WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

SUCCESSFUL DELIVERY REWARD CRITERIA REPORT EVIDENCING METHOD GAMMA WILL PROVIDE OUTLINED LEARNING

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

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Contents

Glossary of terms

Abbreviation	Term
CHP	Combined Heat and Power
DC	Direct Current
DNO	Distribution Network Operator
DPCR-5	Distribution Price Control Review 5
EHV	Extra High Voltage (voltages above 22,000V)
EMF	Electro-Magnetic Field
FCL	Fault Current Limiter
FL	Fault Level
FSP	Full Submission Pro-forma
GSP	Grid Supply Point
GT	Grid Transformer
HSE	Health & Safety Executive
HV	High Voltage (voltages above 1,000V but below 22,000V)
ITT	Invitation to Tender
MVA	Mega Volt Ampere
MW	Mega Watts
PEFCL	Power Electronic Fault Current Limiter
PSCFCL	Pre-Saturated Core Fault Current Limiter
PTN	Post Tender Negotiations
rms	Root Mean Square
RSFCL	Resistive Superconducting Fault Current Limiter
SDRC	Successful Delivery Reward Criteria
WPD	Western Power Distribution
X/R	The X/R ratio is the ratio of the system reactance to the system resistance looking back towards the power source from any point in the network. When a fault occurs the fault current that flows comprises of two contributing elements, ac and dc. The ac symmetrical component is determined by the total system impedance between power source and fault. The dc component represents the asymmetry in the fault and decays over a short period of time. The X/R ratio is effectively a time constant that determines the speed of this decay. The actual fault current that is required to be interrupted by a circuit breaker is a combination of the dc and ac symmetrical currents and hence the slower the decay, the higher the prospective current that requires interrupting.

1 Introduction

This document fulfils the sixth Successful Delivery Reward Criterion of FlexDGrid "Evidencing Method Gamma will provide outlined learning" (SDRC-6). The purpose of this document is to detail that the requirements specified in Section A of the Project Direction document, provided by Ofgem, have been satisfied. Section A of this document is detailed below:

A) Methodology of Method Gamma

The Funding DNO must, prior to signing binding contractual agreements for the fault level mitigation technologies, as described in Section 2 (Project Description), provide a report including the following information:

(i) The progress, including learning to date, of Method Alpha – Enhanced Fault Level Assessment and Method Beta – Real-time Management, as described in Section 2 (Project Description);

(ii) A proposed methodology for Method Gamma – Fault Level Mitigation Technologies, as described in Section 2 (Project Description). This must include a functional description of the five proposed fault level mitigation technologies and five proposed substations. It must also include an explanation of, based on the learning described in (i);

(iii) A description of the process the Funding DNO has followed to consult with other GB DNOs on whether, based on the information provided in (i) and (ii), proceeding to Method Gamma – Fault Level Mitigation Technologies would provide the learning outlined in the Full Submission pro-forma. This must include a written consultation; and

(iv) The written responses received from other GB DNOs to the written consultation described in (iii) together with summaries of all other feedback received.

The Funding DNO may not access any funds from the Project Bank Account for the procurement process for the fault level mitigation technologies or for the fault level mitigation technologies until the Authority is satisfied that there is sufficient evidence provided through feedback in (iv) that GB DNOs consider that proceeding to Method Gamma would provide the learning outlined in the Full Submission pro-forma.

2 Progress and learning to date of Method Alpha and Method Beta (Criterion i)

This section summarises the progress and emerging learning of Method Alpha (Enhanced Fault Level Assessment) and Method Beta (Real-time Fault Level Management) from the beginning of the project up to the point of the DNO consultation workshop, which took place on 4th September 2013 (see Section 4).

2.1 Progress and learning to date of Method Alpha

During the initial phase of FlexDGrid, the Enhanced Fault Level Assessment process was confirmed and contains the following steps, as described in SDRC-1 (Development of Enhanced Fault Level Assessment Processes):

1. Baseline the consistency of application of present fault level assessment processes;
2. Explore assumptions and carry out a sensitivity analysis of present fault level standard calculation methods;
3. Increasing the frequency and granularity of fault level assessments;
4. Network design and deployment of fault level measurement and monitoring technologies;
5. Network design and deployment of fault level mitigation technologies; and
6. Development of connection options for customers based on novel commercial frameworks.

The first FlexDGrid DNO consultation workshop was held on Thursday 2nd May 2013 as part of the base lining process and a questionnaire was submitted to all GB DNOs. The workshop provided a welcome opportunity for DNOs to collaborate and share modelling best practice, as well as voicing concerns and challenges regarding the assessment of HV (11kV and 6.6kV) fault levels. The following learning points emerged from the initial questionnaire responses:

1. Clarifications on the application of Engineering Recommendation (ER) G74[1] to HV electricity networks would be beneficial to the DNO community;
2. A comprehensive sensitivity analysis of HV electricity network fault levels to input parameters would provide further useful learning for DNOs;
3. A generic database of generator and motor plant types could introduce time savings for planning engineers particularly when dealing with missing or inconsistent data from customers;
4. The development of open source fault level mitigation technology models would be of benefit for planning engineers and allow the capacity to accommodate future customers' connections to be readily assessed;
5. The increase in frequency of fault level assessments would be useful for assessing the potential gains from real-time fault level management. However, the gains would need to outweigh the increased modelling effort for this option to be attractive to other DNOs;
6. A move to probabilistic fault level assessments was not deemed to be feasible at this point in time due to the health and safety aspects contained within the Electricity Safety, Quality and Continuity Regulations (ESQCR); and
7. The need was identified for the training processes within DNOs to be more robustly documented so that planning engineers make consistent decisions regarding the assessment of fault levels.

The application of ER G74 to HV networks varies significantly between DNOs and even between different licence areas of the same DNO. For example, based on the initial questionnaire responses, the safety margin applied to fault level assessments can vary from 0 – 10%.

[1] Energy Networks Association, 1992, *Engineering Recommendation G74: Procedure to meet the requirements on IEC 909 for the calculation of short circuit currents*, ENA, London, UK.

During the initial phase of FlexDGrid, the Birmingham HV electricity network has been modelled from Primary Substations (132kV / 11kV) to each Distribution Substation (11kV / 0.4kV) in the same power system analysis package as WPD's EHV network, with interfaces to the transmission system. The ten selected Primary Substations (see Section 2.2) and their associated 11kV feeders have been modelled in this way to create the test bed for trialling the enhanced fault level assessment process throughout the project.

Whilst the present 11kV model for other parts of the network is currently fit-for-purpose, the more detailed electricity model in Birmingham allows the future complexities associated with the integration of low carbon generation to be more fully understood.

Based on the emerging learning from Method Alpha as part of SDRC-1, the following recommendations have resulted:

1. The six steps in the Enhanced Fault Level Assessment process outlined above should be followed and reported on as part of FlexDGrid;
2. A follow-on workshop should be organised to report back on the findings of the base lining process and sensitivity analysis studies. This workshop has been scheduled for 23rd October 2013;
3. It is not clear how the values, reported in ER G74, for the modelling of the fault contribution from asynchronous motors forming part of the general load were originally derived and if these values are still representative of the present distribution network load mix. Therefore FlexDGrid will investigate the fault contribution of different load mixes (demand types) through modelling, measurement and monitoring techniques and report back on the findings by the end of the project;
4. The Energy Networks Association should consider an industry-wide review of ER G74 and consultation with DNOs on its application to HV networks;
5. DNOs should formally document their connection study process so that HV fault level assessments are conducted consistently, assumptions are well-understood and engineering judgements can be made more confidently;
6. DNOs should consider the development of integrated electricity network models, whereby EHV and HV networks are modelled in the same power system analysis software package. This negates the requirement for equivalent models which are known to introduce sources of error and uncertainty into the models; and
7. DNOs should confirm whether or not there is a need to de-rate HV switchgear in line with the method described in CIGRE Technical Brochure 304 for equipment tested to IEC Standard 62271 (High-voltage switchgear and controlgear).

2.1.1 Integration of Methods

During the bid stage of FlexDGrid, 18 Primary Substations were identified for consideration as trial locations for Method Beta (Real-time Management) and Method Gamma (Fault level mitigation technologies) due to their proximity to Birmingham's Central Business District and the fault level information available for each site.

In the initial project delivery phase of FlexDGrid, a series of site surveys were conducted for the 18 Primary Substations identified in the FSP. The results of the site surveys were used as the basis for the "Confirmation of the Project Detailed Design" as detailed in SDRC-2. A brief overview of the substation suitability assessment used to select for the ten Primary Substation sites for the installation of real-time fault level monitoring devices is given in Section 2.2. The same process was also used for selecting the five Primary Substation sites for the installation of fault level mitigation technologies.

Method Alpha built on the initial work to determine the fault level reduction requirements at each of the five Primary Substation sites for the installation of fault level mitigation technologies in order to accommodate generation up to 10% of the firm capacity of each site without exceeding equipment ratings. This aligns with various low-carbon scenarios for the integration of combined heat and power (CHP) in the DECC 2050 Pathways analysis.

An illustrative calculation is given below for break fault levels at an example substation given in Figure 2-1 (similar calculations were made for make fault levels). A typical value of 4.5 MVA per MW[2] was used to represent the fault level contribution from CHP:

Unrestrained fault level (Source1 II Source2) = 300 MVA (150MVA from Source 1 in parallel with 150MVA from Source 2 – identical fault infeed)

Fault level contribution from generation = *Contribution Factor × (10% of Firm Capacity)*
= 4.5 MVA / MW x 0.1 x 156 MVA
= 70.2 MVA

Restrained fault level = *Policy Break Fault Level*[3] *– Generation Contribution*
= 250 MVA – 70.2 MVA
= 179.8 MVA

Required fault level reduction through FCL (from Source 2)

$$= \left[1 - \left(\frac{Restrained\ FL - Source\ 1}{Source\ 2}\right)\right] \times 100\%$$

$$= \left[1 - \left(\frac{179.8\ MVA - 150\ MVA}{150\ MVA}\right)\right] \times 100\%$$

= 80.1%

Reduction as a percentage of Unrestrained FL

$$= \left[1 - \left(\frac{Restrained\ fault\ level}{Unrestrained\ fault\ level}\right)\right] \times 100\%$$

$$= \left[1 - \left(\frac{179.8\ MVA}{300\ MVA}\right)\right] \times 100\%$$

= 40.1%

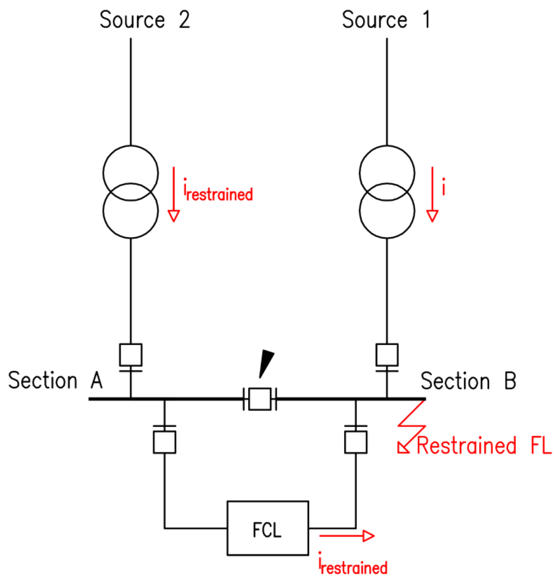

Figure 2-1 Example substation fault current flow diagram

[2] KEMA Ltd, 2005, *The contribution to distribution network fault levels from the connection of distributed generation*, Crown, London, UK.
[3] The limit of Break Fault Level WPD design the 11kV distribution network to attain

For each substation, a 5% contingency was included in the target fault level reduction value. These target reduction values and the overall percentage fault level reduction values are given in Table 2-1 and Table 2-2.

Substation	Firm Capacity	Parallel Fault Levels (MVA)		Target FL (MVA)	
site	(MVA)	3ph Break (rms)	3ph Make (peak)	3ph Break (rms)	3ph Make (peak)
Substation A	156.0	300	901	170.81	531.81
Substation B	78.0	261	770	204.16	565.16
Substation C	78.0	268	753	204.16	565.16
Substation D	78.0	292	837	204.16	565.16
Substation E	78.0	307	908	204.16	565.16

Table 2-1: Substation firm capacities, parallel fault levels and target fault level reductions

	Including 5% Contingency			
	Source 2 FL Reduction		Overall FL Reduction	
Substation	3ph Break (rms)	3ph Make (peak)	3ph Break (rms)	3ph Make (peak)
Substation A	86%	82%	43%	41%
Substation B	44%	53%	22%	27%
Substation C	48%	50%	24%	25%
Substation D	60%	65%	30%	32%
Substation E	67%	76%	34%	38%

Table 2-2: Substation source and overall percentage fault level reductions

A valuable learning outcome and observation from this analysis was that the fault contribution from one source (the Grid Transformer at the faulted busbar) is unaffected by the fault current limiter operation in terms of fault level reduction. Therefore a much more significant fault level reduction is needed from the other source in order to achieve the overall target fault level reduction.

Since the publication of the SDRC-1 report on 1st June, significant progress has been made to implement the trials of Method Alpha. The emerging learning from these trials is detailed in full in the SDRC-4 publication.

2.2 Progress and learning to date of Method Beta

The selection criteria for the ten Primary Substation sites for the installation of real-time fault level monitoring devices is given in Table 2-3 and described in more detail in SRDC-2 (Confirmation of the Project Detailed Design). The results of the selection process are given in Table 2-4 and shown on the map in Figure 2-2.

Criteria	Weighting
Availability of Space	37.5%
Network connection	27.5%
Substation access	20.0%
Investment Plans	10.0%
Auxiliary supply capacity	5.0%
Overall score	**100.0%**

Table 2-3: Site selection criteria

Location	Score	Technology
Substation A	92.5%	Fault current limiter and fault level monitoring
Substation B	85.6%	Fault current limiter and fault level monitoring
Substation C	83.3%	Fault current limiter and fault level monitoring
Substation D	79.2%	Fault current limiter and fault level monitoring
Substation E	78.8%	Fault current limiter and fault level monitoring
Substation F	78.3%	Fault level monitoring
Substation G	77.5%	Fault level monitoring
Substation H	75.8%	Fault level monitoring
Substation I	68.8%	Fault level monitoring
Substation J	65.0%	Fault level monitoring

Table 2-4: Site selection results

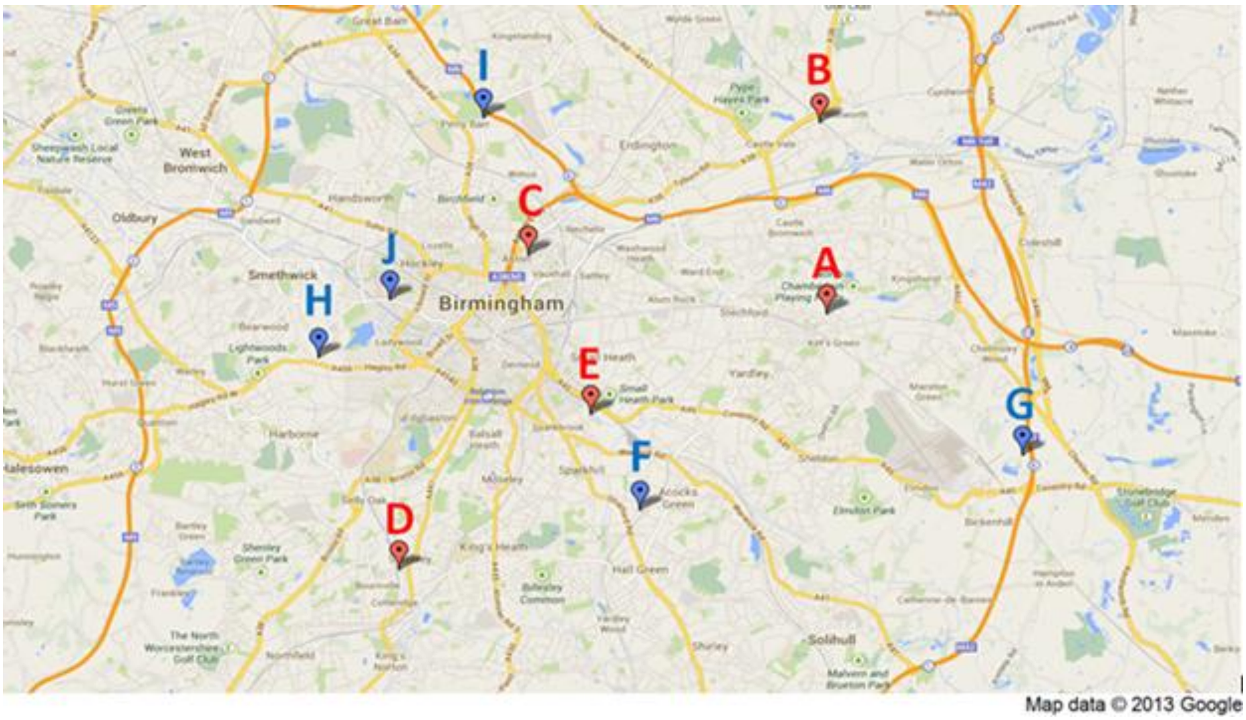

Figure 2-2: Geographical location of selected sites

At the time of producing this SDRC report, and in line with the project plan, WPD were engaged in tender evaluations for fault level monitoring devices.

Fault level measurement devices have been installed at three of the ten selected locations to date (A, B and C). The results from fault level monitoring trials will be reported in SDRC-7 (Installation and open-loop tests of fault level monitoring equipment), SDRC-9 (Closed-loop tests of fault level monitoring equipment) and SDRC-10 (Analysis of test results).

3 Proposed Methodology for Method Gamma (Criterion ii)

3.1 Introduction

The enhanced fault level assessments carried out under Method Alpha and the proposed solutions for undertaking real-time fault level management for Method Beta were used to develop the methodology for Method Gamma. The following sections detail the proposed methodology for Method Gamma including: summary of substations chosen for Method Gamma, technology performance requirements, functional description of technologies offered and the proposed design solutions.

3.2 Method Gamma Substations

The second Successful Delivery Reward Criterion of FlexDGrid, "Confirmation of the Project Detailed Design" (SDRC-2), details the methodology which was applied to determine the five substations for implementation of Method Gamma. Table 3-1 below summaries the substations selected for Method Gamma.

SDRC-2 Reference	Substation Name
Substation A	Kitts Green 132/11kV
Substation B	Castle Bromwich 132/11kV
Substation C	Chester Street 132/11kV
Substation D	Bournville 132/11kV
Substation E	Sparkbrook 132/11kV

Table 3-1: Summary of Method Gamma substations from SDRC-2

As described in Section 2.2 of this report, the substations listed above were selected based on a scoring system that identified the suitability of each particular site to accommodate fault level mitigation technologies. Details of the selection process of technologies for each substation are explained further in section 3.8 of this report.

3.3 Technology Overview

There were a number of technologies that were offered for FlexDGrid during the Invitation to Tender (ITT) process. The technologies offered can be categorised into four distinct technology types: Resistive Superconducting Fault Current Limiters; Pre-Saturated Core Non-Superconducting Fault Current Limiters; Pre-Saturated Core Superconducting Fault Current Limiters; and Power Electronic Fault Current Limiters. Each technology possesses different characteristics that have to be considered when deciding the suitability of connection into an existing substation. The following sections provide a functional description of each technology type.

3.4 Resistive Superconducting Fault Current Limiters

3.4.1 Operation

The Resistive Superconducting Fault Current Limiter (RSFCL) uses the inherent properties of a superconductor to provide high insertion impedance during fault situations to limit the flow of fault current. The RSFCL is designed to be inserted in series with the network. During normal operation the RSFCL operates below the critical temperature in the *superconducting* region with very little losses. Hence, the RSFCL should be designed to ensure that the superconducting region falls within the continuous current rating of the equipment it is being inserted in series with. As current increases in the RSFCL, there is a subsequent rise in conductor temperature. When the temperature increases above the critical temperature, the RSFCL begins to operate in the non-superconducting operating region to provide high insertion impedance. When fault current passes through the superconductor and it transitions from superconducting to non-superconducting, the process is called Quenching. Figure 3-1 below shows the characteristics of a High Temperature Superconductor (HTS) and the quench process from low impedance to high impedance at the critical temperature (T_c).

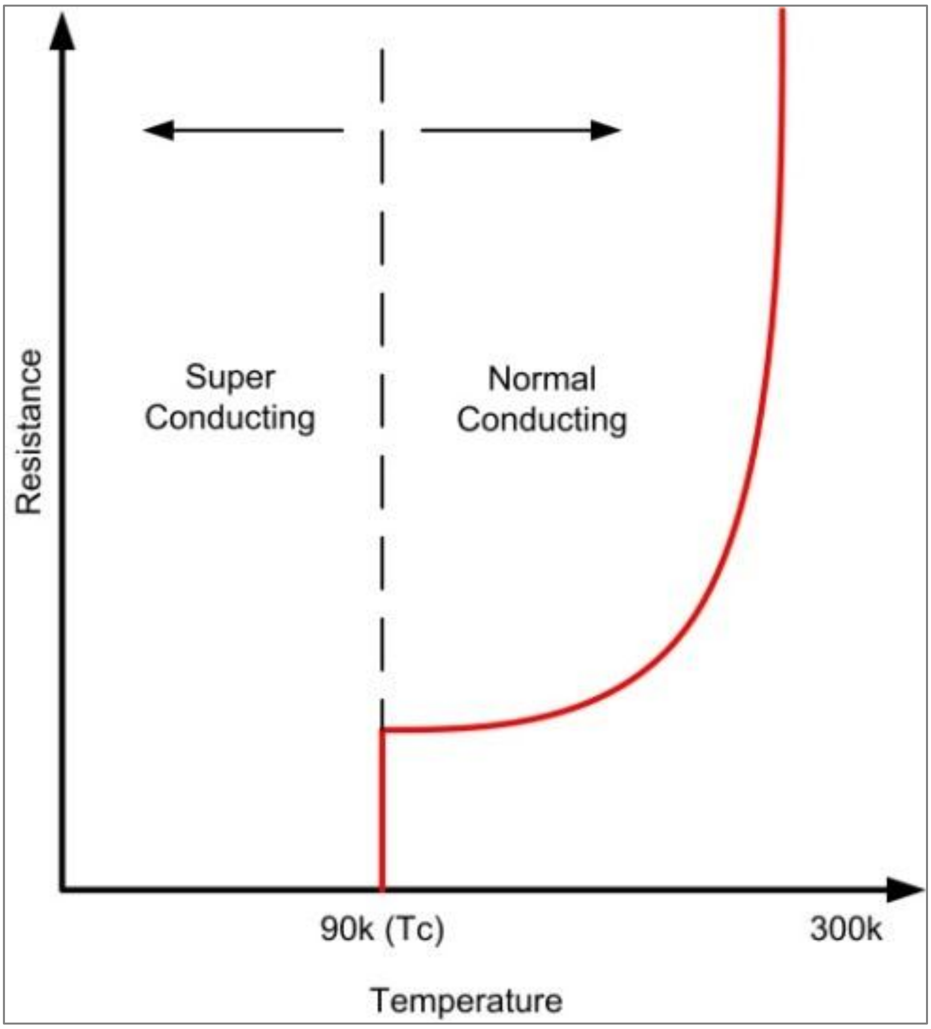

Figure 3-1: Typical Resistance Characteristic of a High Temperature Superconductor

To maintain operation in the superconducting state, the RSFCL requires constant cooling to ensure that the conductor operates below the critical temperature. When the RSFCL transitions from superconducting to non-superconducting mode, the RSFCL becomes extremely hot and requires the current to be diverted / blocked after around 80 milliseconds (although the precise time is dependent on the design of the superconductor) to ensure the device does not overheat and damage insulation material.

There are two distinct methods for diverting / blocking current in the non superconducting mode. The first method is to disconnect the RSFCL by use of fast acting protection and circuit breakers. The alternative is to bypass the RSFCL by use of a reactor in parallel. Once diverted or bypassed, the RSFCL requires a set period of time (around 30 seconds typically) to recover from the fault, cool and return to the superconducting state.

In all instances the device is fail-safe as the superconducting properties will provide high insertion impedance or create an open circuit during a fault event. An example of a typical RSFCL installation can be seen in Figure 3-2 below.

Figure 3-2: Example of a RSFCL

3.4.2 Performance

As the RSFCL may require disconnection during recovery back to the superconducting state after fault inception, it is not desirable to connect it in series with a transformer or other supply incomer. The use of a shunt reactor to prevent the interruption of current could be considered, however, substations with a high X/R system impedance ratio could be adversely affected when additional reactance is inserted into the system.

3.5 Pre-Saturated Core Fault Current Limiters

3.5.1 Operation

The Pre-Saturated Core Fault Current Limiter (PSCFCL) has two variants: non-superconducting and superconducting, whose operation are almost identical. The principal of the PSCFCL is based on the properties of transformer design. In this application, the primary winding of the device is placed in series with the network requiring fault level mitigation. The secondary winding is a DC coil which is used to saturate the core of the PSCFCL. Under normal operation, the flux generated by the DC coil is far greater than that produced by the primary winding and thus the core becomes saturated and the insertion impedance seen by the primary side is very low. As current increases on the primary winding (such as in a fault situation) the opposing flux increases and the core is taken out of saturation and the PSCFCL creates a high insertion impedance.

There are many differing designs for the PSCFCL as manufacturers attempt to keep the footprint of the device to a minimum whilst also ensuring that sufficient biasing flux is generated in the iron core through the DC coils. A typical example of core and winding design is shown in Figure 3-3 below.

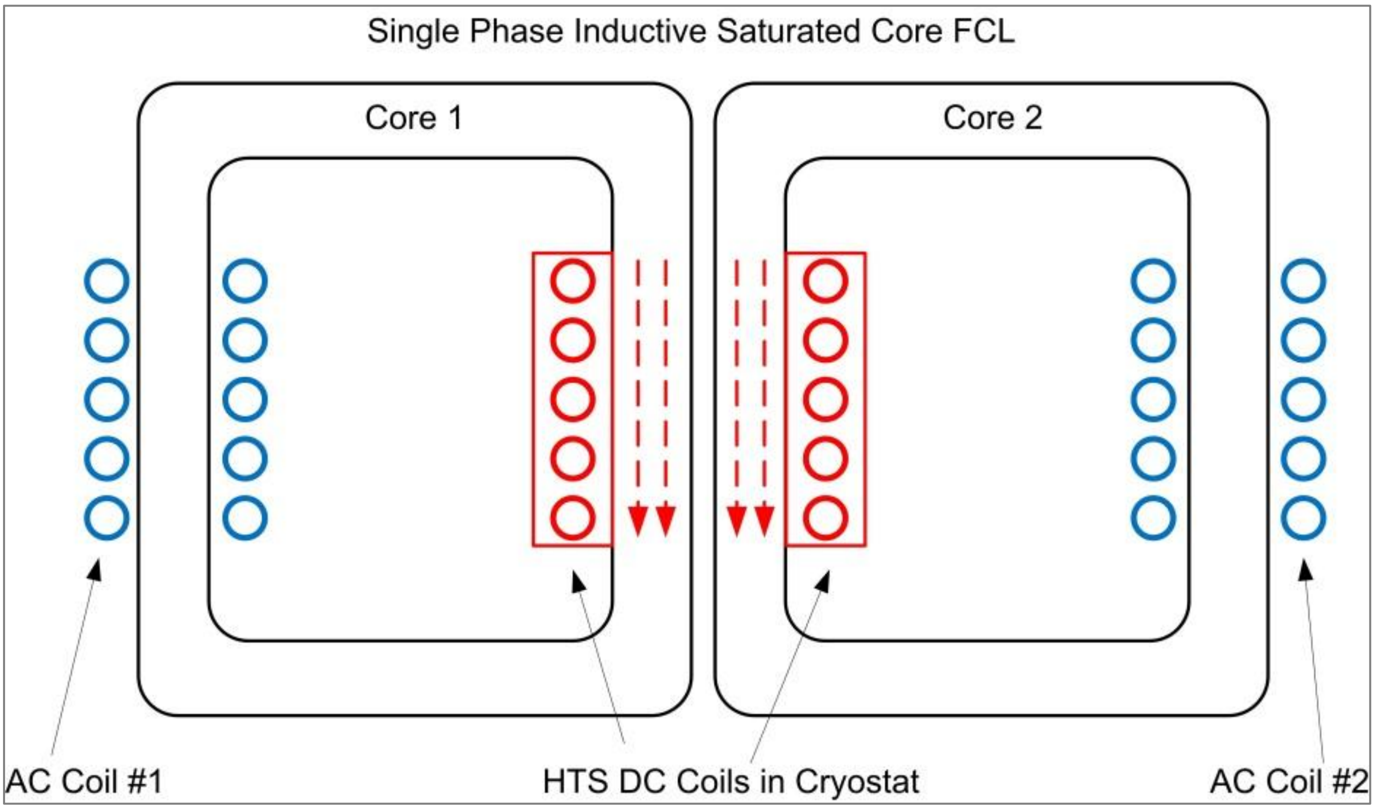

Figure 3-3: Example of Pre-Saturated Core FCL with Superconducting DC coils

The PSCFCL is fail-safe as the DC coil is required to keep the core in saturation in normal operation. Should the DC coil fail (or its controller fail), the core will automatically come out of saturation and the PSCFCL insertion impedance will be high.

3.5.2 Superconducting DC coils

The standard PSCFCL design uses normal DC coils to provide the saturating flux for the core. As the amount of saturating flux required is high, the normal DC coils have to be designed to ensure a closed-loop magnetic field and therefore efficient use of the flux generated. However, if superconducting DC coils are employed on the PSCFCL, the design can utilise an open-field magnetic loop due to the vast amount of flux that can be delivered through the superconductor (with almost no I^2R losses). The main disadvantage with this design is that the exposure levels for magnetic fields (EMF) are much higher than the non-superconducting PSCFCL. Hence, careful consideration must be given before choosing a superconducting PSCFCL where public exposure to EMFs could be an issue. In addition, the superconducting element of the device usually results in much higher capital and on-going revenue costs compared with the non-superconducting version.

3.5.3 Performance

The main benefit of the PSCFCL is that recovery of the device is instantaneous, i.e. the PSCFCL does not need to recover or switch off after fault inception. Thus, the PSCFCL is ideal for instances where supply interruptions cannot be tolerated (for example, when fault level mitigation is required on a transformer feeder). However, consideration should be given to load sharing with other incoming supplies, as the normal insertion impedance of the PSCFCL could be comparable with the source impedance (depending on the level of mitigation required).

3.6 Power Electronic Fault Current Limiter

3.6.1 Overview

The Power Electronic Fault Current Limiter (PEFCL) works on the same basis as a circuit breaker with the main differences being that the device is extremely quick to operate and should the control system fail, the PEFCL will open and thus reduce any fault level contributions. Unlike the RSFCL and the PSCFCL, the PEFCL does not insert an impedance into the network, instead the fault current path is severed, therefore the fault reduction is much higher compared with the other FCL devices. In addition, being a switching device the PEFCL can be controlled to reduce fault current at different magnitudes unlike the other devices which have a fixed level of reduction. The typical PEFCL device configuration is similar to an AC to DC convertor station and is shown in Figure 3-4 below.

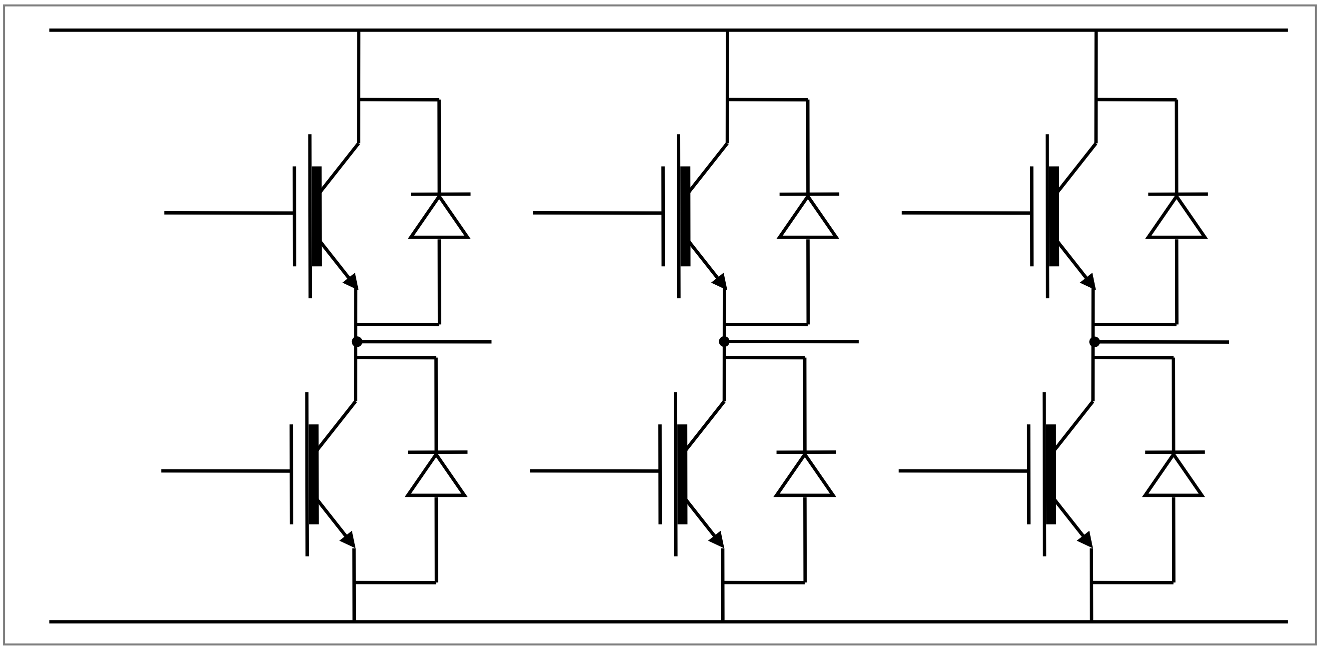

Figure 3-4 Example of an IGBT Bridge circuit

The losses associated with the PEFCL are dependent on the amount of cooling required for the switching devices. As more current is driven through the PEFCL, the greater the amount heat losses, which in turn requires more cooling. With the PEFCL comprising of a number of different power electronic components, the footprint is generally smaller than other FCLs and the general arrangement can be tailored to suit particular installation requirements.

3.6.2 Performance

Considering the “switching” function of the PEFCL and the fact that it requires lots of cooling when operating towards the continuous current rating, it is not recommended for applications in series with a transformer or other supply incomer. Instead, the performance characteristics of PEFCL mean it is suited to bus-section or interconnector applications.

3.7 Technology Tender Process

3.7.1 Overview

One of the aims of FlexDGrid is to install, trial and test five emerging FCL technologies in five substations in Birmingham. As such the ITT for procuring FCL technologies was open and competitive, capturing manufacturers of different technologies all across the globe. To ensure that FlexDGrid trials a variety of different technologies no more than two of the same technology will be installed across the five substations. The tender process for obtaining appropriate technologies is detailed in the sections below.

3.7.2 Invitation to Tender

In addition to the standard ITT documentation requested from tenderers, a questionnaire was included to capture the specific details of the proposed technology. The questionnaire covered aspects including: ratings, operation, accuracy, previous installations/experience, HSE considerations, service/delivery and financial/commercial.

Following submission of the tenderers returns, each technology was scored against the technical, service level and commercial aspects specified in the ITT documentation. The manufacturers which passed the ITT stage were then asked to provide further details on their proposed technologies based on site specific requirements for the five substations.

3.7.3 Site Specific Pro-forma

With the appropriate market ready technologies selected, site specific pro-forma for the five substations were submitted to the manufacturers for completion. The pro-forma detailed the specific functional and fault level reduction requirements for each site with the manufacturers to complete the cost, size and lead-times for each device.

Submissions for each technology type were not received for all substations due to the limitations of the technologies themselves and the high level of fault level reduction at two sites in particular (Kitts Green and Sparkbrook).

3.7.4 Post Tender Negotiations

For each technology, a post tender negotiation (PTN) meeting was arranged, with the manufacturer, for discussions about the proposed product and to ensure compliance with the functional and site specific requirements. Following the PTN, the manufacturers were invited to complete a final resubmission of their offers.

3.8 Substation Technology Selection

3.8.1 Overview

Following the tender process explained above, the appropriate technology had to be selected for each substation. A score for each technology was derived using the same method as explained in section 3.7.2. In addition, technologies that could not meet the critical technical requirements were rejected.

The following sections provide a summary of the detail included in SDRC-2 along with an overview of the technology selection process for each substation.

3.8.2 Kitts Green 132/11kV Substation

Kitts Green substation was commissioned in circa 2008 and is equipped with 3 no. 132/11/11kV transformers 60MVA feeding six sections of 11kV single busbar switchgear. SDRC-2 explored the options for connection of a FCL at Kitts Green. The design analysis identified that the optimal solution for FCL connection was integration into the 11kV interconnector using a new switchboard comprising of 5 circuit breakers. Connecting between switchgear sections U and Z allows for GT1 and GT3 to be paralleled. Further details of Kitts Green Substation and the integration of a FCL can be found in Appendix 4. A single line diagram of the proposed connection and protection and control schematic are shown in Figure 3-5 and Figure 3-6 respectively.

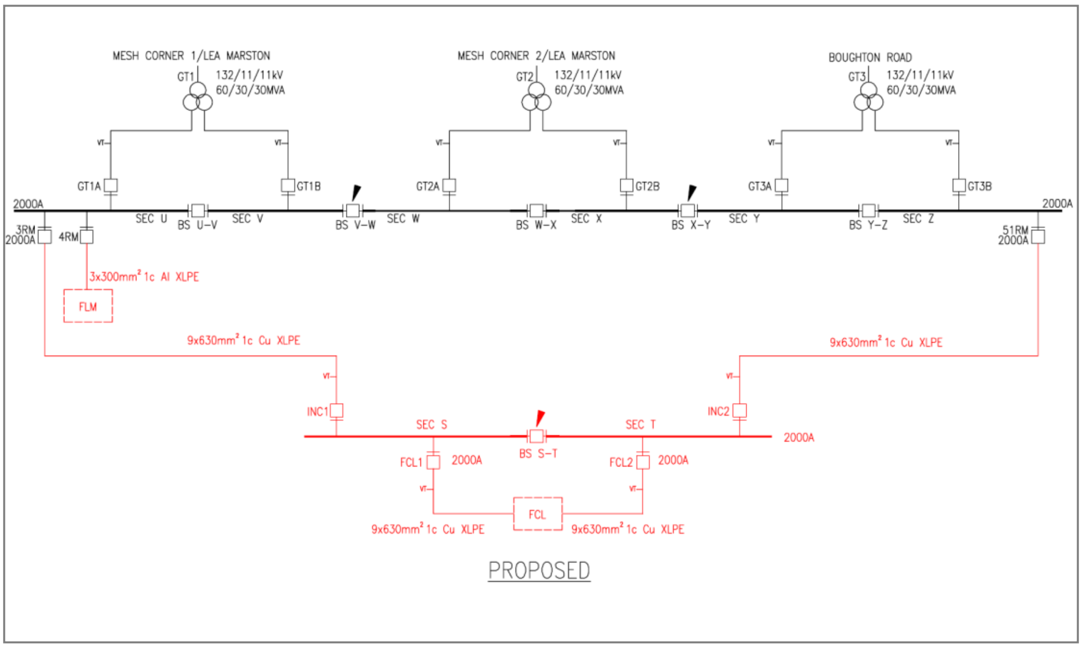

Figure 3-5: Kitts Green outline connection SLD

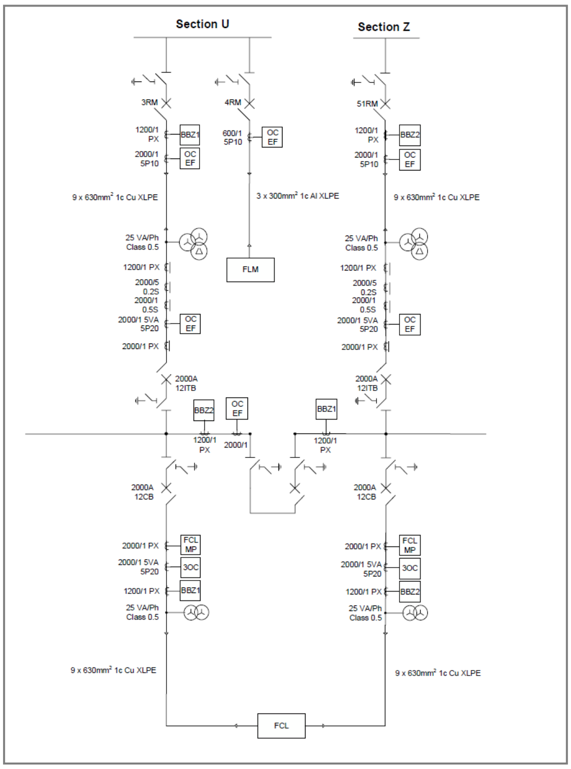

Figure 3-6: Kitts Green Protection and Control Diagram

The initial location and layout proposed in SDRC-2 for the FCL and new switchgear was in the north east corner of the substation plot as indicated in Figure 3-7 below.

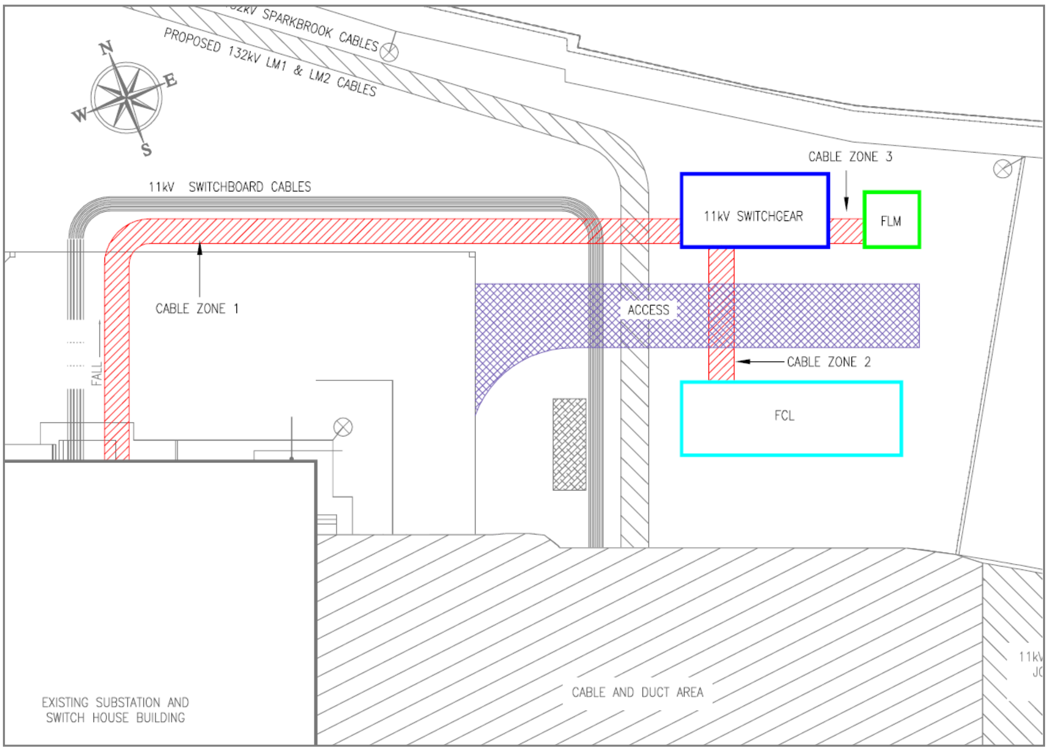

Figure 3-7: Kitts Green outline FCL layout

Of the five sites chosen for fault level mitigation technologies, Kitts Green 132/11kV substation provided the most onerous requirements for fault level reduction due to the high firm capacity available at the substation. Table 2-2 shows that a 43% overall reduction in 3 phase break rms was required to meet the aims of FlexDGrid.

Following the submission of the site specific pro-forma, Table 3-2 below shows that only two technologies were offered as solutions for fault level mitigation at Kitts Green due to the onerous fault level reduction requirements.

	Power Electronic FCL	Resistive Superconducting FCL	Pre-Saturated Core (Non-Supercond.) FCL	Pre-Saturated Core (Superconducting) FCL
Kitts Green	✓	✓	×	×

Table 3-2: Technologies offered for Kitts Green

The key factors summarised in Table 3-3 below were considered when deciding which of the available technologies should be installed at Kitts Green.

Factor	Requirement	Description
Continuous Current Rating	2000A	Required to match the switchgear rating and minimum current to support N-1 scenario.
X/R Ratio	No additional reactance	The X/R ratio is currently well above the normal expected for a 132/11kV substation. The FCL should not increase the reactance and cause an increase the DC component.

Table 3-3: Key factors for FCL installation at Kitts Green

As the RSFCL offered for Kitts Green could not meet the 2000A minimum continuous current rating (required to ensure the interconnector was not de-rated), the only viable option was the Power Electronic FCL. The Power Electronic FCL is ideally suited to Kitts Green as it does not increase the X/R ratio whilst it meets all the functional requirements. A preliminary layout showing the proposed PEFCL using information gathered post tender is shown in Figure 3-8 below.

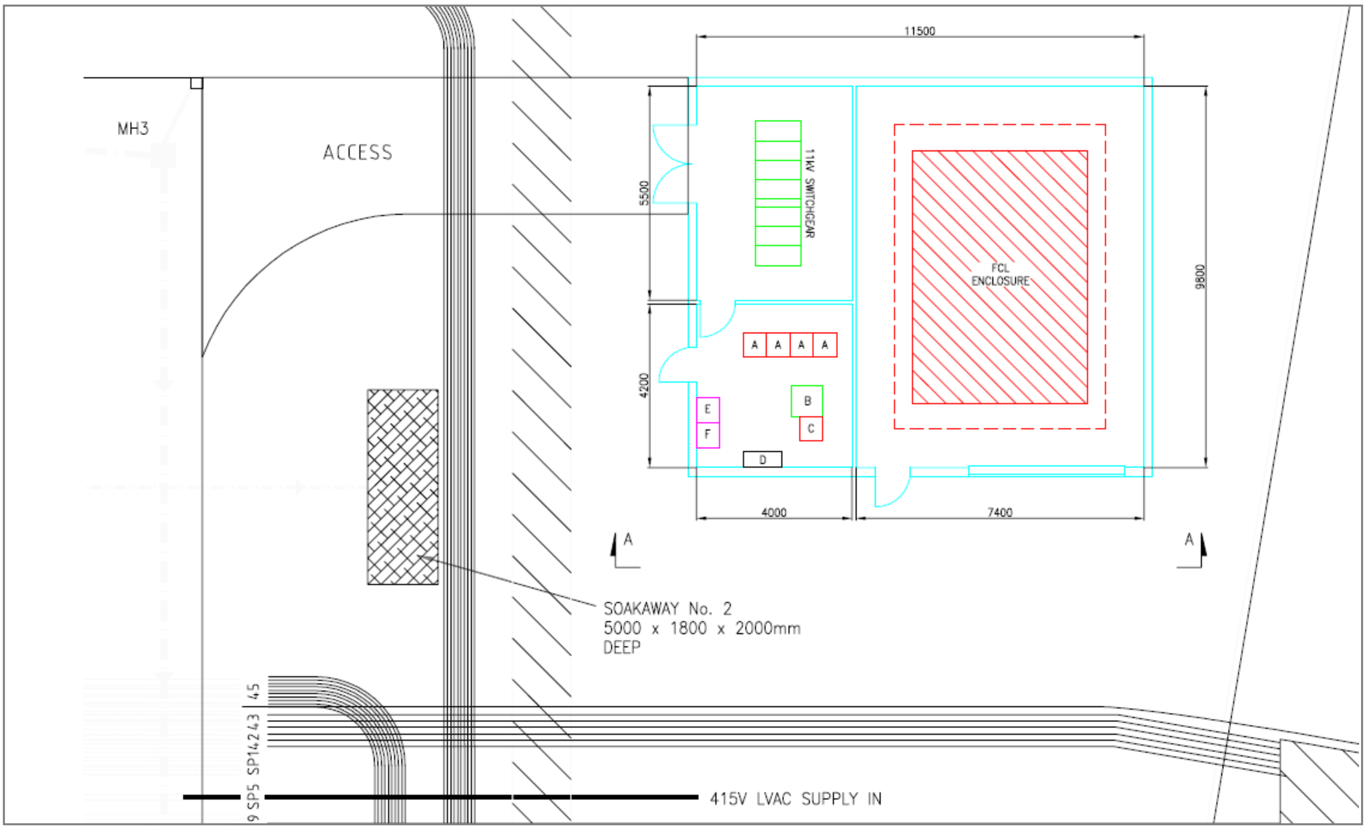

Figure 3-8: Kitts Green preliminary FCL layout

3.8.3 Castle Bromwich 132/11kV Substation

Castle Bromwich Substation consists of 2 no. 132/11/11kV 60MVA transformers with each secondary winding supplying a separate section of 11kV switchgear. The transformers are fed from two separate Grid Supply Points (GSPs) with GT1 fed from Nechells East and GT2 from Lea Marston. The substation has been designed to accommodate a third transformer and additional 11kV switchgear, however the substation is currently only loaded to around 40% of the firm capacity. As paralleling of the GT1 and GT2 was not possible, SDRC-2 identified that the FCL should be integrated into the secondary winding of GT1. Further details of Castle Bromwich Substation and the integration of a FCL can be found in Appendix 5. A single line diagram of the proposed connection and protection and control schematic are shown in Figure 3-9 and Figure 3-10 respectively.

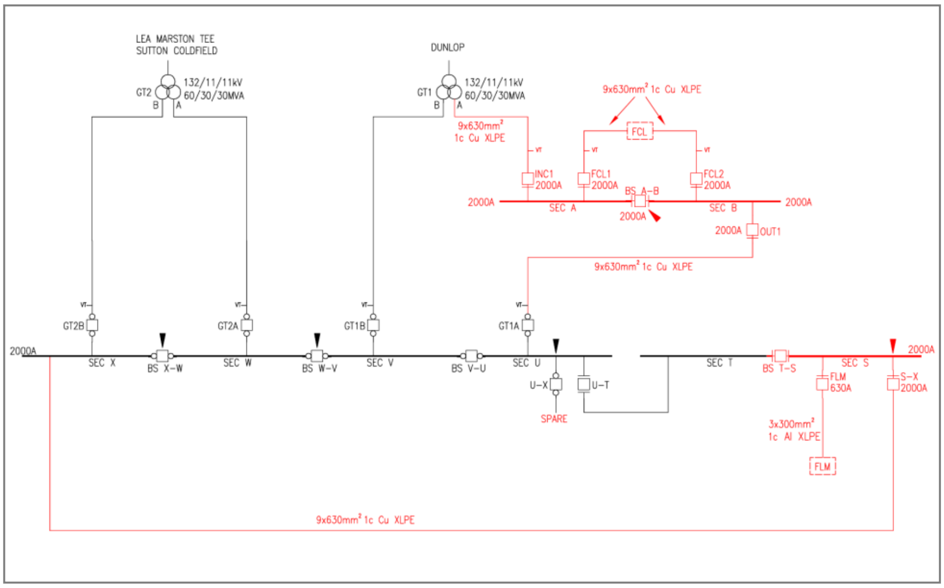

Figure 3-9: Castle Bromwich outline connection SLD

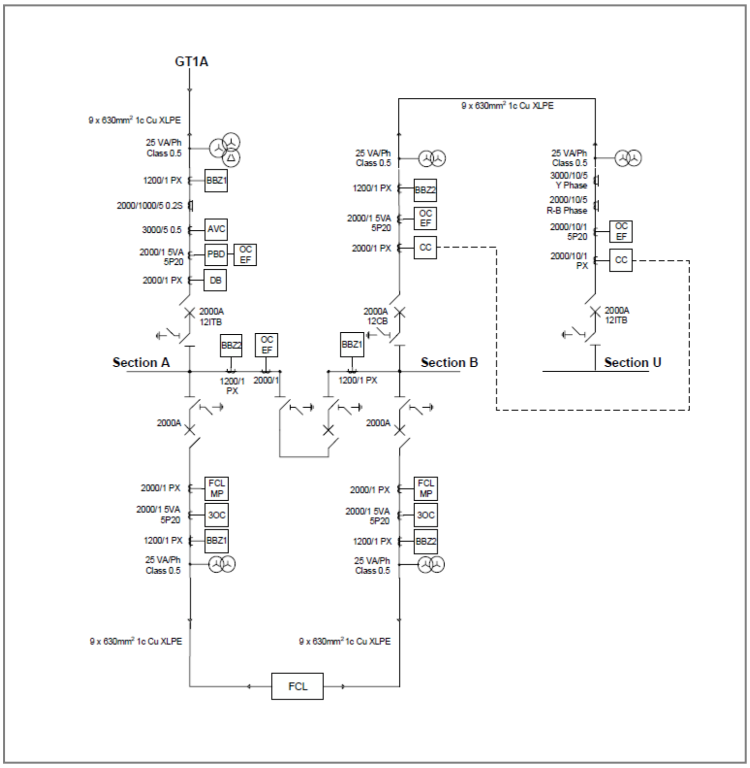

Figure 3-10: Castle Bromwich Protection and Control Diagram

SDRC-2 proposed that the spare transformer bay could be used for accommodating the FCL as there were no long term plans to install a third transformer. New switchgear can be accommodated in the existing switch room. The proposed arrangement is shown in Figure 3-11 below.

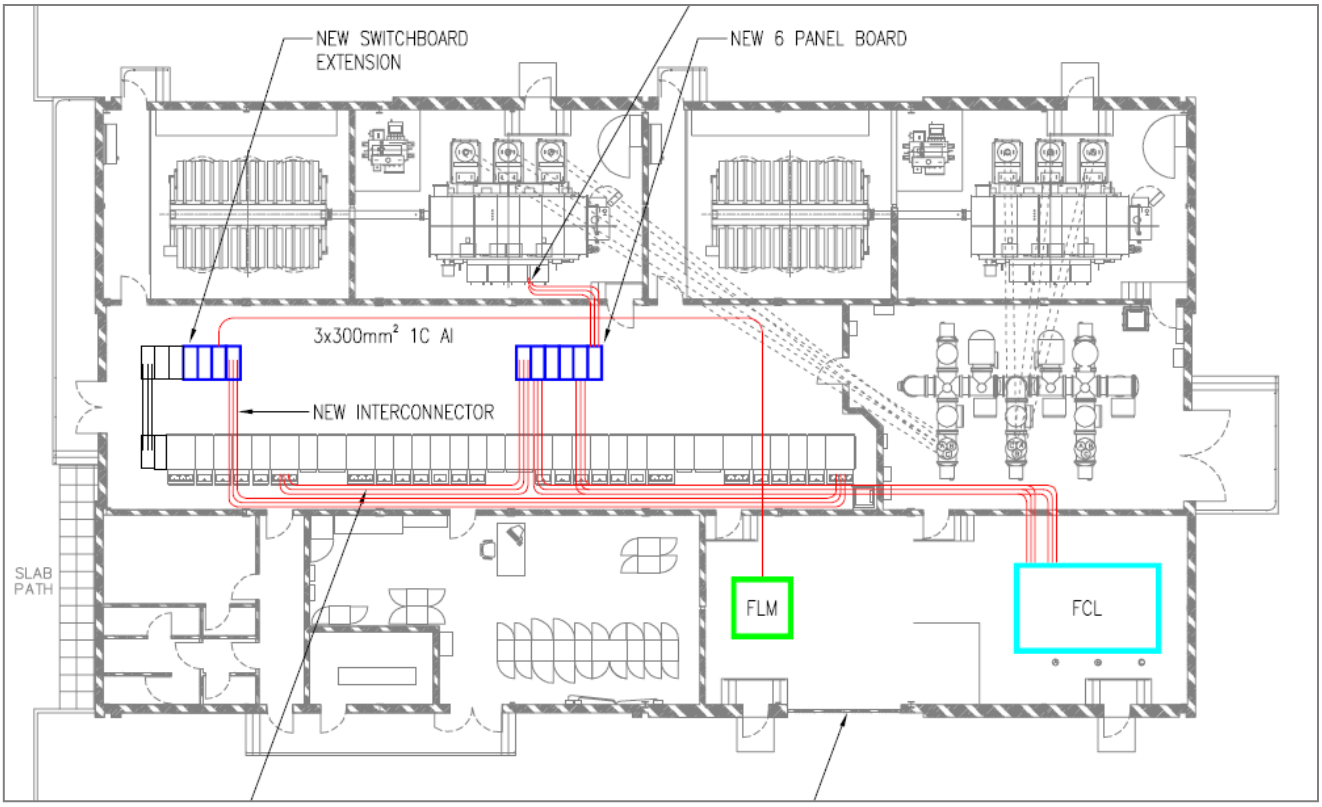

Figure 3-11: Castle Bromwich outline FCL layout

An overall fault level reduction of 22% (3 phase break rms) is required for Castle Bromwich substation as detailed in Table 2-2. As can be seen in Table 3-4 below, a tender return was received for all technology types.

	Power Electronic FCL	Resistive Superconducting FCL	Pre-Saturated Core (Non-Supercond.) FCL	Pre-Saturated Core (Superconducting) FCL
Castle Bromwich	✓	✓	✓	✓

Table 3-4: Technologies offered for Castle Bromwich

The key factors summarised in Table 3-5 below were considered when deciding which of the available technologies should be installed at Castle Bromwich.

Factor	Requirement	Description
Continuous Current Rating	2000A	Required to match the transformer secondary rating to ensure that the secondary winding is not de-rated
Recovery Time	Instantaneous	As the FCL is directly in series with the transformer, no interruptions whilst the FCL is recovering can be tolerated
Limiting Operation	No disconnection	As the FCL is directly in series with the transformer, no interruptions whilst the FCL operates to limit fault current

Table 3-5: Key factors for FCL installation at Castle Bromwich

The key factors for Castle Bromwich require an FCL which has instantaneous recovery and should not interrupt supply during fault inception and as such the PEFCL and RSFCL were not suitable technologies. The fully rated PSCFCL non-superconducting FCL was chosen over the superconducting variant due to commercial and health and safety requirements as detail in section 3.5.2. A preliminary layout showing the proposed PSCFCL using information gathered post tender is shown in Figure 3-12 below.

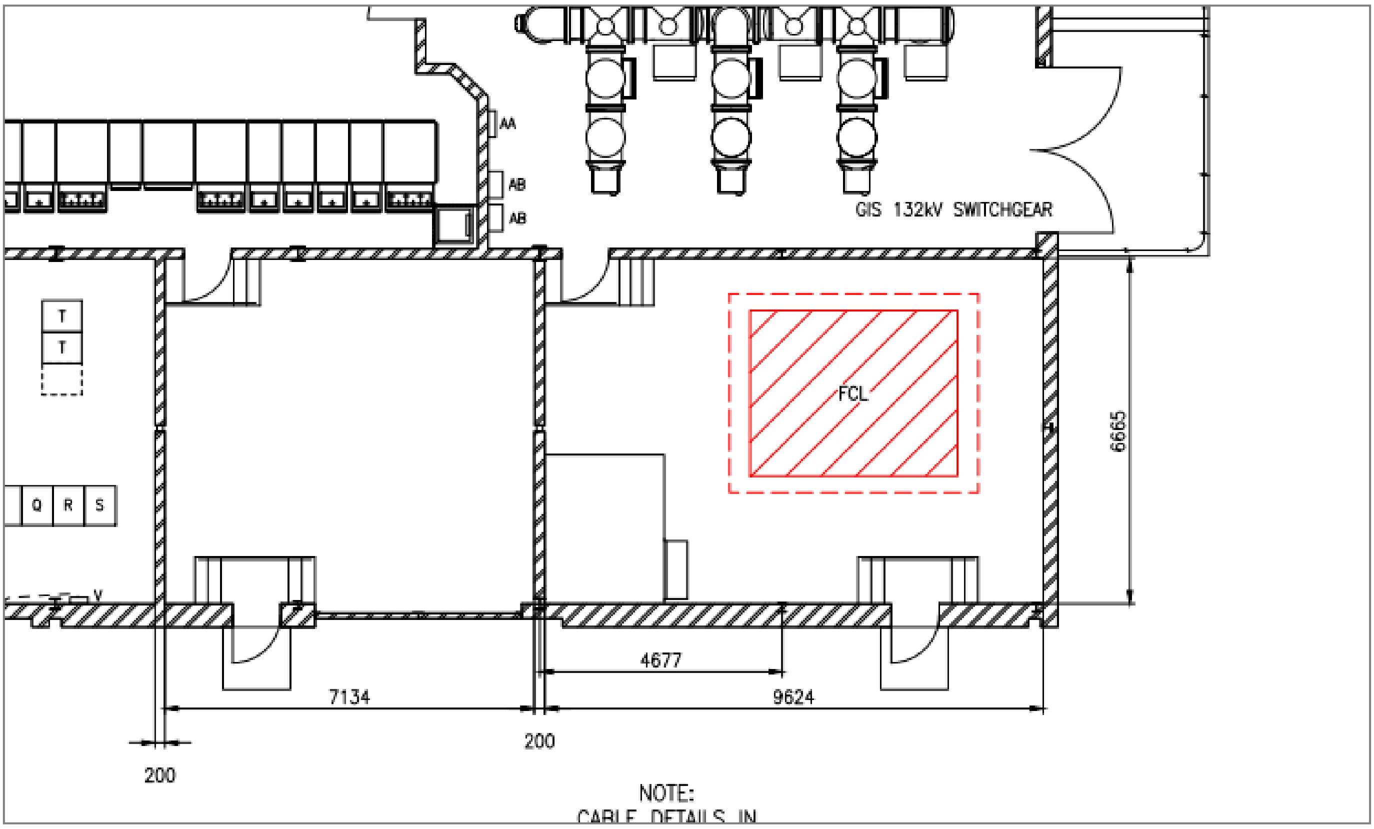

Figure 3-12: Castle Bromwich preliminary layout

3.8.4 Chester Street 132/11kV Substation

Chester Street Substation consists of 3 no. 132/11kV 30MVA transformers supplying GEC KN 11kV switchgear manufactured in 1961. Due to the condition and reliability issues associated with the 11kV switchgear, it has been scheduled for replacement during DPCR5. With this in mind, SDRC-2 proposed that the FCL is integrated by installing two additional circuit breakers in the new switchboard allowing GT2 and GT3 to be paralleled. Further details of Chester Street Substation and the integration of a FCL can be found in Appendix 6. A single line diagram of the proposed connection and protection and control schematic are shown in Figure 3-13 and Figure 3-14 respectively.

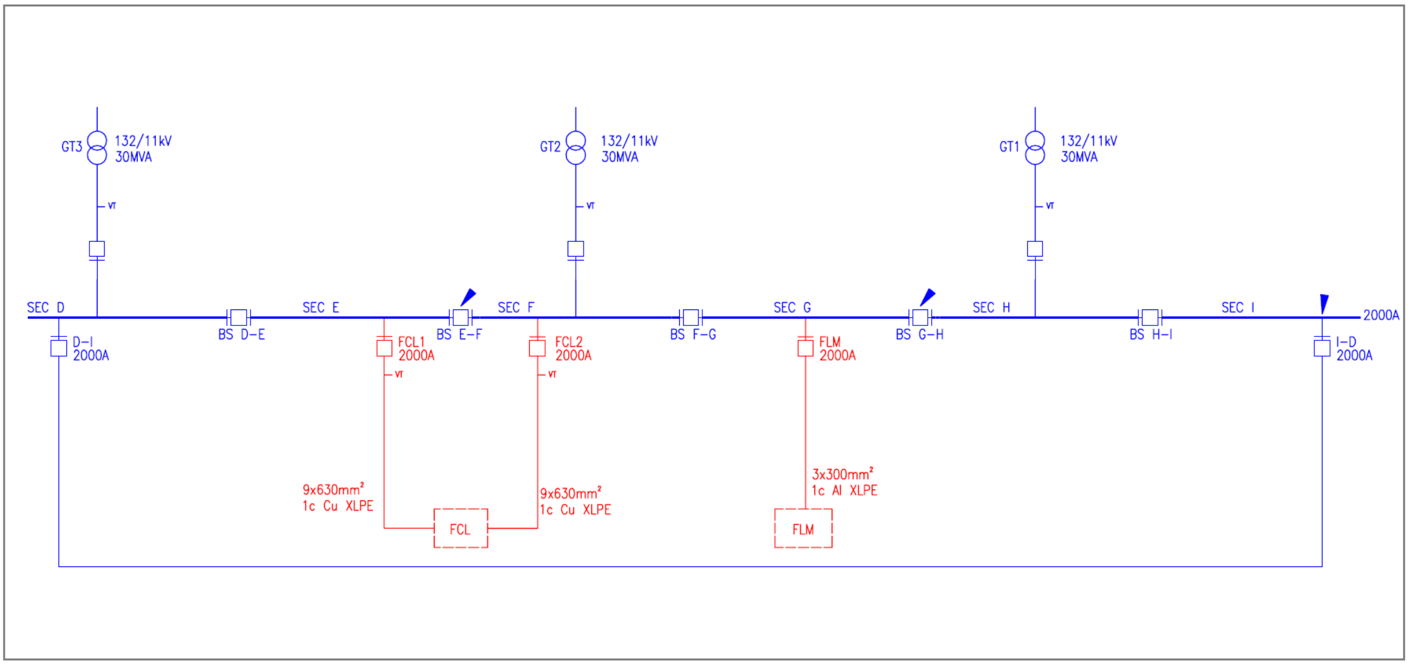

Figure 3-13: Chester Street outline connection SLD

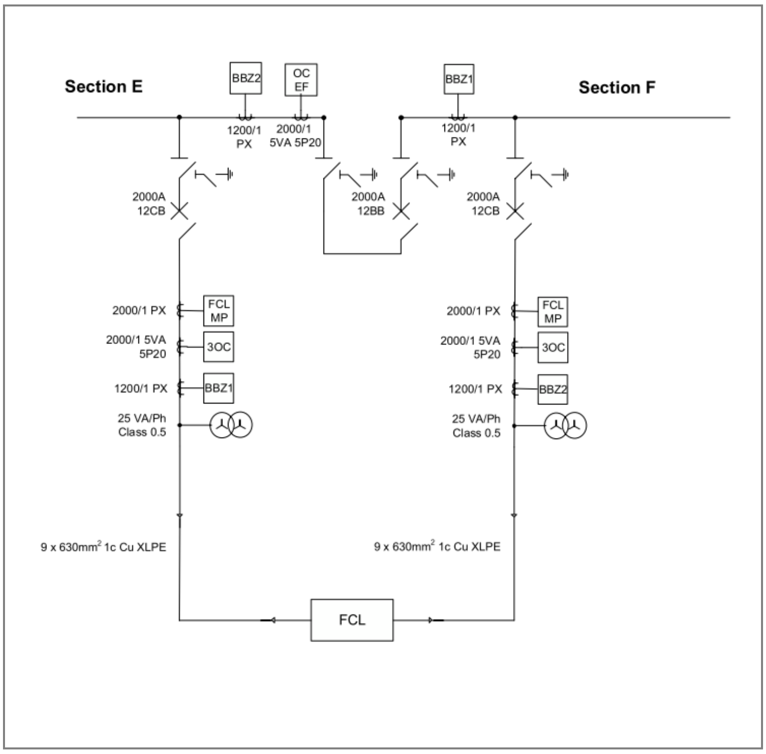

Figure 3-14: Chester Street Protection and Control Diagram

Work for SDRC-2 identified that the most suitable area for the FCL installation was in the spare area on land adjacent to the 132kV compound as shown in Figure 3-15 below.

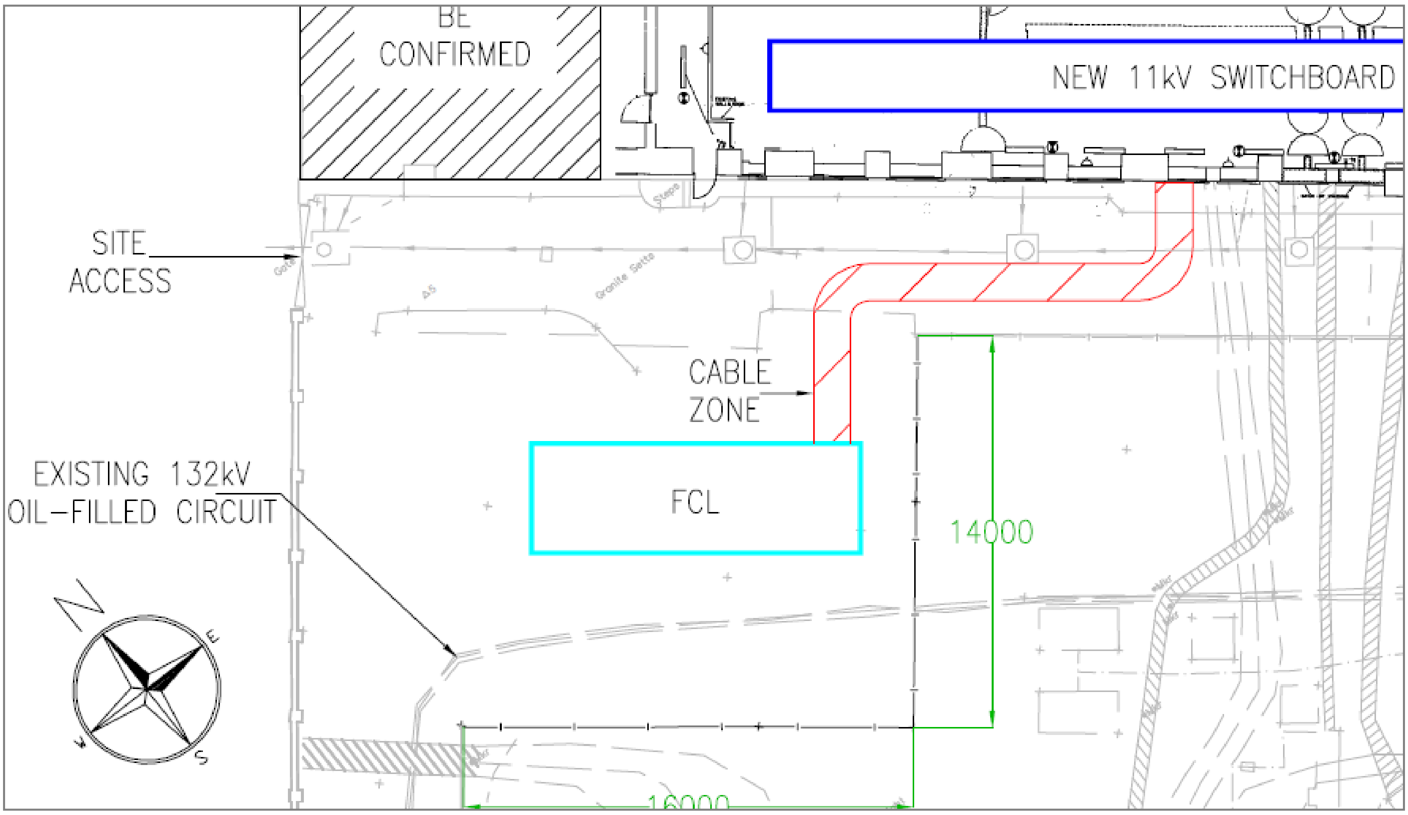

Figure 3-15: Chester Street outline FCL layout

Chester Street substation requires an overall fault level reduction of 24% (3 phase break rms) to meet the headroom requirements for FlexDGrid. Table 3-6 below shows that a tender return was received for all technology types.

	Power Electronic FCL	Resistive Superconducting FCL	Pre-Saturated Core (Non-Supercond.) FCL	Pre-Saturated Core (Superconducting) FCL
Chester Street	✓	✓	✓	✓

Table 3-6: Technologies offered for Chester Street

The key factor summarised in Table 3-7 below was considered when deciding which of the available technologies should be installed at Chester Street.

Factor	Requirement	Description
Continuous Current Rating	1000A	Required to meet the minimum current to support N-1 scenario

Table 3-7: Key factors for FCL installation at Chester Street

As all manufacturers were able to meet the continuous current rating required, the selection of technology was based on the scores using the criteria in the ITT documentation. Although the PEFCL technology was the highest scoring technology, as it was already proposed for both Kitts Green and Sparkbrook, the RSFCL was chosen as it was the next highest scoring technology. Although the RSFCL has a recovery time, no supplies should be lost for a fault on an outgoing 11kV feeder due to the position across the bus-section. A preliminary layout showing the proposed RSFCL using information gathered post tender is shown in Figure 3-16 below.

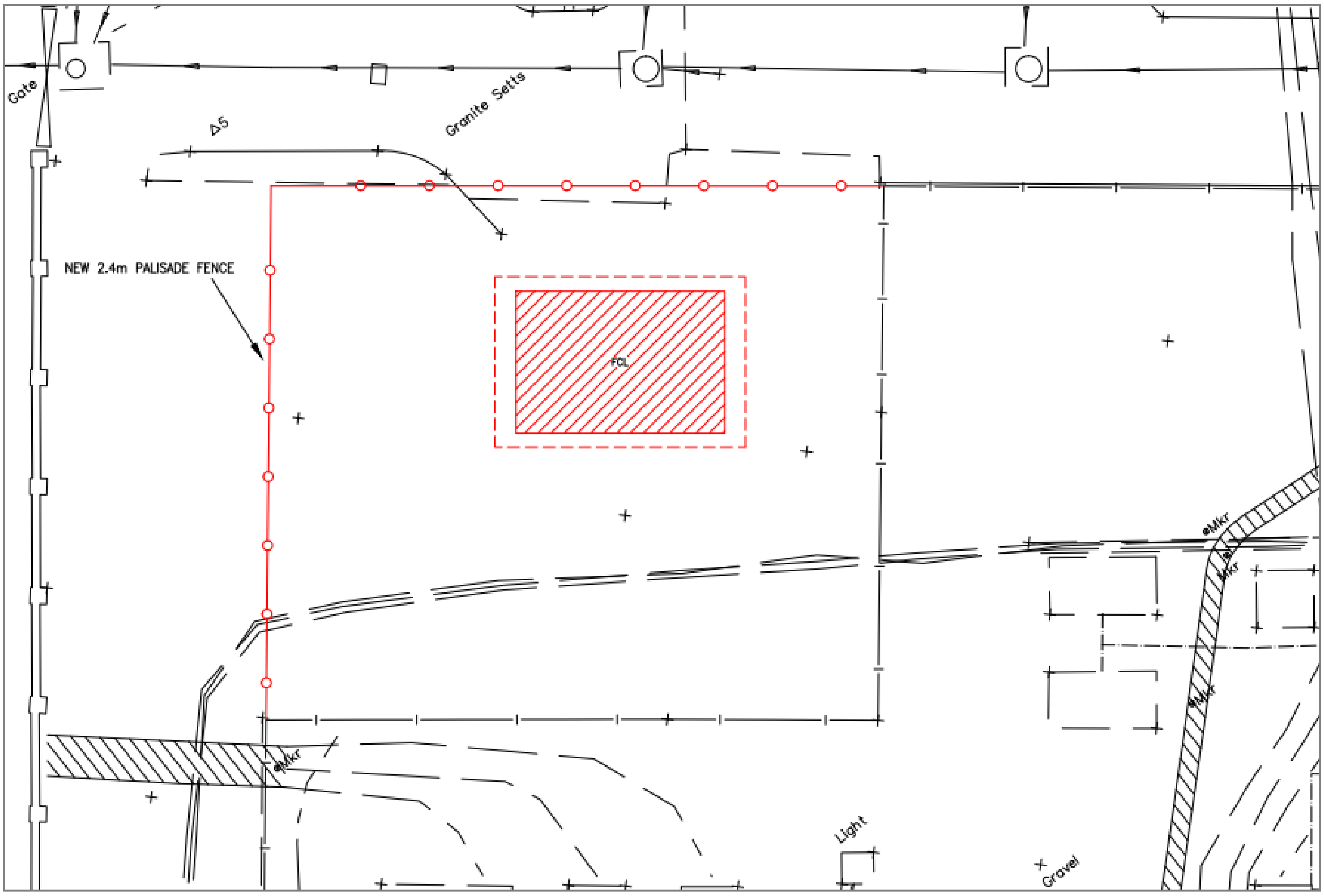

Figure 3-16: Chester Street preliminary layout

3.8.5 Bournville 132/11kV Substation

Bournville Substation is fed from Kitwell GSP and consists of 4 no. 132/11kV 30MVA transformers supplying 4 no. double busbar sections of 11kV switchgear. The substation was constructed in the 1960s and has been modified and developed over the years. Both the transformers and 11kV switchgear at Bournville substation have been identified for replacement in DPCR5. Hence, SDRC-2 proposed the least cost option of connecting the FCL by installing two additional circuit breakers in the new switchboard. Further details of Bournville Substation and the integration of a FCL can be found in Appendix 7. A single line diagram of the proposed connection and protection and control schematic are shown in Figure 3-17 and Figure 3-18 respectively.

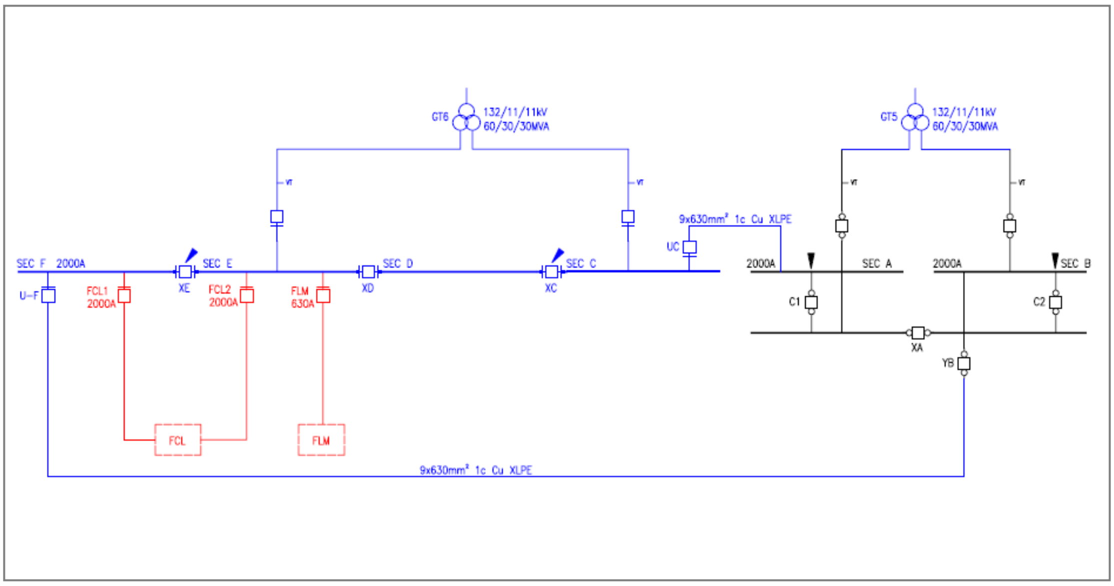

Figure 3-17: Bournville outline connection SLD

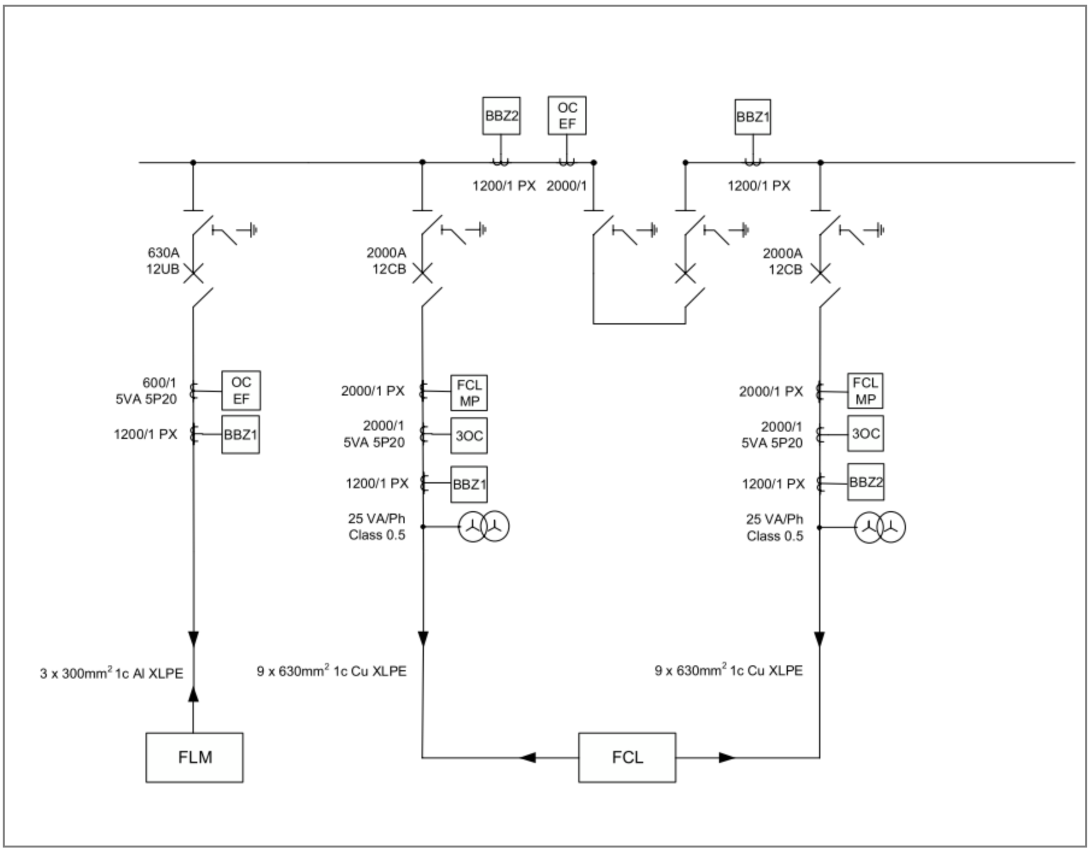

Figure 3-18: Bournville Protection and Control Diagram

The spare area of land between the 11kV switch house and the 132kV compound was identified as the most suitable location for the FCL. Figure 3-19 below shows the position of the FCL as proposed in SDRC-2.

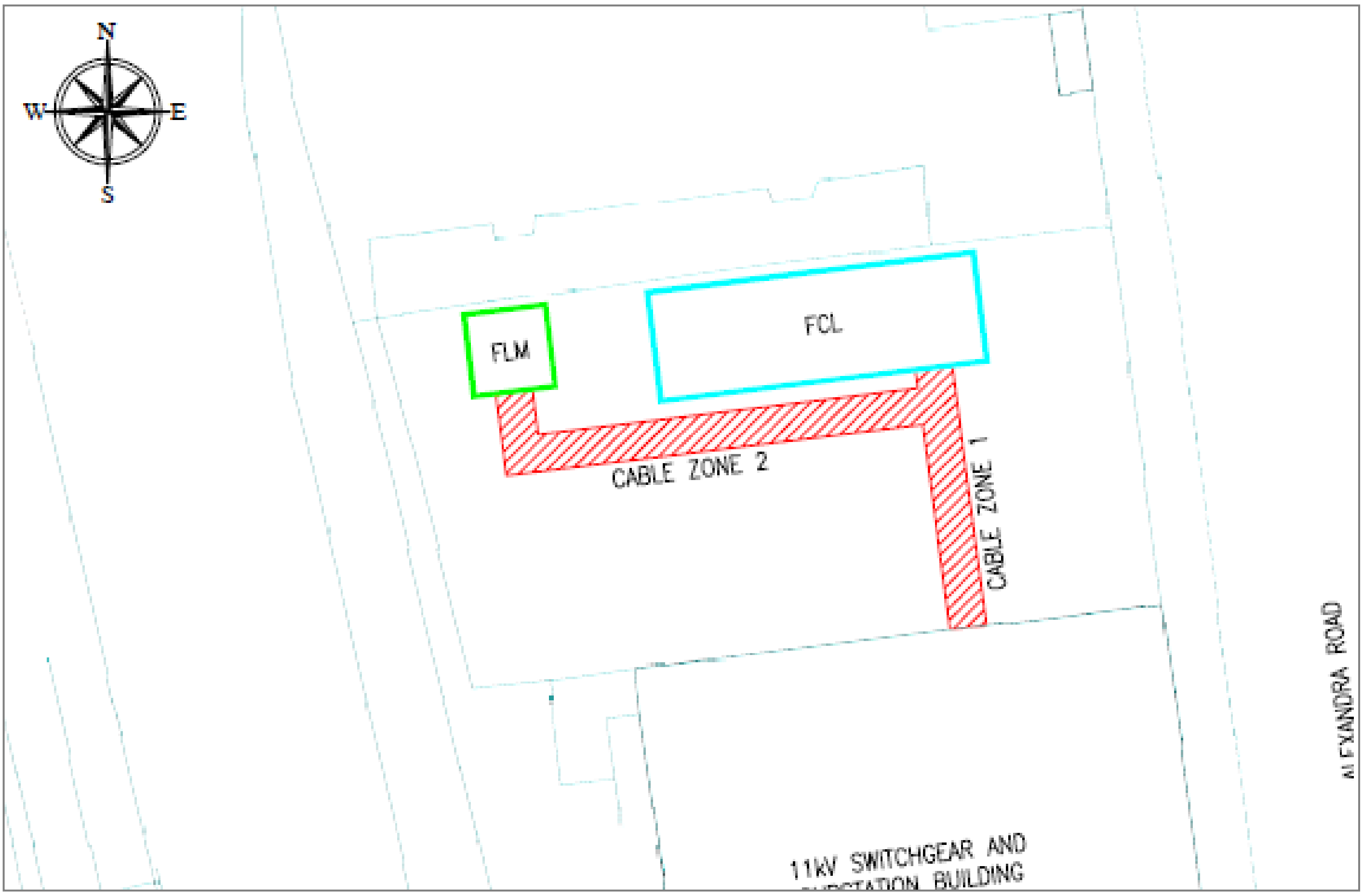

Figure 3-19: Bournville outline FCL layout

An overall fault level reduction of 30% (3 phase break rms) is required for Bournville substation as detailed in Table 2-2. As can be seen in Table 3-8 below, a tender return was received for all technology types.

	Power Electronic FCL	Resistive Superconducting FCL	Pre-Saturated Core (Non-Supercond.) FCL	Pre-Saturated Core (Superconducting) FCL
Bournville	✓	✓	✓	✓

Table 3-8: Technologies offered for Bournville

The key factors summarised in Table 3-9 below were considered when deciding which of the available technologies should be installed at Bournville.

Factor	Requirement	Description
Continuous Current Rating	1600A	Required to meet the minimum current to support N-1 scenario
Space	Maximum of 7000mm x 5000mm	Due to space limitations and potential future capital project plans, the FCL size should not exceed 7000mm x 5000mm

Table 3-9: Key factors for FCL installation at Bournville

As the requirements for Bournville were very similar to Chester Street the outcome of the technology evaluation was the same. All manufacturers were able to meet the continuous current rating required, therefore the selection of technology was based on the scores using the criteria in the ITT documentation. Although the PEFCL technology was the highest scoring technology, as it was already proposed for both Kitts Green and Sparkbrook, the RSFCL was chosen as it was the next highest scoring technology. Although the RSFCL has a recovery time, no supplies should be lost for a fault on an outgoing 11kV feeder due to the position across the bus-section. A preliminary layout showing the proposed RSFCL using information gathered post tender is shown in Figure 3-20 below.

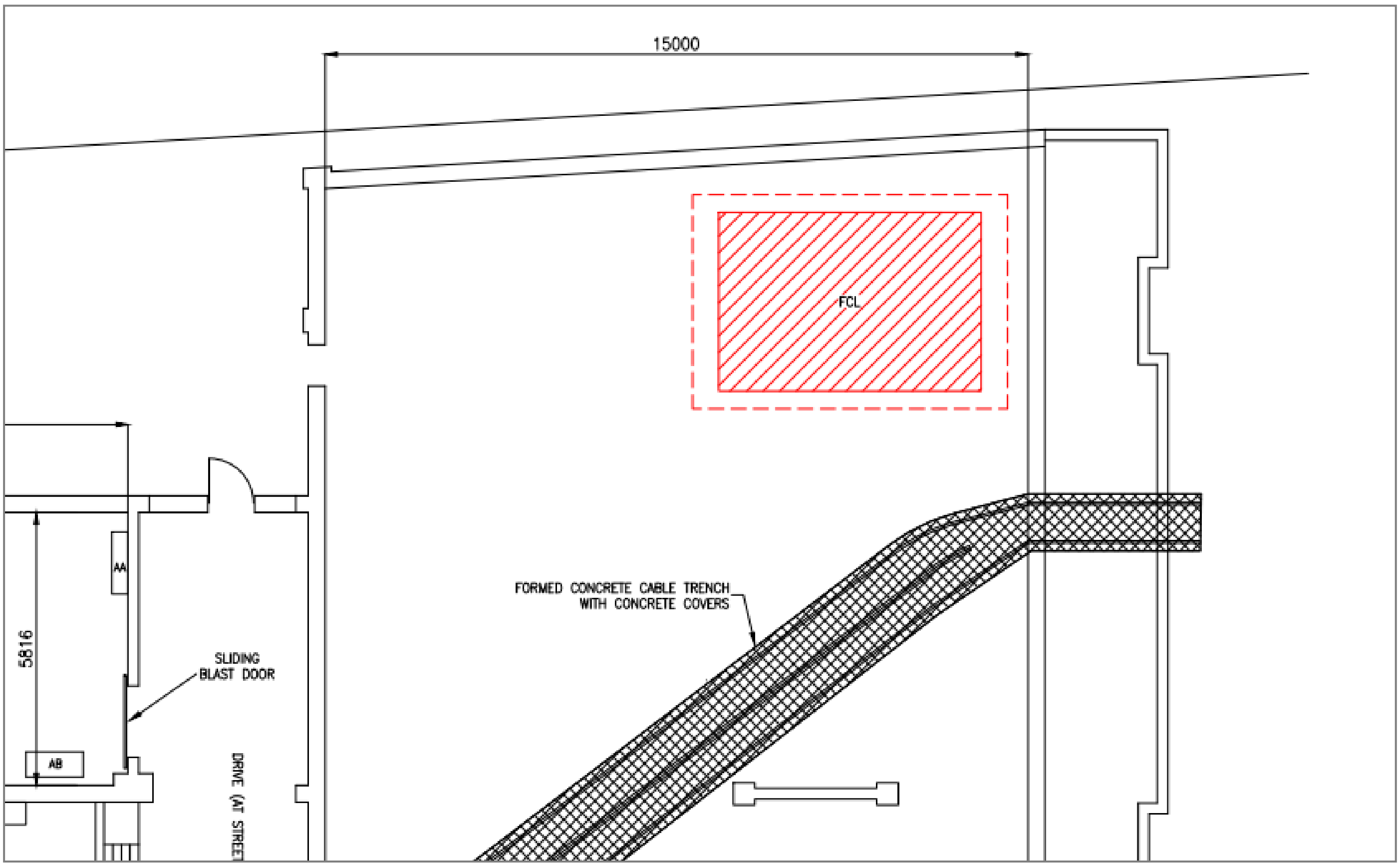

Figure 3-20: Bournville preliminary FCL layout

3.8.6 Sparkbrook 132/11kV Substation

Sparkbrook substation is supplied from Nechells GSP and comprises 2 no. 132/11/11kv 60MVA transformers supplying 2 no. 11kV double busbar switchboards. The switchboards are located in different buildings and are connected together with two 11kV interconnector cables. SDRC-2 proposed that the FCL be integrated into the 11kV interconnector between busbar sections B and E to facilitate a parallel of GT1A2 and GT2A5. Further details of Sparkbrook Substation and the integration of a FCL can be found in Appendix 8. A single line diagram of the proposed connection and protection and control schematic are shown in Figure 3-21 and Figure 3-22 respectively.

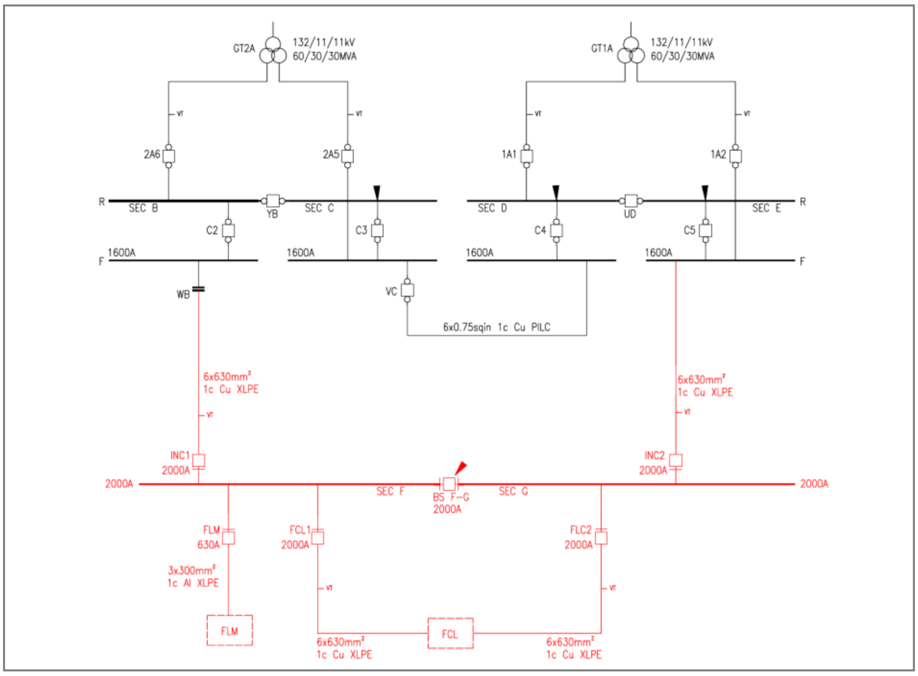

Figure 3-21: Sparkbrook outline connection SLD

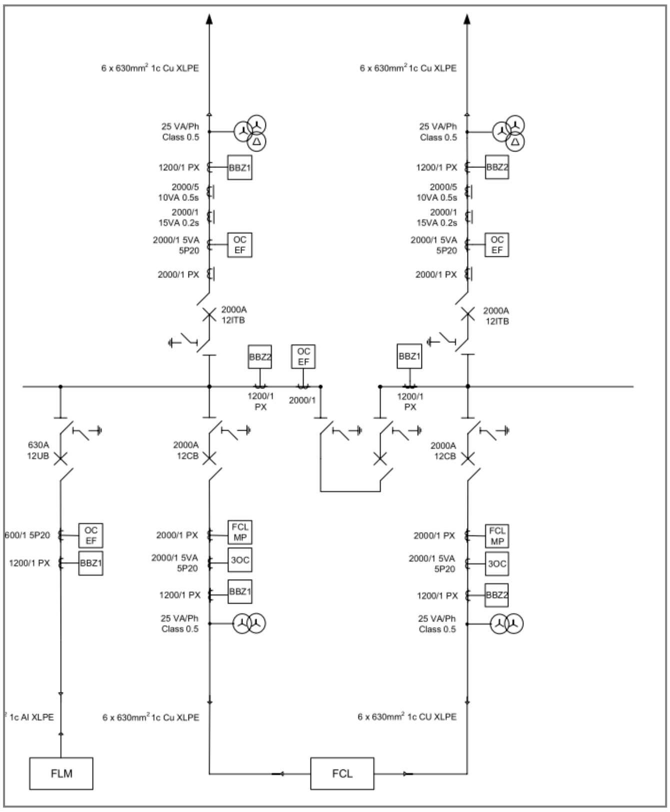

Figure 3-22: Sparkbrook Protection and Control Diagram

The proposed location of the FCL was between the 11kV switchboards in the position of the vacant 33/11kV transformer bays. Figure 3-23 below shows the position of the FCL.

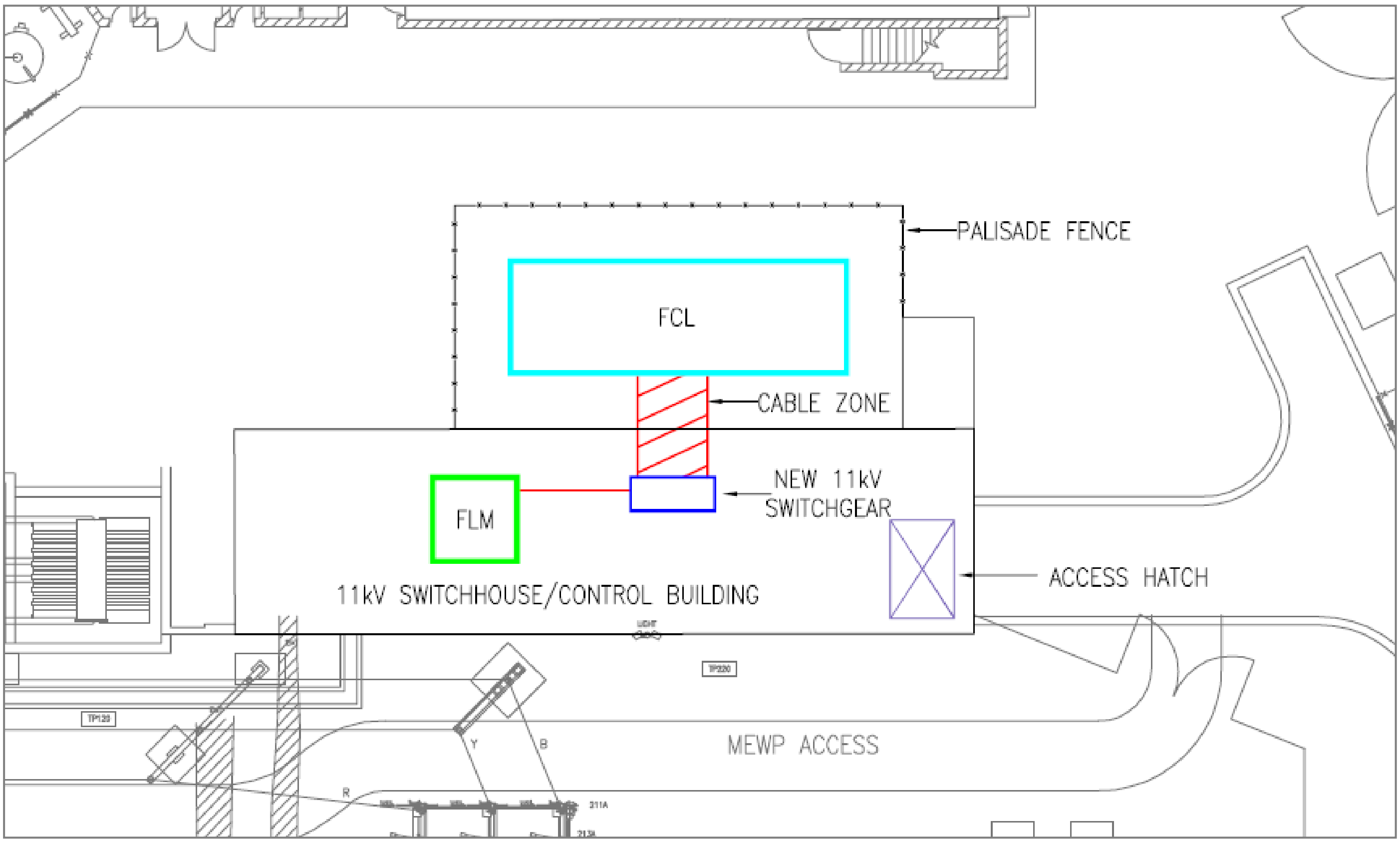

Figure 3-23: Sparkbrook outline FCL layout

Sparkbrook had the second highest overall fault level reduction with a value of 34% (3 phase break rms). Similar to Kitts Green, the technologies offered for Sparkbrook were limited due to the onerous fault level reduction requirements. Table 3-10 below summarises the technologies offered for Sparkbrook.

	Power Electronic FCL	Resistive Superconducting FCL	Pre-Saturated Core (Non-Supercond.) FCL	Pre-Saturated Core (Superconducting) FCL
Sparkbrook	✓	✓	✓	×

Table 3-10: Technologies offered for Sparkbrook

The key factors summarised in Table 3-11 below were considered when deciding which of the available technologies should be installed at Sparkbrook.

Factor	Requirement	Description
Continuous Current Rating	1600A	Required to meet the minimum current to support N-1 scenario
Space	Maximum of 6000mm wide	The location of the FCL is adjacent to an access road – a FCL with a width greater than 6000mm would infringe the existing access

Table 3-11: Key factors for FCL installation at Sparkbrook

The RSFCLs offered for Sparkbrook could not meet the minimum continuous current rating of 1600A therefore these were not considered. When comparing the scores and commercial aspects of the PEFCL and PSCFCL, the PEFCL was the highest scoring along with the smallest footprint, therefore the preferred choice for Sparkbrook. A preliminary layout showing the proposed PEFCL using information gathered post tender is shown in Figure 3-24 below.

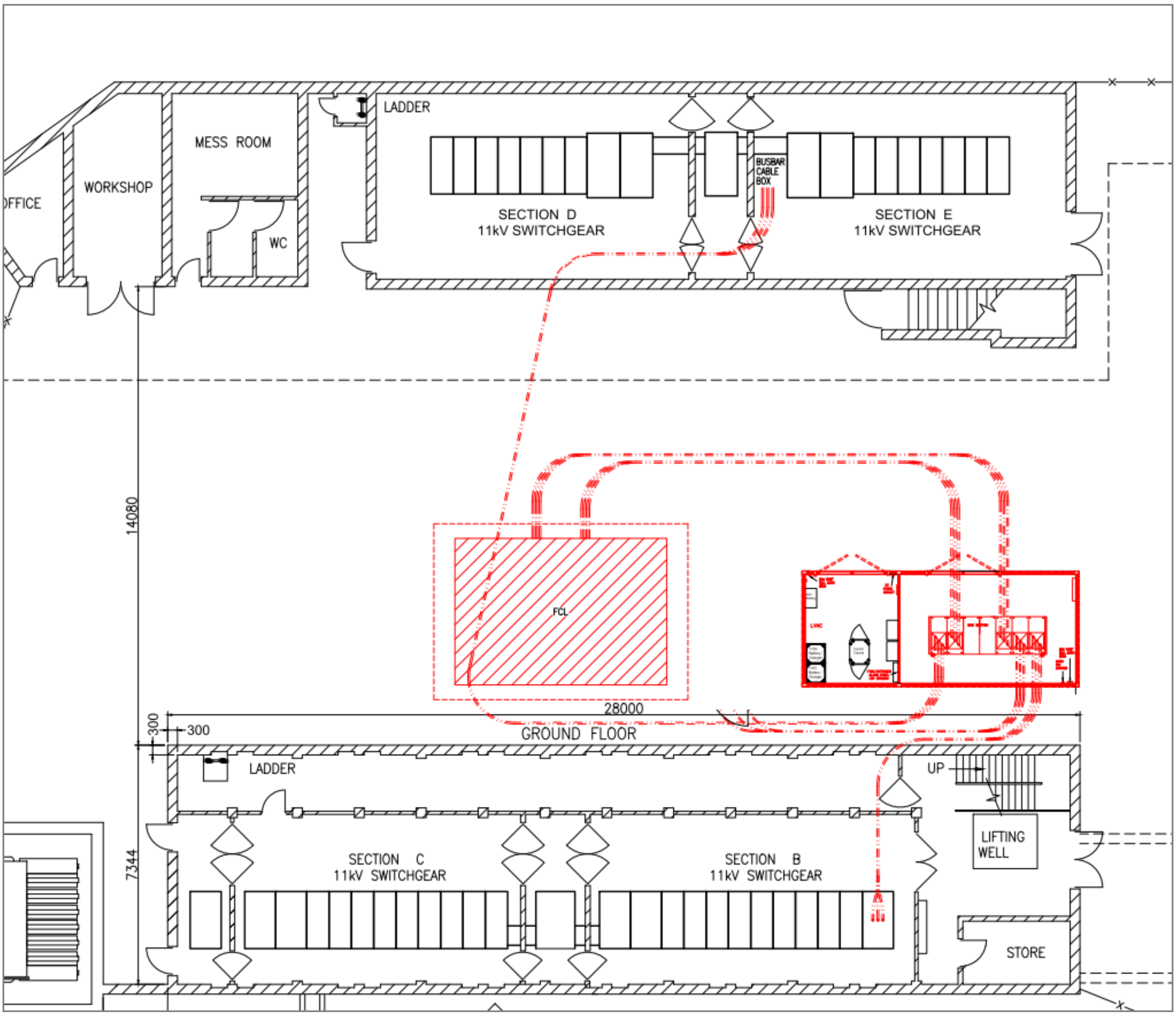

Figure 3-24: Sparkbrook preliminary FCL layout

3.8.7 Summary

Table 3-12 below provides a summary of the chosen technologies for each substation.

Substation	Chosen Technology
Kitts Green	Power Electronic FCL
Castle Bromwich	Pre-Saturated Core (Non-Superconducting) FCL
Chester Street	Resistive Superconducting FCL
Bournville	Resistive Superconducting FCL
Sparkbrook	Power Electronic FCL

Table 3-12: Summary of chosen technologies

4 Process followed to consult other DNOs (Criterion iii)

To enable WPD to fully and comprehensively understand the requirements of Method Gamma and to provide the learning that was outlined in the Full Submission Pro-forma, a robust methodology was developed to investigate the technologies, engineering design requirements and process to consult with the other GB DNOs.

The list below outlines the fundamental considerations to ensure that the learning outlined in the Full Submission Pro-forma are achieved:

- Building on learning outcomes from previous IFI, ETI and LCNF trials, this project will accelerate the technology readiness level (TRL) of Fault Level Mitigation Technologies;
- Providing significant learning and verification to Methods Alpha and Beta;
- Facilitating the connection of generation up to 10% of each Primary Substations firm load capacity;
- Increasing the security of supply to the 11kV network; and
- Providing learning that is transferrable to other DNOs.

The process followed to consult with other GB DNOs on the learning to date of Methods Alpha and Beta (i) is described below:

The aims and learning to date as of the 1st June 2013 of Method Alpha and Beta were documented in the report SDRC-1. This document detailed the requirements of the work and investigation to be undertaken within Methods Alpha and Beta. Included within SDRC-1 was feedback from other DNOs on the benefits proposed in exploring engineering methodologies and refinements to an Enhanced Fault Level Assessment process. This feedback was provided through the completion of surveys on current DNOs' practice for fault level assessment on their networks (surveys were completed by every DNO for each licence area), along with feedback gathered from a FlexDGrid DNO workshop in Birmingham on the 2nd May 2013. To further discuss the aims and learning to date of Method Alpha and Beta, a DNO workshop took place, at the IET in Birmingham, on the 23rd October 2013. The feedback from this workshop will be captured and reported in SDRC-4, the simulation and application of the Enhanced Fault Level Assessment process. This interactive and co-ordinated approach, to sharing learning and gathering feedback from all GB DNOs on Methods Alpha and Beta progress to date, has ensured that the continued development and trialling of these Methods is both appropriate and worthwhile to WPD's network as well as all other GB DNOs distribution networks.

The process followed to consult with other GB DNOs on the proposed methodology for Method Gamma (ii) is described below:

Due to the detailed technical nature of installing five Fault Level Mitigation Technologies in to an existing 11kV network, in a dense urban environment, a robust design and review process was set up. This robust approach underpinned the work completed in SDRC-2, to specify the detailed design requirements of Method Gamma (installation of five Fault Level Mitigation Technologies in to five Substations), completed on the 1st June 2013.

SDRC-2 gave an overview of the requirements and work undertaken to design the integration of technologies in to the existing 11kV network. This document detailed the required fault level reduction of each site, how the technologies were to be connected and the physical installation requirements along with other construction and engineering considerations. This document, whilst completing the requirement of detailed design also acts as a 'how to' guide for the integration of FLMTs in to the 11kV distribution network. This has provided a significant piece of project learning that is transferrable to other DNOs for the connection of FLMTs, as detailed in the Full Submission Pro-forma.

SDRC-2, which is publicly available through WPD's innovation website, provides a summary of the written documentation that was produced to evidence the detailed design work for the sites selected to include the new technologies. Due to the depth of detail and technical nature of the documentation a full design document pack was also produced. This work was carried out and documented in the FlexDGrid Project Design Package document. The information captured within this document, but not exclusively, is:

- Management of Fault Level;
- Installation Objectives of FLMTs;
- Substation Selection process;
- Basis of optioneering;
- FLMT options;
- Protection philosophy;
- Risks;
- Technology overview; and
- Detailed design and survey reports for each substation.

This document was made available to the other GB DNOs, following its production in July 2013, and used to provide written evidence regarding the functional description of the Fault Level Mitigation Technologies, proposed by the manufacturers, for installation along with the proposed methodology of the technologies for inclusion on to the 11kV network. The technology overview section of the FlexDGrid Project Design Package document along with the five specific detailed design packages is included in Appendices 3 to 8.

Following the completion of the detailed design requirements of the substations, the specific technologies suitable for installation at each site were identified through the WPD FlexDGrid procurement process (approved by Ofgem on the 24th April 2013).

As required in the Project Direction relating to FlexDGrid a workshop with other DNOs must have taken place by the 31st October 2013; to allow each DNO to gain a detailed understanding of the learning to date in Methods Alpha and Beta and to further understand the proposed methodology of Method Gamma. This workshop took place on the 4th September 2013, the details of this workshop, its format and DNO specific attendees, are captured in SDRC-3 and the presentation slides are within Appendix 2.

The workshop presentation consisted of the latest updates on the learning from Methods Alpha and Beta and the site specific information relating to Method Gamma. The Method Gamma information presented was a targeted overview of the information previously provided in the FlexDGrid Project Design Package document, offering a further overview of the functional specification of the technology to be installed at each site, the engineering viability and requirements to include it and evidence, further built on from SDRC-2, that the specific technologies meet the needs and learning required from FlexDGrid; set out in the Full Submission Pro-forma.

The aim of consulting with DNOs was to allow a focussed peer review of the methodology employed to integrate the Fault Level Mitigation Technologies in to the 11kV network (proposed Methodology for Method Gamma), ensuring that the original learning proposed would be achieved. Due to the technical nature of this element of FlexDGrid it was decided that the appropriate approach to take was to provide finalised written design documentation to the DNOs and to request formal, written, feedback. Optioneering elements for each site were documented within the information provided, as well as being consolidated in the SDRC-2 document. WPD is satisfied that this approach is an appropriate format for the consultation on technical design and construction information to allow each GB DNO to provide informed formal written feedback.

5 Written responses from other DNOs (Criterion iv)

The process used to consult with other GB DNOs as documented in Section 4 is summarised in the following points:

- DNO workshop on the Enhanced Fault Level Assessment Process;
- Submission to Ofgem and public release of SDRC-1;
- Submission to Ofgem and public release of SDRC-2;
- Release of FlexDGrid Project Design Package document; and
- DNO workshop on the learning to date of Methods Alpha and Beta and the proposed methodology for Method Gamma.

All attendees from the GB DNOs, at the workshop on the 4th September 2013, were provided the complete written documentation of the learning to date of Methods Alpha and Beta, provided in SDRC-1 and the EFLA DNO workshop, and the proposed methodology for Method Gamma in both SDRC-2 and the FlexDGrid Project Design Package document. This information was then provided in the format of presentations (Appendix 2) to enable a targeted overview to be presented to the GB DNOs to enable each of them to provide an informed written response on documentation previously provided.

WPD are satisfied that the level of written information provided was fully comprehensive and afforded the other GB DNOs a sufficient level of detail to make an informed decision as to whether proceeding to Method Gamma would provide the learning outlined in the Full Submission Pro-forma.

Following the workshop, representatives from each DNO were asked to write a letter in response to the information they had been provided. These letters are provided in full in Appendix 1. Representatives from each DNO are all members of their respective DNOs' planning, design or policy teams. This enabled WPD to ensure that each DNO was represented by an individual who fully understands the network needs, requirements and issues for business as usual operation.

All the DNOs have written within their letters that the information provided allowed them to consider that the original learning set out in FlexDGrid's Full Submission Pro-Forma can be met and that there is merit in proceeding with the procurement of the Fault Level Mitigation Technologies.

6 Appendices

- Appendix 1 - Letters of support for Method Gamma
- Appendix 2 – DNO Workshop Presentation – 4th September 2013
- Appendix 3 – Technology overview from FlexDGrid Project Design Package
- Appendix 4 – Kitts Green Detailed Design Package from FlexDGrid Project Design Package
- Appendix 5 – Castle Bromwich Detailed Design Package from FlexDGrid Project Design Package
- Appendix 6 – Chester Street Detailed Design Package from FlexDGrid Project Design Package
- Appendix 7 – Bournville Detailed Design Package from FlexDGrid Project Design Package
- Appendix 8 – Sparkbrook Detailed Design Package from FlexDGrid Project Design Package