging art and this exercise will help to determine what the various parties (notably National Grid and Distribution Network companies) expect in terms of proving the fitness for purpose of SFCL devices. ASL has experience with DNOs in determining test programmes and then performing these tests, on resistive and pre-saturated core SFCLs as part of the three pilot installations currently in progress on the 11kV networks in Electricity North West, Scottish Power and CE-Electric. One unit (Electricity North West) has undergone full-scale short-circuit, voltage withstand and thermal testing, conducted at IPH Berlin and at NaREC. It has been in service in the Bamber Bridge primary for one year (all systems running) and for three months (live and carrying load current). ASL will propose tests where possible in line with the recommendations of document 239 of CIGRE WG A3.10.

Working with National Grid

Within this project, even if the impact of the chosen site on National Grid is minimal, it is hoped that understanding the internal processes, requirements, standards, safety systems and other practical requirements, e.g. site access or safety systems type to adopted when working with National Grid will be an outcome of this project.

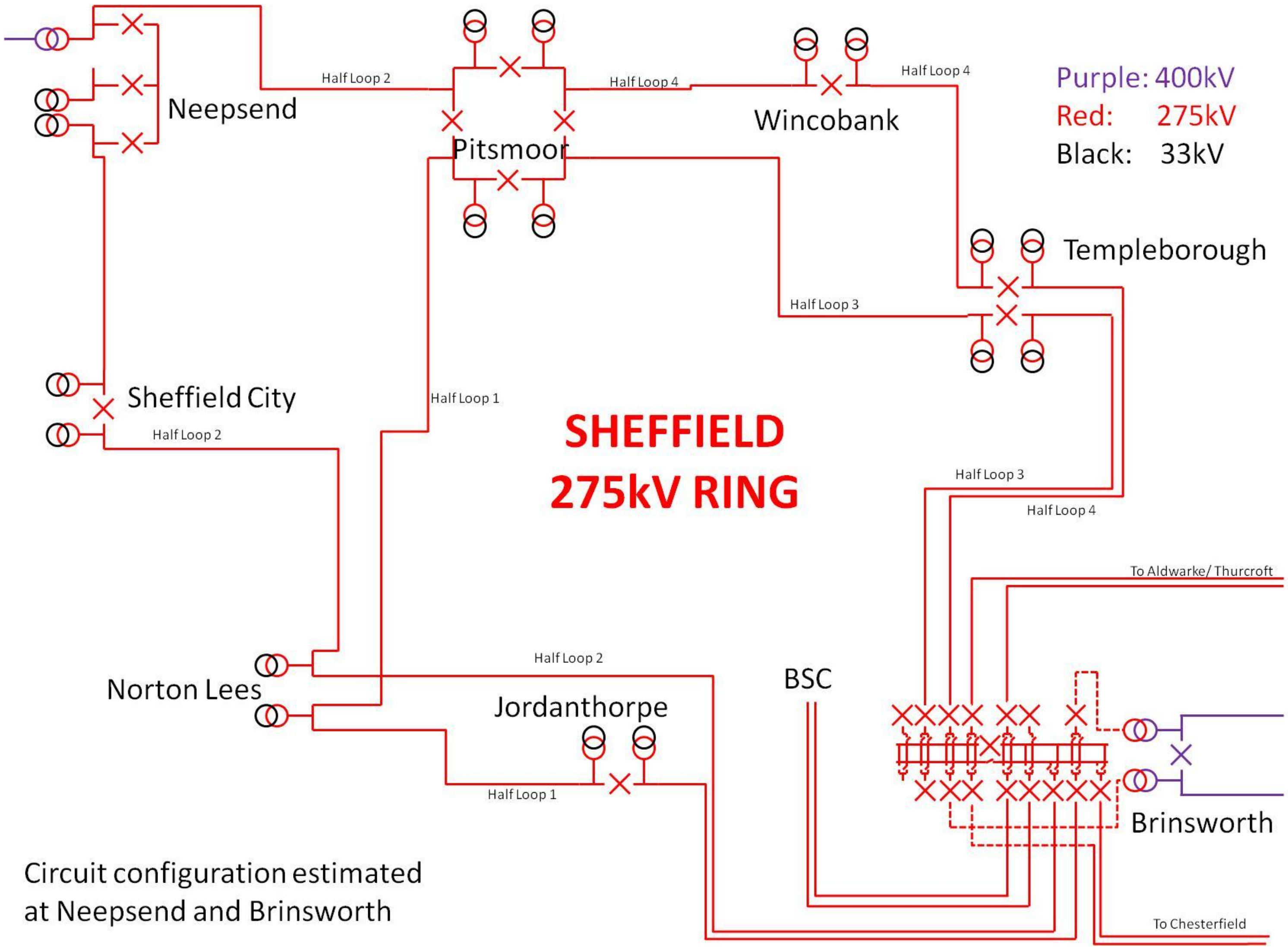
Transformer reverse flow capability

While this scheme is a demonstration of the technology and no additional generation is expected to connect to the substation as part of this project, other constraints to the practical connection of generation probably exist. One of these could be the reverse flow of energy from the Grid transformer. Others, such as voltage control could also exist and this project would hope to identify these issues and find ways of addressing them.

Meeting expectations

This paper has been written as a briefing document to support a meeting to be held between National Grid and CE Electric with support from Applied Superconductor on the 28th October 2010. During that meeting we hope to discuss the sites and technology with the expectation that potential barriers to the deployment of this technology on Grid Supply Points will be identified and plans to address, overcome or circumnavigate those barriers will be made.

Appendix 1



Circuit configuration estimated at Neepsend and Brinsworth

Applied Superconductor

LCN Fund Project

Current Solutions for Future Networks

Agenda

LCNF Project background

ASL Introduction

Technology Introduction - Fault Current Limiters (FCL)

FCL Connection possibilities

Impact on NGET activities, network, planning,...

Next steps

LCNF Project background

LCNF Project background

Ofgem has set up a Low Carbon Networks Fund to allow support to projects sponsored by the DNOs to try out new technology, operating and commercial arrangements.

The objective of the projects is to help all DNOs understand what they need to do to provide security of supply at value for money as Great Britain moves to a low carbon economy.

The Fund will involve the DNOs partnering with suppliers, generators, technology providers and other parties to explore how networks can facilitate the take up of low carbon local generation

One of the barriers to connecting generation to networks is Fault Level.

Sheffield has a number of 33kV substations with Fault Level issues, six fed by the 275kV transmission network and two from the CE 132kV network (which don’t have particular fault level issues).

CE have initiated a LCN Fund project to demonstrate how Fault Current Limiters can facilitate the connection of generation on these sites.

ASL Company history

Applied Superconductor

DNO IFI Consortium

A consortium of 3 DNOs was formed in 2006 to undertake trial installations of 3 11kV fault current limiters, to be supplied by Applied Superconductor, one in each DNO's area.

Building on this experience and the knowledge gained, CE have launched a 33kV project to look at solving problems in the Sheffield Area.

Fault Current Limiting

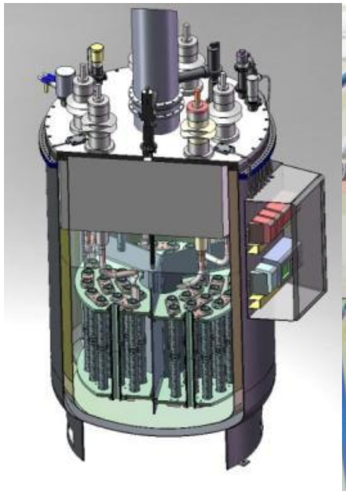
Key characteristics of Fault Current Limiters based on superconducting materials

- Under normal operation a fault current limiter inserts negligible impedance into the network
- When a fault occurs the limiter‘s impedance rises rapidly, reducing the current flowing through it

There are currently two main approaches to fault current limitation utilising superconducting materials

- Resistive where the superconductor carries load current
- Inductive using a pre-saturated iron core, the core driven into saturation using a superconducting winding.

First for UK – Live Oct 09



INSTITUT „PRÜFFELD FÜR ELEKTRISCHE HOCHLEISTUNGSTECHNIK" GMBH IPH

Independent, accredited testing station Member laboratory of STL and LOVAG

TEST REPORT

NO. 3051.2080794.652

Applied Superconductor Ltd
Eddie Ferguson House
Ridley Street
Blyth NE24 3AG
United Kingdom
CLIENT

Applied Superconductor Ltd — MANUFACTURER

High-temperature superconducting fault current limiter — TEST OBJECT

SFCL — TYPE

Test sample — SERIAL NO.

RATED CHARACTERISTICS GIVEN BY THE CLIENT

Rated voltage	U_r	12	kV
Rated short-duration power-frequency withstand voltage	U_d	28	kV
Rated lightning impulse withstand voltage	U_p	95	kV
Rated normal current	I_r	100	A
Rated peak withstand current	I_p	50	kA
Rated short-time withstand current	I_k	20	kA
Maximum duration of short-circuit	t_k	0.12	s

As required by the client and on the basis of
IEC 62271-100: 2008-04
IEC 62271-1: 2007-10
NORMATIVE DOCUMENT

- Dielectric tests
- Short-circuit tests with a prospective value of 100%, 60%, 30% and 10% of the rated short-time withstand current

RANGE OF TESTS PERFORMED

22 and 23 September 2008 — DATE OF TEST

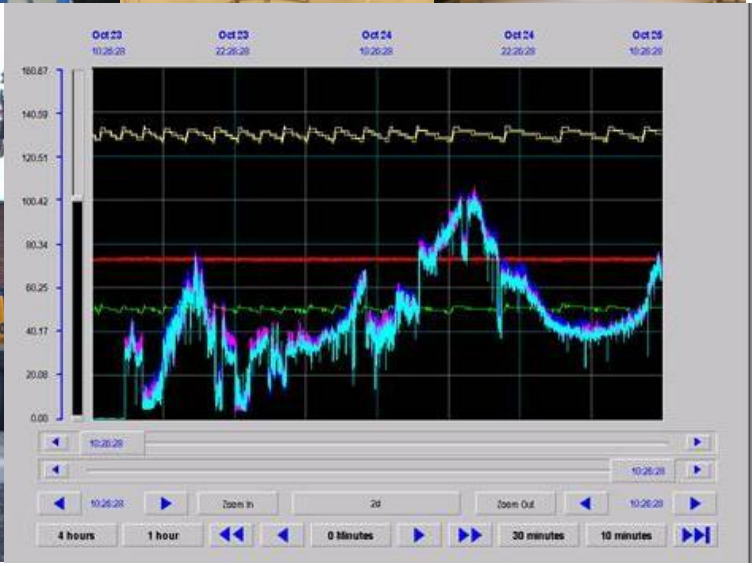
See Sub-clauses 4.6 and 5.6 — TEST RESULT

H. GLAUBITZ
Head of high-power test laboratory
Berlin, 31 October 2008

M. THOM
Test engineer in charge

DAT - P - 019/92

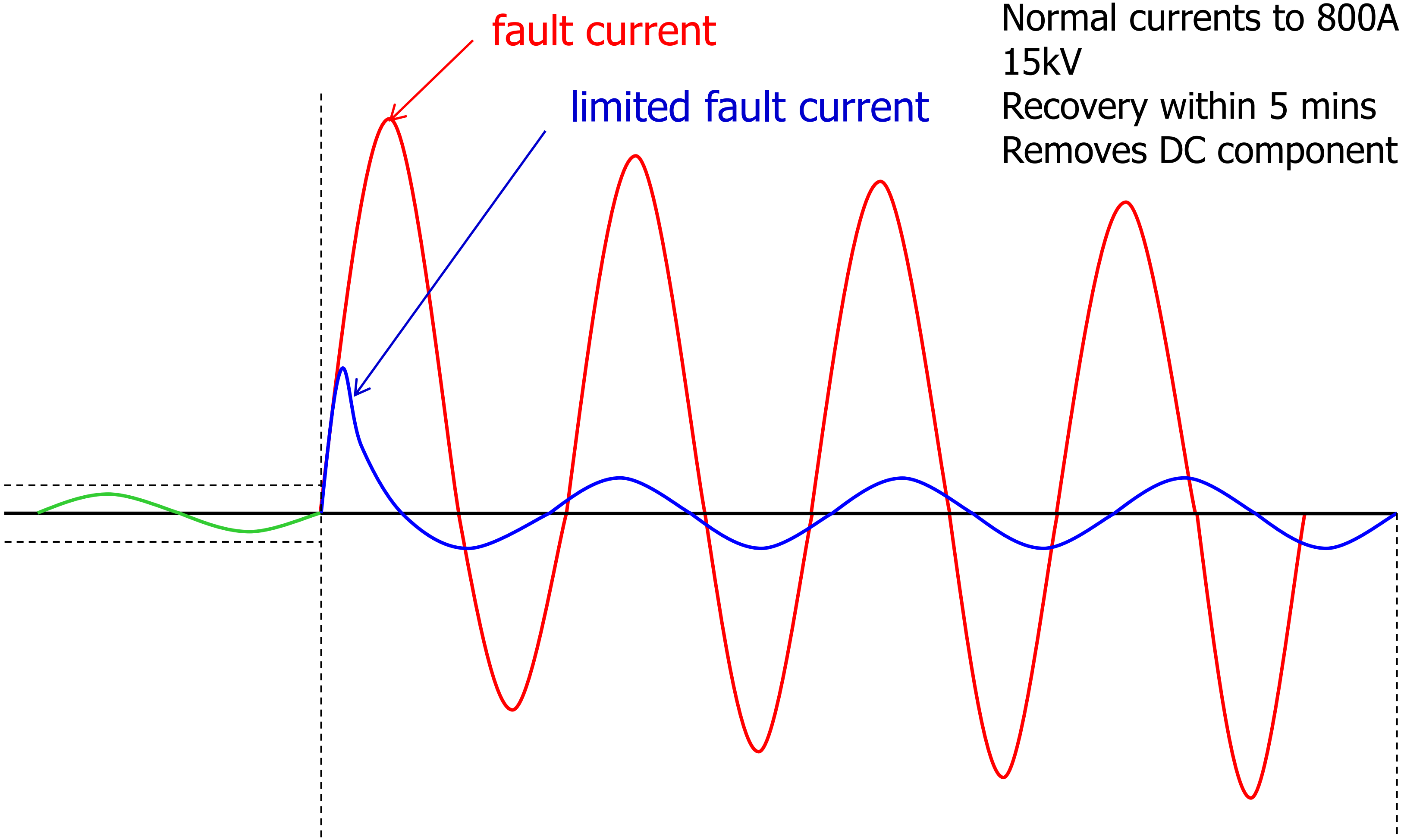
IPH · LANDSBERGER ALLEE 378 · D-12681 BERLIN · TEL. 030/54 96 02 00 FAX 030/54 96 02 22



Resistive FCL - Limiting Behaviour

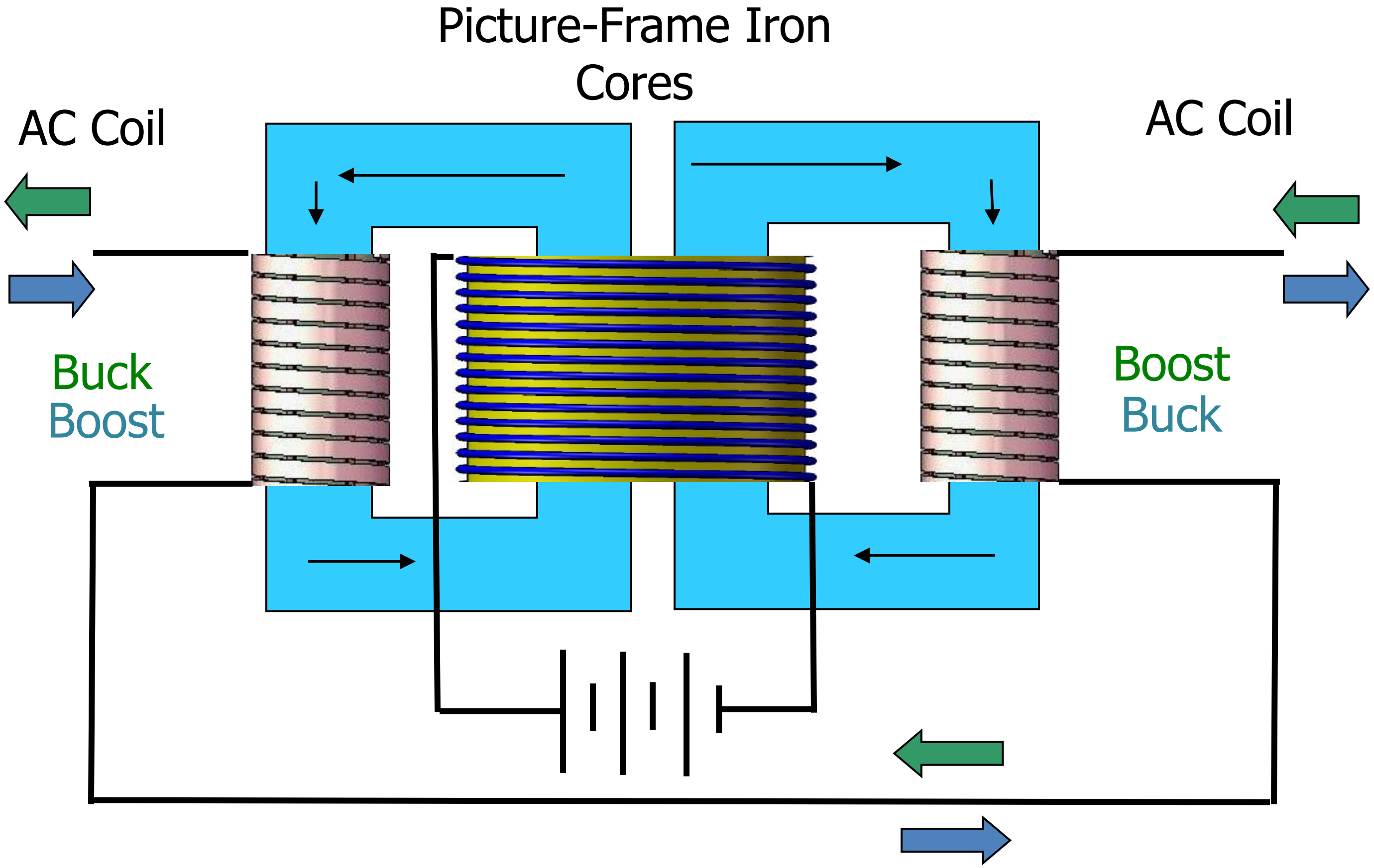
Applied Superconductor

Up to 90% clamping
Clamps within 1.5 ms
Normal currents to 800A at 15kV
Recovery within 5 mins
Removes DC component

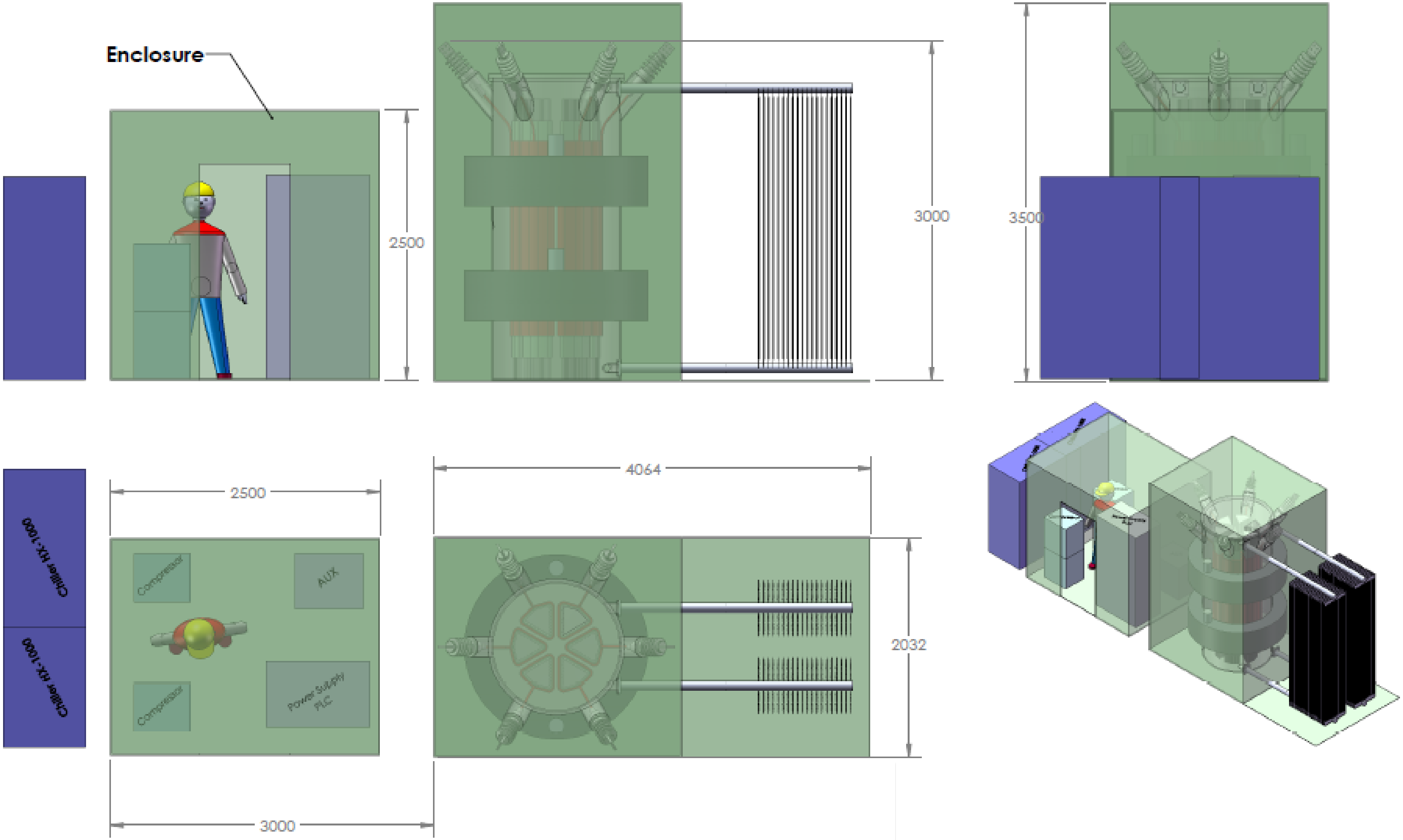


Saturated Core FCL

Applied Superconductor



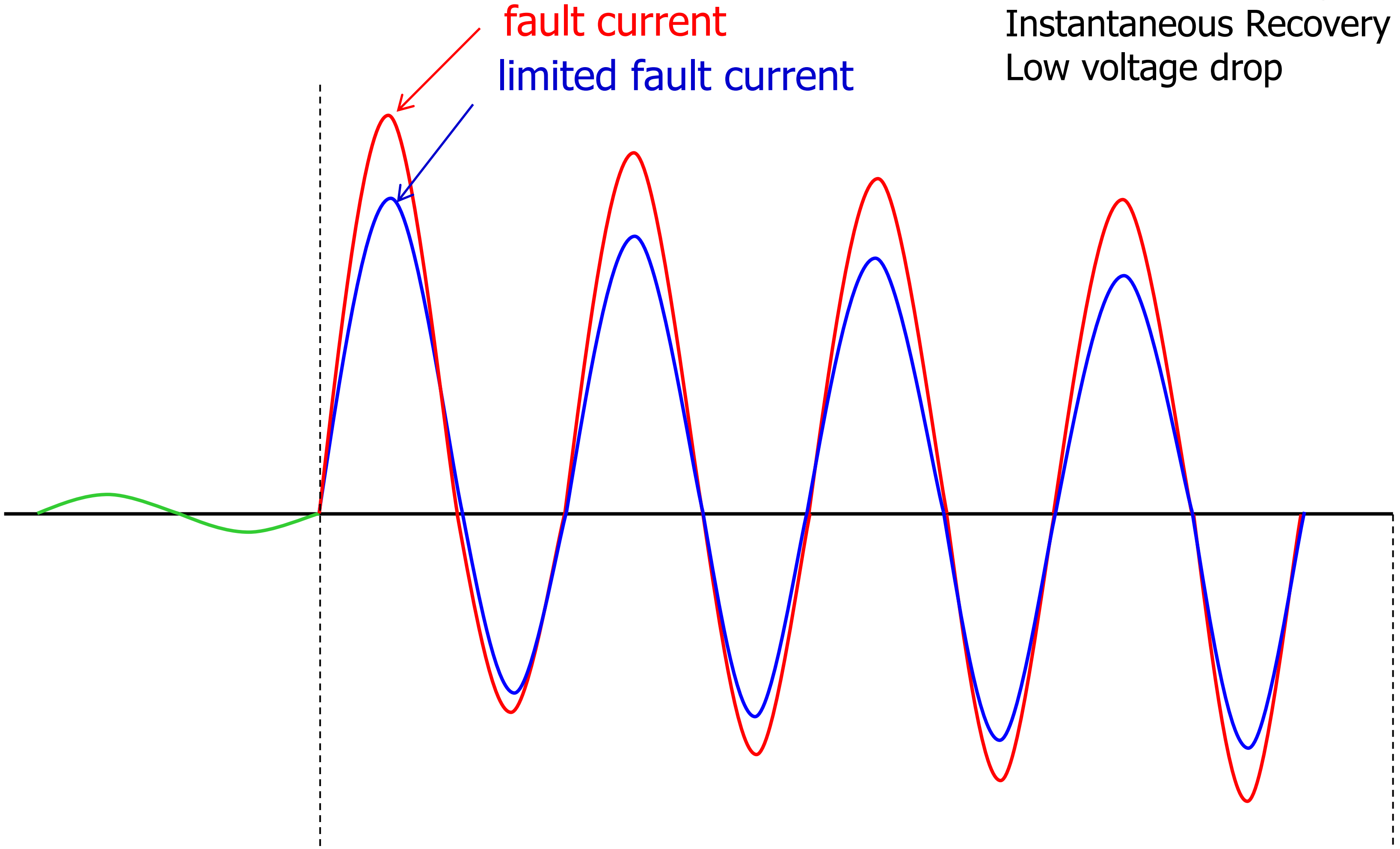
Pre-saturated core FCL



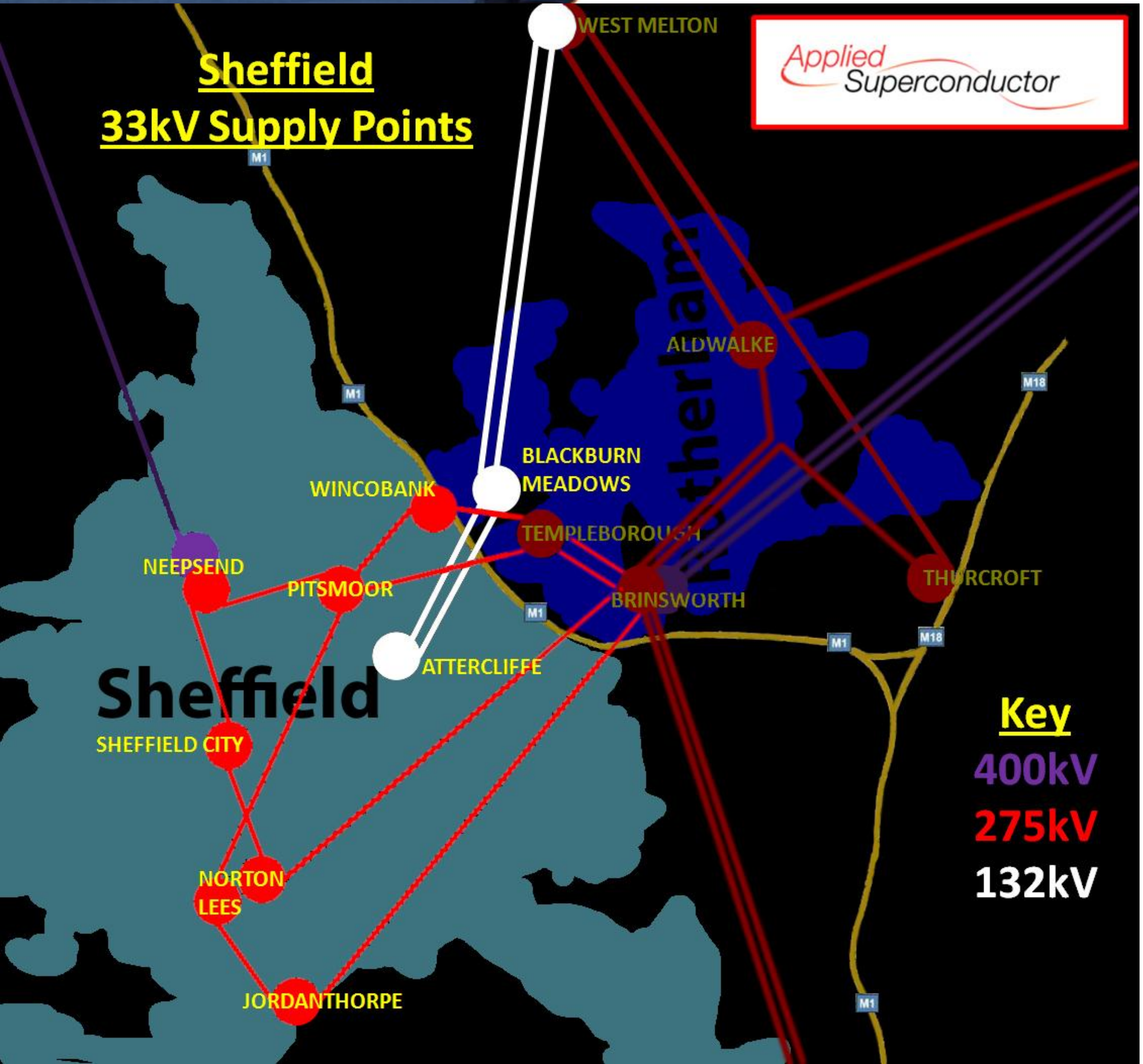
Sat Core FCL - Limiting Behaviour

Applied Superconductor

Up to 50% clamping
Instantaneous Recovery
Low voltage drop



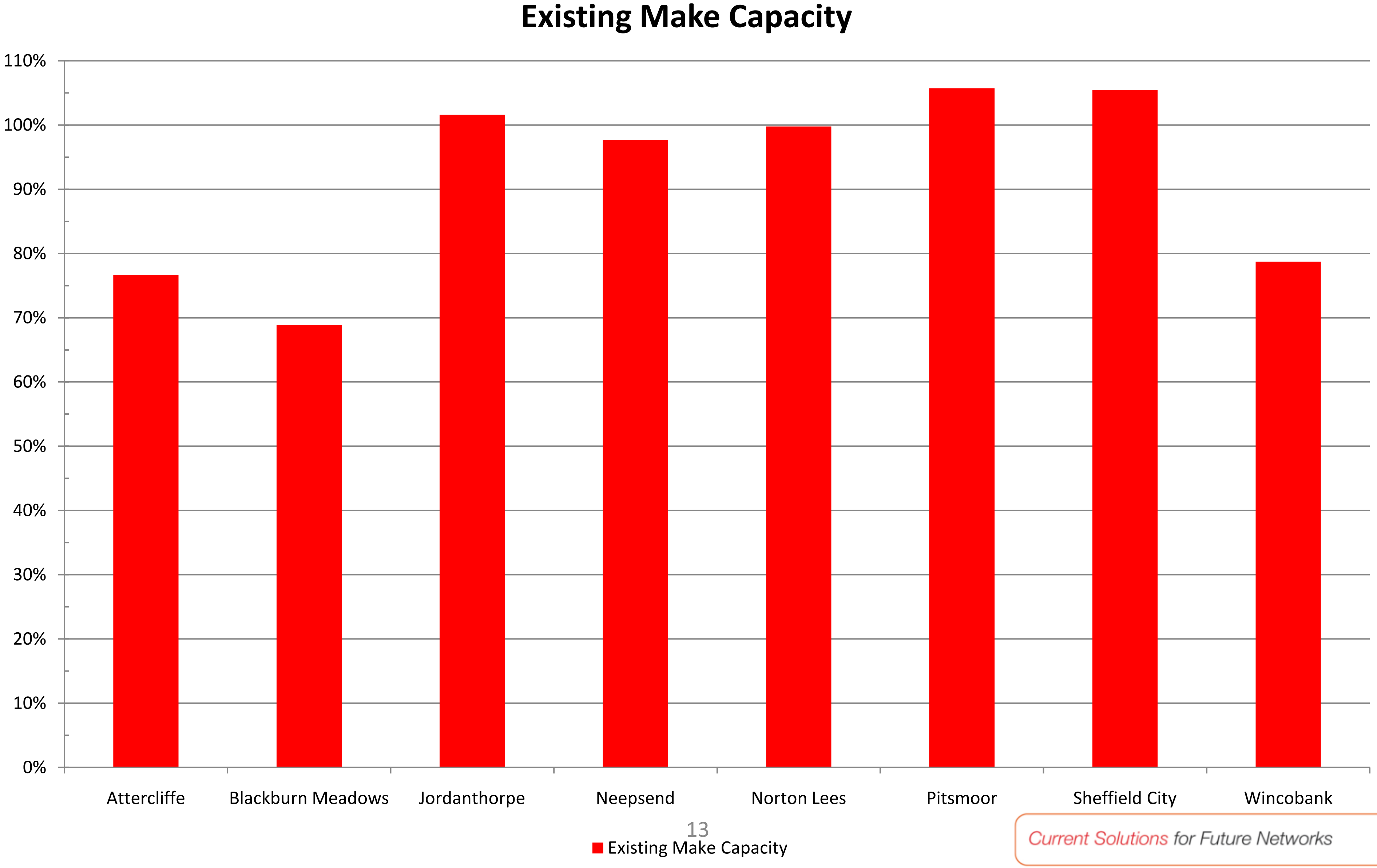
Sheffield 33kV supply points



Switchgear Headroom

Applied Superconductor

% utilisation of boards fault level make capability

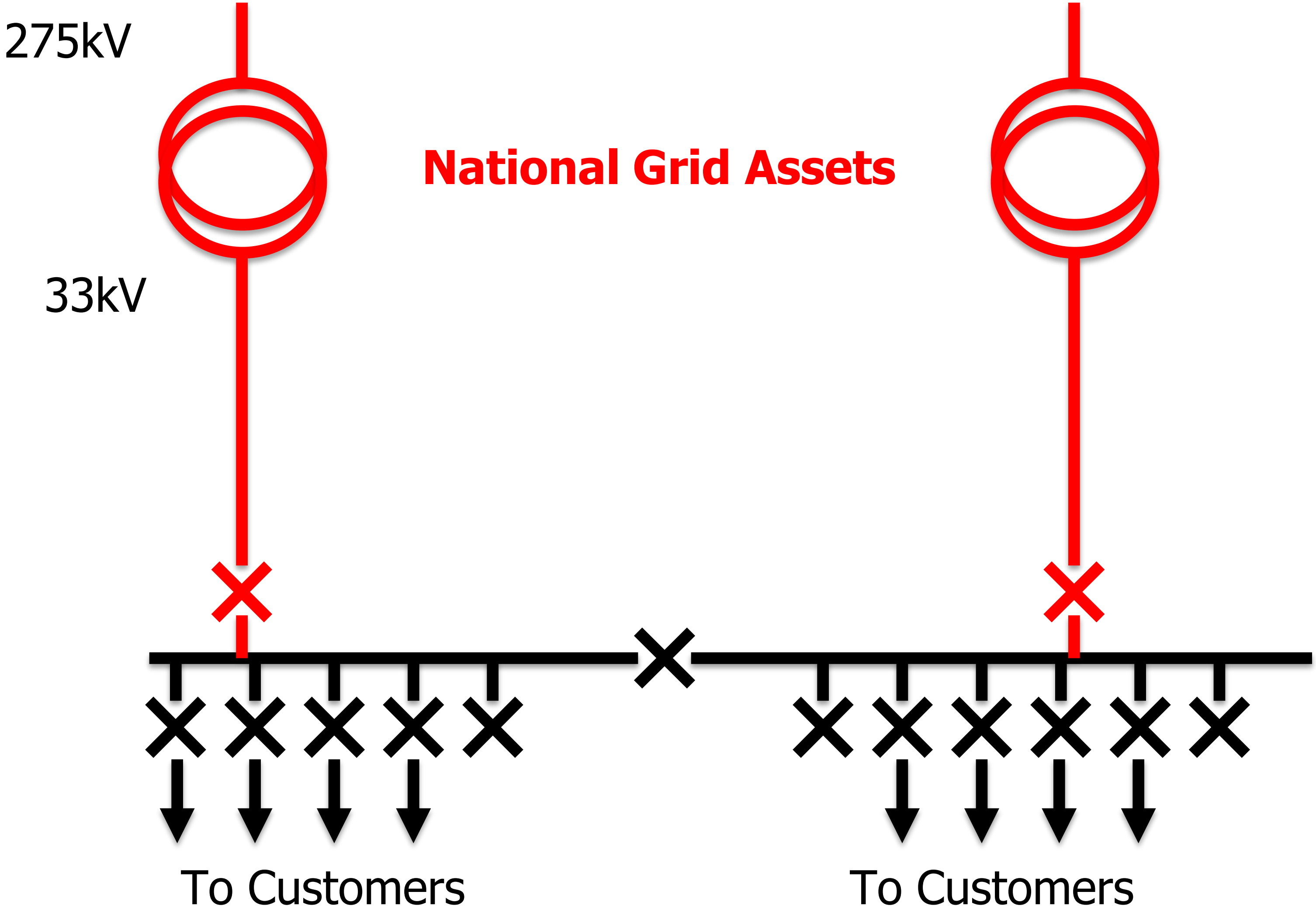


Site visit summary

Applied Superconductor

Site	Space	Fault Level % Make	Fault Level % Break	Board Type	Other
Blackburn Meadows	Tight - probably in transformer compound	68.7	63.6	Reyrolle L42	YEDL Site. Known flood risk. Unused switch lying on floor at end of bus bar
Wincobank	Tight	78.7	69.9	GEC (AEI?)	YEDL/NGC Site
Pitsmoor 3&4	Space	105.7	95.5	South Wales Switchgear	YEDL/NGC Site
Attercliffe	Space in car park	76.6	70.7	Ferguson Pailin	YEDL Site
Neepsend	Space in surrounding area	97.7	81.3	AEI VSLP	YEDL Site. Known flood risk
Sheffield City	No	105.5	90.7	Reyrolle L42	YEDL/NGC Site. Already nominated for upgrade
Norton Lees	Under Trees	99.2	95.5	AEI VSLP	YEDL/NGC Site
Jordanthorpe	Space	101.6	89.4	AEI VSLP	YEDL/NGC Site

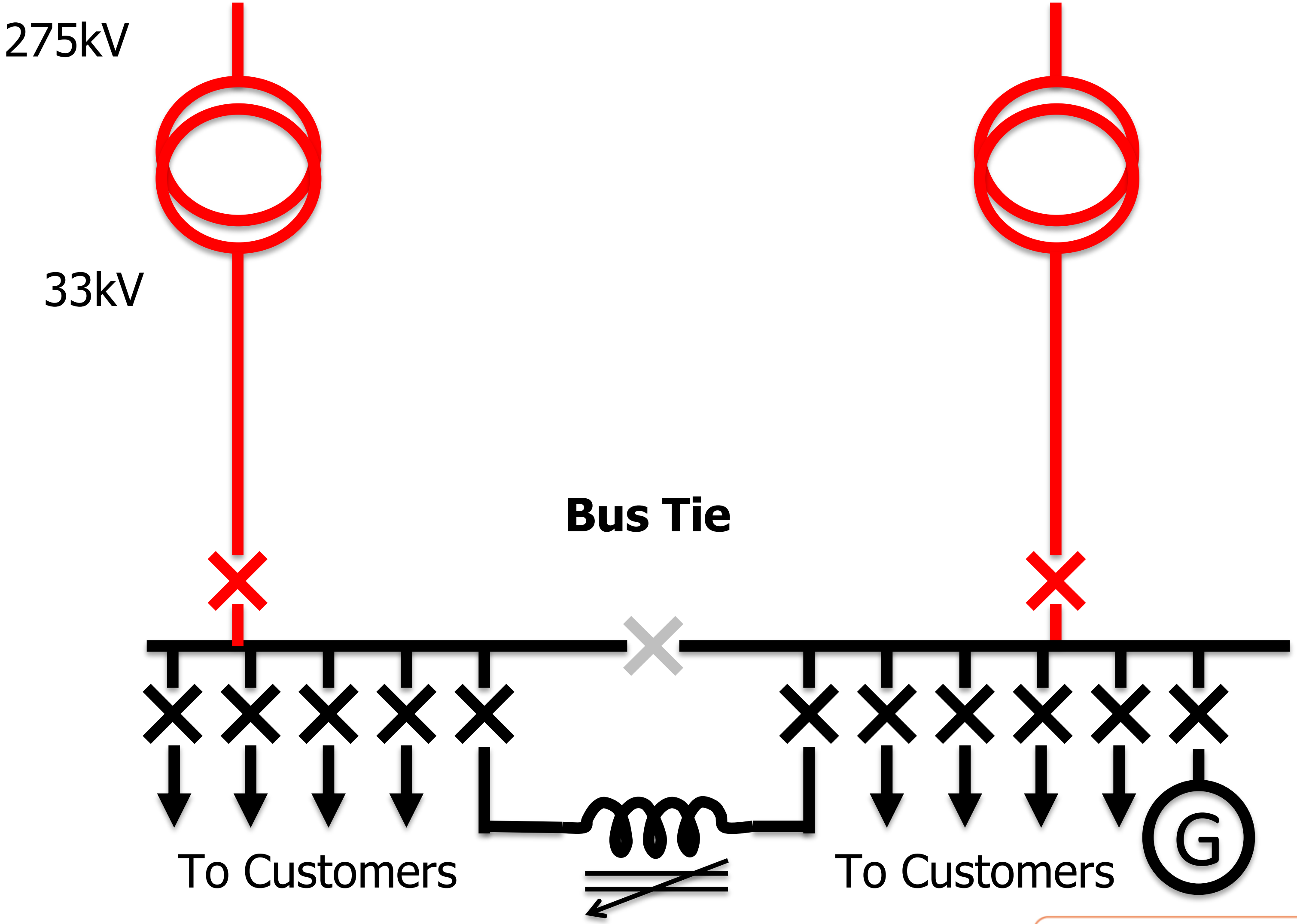
FCL Connection possibilities



FCL Connection possibilities

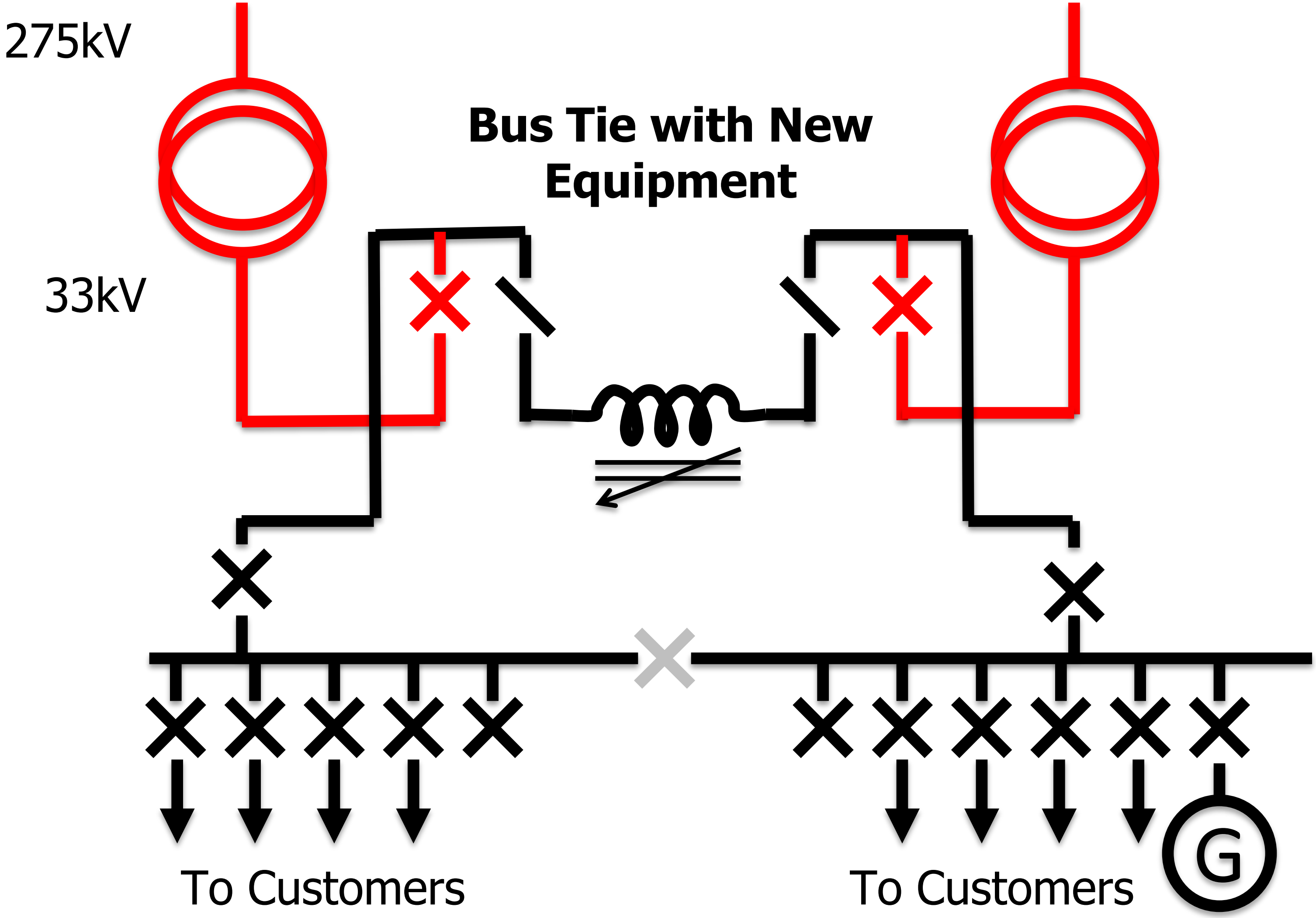
Applied Superconductor

Headroom created approx 20%



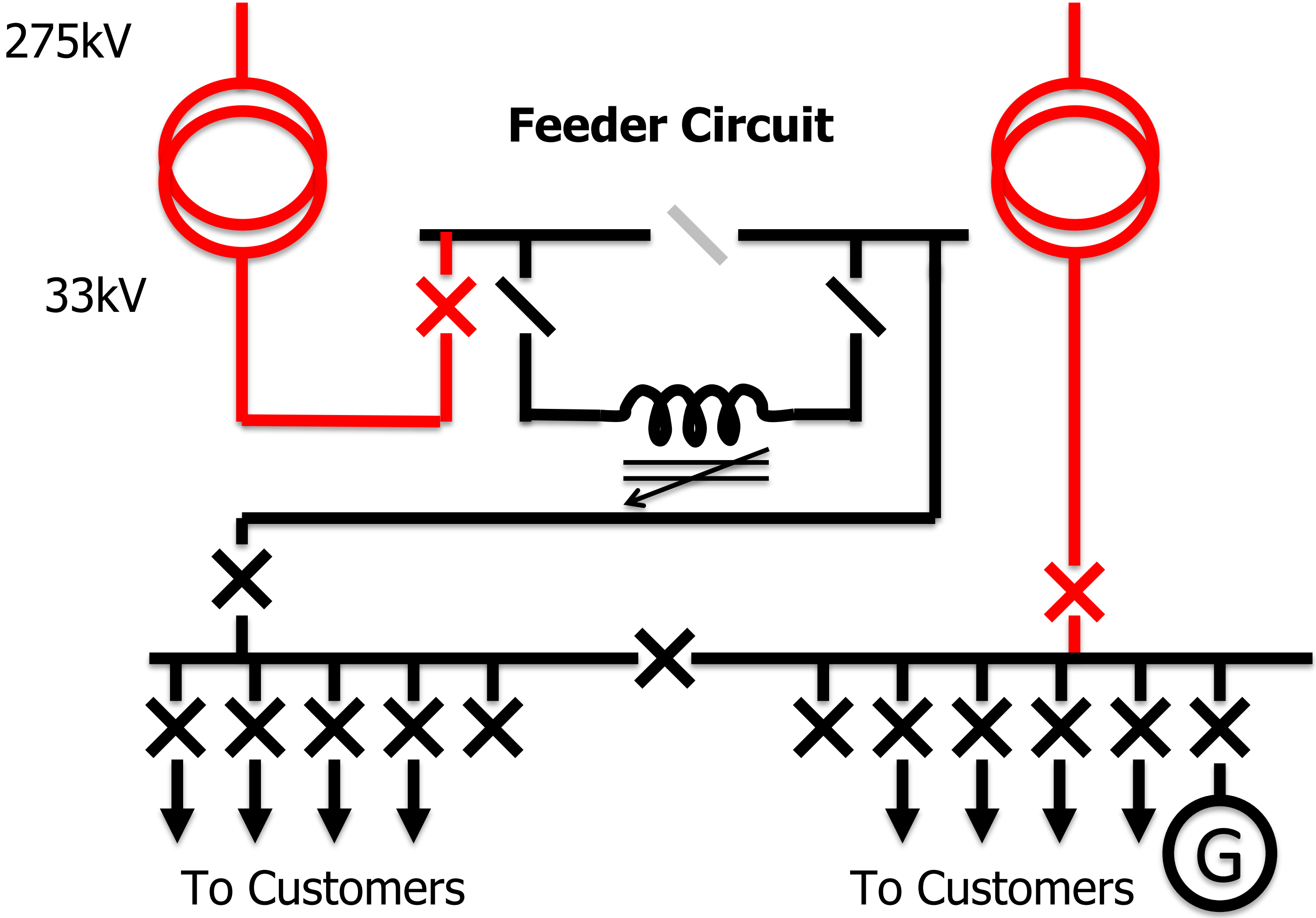
FCL Connection possibilities

Headroom created approx 20%



FCL Connection possibilities

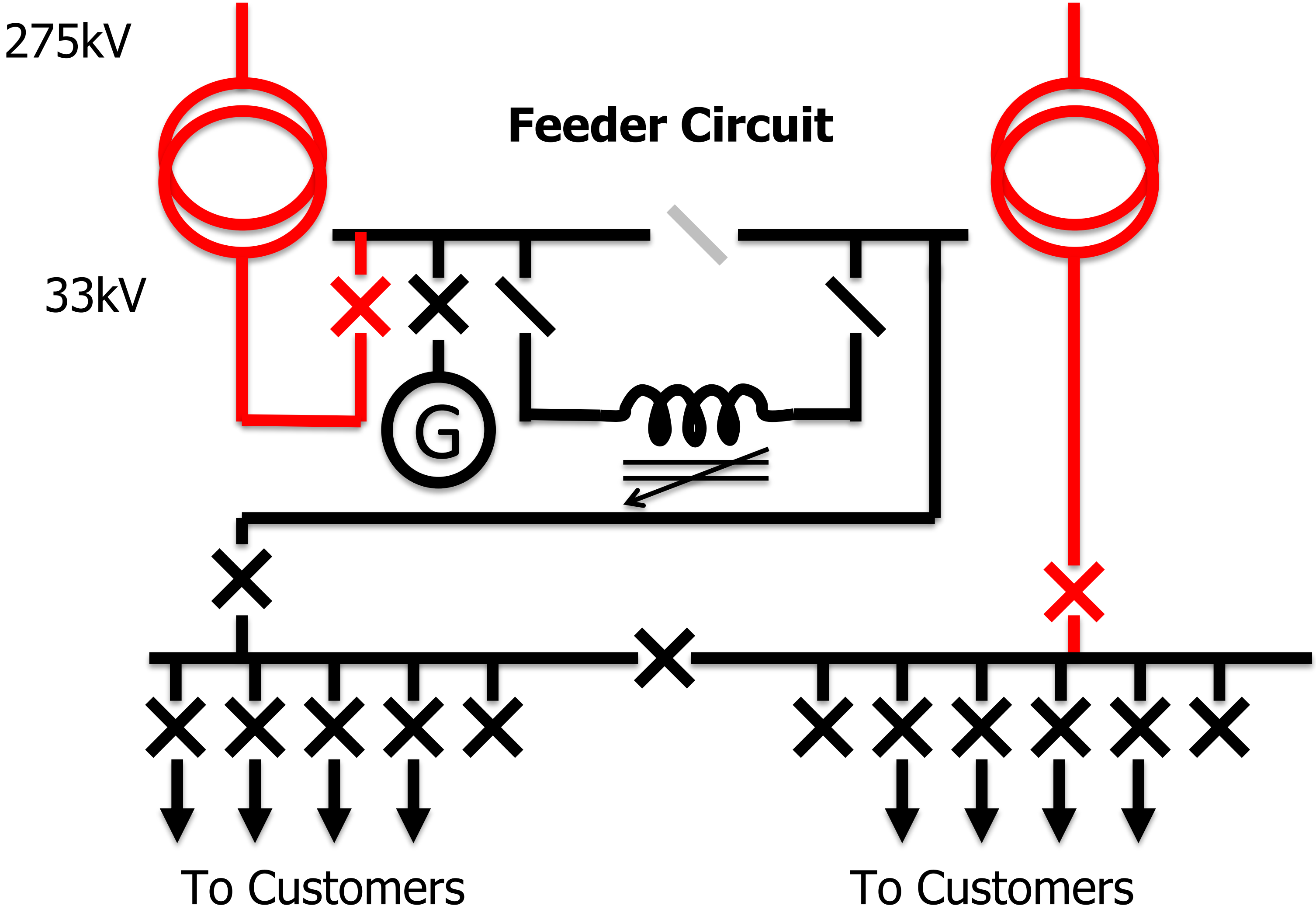
Headroom created approx 16-18%



FCL Connection possibilities

Applied Superconductor

Effective Headroom created approx 26-30%

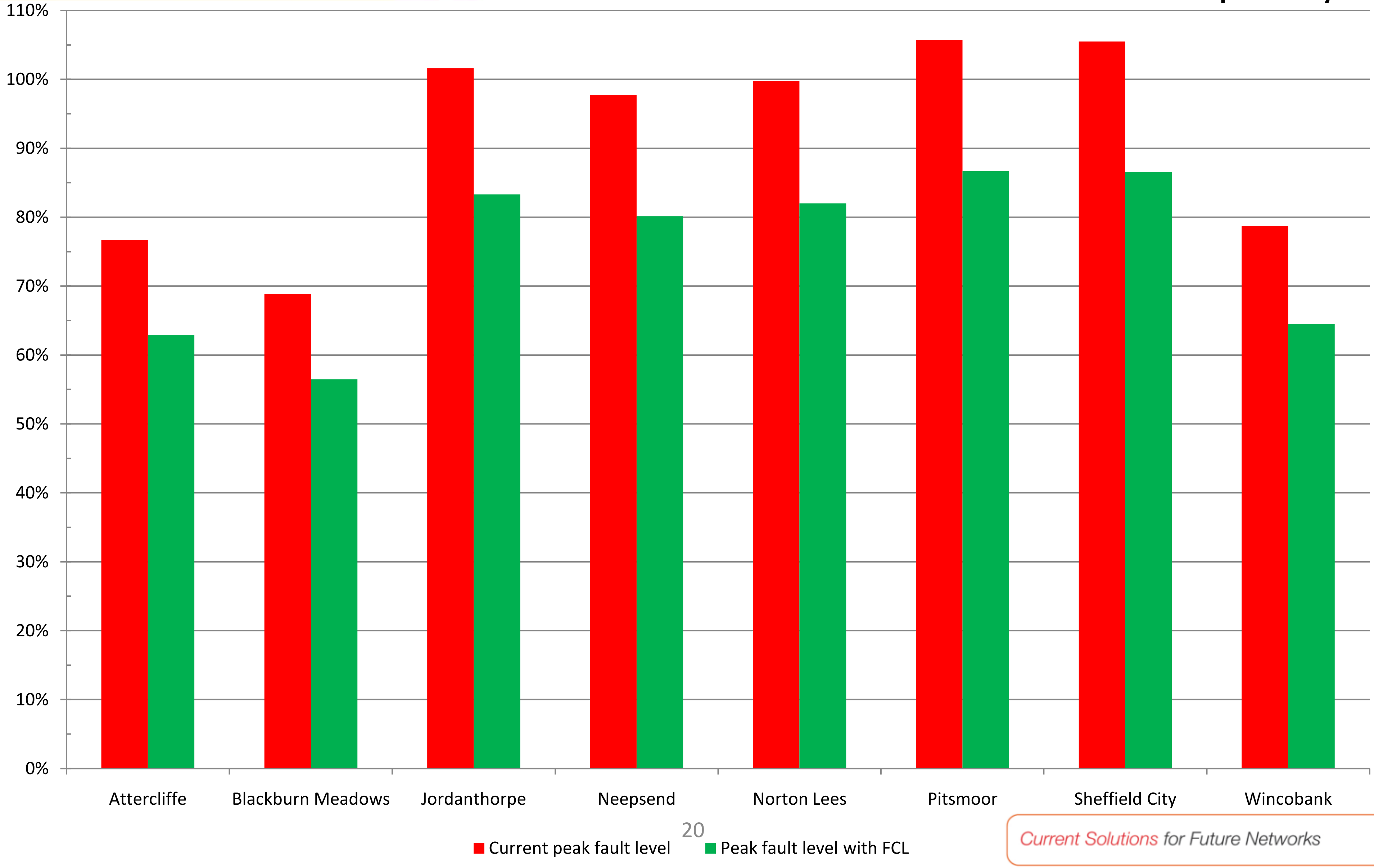


Current Solutions for Future Networks

Switchgear Headroom

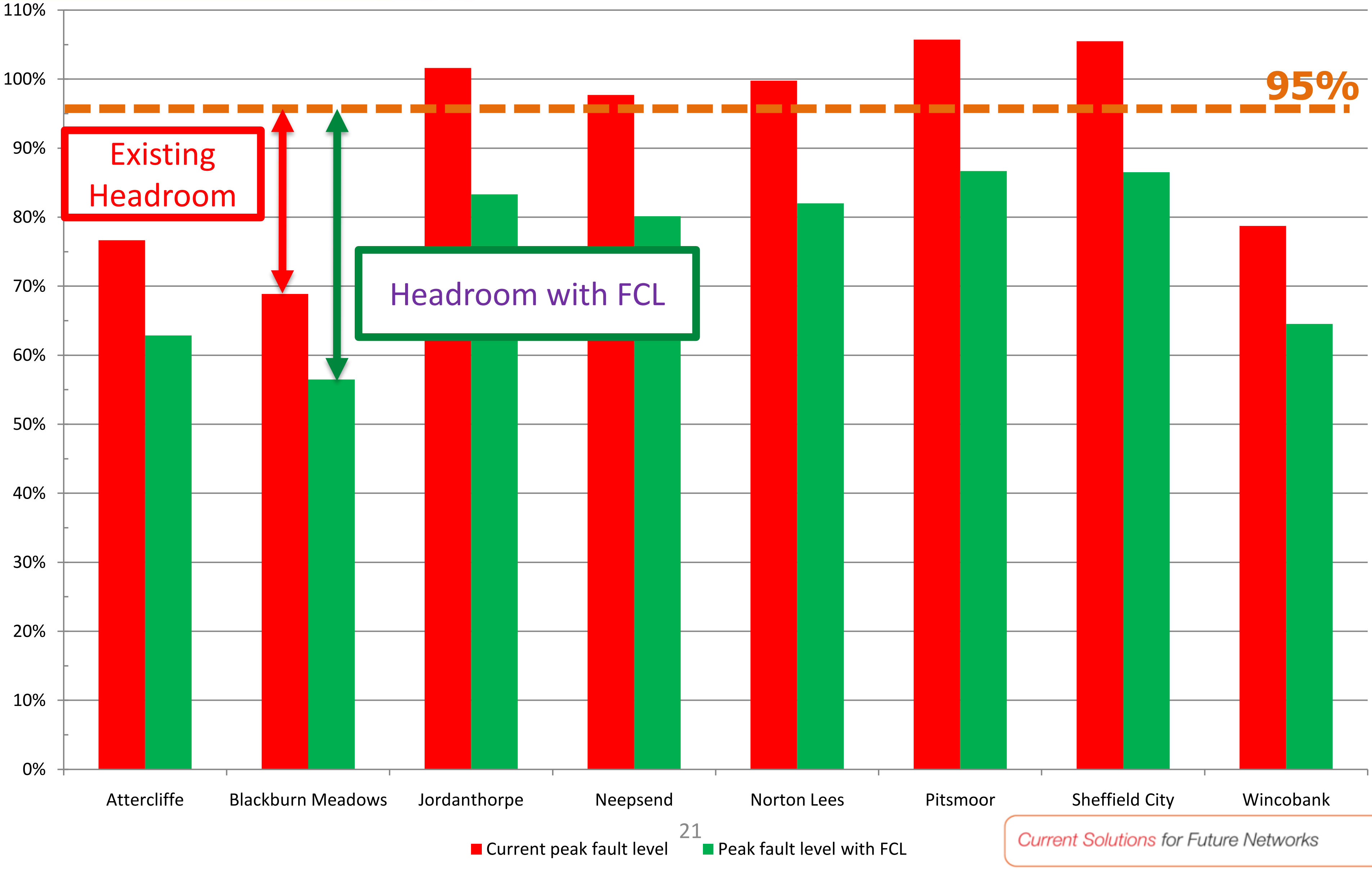
Applied Superconductor

% utilisation of boards fault level make capability



Generator connection headroom

Applied Superconductor



Generator Connection Capability

(in MVA)	Synchronous Generator		Doubly Fed Induction Generator		Converter connected Generator	
	Existing	With FCL	Existing	With FCL	Existing	With FCL
Attercliffe	27.3	60.0	60.0	60.0	60.0	60.0
Blackburn Meadows	38.8	60.0	60.0	60.0	60.0	60.0
Jordanthorpe	0	29.0	0	86.9	0	100.0
Neepsend	0	36.9	0	110.6	0	120.0
Norton Lees	0	15.5	0	46.4	0	100.0
Pitsmoor	0	20.6	0	61.8	0	100.0
Sheffield City	0	21.1	0	63.2	0	100.0
Wincobank	24.2	75.5	72.6	100.0	100.0	100.0

Assumptions: 40% clamping ratio of both one transformer and the generator. Fault current 45% from each transformer; 10% from Network

Max Generator size limited by thermal capacity of the transformer, since all board incomers rated at 2000A (120MVA)

Generator contribution (multiplier of load current): 16.8x (make) / 6x (break) Synchronous, 6x /2x DFIG 1.2x /1.2x Converter

National Grid Engagement

1) Selection of best site

2) Identification of project risks

- Safety
- Asset Ownership
- Protection
- Costs
- Site Ownership
- Testing
- Planned Work
- Transformer Reverse Flow Capability
- Control inc Voltage control
- Timescales
- Control / Indication over CE equipment

3) Activities to reduce risk

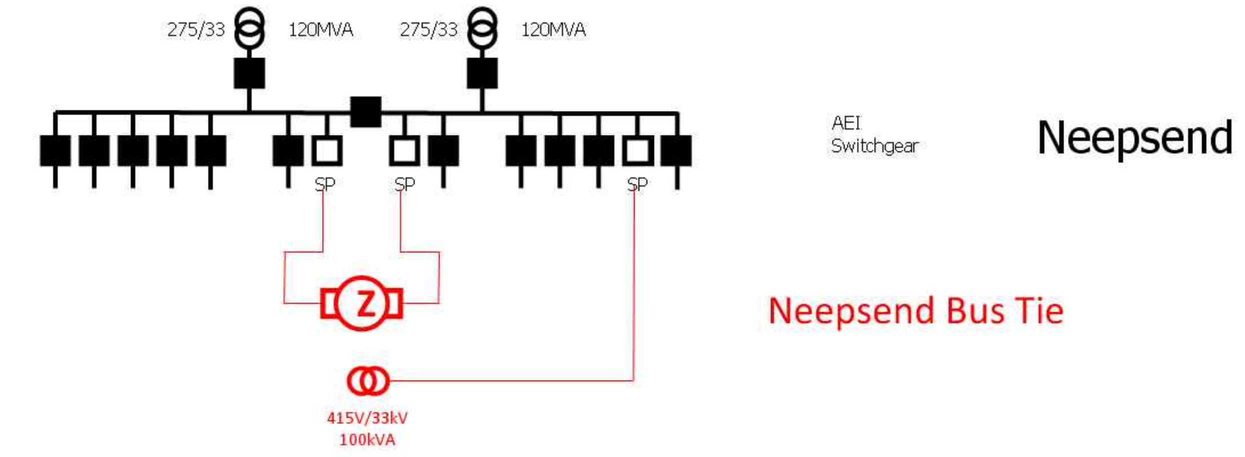
Next Steps

Comments

Questions

Actions

ALL DIMENSIONS ARE IN MILLIMETRES



ADDITIONAL CABLE LENGTHS (INCLUDING 10M ALLOWANCE FOR BENDS) :

AUXILIARY SUPPLY	56.2M
FCL - T1	20.4M
FCL - T2	17.9M
TOTAL	94.5M

🟥	ADDITIONAL CABLE
■	AUXILIARY TRANSFORMER
▬	AUXILIARY ENCLOSURE
✚	FAULT CURRENT LIMITER

NEEPSEND - BUS TIE

REVISION HISTORY

REV	DESCRIPTION	DATE
1		8/10/10

Applied Superconductor

EDDIE FERGUSON HOUSE
RIDLEY STREET
BLYTH
NORTHUMBERLAND
NE24 3AG

GENERAL TOLERANCES
(UNLESS OTHERWISE STATED)

DIM	>0.5-3	3-6	>6-30	>30-120	>120-400	>400-1000
TOL	Ñ0.1	Ñ0.1	Ñ0.2	Ñ0.3	Ñ0.5	Ñ0.8

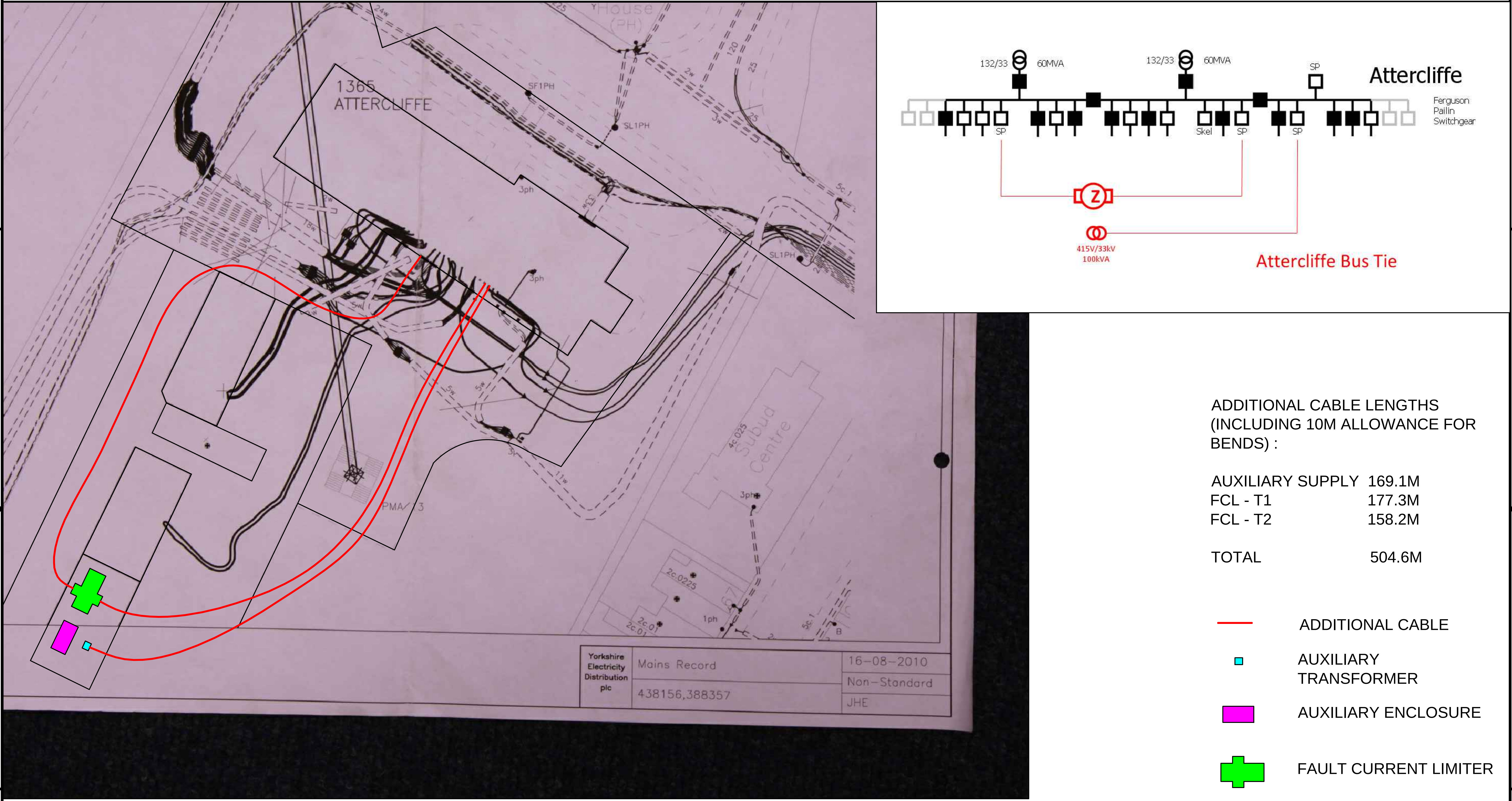
ANGLE Ñ0.5Â

SCALE	N.T.S.
DESIGNED	D.J.C.
CHECKED	A.W.

TITLE FCL CONNECTION PROPOSALS - SHEFFIELD 33KV SITES

DATE	SHEET SIZE	DRG No.	SHEET
8/10/10	A3	SK011	1/6

ALL DIMENSIONS ARE IN MILLIMETRES



ADDITIONAL CABLE LENGTHS (INCLUDING 10M ALLOWANCE FOR BENDS) :

AUXILIARY SUPPLY	169.1M
FCL - T1	177.3M
FCL - T2	158.2M
TOTAL	504.6M

🟥	ADDITIONAL CABLE
■	AUXILIARY TRANSFORMER
■	AUXILIARY ENCLOSURE
✚	FAULT CURRENT LIMITER

ATTERCLIFFE - BUS TIE

REVISION HISTORY

REV	DESCRIPTION	DATE
1		8/10/10

Applied Superconductor

EDDIE FERGUSON HOUSE
RIDLEY STREET
BLYTH
NORTHUMBERLAND
NE24 3AG

GENERAL TOLERANCES
(UNLESS OTHERWISE STATED)

DIM	>0.5-3	3-6	>6-30	>30-120	>120-400	>400-1000
TOL	Ñ0.1	Ñ0.1	Ñ0.2	Ñ0.3	Ñ0.5	Ñ0.8

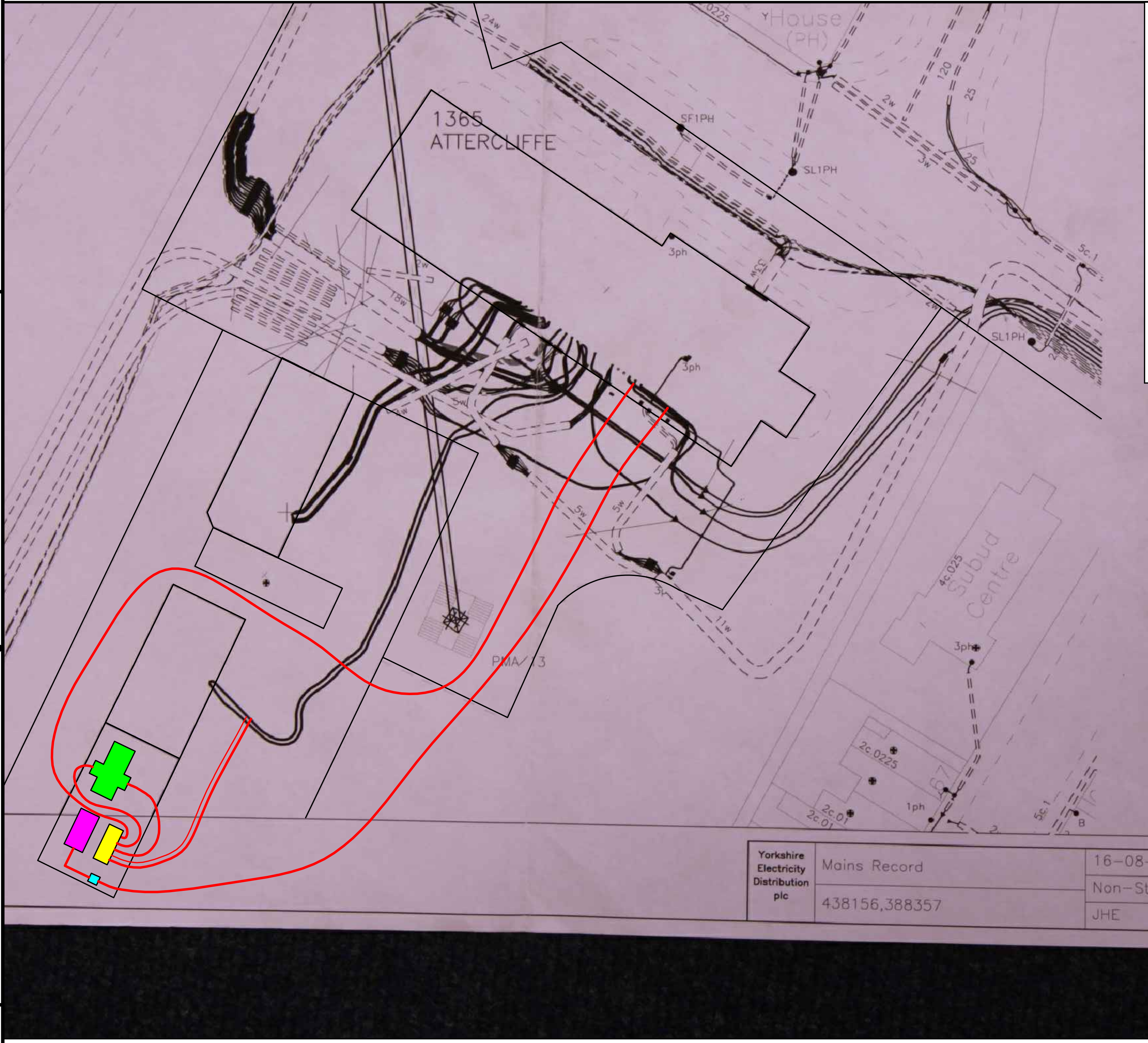
ANGLE Ñ0.5Â

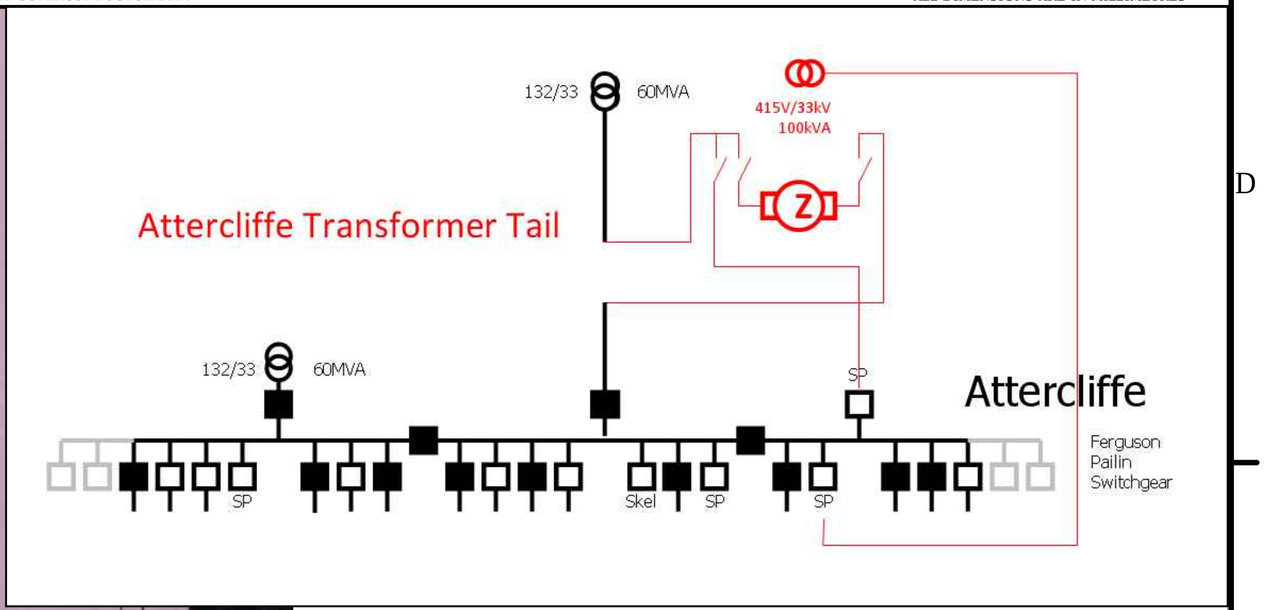
SCALE	N.T.S.
DESIGNED	D.J.C.
CHECKED	A.W.

TITLE FCL CONNECTION PROPOSALS - SHEFFIELD 33KV SITES

DATE	SHEET SIZE	DRG No.	SHEET
8/10/10	A3	SK011	2/6

ALL DIMENSIONS ARE IN MILLIMETRES





ADDITIONAL CABLE LENGTHS (INCLUDING 10M ALLOWANCE FOR BENDS) :

CABLE JOINT TO FCL SWITCHBOARD	57.1M
FCL SWITCH BOARD TO CABLE JOINT	57.1M
FCL SWITCHBOARD TO FCL	37.1M
FCL TO FCL SWITCHBOARD	42.0M
FCL SWITCHBOARD TO T3 BREAKER	228.4M
AUXILIARY SUPPLY	186.6M
TOTAL	608.3M

🟥	ADDITIONAL CABLE
▪	AUXILIARY TRANSFORMER
▬	AUXILIARY ENCLOSURE
✚	FAULT CURRENT LIMITER
▬	SWITCH BOARD

ATTERCLIFFE - TRANSFORMER TAIL

REVISION HISTORY

REV	DESCRIPTION	DATE
1		8/10/10

Applied Superconductor

EDDIE FERGUSON HOUSE
RIDLEY STREET
BLYTH
NORTHUMBERLAND
NE24 3AG

GENERAL TOLERANCES
(UNLESS OTHERWISE STATED)

DIM	>0.5-3	3-6	>6-30	>30-120	>120-400	>400-1000
TOL	±0.1	±0.1	±0.2	±0.3	±0.5	±0.8

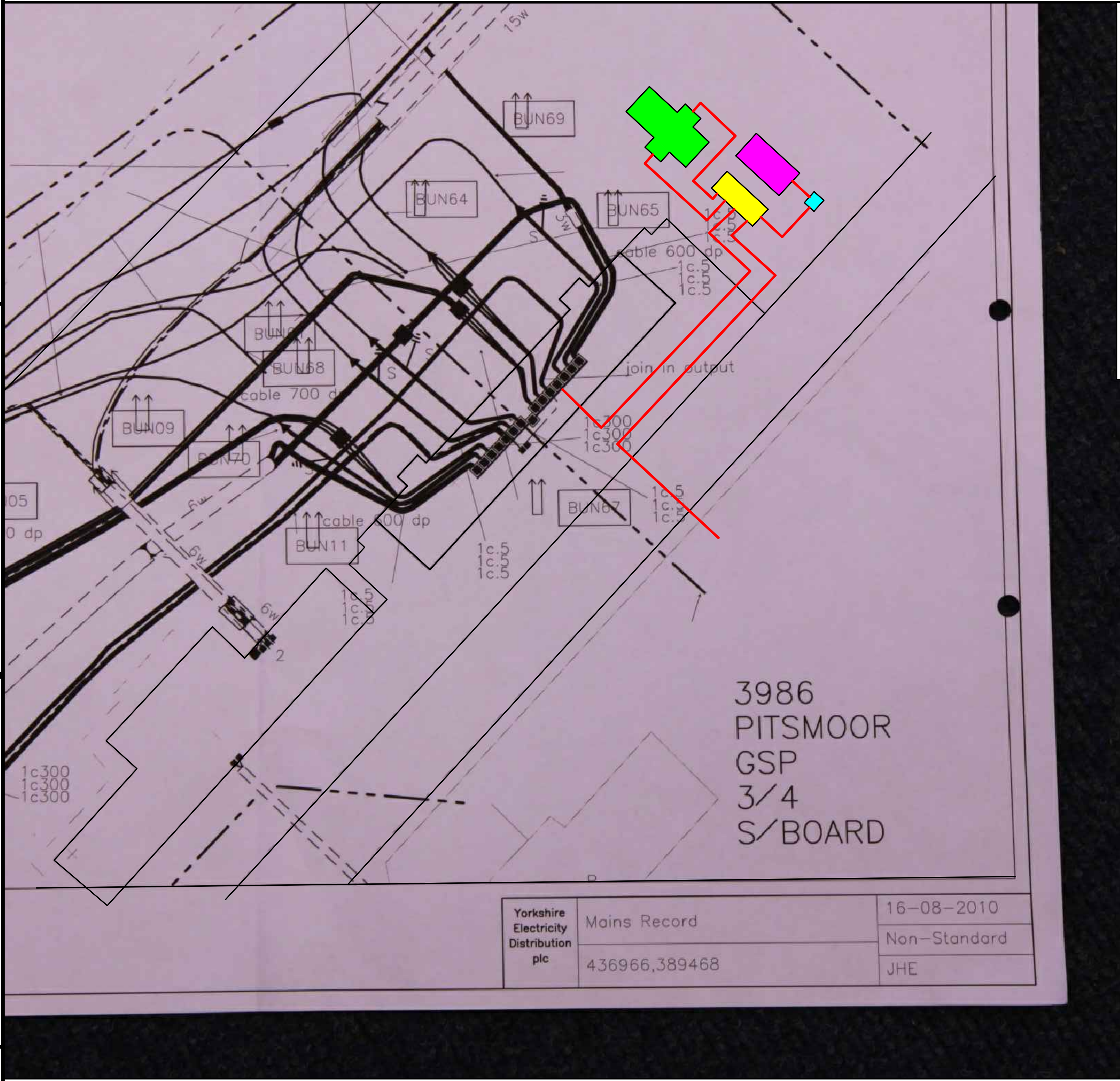
ANGLE ±0.5°

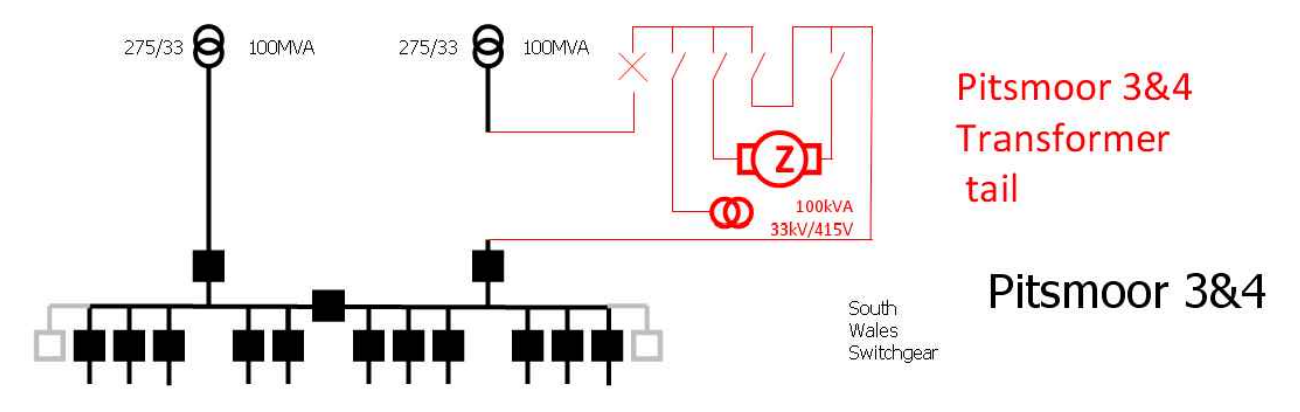
SCALE	N.T.S.
DESIGNED	D.J.C.
CHECKED	A.W.

TITLE FCL CONNECTION PROPOSALS - SHEFFIELD 33KV SITES

DATE	SHEET SIZE	DRG No.	SHEET
8/10/10	A3	SK011	3/6

ALL DIMENSIONS ARE IN MILLIMETRES





Pitsmoor 3&4 Transformer tail

Pitsmoor 3&4

ADDITIONAL CABLE LENGTHS (INCLUDING 10M ALLOWANCE FOR BENDS) :

CABLE JOINT TO FCL SWITCHBOARD	72.3M
FCL SWITCH BOARD TO CABLE JOINT	71.2M
FCL SWITCHBOARD TO FCL	34.6M
FCL TO FCL SWITCHBOARD	41.5M
AUXILIARY SUPPLY	29.1M
TOTAL	248.7M

—	ADDITIONAL CABLE
■	AUXILIARY TRANSFORMER
■	AUXILIARY ENCLOSURE
✚	FAULT CURRENT LIMITER
■	SWITCH BOARD

PITSMOOR 3 & 4 - TRANSFORMER TAIL

REVISION HISTORY

REV	DESCRIPTION	DATE
1		8/10/10

Applied Superconductor

EDDIE FERGUSON HOUSE
RIDLEY STREET
BLYTH
NORTHUMBERLAND
NE24 3AG

GENERAL TOLERANCES
(UNLESS OTHERWISE STATED)

DIM	>0.5-3	3-6	>6-30	>30-120	>120-400	>400-1000
TOL	Ñ0.1	Ñ0.1	Ñ0.2	Ñ0.3	Ñ0.5	Ñ0.8

ANGLE Ñ0.5Â

SCALE	N.T.S.
DESIGNED	D.J.C.
CHECKED	A.W.

TITLE FCL CONNECTION PROPOSALS - SHEFFIELD 33KV SITES

DATE	SHEET SIZE	DRG No.	SHEET
8/10/10	A3	SK011	4/6

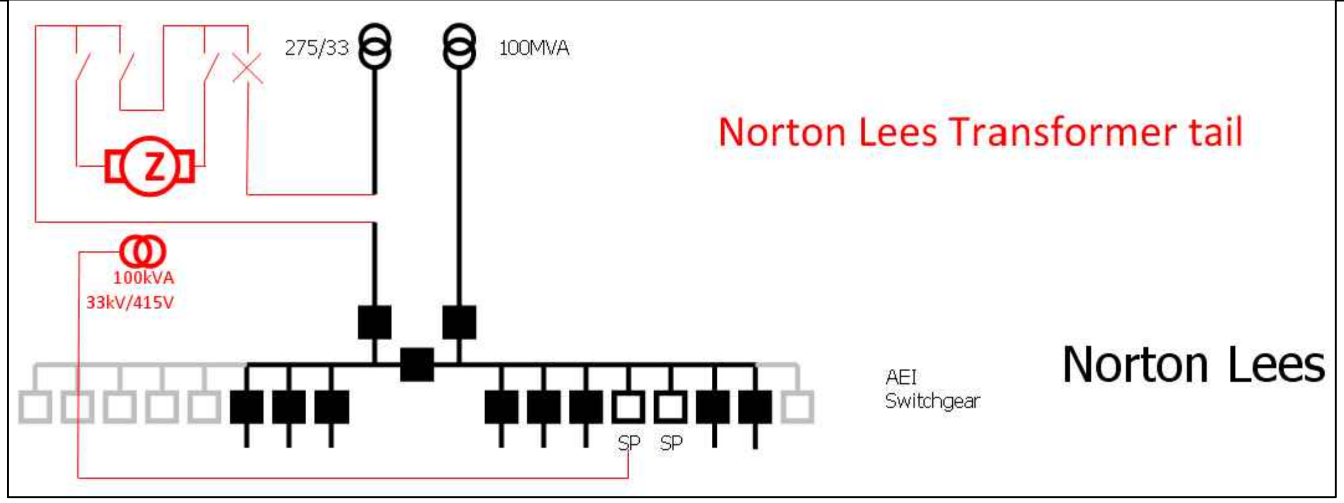
ALL DIMENSIONS ARE IN MILLIMETRES

ADDITIONAL CABLE LENGTHS (INCLUDING 10M ALLOWANCE FOR BENDS) :

CABLE JOINT TO FCL SWITCHBOARD	61.7M
FCL SWITCH BOARD TO CABLE JOINT	60.3M
FCL SWITCHBOARD TO FCL	33.4M
FCL TO FCL SWITCHBOARD	39.6M
AUXILIARY SUPPLY	27.8M
TOTAL	222.8M

🟥	ADDITIONAL CABLE
■	AUXILIARY TRANSFORMER
■	AUXILIARY ENCLOSURE
✚	FAULT CURRENT LIMITER
■	SWITCH BOARD

NORTON LEES - TRANSFORMER TAIL



REVISION HISTORY

REV	DESCRIPTION	DATE
1		8/10/10

Applied Superconductor

EDDIE FERGUSON HOUSE
RIDLEY STREET
BLYTH
NORTHUMBERLAND
NE24 3AG

GENERAL TOLERANCES
(UNLESS OTHERWISE STATED)

DIM	>0.5-3	3-6	>6-30	>30-120	>120-400	>400-1000
TOL	Ñ0.1	Ñ0.1	Ñ0.2	Ñ0.3	Ñ0.5	Ñ0.8

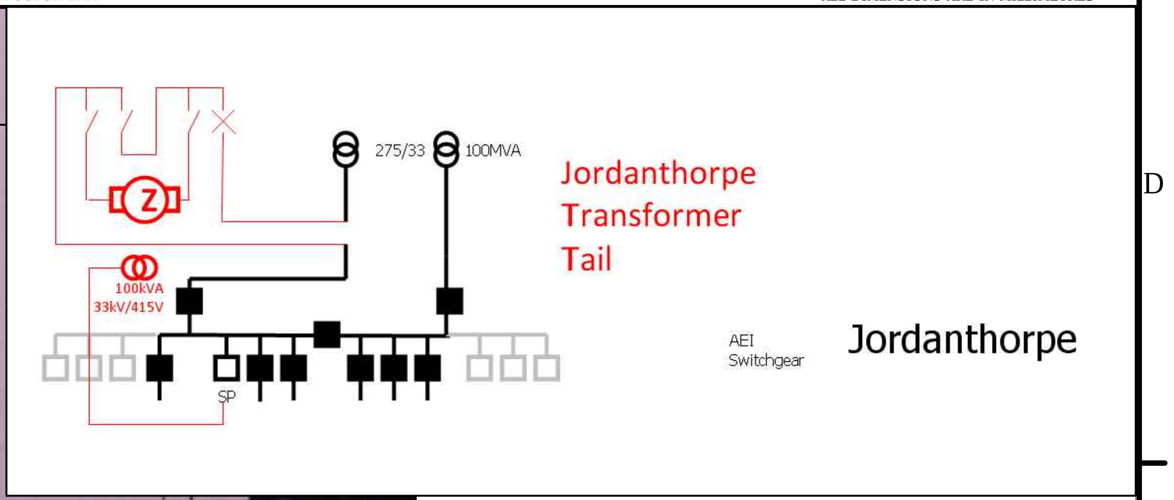
ANGLE Ñ0.5Â

SCALE	N.T.S.
DESIGNED	D.J.C.
CHECKED	A.W.

TITLE FCL CONNECTION PROPOSALS - SHEFFIELD 33KV SITES

DATE	SHEET SIZE	DRG No.	SHEET
8/10/10	A3	SK011	5/6

ALL DIMENSIONS ARE IN MILLIMETRES



ADDITIONAL CABLE LENGTHS (INCLUDING 10M ALLOWANCE FOR BENDS) :

CABLE JOINT TO FCL SWITCHBOARD	62.2M
FCL SWITCH BOARD TO CABLE JOINT	66.5M
FCL SWITCHBOARD TO FCL	46.4M
FCL TO FCL SWITCHBOARD	66.9M
AUXILIARY SUPPLY	197.9M
TOTAL	439.9M

—	ADDITIONAL CABLE
🟦	AUXILIARY TRANSFORMER
🟪	AUXILIARY ENCLOSURE
🟩	FAULT CURRENT LIMITER
🟨	SWITCH BOARD

JORDANTHORPE - TRANSFORMER TAIL

REVISION HISTORY

REV	DESCRIPTION	DATE
1		8/10/10

Applied Superconductor

EDDIE FERGUSON HOUSE
RIDLEY STREET
BLYTH
NORTHUMBERLAND
NE24 3AG

GENERAL TOLERANCES
(UNLESS OTHERWISE STATED)

DIM	>0.5-3	3-6	>6-30	>30-120	>120-400	>400-1000
TOL	Ñ0.1	Ñ0.1	Ñ0.2	Ñ0.3	Ñ0.5	Ñ0.8

ANGLE Ñ0.5Á

SCALE	N.T.S.
DESIGNED	D.J.C.
CHECKED	A.W.

TITLE FCL CONNECTION PROPOSALS - SHEFFIELD 33KV SITES

DATE	SHEET SIZE	DRG No.	SHEET
8/10/10	A3	SK011	6/6

Process/Project
Failure Modes and Effects Analysis
(FMEA)

Process or Product Name:	CE Sheffield 33kV Project	Prepared by: DJC, AW, CW, JH	Pages 5
Responsible:	Applied Superconductor Ltd. / CE Electric UK	FMEA Date (Orig): 18/10/10	(Rev): 2 (CA0036)

Input Ref.	Process Step/Input	Potential Failure Mode	Potential Failure Effects	S E V	Potential Causes	O C C	Current Controls	D E T	R P N	Actions Recommended	Resp.	Actions Taken	p S E V	p O C C	p D E T	p R P N
Reference number to identify the process step/Input under investigation	What is the process step/ Input under investigation?	In what ways does the key input go wrong?	What is the impact on the key output variables (customer requirements) or internal requirements?	How severe is the effect to the customer?	What causes the key input to go wrong?	How often does cause or failure mode occur?	What are the existing controls that prevent either the cause or the failure mode?	How well can you detect the cause/failure before next step?		What are the actions for reducing the RPN. Should have actions only on high RPN's or easy fixes.	Who is responsible for the recommended action?	What actions have been taken and date completed?				
1.1.3.1	NGET Issues	NGET are not involved at all	All sites with NGET assets are eliminated from the project. Learning potential significantly affected	7	NGET Policy or funding structure	7	Briefed NGET, Met and presented to NGET, Sent list of open issues to NGET. Relying on good will in order to issue a Mod App	7	343	Chance up NGET if no reply by 25th November. Issue a Mod App	CE/ASL	Preliminary Meeting Arranged for 28/10/10				0
		NGET involvement is limited	Scope of project is restricted and learning potential is less than anticipated	7	NGET don't fully "buy in" to project objectives.	7	Briefed NGET, Met and presented to NGET, Sent list of open issues to NGET. Relying on good will in order to issue a Mod App	7	343	Chance up NGET if no reply by 25th November. Issue a Mod App	CE/ASL	Preliminary Meeting Arranged for 28/10/10				0
		NGET involvement is limited	Scope of project is restricted and learning potential is less than anticipated	7	Overall project budget limited	7	Identify all likely costs & compare against budget	4	196							
		Involving NGET introduces significant delays in project timing	Significant delays in project timing	7	Lack of flexibility in NGET procedures	7	None	10	490	Mod App ensures a 3 month response	CE	Preliminary Meeting Arranged for 28/10/10				0
				7	Legal process for transfer of land ownership issues	7	None	10	490	Mod App ensures a 3 month response	CE	Preliminary Meeting Arranged for 28/10/10				0
				7	NGET has existing plans for work on sites under consideration	4	Open questions have covered this	7	196	Mod App ensures a 3 month response	CE	Preliminary Meeting Arranged for 28/10/10				0
				7	Not getting agreement on asset transfer / ownership	7	Open questions have covered this	7	343	Mod App ensures a 3 month response	CE	Preliminary Meeting Arranged for 28/10/10				0
				7	Not getting agreement on operational rights	4	There are no rights.	1	28			Preliminary Meeting Arranged for 28/10/10				0
				7	Not understanding impact on NGET protection schemes	7	Open questions have covered this	7	343	Mod App ensures a 3 month response	CE	Preliminary Meeting Arranged for 28/10/10				0
				7	Not understanding impact on control of NGET assets	4	NGET only require local voltage control	1	28			Preliminary Meeting Arranged for 28/10/10				0
				7	Not understanding impact on control of NGET/CE interface	7	NGET only require local voltage control	1	49			Preliminary Meeting Arranged for 28/10/10				0
				10	NGET requirements for FCL performance not clearly defined and understood	4	NGET accept week 24 statement from CE	1	40			Preliminary Meeting Arranged for 28/10/10				0

Process/Project
Failure Modes and Effects Analysis
(FMEA)

Process or Product Name:	CE Sheffield 33kV Project	Prepared by: DJC, AW, CW, JH	Pages 5
Responsible:	Applied Superconductor Ltd. / CE Electric UK	FMEA Date (Orig): 18/10/10	(Rev): 2 (CA0036)

Input Ref.	Process Step/Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken	pSEV	pOCC	pDET	pRPN
Reference number to identify the process step/Input under investigation	What is the process step/ Input under investigation?	In what ways does the key input go wrong?	What is the impact on the key output variables (customer requirements) or internal requirements?	How severe is the effect to the customer?	What causes the key input to go wrong?	How often does cause or failure mode occur?	What are the existing controls that prevent either the cause or the failure mode?	How well can you detect the cause/failure before next step?		What are the actions for reducing the RPN. Should have actions only on high RPN's or easy fixes.	Who is responsible for the recommended action?	What actions have been taken and date completed?				
				7	NGET requirements for site working not clearly defined and understood	4	None	10	280	Meet NGET to discuss specific site working, when site selected	ASL/CE					0
1.1.3.2	Site Development Plans	Site Choice restricted	Scope of project is restricted and learning potential is less than anticipated	7	Existing CE site development plans make some sites unsuitable for the project	4	Information from CE programme and NGET 7 year statement	4	112	Discuss shortlisted sites with CE PEP	ASL					0
1.1.3.3	Environmental Issues	Minor Environmental Issue	Nuisance to neighbours - e.g. noise	4	Site is close to domestic or commercial properties	7	Site specific environmental issues noted at site visit. Experience of similar projects	1	28	Review design against current controls and implement mitigation measures as appropriate	ASL					0
			Objection to removal of trees	4	Removal without consultation	4	Site specific environmental issues noted at site visit. Experience of similar projects	4	64	Review design against current controls and implement mitigation measures as appropriate	ASL					0
		Major Environmental Issue	Potential hazard to CE/ASL personnel and general public - e.g. leak of oil or gas	7	Prevention measures not incorporated into project	4	Environmental issues known from previous designs and experience of similar projects.	1	28	Review design against current controls and implement mitigation measures as appropriate	ASL					0
			Site Flooded	7	Selecting a site where there is a risk of flood	7	Information from Environment Agency	1	49	Information passed to CE PEP	ASL					0
			Objection to impact on a nearby Site of Special Scientific Interest (SSSI)	10	Selecting a site where there is a nearby SSSI	7	Information from SSSI database (MAGIC)	1	70	Information passed to CE PEP Check the SSSI database	ASL					0
1.1.3.4	Sufficient Budget	Insufficient Funds	Project not completed and some learning objectives not delivered	7	Project spend not monitored correctly	4	Monthly Project Meeting	4	112	Get Quotations and Robust Estimates	ASL					0
				7	Delays incur costs outside budget	7	Monthly Project Meeting	4	196	Manage critical path	ASL					0
				7	Budget based on incomplete information	10	Project Scoping document	4	280	Get Quotations and Robust Estimates	CE					0
				7	Insufficient Financial resources	7	Monthly Project Meeting	4	196	Reduce scope of project	CE/ASL					0
				7	Insufficient Financial resources	7	Monthly Project Meeting	4	196	Apply for more funding	CE/ASL					

Process/Project
Failure Modes and Effects Analysis
(FMEA)

Process or Product Name:	CE Sheffield 33kV Project	Prepared by: DJC, AW, CW, JH	Pages 5
Responsible:	Applied Superconductor Ltd. / CE Electric UK	FMEA Date (Orig): 18/10/10	(Rev): 2 (CA0036)

Input Ref.	Process Step/Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken	p SEV	p OCC	p DET	p RPN
Reference number to identify the process step/Input under investigation	What is the process step/ Input under investigation?	In what ways does the key input go wrong?	What is the impact on the key output variables (customer requirements) or internal requirements?	How severe is the effect to the customer?	What causes the key input to go wrong?	How often does cause or failure mode occur?	What are the existing controls that prevent either the cause or the failure mode?	How well can you detect the cause/failure before next step?		What are the actions for reducing the RPN. Should have actions only on high RPN's or easy fixes.	Who is responsible for the recommended action?	What actions have been taken and date completed?				
			Project completed but some learning objectives not delivered	4	Project spend not monitored correctly	4	Monthly Project Meeting	4	64	Get Quotations and Robust Estimates	ASL					0
				4	Delays incur costs outside budget	7	Monthly Project Meeting	4	112	Manage critical path	ASL					0
				4	Budget based on incomplete information	10	Project Scoping document	4	160	Get Quotations and Robust Estimates	ASL					0
				4	Insufficient Financial resources	7	Monthly Project Meeting	4	112	Reduce scope of project	CE/ASL					0
				4	Insufficient Financial resources	7	Monthly Project Meeting	4	112	Apply for more funding	CE/ASL					
1.1.3.5	Sufficient Time	Insufficient Time	Project not completed and some learning objectives not delivered	7	Project timing not monitored correctly	4	Monthly Project Meeting	1	28	Get Quotations and Robust Estimates	ASI					0
				7	Outage time not available	7	Project plan	1	49	Manage critical path/site selection process	CE/ASL					0
				7	Unknown lead times	10	Pilot 3 history	4	280	Get Quotations and Robust Estimates	ASL					0
				7	Lack of resource	7	Project Plan	4	196	Sub-contract	CE/ASL					0
				7	Single key Supplier	10	Weekly meeting with supplier	4	280	Benchmarking alternative suppliers	ASL					0
				7	Availability of Test House Facilities	7	Monitor Test House availability	4	196	Book early	ASL					0
			Project completed but some learning objectives not delivered	4	Project timing not monitored correctly	4	Monthly Project Meeting	1	16	Get Quotations and Robust Estimates	ASL					0

Process/Project
Failure Modes and Effects Analysis
(FMEA)

Process or Product Name:	CE Sheffield 33kV Project	Prepared by: DJC, AW, CW, JH	Pages 5
Responsible:	Applied Superconductor Ltd. / CE Electric UK	FMEA Date (Orig): 18/10/10	(Rev): 2 (CA0036)

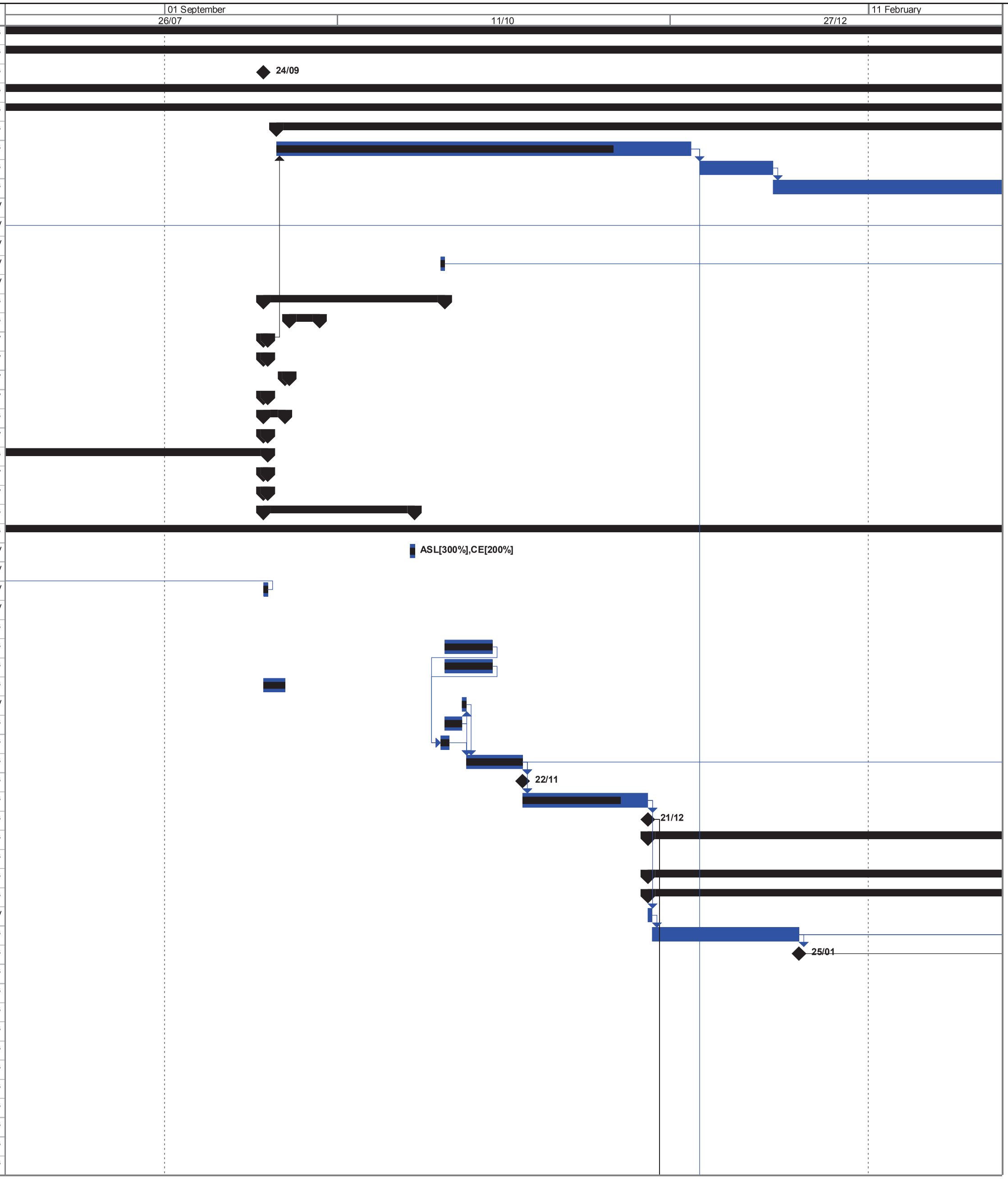
Input Ref.	Process Step/Input	Potential Failure Mode	Potential Failure Effects	S E V	Potential Causes	O C C	Current Controls	D E T	R P N	Actions Recommended	Resp.	Actions Taken	p S E V	p O C C	p D E T	p R P N
Reference number to identify the process step/Input under investigation	What is the process step/ Input under investigation?	In what ways does the key input go wrong?	What is the impact on the key output variables (customer requirements) or internal requirements?	How severe is the effect to the customer?	What causes the key input to go wrong?	How often does cause or failure mode occur?	What are the existing controls that prevent either the cause or the failure mode?	How well can you detect the cause/failure before next step?		What are the actions for reducing the RPN. Should have actions only on high RPN's or easy fixes.	Who is responsible for the recommended action?	What actions have been taken and date completed?				
				4	Outage time not available	7	Project plan	1	28	Manage critical path/site selection process	ASL					0
				4	Unknown lead times	10	Pilot 3 history	4	160	Get Quotations and Robust Estimates	ASL					0
				4	Single key Supplier	7	Weekly meeting with supplier	4	112	Benchmarking alternative suppliers	CE/ASL					0
				4	Availability of Test House Facilities	10	Monitor Test House availability	4	160	Book early	ASL					0
1.1.3.6	SFCL Performance	SFCL Performance documentation is not appropriate	SFCL cannot be accepted onto customer network	10	Customer requirements not clearly defined and understood	4	ASL and CE standards team are defining the test specification	4	160	Ensure test house can do all tests required	ASL					0
	Carbon Case	Carbon case not robust	Acceptance of technology compromised	7	OFGEM / DECC change rules	4	None	10	280	Engage OFGEM. Monitor DECC for July 2011 updates	CE					0
				7	Expert opinion differs	7	None	10	490	Monitor carbon landscape	ASL					
	Business Case	Business case not robust	Acceptance of technology compromised	7	Cost model confidential or not available	7	CE information	4	196	Use external references	CE					
				7	Carbon and time benefits do not flow to DNO	7	None	10	490	Engage OFGEM	CE					
				7	Not able to calculate further benefits	7	CE information	4	196	Use external references	CE/ASL					
	Learning	"How to" Manual not adopted or published	Information not available to future projects	10	OFGEM change rules	4	None	10	400	Engage OFGEM	CE					
				10	Information gained from project is deemed too commercially sensitive for publication	4	CE/ASL Information	1	40	Desensitise information	CE/ASL					

Process/Project
Failure Modes and Effects Analysis
(FMEA)

Process or Product Name:	CE Sheffield 33kV Project	Prepared by: DJC, AW, CW, JH	Pages 5
Responsible:	Applied Superconductor Ltd. / CE Electric UK	FMEA Date (Orig): 18/10/10	(Rev): 2 (CA0036)

Input Ref.	Process Step/Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken	pSEV	pOCC	pDET	pRPN
Reference number to identify the process step/Input under investigation	What is the process step/ Input under investigation?	In what ways does the key input go wrong?	What is the impact on the key output variables (customer requirements) or internal requirements?	How severe is the effect to the customer?	What causes the key input to go wrong?	How often does cause or failure mode occur?	What are the existing controls that prevent either the cause or the failure mode?	How well can you detect the cause/failure before next step?		What are the actions for reducing the RPN. Should have actions only on high RPN's or easy fixes.	Who is responsible for the recommended action?	What actions have been taken and date completed?				
				7	Manual incomplete	7	Project plan	4	196	Engage with relevant stakehoders to complete manual	CE/ASL					

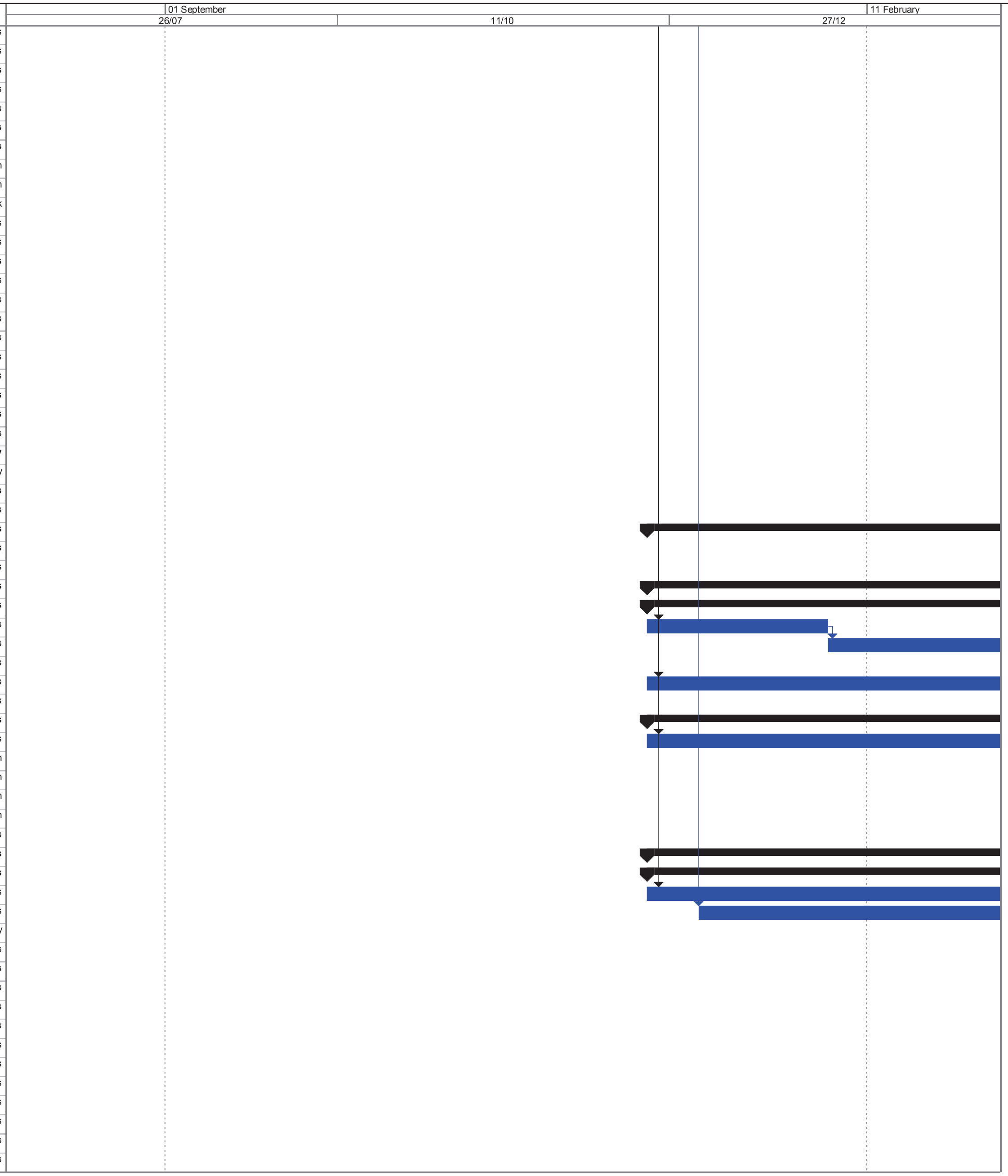
ID	WBS	Task Name	Duration
1	**1**	**Phase 1 Project Detailing**	**207 days**
2	**1.1**	**Identify project scope**	**207 days**
3	**1.1.1**	**Confirm Learning objectives**	**0 days**
13	**1.1.2**	**Identify learning delivery plan**	**206 days**
14	**1.1.2.1**	**1a. Identify suitable site**	**206 days**
15	**1.1.2.1.1**	**Understand NGC Constraints**	**143 days**
16	1.1.2.1.1.1	Get feedback from NGT Meeting questions	70 days
17	1.1.2.1.1.2	Write Mod App	13 days
18	1.1.2.1.1.3	Submit Mod App & receive Feedback	3 mons
19	1.1.2.1.2	Identify shortlist of suitable sites from LTDS	1 day
20	1.1.2.1.3	Carry out site visits to gather data as per check-lists	1 day
21	1.1.2.1.4	Analyse Data from sites	1 day
22	1.1.2.1.5	Analyse data from site carbon case	1 day
23	1.1.2.1.6	Make Site selection	1 day
24	**1.1.2.2**	**1b. Specify unit**	**30 days**
28	**1.1.2.3**	**1c Specify balance of plant/project**	**5 days**
31	**1.1.2.4**	**1d Install equipment**	**1 day**
33	**1.1.2.5**	**2. Operate unit once commissioned**	**1 day**
35	**1.1.2.6**	**3. Identify Type tests & perform them**	**1 day**
37	**1.1.2.7**	**4. Network events monitor**	**1 day**
40	**1.1.2.8**	**5. Measure running costs**	**3 days**
44	**1.1.2.9**	**6. Maintenance manuals and perform maintenance**	**1 day**
46	**1.1.2.10**	**7. Develop audited carbon cases**	**61 days**
49	**1.1.2.11**	**8. Evaluate business options**	**1 day**
51	**1.1.2.12**	**9. Develop IPSA software models**	**1 day**
53	**1.1.3**	**Identify Risks to the project**	**25 days**
60	**1.1.4**	**Identify risk mitigation actions**	**207 days**
61	1.1.4.1	r1a. Meet NGC & Discuss general project	1 day
62	1.1.4.2	r2 Discuss shortlisted sites with CE PEP	1 day
63	1.1.4.3	r3a Establish envirnomental issues from previous design	1 day
64	1.1.4.4	r3b Establish site environmental hazards at Site Visit	1 day
65	1.1.4.5	r3c Design Environmental Mitigation items	5 days
66	1.1.4.6	r4 Get quotations and robust estimates	7 days
67	1.1.4.7	r5 Get Quotations and robust estimates,	7 days
68	1.1.4.8	r6b Plan type tests	3 days
69	1.2	Confirm LCNF rules are met	1 day
70	1.3	Combine learning objectives and risk mitigation items into formal project scope	2 days
71	1.4	Provide de-risked project gantt chart and budget	2 days
72	1.5	Complete Phase 1	9 days
73	1.6	Milestone 1: Phase 1 complete	0 days
74	1.7	Obtain Stage 2 approval	21 days
75	1.8	Milestone 2: Stage 2 Approved	0 days
76	**2**	**Phase 2 - SFCL Supply and Installation**	**413 days**
77	2.1	Select Site	0 days
78	**2.2**	**Supply, Install and Test SFCL**	**382 days**
79	**2.2.1**	**Design & Purchase**	**117 days**
80	2.2.1.1	Place major subcontracts & commence design	1 day
81	2.2.1.2	Studies & simulation	24 days
82	2.2.1.3	Milestone 3: Network Impact report	0 days
83	2.2.1.4	SFCL Design	6 wks
84	2.2.1.5	Milestone 4: Design Report	0 days
85	2.2.1.6	SFCL Material Specification & Procurement	7 wks
86	2.2.1.7	Milestone 5: Material Procurement report	0 days
87	**2.2.2**	**Manufacture SFCL**	**205 days**
88	2.2.2.1	SFCL Build	9 mons
89	2.2.2.2	Factory Test	5 days
90	2.2.2.3	Milestone 7: Factory Test report	0 days
91	2.2.2.4	Ready for Delivery to Test House	20 days
92	**2.2.3**	**Type Test**	**30 days**
93	2.2.3.1	Type test FCL unit	20 days



Project: CE 33kV - Project Plan Issue
Date: Tue 03/12/13

Task ▬	Progress ▬	Summary	External Tasks ▬
Split	Milestone ◆	Project Summary	External Milestone ◆
			Deadline ⇩

ID	WBS	Task Name	Duration
94	2.2.3.2	Milestone 8: Type test completed	0 days
95	2.2.3.3	Deliver to Site	10 days
96	**2.2.4**	**Installation & Test**	**30 days**
97	2.2.4.1	Installation & Commissioning	30 days
98	2.2.4.2	Commissioning Complete	0 days
99	**2.3**	**Design, Purchase and Installation of B Of P**	**105 days**
100	**2.3.1**	**Design & Order B0P**	**105 days**
101	2.3.1.1	Site design	1 mon
102	2.3.1.2	Identify Aux equipment	1 mon
103	2.3.1.3	Design report	1 wk
104	2.3.1.4	Milestone 6: BOP Design report complete	0 days
105	2.3.1.5	Purchase all items	12 wks
106	**2.4**	**Site works & Pre SFCL installation**	**195 days**
107	2.4.1	Prepare FDS	15 days
108	2.4.2	Select contractor to engineer FCL site	20 days
109	2.4.3	Outline design	30 days
110	2.4.4	CE Site works - foundations & breakers	6 mons
111	2.4.5	CE Site works complete	0 days
112	2.4.6	ASL fit aux items on site	2 wks
113	**2.5**	**Commissioning & Energisation**	**31 days**
114	**2.5.1**	**Commissioning**	**10 days**
115	2.5.1.1	Overall Commissioning	10 days
116	**2.5.2**	**Energisation**	**1 day**
117	2.5.2.1	Milestone 9: Energisation	1 day
118	**2.5.3**	**Site Records - Report**	**20 days**
119	2.5.3.1	Completion of Site Documentation	20 days
120	**3**	**Phase 3 - Monitoring Period**	**663 days**
121	**3.1**	**12 Month Monitoring**	**240 days**
122	3.1.1	Monitoring	12 mons
123	**3.2**	**Project Close Out**	**663 days**
124	**3.2.1**	**Carbon Case**	**235 days**
125	3.2.1.1	Brief Sheffield Uni on Carbon case scope	6 wks
126	3.2.1.2	Sheffield Uni Develop Carbon Cases	5 mons
127	3.2.1.3	Review All Carbon cases developed	5 days
128	3.2.1.4	ASL independent carbon case development	5 mons
129	3.2.1.5	Publish Carbon case approach	5 mons
130	**3.2.2**	**Business Case**	**175 days**
131	3.2.2.1	Identify all alternative methods	4 mons
132	3.2.2.2	Identify capex and opex for each alternative	1 mon
133	3.2.2.3	Identify carbon saving for each	1 mon
134	3.2.2.4	Evaluate carbon saving	1 mon
135	3.2.2.5	Evaluate Business cases	1 mon
136	3.2.2.6	Business Case Report	0 days
137	**3.2.3**	**Learning**	**653 days**
138	**3.2.3.1**	**Commercial**	**528 days**
139	3.2.3.1.1	Develop a paper on Generation connection benefits	52 wks
140	3.2.3.1.2	Develop NGET 'how to' road map	104 wks
141	3.2.3.1.3	Workshop on Headroom Generation clusters	1 day
142	3.2.3.1.4	Report from workshop	2 mons
143	**3.2.3.2**	**Operational**	**311 days**
144	3.2.3.2.1	Report on FCL impact on Protection & Control	30 days
145	3.2.3.2.2	Report on Network Stability	30 days
146	3.2.3.2.3	Report on Voltage drop and load sharing	30 days
147	3.2.3.2.4	Report on captured events	20 days
148	3.2.3.2.5	Maintenance & lifetime costs report	20 days
149	3.2.3.2.6	Report on Type Tests and standards	40 days
150	3.2.3.2.7	Environmental impact assessment	30 days
151	3.2.3.2.8	IPSA/DINIS models, Operational Handbook & design policies	90 days
152	3.2.4	Collate Final Report	30 days
153	3.2.5	Milestone 10: Final Report	0 days



Project: CE 33kV - Project Plan Issue
Date: Tue 03/12/13

Task	▬	Progress	▬	Summary	▬	External Tasks	▬	Deadline	⇩
Split	⋯	Milestone	◆	Project Summary	▬	External Milestone	◆		

Generic Carbon Case

1. Introduction

This document presents the Carbon Case for a Tier 1 Project under the LCNF and demonstrates that the project makes a contribution to the UK's Low Carbon Transition Plan, as set out by DECC. It does this by following the general approach documented in the report produced by the CUSC Environmental Standing Group (December 2008)[1] which sets out the main processes of assessing the carbon impact of a proposal:

1. Establish a baseline level of carbon.

2. Calculate how the baseline carbon profile would be altered by the project.

3. Define the period of time over which the analysis should be applied.

4. Calculate the impact of carbon dioxide emissions in CO_2 equivalent terms.

5. Multiply carbon dioxide savings by 'The Traded Price for Carbon'[2].

The carbon case is focused on the enabling and acceleration of renewable generation to distribution networks.

To allow for the connection of generation from renewable sources at the distribution level, the network needs to be able to handle the increases in fault level and bi-directional flow of fault current. Strategically placed Superconducting Fault Current Limiters (SFCLs) will provide distribution networks with this capability and allow for 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. If access to part of a network to new DG connections is constrained by fault level headroom there may be a requirement for the developer to part fund the necessary reinforcement or wait until the issue develops to a stage where the network operator includes reinforcement works in their investment plan; this might not be for several years. Having the capability to respond quickly and economically to a generator related fault level issue could mean that the generator can connect earlier than otherwise possible, accelerating the potential reduction in CO_2 emission and enhancing the business case for deploying SFCLs.

The process of developing the carbon case is as follows:

- Assess the current situation at the selected substation based on the information provided by the DNO. The working assumption is that a renewable generator has submitted a request to be connected to this substation and that excessive fault level at the substation means that reinforcement needs to be completed before the connection can be made.

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[1] Ref to http://www.nationalgrid.com/NR/rdonlyres/D0DB1FBC-263E-4A1B-81CC-71B487C482DE/30033/FinalEnvironmentalGroupReport10.pdf for full text.

[2] The DECC report Carbon Appraisal in UK Policy Appraisal, September 2009 indicates that the government approach is to use the traded price of carbon rather than the Shadow Cost of Carbon previously used and recommended in the CUSC report. Values are included in this report. Prices range from £22/tCO2e in 2010 through to £25/tCO2e in 2020 and £70/tCO2e in 2030.

- Develop and discuss a solution deploying conventional technologies and practices.

- Develop and discuss a solution deploying a SFCL.

- Assess the carbon implications associated with each option and hence establish the carbon saving as a result of implementing a SFCL solution rather than a conventional solution.

- Finally prepare a NPV calculation, including capital and carbon costs comparing the conventional with a SFCL solution.

- Develop a view of the opportunities to implement the SFCL solution at other substations with high fault levels

Wherever data are not available at this point in time assumptions are made to be able to develop a comprehensive framework of the Carbon Case. The basis and rationale behind the assumptions have been captured in the report.

2. Current situation at the 33kV Substation

Substation Data:

Firm Capacity	130MVA	2274A	Load estimate 2012	102MVA	1784A
Incomer/bus section breakers:		2000A			
Peak Make		46.1kA	Rated Make		43.7kA
Break	907MVA	15.9kA	Rated Break	1000MVA	17.5kA

The making capacity of the outgoing feeder breakers is exceeded when the substation is operated normally i.e. with the bus-section and both incoming transformer breakers closed. The outgoing breaker breaking duty is 91% of its capability i.e. it is not at present exceeded. An operational restriction is in place to prevent any outgoing feeder circuit-breaker from being closed (potentially onto a fault) while the bus-section breaker is closed and both transformer breakers are closed.

3. Request for Connection of DG

For the sake of developing this case it is assumed that a Generator has submitted a request for the connection of a 15 MW biomass CHP scheme at the end of 2011. It is assumed that the lifetime of the CHP scheme will be 30 years and it will operate at a load factor of 66%[3].

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[3] Renewable Energy Foundation Renewable Energy Data Technology Analyses April 2002-Jan 2007 (www.ref.org.uk/Files/biomass.overview.2007.pdf) illustrates that load factors of 70-80% are achievable. 66% is used here as a conservative estimate.

A synchronous machine producing 15MW will increase the fault level at the 33kV point of connection.
Assuming 0.95 power factor the machine rating is 15.79MVA
The short circuit contribution is approx 6[4]x MVA rating = 94.74MVA
Fault contribution is therefore 1.66kA rms symmetrical and 4.65kA peak, using a peak factor of 2.8

This would increase the substation busbar fault level to 17.57kA sym / 50.75kA pk.
The circuit-breaker making and breaking capacities at the substation would be exceeded and some form of remedial action is required before the generator can be connected to the network. The various remedial options are considered in the following sections.

4. Conventional Solution

The circuit-breaker making and breaking capacities would be exceeded and a potential operational solution would be to operate the switchboard with the bus section breaker normally open or with one of transformer circuit breakers normally open. There are adverse implications for customer supplies associated with both these options (in addition, the option to operate with a transformer circuit breaker open would increase the load and hence the losses on the remaining transformer). Such an operational solution is not therefore considered to be an enduring solution and it is therefore necessary to replace or upgrade the 15 panel 33kV switchboard at the substation. In this assessment it is assumed that the fault levels at the substations supplied from the 33kV substation will increase (and hence the headroom for future generation connections will reduce) but that there would be no requirement to upgrade the switchgear as part of this generator connection.

The options for accommodating the additional 15MVA of renewable generation connected to the 33kV busbars at the substation are:

Option 1) Replacement of the 33kV switchboard (estimated total costs £3.8m). This option results in the fault level exceeding 1000MVA limit at 33kV, which would be acceptable at the new 33kV switchboard. Detailed analysis would be needed to confirm that no other plant was potentially overstressed for this option to be implemented.

The fault level at the connected Primary substations will rise slightly; and whilst action should not be required to accommodate this 15MW generator, the available headroom for other connected generators will be eroded. This assessment doesn't quantify this erosion in headroom – but a benefit of a SFCL solution is that this headroom would remain available for other generators.

Option 2) Replacement of existing transformers with two high impedance transformers 275/33kV; 100MVA (assumed total costs £6m). They would be specified to reduce the fault level to slightly below the current levels, obviating the need for switchgear replacement at the GSP. The carbon implication associated with the installation of higher impedance transformers is that they would have higher resistance and therefore higher losses.

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[4] The ratio of short circuit contribution to machine rating is dependent on the individual machine. A factor of between 5 and 8 is typical.

Assuming that the fault level is reduced to 12.8kA symmetrical (same reduction as provided by the SFCL option, (see below), half of this would be provided by each transformer i.e. 6.4kA (366MVA). Neglecting the upstream impedance this requires each transformer to have impedance 2.98 ohm[5]. The NGT transformers currently in use have XL =20.79%, R=0.59%, both on 100MVA base. The X/R ratio for the present transformers is thus 20.79/0.59 = 35.

Assuming X/R = 35 for the new, high impedance transformers, the resistance of each phase of each transformer is 2.98 cos(arctan 35) = 0.085 ohm.

Transformer loss at 102MVA peak load, for both transformers (892A in each phase of each Tx) is thus 6 x 892^2 x 0.085 watts = 405kW.

For the present transformers, the resistance of each is, on 100MVA base, 0.59% (NGT SYS 2009)

At 33kV, 100MVA is equivalent to 10.89 ohms
So transformer resistance = 0.064 ohms
At 892A, loss for both transformers = 6 x 892^2 x 0.064 watts = 305kW

There is therefore a “loss penalty”, associated with the high impedance transformers, of 405 - 305 = 100kW when the substation is fully loaded. Over a year this equates to 876,000kWh. However given that the demand on the substation will vary, there is a need to factor this loss figure downwards by the Loss Load Factor (LLF)

LLF = (approx) (0.1 x LF) + (0.9 x LF^2) Where LF is the Load Factor.

If the LF is 0.3[6], the LLF is 0.11

Factoring down the additional energy lost per annum by the LLF, the energy penalty associated with the additional transformer impedance is 96,360kWh.

In addition to the impact of additional losses, fitting high impedance transformers to control the fault level degrades voltage regulation leading to degraded power quality and possibly increased demand on transformer tap-changers.

It is expected that the NGT owned transformers could be replaced and the generator connection provided by the end of 2014.

5. SFCL Solution

Using a pre-saturated core SFCL in the cables between one of the 275/33kV transformers and the transformer circuit breaker, with a clamping ratio of 40% (limiting the fault current to 60% of its unlimited level), would reduce the peak current, with the bus-section breaker closed and without the

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[5] Impedance =(1/3.66) x 33 x 33 /100

[6] LF is the ratio between the energy supplied/energy that would be supplied if the substation operated continually at the MD.

generator connected, to 84% of the making capacity and the symmetrical current to 73% of the breaking capacity, i.e. 36.7kA make; 12.8kA break.

This provides making capacity headroom of (43.7 – 36.7) = 7kA and breaking capacity headroom of (17.5 – 12.8kA) = 4.7kA, where the 15MW distributed generation is contributing 4.65kA peak to the making requirement and 1.66kA to the break requirement.

This solution therefore allows the comfortable accommodation of 15MW of local DG and would allow up to about 20MW (with similar parameters) to be accommodated.

The application of a SFCL means that the need for switchgear or transformer replacement is eliminated and the fault level is kept within the capability of the existing equipment.

The deployment of an SFCL (assumed total costs of this demonstrator project of £2.6m) will have the following benefits:

SFCLs provide substantial (multiple and overlapping) technical and commercial benefits to operators and owners of electrical networks by:

1. Speeding up the connection of Distributed Generation at 6.6kV – 33kV (ultimately at higher voltages) and eliminating the costs of network reinforcement associated with rising fault levels. This also supports the use of locally available primary energy resources

2. Reducing losses. They allow the network to be interconnected (meshed) without replacing switchgear to cope with rising fault levels. Meshed networks generally have lower losses and more load capacity headroom, allow for improved power quality (due to lower network impedances at times other than at times of network faults) and availability. Application of SFCLs will further allow the use of lower impedance transformers in asset replacement / reinforcement schemes) and removal of series reactors both of which would reduce network losses

3. Reducing asset management costs whilst improving network safety, stability and efficiency. SFCL should be able to offer lower cost alternatives compared to conventional means of reinforcing and maintaining fault levels at an acceptable level.

4. Bi-directional fault flow in smart networks arising from the connection of distributed generation can have an adverse impact on the performance of some protection schemes. Depending on the relative magnitude of the fault currents from generation and the transmission system, application of SFCLs can improve the capability of an existing protection system to cater for increased levels of distributed generation[7].

5. Allowing for a safe and sustainable solution at substations where reinforcement related time constraints could defer a generation connection

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[7] For example, a SFCL restricting the fault current from a generator to a low value could means that the existing protection at the source substation sees little change to the fault contribution from the substation and hence continues to work as originally designed.

6. Allowing for increased overall network lifetime and reduced likelihood of subsequent faults, as a result of limiting short circuit currents rather than installing higher rated equipment to cater for them.

6. The Carbon Case

Carbon Case 1 Benefit from bringing the connection of renewable DG (CHP) forward by 3 years from 2014 to 2011.
The 15MW generator will produce an estimated 86.7GWh of electricity per annum (15 [MW] * 24 [h/d] * 365 [d per annum] * 0.66 (load factor) = 86.7 [GWh per annum]. This will enable electricity generated from marginal plant, assumed to comprise CCGT and coal to be displaced; however in this assessment an average of 0.543kg CO_2/kWh is used[8] i.e. 543 tonnes CO_2/GWh. The CO_2 displaced by the renewable generator is therefore 47,078 tonnes $CO_{2.}$

Based on the 2010 value of the Traded price of Carbon of £22/tonne, this equates to an annual CO2 saving of £1,036,000 per annum, or some £3.1M associated with advancing the generation connection by 3 years.[9]

Carbon Case 2 Benefit from the reduction of losses resulting from the operation of the generator.

In an urban environment large loss reductions are provided by having generation nearer to load, eliminating all transmission and most distribution losses. This amounts to a saving of about 5%[10], so a 15MW generator operating at load factor 0.66 will reduce network losses by 4.34GWh per annum, having an annual value of £217,000 (at £0.05/kWh) and a carbon equivalence of (4.34 [GWh] x 543 [tonnes CO_2/GWh]), giving 2356 tonnes CO_2, worth £51,545 at £22/tonne.

It is necessary to offset the loss saving against the power consumed by the SFCL cooling system, which is of the order of 50kW, i.e 438MWh/annum, having a value of £21,900 (at £0.05/kWh) and a carbon equivalence of 238 tonnes, worth £5,236 at £22/tonne. This reflects a reduction in the overall loss saving of about 10%.

Hence, the value of annual CO_2 reduction is £46,309.

Carbon Case 3 Benefit arising from the use of higher impedance transformers

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[8] 2009 Guidelines to Defra / DECC's GHG Conversion factors for company reporting Version 2.0 (table 3a)

[9] The traded cost of carbon is forecast to increase significantly to 2030, and an annual figure could be used in the NPV assessment. However this assessment is based on advancing a project 3 years and hence the 2010 figure of £22/tonne has been used.

[10] 2009 Guidelines to Defra / DECC's GHG Conversion factors for company reporting Version 2.0 (table 3a) gives a figure of total transmission and distribution losses of 7.2%, a conservative figure of 5% is used in this assessment.

The second conventional solution involves the installation of higher loss 275/33kV transformers, which will increase the transformer losses by 96,360kWh pa.

Using 0.543kg CO_2/kWh[11] this equates to 52.3 tonnes CO_2

Based on the 2010 value of the Traded price of Carbon of £22/tonne, this equates to an annual CO_2 value of £1,151 per annum. This is the value of the CO_2 produced due to the additional loss of the high-impedance transformers.

7. NPV Calculation

NPV calculations have been made for the following solutions associated with the generation connection:

A discount rate of 3.5% has been applied for 30 years and 3% for the balance of the period until 2050 in accordance with the LCNF Tier 2 guidance document

The NPV calculation focuses on the capital costs and carbon cost and the operating costs associated with purchase of the losses has not been included.

Solution	**Conventional Option 1 (Replace switchgear)**	**Conventional Option 2 (replace transformers)**	**SFCL**
Total capital cost	£3.8m	£6.0m	£2.6m
Connection year	2014	2014	2011
Carbon saving – Generator operation	£1,036,000pa	£1,036,000pa	£1,036,000pa
Carbon saving - Generator Losses	£51,545pa	£51,545pa	£51,545pa
Carbon saving - SFCL losses	n/a	n/a	-£5,236
Carbon saving Transformer Losses	Base case	-£1.151pa	Base case

The NPV of the three Options are:

Option	**NPV**
Option 1 Commission Generation 2014, Replace 33kV switchgear	£ 13,888,322
Option 2 Commission Generation 2014, Replace 275/33kV transformer	£ 11,983,205
Option 3 Commission Generation 2011, Install SFCL	£ 16,087,199

In this example the financial benefits arise due the SFCL being the lowest costs solution and from the provision of the connection in 2011 rather than 2014 for those options where traditional reinforcement is required.

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[11] 2009 Guidelines to Defra / DECC's GHG Conversion factors for company reporting Version 2.0 (table 3a)

From a carbon perspective, the key benefit is a saving of 141,23 tonnes of CO_2 arising from the early commissioning of the renewable generator.

In the following additional benefits listed are not included in the NPV calculation but could be the basis for new commercial arrangements or charging methodologies:

- Earlier Generator Revenue. Additional revenues for the generator from the installation brought forward by 3 years. (15 [MW] * 24 [h/d] * 365 [d] * 0.66 (load factor) = 87 [GWh generation annually] * 0.05 [£/kWh] = £5.21m revenues from generation annually. In addition the generator would benefit earlier from the payment for ROCs
- Reduction need to purchase 'lost units. In an urban network, where the generated energy is used locally, there is a reduction in the transmission and most distribution losses. This amounts to a saving of £217,000 pa. This benefit would ultimately be seen by end consumers.
- Improved power quality, CML and CI.
- Reduced likelihood of subsequent faults due to reduced mechanical and thermal stress and arc energy during the occurrence and clearing of a fault

8. UK Carbon Outlook

Detailed data regarding CO_2 savings will be gained from actual Tier 1 and Tier 2 projects. Nevertheless in the following two Carbon cases we try to give an outlook on the magnitude of potential impact that a widespread deployment SFCL technology could give to the UK network.

Carbon Case 1

In 2008 EU members agreed a number of energy targets aimed at tackling global climate change. These are commonly termed the '20-20-20 targets' and constitute a commitment for the EU to deliver a 20% cut in emissions of greenhouse gases by 2020, compared with 1990 levels; a 20% increase in the share of renewables in the energy mix (i.e. electricity, heat and transport sectors) and a 20% cut in energy consumption through improved energy efficiency by 2020. As an important component of UK energy consumption, electricity generation and supply will play a large role in achieving the UK's share of the EU 2020 energy targets and longer term energy and climate goals to 2050. By 2020, around 40% of our electricity is expected to come from low-carbon sources.[12]

Early 2010 we are now at approximately 6% (24 TWh) of all electrical energy being generated in the UK comes from renewable sources. The UK has committed to increase this to 40% by 2020. This would mean an additional 160TWh of generation between now and 2020. Using a CO_2 equivalent for

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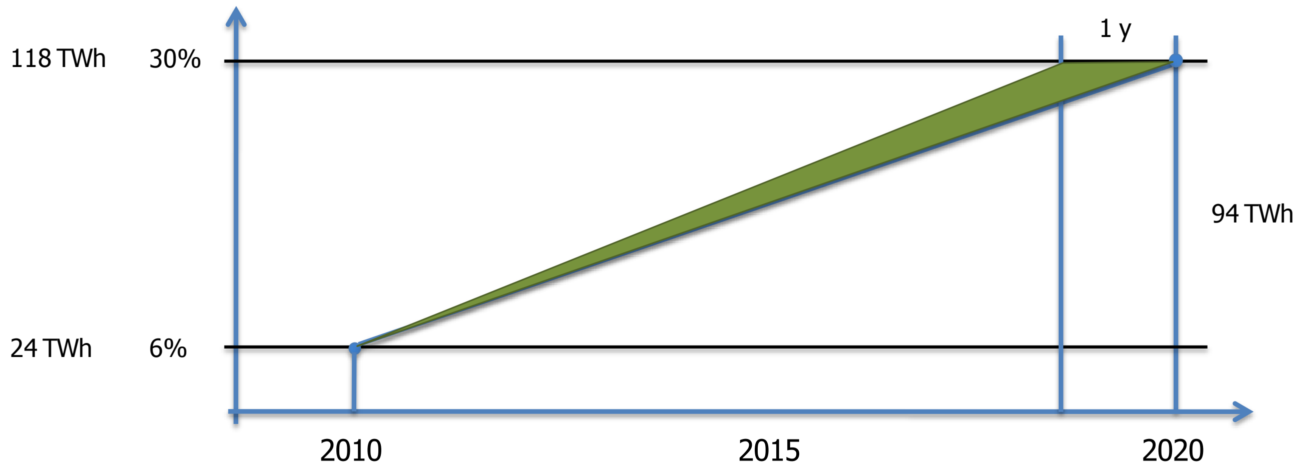
[12] DECC Smart Grid a UK Vision 2009

the use of renewable sources of 543 tonnes CO_2/GWh, this equates to a reduction of 86,880,000 tonnes pa.

Energy from renewable sources



If we assume for the sake of this consideration that these new distributed generation projects could be connected 1 year earlier by use of the SFCL technology the additional CO_2 saved by displacing fossil fuel a year earlier (assuming they are all renewables) would be the area shaded green in the diagram above:

136 [TWh] x 0.5 x 0.543 [MTonnes CO_2/TWh] = 37 [MTonnes CO_2] savings over the period 2010-2020, i.e. 4.3% of the total CO2 saving for the period 2010-2020

Carbon Case 2

Losses are incurred on transmission and distribution networks in order to transfer electricity from the point of generation to the point of use. Total UK transmission and distribution network loses are approximately 7.2% of the energy it is handling which equals 28.8TWh[13] of electrical energy. Again, there is a significant potential to reduce CO_2 emissions from the deployment of the SFCL technology.

We assume in this calculation that the widespread use of SFCL technology can reduce the overall network losses by 10%, primarily by improving the efficiency of the network by, facilitating the connection of Distributed Generation (generator closer to load), facilitating the interconnection of networks, the removal of high loss devices such as high impedance transformers, the asset replacement of transformers with lower loss transformes. Then the CO2 saving would be:

10% x 28.8 [TWh] x 0.543 [MTonnes CO2/TWh] = 1.6 [MTonnes CO2] savings per year

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[13] DUKES 2009: UK electricity consumption is approx 400TWh per annum

9. Attachments

Attachment 1	NPV calculations